RADIATION HARDENING OF COMPONENTS AND SYSTEMS FOR NUCLEAR ROCKET VEHICLE APPLICATIONS*

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INTRODUCTION

The Nuclear Rocket Vehicle (NRV) is an advanced space vehicle employing the NERVA engine and liquid hydrogen as fuel. The final design and ultimate selection of NRV components and systems will evolve from various technical approaches presented below.

TECHNICAL APPROACHES

As shown in Figure 1, the various procedures which can be employed in the development of NRV components and systems include: (1) experimental, (2) shielding, (3) research, (4) analytical, and (5) radiation hardening. Since all of the procedures may be employed before the NRV is a reality, the merits of each are briefly reviewed here.

Experimental

Candidate "off-the-shelf" components, such as transducers, will be tested in a combined nuclear and simulated space environment to determine the best designs for various applications and establish their safe operating limits. This approach is very costly but results in a high confidence level since the component is required to operate before, during, and after irradiation.

Shielding

The shielding approach is an extension of the experimental approach in that shielding is employed to attenuate the nuclear radiation to levels below the components recommended radiation tolerance if the component cannot be relocated in a lower radiation environment. Because of the weight penalty, the use of shields must be minimized.

Research

In some instances, materials and components unique to the NRV, e.g., reactor components, must be designed and developed. Preliminary design data, which are obtained from radiation effects tests conducted on materials and subassemblies, are integrated into prototype systems which are proof tested and modified, as required, prior to incorporating them into the NRV preliminary design.

Analytical

This technique, which is described later, requires detailed analysis of component drawings and specifications as well as establishing radiation tolerance limits for each material application. Since many NRV components are located in areas in which the predicted nuclear environment is considerably below the recommended radiation tolerance for each material contained in the component or system under consideration, their usage can be justified on the basis of this analysis.

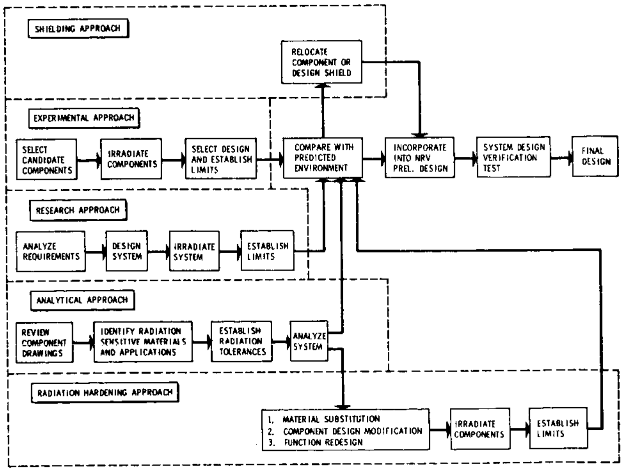

Figure 1 EVOLUTION OF RADIATION RESISTANT COMPONENTS AND SYSTEMS

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Radiation Hardening

The analytical procedures provide the basis for radiation hardening studies. Those components and systems which contain radiation sensitive materials are hardened by: (1) material replacement, i.e., radiation stable materials are substituted for materials with low radiation tolerance; (2) system design modifications; or (3) redesign of functional roles of components. The modified or redesigned system is then irradiated to verify its performance in a simulated NRV environment.

RADIATION HARDENING

Analytical and radiation hardening procedures are being employed by General Dynamics for analyzing the mechanical components of the S-II and S-IVB stages of the Saturn V vehicle to determine those which might be considered suitable, or which might require modification to a sufficient level of radiation hardness, for NRV applications. The technical approach is best visualized through the following steps:

1. S-II and S-IVB drawings and specifications were examined to identify the materials prone to radiation damage and determine their locations and applications.

2. Recommended radiation tolerance limits were established for each material and application on the basis of previous test experience.

3. Each major component and subsystem was carefully analyzed, and the radiation tolerance of the basic "as designed" system was assessed.

4. Assuming the system to be located in a reasonable position on the NRV, the recommended radiation tolerance limits were compared to the predicted nuclear environment for missions requiring 10 hours of engine operation. (Radiation levels are based on ANSC nuclear flux data for the NERVA full-flow engine.)*

5. If the radiation tolerance of the basic system was less than the predicted environment, recommendations were made to radiation harden it in a multistep procedure in which (1) materials with low radiation resistance were replaced by materials having greater stability in a nuclear environment and yet can satisfy the requirements of the particular application, or (2) vulnerable components which limit its usage were replaced, or (3) a system redesign was suggested to overcome the deficiency.

6. Radiation effects test programs were designed to test modified components and systems as well as to obtain materials data for components critical to the mission whenever sufficient information was not available.

A review of stages S-II and S-IVB drawings and specifications indicated that 33 different radiation sensitive materials were employed in over 100 types of applications. Recommended radiation tolerances were established for each material application on the basis of previous radiation effects tests performed at General Dynamics and other test facilities. Table 1, which presents the recommended radiation tolerances for Buna N and the criteria employed in establishing these limits, is typical of data resulting from this analysis. In this example, the recommended limits are conservative. A high confidence level is required for the mission, and component designers must be alerted to potential problems which might result from indiscriminate usage or failure to adequately specify materials. This conservatism results from:

1. Basing recommended limits on radiation damage to the least radiation stable chemical formulation of the particular class or type of material.

2. Criteria established for mechanical properties limits. These limits correspond to radiation exposures beyond which the degradation might compromise the functional performance of the material as used.

3. Not taking advantage of improved performance which might result from operating in the space environment where oxygen is excluded unless adequate test data are available from tests conducted in a vacuum.

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*NERVA Reference Data (Full-Flow) Engine, Aerojet Nuclear Systems Company Report S130-CP-090290-F1-PREL, April 1970.

Table 1

RECOMMENDED RADIATION TOLERANCES FOR BUNA N

Application	Recommended Tolerance ergs/gm(C)	Basis for Recommendation
Hoses	1×10^8	Hose Tests
Gaskets and Seals	1×10^9	25% Decrease in Elongation
Sealants	8×10^9	Absolute Elongation > 30%
Packing	1×10^{10}	Physical Deterioration
Grommets	1×10^{10}	

Material applications were arranged into four classes according to their recommended limits. Figure 2 shows the unattenuated full-flow engine gamma dose rates as well as the regions in which each class of material applications may be safely employed, assuming a 10-hr engine operation. As illustrated in Figure 2, components for a specific subsystem can be distributed from one end of the vehicle to the other, thus permitting use of materials from each class.

Table 2 summarizes the stage S-II and S-IVB systems investigated; however, it should be noted that electrical and/or electronic components were only evaluated if they were an integral part of a mechanical component, e.g., a solenoid within the actuator of a valve would be analyzed, but switching relays would not be examined.

The principles of radiation hardening can be illustrated with the 17-in. rotary shutoff valve (P/N 138025A) designed by the Whitaker Corporation for potential application as the LH_2 tank shutoff valve. The valve, which was initially designed as the LOX valve for stage S-1C of the Saturn V, was radiation hardened by the Whitaker Corporation. The modified valve assembly, which is comprised of three major subassemblies (the actuator and the upstream and downstream shell assemblies), is a spring-opened, pneumatically closed, spherical rotary shutoff valve intended for LH_2 service in a radiation field. The

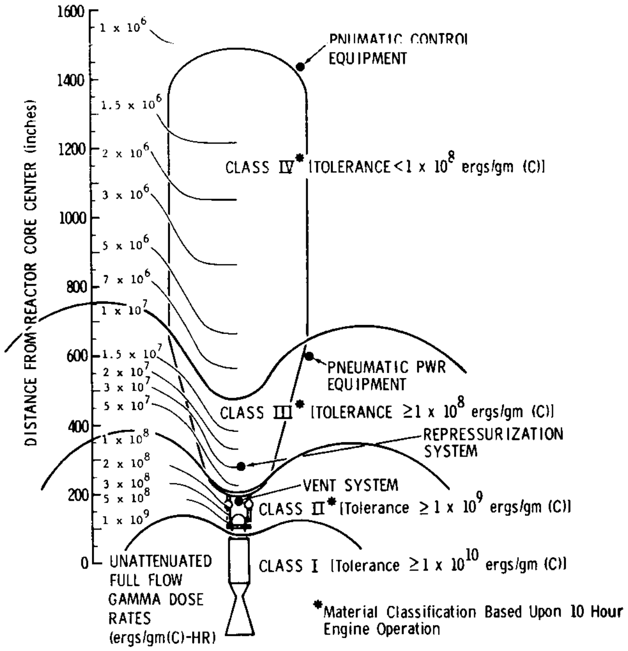

Figure 2 ASSUMED LOCATIONS OF PRESSURIZATION SYSTEM COMPONENTS

Table 2 SYSTEMS ANALYZED

SATURN V

STAGE S-II	STAGE S-IV B
• PROPELLANT FEED	• HYDRAULIC
• PROPELLANT MANAGEMENT	• PROPULSION
• PRESSURIZATION	• ENGINE
• LEAK DETECTION & PURGE	• AUXILIARY PROPULSION
• PROPULSION	• STRUCTURES
• AUXILIARY PROPULSION	• SUPPORT
• CONDITIONING	• THERMO-CONDITIONING
• ENGINE ACTUATION	• DESTRUCT

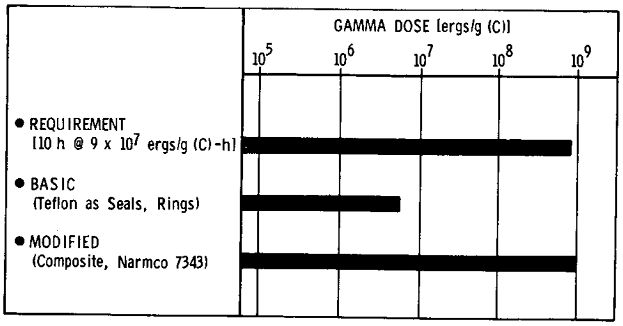

Figure 3 RADIATION TOLERANCE OF 17-INCH VALVE

valve, which has a nominal line size of 17 inches, would be flange-mounted between the LH_2 tank and the suction side of each engine turbo pump on the NRV where it would be subjected to an integrated exposure of approximately 8 x 10^8 ergs/gm(C) over a vehicle life requiring 10 hours of engine operation.

Radiation hardening of the valve for operation in the LH_2 environment was achieved primarily by replacement of the radiation sensitive materials Teflon and Rulon (reinforced PTFE). Replacement materials were (1) Kynar (vinylidene fluoride resin), (2) a composite seal of Kynar, glass, and TFE Teflon fibers, and (3) a polyurethane elastomer (NARMCO 7343). As shown in Figure 3, the valve assembly has been radiation hardened by material substitution such that its recommended radiation tolerance has been increased from 7 x 10^6, as limited by Teflon TFE, to 1 x 10^9 ergs/gm(C), which is slightly higher than the predicted exposure of 8 x 10^8 ergs/gm(C). The modified valve assembly is scheduled for testing later this year in a nuclear radiation environment with LH_2 flow, using the Ground Test Reactor (GTR) at the Fort Worth operation of the Convair Aerospace Division of General Dynamics.

In the radiation hardening analysis of S-II and S-IVB components, radiation sensitive material applications were identified and classified into two categories: critical and non-critical. In a critical application the mission would be compromised if the material properties degraded below the requirements of the particular application. If material substitution increases the recommended radiation tolerance to a value in excess of the predicted environment, it was recommended; otherwise, minor design modifications were suggested. The results of these analyses are typified by the data presented in Table 3.

SUMMARY

The results of the analysis of the S-II and S-IVB components, although incomplete, indicate that many Saturn V components and subsystems, e.g., pumps, valves, etc., can be radiation hardened to meet NRV requirements by material substitution and minor design modifications. Results of these analyses include: (1) recommended radiation tolerance limits for over 100 material applications, (2) design data which describes the components of each system which can be employed on the NRV and the modifications necessary to radiation harden other components, (3) presentation of radiation hardening examples of systems which will provide guidance to component designers, and (4) designing radiation effects tests to supply data for selecting materials with confidence.

Table 3 RADIATION HARDENING SUMMARY

COMPONENT	APPLICATION	MATERIAL	CRIT. APPLIC.	GAMMA ENVIRONMENT [ergs/gm (C)]		RECOMMENDATION
				PREDICTED	RECOMMENDED	
HOSE ASSEMBLY	HOSE	TEFLON TFE	YES	1×10^9	3×10^6	WELD METAL TUBING AND ELIMINATE SEALS
	SEAL	BUNA N	YES	1×10^9	1×10^9	
VALVE ASSEMBLY	SEAL	TEFLON FEP	YES	1.5×10^9	7×10^8	REPLACE WITH KYNAR
	SEAL	KEL-F	NO	↕	1×10^9	
	SLEEVE	TEFLON TFE	NO	↕	1×10^8	
	GROMMET	TEFLON FEP	NO	↕	7×10^8	
	ELEC. INSULATION	SILICONE RUBBER	YES	1.5×10^9	1×10^9	REPLACE WITH MYLAR