FZK-373
15 September 1970

**EVALUATION OF INSULATION MATERIALS
AND COMPONENTS FOR USE IN A
NUCLEAR RADIATION ENVIRONMENT**

**Redesign of Propellant Heating Experiment and
Radiation Analysis of Saturn V Materials,
Systems, and Components**

First Quarterly Progress Report
21 May through 31 August

Prepared for
**George C. Marshall Space Flight Center
Huntsville, Alabama 35812**

Contract NAS8-25848
DCN 1-0-50-09589 & S1(TF)

NUCLEAR AEROSPACE RESEARCH

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This report was prepared by the Fort Worth Division of General Dynamics under Contract NAS8-25848, Evaluation of Insulation Materials and Composites for Use in a Nuclear Radiation Environment, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Astronautics Laboratory, Engineering Physics Branch of the George C. Marshall Space Flight Center, with Dr. R. L. Gause acting as contracting officer's representative.

FOREWORD

The Fort Worth division of General Dynamics Corporation (GDFWD), under Contract NAS8-25848 with the George C. Marshall Space Flight Center, is participating in a study that is part of the overall effort necessary to develop the technology required for the design of a Nuclear Rocket Vehicle. This work is based in part on the nuclear flight systems concepts being generated under Contracts NAS8-24714 (McDonnell Douglas Corp.), NAS8-24715 (Lockheed Missile & Space Co.), and NAS8-24975 (North American Rockwell Corp.). The propulsion system for the flight system is the 1700-MW, 75,000-lb-thrust NERVA engine being designed under Contract SNP-1 (Aerojet Nuclear Systems Company and Westinghouse AstroNuclear Laboratory). This study is an extension of Nuclear Rocket Vehicle development work previously performed by the Nuclear Aerospace Research Facility of General Dynamics Fort Worth division under Contract NAS8-18024.

This report is the first quarterly progress report to be issued under Contract NAS8-25848. In addition to reporting work performed during the period, this report presents the objectives of the study and the schedule by which work is to be completed. Monthly and quarterly progress reports will be issued throughout the contract duration updating information contained herein.

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I. INTRODUCTION

Contract NAS8-25848 is being undertaken at the Nuclear Aerospace Research Facility (NARF) of the Fort Worth division of General Dynamics at the direction of, and under contract with, the George C. Marshall Space Flight Center, National Aeronautics and Space Administration. The work to be performed, which is an extension of previous GDFWD efforts (Contract NAS8-18024) in support of the Nuclear Rocket Vehicle development program, is directed toward two primary tasks: (1) redesign of the Propellant Heating Experiment (Ref. 1), and (2) a radiation effects analysis of Saturn V materials, systems, and components.

1.1 Task I - Redesign of Propellant Heating Experiment

The objective of this task is to revise the analytical data generated previously under Modification 2 of Contract NAS8-18024 to conform with the concepts of the nuclear flight systems currently being generated under Contracts NAS8-24714 (Ref. 2), NAS8-24715 (Ref. 3), and NAS8-24975 (Ref. 4). The flight system concepts are based on use of the 1700-MW, 75,000-lb-thrust NERVA I engine being designed under Contract SNP-1. These new concepts will impact severely the parameters of the experiments to establish the amount of nuclear energy deposited in liquid hydrogen, to delineate associated changes in the thermodynamic state of the fluid, and to evaluate the various propellant heating codes

developed to predict nuclear heating effects in liquid-hydrogen-fueled nuclear rocket stages.

This effort will be closely coordinated with MSFC and other government contractors engaged in the Nuclear Rocket Vehicle development program. In addition to the normal reporting of information, two technical presentations by GDFWD personnel are scheduled. In the first presentation, midway through the contract, work accomplished will be summarized and the technical approach for remaining work will be presented. The final presentation will summarize all work accomplished during the program and will give the study results, conclusions, and recommendations.

1.2 Task II - Radiation Analysis of Saturn V Materials, Systems, and Components

This task is an extension of work initiated under Modification 5 of Contract NAS8-18024. The objectives are: (1) to evaluate current flight-qualified Saturn V materials, systems, and components for use, with or without modification, on the nuclear flight system, (2) to select those materials, systems, and components that potentially can be radiation-hardened, and (3) to determine the nuclear environment at the most probable location of these materials and components for various engine operating cycles.

The nuclear radiation environment is to be determined for various probable mission profiles. From this information the radiation levels at the assumed location of all major components

will be estimated for two conditions. The first, or worst case, will be based upon the stage configuration and the engine operation profile, but excluding attenuation from vehicle structures and LH₂ fuel. The second calculation will be a time-integrated value taking into account the engine operation profile, mission profile, vehicle shielding, and attenuation of radiation through the propellant during the engine operating cycle.

A detailed analytical study of the technologies, systems, hardware, software, and components of the Saturn V vehicle, with emphasis on the S-II and S-IV B stages, will be performed to determine those materials and components that can be utilized on the nuclear flight systems currently being defined for MSFC by McDonnell Douglas Corporation (Ref. 2), Lockheed Missiles and Space Company (Ref. 3), and North American Rockwell Corporation (Ref. 4). This study is intended to serve as a baseline reference for the development of future radiation effects analytical and experimental programs.

This effort will be closely coordinated with MSFC. The technical presentations and the final results of this study, including recommendations and conclusions, will be given concurrently with the presentations of Task I activities.

II. REDESIGN OF PROPELLANT HEATING EXPERIMENT

The objective of this task is to revise the analytical data and experiment designs previously generated under Modification 2 of Contract NAS8-18024 (Ref. 1) to conform with the new concepts of the Nuclear Flight Systems currently being generated under Contracts NAS8-24714 (McDonnell Douglas Astronautics Co.), NAS8-24715 (Lockheed Missiles and Space Co.), NAS8-24975 (Space Division, North American Rockwell), and SNP-1 (Aerojet Nuclear Systems Co.). Completion of this task will result in the design of a ground test of a propellant tank containing liquid hydrogen exposed to a nuclear radiation field. This is intended to (1) establish the amount of nuclear energy deposited in liquid hydrogen for well defined nuclear environments, (2) identify the associated changes in the fluid dynamic and thermodynamic state of the fluid, and (3) provide experimental data for comparison with the various propellant heating analyses developed to predict nuclear heating effects in liquid-hydrogen-fueled nuclear flight systems.

A small-scale fluid-flow visualization test will be conducted as an adjunct to the task described above. The objective of this test is to determine in a qualitative manner the effects of tank-bottom geometry on the propellant fluid dynamics during drain.

The program plan is shown in Figure 2-1.

Figure 2-1 Program Plan for Redesign of the Propellant Heating Experiment

2.1 Nuclear Flight System Concepts

The Reusable Nuclear Shuttle (RNS) configurations initially studied were those baseline configurations defined by the various contractors at the conclusion of their Phase II Nuclear Flight System (NFS) Definition Studies (Refs. 2, 3, and 4). Currently, in Phase III of these studies, several of the baseline configurations have been extensively changed. Therefore, the configurations being investigated in the present task have been changed to conform to those presented by the Phase III NFS Definition Study contractors at the first interim briefing held at NASA/MSFC on September 2 and 3, 1970. The three basic tank concepts chosen for study are shown in Figure 2-2. These concepts are consistent with RNS data and configurations presented at the Phase III briefing.

Work is currently underway on the single tank concept. Drain-temperature profiles and pressurant requirements are being determined for two cone angles and cap radii, namely, 15-degree half-cone angle, 100-in. cap radius and 8.5-degree half-cone angle, 25-in. cap radius. Work on the remaining two concepts is expected to start within two to three weeks. Because of the short time between the Phase III briefings and subsequent configuration revision and this report, no results on the revised concepts are available for publication at this time.

Single Tank

Hybrid

Modular

Figure 2-2 RNS Tank Concepts

2.2 Computer Code Update

The two computer codes presently being used to predict the nuclear heating effects in liquid-hydrogen-fueled nuclear flight systems are the LMSC Asymmetric Propellant Heating Code (GDFWD Code AG-4) and a program developed by NASA Lewis Research Center (GDFWD Code RI-0). Both codes required modification for the present program — AG-4 to conform to technical improvements made by LMSC and RI-0 because of tank geometry changes.

The changes to AG-4 have been made and the program is currently being checked out. Several system errors have been found and corrected and full code utilization is expected within a week.

Modifications to RI-0 to include conical, hemispherical, and elliptical tank configurations have been initiated and check-out problems are being formulated. Check-out of this code should be completed within two weeks.

2.3 RNS Dual-Cell Concept Analysis

The concept of the Reusable Nuclear Shuttle propellant storage system that consists of a single external tank with an internal tank was reviewed to determine possible problems based on thermodynamic considerations. This configuration of the RNS is defined by North American Rockwell Space Division (Ref. 4).

Nuclear data for this analysis was based on the Aerojet-General source terms for the 1500-MW hot-bleed NERVA engine given

in Reference 5.

No specific problems were found that would cause the feasibility of this concept to be questioned. However, the addition of the internal tank does cause several additional weight penalties and thermodynamic problems not present in a single-tank design. Three problem areas have been investigated and the results are discussed: (1) local boiling, (2) prepressurization requirements, and (3) drain temperature.

2.3.1 Local Boiling

The possibility of boiling within the tank during prepressurization, firing, and cool-down modes was investigated. The prime problems are associated with the internal tank and inter-cell feed lines where they interface with hot ullage and the penetration heat leak at the internal tank mount. It was estimated that the highest heat flux to the fluid, during proper operation of the thermodynamic vent system, will be 11 Btu/h-ft^2 OR, which is well below the incipient boiling critical heat flux. Failure of the thermodynamic vent system could, however, result in heat fluxes large enough to cause boiling under coast and cool-down conditions at the point where the internal tank mounts to the external tank (one of the vent system functions is to produce subcooled liquid in the lower regions of the tank). The consequences of boiling at this point would be particularly severe since the vapor would be trapped under the zero-g propellant

retention screens. Vapor trapped in this location could enter the intercell feed lines resulting in a higher pressure required to force feed the internal tank.

2.3.2 Prepressurization Requirements

Figure 2-3 presents the relationship of the liquid levels to the tank geometry after the completion of the TLI burn. The cold column of liquid hydrogen contained in the internal tank not only reduces the average ullage temperature but also provides a cold surface on which the gaseous hydrogen (ullage) may condense. The net effect is about a threefold increase in the mass of auxiliary pressurization gas required compared with a single-tank concept. Because of condensation, the pressurization gas required during firing is greater for the dual-cell concept than for a single-tank design. For example, a peak pressurization flow rate without an internal tank is estimated to be 0.75 lb/sec while with the internal tank this peak pressurization flow rate is increased to 1.7 lb/sec.

It can be concluded from the above that the presence of the internal tank substantially increases the mass of stored prepressurization gas requirements. This condition appears to have been included in NAR's assessment of the auxiliary pressurization system weight penalty.

Figure 2-3 Dual-Cell Design RNS

2.3.3 Drain-Temperature Profiles

Drain-temperature profiles were generated for each of the four main engine burns of the lunar shuttle mission. The drain-temperature analysis is based on a mixed model and uses the nuclear heating rates presented in Figure 2-4. The mixed model assumes that the energy being absorbed by the LH₂ is completely and instantly mixed throughout the LH₂ remaining at any time step. The ambient heat flux to the external tank is proportional to the tank surface area wetted by the LH₂ at any time step. The nuclear heating is also time variant since it depends upon the LH₂ remaining in the tanks at any given time. The tanks were analyzed assuming that they were drained in series.

Figures 2-5 through 2-8 present the drain-temperature profiles for the TLI, LOI, TEI, and EOI burns. The LH₂ was assumed to be initially at 24 psi saturated conditions for each burn.

The use of an internal tank creates an additional heat load on the draining fluid caused by the increase in wetted area. The primary heat load is due to ullage condensing on the exposed area of the internal tank. This heat load can produce up to 66 percent of the total increase in drain temperature (main tank empty, internal tank draining). A secondary heat load is created by the LH₂ passing through the high radiation field twice. In addition, the fact that the internal tank is used as a shield means that a significant amount of energy is deposited in the internal tank and

Figure 2-4 Nuclear-Energy Deposition Rate

Figure 2-5 Drain-Temperature Profile for TLI Burn

Figure 2-6 Drain-Temperature Profile for LOI Burn

Figure 2-7 Drain-Temperature Profile for TEI Burn

Figure 2-8 Drain-Temperature Profile for EOI Burn

with the new full-flow engine this could be significant. The effect of this design change on drain temperature was not analyzed at this time because adequate design data were not available.

The net effect of the drain-temperature rise is an increase in saturation temperature and pressure of the LH_2 in the tank. For the four main engine burns, the saturation pressure will not exceed the tank pressure operating limit of 32.1 psia. The maximum drain temperature of 41.55°R occurs after the external tank is empty during the EOI burn. This temperature corresponds to a pressure of 30.5 psia. With an estimated 0.6-psi feed-system loss and a 0.5-psi margin, the required saturation pressure will be 31.6 psia.

After each burn the tank will be vented to 24 psia. Boil-off losses due to this venting were estimated at 1410 pounds.

2.4 Future Work

Work scheduled for the next quarter will be directed towards:

1. Completion of computer code updates.
2. Completion of drain temperature and pressurization requirement predictions for the three RNS tank concepts.
3. Initiation of parameterization studies of the fluid dynamic and thermodynamic variables that characterize the propellant phenomena of the test tank and RNS.
4. Definition of the flow visualization experiment and initiation of design and construction of the test tank and auxiliary equipment.

Activities and schedules are shown in Figure 2-9.

Figure 2-9 Activities and Schedule for Redesign of the Propellant Heating Test

III. RADIATION ANALYSIS OF SATURN V MATERIALS, SYSTEMS, AND COMPONENTS

3.1 Program Plan

The basic program plan is illustrated in Figure 3-1. During a meeting at the Marshall Space Flight Center, the representatives of the contracting officer and General Dynamics established the schedule shown in Figure 3-2 and general method of approach outlined below.

The S-II and S-IVB stages of vehicle AS-512 have been selected for analysis since they are representative of current liquid-hydrogen-fueled vehicles. A preliminary survey was performed to identify the various systems on each stage and to establish their locations on the stages. Those systems located on or near the aft end of the S-IVB and S-II stages, and which would possibly require similar location on the nuclear vehicle, were selected for primary emphasis in the analysis. Systems located toward the forward end of the stages, and which would be expected to be in the lower radiation fields of the nuclear vehicle, are being included only if especially radiation sensitive materials are used in their design. Electrical and/or electronic components will be evaluated only if they are an integral part of a mechanical component. For example, a solenoid within the actuator of a valve will be considered; however, a signal switching relay will not be considered. In general, the electrical/electronic components located in the

Figure 3-1 Program Plan for the Analysis of Saturn V System

Figure 3-2 Activities and Schedule for Saturn V Radiation Effects Analysis

Instrument Unit (IU) of a stage will not be included in the study.

Drawings of each system to be analyzed have been received from the MSFC repository. These drawings have been reviewed to identify subsystems or components containing, or suspected of containing, radiation sensitive materials. Additional drawings or specifications were then ordered from the MSFC repository. This process is being repeated until the materials of interest are identified or, as in many cases, the vendor and part number are obtained. The results of this review are tabulated on forms, of which Figure 3-3 is an example, designed to facilitate the compilation of data and the subsequent evaluation of each system.

From the working tables (Fig. 3-3) tabulations of materials and vendors are being prepared. Data tables will also be prepared for each material and application determined from the survey of drawings. Information concerning the radiation tolerance of these materials and applications will be obtained from previous radiation effects tests performed at GDFWD and other facilities. If experimental data do not exist, engineering judgement will be employed to estimate the radiation tolerance of the material/component. If the advisability of utilizing a material is marginal, and experimental data do not exist, an experimental program will be recommended.

Upon completion of the drawing review, a radiation hardening analysis will be performed; this will result in data presentation

SIV-B HYDRAULIC SYSTEM (1B62563-505)

Part Number	Sub-System	Component	Item	Material	Remarks or Status
<u>1B55408-503</u>	<u>Tank Assembly</u>				Drawing reviewed 6-15-70
1B31295-1		Valve			238128-1 Tavco Inc., 612 Colorado Ave., Santa Monica., C.I. 99221
1B55647-1		Gage			6914-760 American Standard, C.I. 05167, 1401 S. Shamrock Ave., Monrovia, Calif.
MC266J904		Packing		Rubber-silicone	
MC266J905		Packing		Rubber-silicone	
<u>1A86847-513</u>	<u>Pump Assembly</u>				Drawing reviewed 6-15-70
MC237C10W		Adapter		Aluminum	
MC237C12W		Adapter		Aluminum	
MC266B902		Packing		Buna-N	
MC266B906		Packing		Buna-N	
MC266B908		Packing		Buna-N	
MC266B910		Packing		Buna-N	
MC266B912		Packing		Buna-N	
MS28775-014		Packing			See MIL-P-25732
MS28775-013		Packing			See MIL-P-25732
MS28774-014		Retainer		Tetrafluoroethalene	
MS28774-013		Retainer		Tetrafluoroethalene	
MS28777-6		Ring			See MIL-R-5521
MC185-B		Crush Washer		Metel	
5140D75S262		Seal Assembly			Vendor - E. B. Wiggins, Inc., C.I. 79326
1A66245-501		Valve			263028 Parker Acft, 58247W Century, LA, 9, Calif., C.I. 92003
1A66240-505		Pump			L-5699 Vickers Inc., Div. of Sperry Rand, Detroit, Mich., C.I. 62083
1A74764-501		Switch			2627-1-4 United Control Corp., Overlake Ind. Park, Seattle 14, Washington, C.I. 97896

Figure 3-3 Example of Data Tabulation Sheet

similar to that shown in Figure 3-4. Radiation hardening can be visualized as a multistep operation in which the materials most prone to failure in a low radiation environment are replaced by more radiation resistant materials or the design of the component is modified to eliminate radiation sensitive materials. Components of each system will be analyzed separately. The radiation level at which little or no degradation in component performance is to be expected will be given for the unmodified basic system as well as for various stages of modification, thus facilitating rapid assessment of location changes and/or system redesign.

The estimated radiation level at the assumed component location will be compared with its radiation tolerance. If the component can function satisfactorily in its predicted environment, it will be recommended for flight service; otherwise the necessary modification or recommendations are noted. These data will be presented for materials, components, subsystems, and systems in order that designers can evaluate changes in location or design.

3.2 Materials, Components, and Systems Evaluation

The radiation analysis of Saturn V materials, components, and systems was initiated by the acquisition from the MSFC repository of the top assembly drawing (10M15112) of vehicle AS-512. From this drawing, stage assembly drawings for the S-IVB (Drawing 1A39300-517) and S-II (Drawing V7-000002-2691) were identified. Working down from the stage drawings, drawings for all of the S-II

RADIATION HARDENING OF PROPELLANT FEED SYSTEM

Figure 3-4 Example of Format for System Analysis

and S-IVB systems noted in Table 3-1 have been ordered and received from the MSFC repository. From the system drawings, additional component and/or part drawings have been ordered. During this quarter approximately 300 S-IVB and 90 S-II drawings, pertaining primarily to the hydraulic and propellant systems, have been received and reviewed. Approximately 200 additional component or part drawings and specifications have been ordered from the MSFC repository.

Information related to subsystems, drawing and/or part numbers, component items, materials, and applications of organics for each system are being tabulated on work sheets (Fig. 3-3). When all pertinent sources of information have been researched, the materials of interest for the analysis and their applications will be identified. These data will then be the basis for the radiation hardening analyses.

Other information that has been received from MSFC includes:

1. NASA Engineering Standards Manual, Volumes 1 through 4
2. Spare Parts List for S-II Stage
3. Engineering Configuration List

Items 2 and 3 have been reviewed for the primary purpose of establishing procedures to expedite the identification of materials used in the S-II and S-IVB stages. However, based on this investigation, the most reliable method for determining organic material usage is the procedure initially embarked upon, i.e., that of

Table 3-1

PRINCIPAL SYSTEMS BEING REVIEWED

S-II Stage

Aft end

Engine actuation
Propellant feed
Propellant management
Leak detection and purge
Pressurization
Structure
Insulation
Conditioning
LOX feed system
Separation and field ordinance
Auxiliary propulsion

Forward end

Leak detection and purge
GH₂ exhaust

S-IVB Stage

Aft end

Hydraulic
Thermo-conditioning and purge control
Auxiliary propulsion
Propulsion
Structure
Thermo-conditioning
Instrumentation
Harness

working down from the stage drawings 1A39300-517 (S-IVB) and V7-000002-2691 (S-II).

3.3 Radiation Environment Evaluation

The unattenuated dose rates corresponding to the PVARA leakage rates given in AGC Report S130-CP-090290 (Ref. 6) have been calculated in the form of isodose contours which extend over the portion of the propellant tank where radiation-damage to organics is expected to be significant. The geometrical attenuation at points along a given azimuth with respect to the core center is based upon an effective point source inferred from the full-flow-engine leakage rates. The unattenuated gamma dose rates, shown in Figure 3-5, are superposed upon the original RNS baseline inboard profile, viz., a dual-tank configuration with a $\sqrt{2}$ -elliptic outer-tank bottom (Ref. 4).

A set of mission-dose contours for the baseline configuration is being generated by performing drain-time integrations over the propellant-attenuated dose rate derived from an exponential representation of dose-rate build-up. A similar set of mission-dose contours will be obtained for one or more other configurations, e.g., an engine-module system and/or a conical bottom tank (Fig. 2-2), during the next quarter.

3.4 Future Work

During the next quarter, acquisition and compilation of materials data, including the preparation of data tables, will

Figure 3-5 Unattenuated Gamma Dose Rates for NERVA Full Flow Engine

continue. Vendors will be contacted for drawings and information concerning organic materials and their applications in Saturn V components and systems. Radiation effects data pertaining to the identified organic materials will be gathered and the radiation effects analysis will be started. The definition of the radiation environments for the selected configurations will be completed.

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4. Nuclear Flight System Definition Study Phase II Final Report, North American Rockwell Space Division Report SD70-117, April 1970.
5. Review of NERVA Radiation and Shielding Studies, Aerojet General Corporation Report RN-PA-0021, 30 September 1969.
6. NERVA Reference Data (Full-Flow) Engine, Aerojet Nuclear Systems Company Report S130-CP-090290-F1-PREL, April 1970.

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