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ROCKET ENGINE OPERATIONS — NUCLEAR

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REPORT NO. RN-S-0072

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

STATUS REPORT

FOR

BI-FUNCTIONAL DESTRUCT SYSTEM (U)

NERVA PROGRAM

CONTRACT SNP-1

APRIL 1964

AEROJET-GENERAL CORPORATION

AZUSA, CALIFORNIA

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STATUS REPORT
FOR
BI-FUNCTIONAL DESTRUCT SYSTEM
APRIL 1964

ROCKET ENGINE OPERATIONS - NUCLEAR

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NERVA PROGRAM, CONTRACT SNP-1

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ABSTRACT

This report presents a summary of the effort expended on Subtask 1.6 in Contract SNP-1 during the first three months of Contract Year 1964, prior to cancellation of this subtask on 31 December 1963. The report contains recommended design specifications and the results of initial design studies in evaluation of the Mark D bifunctional destruct system for application in the NERVA engine. In addition, a brief analysis of engine simulation and core fragmentation is presented plus an operational analysis of the anticriticality and postoperational destruct modes.

The work described herein was performed by the Aerojet Ordnance Research Division, Terminal Ballistics Department under the direction of REON.

W. D. Stinnett
REON Technical Systems Manager

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I. INTRODUCTION

This report is submitted to AEC-NASA Space Nuclear Propulsion Office (SNPO) by Aerojet-General Corporation, to outline and summarize the work accomplished by the Ordnance Research Division during the first three months of Contract Year 1964 under the provisions of Contract SNP-1, Subtask 1.6. All further effort on this work program was suspended when Subtask 1.6 was cancelled 31 December 1963. Conclusions have been drawn where conclusive analyses were performed prior to the interruption of the program.

The long range objective of the program was to develop a countermeasure system that would provide safe RIFT flights. An immediate objective of the program was to determine the feasibility of explosively destroying the NERVA engine reactor core. Two destruct modes are envisioned: an anticriticality destruct system (ACDS) for launch-pad, launch, and preoperation flight safety; and a post-operation destruct system (PODS) for safe disposal of the reactor prior to its reentry into the earth's atmosphere.

The function of the ACDS is to destroy and to disperse the reactor core material into noncritical masses in the event of reactor-control or booster-control malfunction. The tentatively established ACDS criteria requires that the maximum concentration of the disbursed core be no more than 13 lb of fuel-enriched core debris within a 25-in.-dia circle (Reference 1).*

The function of the PODS is to completely pulverize the reactor core into aerosol fragments so that its reentry into the earth's atmosphere will not constitute a radiological health-safety hazard. The tentatively established PODS criteria requires that no portion of the fuel-enriched core material shall exceed a maximum fragment size of 1/32 in. in the greatest dimension (Reference 2).*

* See list of References at the end of this report.

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During Contract Years 1962 and 1963 investigations were made to determine the feasibility of various conceptual ACDS and PODS. At the conclusion of the Contract Year 1963 program, the investigation of the ACDS as a separate system was discontinued and the investigation of a combined PODS/ACDS (bifunctional) destruct system was initiated. The Mark D concept (multiple explosive-projectiles implanted and detonated in the reactor core) proved to be the most promising PODS that was investigated during the program in Contract Year 1963 and therefore was established as the basis of the bifunctional destruct system (BDS) designated to be investigated in the program for Contract Year 1964. Since the PODS fragment-size objective imposes the more stringent requirements on the BDS, (Bifunctional Destruct System, also called BiPODS in other reports) the investigation of the ACD core-dispersion characteristics of the Mark D system was limited to an operational analysis. The program of Contract Year 1964 was basically concerned with investigating the Mark D concept for PODS application.

The objectives of the program for Contract Year 1964 were:

- (1) To conduct preliminary design and to initiate the development of components capable both of withstanding flight and space environments, and of introducing the explosives into the reactor core.
- (2) To investigate techniques for controlling the explosive fragmentation of the core to meet the established system criteria.
- (3) To analyze the operational system performance (ACDS and PODS).

There were three areas of component design activity; projectile, projectile launcher (gun), and projectile propellant. The proposed projectile-design study was planned to include the following:

- (1) An analysis of structural design to withstand launch and penetration loads.
- (2) An analysis of projectile-nose geometries to minimize deceleration loads during target penetration.
- (3) An analysis of fuzing and explosive initiation performance.

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The proposed launcher-design activity was to consist of a threeway weight tradeoff and performance analysis of front-orifice-recoilless vs rear-orifice-recoilless vs closed breech guns. The initial effort on the launcher design problem was the preparation of the Design Criteria which included tentative design specifications including the projectile acceleration limits, the required impact velocities, and the environmental conditions the launcher system would be required to withstand.

The purpose of the propellant study was to investigate the characteristics of conventional military propellants needed to provide the proper projectile acceleration and terminal velocity during projectile development tests, and to ascertain the ballistic characteristics of certain "unconventional" propellants. The unconventional propellants are rocket propellants that were chosen primarily because of their expected capability to withstand radiation damage. These propellants appear to have burning characteristics that are potentially superior to standard nitrocellulose-base powders. The analysis of the accelerated burning characteristics of these propellants was to be accomplished by using a specially designed strand-burning bomb that would permit inert gas atmosphere pre-pressurization of up to 60,000 psi. The final choice of propellant was to be based upon accumulated performance data and the results of radiation damage susceptibility tests.

As directed by SNPO-C, the proposed projectile and launcher development program was to utilize existing military guns to perform the initial tests. The guns were to be used with only a minor firing mechanism modification to provide for electrical detonation rather than percussion primer initiation of the propellant charges. Use of the military guns necessitated the design of additional hardware, such as a free-rotating obturator to minimize the undersirable projectile rotation produced by the rifling in the barrel.

The BDS design activities were to be supplemented by efforts at the U.S. Army Watervliet Arsenal (WA) and Aberdeen Proving Ground (APG). These support activities consisted of launcher design studies at WA and projectile development tests at APG, and were to be performed under Aerojet cognizance. The launch-tube

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design studies initially were to be based upon interior ballistics data provided by Aerojet, and later upon inputs of additional design data from both Aerojet and APG as the testing activity progressed.

APG was to conduct both investigation and evaluation as necessary on the projectile-casing design, nose geometry, minimum impact (muzzle) velocities, obliquity of impact, ejection of core material during projectile insertion, multiple-projectile interaction during insertion, and dynamic loads induced on explosives and fuzing mechanisms during reactor penetration. For these initial tests, APG was to utilize standard military guns and conventional military propellants as recommended by Aerojet. Later tests would use propellant compositions and grain configurations manufactured by the Government arsenal to Aerojet specifications. Presumably, these propellants would be of somewhat conventional composition (nitrocellulose base) and grain configuration. Concurrently, modified conventional military guns and existing military propellants would be used in the initial Aerojet design test phases, and the unconventional gun propellants and propellant configurations would be used during later phases.

The study objective of the proposed explosive fragmentation program was twofold; as follows:

- (1) To investigate optimizing projectile-fragmentation/core-fragmentation effects.
- (2) To define the limitations of system performance or design flexibility.

Optimizing fragmentation effects was to be accomplished by investigating related variations in projectile-casing thickness, metal condition, and controlled fragmentation pattern geometry, as applied to an "axial-area simulant" target. The axial-area simulant target represents a full-scale simulation of the reactor core modules radially adjacent to the implanted projectile.

The limitations in system performance were to be investigated by varying the spatial distribution of "optimized" projectiles within full-scale simulated engine (FSSE) targets (designated Mod 2H), and by analyzing the variations in core fragments the system produced. Analyses of these "extreme-condition" situations were to be used for tentatively establishing acceptable limits of performance or design objectives.

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Since NERVA engines nor NERVA engine component hardware were available, the proposed BDS development program was to utilize simulated engine targets that were fabricated from the best available simulations of the actual reactor hardware, within the limitations of material availability and reasonable cost. These factors necessitated the use of a relatively crude simulated engine. Therefore, a portion of the proposed program was to analyze and fabricate targets to simulate the static and dynamic characteristics of the actual NERVA NRX-A1 engine to the degree required by this phase of the program. Three types of targets are required; the axial-area simulant, the projectile penetration, and the FSSE. The simulated axial-area and the projectile penetration targets vary only in the degree to which the shadow-shield-penetration barrier has been represented.

An analysis of the operational performance of the BDS was partially completed. This partial analysis included an investigation of the anticipated capability of the BDS to perform the ACDS objectives under various failure modes during the flight mission. The completion of this analysis was to be accomplished with further data inputs during the test program in Contract Year 1964, and with the mathematical (computer) solution of the "theoretical subcriticality model" destruct event.

Performance analysis of the BDS pursuant to the PODS objective was to be limited to determining the most accurate fragment-size distributions and fragment space-time relationships achievable under the program funding limitations. The establishment of these parameters would then permit an analysis of the destruction of the "theoretical postoperation model" under various failure or reentry conditions.

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II. SUMMARY

Certain of the design activities planned for Contract Year 1964 had been sufficiently completed to permit a partial evaluation of technical progress when this portion of the contract was discontinued. The projectile and launcher design specifications were tentatively established, and were based upon achieving both the ACDS and the PODS performance objectives with the BDS. Limitations were established as to the extent of operational system development capabilities within the program constraints of Contract Year 1964. The specifications permitted design activities to proceed toward generation of a flight version of the BDS to be based upon the NRX-A type engine design, while the developmental work required generating experimental guns and projectiles to evaluate the interior and exterior ballistic parameters upon which the BDS is based.

The projectile design study required an analysis of the component parts of the projectile. The exterior ballistics relating to projectiles penetrating into the NERVA engine core were established from reasonable launcher emplacement positions about the upper thrust structure, minimum interference trajectories, and design details of the forward head structure, the core support, and the core. This study led to a stacked plate target design, considered to be dynamically equivalent of the real engine.

Considerable investigation was made of various nose geometries to select the most promising configuration. Smooth deceleration and uniformity of performance were governing factors. Since most of the target is impacted at oblique angles, tending to deflect the projectiles radially outward from the aim trajectory, the nose geometry selection is an important function. Even the concentric asymmetry of the core would tend to aggravate this deflection as the velocities are reduced. The two-caliber-radius nose is postulated to be the most promising. However, confirmation testing must be conducted to verify this belief.

Although the projectile-casing design will be primarily dependent upon fragmentation performance, the preliminary design was based upon the structural requirements induced by the high deceleration forces during penetration. Extremely high forces, which can exceed 10,000 g, are anticipated.

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Preliminary study of the shock pressures, to which the projectile explosive charge would be subjected during penetration, indicated that the explosive would probably not be detonated. As a precautionary measure, thin shock discs would be incorporated into both ends of the projectile to reduce the possibility of inadvertent detonations.

Utilizing the available military runs (which are rifled) imposes an additional problem on the projectile design, since rotation of the projectile is not desirable in the BDS design. A free-wheeling hydrostatic oil pad was designed to reduce this rotation.

The projectile fuze and explosive train were difficult to design because of the critical function-time dependency, and the high penetration deceleration anticipated. A rolling-ball-fuze design was selected as the most promising, and the more conventional military base-detonating fuze with an explosive-delay train was selected as an alternative.

A test program was formulated to complement the projectile evaluation experiments to be conducted by APG. These tests included evaluating candidate shock attenuators, preliminary projectile designs, planarity of impact and uniformity of penetration characteristics, and prototype fuze mechanisms, all under simulated dynamic loads. A modified Government-furnished equipment (GFE), gun was scheduled for use in the preliminary tests, with eventual phase-in of an Aerojet-designed test guns for use in subsequent refined experiments.

The Aerojet design of the 105mm closed breech test gun was completed. The interior ballistics were defined using the "Heydenreich" method solution. The test gun was to be fabricated from SAE 4340 Steel alloy with a minimum of external contour, and was to be equipped with a pressure transducer in the breech section and strain gages on the barrel section to monitor pressure-distance-time histories of initial test firings. A simple shot-start mechanism was designed to release the projectile at $\sim 6\% P_{\max}$. It consists of a tension rod passing from the projectile base through the propellant package and breech block. The gun mount was designed as a massive free-recoiling "sled" to be constructed of prestressed and steel-reinforced concrete.

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The GFE 105mm military howitzer was delivered to Aerojet and the test instrumentation and firing mechanism modifications were completed through the design stage only.

The Aerojet design of the 105mm rear-orifice recoilless test gun was completed, based on the design procedures and parameters obtained from the Armour Research Foundation Report LO-34, Volume I. The test gun was to be fabricated from SAE 4340 Steel alloy with a minimum of external contour. A pressure transducer was to be mounted in the expansion chamber (breech) and strain gages were to be affixed to the external barrel surface. Three expansion nozzles, having exit-to-throat area ratios of 2.0, 3.0, and 4.0, respectively, were considered. The shot-start device consists of a soft metal band at the base of the projectile, sized to yield at $\sim 6\%$ of $P_{\max}$. The nozzle-start device design is an externally constrained nozzle restriction, using restraining bolts that are sized to fail at a given pressure loading. The recoilless test gun mount design consists of a free-recoiling "pendulum" type system suspended from A-frames that are 10 feet high.

The GFE 105mm military recoilless rifle was delivered to Aerojet, and the test instrumentation and firing mechanism modifications were also completed through the design stage only.

The front-orifice recoilless rifle design study was only partially completed. However, a set of pressure- and velocity-vs-projectile-travel curves were derived. A computer program was planned to compare the parametrical performances of the closed breech, the rear-orifice recoilless, and the front-orifice recoilless launchers. From the initial study, it appeared that the front-orifice recoilless launcher could be designed to be competitive with the other two devices.

Several test series were planned for developing the closed breech launcher assemblies. The planned closed breech tests were designed to achieve a number of combined objectives. These tests included preliminary evaluation of the barrel, breech block, shot-start mechanism, gas check, propellant package, and interior and exterior ballistics.

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A propellant study was initiated that included the selection of a composition, a grain geometry, and a propellant-initiation system. Two basic types of propellants were considered; nitrocellulose base (standard military) and composite (rocket propellants). The nitrocellulose base materials, while reliable and widely used, are known to be more susceptible to radiation damage than are the composite materials. However, little is known of the performance of composites in gun applications. In addition, the thermal stability of propellants must be considered when the final selection is made.

A preliminary study of propellant grain geometries was made so that a specific propellant could be placed on order early enough to be available when required for component testing. The limited interior ballistic studies that were completed indicated that the grain would probably be a single perforated shape, with l/d ratios of >2 . The initial web size for the closed breech guns using military propellants would be ~ 0.1 in., and for the recoilless rifles it would be ~ 0.3 . For composites, the size will be about an order of magnitude larger, which for the recoilless rifles means a single grain nearly as large as the propellant chamber.

Propellant initiation system materials were studied to determine which offered the most promise in a radiation environment. A considerable amount of design data were derived from the initiation system for the Davy Crockett recoilless rifle. For the closed breech guns, however, the projectile-start mechanism influences the initiation system design, since the tension rod would penetrate the propellant package. Experiments were planned in which the burning rates of propellants at anticipated gun pressures could be determined if this information was not available from existing literature.

The initiation studies included determining of the following:

- (1) The burning characteristics of the ignition materials at elevated temperatures.
- (2) Their ease of initiation.
- (3) The reliability of their initiation.
- (4) Their ability to ignite materials.

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The propellant packages used in the GFE guns were to be modified from inert cartridges which would also be supplied as Government-furnished material (GFM). Refined packages were to be designed for firing in the Aerojet-designed launchers when those devices became operational.

The Government supporting operations were to consist of two activities under the technical direction of Aerojet. Aberdeen Proving Ground was to conduct projectile, fuze, and interior ballistics experiments of a preliminary nature. Watervliet Arsenal was selected to perform a parametric design study of launchers for the Mark D Bifunctional Destruct System (BDS). The necessary design and test specifications covering this effort were completed by Aerojet prior to termination of the project.

The explosive fragmentation study was planned to continue investigating the parameters affecting core pulverization performance. Because of the need to obtain statistically valid samples of fragments resulting from destruct performance tests, concentrated effort was placed on better means of data recovery and analysis. Also under consideration were means for determining fragment space-mass-time relationships necessary for the reentry-hazards evaluation. The eleven major tests planned for Contract Year 1964 consisted of six axial-area targets for defining both the optimum charge-casing geometry and the metal condition producing the greatest core fragmentation. The remaining five tests were to use FSSE with four optimized 105mm charges emplaced within the core. These tests were designed to study the effects of radial, longitudinal, angular, and combined "worst conditions" distribution of projectile and gun "jitter" parameters.

The fragment-recovery system was redesigned to permit analyzing up to a 90° segment from Ground Zero, instead of the previous 10° segment. Vacuum sweepers were to be used for discrete collection from an overlapping thin-steel plate array of 400-ft-radius placed on a 6-in.-thick gravel base. Continued emphasis was to be placed on photographing the expanding graphite dust cloud in an attempt to identify fragment size, shape, and velocity values to be related to ground-deposited array patterns.

The reactor simulation study was a necessary part of the program to permit designing adequate FSSE when accurate core materials would not be available in

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the required quantities. The prime design specification was to simulate, as accurately as possible, the anticipated overall NERVA engine dynamic response to destruct action from four full-core-length 105mm charges. As such, two Mod 2 target configurations were designed that consisted of different component parts. In addition, all other exterior ballistics targets were designed for the specific impact and penetration objectives desired.

An ACDS operation analysis was begun with establishment of an ACDS "analytical model" as its goal. A method of analysis was suggested for manipulating a wide variety of uncontrolled variables, and an analog computer setup was envisioned. This analysis was to investigate the adequacy of fragment dispersal, consider whether an "overskill" could be permitted and determine, if possible, the circumstances of booster failure that would materially affect or oppose the methods of anticritically assurance that would be employed. Sample calculations were completed permitting qualitative evaluation of the expected performance of various versions of the Mark D BDS as measured against ACDS criteria.

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III. TECHNICAL DISCUSSION

A. DESIGN SPECIFICATIONS

1. Bifunctional Destruct System (BDS)

The projectile and launcher design specifications were tentatively established at the outset of the program for Contract Year 1964, and were based on achieving both the PODS and ACDS performance objectives with a BDS. Consequently, the hardware design specifications are in the composite form of combined functional and operational requirements, each defining the other to some degree. Initial designs were based upon the known, or tentatively established, system requirements and were to be modified or upgraded as the interpretation of performance objectives, in terms of design specifications, was made.

Tentative design specifications are:

RIFT flights only

Suborbital startup only

NRX-A reactor configuration only

Mark D PODS bifunctional analysis only

Four-105mm-projectile concept performance-testing evaluation only

ACDS fragment dispersion objective. (Disperse entire mass of fueled NERVA core elements such that fragment concentration after destruct is less than 13 lb within any flat 25-in.-dia surface.)

PODS fragment-size objective. (Reduce the greatest possible portion of the NERVA reactor-core elements to fragments of less than 1/32 in.)

ACDS functional reliability and safety. (Destruct system must be capable of functioning safely and reliably while performing the ACDS fragment dispersion objective from launch pad to NERVA engine startup, at $\sim 6\%$ power, while in the confinement of the RIFT interstage structure.)

PODS functional reliability and safety. (Destruct system must be capable of functioning safely and reliably while performing the PODS fragment-size reduction objective from NERVA engine startup, at $\sim 6\%$ power, to incipient reentry, without the presence of the RIFT interstage structure.)

Envelope and attachment. (Insofar as possible, destruct system envelope and attachment should be limited to the Aerojet interface envelope.)

Radiation environment per overlay Figures 1 and 2.

Component environments are presented in Table 1.

Launcher requirements:

Bore diameter = 4.125 to 5 in.

Maximum pressure for closed breech = 20 to 50 ksi

Maximum pressure for recoilless = 10 to 32 ksi

Barrel length $\leq$ projectile length

Projectile requirements:

Projectile weight = 92.5 to 135.0 lb

Projectile length = 64 to 73 in.

BDS functional requirements:

Muzzle velocity = 950 to 1300 fps

Projectile travel $\leq$ one projectile length

Response time for closed breech* = 8 to 12 msec

Response time for recoilless* = 11 to 17 msec

2. Ballistic Test Guns

The process of designing the test guns, both closed breech and recoilless, essentially consists of satisfying external ballistic requirements, while observing either established or recommended design procedures. Given a series of values for various design parameters, a reasonably straightforward solution to a design procedure can be defined. For the test guns,

* Time from propellant fire pulse to terminal velocity attainment.

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Figure 1

Mod D Bifunctional PODS

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Figure 2

Radiation Environment

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TABLE 1

DESTRUCT SYSTEM COMPONENT ENVIRONMENTAL SPECIFICATIONS

Temperature

Propellant and initiation train:	0° to +125°F
Launcher:	20°F to +180°F
Support structure:	-234°F to +250°F

Vibration

In any three mutually perpendicular axes; components to withstand vibration at major resonances for not less than 6 min;	0.67 g, 0 to peak for 5 to 45 cps; 0.0065 double amplitude, 45 to 85 cps; 2.5 g, 0 to peak for 35 to 2000 cps
--	---

Random Vibration

Flat spectral density of 0.045 g²/cps
5 to 3500 cps. for 16 minutes

Shock

In any three mutually perpendicular axes; three times in any direction:	If rise time of primary frequency is ≤ 350 cps, then duration = $\left(\frac{700}{\text{primary frequency}} \right) - 1$ msec; if rise time of primary frequency of < 350 , then duration = 0 - 1.5 ms
---	---

Pressure

30 in. Hg to 10⁻¹² mm Hg

Humidity

0 to 100%

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primary design parameters include allowable barrel length, maximum allowable chamber pressure, projectile weights, and computed projectile velocity requirements. Since weight optimization and space limitations are of extreme importance with the actual destruct system, a minimum overall barrel length was sought for both the closed breech and the recoilless guns. This approach dictates working with chamber pressures toward the upper limit. The primary design parameter, or limitation, therefore becomes a matter of establishing a maximum allowable working pressure, based on qualified recommendations that consider interior ballistics and material strengths. From these sources, allowable peak chamber pressures of 32,000 psi for the recoilless gun, and of 50,000 psi for the closed breech gun were established. A projectile weight of ~ 130 lb was established for the projectile design. Corresponding velocity requirements were computed, and with these values for basic design parameters, the actual design of the test guns was undertaken.

B. PROJECTILE DESIGN STUDY

1. Exterior Ballistics

Stacked plate targets were designed to simulate the NRX-A1 engine forward-head assembly for the projectile development and penetration tests. Scaled layout drawings of the engine were made to determine the best points of impact and paths of penetration. Four 105mm launchers were assumed to be mounted above the engine gimbal on the upper thrust structure, and the engine was assumed to be locked in its centered position.

The limiting insertion angles (angles between centerline of the projectiles and the longitudinal axis of the engine) were determined by the dimensions of the exterior hardware and the core. The minimum insertion angle was found to be 1° and was defined as 1/2 caliber outside the engine turbopump and 1/2 caliber inside the top edge of the core. The maximum angle was found to be 20° , passing 1/2 caliber inside the top of the control drum actuator and exiting 1/2 caliber inside the opposite edge of the core bottom. An intermediate limit of 8° existed within this range, above which the projectile trajectories had to be offset from the engine cross-sectional centerline and criss-crossed inside the core without intersecting. All paths were through the lower thrust structure, but for the preliminary study the structure was assumed to be ported or tunneled to avoid penetrating any layer before impacting the top closure.

Some of the layers to be penetrated were expressed as average thicknesses, since the thickness varied across the diameter of the projectile path. Other layers were composites of various materials and voids; thus, equivalent solid thicknesses that would give similar penetration results had to be estimated.

The three limiting insertion angles (1° , 8° , and 20°) were selected as representative and were used to calculate the simulating stacked plate targets, although all of the layer thicknesses did not follow the conventional insertion angle trend (increasing thickness with increasing angle).

Because of low cost and availability, the material selected for the targets was universal mill plate (ASTM-A7) for the metal layers, and graphite, Grade AGSX (National Carbon Co.) for the core.

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Equivalent layer thicknesses were determined (Reference 1)* by the following equation:

$$t = k \frac{mV^2}{A\sigma} \quad (1)$$

where

t = depth of penetration, in.

k = scaling factor, dimensionless

m = projectile mass, (lb-sec²)/in.

V = impact velocity, fps

A = cross-sectional projectile area, ft²

σ = target tensile strength, psi

For scaling, k , m , V , and A are constants for any layer penetrated. Hence:

$$t_s = t_R \frac{\sigma_R}{\sigma_s} \quad (2)$$

where subscripts

s = simulated target

R = real target

The equivalent thicknesses thus determined were rounded off to the nearest available plate size.

For the impact velocity of each layer, Equation 1 was modified as follows:

$$\frac{\text{loss of kinetic energy}}{\text{penetration}} = \frac{mV_i^2 - mV_e^2}{t} = \frac{A\sigma}{k} \quad (3)$$

* See list of References at the end of this report.

so that:

$$v_i^2 - v_e^2 = \frac{tA\sigma}{mk} \quad (4)$$

where subscripts

i = impact

e = exit

It was assumed that the projectile came to rest centered in the core so that impact velocities calculated for the top closure were minimums.

The time (in seconds) to penetrate each layer was determined with:

$$T = \frac{2t}{12 (v_e + v_i)} \quad (5)$$

The times required to pass through the voids between layers were assumed to be negligible.

Because of the similitude of basic requirements for the three conditions considered (i.e., dimensions, velocities, and penetration times), an average target (Figure 3) was selected in lieu of employing three separate units (Table 2).

2. Nose Geometry

It was recognized that a long, pointed projectile nose would penetrate a target with less resistance than would a stubby-nosed unit. However, with a slender nose, the chances of breaking (by oblique impacts) and of obtaining nonuniform penetration are greater. Since the spatial distribution relationship of the implanted projectiles within the reactor core is of primary concern for optimum fragmentation performance, ogive designs known to yield maximum uniformity of performance were being evaluated for the NERVA engine countermeasure system. The most promising nose geometries considered were:

Figure 3
Simulated Reactor Target

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TABLE 2

PROJECTILE VELOCITY AND PENETRATION TIMES FOR THREE INSERTION ANGLES

Conditions	Insertion Angle		
	1°	8°	20°
Minimum impact velocity at top closure to penetrate to the bottom of the core (ft/sec)	1074	1036	1048
Total time to penetrate the simulating target from impact to bottom of the core (msec)	20.001	20.056	20.611

Two-caliber radius ogive (Figure 4)

5-1/4-inch radius ogive (Figure 5)

Parabolic nose (Figure 6)

APG biconical head (Figure 7)

In the designs presented by Figures 5, 6, and 7, the heights of the ogive (the distances from the tip to the full caliber of the projectile) were each equal to 1 cal or 4.125 inch. By holding this height constant and by maintaining the steel in each head at identical physical properties, true penetration characteristics of each nose geometry could be evaluated for projectile design comparison studies. The parabolic nose was designed to give equal amounts of lateral target displacement for equal increments of target penetration, thus yielding the least projectile chatter as it penetrated the multiple layers of the simulant target. Any nose, once buried in a homogeneous target, will experience smooth deceleration; however, in the process of burying itself, the resisting force on the nose will be a function of the rate at which the target material is displaced. A nonuniform increase of target material displacement will cause nonuniform deceleration and will create chatter. Since the individual layers of the target will create chatter in the projectile, and the fuze mechanism is armed upon initial impact of the projectile, it was anticipated that a nose in the form of a paraboloid of revolution might offer the smoothest deceleration to the

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Figure 4

Two-Caliber Radius Ogive

Figure 5

5-1/4-Inch Radius Ogive

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Figure 6
Parabolic Nose

Figure 7
APG Biconical Head

projectile and ensure proper function of the mechanical fuzing device. However, the comparative performance of this nose geometry, at oblique angles of impact, may be inferior to the biconical head because of its greater tendency toward lateral offset at the instant of initial target impact. Empirical data derived from the APG projectile tests would be assimilated for subsequent refined experiments evaluating destruct function and integrity against a dynamically simulated NERVA engine.

3. Casing Configuration

Although the final design of the projectile casing may be primarily dependent upon fragmentation performance requirements, the preliminary design was based upon the structural requirements of the high deceleration forces imposed during reactor penetration. Analysis of the critical buckling loads during successive impact with the stacked plate targets indicated that the wall thicknesses selected for the initial Aberdeen tests were satisfactory from an elastic stability standpoint. These calculations are, however, only an indication of what might happen. The following conditions were not taken into account:

- (a) The inertia of the wall against buckling.
- (b) The columnar support provided by the explosive under high gravitational loading.
- (c) The exact time durations during which the deceleration forces act through the entire target penetration process.
- (d) The local plastic deformation of the ogive that will reduce the magnitude of energy transmitted to the projectile wall.

Furthermore, it was difficult to achieve a rational analysis of the stresses acting on the casing, at an oblique impact angle, since the magnitude and time duration of the lateral force vector acting on the nose could not be rigorously determined. This problem was eventually resolved by approximating the lateral component of the total impact force and the lateral acceleration given to the nose, assuming the projectile to be a rigid body. From this analysis it was determined that the 0.438 inch thick wall would withstand a 10,000 g minimum impact. Partial assurance of this is given by the fact that 0.25 inch thick wall

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projectiles have been successfully fired at lesser terminal velocities into crude simulated NERVA targets at APG without appreciable damage to the projectile casing. To preclude any delay in the proposed APG and Aerojet tests, an alternate casing with a 0.500 inch thick wall was made available in the event of failure of the thinner casing.

4. Shock Discs

A preliminary examination of the shockwave pressure, to which the projectile explosive charge would be subjected during penetration, indicated that the explosive would probably not be detonated. In armor piercing shells where much higher velocities exist, the only shock-attenuating device is the inside protective coating that is used to prevent corrosion between the contained explosive and the steel shell. It is possible, however, that the extensive delay in projectile-charge initiation would be complicated by shockwaves propagated within the structural envelope of the carrier. As a precautionary measure, shock-attenuating discs of acrylic plastic were incorporated in the nose and base ends of the projectile to preclude the possibility of shock-interaction effects that might cause inadvertent detonations.

5. Obturating Band

Previous investigators have shown that the rubber obturating ring (Figure 8, Part No. 514918-1) will not eliminate rotation of the projectile when fired from a standard military 105mm rifled gun. An alternate obturating ring, employing a free-wheeling hydrostatic oil pad (Figure 9, Part Nos. 514931-1, 514933-1, 514935-1, and 514936-1), was designed to eliminate all rotation.* Although it was anticipated that the ultimate launcher would not employ rifling (and hence, no free-wheeling obturator would be necessary), appreciable rotation of the projectile could interfere with the fuzing time of live projectiles fired from rifled guns through the action of centrifugal force accelerating the travel of the striker. As illustrated in Figure 9, the oil reservoir is the only physical connection between the free-wheeling obturating ring and the projectile. Pressure from the breech is transmitted to the projectile through the oil pad.

* Figures 8 and 9 are photoreduced assembly drawings less the detail part descriptions. The part descriptions are given in Table 3.

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Figure 8

Rubber Obturating Ring (Part No. 514918-1)

Figure 9

Free-Wheeling Hydrostatic Oil Pad
(Part Nos. 514931-1, 514933-1, 514935-1, and 514936-1)

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TABLE 3

PART DESCRIPTIONS FOR FIGURES 8 AND 9

<u>AGC P/N</u>	<u>Description</u>
<u>Details - Figure 8</u>	
514917-3	Projectile Base Plug
514918-1	Obturating Ring
514919-3	Ring Retainer Plate
NAS1352-3LE1OP	Retainer Screw
<u>Details - Figure 9</u>	
514935-1	Projectile Base Plug
514931-1	Obturating Assembly Retainer
514936-1	Obturating Assembly Inner Bushing
514933-1	Obturating Assembly Housing
125-27 NPT	Oil Filler Plugs
Pipe Plug, 2 Req'd	
MS 35225-22	Positioning Screw
514934-1	Obturating Ring and Base

At 50 ksi breech pressure, the resultant oil reservoir pressure is approximately 135 ksi. There is no oil seal to bind under this extreme pressure, and leakage is controlled by diametrical clearance, viscosity of the oil, and time. Calculations predict that approximately half of the castor oil will be forced out of the reservoir during the projectile acceleration phase. Therefore, the probability of the contacting metal parts causing excessive friction and resultant projectile rotation is minimal. Castor oil was selected to supplant conventional lubricants since it provided superior viscosity/pressure characteristics.

6. Fuze and Explosive Train Design

The critical nature of function time-dependency and the anticipated high penetration deceleration presented a difficult problem in the design of the fuze. Common black-powder delay trains were investigated and discarded

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as not being sufficiently reliable to provide the desired accuracy. Mechanical devices that were investigated included the projecting-appendage-types. These designs were eventually discarded because they were susceptible to malfunction caused by vibration, shock, flying target debris, and projectile rotation. Extreme deceleration forces would create locking friction on any weight that would be required to slide normal to the projectile motion. This is not true of a rolling ball which can benefit by the additional friction, provided the mating bearing surfaces are structurally compatible. Figure 10 illustrates such a ball fuze arrangement. With a known ball weight, travel, and time, the driving spring can be readily sized. While it was recognized that vibration would be initiated by multiple penetration interaction could cause the observed fuze time to vary from that predicted, the desired duration could be obtained by varying the spring load by using a trial-and-error technique. It was planned to use exploratory experiments employing "tell-tale" charges to achieve this objective.

As an alternate to the rolling-ball fuze, it was proposed to use the standard military Base Detonating Fuze M58 (Figure 11), or an equivalent. The initiation train would consist of a duPont 820 Pyrocore, an X310-A primer, a C-63 booster, and the projectile explosive charge.

The time delay is directly proportional to the length of Pyrocore, which burns at the rate of 14,000 ($\pm 3\%$) ft/sec. Thus, the time delay for a 0.015-sec fuze would be accurate to within 0.00045 sec. The exact length of the Pyrocore was to be determined experimentally. While this Pyrocore fuze offers extremely accurate time delays, approximately 200 ft are required per fuze; consequently, with a redundant system, 400 ft would be required. Since the outside diameter of Pyrocore is 0.073 inch, and a separation of ~ 0.010 inch is adequate between adjacent strands to prevent cutoff, it was planned to turn a U-shaped double thread of 0.2-in. lead, 0.1-in. pitch on the outside diameter of an aluminum liner. The necessary Pyrocore would then be wrapped on this threaded mandrel, and the assembly would be inserted into the projectile. The M58 impact fuze initiation in the base of the projectile would travel through the Pyrocore and ignite the projectile explosive charge. Although somewhat cumbersome, the Pyrocore fuze appears to be free from all the extraneous factors that might cause erratic time spreads between projectiles.

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Figure 10
Rolling Ball Fuze Design

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- A = BOOSTER EXPLOSIVE
- B = BOOSTER CASE
- C = FUZE BODY
- D = DETONATOR HOLDER
- E = FIRING PIN
- F = PLUNGER
- G = HOLD-BACK RING
- H = SPRING
- I = DETONATOR

Figure 11
Base Detonating Fuze Design

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7. Testing Procedure and Instrumentation Techniques

A test program was planned to complement the projectile-evaluation experiments to be conducted by APG. The following series of projectile design tests were to be conducted:

Preliminary evaluation of candidate shock attenuators

Preliminary design (structural integrity and penetration characteristics) evaluation

Evaluation of refined projectile designs (inert) for uniformity of penetration characteristics and for spatial distribution

Preliminary evaluation of prototype fuze mechanisms under simulated dynamic loads to determine arming, delay timing, and safing requirements

Evaluation of function and integrity of projectile/fuze designs - interior and exterior ballistics effects

Final evaluation of projectile design, to ascertain planarity of impact and penetration characteristics.

GFE guns were scheduled for the preliminary tests with an eventual phase-in of Aerojet test guns on subsequent refined experiments.

The purpose of the first test series was to evaluate "setback" and penetration effects upon candidate shock disc materials for possible use in the BDS projectile assembly. Targets for these experiments were to consist of steel plates to simulate the forward head structure. Pressure-time history of the gun and projectile time-of-arrival during penetration of the target were to be monitored to substantiate the anticipated dynamic environment.

The second test series was to evaluate the structural integrity of prototype projectiles of various nose geometries for varying planarities of impact angles and penetration. Targets used for these tests were to consist of multiple, stacked steel plates to simulate the penetration toughness and characteristics of materials encountered for forward insertion into the NERVA engine. In addition to projectile travel, time, and velocity; its penetration into the target would be recorded by Fastax camera and electronically timed by placing timer-actuating foil switches within the stacked target array.

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Design evaluation of refined projectile assemblies for the third series was to employ similar instrumentation as the second series. Targets proposed for these tests consist of a crude simulated core behind the forward simulated shadow shield for preliminary penetration and core positioning studies of the projectile.

The primary objective of the fourth series of tests was to evaluate the basic functions of the fuze such as safety, arming, and delay timing. Targets or projectile assemblies were not required. Candidate fuze mechanisms would be encased in dummy containers and subjected to various g loadings by drop impact or sled mechanisms. No specific instrumentation was planned other than photographic documentation after calibration of the installation was completed.

Projectile designs with live fuze assemblies would be used in the fifth series of tests. The initial rounds would primarily be used to investigate function and nonfunction limits to establish bore-safe criteria for the fuze mechanisms. Subsequent rounds would be used to evaluate fuze function and delay time when fired into axial-area simulated targets. Pertinent parameters would be monitored to ensure adequate interior and exterior ballistics effect coverage.

In the final series of tests, refined projectile assemblies with either live or tell-tale charges would be fired into axial-area simulated targets for final evaluation of uniformity of performance, structural integrity, spatial deployment, and apparent fragmentation performance.

Various instrumentation arrangements and techniques were developed for recording the different parameters necessary for the projectile development phase. The primary test data that were to be accumulated during the projectile test series included:

- Breech or chamber pressure-vs-time
- Projectile start and travel
- Projectile terminal velocity
- Target penetration.

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The following test instrumentation would be used.

a. Pressure-vs-Time

A pressure transducer was to be installed in the breech section of the closed breech gun and in the chamber of the recoilless rifle to obtain dynamic performance data during shot initiation, start, and expulsion. The instrumentation purchased for this purpose consisted of a Kistler ballistic pressure transducer (0 to 100,000 psi) Type 605B/633B, a Kistler charge amplifier Type 566M3, and a low-noise cable between transducer and charge amplifier. Sensor traces were to be recorded on an oscilloscope or an oscillograph, or both.

b. Projectile Start and Travel

Since most of the experiments involved launchers having a barrel length shorter than the projectile length, a series of probes were to be located immediately in front of the muzzle so that the initial projectile start and acceleration phenomena could be recorded external to the gun barrel. Design was completed on a mixer circuit that would provide positive and negative pulses with varying time duration, to be used in conjunction with ionization or mechanical probes that would record the time-vs-displacement history of the projectile. A Tektronix Type 535A oscilloscope with raster modification would be used for the data pickup.

c. Projectile Velocity

A series of foil switches (or probes) located in front of the target impact zone were to record the projectile terminal velocity. Fabrication was initiated on a pulse-producing system that would provide the input to the oscilloscope for the time-of-arrival studies of the projectile during flight and target penetration. A Tektronix Type 535A oscilloscope with a modified raster was to be used for data pickup.

d. Projectile Target Penetration

Foil switches located on each side of the stacked target array were to be used to record the projectile time-of-arrival through each major interface of the target. Pulse-time histories were to be monitored on oscilloscopes. In addition, it was planned to use photographic documentation to facilitate data reduction of selected experiments.

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8. Projectile Deceleration Studies

Various empirical formulas have been developed to predict the depth-of-penetration of a projectile into homogeneous targets. While the factors of projectile velocity, projectile mass, projectile diameter, and target strength are included in these formulas; the nose geometry, or shape of the ogive, is not included. It was reasoned that this nose geometry becomes increasingly important as the homogeneous target approaches a series of stacked plates with air spaces between them. A basic penetration formula is shown as follows:

$$P = \frac{kMV^2}{SA} \quad (6)$$

or

$$PA = \frac{2k \frac{MV^2}{2}}{S} \quad (7)$$

where

P = penetration

k = a constant depending on target material

M = mass of projectile

V = velocity of projectile

S = tensile strength of target

A = area of projectile

Since PA is the volume of the hole in the target and $MV^2/2$ is the kinetic energy, the formula may be written

$$Vol = 2k \frac{K.E.}{S} \quad (8)$$

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showing that the volume of the hole varies directly with the kinetic energy of the projectile. By finding the number of foot-pounds of kinetic energy per cubic inch of target hole, and by calculating the cubic inches of the target plates displaced by the nose of the projectile as it travels through in increments, both velocity and deceleration of the projectile may be calculated at any point in the target. Such information is plotted on the curve presented in Figure 12. A blunt projectile nose displaces more target material faster than a slim nose, and results in a greater loss of kinetic energy and velocity, and a higher deceleration rate than a projectile with a slim nose.

Figure 12
Two-Caliber Nose Penetration Performance

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C. LAUNCHER DESIGN STUDY

1. Test Guns

a. Closed Breech

(1) Aerojet Design

The Aerojet design of the 105 mm closed breech test gun has been completed. The ballistic design was achieved principally through utilizing the "Heydenreich" method of solution. This approach combines analytical solutions with appropriate empirical corrections obtained from extensive tests conducted with existing gun designs. It is generally regarded as being the most satisfactory approach to the early stages of closed breech gun design. Upon establishing basic design factors (peak chamber pressure, projectile weight, and velocity), the completion of such a gun design becomes quite straightforward. Insofar as materials selection is concerned, SAE 4340 Steel Alloy was chosen for all major gun components because of its high tensile strength and excellent resistance to failure under shock or impact loading. Components were to be heat-treated to produce a moderate yield strength of approximately 115,000 psi to avoid the possibility of brittleness usually associated with higher heat-treat levels.

A refined breech-block was incorporated into the Aerojet-designed test gun. Basically, this improved version is contoured internally to give a constant shear stress, or constant thread loading, along the full-thread-length of the block. This is achieved by providing a constant pressurized area per thread turn, loaded axially by combustion gases during firing. The advantage of this type of thread loading is in that, since the full length of the thread is loaded (rather than the first one-third to one-half of the total thread length as in conventional design, flat pressure-loaded face breech block) overall thread length may be shortened considerably for a given induced stress. Shortening the block manifests itself in substantially reducing the weight of the breech block component. The breech of the test gun was to be fitted with a threaded hole to accommodate installation of a pressure transducer for monitoring a pressure-time history of initial test firings. The barrel of the closed breech

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gun was to be machined from SAE 4340 forged round stock. Machine work on the external profile of the barrel was limited to a series of machined "bands" along the length of the barrel, upon which strain gages would be installed.

A shot-start mechanism was incorporated into the design of the Aerojet closed breech gun. This consists of a steel alloy rod threaded into the base of the projectile and passed through the breech block at the rear of the barrel, where it is restrained by means of a threaded nut. A groove is machined into the rod near the forward threaded end. This groove is sized to fail at a desired loading, leaving the projectile free to be accelerated down the bore of the gun. The "preloading," or more accurately, the prepressurization of the gun breech, thus results in improved ballistic performance for a given barrel length. The closed breech gun is illustrated in Figure 13.

Mounting the closed breech gun for test purposes presented design problems because of the extreme loads imposed upon a mount system when the gun is fired. The most satisfactory approach to this problem was a free-recoiling sled, on which the test gun will be mounted. The sled was to be of steel and concrete construction, having a design weight limiting maximum

Figure 13
Closed Breech Gun

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recoil velocity to ~ 20 ft/sec and limiting recoil displacement to ~ 8 ft. Sled weight required to satisfy these conditions is approximately 15,000 lb. Structural steel was to comprise about one-third of the total weight, with the remaining ballast consisting of reinforced concrete.

In the sled design, the major portion of recoil loading was absorbed by two large wide-flange beams running the length of the sled. Approximately 30 steel alloy rods extended lengthwise throughout the concrete structure. They were to be secured into position before the concrete was poured, and were to prestress the concrete matrix. This would permit the concrete to be loaded in compression at all times, thus greatly increasing its load-carrying capacity. In addition, transverse tension rods were to be used to further strengthen the concrete structure. A series of steel alloy collars were to be used to mount the test gun barrel to the sled. A major advantage of this type system is that the complete assembly can be transported to various test sites, should conditions so dictate. The recoil sled with closed breech test gun installed is illustrated in Figure 14.

Figure 14
Closed Breech Test Gun Recoil Sled

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(2) Government-Furnished Gun

To expedite testing and evaluating both interior ballistics and projectile performance, initial test firings were to be conducted with a military 105 mm howitzer supplied as GFE, and modified to the extent that pertinent performance test data could be monitored. Major additions included installing strain gages along the barrel length, installing a pressure transducer in the breech section, and modifying the mechanical firing mechanism to permit electrical ignition of the propellant. It was expected that the modified howitzer would be operational at a considerably earlier date than would the newly designed Aerojet closed breech test gun, and that much could be learned about projectile and propellant characteristics, which could be applied to later tests with the Aerojet-designed test gun.

b. Recoilless

(1) Aerojet-design

Basic Aerojet design of the 105 mm recoilless test gun was completed. Considerable information concerning design procedures and parameters was obtained from the Armour Research Foundation report (Reference 2),* which deals with a similar development program. The Aerojet-designed gun is composed of three basic components; the barrel, the breech (propellant chamber), and the expansion nozzle. Various expansion nozzle configurations were under consideration, the principle parameter being the ratio of exit-to-throat areas for each nozzle. Initially, three expansion nozzles were to be fabricated, having ratios of exit-to-throat area of 2.0, 3.0, and 4.0, respectively. Barrel length was established at 144 in., which is long enough to allow considerable flexibility in projectile weights. As the test gun was refined and evaluated, the barrel length was to be shortened in interests of performance and weight optimization studies.

In the design, a shot- and nozzle-start mechanism is incorporated into the recoilless design to improve ballistic performance. The projectile (shot-start) is restrained by means of a soft metal band at the rear of the projectile, which is sized to collapse (yield) at the desired propellant chamber pressure ($\sim 6\%$ of $P_{\max}$). The nozzle-start mechanism consists of an

* See list of References at end of this report.

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externally constrained nozzle restriction, having restraining bolts that are sized to fail at a given pressure loading. Final sizing of these shot-start constraints will depend to some degree on their observed performance in initial test firings. Major components of the Aerojet designed recoilless test gun were to be fabricated of SAE 4340 Steel Alloy because of the ability of this alloy to sustain repeated shock loads. Heat treatment was to be kept relatively moderate (115,000-psi yield) to avoid the characteristics of failure normally associated with more brittle materials, and to ensure transmissibility of accurate stress signals. The recoilless test gun is illustrated in Figure 15.

Figure 15
Recoilless Test Gun

Mounting the recoilless gun for test purposes would present considerably less difficulty than would the closed breech model, because of the relatively low firing forces imposed upon the mount system. A

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free-recoiling pendulum-type mount system was suggested for the recoilless test gun in view of this low loading. Such a mount would consist of a pair of upright A-frames ~10 ft high, with an I-beam for connecting the two A-frames and suspending the gun. Attachment to the gun would be at two places, one near the forward end and the other at the combustion chamber. The gun would be secured by means of steel collars attached to flexible steel cables. Upon firing, any recoil imbalance would result in a slight gun-rocking that should be of short duration. This mount offered the advantages of extreme simplicity in construction and portability, and is presently regarded as the most promising approach for the recoilless test gun. Figure 16 is an artist's conception of the recoilless test gun and mount system.

(2) Government-Furnished Gun

Modification of a 106 mm military recoilless rifle for test purposes would result in expediting projectile and propellant performance evaluation for the recoilless concept. This procedure was suggested since modifications required on the GFE gun were minor in nature and would result in an operational unit well ahead of the anticipated date of completion of the Aerojet-designed recoilless test gun. The modifications were quite similar to those planned for the GFE closed breech howitzer. They included installing strain gages along the external length of the barrel, installing a pressure transducer into the combustion chamber section of the gun, and making minor alterations to the ignition (firing) mechanism. It was expected that results of initial tests with the modified GFE gun would be applied directly to subsequent testing of the Aerojet-designed unit, thus materially expediting further refinement of the Aerojet test gun.

2. Front-Orifice Recoilless Rifle

The planned study of launchers for the BDS included the front-orifice recoilless (FOR) rifle. The primary object was to determine its total competitiveness with the other candidates, the closed breech gun and the rear-orifice recoilless (ROR) rifle.

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Figure 16
Recoilless Test Gun Pendulum Mount

The total competitiveness of the FOR launcher was not determined because of termination of the project. However, some interior ballistics work was accomplished. Figure 17 describes a typical set of pressure and velocity

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Figure 17

Typical Interior Ballistics of a Front Orifice Recoilless Rifle

vs projectile travel curves for an FOR rifle. The method (Reference 2)* used to develop these curves required many trial solutions before arriving at a desired result because of the number of independent variables. It did, however, help define the limits of the variables. A parametric study would have used solutions generated by a computer, the amount of computation then being relatively

* See list of References at the end of this report.

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unimportant. The complete parametric study would have specified (by curves) the interrelationship between propellant composition, initial propellant weight, projectile weight, and muzzle velocity. Hence, any given closed breech or ROR launcher could have been compared directly with the equivalent FOR launcher. Since exact penetration and environmental specification had not been decided upon, these parametric curves would have been essential when such specifications were defined. At that time, specific launchers could be quickly compared for selecting the best type of launcher and for achieving the optimum design of the selected type.

The FOR rifle is a combination of the closed breech gun and ROR rifle. The closed breech gun has a large unbalanced recoil impulse rearward, while the ROR rifle has essentially a zero unbalanced impulse, because of the nozzle thrust of its escaping propellant gases. Initially, the FOR rifle operates as a closed breech gun, producing a rearward recoil force. After a short projectile travel, the base of the projectile uncovers several ports in the barrel wall leading to rear-facing nozzles. This allows the propellant gas to escape to the rear of the rifle, producing an unbalanced forward recoil force, and thus, offsetting the initial rearward unbalance. A properly designed FOR rifle produces a net impulse of zero for the ballistic cycle.

Because of this small recoil impulse, the FOR rifle supporting structure is required to absorb less energy than it would for an equivalent closed breech gun. Consequently, the FOR rifle/propellant assembly may be heavier than the other types, but the supporting structure should be much lighter, resulting in an overall system weight competitive with the other types of launchers.

In response time, the FOR rifle should be competitive with the ROR rifle, but will probably be slower than the closed breech launcher because of the gas-leaking feature of recoilless rifles.

3. Test Procedures and Instrumentation Techniques

Several test series were planned for developing the closed breech and recoilless rifle launcher assemblies. Original test plans required for more elaborate individual component evaluation, but a subsequent reduction in level of effort resulted in plans to combine several previously scheduled evaluation studies into a fewer number of combined objective tests. It is expected that this approach, while not as thorough as originally desired, would result in valid and applicable test results.

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The following test series were tentatively established:

Closed Breech Gun

Preliminary evaluation of launcher components (barrel, breech block, shot-start mechanism, gas check, and propellant package).

Interior ballistics evaluation (propellant performance characteristics, and ignition train).

Final evaluation of PODS system feasibility (exterior ballistics studies).

Recoilless Rifle

Preliminary component evaluation (barrel, propellant chamber, expansion nozzles, shot-start system, and propellant-package structure).

Interior ballistics evaluation (propellant performance characteristics, and ignition train).

Final evaluation of PODS system feasibility (exterior ballistics).

The first series of tests for each launcher assembly were to evaluate basic launcher designs. Slug projectiles would have been used in these tests until the desired performance characteristics were attained. The slug projectiles were to be fired into recovery boxes for subsequent re-use if deemed feasible. Depending upon the success of the initial rounds, inert projectile assemblies could have been substituted. These would have been fired into stacked plate targets for gross penetration data.

The second test series was to be conducted primarily to evaluate component compatibility and system operational performance. Loaded projectiles utilized in these tests were to be fired into axial-area simulating targets for impact and core-penetration performance data.

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The objective of the third test series was to finally evaluate the system operation and to monitor projectile velocities, penetration performance, and fuze functioning adequacy.

Test data accumulated during evaluation of the launchers would include the following.

- a. Breech pressure vs time
- b. Breech (or chamber) and barrel strain values
- c. Projectile start and travel
- d. Projectile velocity
- e. Projectile target penetration performance

The test instrumentation required for Items a, c, d, and e are described in Section III,B,7. Instrumentation required for breech and barrel strain would involve a series of strain gages strategically located on the launcher assemblies. These gages would provide design data as to stress conditions at various places on the components.

Instrumentation that was either acquired or in the process of being acquired for this purpose consisted of Baldwin-Lima-Hamilton strain gages Type EBF-135+ (0.0 to 500 μ in./in.). These were to be utilized to obtain hoop-stress levels in the launcher chamber and barrel during projectile firing. A Tektronix Type 555 oscilloscope was to be used to observe strain gage data. Design of a range-and-balance system for the strain gages was completed to permit recording the stress/strain-vs-time history of the launcher during firing.

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D. PROPELLANT STUDY

The propellant study for the BDS consisted of investigations in three principal areas. The first was to select the basic propellant composition and establish the attendant preparation techniques that would meet the environmental and ballistic requirements. The second was to determine the grain geometry, which is concerned only with ballistic results. The third was to select the propellant-initiation system. In addition, there were plans for experimental and developmental tests to produce basic data and to substantiate component designs.

1. Propellant Composition

Of the materials available for use as propellants, the following were selected as candidates for the BDS:

Military Propellants

M-2

M-6

nitrocellulose base

Rocket Propellants

ANP-3095

Polyurethane - ammonium
perchlorate

AK-14

Polyurethane - potassium
perchlorate

ANP-512DS

Polyurethane - ammonium and
potassium perchlorate

BF-151

Polysulfide - ammonium
perchlorate

The military gun propellants were selected on the basis of current usage in conventional guns of the size proposed for the BDS. These propellants are in wide usage and considerable existing technical information is available. They can be easily manufactured by extrusion in a wide variety of shapes. However, military propellants would probably be susceptible to degradation by the magnitude of the radiation generated by the NERVA engine, and hence, become unusable as propellants. Consequently, they could be used in the BDS only if the launchers were adequately shielded. They could, of course, be used for component testing where specific ballistic results are required.

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Inherently, the composite rocket propellants are slightly more stable in a radiation environment, although their usefulness as gun propellants is undetermined at this time.

The composite propellants will not hold an extruded shape in the slurry form, so the desired grain shape would have to be achieved by casting. This may limit the shapes that could be used, but the techniques of manufacturing rocket shapes should be applicable. Sufficient information is not available as to the applicability of rocket propellants to guns; consequently, a sequence of tests were planned to be conducted by APG (Section III,E).

The effect of temperature rise on the propellant, caused by absorbed radiant energy, is another factor to be considered during the selection. A propellant cooling system might be required to avoid this difficulty. A propellant with good thermal stability would require less cooling. The propellant temperature, however, affects ballistic results, so a temperature-control system might be required to reduce launcher-to-launcher variations to control the BDS response time.

2. Propellant Grain Geometry

Most propellants are used in the form of individual grains (pieces) having identical shape and size, and having one or more lengthwise perforations. This produces more predictable interior ballistic results. The size and shape determine whether the propellant is loaded in a random or in an orderly manner. The rate of gas evolution, and hence, the peak pressure, depends on the grain shape. The critical grain dimension is the web size; i.e., the smallest cross-sectional width between adjacent surfaces. Web size thus determines the total burning time of the propellant charge. From this, the grain shape and size are an integral part of interior ballistic calculations.

From the limited interior ballistic studies, a few tentative conclusions can be drawn. The shape of the grains will probably be single and perforated, having lengths several times their diameters. The initial web size for closed breech guns using military propellants will be approximately 0.1 inch,

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and for recoilless rifles it will be approximately 0.3 inch. The latter may require ordered loading of the grains to obtain the necessary bulk-loading density in the propellant chamber. For composite propellants, the initial web size may be nearly an order-of-magnitude larger than it is for military propellants because of the propellant's higher burning rates. This means, for recoilless rifles, the propellant may be a single grain nearly as large as the rifle propellant chamber, merely to achieve the required web size.

Several military-propellant web sizes were specified for use during component testing. The techniques that were used required pressure-vs-time curves developed by the Heydenreich method of interior ballistic calculations. The curve was divided into increments on the time axis and an average pressure was found for each increment. The propellant burning rate for each average pressure was multiplied by the length of the time interval to give incremental thickness of propellant burned. With a suitably selected point for all-burnt, the increments were summed to give the required initial web size.

3. Propellant Initiation

To initiate propellants, a high-temperature flame is flashed over the individual grains. For uniform, quick initiation, the igniter material (flash mixture) is positioned so the resulting flame reaches as much of the propellant charge as possible to simultaneously initiating many grains. The initiation system is usually composed of several materials to ensure reliability and to produce a high-temperature flame front. For an initiation system, the most important requirements are high reliability, low launcher-to-launcher variation, and low radiation sensitivity.

Suitable initiation system materials were selected by a brief literature search in which several explosives manufacturers were contacted. Of all materials reviewed, those listed below offered the most promise.

Compound	Contents (%)
Boron/Calcium Oxide	9.1/90.9
Magnesium/Cupric Oxide	25.2/74.8
Magnesium/Manganese Oxide	22.4/77.6

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Compound	Contents (%)
Magnesium/Cuprous Oxide	23.4/76.6
Aluminum/Cupric Oxide	20.0/80.0
Aluminum/Cuprous Oxide	18.4/81.6
Boron/Barium Chromate	7.0/93.0

All of these materials are commercially available and are relatively insensitive to radiation.

A considerable amount of design information was derived from the initiation system for the Davy Crockett recoilless rifle (Reference 6).^{*} That design consisted of a central length of duPont Pyrocore 2040 surrounded by Al-black powder or Flare Northern igniter material 2K, and contained in a round tube formed from copper-wire screen. The propellant then surrounded this sub-assembly. The design produced even burning from the Pyrocore through the powder and propellant.

The projectile-start mechanism influenced the proposed initiation system design for the closed breech test gun (Figure 18). The tension rod through the center of the propellant package precluded a direct application of the Davy Crockett design. Therefore, the system was modified so the Pyrocore was helically coiled around the tension rod with a pitch of approximately 1/2 in. The igniter material and wire screen then surrounded the rod. The propellant was contained in a cardboard cylinder with closed ends. The entire package was to be sealed with lacquer to reduce its hygroscopicity. Hence, the initiation system was an integral part of the propellant assembly.

The recoilless rifle would not contain a projectile start rod. The anticipated initiation system for that rifle would closely resemble the Davy Crockett design. A program of initiation system development was planned and better designs were expected to evolve from these basic ideas.

4. Testing Procedure and Instrumentation Techniques

The experiments to be conducted with propellants were to obtain basic design data and to develop a propellant package capable of meeting the

^{*} See list of References at the end of this report.

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Figure 18

Closed Breech Test Gun Propellant Package

destruct system requirements. This involved analysis to determine burning rates that were not known, developing an initiation system, and evaluating propellant assembly designs.

a. Burning Rates

Some of the candidate propellants have unknown burning rates at the expected launcher chamber pressures. The burning rates vs pressure for the composite propellants are known up to ~ 20 ksi, while the military propellants are known up to ~ 50 ksi, which is the anticipated peak launcher pressure.

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Near the 20-ksi level, the composite propellant burning rate curves rise, and near 50 ksi, the theories available for extrapolating the curves yield widely variant results. Consequently, it was decided to conduct burning rate experiments with composite propellants.

The composite propellants to be tested were not those specifically selected as candidates for the BDS. Samples of the candidates were not available at the time of testing so substitutions were made. The actual test samples were expected to have burning rates close enough to the candidate propellants to allow good approximation of the latter from the test results.

The burning tests were to be conducted in an Aerojet-designed strand-burning bomb capable of prepressurization to 60 ksi. Samples were to be burned in an inert atmosphere at several pressures between 20 ksi and 50 ksi to extend the burning rate curve of two propellants, AK-14 and ANP-2639AF (polyurethane-ammonium perchlorate). The equipment was nearly ready for the first test when the program was cancelled in December 1963.

5. Propellant Package and Initiation System Study

Experiments with initiation devices were planned for selecting materials, configurations, and amounts. Several exploratory tests were conducted to estimate propagation capabilities of Pyrocore in different geometrical configurations. Mild detonating fuze (MDF) replaced Pyrocore in the tests because MDF was readily available and was expected to exhibit characteristics similar to Pyrocore. The basic observations indicated the following.

- a. MDF is difficult to initiate by detonation of a nearby MDF, even if the two are mutually perpendicular
- b. MDF will not initiate PETN sheet explosive
- c. MDF will initiate M55 stab detonators
- d. MDF coiled around a steel or brass rod will slightly mark or etch the rod (such as the tension rod in a projectile-start mechanism)

A propellant package design is illustrated in Figure 18.

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A sequence of initiation-system-evaluation experiments was planned for the candidate ignition materials. The tests were to be sub-component investigations and would not have involved launchers, projectiles, or targets. The purpose of the experiments was to determine the following.

- a. The burning characteristics of igniter materials at elevated temperatures
- b. Their ease of initiation and reliability
- c. Their ability to ignite propellants

A proposed test setup for ease of initiation and burning rate evaluation is illustrated in Figure 19. The igniter materials are contained in a plastic tube where the temperature is maintained by a blanketing electric heater. A thermocouple measures the ambient and specimen temperatures in conjunction with a recording potentiometer. Wires at specific intervals through the container are connected to a recording oscillograph for measuring the burning rate. The whole assembly is placed in a small pressure vessel in which the test would be conducted. A transducer, connected to a recording oscillograph, measures the pressure increase caused by the burning igniter material.

Subsequent experiments were to be devised for determining the ability of promising systems to initiate propellants. Small propellant packages were to be assembled with initiation systems. Various combinations of candidate propellants and initiation materials were to be used.

The planned propellant-package development program included experiments with launchers to evaluate, refine, and confirm package designs.

The preliminary tests would evaluate the initiation system and propellant assembly proposed by APG (Section III,E). The GFM cartridges would be modified for that purpose and fired in GFE guns using inert GFM projectiles. The data to be recorded were projectile velocity and internal pressure vs time. Tests for the closed breech gun and the recoilless rifle were basically the same.

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Figure 19
Igniter Material Test Set-Up

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The data from the preliminary firings were to be reviewed for necessary modifications of the initiation system and package designs. The sequence of firings of the refined packages was to be made with Aerojet test launchers and inert projectiles. The same data were to be collected in these tests.

Finally, the confirmation tests were to include minor changes in the propellant package indicated by the preliminary tests. The object was to confirm the proper grain size, initiation configuration, and initial charge weight. Refined test guns were to be used to fire slug projectiles into recovery pits, and instrument pickups were to be recorded to determine the variation of chamber pressure and projectile velocity.

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E. GOVERNMENT-FURNISHED SUPPORTING OPERATIONS

Design and development testing support for this Sub-subtask was to have been provided by two Government facilities, with technical assistance and direction from Aerojet. Watervliet Arsenal was selected to perform a design study of launchers for the BDS, and Aberdeen Proving Grounds (APG) was to conduct projectile and propellant experiments of a preliminary nature.

1. Aberdeen Proving Ground

The experiments to be performed by APG were in three specific areas:

Projectile development

Fuze development

Interior ballistics.

The results of these tests were to provide Aerojet with intermediate design information that could be used to redesign the projectile and propellant assemblies prior to the planned Aerojet launcher and penetration experiments.

a. Projectile Development Experiments

Projectile development experiments would evaluate different projectile-casing designs and nose geometries, and determine the effects of impact obliquity on these designs and on projectile penetration. They would also observe or measure the minimum impact velocity for complete penetration of the target, the ejection of target material during penetration, the multiple-layer penetration interaction, and the dynamic loads on the fusing mechanism during penetration. The Aerojet projectile designs to be used by APG included four nose shapes and two casing wall thicknesses, so that various combinations could be tested (Section III,B). All of the tests were to be made with projectiles loaded with an inert material having a bulk density identical to the explosive it replaced. The crudely simulated targets to be manufactured and used by APG for these experiments were specified by Aerojet (see Figure 3). Aberdeen Proving Ground planned to use existing guns and conventional military propellants that

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could be easily designed for specific ballistic results. The preparation for the experiments had progressed to the point of transmitting fabrication drawings to APG when the project was cancelled.

b. Fuze-Development Experiments

Several fuze designs were to be tested by incorporation into projectiles developed during the projectile experiments previously described. The projectiles were to be used again against crudely simulated targets so that the integrity and operation of the fuze mechanism could be demonstrated during penetration. The projectiles would be filled with explosive. Two types of fuzes would have been tested, mechanical and pyrotechnic (Section B). When the program was terminated in December 1963, fabrication drawings of the mechanical fuze were nearly complete and the layout drawing of the pyrotechnic fuze had been made.

c. Interior Ballistic Experiments

The object of the interior ballistic experiments was to evaluate the usefulness of composite rocket propellants as gun propellants. The propellants to be tested were two of those selected as candidates for the BDS (Section III,D), namely, ANP-3095 (polyurethane-ammonium perchlorate) and BF-151 (polysulfide-ammonium perchlorate). It was planned to conduct 100 tests with existing guns, using slug projectiles and various initiation materials (including J-2 squibs, Alclo-iron powder and Pyrocore). The Aerojet-furnished propellants were to have been in the form of single, perforated cylindrical grains approximately the size of the gun propellant chamber. This grain size was required because of the high burning rates for these propellants. The experimental results were to include pressure vs time or vs projectile travel, burning rate vs pressure, muzzle velocity, and stress in the launcher. No tests were conducted prior to cancellation of the project.

2. Watervliet Arsenal (WA)

The supporting work to be accomplished by WA was a parametric design study of launchers for the BDS. The investigation was to have included the barrels, breeches, firing mechanisms, and supporting structures for both

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closed breech and recoilless launchers. Aerojet provided the design specifications to WA (see Table 3). Typical ballistic curves for closed breech and recoilless launchers are included as Figures 20 and 21. The curves were developed by the "Heydenreich" method of interior ballistic calculations. The results of the study were to have included the selection of the best of the two types of launchers and the refinement of that launcher to the point of preliminary design drawings with attendant weight, stress, vibration, and material analyses. The results were to have been evaluated by Aerojet. The study was not completed because of cancellation of the project.

PROJECTILE DIA = 4.375 IN.
PROJECTILE WT = 120 LB.
SHOT START FORCE = 37,500 TO 56,400 LB.
RESPONSE TIME = 9.02 m SEC

Figure 20

Typical Ballistic Curve for Closed Breech Launcher

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Figure 21
Typical Ballistic Curve for Recoilless Launcher

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F. EXPLOSIVE FRAGMENTATION STUDY

The objective of the explosive fragmentation study was to investigate the function of the BDS with respect to the objective of the PODS, and to define the limitations that would be imposed on the design and operation of the BDS system to meet the performance requirements of the PODS.

To provide adequate data for the study it was necessary to plan an analysis of the techniques required to evaluate the results of the fragmentation tests. Two problems exist in this area: determining means for the physical recovery and subsequent treatment of statistically valid samples of fragments resulting from tests, and developing methods for determining the fragment space-time relationships.

A total of eleven tests were planned. The first six were to use axial-area simulant targets and single charges (symmetrically preimplanted) to define the "optimum" explosive charge casing geometry and metal condition that would produce the greatest core fragmentation. The remaining five (tests 7 through 11) were to use Mod 2H FSSE with four "optimized" 105mm charges emplaced in the core. Test number 7 was to be used as a standard of reference to define the relative variation of fragment-sizes resulting from the last four tests. Tests 8, 9, and 10 were to study the effects produced by extreme radial, longitudinal, and angular distribution of the explosive charges. The final test (Number 11) was to investigate the effects produced by the combined extreme conditions as defined by the previous three tests, and was to use the anticipated maximum gun jitter time-dispersion for random initiation of the four charges.

The recovery and quantitative evaluation of fragment-sizes presents a major problem. Because of the vast quantity of fragments that normally are deposited in a somewhat unsymmetrical and unpredictable pattern over a wide area of ground, recovery and analysis of a statistically valid sampling of the array becomes a formidable, costly operation. During the test program in Contract Year 1963 it was necessary to rely upon a somewhat inexpensive evaluation which was based upon and analyzing a small portion of the total fragment array (~ 2.8% of total fragment-pattern area of each test). Although presumably accurate

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enough for evaluation (the attendant error accrual for each test was assumed constant), this sampling technique does not permit a rigorous quantitative appraisal of resultant fragment-size distributions, such as would be required for an analysis of fragment-reentry radiation-hazard probability. Therefore, it was planned that the test program for Contract Year 1964 would utilize a specially constructed fragment recovery system that would both reduce the number of error-contributing factors and allow for a more accurate and quantitative calculation.

The proposed recovery system was to be installed on the dry lakebed surface of the Garfield Flats test site, Hawthorne, Nevada. The recovery system area basically was to consist of a 400-ft rad by 90° quadrant of overlapping steel plates elevated ~ 6 in. above the lakebed surface. Fragment recovery was to be accomplished by using a small selfpowered industrial vacuum sweeper. A maximum of 25% of the total fragment array could thereby be recovered. The recovered fragments would then be sieved and weighed to obtain a fragment-size distribution that could, in turn, be extrapolated to a mass balance. The miss-match between calculated recovered mass and actual reactor core mass would constitute the quantity of core material that was pulverized into microscopic aerosols and wind-dispersed.

Development of new techniques to resolve fragment space-time relationships was investigated, but no exacting solution to the inherent problems was forthcoming. The destructive effects of the explosive blast do not permit placing photographic equipment near enough to the target to optically resolve finite fragment-mass/velocity relationships, and the fire-flash and initial escaping gasses tend to obscure visibility. Investigations were, therefore, being made to determine if either radiographic or infrared photographic techniques could be adapted to this application. In lieu of improved measurement techniques, it was planned to photographically measure the velocity of the expanding dust cloud profile (as accomplished in Contract Year 1963) and to identify maximum fragment velocities with ground-deposited (and recovered) fragments by virtue of their projected trajectories. It was anticipated that the composite analysis of highspeed

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photographs and ground-deposited fragment-array patterns would permit establishing approximate space-time relationships for use in prompt reentry fragment calculations. This type of analysis was not feasible during the test program of Contract Year 1963 because of the inadequacy of the fragment-recovery apparatus.

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G. TARGET SIMULATION STUDY

1. Full-Scale Simulated Engine (FSSE) Target Designs

A total of five FSSE targets had been planned for the fragmentation evaluation tests scheduled for Contract Year 1964. The detailed objectives of these tests are defined in Section III,E. For maximum data output, the test series requires one target with a full core module of GFM depleted fuel-loaded NERVA B-4 elements, and four targets with full core modules of GFM unloaded NERVA B-4 elements. If the GFM could not be made available as scheduled, the test program would either be delayed or a less desirable alternative would be utilized. It was determined that this alternate plan would be based upon the use of one target with a full core module of GFM depleted fuel-loaded NERVA B-4 elements (already received by Aerojet) and four targets with full core modules of 0.75-inch-diameter solid graphite rod material purchased with program funds.

Except for the above variations in core material, the FSSE targets were designed in accordance with the basic configuration of the Mod 2 FSSE targets used in the program of Contract Year 1963 (previously described in REON Report RN-S-0033).

The basic design of a Mod 2 FSSE target, illustrated in Figure 22, consists of an aluminum pressure vessel containing the various simulated engine components. The simulated inner (graphite) and outer (magnesium) reflectors are supported from an upper support ring that is bolted to the pressure vessel. The core module is suspended by steel rods passing through the aluminum core support plate, the core, and a 3/4-in.-thick plywood disc that supports the core. A 3/8-inch thick steel truncated right cone is attached to the aluminum pressure vessel to simulate the end effects produced by the nozzle. The shadow shield and pressure vessel head are simulated by a dynamic head structure consisting of aluminum and steel plates that are assembled to represent equivalent thickness, spacing, and mass. The targets are designed for internal placement of burster charges, as shown in Figure 22.

An evaluation was made of the target geometries and engine simulated component, and a review was made of the latest NERVA(NRX-A1 reactor) drawings

Figure 22
Full Scale Simulated Engine Target, Mod 2H

to upgrade the existing target designs. As a result, a more representative simulation of the graphite inner-reflector assembly was conceived using rectangular graphite slabs housed within an aluminum barrel with longitudinal spacer strips on its outer surface. This arrangement more nearly conforms to the NRX-A1 cylindrically shaped complex, and reduces the unrealistic void volume imposed by the original Mod 2 target design.

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However, because of the use of different core materials and their inherent differences in void volumes, strength, shock, and load transmission, (solid rod vs NERVA B-4 configuration), it became evident that a re-evaluation and specific grouping of the various simulated engine components was necessary. These components would be required to dynamically simulate the entire group of restraint materials (pressure vessel, and inner and outer reflectors) with respect to the selected core materials. As indicated, three basic target variations are involved.

- (1) Mod 2 with crude rod core.
- (2) Mod 2 with unloaded NERVA B-4 core.
- (3) Mod 2 with fuel-loaded NERVA B-4 core.

Although the depleted fuel-loaded NERVA B-4 elements probably will fracture and break easier than the unloaded B-4 elements, but the extent of difference being unknown, it was decided to treat these two core materials in an identical manner in this particular series of tests. Therefore the two target types involved are:

- (1) FSSE target with either loaded or unloaded NERVA B-4 core, designated Mod 2H.
- (2) FSSE target with solid-rod core, designated Mod 2I.
 - a. Mod 2H Target (Figure 23)

Because of the energy-absorbent characteristics of the geometrically similar loaded or unloaded NERVA B-4 elements, a closely simulating inner reflector assembly was selected. The assembly consists of rectangular graphite slabs (2 inch thick x 2 inch wide) housed within an aluminum barrel with longitudinal spacer strips. This configuration exhibits better shock and load transmissibilities than did the original Mod 2 configuration. The outer reflector assembly is simulated by a solid casting of magnesium alloy (AX91C). The pressure vessel is made from 0.83-inch thick 6061-T6 Aluminum Alloy.

- b. Mod 2I Target (Figure 23)

Since a core consisting of the solid-rod produces greater shock transmission than the NERVA B-4 geometry, and therefore has considerably less energy absorbing properties, the original Mod 2 inner reflector assembly was

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Figure 23

Mod 2I Fuze Target

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retained in the Mod 2I target. This assembly, consisting of two essentially concentric cylinders of thin, flat graphite slabs housed within a steel barrel with three circumferential spacer strips encircling the barrel on its outer surface, has a greater void volume, and therefore, has a higher energy absorbing capability. The outer reflector assembly is fabricated from cast magnesium sections with a longitudinal hole representing the control-drum interface. Extruded magnesium bars (simulated control rods) will be inserted in the holes. This arrangement, coupled with a pressure vessel of 1.13-inch thick 6061-0 Aluminum Alloy is considered satisfactory to balance out the various shock and load transmission characteristics.

2. Axial-Area Simulant Target Design

The design of the axial-area simulant target is illustrated in Figure 24. It consists of a full-length core bundle simulating the area adjacent to the explosive charges, and is encased in a steel cylinder having a dynamically simulated forward shield (3-inch thick steel plate) at its forward end and a closure plate at the aft end. A thin-wall aluminum tube is located in the appropriate position within the core during assembly for subsequent placement of the explosive charge. This aluminum tube will be removed after the explosive charge has been inserted.

3. Projectile Penetration Target Design

The target designs proposed for component development tests for Contract Year 1964 range from crude stacked plate targets for preliminary projectile design and obliquity of impact and penetration evaluation, to more refined simulated targets for projectile insertion, penetration, and time-of-arrival experiments.

The basic targets developed include the following.

a. Stacked Target - Penetration

The target illustrated in Figure 25 consists of a series of steel plates of composition, thicknesses, and spacing so as to simulate the penetration toughness and characteristics of the forward reactor shield assembly. These targets will be used for preliminary projectile design, projectile obliquity of impact, and penetration experiments.

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Figure 24

Axial Area Simulated Target - Fragmentation Evaluation

b. Stacked Target With Crude Simulated Core

The target illustrated in Figure 26 is basically the same as Figure 25, plus a core bundle consisting of 2 inch x 2 inch graphite modules. These targets will be used for preliminary obliquity of impact and penetration studies of refined or modified projectile assemblies.

c. Axial-Area Simulated Target (Subscale Target)

Figure 27 illustrates a 24-inch diameter steel cylinder encasing a forward simulated shield with a full length core of solid rod simulant.

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Figure 25

Stacked Target - Penetration

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Figure 26
Stacked Target with Crude Simulated Core

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Figure 27

Axial Area Simulated Target - Component Development

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These targets are to be used for refined obliquity of impact and penetration evaluation of projectile assemblies, and fuze assemblies.

d. Refined Simulated Target

Figure 28 illustrates a more accurately simulated forward shield with a full-diameter, full-length core of solid rod simulant encased in a steel or aluminum casing. These targets will be used for final evaluation of PODS system feasibility, such as system functioning, projectile penetration, time-of-arrival, and fuze functioning.

Based on emplacement and integration studies, three basic projectile insertion angles were centerlines of the projectiles and the NERVA engine. The targets will consist of separate basic components so that the

Figure 28
Refined Simulated Target

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adjustments can be made to accommodate an evaluation of the various insertion angles. Figure 29 illustrates this arrangement of a stacked target with a crude simulated core assembly.

Figure 29
Target Arrangement for Various Projectile Angles

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