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To: R. E. Berry - 9312

From: W. F. Carstens - 3410

Re: Your Paper Entitled "Aerospace Safety Results From A ROVER/NERVA Post-Operational Destruct Test," SC-DC-65-1806.

This material was prepared for presentation and possible publication as a hand-out at the meeting of the American Nuclear Society Winter Meeting, November 17, 1965 at Washington D. C.

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AEROSPACE SAFETY RESULTS FROM A ROVER/NERVA POST-OPERATIONAL DESTRUCT TEST

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ABSTRACT

The destruction of a full scale mockup ROVER/NERVA propulsion engine was performed under the direction of the joint AEC/NASA Space Nuclear Propulsion Office. The instrumentation was developed and installed by Aberdeen Proving Ground and Sandia Corporation. The data collected included information about the destruct debris velocity, size, weight, and spacial distribution. These data are a satisfactory source term for the computer analysis of the ROVER/NERVA Program safety.

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AEROSPACE SAFETY RESULTS FROM A ROVER/NERVA POST-OPERATIONAL DESTRUCT TEST

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Introduction

Prior to the use of nuclear material in space, an acceptable evaluation of the safety criteria must be completed. The safety analysis depends on the method of destruction proposed for the vehicle carrying the nuclear material.

For the ROVER/NERVA propulsion engine, a suitable nonnuclear post-operational explosive destruct system has been developed by Aberdeen Proving Ground and Picatinny Arsenal, but the character of the resulting debris has not been fully defined. The characterization of debris is the source term for a computer analysis from which the resulting dispersion, fallout, and the ultimate safety can be established.

To acquire this input information which includes three dimensional debris distribution, debris size and mass, and debris velocity, a full scale mockup of the ROVER/NERVA nuclear propulsion engine was destroyed using four statically emplaced 105 mm special explosive charges.

The destruction of the mockup ROVER/NERVA propulsion engine was requested by the joint AEC/NASA Space Nuclear Propulsion Office (SNPO). Further, SNPO requested that data about the debris resulting from the destruction be collected.

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The collection of explosive destruct data and analysis of that data was jointly done by the Army's Aberdeen Proving Ground and Sandia Corporation. These two facilities independently instrumented and collected as much data as possible to fulfill the safety requirements.

Figure 1 lists those data requirements considered to be fundamental, or that data which can be collected directly with on site instrumentation. Figure 2 lists those data requirements which are a direct result of fundamental data reduction and presented in usable format. Figure 3 lists those data requirements which require additional mathematical analysis to remove the effects of gravity and the atmosphere on the debris pattern and velocity resulting from the explosive destruct test.

The previous three Figures outline the data requirements and Figure 4 is a photograph of the mockup ROVER/NERVA space propulsion engine destroyed with chemical explosives on June 22, 1965, at Aberdeen Proving Ground.

This mockup space engine contained a simulated uranium core, control drums, reflector segments, core support plate, shield, and the outer pressure vessel. That is, all components which were considered important to the vessel reaction to explosive destruct were simulated.

Simulated entry holes were placed in the vessel and four statically emplaced 105 mm special explosive charges were used for the destruct test.

The mockup space engine was surrounded by instrumentation as shown schematically in Figure 5. This instrumentation is also shown photographically in Figure 6.

Duplicate instrumentation techniques were used throughout to provide a high confidence that the required data would be obtained.

Description of Instrumentation

A. Air Sampling

The purpose of the air sampling program was to collect atmospheric samples in the vicinity of ground zero after the NERVA reactor had been destroyed with 111.17 pounds of high explosive, to determine the concentration of graphite dust particles in the resulting cloud and to ascertain the shape and size distribution of the particles that remained airborne.

The atmospheric samples were collected by means of midget impingers suspended from overhead cables. The cables were held about 80 feet above and around ground zero. Three midget impingers were secured to each of 8 drop lines from the overhead cables and were located so that samplers were fixed at 20 feet, 50 feet, and 70 feet above the ground. Each line of impingers was located 100 feet from ground zero, and the resulting array of 24 samplers formed a cylinder 200 feet in diameter and 70 feet high. This array of samplers provided 360° coverage and allowed a representative sample to be taken in a light and variable wind.

B. Pressure Measurement

The blast pressures developed during the destruction of the mockup space engine were recorded on an Ampex CP 100 Magnetic Tape Recorder. Susquehanna ST-2 pressure transducers were connected through 1,000 feet of Microdot cable to an Endevco Model 2641M1 Charge Amplifier which provided the input to the tape recorder.

Twelve transducers were mounted in the blast area, each 6 feet above ground level. Four transducers were located 20 feet from ground zero - one in a jet, one at 45° between jets, and two 5° on either side of a second jet. Four additional transducers were located at 30 feet and also at 40 feet in the same way as described above.

C. Glass Rod Velocity Measurements

To measure the velocity of the particles resulting from the destruction of the test vessel, conducting glass rods were employed. These rods were constructed of 3/16" x 8" glass tubing painted with a conductive paint which provided a path of electrical continuity between each end. Measurements revealed that each 8-inch rod possessed a resistance of approximately 2 ohms.

Electrical connections were made to the rods through the use of fuse clips attached to each end of the rod.

The glass rods were positioned above the simulated nozzle, below the simulated dome, adjacent to the pressure vessel wall and at 10 feet, 20 feet, 30 feet, 40 feet, 50 feet, 60 feet, and 70 feet along the west jet and also at 10 feet, 30 feet, and 50 feet along the south jet.

The glass rods were positioned to be broken by the moving debris, either the metal components or the core material, which is deployed in the 5 major jet areas.

D. Rotating Foam Particle Collectors & Velocity Devices

1. Rotating Single Disc

The single disc was designed (a) to measure the time of arrival of particles from which the average velocity could be calculated, and (b) to catch and preserve the particles that reached it. The unit consists of a flat disc of 1.9 lbs/ft^3 polystyrene foam 3" thick and 15" in diameter. The disc is driven at a constant rotational velocity of 1725 rpm by a 3/4 hp 220 volt AC single phase electric motor. The rotating disc and motor are housed in a fabricated aluminum cabinet measuring 26" long, 18-1/2" high, and 18" wide, the front face of which contains a 4-3/4" x 1" stationary slit which faces the explosion center and allows a debris sample to enter the polystyrene foam disc. A dual spark

source, one from a modified transistorized automobile ignition system and one from a high energy capacitive discharge system were mounted to provide a mark at detonation (zero time) on heat sensitive recorder tape attached to the periphery of the disc.

As the explosion debris reaches the instrument, a line of particles are permitted to enter through the stationary slit and embed into the rotating polystyrene foam disc. With the known disc angular velocity and the angle the particles (debris) make with respect to the zero time mark, the arrival time (T) can be calculated. The distance (D) is determined by measurement; therefore, the average velocity (Va) is determined by the equation: $Va = D/T$.

Figure 7 is a schematic representation of this single disc particle collector and velocity device.

2. Rotating Drum

The rotating drum was designed to perform the same functions as the single disc described above. Its principle and operation are the same except that the particles enter a 1" x 18" slot and strike the drum normal to the drum surface and axis. Further, the drum is rotated at 1000 rpm but the speed may be varied by installing the proper pulleys and belt.

The drum is of polystyrene foam 18" long by 21" in diameter. Total weight of the drum assembly is approximately 210 pounds. The drum and drive are housed in an aluminum skin and stringer structure stressed for 20 psi overpressure.

Figure 8 is a schematic representation of the rotating drum particle collector and velocity device.

3. Rotating Twin Disc

The twin disc was designed to provide: (a) average velocity, which is calculated by measuring time of arrival of particles, (b) final velocity, which is calculated by determining the time interval between particle penetration of the front disc and rear disc, (c) initial velocity which is calculated using the average velocity and the final velocity found in (a) and (b), and (d) particles for later examination.

The twin disc consists of two spoked discs, spaced 8 inches apart on a common driver shaft. Paper is glued over each disc. The rear disc is backed with a polystyrene foam which captures and preserves the particles.

Dual spark sources are located inside the housing along the periphery of the disc assembly and are

arranged to mark the rotating assembly when energized at the time of detonation (time zero). The disc assembly, motor, and time mark systems are housed in an aluminum skin and stringer structure stressed to withstand 20 psi overpressure.

Figure 9 is a schematic representation of the rotating twin disc particle collector and velocity device.

As the explosion debris reaches the instrument, a line of particles is permitted to enter through a stationary slit on the front cover. The particles pass through the paper on the front and rear discs and then embed in the foam. The particle time of arrival can be calculated by knowing the rotational speed and by measuring the particle angular displacement with respect to the zero time mark. The average velocity can be calculated by using the time of arrival and the distance the particles traveled from the point of detonation to the sampler.

The final velocity is calculated by using the measured displacement of the particle penetration imprint on the front disc paper with respect to the imprint on the rear disc paper, the distance traveled between the two disc papers (8 inches), and the rotational speed.

The initial velocity can be computed using the calculated average velocity and final velocity in the formula

$$Va = \frac{Vi + Vf}{2}$$

where

Va = average velocity
Vi = initial velocity
Vf = final velocity

Each particle can be recovered from the foam and its size and shape correlated with its three velocities.

E. Fixed Foam Particle Collectors

The polystyrene foam plastic placed in front of the rotating foam collectors had a threefold purpose: (a) collect the debris from the destruction of the propulsion engine, (b) act as an energy absorption media to protect the rotating foam collectors from large missiles, and (c) show the relative quantity of debris in the jets and in between jets.

Figure 4 shows the fixed foam particle collectors arranged behind the mockup space propulsion engine.

Test Results

The data obtained from this test were good and the test objectives were accomplished. Figure 10 shows some of the destruction inflicted on the instrumentation; however, data were obtained and enough of the instruments survived to give a good data sample.

Figures 11 and 12 show the resulting debris pattern when using four explosive charges. Figure 11 is a side view showing the two horizontal jets emanating from ground zero and a vertical jet above ground zero. Figure 12 is a photograph taken from a helicopter and shows the four strong jets originating at 45° between explosive charges.

A. Air Sampling

The sample of airborne core material obtained from the midget impingers was quite small but representative of the material contained within that portion of the debris cloud. Because of the jetting action created by the four explosive charges and the variable wind at the time of firing, the percentage of core material can only be estimated. Indications were that approximately 2 or 3 percent was contained in the airborne cloud. The core material that was collected provided the information that about 80% of the air borne debris is between .5 and 3.5 microns, about 19% is between 3.5 and 10 microns, and the remainder is between 10 and 20 microns. Further, the samples collected contained no measurable quantity of uranium. Two techniques were used for uranium analyses - Gamma counting and fluorometric. Both analyses showed no uranium present.

B. Pressure

There is a very slight variation of pressure when measured in a jet or between jets but this is small. Pressures were 23 psi at 20 feet, 8 psi at 30 feet, and

4.2 psi at 40 feet. These pressures are about 60% of that pressure expected from an uncontained explosion of the same size.

C. Velocity

The velocities measured by the glass rods, rotating foam velocity devices, and from the photographic film are shown in Figure 13.

The glass rod velocity data and the rotating foam velocity data are acquired before the camera is able to see through the combustion cloud. However, the camera is able to provide data for a longer time after detonation.

D. Debris Distribution

The metal debris from the explosive destruct of a mockup space propulsion engine is generally distributed radially for the pressure vessel skin, the simulated reflector segments, and the simulated control drums. The nozzle is projected upward and the dome and core support plate are propelled down. The remainder of the reactor is distributed among the five jets.

Figure 14 is a two-dimensional plot of these metal pieces found after the destruct test and generally verify the above statement about distribution of the mockup space propulsion engine debris.

Figure 15 is a plot of the weight percent of core material in each particle size range recovered from the fixed foam, as

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well as the plot of uranium found within each particle size range. Observe the concentration of uranium at 75 to 200 microns. This is the approximate size of the uranium particles which are imbedded in the graphite matrix.

Figure 16 is a plot of the accumulated weight percent of each particle size range, as well as the accumulated weight percent of the uranium recovered from each particle size range.

Conclusion

The ROVER/NERVA Destruct Systems Test was quite successful. The data obtained with respect to debris velocity, size distribution, and spacial distribution agrees very closely with the data obtained by the Army's Aberdeen Proving Ground.

These data are acceptable as the source term for the computer analysis of the ROVER/NERVA Program Safety.

The techniques used for data collection performed satisfactorily and the data obtained by both Aberdeen Proving Ground and Sandia Corporation were in fact complimentary.

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