NASA CONTRACTOR REPORT

NASA CR-2045

NASA CR-2045

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

Phase I

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MAY 1972

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-2045		
4. Title and Subtitle EVALUATION OF INSULATION MATERIALS AND COMPOSITES FOR USE IN A NUCLEAR RADIATION ENVIRONMENT , Phase I		5. Report Date May 1972 6. Performing Organization Code
7. Author(s) W. A. Greenhow and J. H. Lewis		8. Performing Organization Report No. FZK-378
9. Performing Organization Name and Address General Dynamics Convair Aerospace Division Fort Worth Operation		10. Work Unit No. 11. Contract or Grant No. NAS 8-25848
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		13. Type of Report and Period Covered Contractor Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This study has been carried out to evaluate flight-qualified Saturn V materials, components, and systems for use, with or without modification, in the radiation environment of the nuclear flight system. The results reported herein are primarily intended to aid designers in their evaluation and selection of "off-the-shelf" equipments which may meet the stringent requirements and specifications associated with application on a reusable nuclear-powered space system, i.e., the Reusable Nuclear Shuttle. One of the factors which must be evaluated in the design of the RNS is the effects of radiation on materials; and it is toward this aspect of the overall effort that this analysis has been directed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Radiation Saturn V materials Nuclear flight system	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	329	$6.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

This report was prepared by the Fort Worth operation of General Dynamics, Convair Aerospace Division, 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 radiation effects analysis described in this report was performed at the Fort Worth operation of the Convair Aerospace Division of General Dynamics for the George C. Marshall Space Flight Center under Contract NAS8-25848. This contract is an extension of previous technology studies conducted at the Nuclear Aerospace Research Facility in support of nuclear rocket vehicle development.

Two primary tasks were accomplished under Contract NAS8-25848, both of which were based in part on the nuclear flight system concepts generated under Contracts NAS8-24714, NAS8-24715, NAS8-24975, and SNP-1. Task II, the radiation effects analysis of Saturn V materials, components, and systems, is documented herein. The results of the Task I study, the design of a propellant heating experiment compatible with contemporary flight vehicle concepts, are given in the Fort Worth operation report FZK-380.

The authors wish to acknowledge the contributions of H. G. Carter and P. R. Cheever of the Fort Worth operation; Mr. Carter performed the calculations of the mission-integrated gamma doses given in Section V, and Mr. Cheever assisted in the preparation of the radiation effects data summaries.

Mr. E. E. Kerlin, also of the Fort Worth operation, was instrumental in the initiation of the Saturn V analyses. He provided valuable comments and suggestions pertaining to this report as well as the principal liaison with the Marshall Space Flight Center.

Also to be acknowledged is Mr. C. L. Peacock, the Assistant COR at MSFC, for his efforts in coordinating the acquisition of the voluminous quantities of Saturn V reference data required for this study.

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I. INTRODUCTION

The Saturn V radiation effects analysis is an evaluation of flight-qualified S-II and S-IVB stage materials, components, and systems for possible use on a Reusable Nuclear Shuttle (RNS). The objectives of this study were (1) to determine those components and systems suitable for use in the RNS radiation environment, and (2) to determine those components and systems potentially hardenable to RNS requirements by material substitution or minor design modifications. In addition to the identification of radiation sensitive materials and their applications, it was necessary to determine the radiation environment at possible locations of the components and systems on the nuclear vehicle.

The RNS configurations are based on the nuclear flight system definition studies performed by McDonnell Douglas (Ref. 1), Lockheed Missiles and Space Co. (Ref. 2), and North American Rockwell (Ref. 3). Source terms for the nuclear radiation are from Aerojet Nuclear System Company's reference data for the full-flow NERVA engine (Ref. 4). Data for the S-IVB and S-II stages of the Saturn V were obtained from drawings and specifications provided by the film repository at MSFC and, in part, from information provided by the vendors of commercial parts.

Although the data and results for the S-IVB and S-II stages are quite detailed and specific, an effort has been made to organize and present the data, e.g., radiation effects data and radiation environment, in such a manner that it will have utilitarian value to designers or in future radiation effects analyses as the RNS becomes more precisely defined.

II. SUMMARY AND RECOMMENDATIONS

This study has been carried out to evaluate flight-qualified Saturn V materials, components, and systems for use, with or without modification, in the radiation environment of the nuclear flight system. The results reported herein are primarily intended to aid designers in their evaluation and selection of "off-the-shelf" equipments which may meet the stringent requirements and specifications associated with application on a reusable nuclear-powered space system, i.e., the Reusable Nuclear Shuttle. One of the factors which must be evaluated in the design of the RNS is the effects of radiation on materials; it is toward this aspect of the overall effort that this analysis has been directed.

2.1 General Methods

Drawings and specifications for the mechanical systems of the S-II and S-IVB stages, which are representative of current liquid-hydrogen-fueled vehicles, have been examined to determine the types and applications of radiation sensitive materials. Based upon radiation effects test data, radiation tolerances (maximum recommended radiation exposure) were established for each application of each material. These tolerances were then compared to the predicted radiation exposure at the assumed component (or subsystem) location on the RNS. When the radiation tolerance was felt to be inadequate for the particular application, modifications by material substitution or minor design changes were recommended such that reliable performance could be expected.

Electrical and electronic systems per se were not a part of this study. Of the mechanical systems and their associated electrical components, the materials of interest are some forty organics used in a variety of applications. Only a few of these, and most often Teflon, set the limit for the maximum recommended radiation exposure of individual components. The analysis indicates, however, that almost every component can be radiation hardened to exposure levels of at least 1×10^{10} ergs/gm(C), which exceeds the maximum predicted exposure accumulated during missions involving ten hours of full-power NERVA I reactor operation for all components located forward of the engine-gimbal interface.

The recommended material substitutions are based on the use of relatively radiation stable materials which can perform the same or similar functions. It is realized, however, that the recommended materials will not always result in designs capable of satisfying the component specifications due to material characteristics or material processing procedures unique to the material selected for the original design. For this reason, Table 2-1 lists some materials preferred for several common applications

Table 2-1

PREFERRED MATERIALS FOR VARIOUS APPLICATIONS
IN A RADIATION ENVIRONMENT

Application	Material	Recommended Tolerance (ergs/gm(C))
Gaskets and Seals	Aluminum	--
	Kynar	$3x10^{10}$
	Polyimide	$2x10^{10}$
	Kynar Composite	$1x10^{10}$
	Viton A	$6x10^{9}$
	Mylar	$6x10^{9}$
Packing	Kynar	$3x10^{10}$
	Polyimide	$2x10^{10}$
	Viton A	$6x10^{9}$
Electrical Insulation	Diallyl Phthalate	$2x10^{10}$
	Polyimide	$1x10^{10}$
	Mylar	$1x10^{10}$
	Kynar	$1x10^{10}$
Spacers	Aluminum	--
	Silicone/glass	$2x10^{11}$
	Polyester/glass	$6x10^{10}$
	Kynar	$3x10^{10}$
	Polyimide	$3x10^{10}$
	Rubber/asbestos	$3x10^{10}$
Backup Rings	Polyimide	$3x10^{10}$
	Kynar	$3x10^{10}$
	Teflon/glass	$1x10^{10}$
	Mylar	$1x10^{10}$

to assist the component designer in the final selection of materials.

Section IV presents a brief discussion of the radiation effects data for each of the organic materials identified and those recommended for use in the radiation hardening. Since the particular application of a material has a bearing on its usefulness in the radiation environment, the tolerance levels, given in Table 4-1, are based on specific applications. The bases for these recommended tolerances are discussed in Section IV; here again, the material criteria should be carefully examined by the designer to ascertain which property, or properties, are of greatest importance in a given application. In some instances, the radiation effects data were insufficient to confidently establish safe operating limits for material applications in the RNS environment of vacuum, possible cryotemperature, and nuclear radiation. Some recommendations for additional testing are discussed in Section 2.5.

2.2 Doses for Baseline RNS Tank Configurations

Four different propellant tank concepts, namely, (1) single tank with 8.5-deg conical aft bulkhead, (2) single tank with 15-deg conical aft bulkhead, (3) two-tank hybrid, and (4) single-tank modular, have been used in the computation of mission-integrated gamma doses within the tank and along the tank walls. These tank concepts were selected as being representative of those under active consideration at the time this study was initiated. The computational method and results are given in Section V, and specific tank dimensions are in Section III.

The isodose contours (Sec. 5.2) correspond to a single mission in which the initial propellant mass is 290,000 lb, the drain-rate is 90 lb/sec, and the residual fuel mass is 7,500 lb. The assumed separation between the core center of the 1575-MW NERVA and the tank bottom is 200 in. Figure 2-1 depicts a portion of these results converted to a ten-mission dose and shows a comparison between the four configurations.

Because of unresolved questions such as final tank configuration, the actual location of various subsystems and components, and the requirement for an external shield, the doses used in the analyses of the S-II and S-IVB stages are derived directly from the ANSC source-term data (Ref. 4) by use of R^{-2} attenuation (Sec. 5.1) and assuming 10 hours of engine operation. Although this results in an over estimate of the dose within the tank and along the tank walls, it has the advantages of being configuration independent and of representing a worst-case dose. Furthermore, as would be expected and as shown in Figure 2-1, the doses at and near the bottom of the tanks are essentially the same for all the configurations; this is the region of primary interest since a number of subsystems, or at least parts thereof, must necessarily be located near the engine. The

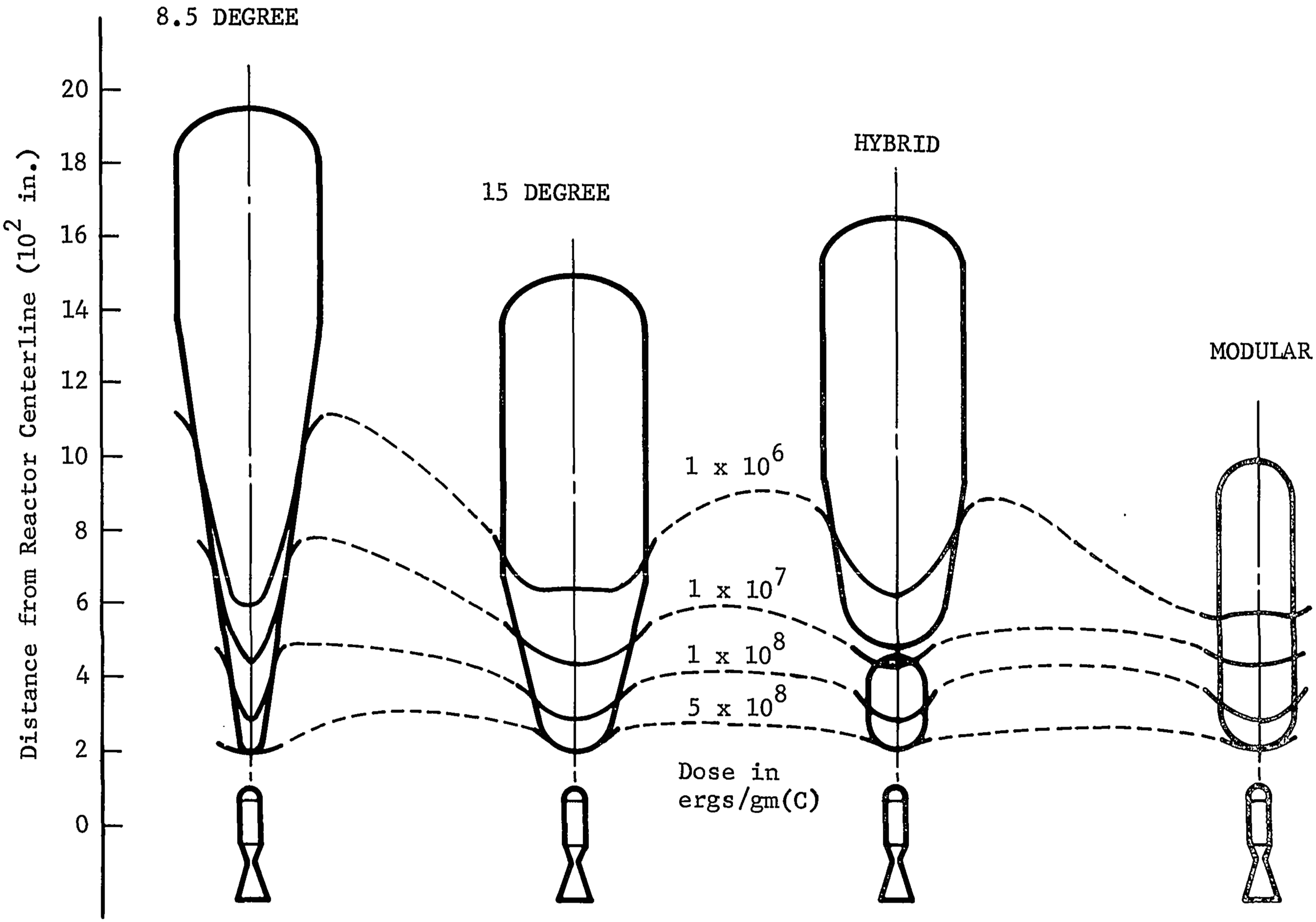


Figure 2-1 Gamma Dose Accrued in Ten Missions of The Baseline RNS Tank Configurations

location of components or subsystems along the lower walls of the tank may be somewhat arbitrary, and here the hydrogen attenuation and tank geometry become important. The data given in Section 5.2 may be used in evaluating specific situations.

2.3 Summary of S-IVB and S-II Analyses

Major systems of the S-IVB and S-II stages, discussed in detail in Sections VI and VII, respectively, have been examined and found to contain radiation sensitive organic materials which would preclude their use on the RNS in their present design configurations. However, it is believed that radiation hardening by material substitutions or minor design modifications would enable virtually all of the examined components to withstand radiation dosages in excess of those predicted.

Nevertheless, it must be emphasized that material substitutions might be a relatively simple matter or they could result in a major redesign of possibly greater magnitude than starting from scratch. Every material, component, or system considered for use on the RNS will eventually have to be evaluated on its own merits for the particular application in a particular environment. It is hoped that this effort is a step in that direction.

The following bar charts, Figures 2-2 through 2-14, depict the general analytical results by subsystem for the S-IVB and S-II systems examined (with the exception of the S-IVB support assembly, which was found to contain no organics, and the S-IVB thermocondition system, which uses only a few organics). Each chart shows a comparison between the predicted exposure level, the tolerance of the as-designed subsystem, and the tolerance of the subsystem as modified (if required).

A distinction is made between material applications which were considered critical to mission success and those which were considered not to be critical. These rather arbitrary assignments, based on engineering judgment, have been made to avoid the implication that all usages of radiation sensitive materials are equally important insofar as replacement is concerned. In the figures, a noncritical application of a material of lower radiation tolerance than that assigned to the subsystem is indicated by the triangle; if all organic material applications in the subsystem are considered noncritical, the striped bar is used.

The lowest tolerances are set by hoses lined with Teflon TFE (3×10^6 ergs/gm(C)) and Teflon TFE seals, gaskets, etc. (7×10^6 ergs/gm(C)). Other Teflon TFE applications are given radiation tolerances of from 2×10^7 to 1×10^8 ergs/gm(C). Other material applications having relatively low radiation tolerances are: Buna N hoses, 1×10^8; nylon seals, 5×10^8; hydraulic fluid (MIL-H-5606), 5×10^8; neoprene seals, 6×10^8; Teflon FEP seals, gaskets, bearings, etc., 7×10^8; silicone rubber seals, 8×10^8; and silicone lubricant (DC-510), 8×10^8.

Figure 2-2

RADIATION HARDENING SUMMARY — S-IVB HYDRAULIC SYSTEM

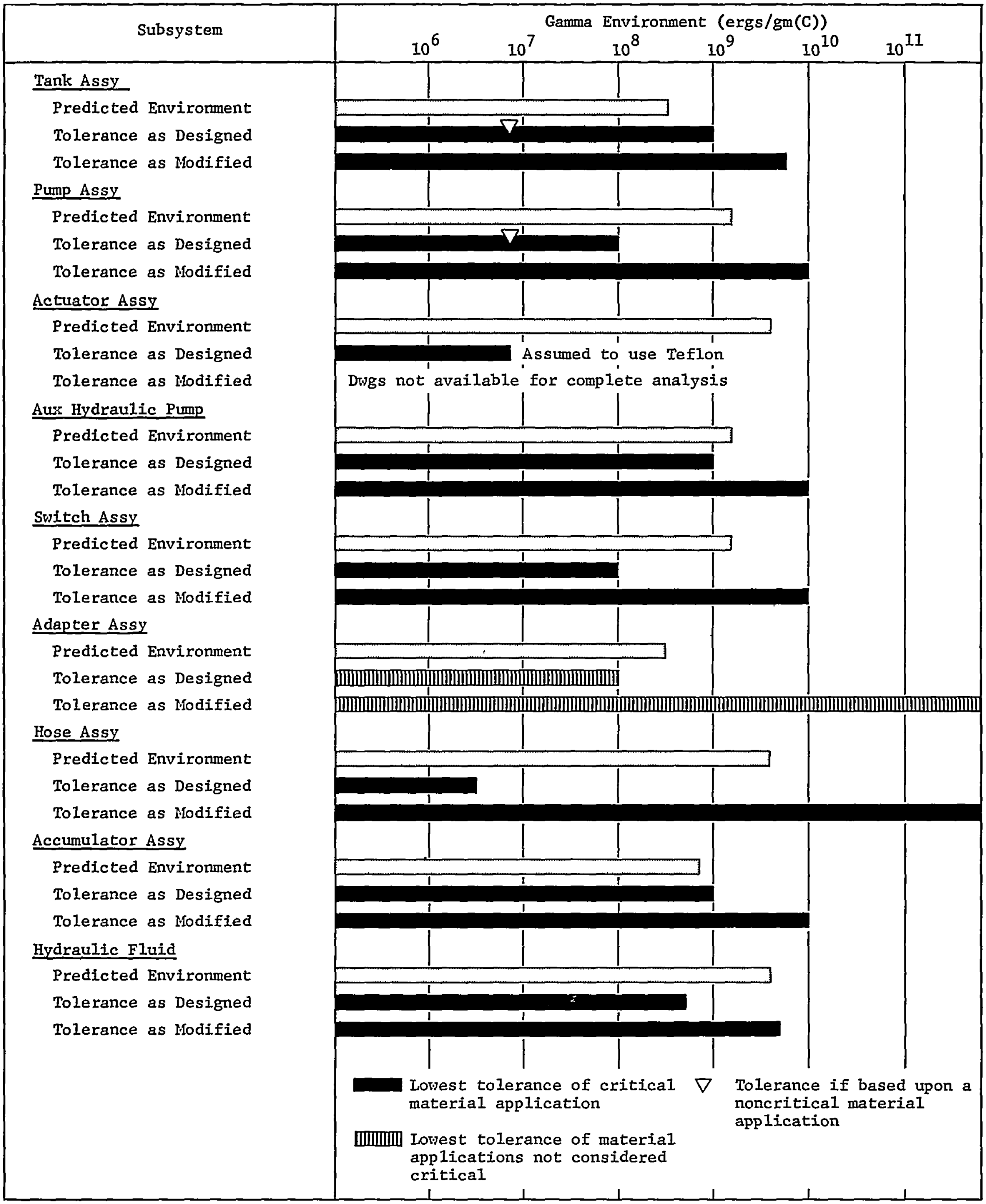


Figure 2-3

RADIATION HARDENING SUMMARY — S-IVB AUXILIARY PROPULSION SYSTEM

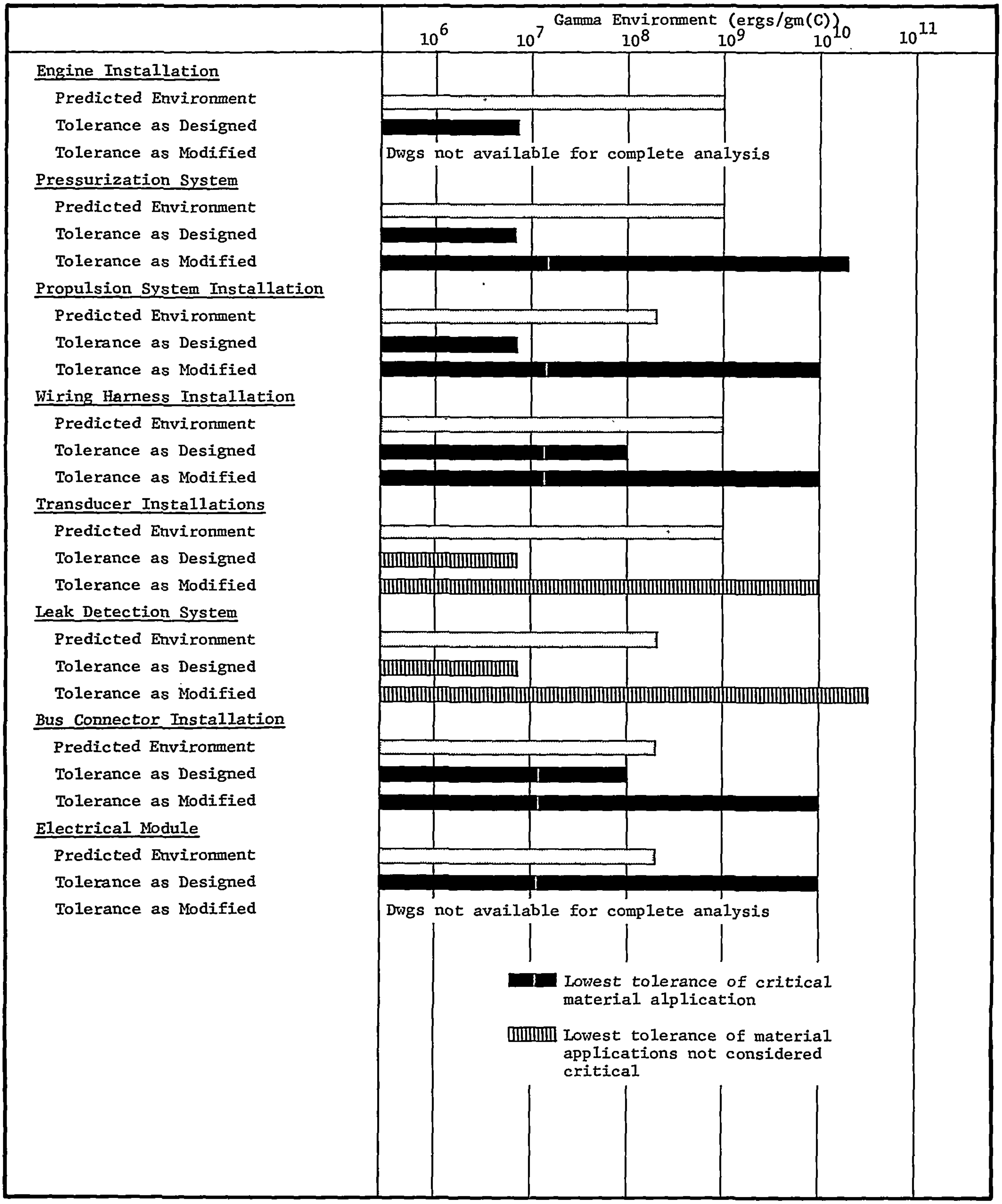


Figure 2-4

RADIATION HARDENING SUMMARY — S-IVB PROPULSION SYSTEM

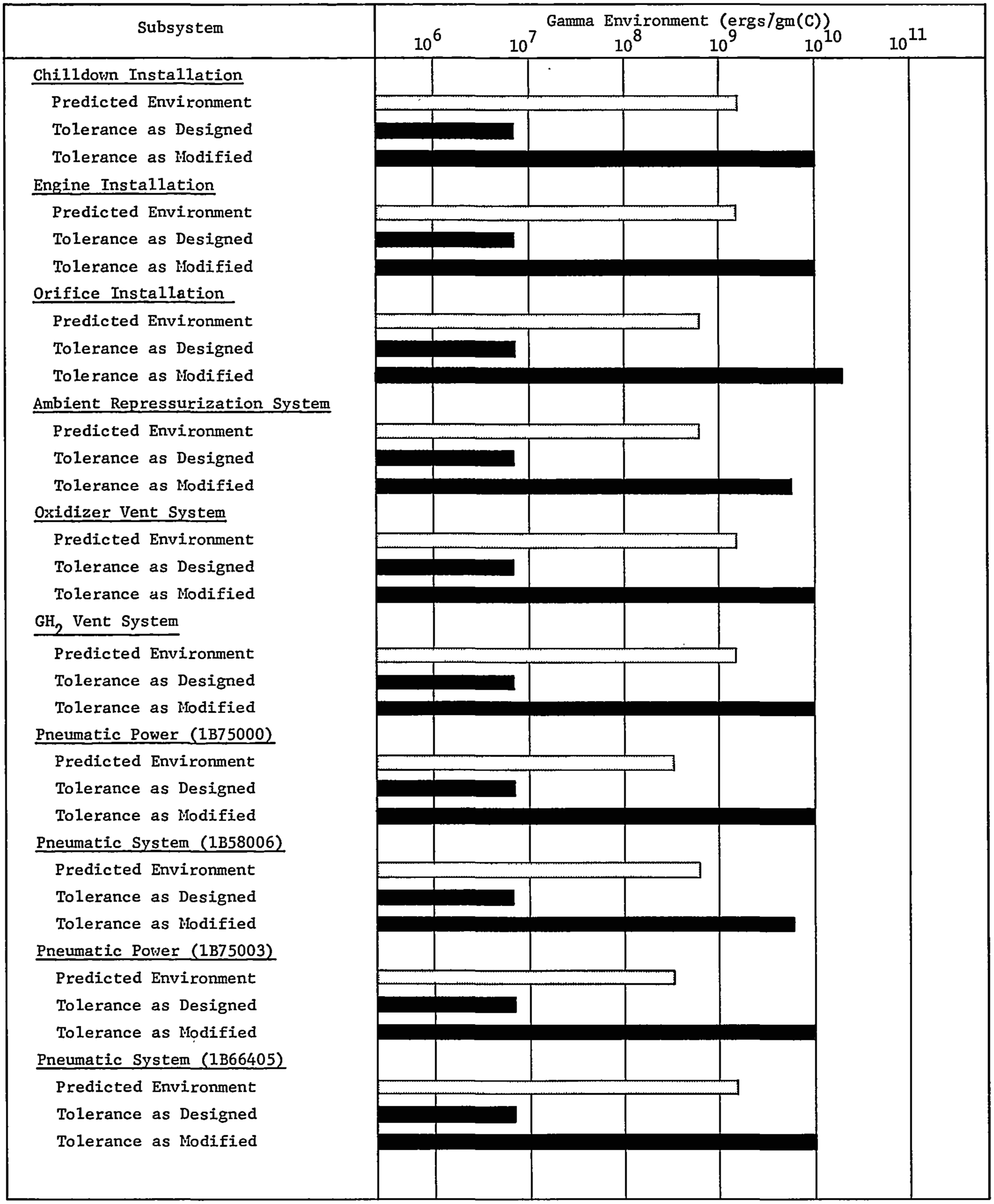


Figure 2-4 (cont'd)

RADIATION HARDENING SUMMARY — S-IVB PROPULSION SYSTEM

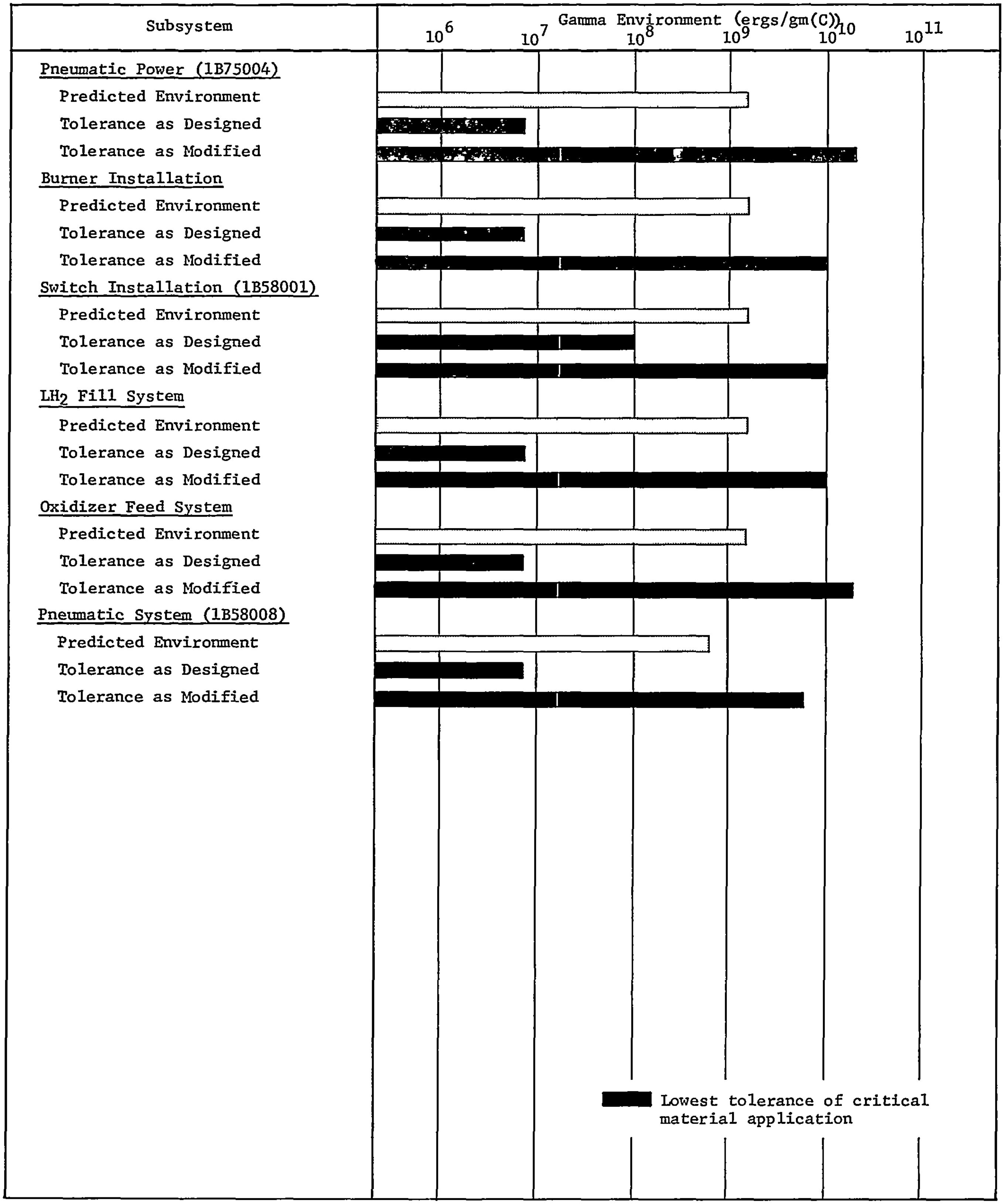


Figure 2-5

RADIATION HARDENING SUMMARY — J-2 ENGINE SYSTEM

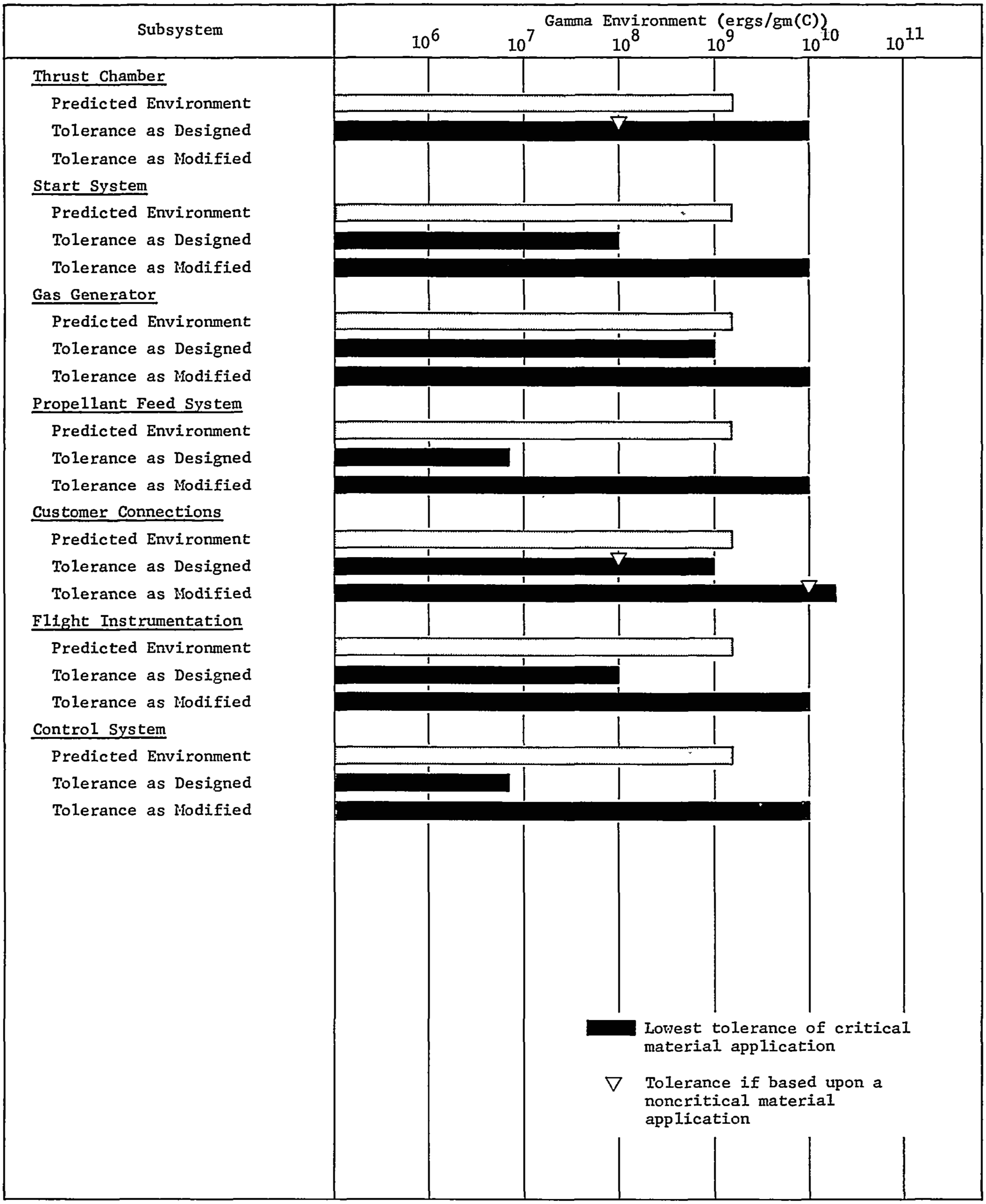


Figure 2-6

RADIATION HARDENING SUMMARY — S-IVB STRUCTURES ASSY

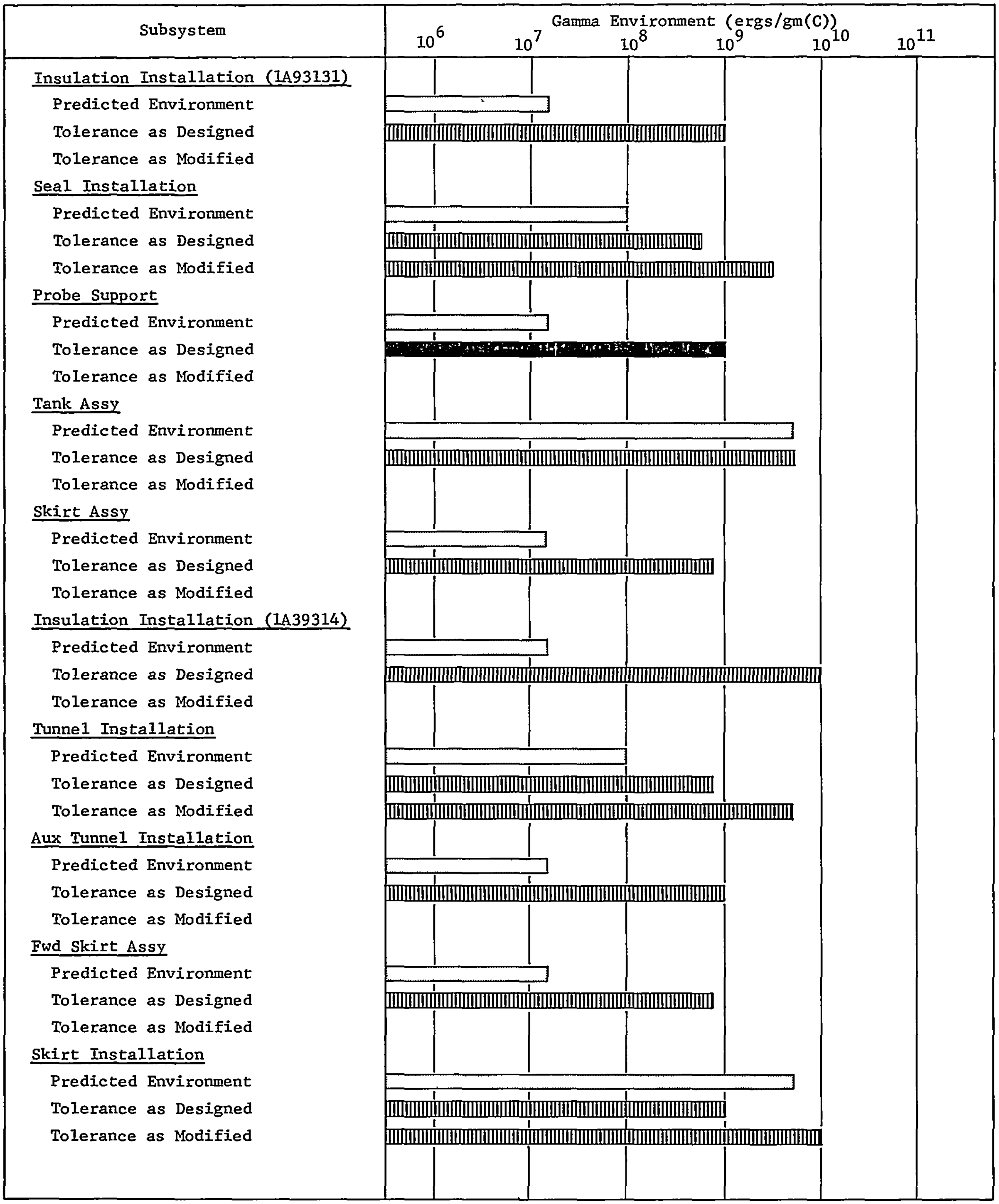


Figure 2-6 (cont'd)

RADIATION HARDENING SUMMARY — S-IVB STRUCTURES ASSY

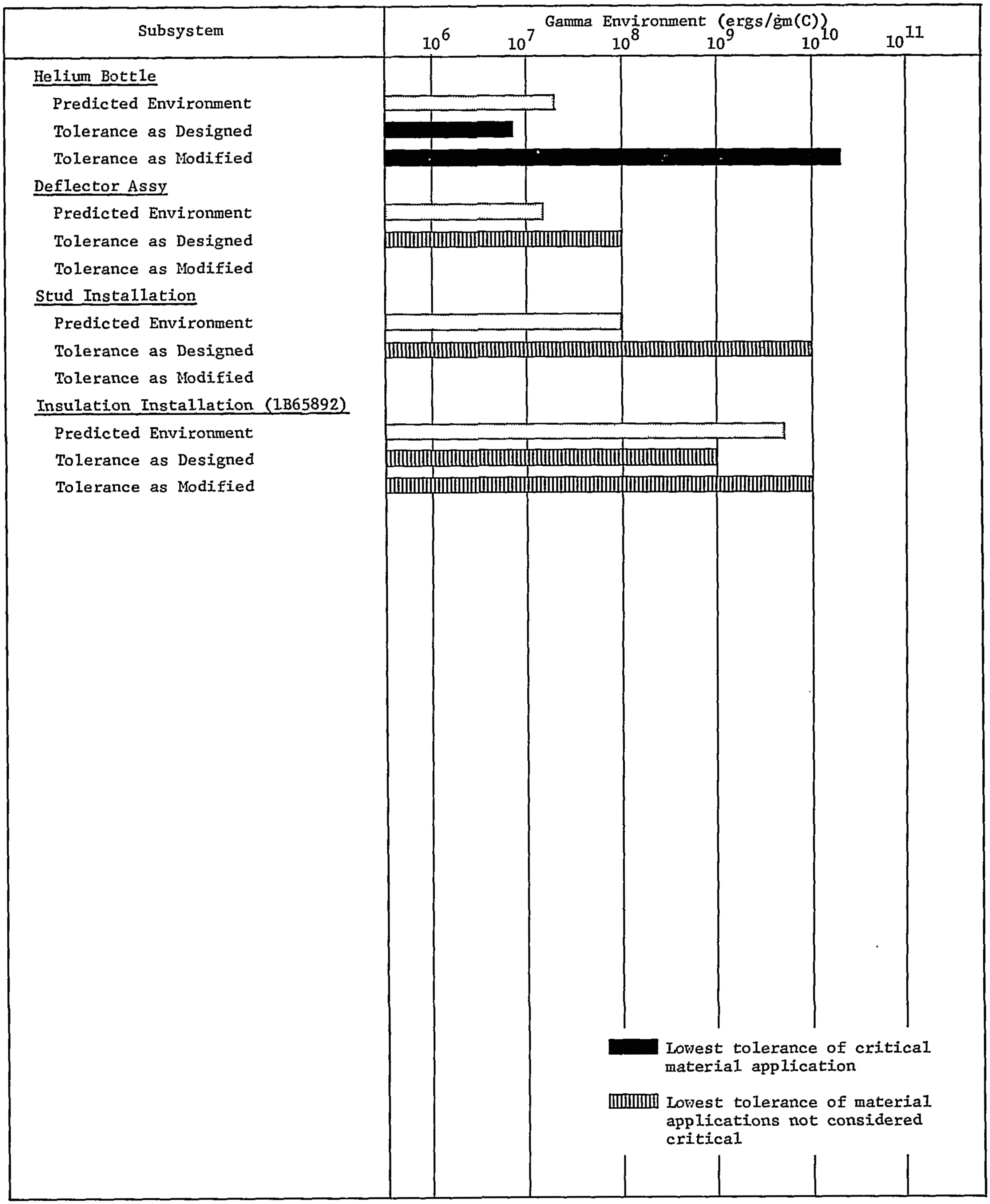


Figure 2-7

RADIATION HARDENING SUMMARY — S-II ENGINE ACTUATION SYSTEM, HYDRAULIC

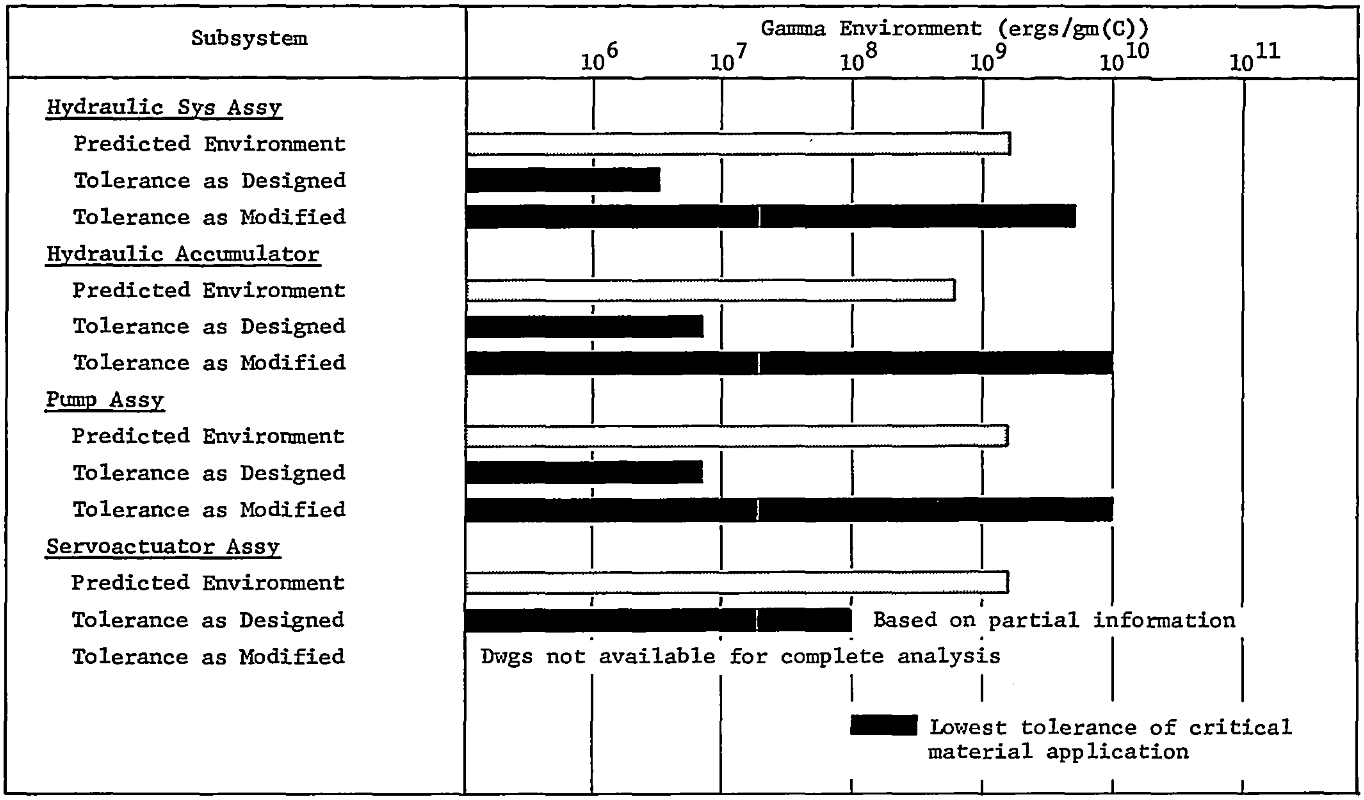


Figure 2-8

RADIATION HARDENING SUMMARY — S-II PROPELLANT FEED SYSTEM

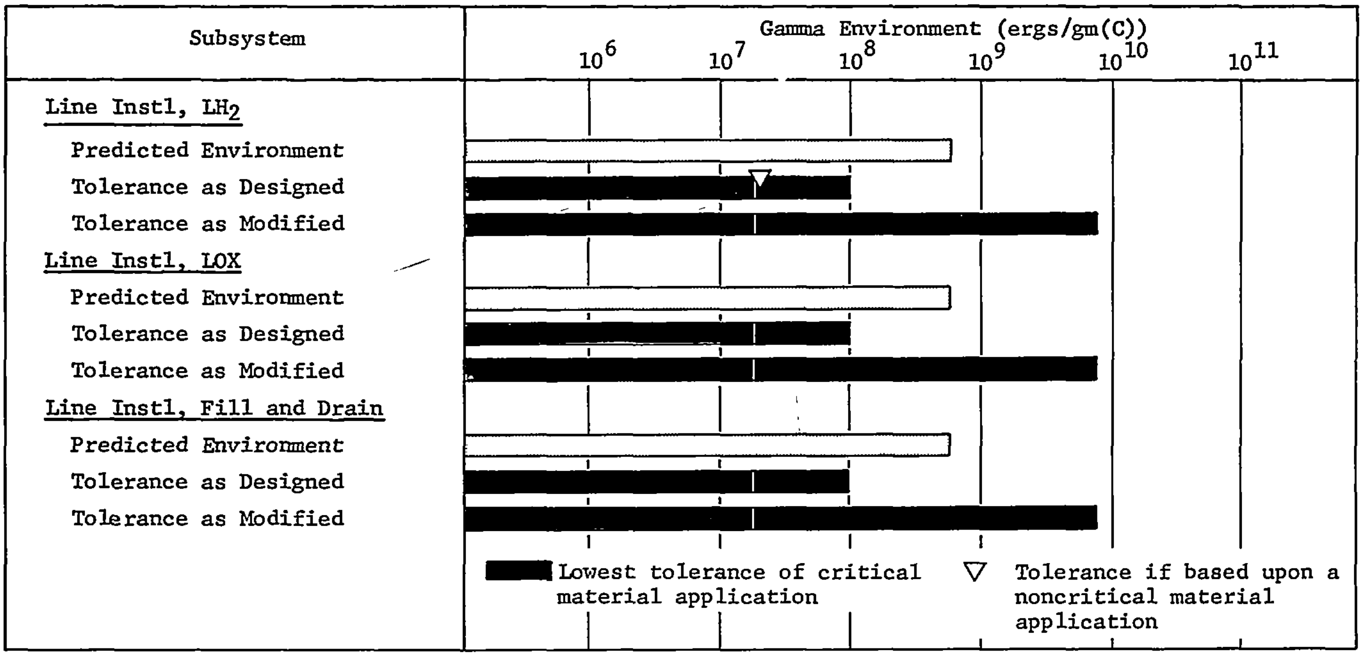


Figure 2-9

RADIATION HARDENING SUMMARY — S-II PRESSURIZATION SYSTEM, LH_2 AND LOX TANKS

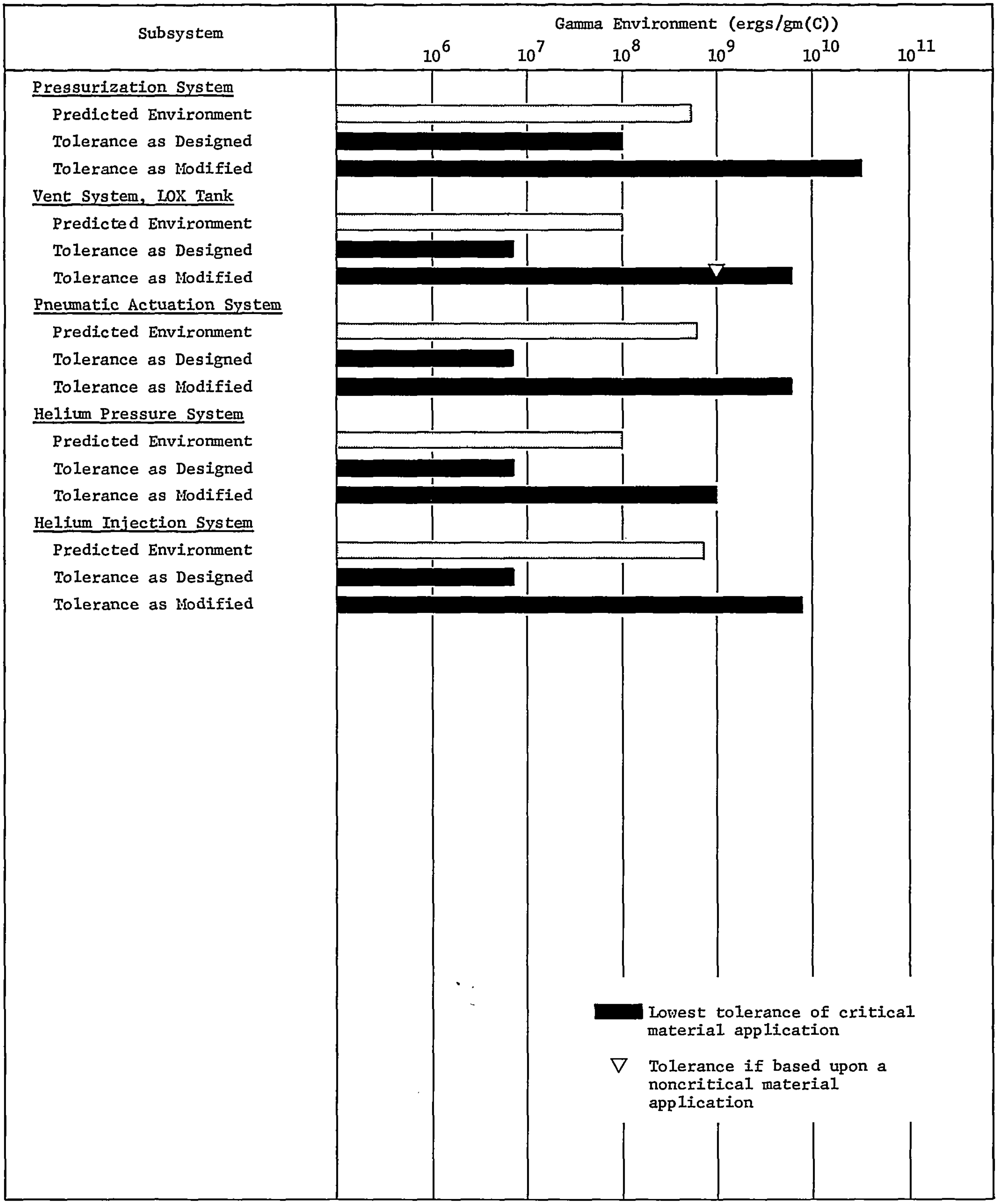


Figure 2-10

RADIATION HARDENING SUMMARY — S-II LEAK DETECTION AND PURGE SYSTEM

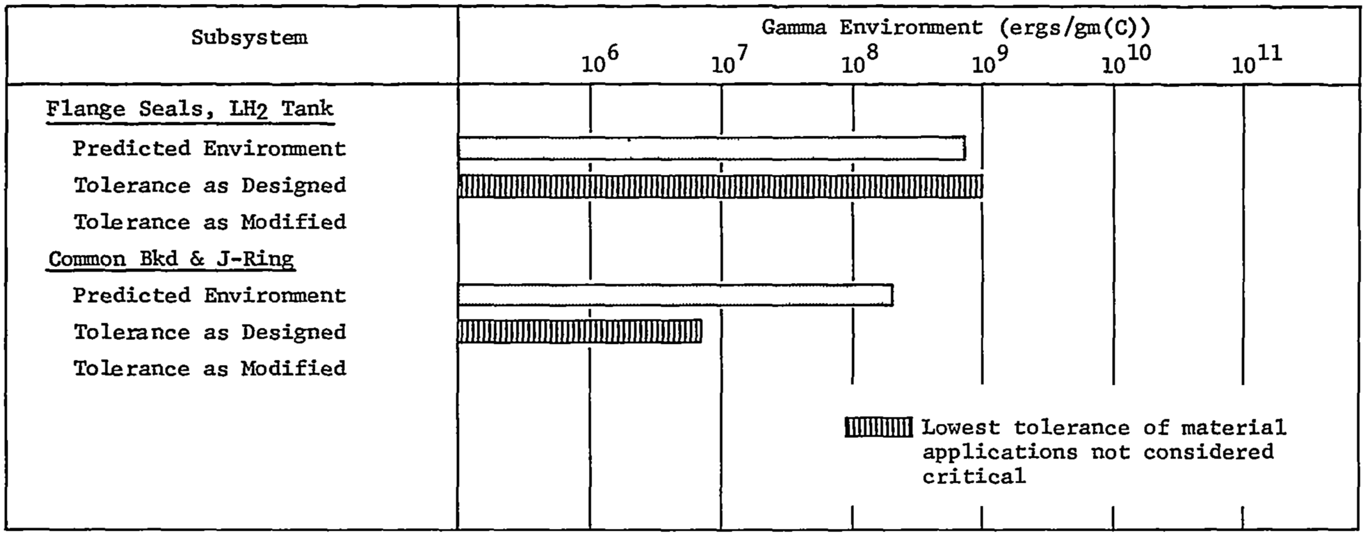


Figure 2-11

RADIATION HARDENING SUMMARY — S-II ELECTRICAL SYSTEM, GENERAL

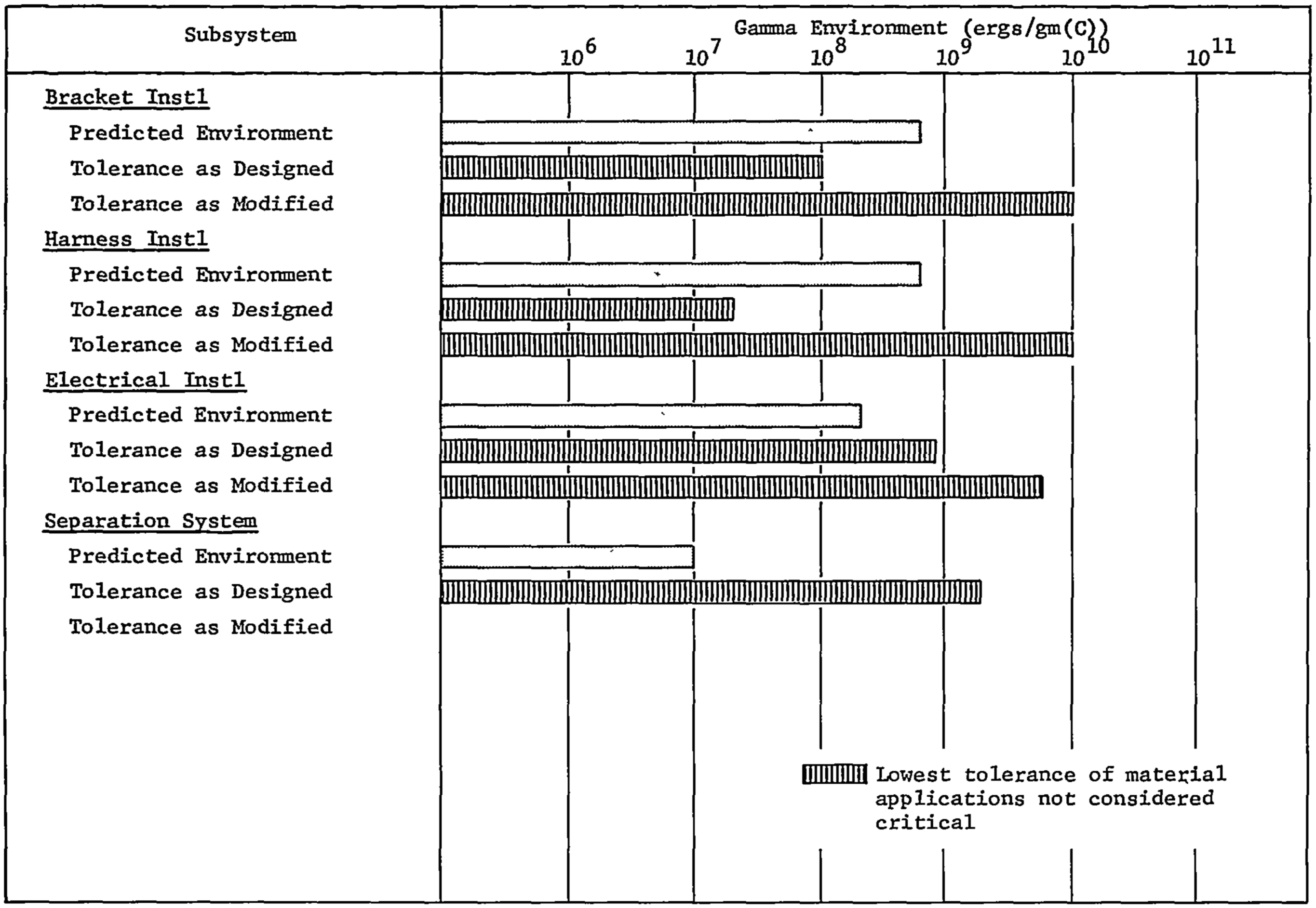


Figure 2-12

RADIATION HARDENING SUMMARY — S-II ENGINE INSTALLATION

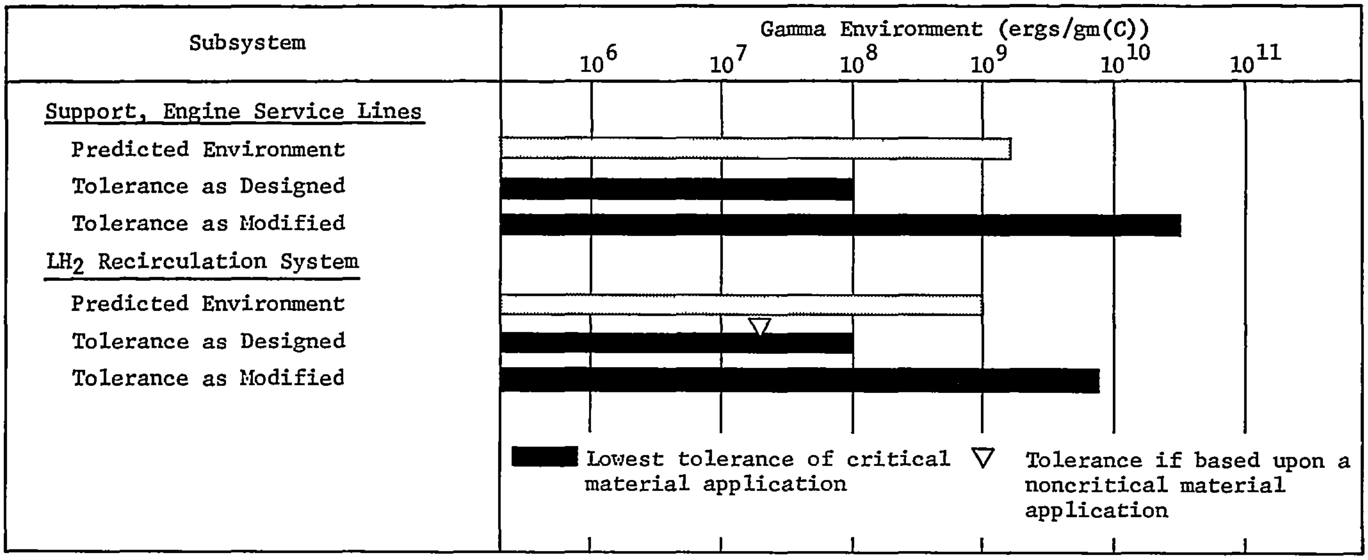


Figure 2-13

RADIATION HARDENING SUMMARY — S-II STAGE STRUCTURE

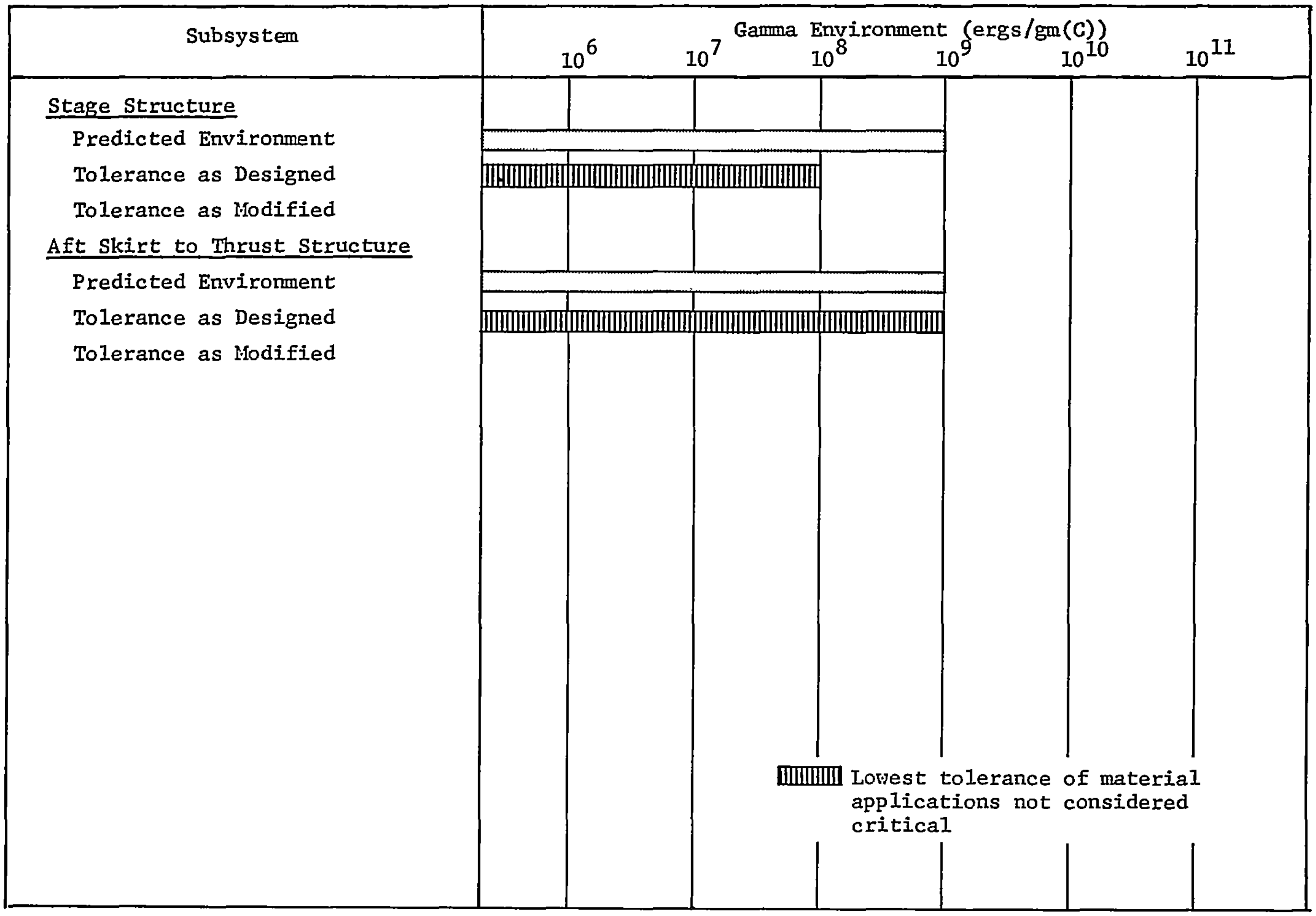
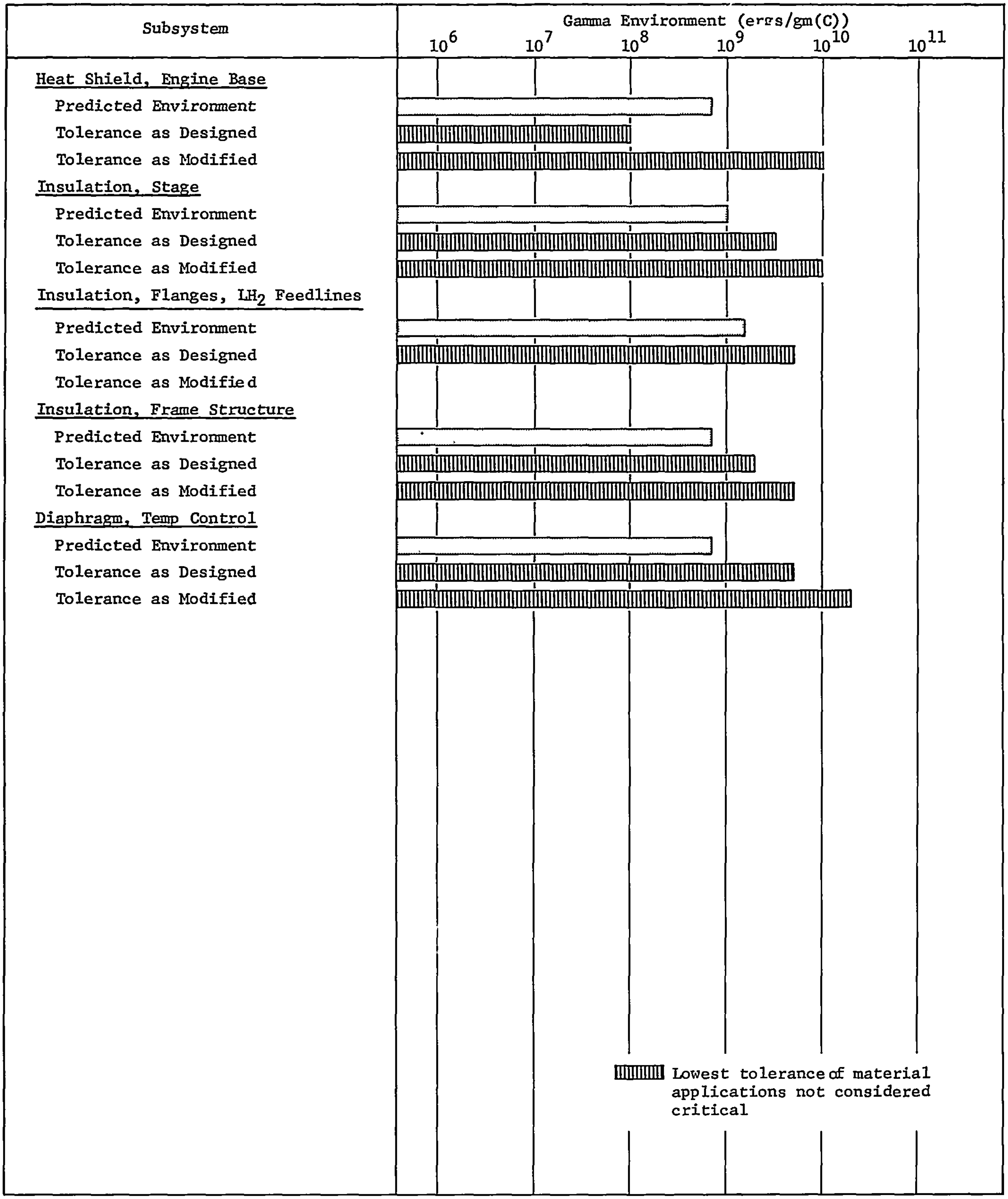


Figure 2-14

RADIATION HARDENING SUMMARY — S-II INSULATION AND HEAT SHIELDS



2.4 Summary of Propellant Shut-off Valve Analysis

A 17-in. rotary shutoff valve (Whittaker Corporation; P/N 138025A), which was specifically designed to function as the LOX prevalve for the SI-C stage of the Saturn V, was redesigned and radiation hardened by the Whittaker Corporation for potential application as the RNS hydrogen tank shut-off valve. A description of these design modifications and a discussion of the radiation effects analysis for this valve are given in Section VIII. These data indicate that reliable operation of the valve is expected at exposures up to 1×10^{10} ergs/gm(C).

2.5 Recommended Radiation Effects Testing

All modified components and systems will require testing to determine their compliance with system requirements. This test program will require both nuclear and non-nuclear tests in a vacuum environment at appropriate temperatures prior to finalization of design configurations. The recommended radiation tolerances for most materials (Sec. IV) are based upon radiation effects tests performed at ambient conditions, although it is realized that their performance can differ significantly at cryogenic temperatures and in vacuum. In general, radiation stability improves in a vacuum due to the absence of oxygen, Teflon being an outstanding example; however, there are exceptions. The effects of cryotemperature influence the radiation stability in a random manner, with some materials showing marked improvements when irradiated at cryotemperature and others being more stable at room temperature.

With the possible exception of Teflon, combined vacuum and cryotemperature effects are not expected to greatly influence the radiation tolerance limits used in this analysis. However, it would certainly be desirable to refine the useable limits of the more critical materials to more accurately reflect the influence of the combined environments. If combined environmental data are lacking, either for organic materials used in the Saturn V or new materials considered for use on the RNS, such testing should be considered mandatory.

Some additional uncertainty is injected into any discussion of radiation effects on materials in specific RNS applications due to the paucity of data for materials irradiated under load and the general lack of data for repeated low-dose exposures over a long period of time. Both of these factors are probably of little significance for many organic materials, particularly rigid plastics and those used without being under any particular load. However, materials under load, such as seals, O-rings, and valve seats, or subject to other stresses or wide temperature variations may be adversely affected to a greater extent than indicated by data from static tests.

A general recommendation is, therefore, that:

As RNS materials and applications become defined, these be reviewed from the standpoint of the adequacy of the radiation effects data and appropriate testing be accomplished as required.

In several instances, additional radiation effects data would be of immediate value in the prediction of material performance on the RNS. These are discussed briefly below.

2.5.1 Teflon

Teflon is the most widely used organic material in S-II and S-IVB components, appearing in a variety of applications from one end of the vehicle to the other. It has outstanding value for use with liquid hydrogen. Since it also has the lowest recommended radiation tolerance of all the organic materials, a large number of components are affected by the perhaps unnecessarily conservative limits used in this analysis. For this reason, it appears profitable to perform additional radiation effects test to more accurately determine the safe operating limits for Teflon under conditions more directly relatable to RNS applications. If the recommended tolerance level can be increased, the material can be specified for use over a greater portion of the vehicle. Whether considering existing or totally new components, Teflon is unexcelled for some applications.

2.5.2 Kynar

Based on tests performed at Convair Fort Worth in 1965, Kynar, a vinylidene fluoride manufactured by the Pennsalt Corp., is radiation resistant to exposures greater than 3 x 10^{10} ergs/gm(C). These data, coupled with its mechanical properties, make Kynar a prime candidate material for use in radiation hardened components. Since the radiation effects data are very limited, additional testing is recommended for Kynar seals, gaskets, O-rings, etc. in order to investigate the mechanical properties of Kynar in different applications and the influence of various processing techniques. (See Section VIII for applications of Kynar and a Kynar composite in the modified 17-in. LOX prevalve. This valve is scheduled for testing in the radiation/liquid hydrogen environment at Convair Fort Worth in December 1971.

2.5.3 <u>Kel-F</u>

Kel-F has useful properties over a wide temperature range. Important uses are as seals, gaskets, O-rings, valve seats, and bearings. Data for Kel-F irradiated in air indicate that its properties deteriorate rapidly at doses above about 1 x 10^9 ergs/gm(C). In vacuum its properties appear to be retained to higher dose levels, but the data are too few and scattered over too wide a dose range to permit definition of a valid upper limit for use. This material, which is widely used on the Saturn V, cannot be recommended for use in the high-dose areas of the RNS. It is therefore recommended that additional testing in vacuum be conducted to determine the upper limit for its use on the RNS.

2.5.4 Elastomers

Elastomers (e.g., nitrile, silicone, urethane) are widely used in Saturn V components and can be expected to have numerous applications on the RNS. The effects of radiation on elastomers generally varies widely depending upon the particular property measured. Some limited data indicates, for example, that compression set of some elastomers may become evident at much lower doses when they are irradiated under compression. Tensile properties may be a poor indicator of elastomer performance.

In the early 1960s, considerable research was conducted to develop radiation resistant elastomers. Radiation effects testing showed that many of these formulations did indeed have improved radiation stability - in some cases by very significant amounts. Some of these products may be commercially available; others may not. In any case, as the requirements for elastomers on the RNS become defined, these radiation resistant elastomers should be investigated as possibly suitable materials. Additional testing will be required to assure that the radiation effects data are appropriate to the various applications.

2.5.5 Hypergolic Propellants

Very little data exist regarding the effects of radiation on hypergolic propellants such as monomethyl hydrazine or nitrogen tetroxide. Radiation effects tests must be performed to determine if hypergolic propellants, which are used in the auxiliary propulsion system, will function properly in the RNS environment.

2.5.6 Hydraulic Hoses

The Teflon-lined hydraulic hoses used on the S-II and S-IVB stages have poor radiation resistance. The use of welded aluminum or steel lines, as recommended in the analyses, may not be satisfactory for all applications. Therefore, the testing of flexible hoses constructed of such materials as Teflon FEP, Kynar, or fiberglass laminated with Kynar is recommended.

2.5.7 Hydraulic Fluid

If a hydraulic actuation system is to be considered for use on the RNS, additional data on hydraulic fluids will be required. The petroleum-base fluid conforming to specification MIL-H-5606A which is used for both the S-II and S-IVB hydraulic systems has a recommended tolerance of 5×10^8 ergs/gm(C). This is about the exposure that would be received in one hour of engine operation (at least at the actuator position). Frequent replacement of the fluid or use of a remotely located reservoir would both add undesirable complications. The use of Oronite 8515 (radiation tolerance of 5×10^9 ergs/gm(C)) is a possibility, and this and more recently developed fluids should be investigated.

III. PROCEDURES

3.1 Scope of the Analysis

Components and systems of the S-IVB and S-II stages, being representative of current liquid-hydrogen fueled vehicles, have been analyzed to determine those components which can be utilized as presently designed or the modifications necessary to radiation harden them for analogous RNS applications. The only other component analyzed is the S-IC stage LOX shutoff valve, which has been redesigned for potential application as the RNS propellant tank shutoff valve.

In general, systems located on or near the aft end of the stages were selected for analysis on the assumption that a similar location on the nuclear vehicle would be necessary or desirable. It was evident that systems located on the forward end of the nuclear vehicle would be satisfactory from the standpoint of this analysis, so they were considered only to a minor extent.

It did not fall within the scope of this contract to evaluate electrical and electronic components unless they were an integral part of a mechanical system. In addition, those systems involving the use of pyrotechnics and explosives are being evaluated separately under Contract NAS8-18024. Otherwise, all of the major mechanical systems - including the LH_2, LOX, hydraulic, and engine systems - were investigated in order to obtain a comprehensive coverage of materials and components and their applications.

It was, of course, necessary to exercise judgment in the number and types of subsystems investigated in order to keep the study within manageable limits. The S-IVB stage has been broken down in considerable detail and the S-II stage in lesser detail; however, the components and materials are generally similar from the radiation effects standpoint.

3.2 Saturn V Data

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 and S-IVB systems were ordered from the MSFC repository. These drawings were reviewed to identify subsystems or components containing, or thought to possibly contain, radiation sensitive materials, and additional drawings and specifications were ordered. This process was continued until one of the following ends was reached:

1. The radiation sensitive materials were identified.

2. The component or subsystem could be eliminated from further consideration based on the absence of radiation sensitive materials (where "radiation sensitive" is interpreted in terms of this analysis).

3. A part number and vendor for a commercial part was identified.

4. The pursuit was discontinued due to insufficient data or for lack of time to follow up. A relatively small number of the total components investigated fall into this category, and it is believed that little if any basic information was lost.

To obtain information on the materials used in commercial components, part numbers and vendor names were forwarded to the Contracting Officer's Representative. Letters were then sent to the vendors from the Astronautics Laboratory at MSFC requesting the required data. Of inquiries to 93 vendors, replies were received from 64.

Pertinent specifications and standards were also reviewed; these included those of the stage contractors, NASA, and the military. Data related to these specifications are tabulated in Section 4.2.

The approximate numbers of drawings and other data sources utilized in the identification of materials and applications are:

S-IVB Drawings - 462

S-IVB Specifications - 92

S-II Drawings - 272

S-II Specifications - 130

MIL, MC, MS, AMS, and NAS Specifications - 100

Vendor Responses - 64

3.3 Baseline RNS Tank Configurations

Data presented at the first interim briefing of Phase III of the Nuclear Shuttle Definition Study (September 2 and 3, 1970) have been used to define four propellant/propulsion tank concepts, namely (1) single tank with an 8.5-degree conical aft bulkhead (Fig. 3-1), (2) single tank with a 15-degree conical aft bulkhead (Fig. 3-2), (3) two-tank hydrid (Fig. 3-3), and (4) single tank modular (Fig. 3-4); the first three of these tanks have a nominal 300,000-lb LH_2 capacity and the modular tank has a nominal 38,000-lb LH_2 capacity.

Since it was evident from the Phase III definition studies that several configurations were still under active consideration, radiation flux profiles were calculated within and along the walls of the tanks for each configuration. The 15-degree conical tank configuration was used as the reference design for predicting the exposures of the components at their assumed locations. The assumption of a different configuration or a different location on the configuration can be evaluated from the radiation flux data given in Section V for the other configurations.

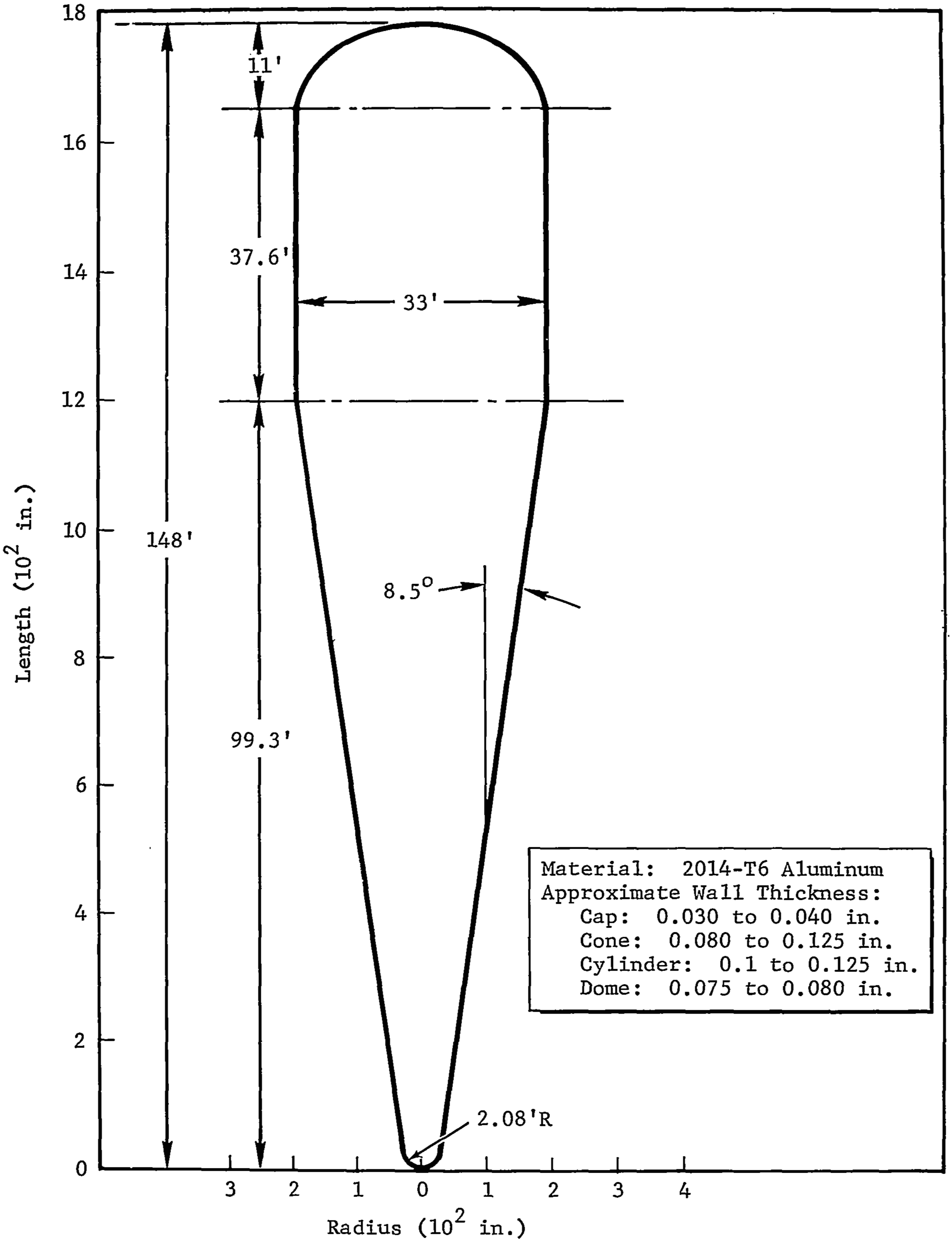


Figure 3-1 Single Tank Configuration with 8.5-Degree Conical Aft Bulkhead

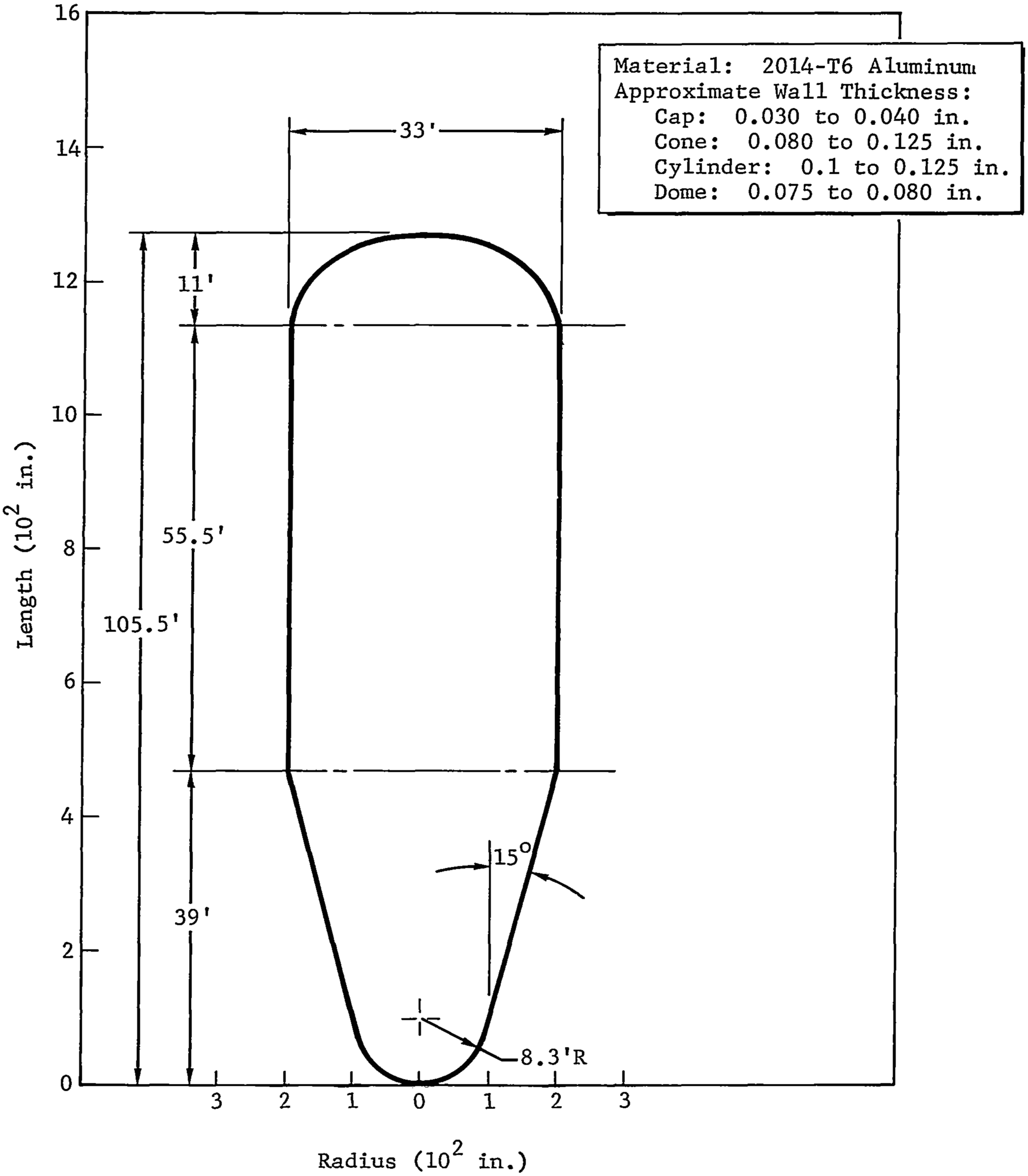


Figure 3-2 Single Tank Configuration with 15-Degree Conical Aft Bulkhead

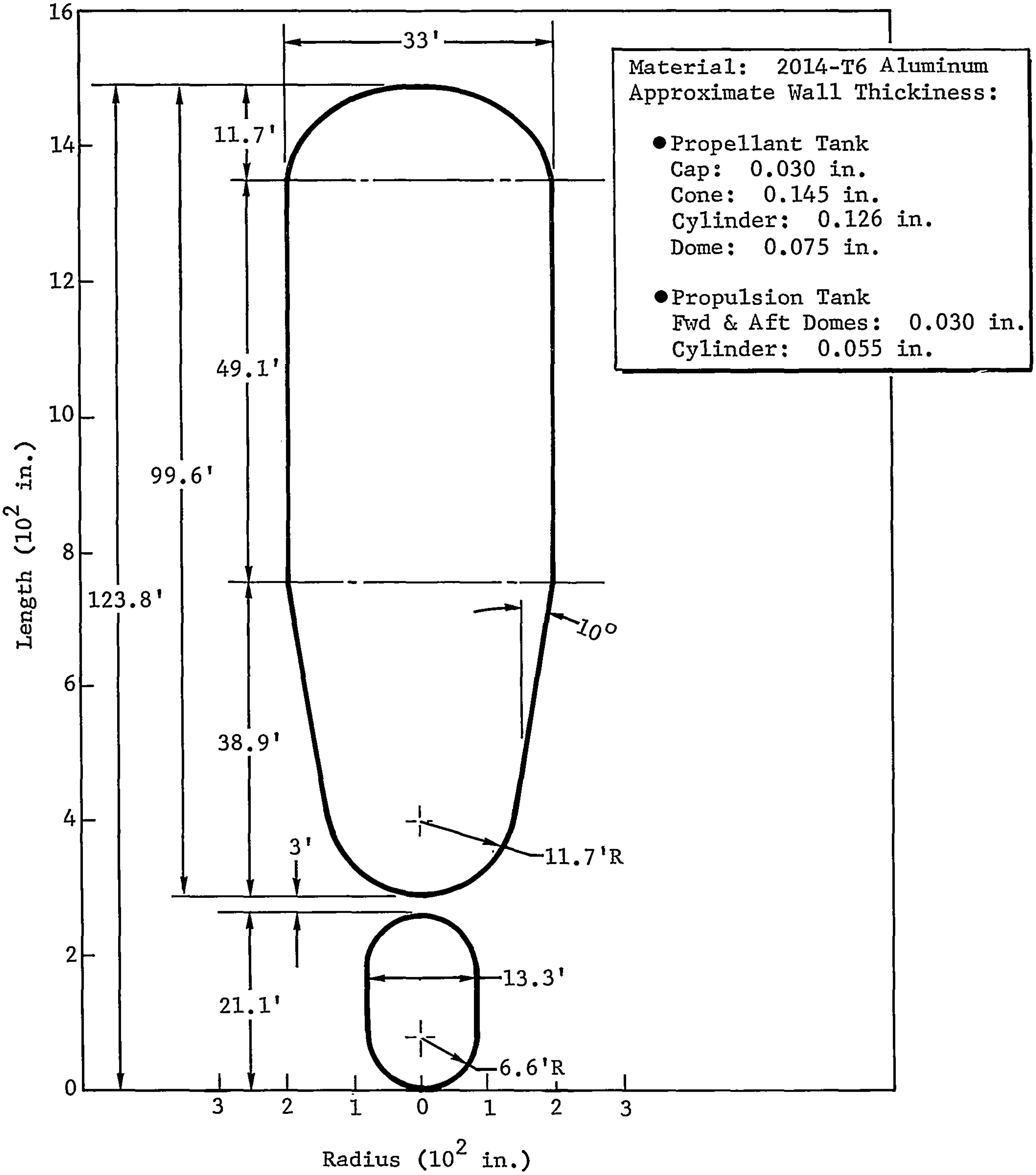


Figure 3-3 Hybrid Tank Configuration

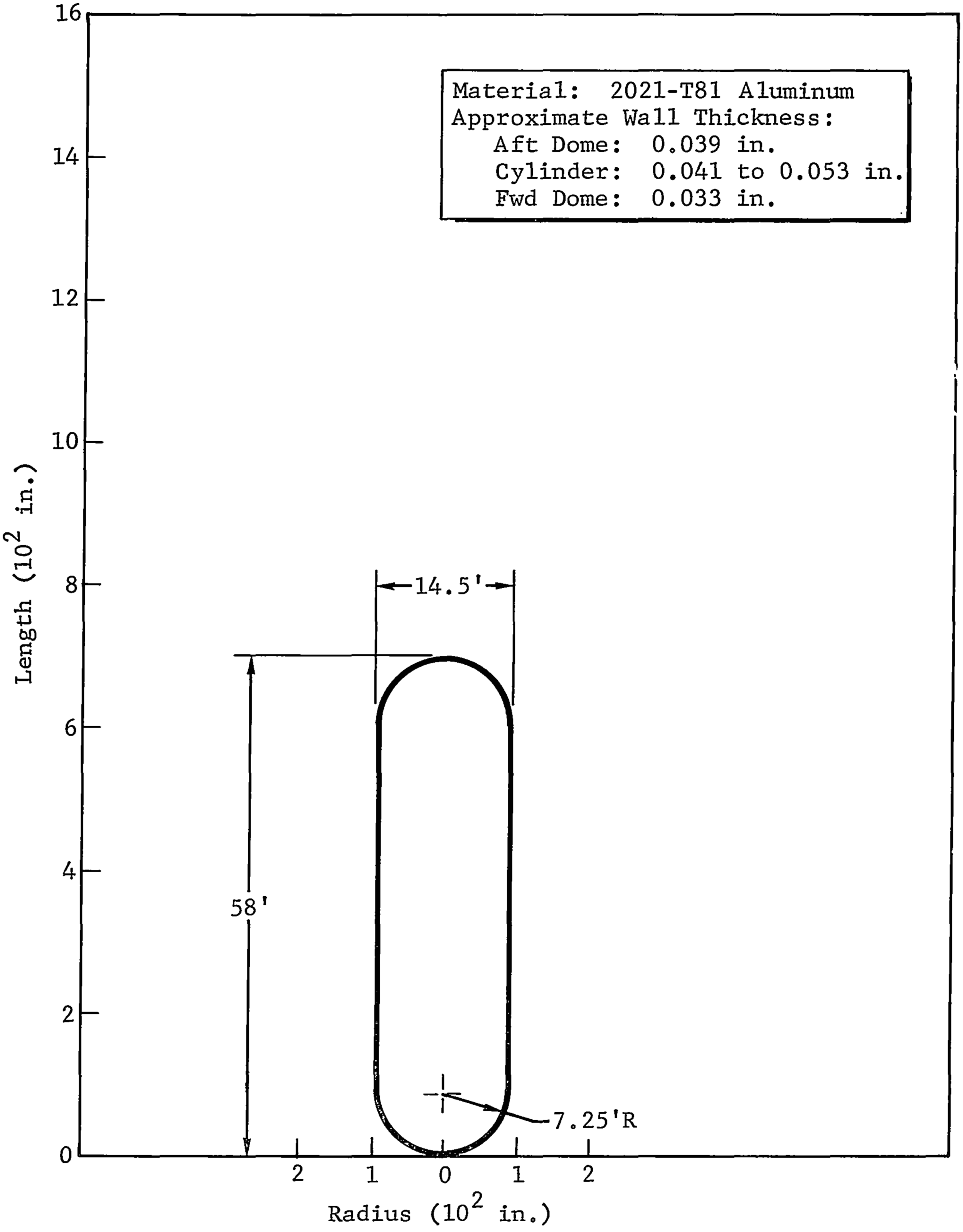


Figure 3-4 Modular Configuration Propulsion Module

3.4 Radiation Environment

The radiation levels used in this analysis are based on Aerojet Nuclear Systems Corporation source data for the full-flow NERVA engine given in Reference 4. The radiation field was assumed to be unattenuated by any external shielding, equipment, or propellant. Therefore, the predicted radiation levels used in Sections VI, VII, and VIII are for worst-case radiation levels and 10 hours of engine operation. All subsystem and component locations are taken with respect to the 15-degree tank configuration.

In order to evaluate the effects of configuration and propellant shielding on the radiation levels, mission-integrated gamma doses have been computed for each of the tanks shown in Figures 3-1 through 3-4; these data are given in Section 5.2. The configurations are compared from the standpoint of total dose levels in Section 2.2.

3.5 Radiation Effects Data

The radiation effects data used in the analysis are summarized in Section IV. Experimental data from many sources were reviewed in arriving at a relatively concise compilation of data pertinent to the study. To ensure completeness, literature searches were obtained from:

1. NASA Scientific and Technical Information Facility

2. Defense Documentation Center

3. Radiation Effects Information Center

The radiation effects data have been examined, and recommended radiation tolerance levels have been established for the various applications of each material. The criterion for these recommended upper limits on exposure dose is that degradation in mechanical properties important to the application should not be great enough to compromise the functional performance of the material.

3.6 Radiation Hardening Analysis

The radiation hardening analysis described herein was performed in accordance with the following procedures:

1. The top assembly drawings of each stage were reviewed and drawings of each major system were ordered from the MSFC repository. These drawings were examined and each system containing components which might be employed in the RNS were selected for detailed analysis.

2. Subsystem drawings were investigated for potential applications requiring organic materials or other radiation sensitive materials. Work sheets were prepared to facilitate a thorough and complete analysis of each subsystem. In the initial survey, all components suspected of containing organic or other radiation sensitive materials were listed and additional research of component drawings, standards, specifications, and vendor data was performed until each radiation sensitive material and its application could be identified or the materials of construction could be determined. From these analyses, a summary table of radiation sensitive materials and their applications was prepared.

3. The functional requirements of each application employing radiation sensitive materials was examined and the application was classified either critical or not critical, depending upon its involvement with respect to the achievement of all RNS mission goals. This classification, which is based upon engineering judgment, facilitated the radiation hardening analysis by emphasizing the components requiring modification and more accurately reflects the ability of the component or system to perform its required functions.

4. Data were compiled concerning the effects of radiation on the mechanical properties of each material identified in Step 2 above and for each material considered as a replacement. Recommended radiation tolerances were established for each material application. The basis for these recommended limits are discussed in Section IV.

5. Each component or subsystem analyzed was examined with respect to its relative placement if it were utilized on the RNS. The predicted nuclear environment of each Saturn V component and system was determined by superimposing the assumed locations of each component onto the predicted radiation flux profile described in Section 5.1.

6. Each basic, i.e., as designed, system was analyzed. The recommended limit for each component was established by the lowest recommended radiation tolerance of material applications critical to flight safety or the functional performance of the specific component.

7. The recommended tolerance for each component was then compared to the predicted nuclear environment. If the tolerance exceeded the predicted environment by a factor of ten or more, it was considered suitable for the application under investigation and no additional analysis was performed. If the recommended tolerance was at least as great as the predicted environment but exceeded it by less than a factor of 10, a radiation hardening procedure was considered desirable. Radiation hardening was considered mandatory if the recommended tolerance did not meet the predicted environment and if the application was also judged to be critical. Modifications were recommended for both critical and non-critical applications;

however, the assigned classification for non-critical applications is denoted "non-critical."

8. In most instances, radiation hardening was achieved through material substitution, i.e., materials with low radiation tolerances were replaced by more radiation resistant materials whose mechanical properties can satisfy the system requirements. However, several components and subsystems could only be radiation hardened through minor design modifications. If design modifications were believed to be necessary, these changes and resultant improvements are discussed.

9. In some instances, recommendations and conclusions regarding usage of radiation sensitive materials could not be made with confidence due to lack of radiation effects test data. In these instances, recommendations are provided in Section II regarding the requirements for additional data and radiation effects tests.

The assumptions used in this analysis result in what is probably a worst-case since the maximum radiation levels (unattenuated) for 10 hours of engine operation were used, and the recommended radiation tolerances for each material application were chosen to be conservative.

A 15-degree conical tank configuration was used as a reference to indicate the assumed component locations. The assumption of a different configuration or a different location on the configuration can readily be evaluated from the flux data for other configurations given in Section V. The doses at vehicle locations of primary concern - those around the bottom of the tank - are relatively uneffected by the choice of configuration, but in moving forward along the tank walls rather significant differences between configurations are apparent.

The analyses in Sections VI, VII, and VIII, which are based on 10 hours of engine operation at full power, are assumed to be unaffected by the time sequence in which the total dose is applied. The effects of shorter operating times or different reactor power levels can be evaluated simply by scaling down the given doses. This, of course, ignores the possibility of more serious adverse effects resulting from periodic engine operation spread over a period of, say, three years. It can be presumed that material degradation resulting from other environmental or operational factors would act in addition to the radiation, but the consequences of cyclic operation are largely unexplored. It is known that vacuum and cryotemperature alter (usually favorably) the radiation response of some materials; where these data are available they are pointed out. Furthermore, radiation induced changes in organic materials are irreversible and annealing does not occur, so in this respect the assumption of accumulation of dose is valid.

The compilation of radiation sensitive materials (Sec. IV) is quite complete; however, in some instances part materials were not identified either because it was felt no new information would be gained or due to the unavailability of vendor drawings and specifications. This condition is denoted in the tables of radiation sensitive materials, e.g., Table 6-3, by either N/A or N/R, where N/A designates that no attempt was made to obtain the drawings or specifications and N/R indicates that the drawings were requested but not received.

Obviously, the predicted nuclear environment can be lessened by either relocating the component in a region further away from the reactor or by placing the component behind a shield; however, these radiation hardening techniques were not utilized in this analysis because the purpose of this study was to determine if the components could be radiation hardened.

Radiation hardening was accomplished primarily through material substitution, i.e., replacing the radiation sensitive materials which have low recommended tolerances with radiation stable materials having mechanical properties thought to be compatible with the requirements of the particular application. It is recognized that redesigning a component with new materials to have the same operating characteristics and size envelope as originally designed is not easy, as is illustrated in the effort to radiation harden the S-IC LOX prevalve for liquid hydrogen usage on the RNS (Sec. VIII). The recommended material substitutions were based largely upon the replacement material providing the required mechanical strength in the predicted nuclear environment. Material processing techniques, which may have been the criteria employed in the original material selection, might prevent usage of materials selected on the basis of radiation stability. Engineering judgment was the basis for recommended material substitutions, however, the component or material might be required to satisfy a unique design or system requirement. Therefore, component designers, familiar with all design aspects, must examine the recommended design modifications and in some instances must select alternate materials. To facilitate this alternate selection, Table 2-1 has been prepared. It summarizes the best materials for each type of application. In many instances the design can be modified to eliminate organic materials. These improvements can only be incorporated by the component designer who is familiar with system requirements.

IV. RADIATION EFFECTS DATA

The recommended radiation tolerances, i.e, the maximum recommended exposure levels, for various Saturn V applications of radiation sensitive materials are presented and discussed in this section. Table 4-1 lists the identified materials, their applications, and the radiation tolerances based on data summarized in subsequent subsections; Table 4-2 gives supplementary information for materials described by military and stage contractor specifications. The recommended limits are conservative for the following reasons:

1. The recommended tolerances are predicated upon radiation damage to the least radiation stable chemical formulation of the particular class or type of material.

2. The limits are established below the exposure required to degrade the mechanical properties sufficiently to compromise the functional performance of the material as used.

3. The recommended tolerances are based primarily upon tests conducted in air, although it is realized that most organics have higher thresholds for damage in the space environment where oxygen is excluded. Limits were based upon data from tests conducted in a vacuum when sufficient test data are available or whenever test data indicate the material properties of interest degrade at lower exposures in a vacuum than in air. Data from tests conducted at cryotemperatures were considered when available.

The recommended limits were established conservatively because (1) a high confidence level is required for the mission,

Table 4-1

RECOMMENDED RADIATION TOLERANCES
FOR ORGANIC MATERIALS

Material	Application	Recommended Tolerance (ergs/gm(C))
	Elastomers and Plastics	
Aclar	Sleeves	2×10^9
Buna N	Hoses	1×10^8
	Gaskets, seals, O-rings, and retainer rings	1×10^9
	Sealants	8×10^9
	Packing	1×10^{10}
	Grommets	1×10^{10}
Diallyl Phthalate	Insulation, electrical	2×10^{10}
	Molded parts	2×10^{10}
Epoxy	Potting	2×10^{10}
Kel-F	Seals, gaskets, and valve seats	1×10^9
	O-rings	1×10^9
	Bearings	1×10^9
	Rings, retainer	1×10^9
	Insulation, electrical	2×10^9
	Spacers and washers	3×10^9
Kynar	Insulation, electrical	1×10^{10}
	Seals, gaskets, & backup rings	3×10^{10}
	Spacers & pads	3×10^{10}
Kynar Composite with Teflon & Fiberglass	Seals	1×10^{10}
Mylar	Seals & gaskets	6×10^9
	Diaphragms	6×10^9
	Backup rings	1×10^{10}
	Insulation, electrical	1×10^{10}
	Tape, electrical	1×10^{10}
	Liners	3×10^{10}

Table 4-1

RECOMMENDED RADIATION TOLERANCES
FOR ORGANIC MATERIALS (cont'd)

Material	Application	Recommended Tolerance (ergs/gm(C))
Neoprene	Seals	$6x10^8$
	Grommets	$1x10^9$
	Packing & O-rings	$1x10^9$
Nylon	Seals	$5x10^8$
	Insulation, electrical	$3x10^9$
	Fabric and cord	$3x10^9$
	End plugs, inserts, and fasteners	$3x10^9$
Phenolics	Molded parts	$1x10^{10}$
Phenolics, Cotton Filled	Spacers	$3x10^9$
	Laminated rods	$3x10^9$
Polycarbonate	Molded parts	$4x10^9$
Polyethylene, Aluminized	Liners	$1x10^9$
Polyimide	Insulation, electrical	$1x10^{10}$
	Varnish, insulation	$1x10^{10}$
	Tape, electrical	$1x10^{10}$
	Seals, valve seats, and gaskets	$2x10^{10}$
	Spacers and backup rings	$3x10^{10}$
Polyolefin, Irradiated	Sleeves	$3x10^9$
Polyurethane	Insulation, thermal	$5x10^9$
	Spacers	$5x10^9$
	Potting and molding	$1x10^{10}$
Rubber, Natural	Gaskets and seals	$5x10^9$
	Tape, electrical	$1x10^{10}$
Rubber, Asbestos Filled	Seals and gaskets	$5x10^9$
	Spacers	$3x10^{10}$

Table 4-1

RECOMMENDED RADIATION TOLERANCES
FOR ORGANIC MATERIALS (cont'd)

Material	Application	Recommended Tolerance (ergs/gm(C))
Silicone Rubber	Gaskets, seals, & O-rings	$8x10^8$
	Insulation, electrical	$1x10^9$
	Sealants	$1x10^9$
	Packing	$1x10^9$
	Tape	$1x10^9$
	Inserts	$1x10^9$
	Insulation, thermal	$2x10^9$
	Molding	$2x10^9$
	Grommets	$2x10^9$
	Sleeves & tubing	$2x10^9$
	Spacers	$2x10^9$
	Liners	$2x10^9$
	Potting	$2x10^9$
Silicone Resin	Coatings	$1x10^{10}$
	Primers	$1x10^{10}$
Teflon TFE	Hoses	$3x10^6$
	Gaskets, seals, & valve seats	$7x10^6$
	Retainer rings	$7x10^6$
	Packing & O-rings	$7x10^6$
	Tape	$2x10^7$
	Bushings & bearings	$3x10^7$
	Inserts	$3x10^7$
	Backing for explosives	$5x10^7$
	Face coated seals	$1x10^8$
	Insulation, electrical	$1x10^8$
	Grommets	$1x10^8$
	Adapters, pads, & spacers	$1x10^8$
	Sleeves	$1x10^8$
Teflon FEP	Gaskets and seals	$7x10^8$
	Bearings	$7x10^8$
	Retainer rings	$7x10^8$
	Packing & O-rings	$7x10^8$
	Insulation, electrical	$1x10^9$
	Grommets	$1x10^9$
	Adapters, pads, & spacers	$1x10^9$

Table 4-1

RECOMMENDED RADIATION TOLERANCES FOR ORGANIC MATERIALS (cont'd)

Material	Application	Recommended Tolerance (ergs/gm(C))
Teflon, Asbestos Filled	Spacers	$1x10^{10}$
Teflon, Fiberglass Filled	Seals, gaskets, & valve seats	$5x10^{9}$
	Bearings	$8x10^{9}$
	Inserts	$8x10^{9}$
	Retainer and backup rings	$1x10^{10}$
	Tubing	$1x10^{10}$
	Spacers & pads	$1x10^{10}$
Viton A	Ring seals	$6x10^{9}$
	O-rings	$6x10^{9}$
	<u>Adhesives</u>	
Polysulfide	Adhesive	$6x10^{9}$
Polyurethane	Adhesive	$1x10^{10}$
Epoxy	Adhesive	$1x10^{10}$
Buna N	Adhesive	$1x10^{10}$
Silicone	Adhesive	$1x10^{10}$
	<u>Fiberglass Laminates</u>	
Phenolic	Spacers and doublers	$2x10^{10}$
Epoxy	Spacers and doublers	$2x10^{10}$
Polyurethane	Spacers and doublers	$2x10^{10}$
Polyester	Spacers and doublers	$6x10^{10}$
Silicone	Spacers and doublers	$2x10^{11}$
	<u>Fluids and Lubricants</u>	
MIL-H-5606	Hydraulic fluid	$5x10^{8}$
Oronite 8515	Hydraulic fluid	$5x10^{9}$
Silicone (DC-510)	Lubricant	$8x10^{8}$
Silicone (DC-710)	Lubricant	$1x10^{10}$
Halocarbon	Grease	$1x10^{9}$
Drilube (Teflon)	Grease	$1x10^{8}$

Table 4-1

RECOMMENDED RADIATION TOLERANCES
FOR ORGANIC MATERIALS (cont'd)

Material	Application	Recommended Tolerance (ergs/gm(C))
	Miscellaneous Materials	
Leather	Backup rings	$5x10^9$
Cork	Insulation	$1x10^{10}$

Table 4-2

RECOMMENDED RADIATION TOLERANCES FOR MATERIALS IDENTIFIED BY SPECIFICATIONS

Specification	Description	Basic Material	Recommended Tolerance (ergs/gm(C))	Basis for Recommendation
1P20001	Adhesive, RTV	Epoxy base	$1x10^{10}$	See Section 4.4
1P20005	Adhesive, nitrile type	Acrylonitrile rubber with phenolic adhesive	$1x10^{10}$	Similar to Buna N adhesives; see Section 4.4
1P20011	Foam	Polyurethane	$1x10^{10}$	See Section 4.3.15
1P20014	Adhesive, RTV	Silicone rubber	$1x10^{10}$	See Section 4.4
1P20016	Potting & cable molding	Polyurethane	$1x10^{10}$	See Section 4.3.15
1P20025	Adhesive, flexible	Modified epoxy	$1x10^{10}$	See Section 4.4
1P20040	Primer	Silicone rubber	$1x10^{10}$	See Section 4.3.18
1P20056	Lubricant	Perfluorinated aliphatic	$1x10^{8}$	See Section 4.6.2
1P20057	Sealant	Synthetic rubber	$1x10^{9}$	Requirements can be met with silicone rubber; see Section 4.3.18
1P20066	Primer	Synthetic rubber	$1x10^{10}$	Requirements can be met with silicone rubber; see Section 4.3.18
1P20075	Adhesive, flexible	Polyurethane base	$1x10^{10}$	See Section 4.4
1P20098	Adhesive	Polysulfide rubber	$6x10^{9}$	See Section 4.4
1P20111	Primer	Silane base	$1x10^{10}$	Similar to silicone primer; see Section 4.3.18
AB0150-001	Tubing	Teflon TFE	$1x10^{8}$	See Section 4.3.19
AB0150-006 (Type IV)	Wire	Teflon TFE insul.	$1x10^{8}$	See Section 4.3.19
AB0150-007	Wire	Teflon TFE insul.	$1x10^{8}$	See Section 4.3.19
AMS 3209	Packing	Synthetic rubber	$1x10^{9}$	Requirements can be met with neoprene; see Section 4.3.8
AMS 3302	Grommets	Silicone rubber	$2x10^{9}$	See Section 4.3.18
AMS 3650	Molded rubber:			
	Bearing	Kel-F	$2x10^{9}$	See Section 4.3.5
	Insert	Kel-F	$8x10^{9}$	See Section 4.3.5
	Gasket	Kel-F	$1x10^{9}$	See Section 4.3.5
AMS 3651	Seal	Teflon TFE	$7x10^{6}$	See Section 4.3.19
AMS 3653	Tubing	Teflon TFE	$1x10^{8}$	See Section 4.3.19
AMS 7271	Backup rings	Synthetic rubber	$1x10^{9}$	Requirements can be met with dimethyl siloxane silicone rubber; see Section 4.3.18
L-T-100	Tape, identification	Cellulose acetate and silicone adhesive	$2x10^{9}$	Exposure is 25% damage threshold for both tensile strength & elongation (Ref. 5, p. 94)
MB0120-008	Adhesive	Epoxy base	$1x10^{10}$	See Section 4.4
MB0120-023	Adhesive	Modified eposy	$1x10^{10}$	See Section 4.4
MB0120-024	Sealant	Polyurethane resin	$1x10^{10}$	See Section 4.3.15
MB0120-041	Sealant	Silicone rubber	$1x10^{9}$	See Section 4.3.18
MB0130-015	Molded plastic	Polyurtheane	$1x10^{10}$	See Section 4.3.15

Table 4-2 (continued)

RECOMMENDED RADIATION TOLERANCES FOR MATERIALS IDENTIFIED BY SPECIFICATIONS

Specification	Description	Basic Material	Recommended Tolerance (ergs/gm(C))	Basis for Recommendation
MB0130-019	Rubber composition:			
	Seal	Silicone rubber	8×10^{8}	See Section 4.3.18
	Sealant	Silicone rubber	1×10^{9}	See Section 4.3.18
	Adhesive	Silicone rubber	1×10^{10}	See Section 4.3.18
MB0130-020	Insulation	Cork	1×10^{10}	See Section 4.7.2
MB0130-034	Insulation	Silicone rubber	2×10^{9}	See Section 4.3.18
MB0103-052	Bearing	Teflon FEP	7×10^{8}	See Section 4.3.19
	Spacer	Teflon FEP	1×10^{9}	See Section 4.3.19
MB0130-053	Seal	Kel-F	1×10^{9}	See Section 4.3.5
MB0130-060	Seal	Mylar	6×10^{9}	See Section 4.3.7
MB0130-069	Insulation	Polyurethane	1×10^{10}	See Section 4.3.15
MB0130-077	Insulation	Polyurethane	1×10^{10}	See Section 4.3.15
MB0135-021	Fabric	Nylon	3×10^{9}	See Section 4.3.9
MB0150-025	Tubing	Teflon	1×10^{8}	See Section 4.3.19
MB0295-009	Gasket	Teflon	7×10^{6}	See Section 4.3.19
MC252C4TA	Face coated seal	Teflon TFE coated	1×10^{8}	See Section 4.3.19
MC266B-xxx	Packing	Buna N	1×10^{10}	See Section 4.3.2
MC266J-xxx	Packing	Silicone rubber	1×10^{9}	See Section 4.3.18
MIL-A-5092	Adhesive:			
	Type I	Natural rubber	1×10^{10}	See Section 4.4
MIL-A-7021	Gasket	Asbestos/rubber	5×10^{9}	See Section 4.3.17
MIL-A-17472	Gasket	Asbestos/rubber	5×10^{9}	See Section 4.3.17
	Spacer	Asbestos/rubber	3×10^{10}	See Section 4.3.17
MIL-C-5015	Connector:			
	Insert	Silicone rubber	1×10^{9}	See Section 4.3.18
	End plug	Nylon	3×10^{9}	See Section 4.3.9
MIL-G-3036	Grommets	Synthetic rubber	2×10^{9}	Requirements can be met with silicone rubber; see Section 4.3.18
MIL-G-5510	Preformed packing	Synthetic rubber	1×10^{9}	Requirements can be met with silicone rubber; see Section 4.3.18
MIL-H-5606A	Hydraulic fluid	Petroleum base	5×10^{8}	See Section 4.6.1
MIL-I-631	Insulation, electrical			
	Type G	Mylar	1×10^{10}	See Section 4.3.7
MIL-I-002707	Insulating varnish	Polyimide	1×10^{10}	See Section 4.3.13
MIL-I-17091	Molded parts:			
	Seal	Nylon	5×10^{8}	See Section 4.3.9
MIL-I-18057	Insulation, sleeve	Silicone rubber	2×10^{9}	See Section 4.3.18
MIL-I-22129	Insulation, tubing	Teflon TFE	1×10^{8}	See Section 4.3.19
MIL-M-14	Molding	Diallyl phthalate	2×10^{10}	See Section 4.3.3
MIL-M-19833	Insulation	Diallyl phthalate	2×10^{10}	See Section 4.3.3
MIL-P-997	Washer, insulation	Laminated silicone rubber & fiberglass	2×10^{11}	See Section 4.5
MIL-P-3115	Plastic sheet	Laminated paper and phenolic resin	1×10^{10}	See Section 4.5
MIL-P-5315	Preformed packing	Synthetic rubber	6×10^{9}	Requirements can be met with Buna N (Sec. 4.3.2) or Viton A (Sec. 4.3.21)

Table 4-2 (continued)

RECOMMENDED RADIATION TOLERANCES FOR MATERIALS IDENTIFIED BY SPECIFICATIONS

Specification	Description	Basic Material	Recommended Tolerance (ergs/gm(C))	Basis for Recommendation
MIL-P-5516	Preformed packing	Synthetic rubber	$1x10^{10}$	Requirements can be met with Buna N; see Section 4.3.2
MIL-P-15035	Laminate	Cotton fabric and phenolic resin	$3x10^{9}$	See Section 4.3.10
MIL-P-18177	Laminate	Epoxy/fiberglass	$2x10^{10}$	See Section 4.5
MIL-P-25732	Preformed rubber:			
	Packing	Synthetic rubber	$1x10^{10}$	Similar to Buna N; see Section 4.3.2
	Seals	Synthetic rubber	$1x10^{9}$	Similar to Buna N; see Section 4.3.2
MIL-P-25988	Packing	Silicone rubber	$1x10^{9}$	See Section 4.3.18
MIL-R-79	Laminated rods	Cotton fabric and phenolic resin	$3x10^{9}$	See Section 4.3.10
MIL-R-003065	Rubber composition:			
	Type RN	Natural rubber	$1x10^{10}$	See MIL-STD-417
	Type RS	Synthetic rubber	$1x10^{9}$	
MIL-R-5521	Backup washer	Leather	$5x10^{9}$	See Section 4.7.1
MIL-R-5847	Rubber composition:			
	Seal	Silicone rubber	$8x10^{8}$	See Section 4.3.18
	Insert	Silicone rubber	$1x10^{9}$	See Section 4.3.18
MIL-R-9300	Resin for laminating fiberglass cloth	Epoxy base	$2x10^{10}$	See Section 4.5
MIL-R-25897	Preformed rubber:			
	Seals	Viton A	$6x10^{9}$	See Section 4.3.21
	Packing	Viton A	$6x10^{9}$	See Section 4.3.21
MIL-S-8784	Sealant	Synthetic rubber	$5x10^{9}$	Requirements can be met with polysulfide rubber; see below
MIL-S-8802	Sealant	Polysulfide rubber	$5x10^{9}$	Elongation decreases 50%; tensile strength decreases 25% (Ref. 5, p. 113)
MIL-S-22473	Sealant	Synthetic rubber	$1x10^{9}$	Requirements can be met with silicone rubber; see Section 4.3.18
MIL-STD-417	Rubber composition:			
	Type RS	Synthetic rubber	$1x10^{9}$	Similar to silicone rubber; see Section 4.3.18
	Type RN	Natural rubber	$1x10^{10}$	See Section 4.3.16
MIL-T-713	Twine	Waxed nylon	$3x10^{9}$	See Section 4.3.9
MIL-T-9906	Tape, identification	Polyester backing w/silicone adhesive	$2x10^{9}$	Exposure is 25% damage threshold for both tensile strength & elongation (Ref. 5, p. 94)
MIL-T-22742	Tape, electrical	Teflon TFE backing w/silicone adhesive	$2x10^{7}$	See Section 4.3.19
MIL-T-23594	Tape, electrical	Teflon TFE backing w/silicone adhesive	$2x10^{7}$	See Section 4.3.19
MIL-W-583	Wire, insulated:			
	Class 220-M	Polyimide	$1x10^{10}$	See Section 4.3.13
	Class F	Synthetic fiber	$3x10^{9}$	Specification can be met with nylon; see Section 4.3.9
MIL-W-7139	Wire, insulated	Teflon TFE	$1x10^{8}$	See Section 4.3.19
MIL-W-16878	Wire, insulated:			
	Type 3	Teflon TFE	$1x10^{8}$	See Section 4.3.19
	Type 4	Teflon FEP	$1x10^{9}$	See Section 4.3.19

Table 4-2 (continued)

RECOMMENDED RADIATION TOLERANCES FOR MATERIALS IDENTIFIED BY SPECIFICATIONS

Specification	Description	Basic Material	Recommended Tolerance (ergs/gm(C))	Basis for Recommendation
MMM-A-188	Adhesive	Urea resin	$1x10^{10}$	See Section 4.4
MS 21266	Grommet	Teflon TFE	$1x10^{8}$	See Section 4.3.19
MS 28774	Retainer	Teflon TFE	$7x10^{6}$	See Section 4.3.19
MS 28775	Packing	Synthetic rubber	$1x10^{10}$	Requirements can be met with Buna N; see Section 4.3.2
MS 28777	Backup ring	Leather	$5x10^{9}$	See Section 4.7.1
MS 28778	Packing	Synthetic rubber	$1x10^{9}$	Requirements can be met with silicone rubber; see Section 4.3.18
MS 28782	Retainer	Teflon TFE	$7x10^{6}$	See Section 4.3.19
MS 29512	Preformed packing	Synthetic rubber	$6x10^{9}$	Requirements can be met with Buna N (Sec. 4.3.2) or Viton A (Sec. 4.3.21)
MS 29513	Preformed packing	Synthetic rubber	$6x10^{9}$	
MSFC-222	Potting	Epoxy base	$2x10^{10}$	See Section 4.3.4
MSFC-276	Tubing	Irradiated polyolefin	$3x10^{9}$	See Section 4.3.14
NAS-1593	Packing	Synthetic Rubber	$1x10^{10}$	Requirements can be met with Buna N; see Section 4.3.2
PPP-T-97	Tape, identification	Polyester reinforced with fiberglass filaments	$2x10^{10}$	See Section 4.5
RA0106-004	Potting	Epoxy, silica filled	$2x10^{10}$	See Section 4.3.4
RA0106-035	Potting	Silicone rubber	$2x10^{9}$	See Section 4.3.18
RB0120-005	Potting	Silicone rubber	$2x10^{9}$	See Section 4.3.18
RB0130-005	Gasket	Kel-F	$1x10^{9}$	See Section 4.3.5
RB0130-007	Seal	Teflon FEP	$7x10^{8}$	See Section 4.3.19
RB0130-009	Retainer ring	Kel-F	$5x10^{9}$	See Section 4.3.5
RB0130-039	Seal	Mylar	$6x10^{9}$	See Section 4.3.7
RB0130-064		Not received		
RB0130-065	Tubing Molding	Silicone rubber Silicone rubber	$2x10^{9}$ $2x10^{9}$	See Section 4.3.18 See Section 4.3.18
RB0130-068	Insulation, thermal	Silicone foam	$2x10^{9}$	See Section 4.3.18
RB0150-009	Tubing	Not received		
RB0150-015	Cable, jacket	Teflon FEP	$1x10^{9}$	See Section 4.3.19
RB0150-019	Wire, electrical	Teflon TFE	$1x10^{8}$	See Section 4.3.19
RB0150-028	Wire, electrical	Teflon TFE insulated	$1x10^{8}$	See Section 4.3.19
RB0150-029	Cable, jacket	Teflon FEP	$1x10^{9}$	See Section 4.3.19
RD414-1010	Receptacle, electrical: Insert End plug	 Silicone rubber Nylon	 $1x10^{9}$ $3x10^{9}$	 See Section 4.3.18 See Section 4.3.9
ZZ-R-765	Rubber composition: Liner Grommet	 Silicone rubber Silicone rubber	 $2x10^{9}$ $2x10^{9}$	 See Section 4.3.18 See Section 4.3.18

and (2) component designers must be alert to potential problems which might result from indiscriminate usage or failure to adequately specify materials. Component designers should be cognizant of the following information if deviations from the recommended tolerances are necessary:

1. Most materials retain their useful properties to higher exposures in vacuum than in air.

2. Antirads, i.e. chemical compounds which increase radiation stability, can be compounded with most elastomers to increase the recommended limits to exposures ten times greater than the tolerances recommended in Table 4-1.

3. Oriented films have greater radiation stability than the random polymer.

4. Polymers filled with fiberglass or similar materials are much stronger than unfilled polymers.

Table 4-3 lists several radiation resistant materials that are relatively unaffected at exposures below 1×10^{12} ergs/gm(C). In many instances, they can be used to radiation harden components and systems. For example, ceramic inserts can be used to replace organic inserts in electrical connectors. Other applications of these radiation stable materials are discussed in the radiation hardening analyses found in Sections VI, VII, and VIII.

4.1 Radiation Tolerances for Organics

Table 4-1 summarizes the recommended radiation tolerances for various applications of radiation sensitive materials. Supporting test data and the criteria used in establishing these

Table 4-3

MATERIALS ESSENTIALLY UNAFFECTED BY RADIATION IN AREAS ABOVE UPPER THRUST STRUCTURE

Material	Comment
Metals	Mechanical properties of metals are not affected when irradiated with fast neutrons to fluences up to, and usually greater than, 1×10^{16} n/cm^2.
Asbestos	Mechanical properties were not affected when irradiated with fast neutrons to fluences greater than 1×10^{20} n/cm^2.
Fiberglass	The thresholds for damage are about 2×10^{17} n/cm^2 and 1×10^{11} ergs/gm(C) (Ref. 5, p. 634).
Ceramics	Ceramic materials, as a class, are radiation resistant. No changes in mechanical properties have been noted at exposures below 1×10^{10} ergs/gm(C). However, F-center formation and color changes can be expected at exposures above 1×10^9 ergs/gm(C) (Ref. 5, p. 43)
Solid-Film Lubricants	Solid-film lubricants of non-organic base, e.g., graphite or MoS_2 base, are not affected at exposures of up to at least 1×10^{11} ergs/gm(C).

limits are discussed in Sections 4.3 through 4.7: plastics and elastomers are discussed in Section 4.3; adhesives are discussed in Section 4.4; fiberglass laminates are discussed in Section 4.5; organic fluids and lubricants are discussed in Section 4.6; and miscellaneous radiation sensitive materials are discussed in Section 4.7.

4.2 Specifications Pertaining to Organics

Table 4-2 gives the recommended radiation tolerances for various materials identified by military and stage contractor specifications. In situations in which the material was not explicitly stated, the least radiation stable material which could satisfy the requirements was assumed to be used. The bases for these recommendations are described in Sections 4.3 through 4.7.

4.3 Data Summary for Plastics and Elastomers

4.3.1 Aclar

Aclar is a fluorocarbon film (polychlorotrifluoroethylene) manufactured by Allied Chemical Corporation. The effects of radiation on Fluorthene, which is also a polychlorotrifluoroethylene, are given below (Ref. 5, p. 94):

Property Affected	Damage at Dose in ergs/gm(C)		
	Incipient	25%	50%
Tensile strength	$4x10^9$	$8x10^9$	$1x10^{10}$
Elongation	$4x10^8$	$1.8x10^9$	$4x10^9$
Impact strength	$4x10^8$	$1.8x10^9$	$4x10^9$

Sleeves. The recommended radiation tolerance of Aclar sleeves, 2×10^9 ergs/gm(C), is the exposure at which its elongation and impact strength begin to degrade very rapidly.

4.3.2 Buna N

Buna N, a nitrile butadiene rubber, is employed for various applications throughout the Saturn V system. Radiation effects test experience indicates:

1. Buna N appears to be less satisfactory when irradiated in a vacuum than when irradiated in air as is evidenced from the following data (Ref. 6, p. 61):

Mechanical Property	Exposure (ergs/gm(C))	
	In Vacuum	In Air
25% Damage for Elongation	1.5×10^9	3×10^9
50% Damage for Elongation	2×10^9	6×10^9
25% Damage for Tensile Strength	2×10^9	1×10^{10}
50% Damage for Tensile Strength	8×10^9	Not reached at 2×10^{10}

2. The mechanical properties of Buna N O-rings were investigated in both air and vacuum after irradiation to exposures up to 1×10^{10} ergs/gm(C) with results lower than those shown in Item 1 above by a factor of 3 (Ref. 7, p. 84).

3. The effects of radiation on Buna N formulation depends on the acrylonitrile content which varies depending on the application. Also, the effects of radiation depend on the loading during irradiation. Data from only one set of tests available showed an increase in compression set values for test conducted in air from 17.8% for the controls to 26.8% at 1.1×10^6 ergs/gm(C) and to 64.6% at 1.7×10^7 ergs/gm(C). This is an increase of 56% and 275%, respectively, in compression set (Ref. 8, p. 79).

4. A Buna N O-ring formulation with three parts FLX antioxident as an antirad showed no decrease in ultimate elongation at 1.3×10^9 ergs/gm(C) and 50% decrease at 9.8×10^9 ergs/gm(C) (Ref. 9, p. 234).

5. When irradiated in air at room temperature to an exposure of 2.4×10^9 ergs/gm(C), Buna N with a Shore-A durometer hardness of 80 showed a 10% decrease in compression set (reduced from 56% to 50%), and a 20% decrease in elongation. Buna N with a Shore-A durometer hardness of 40 was only slightly affected in this environment (Ref. 10, p. A-87).

6. Buna N hoses appear to be functionally satisfactory at exposure doses up to about 4×10^8 ergs/gm(C) at elevated temperatures (up to 350°F) and static pressures of 1200 psig, although in some tests leaks were noted below this exposure level. An intermittent-pressure test (0 to 1000 psig) at 350°F indicated Buna N hoses to be satisfactory to at least 1×10^8 ergs/gm(C) (Ref. 5, p. 151).

Hoses. The recommended radiation tolerance for Buna N hoses is 1×10^8 ergs/gm(C); however, caution must be exercised in using this limit since data are not available at low temperatures.

Gaskets, Seals, O-Rings, and Retainer Rings. The recommended radiation tolerance for these applications is 1×10^9 ergs/gm(C). This is the exposure at which gross changes in the mechanical properties begin for materials irradiated in a vacuum. No physical deterioration is expected at this exposure.

Sealants. The recommended radiation tolerance for sealants whose basic ingredient is Buna N is 8×10^9, the exposure at which its elongation decreases by 90% and its tensile strength decreases by 50%, when irradiated in a vacuum.

Packing and Grommets. The recommended radiation tolerances for these applications, 1×10^{10}ergs/gm(C), is the exposure at which Buna N becomes very brittle and physical deterioration begins when it is irradiated in a vacuum.

4.3.3 Diallyl Phthalate

Diallyl Phthalate is employed as electrical insulation and molded parts. Limited radiation effects test data indicate:

1. Coil forms, insulators, and standoffs were relatively unaffected at an exposure of 6×10^{12} ergs/gm(C) (Ref. 6, p. 92) when irradiated in air at 100^oF.

2. Diallyl phthalate laminated fiberglass was reactor irradiated in air to several doses up to 1.3×10^{11} ergs/gm(C) and in vacuum to two doses, the highest of which was about 3×10^{10} ergs/gm(C). Its mechanical properties were essentially unaffected at the highest doses under either condition (Ref. 11).

Molded Parts and Electrical Insulation. The recommended radiation tolerance of diallyl phthalate electrical insulation and molded parts is 2 x 10^{10} ergs/gm(C). Although the material is probably usable to much higher doses, the limited data do not permit reliable conclusions to be drawn for general applications.

4.3.4 Epoxy

Thermosetting epoxy is employed as molded parts and for potting electrical components. Radiation effects test data indicate:

1. The predominant effect of the irradiation of epoxy polymers is cross linking as is evident from increases in viscosity and hardness.

2. Aromatic curing agents result in more radiation resistant materials than those with aliphatic curing agents. Cure is an important factor with potting compounds subjected to the radiation and vacuum conditions of a space environment; a higher temperature cure is preferred to a room temperature cure.

3. When irradiated in a vacuum to an exposure of 3 x 10^{10} ergs/gm(C), Scotchcast 212, an epoxy potting compound manufactured by Minnesoto Mining and Manufacturing Company, showed a 20% increase in crushing load and a 40% increase in compression strength (Ref. 9, p. 354).

4. Fiberglass-epoxy compounds are more resistant to radiation than the bulk resin alone. Laminated specimens of 30% resin content showed no loss of flexural strength after irradiation in air at room temperature to an exposure of 1 x 10^{11} ergs/gm(C) (Ref. 12).

Potting Compounds. The recommended radiation tolerance of epoxy potting compounds is 2 x 10^{10} ergs/gm(C). Proper curing can increase this limit as can the addition of inorganic fillers.

4.3.5 Kel-F

Kel-F, a fluorocarbon manufactured by Minnesoto Mining and Manufacturing Company, is employed in numerous applications throughout the propellant feed system. Radiation effects test experience indicates:

1. In air, the damage threshold at room temperature is approximately 1 x 10^8 ergs/gm(C). The exposures at which the tensile strength and elongation decrease by 25% are 2 x 10^9 and 1.5 x 10^9 ergs/gm(C), respectively. The tensile strength and elongation decrease by 50% at 2 x 10^9 ergs/gm(C) (Ref. 9, p. 157). Kel-F crumbled after an exposure of 8 x 10^9 ergs/gm(C) (Ref. 7, p. 96).

2. Kel-F is more stable in vacuum than in air. It became brittle with vacuum irradiation at an exposure of 1 x 10^{10} ergs/gm(C) and crumbled after an exposure of 1.5 x 10^{10} ergs/gm(C) (Ref. 7).

3. At LN_2 temperature, there was no strength degradation after an exposure of 8.7 x 10^8 ergs/gm(C) (Ref. 13, p. 126).

4. Kel-F becomes soft and tacky at doses approaching 1 x 10^9 ergs/gm(C), whereas embrittlement dominates at doses above 1.4 x 10^9 ergs/gm(C) (Ref. 5, p. 137).

5. The effects of radiation are influenced by oxygen as is evidenced by the fact that the tensile strength of Kel-F decreased 25% at 6 x 10^8 ergs/gm(C) in air, whereas the tensile strength was unaffected when Kel-F was irradiated in silicate ester fluids at room temperature to 10^{10} ergs/gm(C) (Ref. 6, p. 58).

6. After irradiation to 10^8 ergs/gm(C), Kel-F liberates either molecular F_2, a powerful corrosive agent with respect to metals, or HF gas which reacts vigorously with glass and many other silicon bearing compounds.

Seals, Gaskets, Valve Seats, and O-rings. The recommended radiation tolerance for Kel-F in these applications is 1×10^9 ergs/gm(C), which is below the exposure at which its mechanical properties begin to degrade very rapidly in air. At this exposure, no physical degradation of the material is anticipated. The effects of corrosive products should be evaluated on the basis of application, quantity of Kel-F, and the exposure dose. As indicated above, Kel-F should be more stable in the RNS environment, i.e., at low temperature and in vacuum.

Bearings. The recommended radiation tolerance for Kel-F bearings is 1×10^9 ergs/gm(C). At this exposure, its compressive strength has decreased by approximately 25%.

Rings, Retainer. The recommended radiation tolerance for Kel-F retainer rings is 1×10^9 ergs/gm(C). At this exposure, Kel-F retains at least 75% of its preirradiation values for both its tensile strength and elongation.

Electrical Insulation. The electrical insulating charactersitics of Kel-F are not expected to degrade significantly as long as it retains its physical integrity. Therefore, the recommended radiation tolerance for Kel-F insulation is 2×10^9 ergs/gm(C), which is a factor of 5 below the exposure at which Kel-F crumbles in a vacuum.

Spacers and Plugs. The recommended radiation tolerance for these applications of Kel-F, 3×10^9 ergs/gm(C), is a factor of

3 below the exposure at which Kel-F crumbles in a vacuum.

4.3.6 Kynar

Kynar (vinylidene fluoride resin manufactured by Pennsalt Corporation) is a high molecular weight fluorocarbon polymer characterized by excellent physical, mechanical, thermal, electrical, and chemical properties; it is stable in vacuum. Unlike other fluorocarbons, it has good radiation resistance. The manufacturer reports (Ref. 14) that "at a dosage level exceeding 3×10^{10} ergs/gm(C) (CO^{60} source), Kynar shows no change in tensile strength though the polymer darkens in color and elongation is reduced."

The tensile properties and dielectric properties of Kynar have been tested under irradiation in air at room temperature and in vacuum at both room temperature and at cryotemperature. The results of these tests are summarized below (Ref. 15):

1. Under irradiation the material progressively changes color from light cream to yellow, to tan, and finally to dark brown.

2. At cryotemperatures the tensile strength increases and the percent elongation decreases with radiation exposures up to 3×10^{10} ergs/gm(C). At higher exposures, its tensile strength decreases.

3. Break patterns of tensile specimens change with irradiation at room temperature — necking is extensive at first with the material becoming more and more brittle at higher exposure levels.

4. Break patterns at cryotemperatures were brittle fractures with the ultimate strength and tensile strength at rupture virtually identical.

5. No significant changes in tensile properties were observed in air irradiations at doses in excess of 3×10^{10} ergs/gm(C). At a dose of 1×10^{11} ergs/gm(C) there was a definite decrease in both ultimate tensile strength and percent elongation.

The effects of radiation on the mechanical and electrical properties of Kynar are summarized below.

Characteristic Property	Incipient Damage (ergs/gm(C))	Intermediate Damage (ergs/gm(C))
Tensile strength	3×10^{10}	-50% at 2×10^{11}
Elongation	3×10^{10}	-50% at 1×10^{11}
Compression strength	1×10^{10}	Not reached at 3×10^{10}
Impact	Not meas.	-50% at 1×10^{10}
Dielectric constant	2×10^{10}	Essentially unchanged at 3×10^{10}
Dissipation factor	2×10^{8}	Significantly increased at 3×10^{10}
Volume resistivity	1×10^{7}	Decreased several orders of magnitude at 1×10^{10}

<u>Insulation, Electrical</u>. The recommended radiation tolerance for Kynar insulation, 1×10^{10} ergs/gm(C), is the exposure at which the impact strength decreases by 50% for air irradiation. The decrease in volume resistivity is not serious since the pre-irradiation value, 10^{14} ohm-cm, is extremely high. It should be noted that stiffness increases rapidly at cryotemperatures; however, the material retains a moderate degree of impact strength at -300^{o}F.

Seals, Pads, and Spacers. The recommended radiation tolerance for Kynar seals, pads, and spacers is 3×10^{10} ergs/gm(C), the exposure at which degradation begins.

Composite Seal of Kynar, Teflon TFE, and Fiberglass. A special seal, which consists of a molded multilayer of fiberglass fabric and Teflon TFE encapsulated in Kynar, is employed in the modified S-IC propellant shut-off valve. It was fabricated to Whittaker Corporation's specification PS 2014, "Process Specification for the Fabrication of Gasket, Cryogenic and Radiation Service."

Leak-tests were conducted on the composite seal (flat, 2-in.-diam gaskets) before and after irradiation to 2×10^{10} ergs/gm(C). No leakage was detectable at -320°F with a 2000-psi flange load and helium pressure of 275 psi. Load-deflection and stress-relaxation tests were conducted on both control and irradiated gaskets. Test specimens were loaded 10 times in compression from 0 to 2000 psi and the compressive deflection was recorded each time; irradiated specimens had a greater deflection than similar control specimens. Stress-relaxation tests indicated negligible cold flow and therefore a single torquing sequence would suffice.

The recommended radiation tolerance for these composite seals is 1×10^{10} ergs/gm(C). At this exposure, some damage is expected; however, the seal should function satisfactorily.

4.3.7 Mylar

Mylar, an oriented polyethylene terephalate polyester film, is employed as electrical insulation, diaphragms, backup rings, and seals in the design of actuators, valves, and various other components. Aluminized Mylar, i.e., Mylar film coated with aluminum on one side, is utilized as a liner to reflect engine heat from heat sensitive components and systems.

Radiation effects testing of both Mylar and aluminized Mylar film indicates:

1. The threshold and 25% damage points for the tensile strength of Mylar film when tested in air at room temperature are 4.4×10^8 and 8.7×10^9 ergs/gm(C), respectively (Ref. 5, p. 150).

2. The 25% and 50% damage points for the elongation of Mylar films when irradiated and tested in air at room temperature are 4×10^9 and 6×10^9 ergs/gm(C), respectively (Ref. 9, p. 155).

3. Irradiation in vacuum to 8.7×10^9 ergs/gm(C) produced the same damage as 4.4×10^9 ergs/gm(C) in air, thus indicating that oxidation plays some part in the damage induced (Ref. 5, p. 150).

4. No significant degradation in the mechanical properties were measured for either Mylar film or aluminized Mylar when tested at LN_2 temperatures after irradiation to 2.7×10^9 ergs/gm(C) (Ref. 6, p. 105).

5. The electrical properties of Mylar are stable to an absorbed dose of 1×10^{10} ergs/gm(C) (Ref. 5, p. 150). During irradiation, the dielectric constant and dielectric loss undergo significant changes, but they recover on removal from the radiation field.

Gaskets, Seals, and Diaphragms. The recommended radiation tolerance of Mylar gaskets, seals, and diaphragms used in actuators, valves, and regulator assemblies is 6 x 10^9 ergs/gm(C). At this exposure, in a vacuum environment, Mylar would retain approximately 75% of its preirradiation values for both elongation and tensile strength. No physical deterioration is anticipated at this exposure.

Insulation, Electrical. Although Mylar retains its electrical insulating properties at absorbed doses greater than those which result in physical deterioration, its recommended radiation tolerance limit, 1 x 10^{10} ergs/gm(C), is based upon physical deterioration limiting its application since the Mylar insulation could be subjected to mechanical strain.

Backup Rings. Radiation causes Mylar to become hard and brittle; however, this will not effect its usefulness as backup rings at exposures below those which result in physical deterioration. Therefore, the recommended radiation tolerance for Mylar backup rings is 1 x 10^{10} ergs/gm(C). In a vacuum at this absorbed dose, Mylar retains approximately 80% and 50% of its preirradiation values of tensile strength and elongation, respectively.

Tape, Electrical. The recommended radiation tolerance of Mylar-backed electrical insulating tape, 1 x 10^{10} ergs/gm(C), is based upon physical deterioration of both Mylar and the adhesive limiting its usage.

Liners. Since the RNS environment for aluminized Mylar is a vacuum and the structural requirements are not severe, some physical deterioration will not seriously effect its function as an insulated liner. Therefore, the recommended radiation tolerance for aluminized Mylar liners is 3×10^{10} ergs/gm(C). In air at this absorbed dose, Mylar retains approximately 60% of its preirradiation tensile strength and 25% of its elongation.

4.3.8 Neoprene

The mechanical properties of neoprene (chloroprene rubber) elastomers as well as their stability in a radiation environment depend upon the specific polymer, cure, and additives. The data in Table 4-4 show the effect of radiation on various neoprene rubber compounds when irradiated and tested in air at room temperature.

Radiation effects test experience indicates:

1. Data obtained on the effects of radiation on neoprene in vacuum as compared with irradiation in air are conflicting. These differences are probably due to the type of neoprene studied, differences in compounding, and cure. In most instances, the effects of radiation are more severe in air than vacuum.

2. Neoprene rubber is not normally recommended for applications at cryogenic temperatures; this probably explains the fact that no data were reported for cryogenic temperature.

Seals. The recommended radiation tolerance for neoprene seals is 6×10^{8} ergs/gm(C). This limit is based upon a 25%

Table 4-4

EFFECTS OF RADIATION ON NEOPRENE*

Type	Property and Preirradiation Value	Damage Threshold (ergs/gm(C))	25% Damage (ergs/gm(C))	50% Damage (ergs/gm(C))
Neoprene-W (A-109D-73)	Tensile Strength (2.9 ksi) Elongation (450%) Set at break (6%) Compression set (9%) Shore Hardness (H=78)	1×10^{9} 4.1×10^{8} 1.6×10^{9} 1.8×10^{8} 4.1×10^{9}	6.6×10^{9} 1.8×10^{9} 3.2×10^{9} 6×10^{8} (Decrease) 9.1×10^{9} (H=83)	1.6×10^{10} 4.1×10^{9} 4.1×10^{9} 1.3×10^{9} (Decrease) 1.4×10^{10} (H=88)
PR-2270** (O-rings)	Tensile Strength (2.7 ksi) Elongation (290%)	1×10^{9} 1×10^{9}	1×10^{10} 2×10^{9}	-- 5×10^{9}
Neoprene (WRT) (139-62)	Tensile Strength (2.1 ksi) Elongation (520%) Shore Hardness (H=68)	Not measured Not measured Not measured	Not measured Not measured Not measured	4×10^{9} 6×10^{8} 4×10^{9} (H=74)

*Ref. 5, p. 113, Ref. 16, p. 28, Ref. 9, p. 240, Ref. 15, p. 158, and Ref. 6, p. 60.

**Values are approximately the same for irradiations in both air and vacuum.

change in some properties and the fact that neoprene is not recommended for the low temperature anticipated for the RNS missions. Since the results of irradiation tests depend upon the particular material formulation and the test conditions (temperature, medium, etc.), care must be used in the selection of a neoprene.

Grommets. The recommended radiation tolerance for neoprene grommets, 1×10^9 ergs/gm(C), is considerably below the exposure at which physical degradation occurs. This conservatism is based upon the lack of radiation effects test data at cryogenic temperatures.

4.3.9 Nylon

Nylon (polyamide) is used to hold thermal insulation in place and as seals in the construction of valve and regulator assemblies.

Various chemical formulations of nylon have been tested in radiation environments. The following data summarize the results of these tests:

1. At an exposure of 2×10^{10} ergs/gm(C), Nylon 6-6 lost 68% of its tensile strength when irradiated and tested in air at 75°F. At an exposure of 1×10^{11} ergs/gm(C), Nylon 6-6 crumbled (Ref. 17).

2. At an exposure of 1.4×10^9 ergs/gm(C), Nylon 700L lost 28% of its tensile strength and 16% of its elongation when irradiated and tested in air at 75°F (Ref. 17).

3. Nylon 300 showed decreases in tensile strength and elongation of 64% and 54%, respectively, when irradiated and tested in air after an exposure

of 4.6×10^8 ergs/gm(C). When irradiated in nitrogen to the same exposure, the material was not damaged (Ref. 17), thus illustrating that the mechanical properties of nylon are markedly improved by the exclusion of oxygen.

4. At an exposure of 8.5×10^8 ergs/gm(C), nylon lost 50% of its tensile strength when irradiated in air, but only 15% when irradiated in vacuum (Ref. 17).

5. Coating nylon with vinyl will increase the radiation tolerance of the material. The 25% damage threshold was a factor of 10 higher for the coated fabric (Ref. 18).

Seals. The recommended radiation tolerance for nylon seals, which are incorporated into propellant management components, is 5×10^8 ergs/gm(C). This limit, which is based upon tests conducted with the least radiation stable chemical formulation in air (the radiation stability of nylon is much better in a vacuum), is predicated upon the material retaining at least 50% of its preirradiation tensile strength and elongation.

Insulation, Electrical. The recommended radiation tolerance for electrical insulation is 3×10^9 ergs/gm(C). The dissipation factor and the electrical characteristics are not significantly effected at this exposure; however, the possibility of physical deterioration established this limit.

Fabric, Cord, and Fasteners. Since the nylon fabric, cord, and fasteners which hold thermal insulation in place are not related to flight critical components, the recommended radiation tolerance, 3×10^9 ergs/gm(C), is based upon the exposure slightly below that which results in physical deterioration.

End plugs. The recommended radiation tolerance for the nylon end plugs which fit into electrical connectors is 3×10^9 ergs/gm (C). At this absorbed dose, the electrical insulating characteristics of nylon are not affected by nuclear radiation; however, its usage is limited by the possibility of physical deterioration which may occur at higher exposures.

4.3.10 Phenolic – Filled and Unfilled

Phenolics similar to phenol-formaldehyde are quite brittle, exhibiting an elongation of only 2% at room temperature; hence most of their applications are based upon tensile or impact strength. This material is affected by radiation in an unusual way; at an exposure of 1.1×10^9 ergs/gm(C), its elongation increases by approximately 25%, and at 1×10^{10} ergs/gm(C) its elongation is almost twice as great as its preirradiation value (Ref. 19, p. 55). The tensile, shear, and impact strengths of unfilled phenolics decrease from their preirradiation values by approximately 50% when irradiated at room temperature to an exposure of 3×10^{10} ergs/gm(C) (Ref. 5, p. 96). When irradiated, unfilled phenolics swell, become very brittle, and tend to crumble.

The addition of fillers, particularly mineral fillers, increases the stability of phenolics. The type of filler and the processing procedures significantly effect the radiation stability of filled phenolics. Phenol-formaldehyde with asbestos filler

(Haveg 41) shows excellent radiation stability, being unaffected by dosages of 3.9×10^{10} ergs/gm(C). The tensile strength of paper filled phenolic degrades by 25% at 3×10^{9} ergs/gm(C), whereas the tensile strength and elongation of cotton filled phenolics degrade rapidly at exposures above 7×10^{9} ergs/gm(C) (Ref. 5).

Phenolics — Molded Parts. At the recommended radiation tolerance of 1×10^{10} ergs/gm(C), tensile strength decreases by 25% from its preirradiation value.

Cotton Filled Phenolics — Spacers and Laminated Rods. The recommended radiation tolerance, 3×10^{9} ergs/gm(C), is below the exposure at which physical deterioration occurs.

4.3.11 Polycarbonate

Polycarbonate, a polyester of carbonic acid and bisphenol A, was found in only a few applications in the Saturn V. This material has been irrradiated in both sheet and film form. Data for polycarbonate sheet irradiated in air to five dose levels between 3×10^{8} and 1.2×10^{10} ergs/gm(C) show no significant changes in ultimate tensile strength and Shore-D hardness up to a dose of 1.5×10^{9} ergs/gm(C). Yield stress decreased with dose, having dropped by about 10% at a dose of 3.6×10^{9} ergs/gm(C); samples irradiated to 1.2×10^{10} ergs/gm(C) did not exhibit a yield point. Ultimate tensile strength was essentially unaffected at a dose of 1.5×10^{9} ergs/gm(C) (Ref. 20).

The above data were confirmed in a separate experiment (Ref. 11) in which polycarbonate sheet was irradiated in air and in vacuum to maximum doses of 2×10^{11} and 3×10^{10} ergs/gm(C), respectively. The tensile properties were essentially unaffected through a dose of 3.6×10^{9} ergs/gm(C) in air, but deteriorated rather rapidly at higher doses. The data from the vacuum irradiation gave similar results.

Formed Parts. The recommended radiation tolerance for polycarbonate formed parts, 4×10^{9} ergs/gm(C), is based upon minor changes in its tensile properties.

4.3.12 Polyethylene (Aluminized)

Polyethylene films coated with aluminum on one side are used as liners to reflect engine heat away from heat sensitive components. Radiation effects data indicate:

1. The radiation damage threshold for low-density polyethylene films irradiated in air at room temperature is about 4.4×10^{8} ergs/gm(C) and the 25% damage threshold is about 9×10^{8} ergs/gm(C) (Ref. 5, p. 150). Polyethylene is subject to oxidation when irradiated and this tends to explain the variability of results obtained in testing samples with thicknesses ranging between 2 and 15 mils. Polyethylene films are damaged less when irradiated in a vacuum than when irradiated in air.

2. A 2-mil film of high-density polyethylene (Marlex) was extremely brittle and crumbled when irradiated to an exposure of 4.4×10^{9} ergs/gm(C) in air and tested at room temperature. At an exposure of 4.4×10^{8} ergs/gm(C) the elongation had decreased 92% and tensile strength 12%.

3. Doubly aluminized Mylar (Mylar-Al-Al-Mylar) vapor barrier irradiated to a dose of 6.7×10^{10} ergs/gm(C) in air and tested in air retained 28% of its original tensile strength at break and less

than 10% of its original elongation. Irradiated in liquid hydrogen to a dose of 3.2×10^{10} ergs/gm(C) and tested in air, this material retained 79% of its original tensile strength and 52% of its original elongation. Bubbles in the film surface were clear evidence of gas evolution, the specimens irradiated in air (to the higher dose) showing considerably more bubble formation (Ref. 21, p. 118).

Liners. The recommended radiation tolerance for aluminized polyethylene film when employed as a liner is 1×10^{9} ergs/gm(C). At this exposure, the material will be slightly brittle; however, no physical deterioration is anticipated.

4.3.13 Polyimide

Polyimide has been tested in various forms, and in each instance it has exhibited excellent stability in a radiation environment. The tensile strength of HT-1 polyimide fibers (DuPont Nomex yarn), which have approximately the same strength characteristics as nylon, was relatively unaffected by exposures to 3.3×10^{10} ergs/gm(C) (Ref. 6, p. 108).

The mechanical properties of polyimide H-Film, which is considered for use as a hydrogen barrier, did not change significantly after a vacuum-irradiation exposure of 1.1×10^{10} ergs/gm(C). After an exposure to 2.9×10^{10} ergs/gm(C), the elongation decreased by 20% (Ref. 9, p. 182). Radiation did not affect hydrogen permeability. At an exposure of 3.9×10^{10} ergs/gm(C) in air, the elongation of H-film decreased only 35%.

Polymer SP-1, which is the same base polymer type as H-film but compounded by a different process, was virtually unaffected when irradiated at liquid-nitrogen temperature to an exposure of

1×10^{10} ergs/gm(C) (Ref. 9, p. 187).

DuPont Pyre-ML, a polyimide resin enamel electrical insulation, did not exhibit a noticeable degradation of dielectric properties after an exposure of 1×10^{10} ergs/gm(C). The insulation was used on the stator of a generator (Ref. 22, p. B-22).

Electrical Insulation, Varnish, and Electrical Insulating Tape. Although the dielectric properties of polyimide are unaffected at 1×10^{10} ergs/gm(C) and it should function satisfactorily at higher exposures, the recommended radiation tolerance for these applications is 1×10^{10} ergs/gm(C). Additional testing in a combined vacuum, cryogenic temperature, and radiation environment is required to provide confidence at higher exposures. Deterioration of the adhesive limits the recommended radiation tolerance for polyimide tape to 1×10^{10} ergs/gm(C), even though polyimide possesses good mechanical properties at 3×10^{10} ergs/gm(C).

Gaskets, Seals, and Valve Seats. The recommended radiation tolerance of polyimide gaskets, seals, and valve seats is 2×10^{10} ergs/gm(C). At this exposure in a cryogenic environment, polyimide is very stable, possessing greater than 90% of its preirradiation tensile strength and 75% of its elongation. Physical deterioration is not anticipated at exposures below 1×10^{11} ergs/gm (C).

Spacers. The recommended radiation tolerances for Polyimide spacers, 3×10^{10} ergs/gm(C), is below the exposure at which severe physical deterioration occurs.

4.3.14 Irradiated Polyolefin

Limited data on industrially irradiated polyolefin (heat shrinkable polyvinyl chloride, Thermofit RNF) indicate that a threshold of damage occurs between doses of 1 x 10^9 and 1 x 10^{10} for irradiation in both air and vacuum at room temperature. Ultimate elongation decreased about 25% at a dose of 1 x 10^9 ergs/gm (C) in both air and vacuum and was near zero at 1 x 10^{10} ergs/gm (C). Ultimate tensile strength was essentially unaffected at 1 x 10^9 ergs/gm(C), and had decreased moderately at 1 x 10^{10} ergs/gm (C) (Ref. 9, p. 182).

Heat Shrinkable Sleeve. The recommended radiation tolerance, 3 x 10^9 ergs/gm(C), is based on a 50% decrease in ultimate elongation for the polyvinyl chloride material.

4.3.15 Polyurethane

Rigid polyurethane foam, both preformed and cast in place, is used throughout the Saturn V as thermal insulation and as spacers to maintain the relative position of components and plumbing. In addition, polyurethane is also employed as molding and potting.

Radiation effects test experience with polyurethane foam materials is summarized below:

1. Two polyurethane foam materials manufactured by Chemical Plastics Research Company were irradiated in vacuum and tested for compression strength at 25% deflection in both air and vacuum. After a radiation exposure of 10^9 ergs/gm(C), the

compression strength of CPR-200 did not change when tested in air (100 psi to 99 psi). When tested in vacuum after a radiation exposure of 5×10^8 ergs/gm(C), compression strength for 25% deflection increased to 124.5 psi. With the second material, CPR-1021-2, compression strength for 25% deflection again did not change significantly when tested in air after being irradiated in vacuum to 5×10^8 ergs/gm(C). (Values were 33 psi before and 29.8 psi after irradiation.) When tested in vacuum after the same radiation exposure, compression strength increased to 49.4 psi (Ref. 9, p. 213).

2. Stayfoam AA 402, a polyurethane thermal insulation material, was irradiated at cryogenic temperatures. There appeared to be an approximate threshold point for compressive resistance of this material at an exposure of about 5×10^9 ergs/gm(C) (Ref. 13, p. 195).

3. A flexible polyurethane foam, a blown polyester urethane produced by General Foam Co., was irradiated and tested at 75°F. The compression set at 50% deflection increased from its preirradiation value of 8% to 20% at 1×10^9 ergs/gm (C) to 95% at 8.3×10^9 ergs/gm(C) and 100% at 2.8×10^{10} ergs/gm(C). At the highest dose, 9.4×10^{10} ergs/gm(C), the material adhered to the plates (Ref. 6, p. 68).

Thermal Insulation and Spacers. Based on the above data, the recommended radiation tolerance for rigid polyurethane thermal insulation and spacers is 5×10^9 ergs/gm(C). At this exposure the compression set will be significantly increased and the compression-resistance strength should increase. However, these changes in its mechanical properties should not adversely affect its usage as a thermal insulator or spacer.

Potting and Molding. The recommended radiation tolerance for polyurethane base potting and molding materials is 1×10^{10} ergs/gm(C). Its tensile properties should be adequate at higher exposures; however, additional testing is required if this material is to be used confidently at exposures greater than 1×10^{10} ergs/gm(C).

4.3.16 Natural Rubber

Natural rubber products are only employed in limited applications on the Saturn V vehicle. Considerable research has been performed with regards to improving the radiation stability of natural rubber by the use of antirad materials. This research and development has resulted in marked improvements in the mechanical properties of rubber.

The effects of radiation on natural rubber without antirads are summarized below for room temperature tests (Ref. 5, p. 112):

Property Affected and Preirradiation Value	Damage at Dose in Ergs/gm(C)		
	Incipient	25%	50%
Tensile strength (2600 psi)	2.2×10^9	1.4×10^{10}	3×10^{10}
Elongation (420%)	6.8×10^8	4.5×10^9	1.2×10^{10}
Set at Break (32%)	4.5×10^8	5×10^9	1×10^{10}
Compression Set (13%)	1.8×10^8	5×10^9	1×10^{10}

Gaskets and Seals. The recommended radiation tolerance of natural rubber gaskets and seals, 5×10^9 ergs/gm(C), is the exposure at which most of the mechanical properties retain at least 75% of their preirradiation value.

Tape. The recommended radiation tolerance of rubber electrical insulation tape is 1×10^{10} ergs/gm(C). At this exposure the tensile strength retains over 75% of its preirradiation value; however, most adhesives degrade very rapidly at higher exposures, thus limiting the usage of rubber tape.

4.3.17 Rubber, Asbestos Filled

Although the addition of asbestos fillers in plastics can improve their radiation stability by an order of magnitude or more (e.g., the addition of asbestos to phenolics changes the 25% damage threshold from 1.1×10^9 ergs/gm(C) to 3.9×10^{11} ergs/gm(C), Ref. 5, p. 96), asbestos fillers do not improve the stability of rubbers (Ref. 5, p. 96). The radiation stability of asbestos/rubber compounds is approximately the same as for rubber stock.

Seals and Gaskets. The recommended radiation tolerance of asbestos/rubber gaskets and seals is 5×10^9 ergs/gm(C), the exposure at which most of the mechanical properties of rubber have degraded by 25%.

Spacers. The recommended radiation tolerance of asbestos/rubber spacers is 3×10^{10} ergs/gm(C), the exposure at which the material begins to deteriorate very rapidly.

4.3.18 Silicone

4.3.18.1 Silicone Rubber

Silicone rubber is used throughout the Saturn V vehicle for numerous applications. The usages are varied and require silicone rubber of different forms, e.g., sponge, sheet, formed, and filled with fiberglass or other materials. In addition, a variety of silicone elastomers having different chemical constituents are manufactured, thus confounding the radiation effects test data.

The data in Table 4-5 show the effect of radiation on various formulations of silicone rubber when irradiated and tested in air at room temperature.

Radiation effects test experience indicates:

1. The stability of silicone rubber compounds in a vacuum, as contrasted to irradiation in air, depends on the specific chemical formulation. Those showing better mechanical properties in vacuum than in air include dimethyl, dimethyl-phenyl, and dimethyl-vinyl types, whereas the reverse was true for the methyl-phenyl-vinyl compound (Ref. 6, p. 74).

2. Upon irradiation, the damage to silicones will vary with the type and amount of radiation, the composition of material, time of cure, the volume of the sample exposed, and environmental factors.

3. Certain types of stresses increase the radiation damage, e.g., stretching, twisting, shearing, and swelling forces. On the other hand, compression may result in less radiation damage (Ref. 5, p. 132).

Table 4-5

EFFECTS OF RADIATION ON SILICONE RUBBER*

Chemical Formulation	Property and Original Value	Damage at Dose in ergs/gm(C)		
		Threshold	25%	50%
Dimethyl-siloxane (Silastic 7-170)	Tensile strength (520 psi)	1.2×10^8	4.9×10^9	1.5×10^{10}
	Elongation (95%)	1.4×10^8	6.8×10^8	1.6×10^9
	Compression set (1.4%)	1.2×10^8	3.8×10^8	9.1×10^8
	Shore hardness (H=59)	1.2×10^8	1.2×10^9	1×10^{10}
Dimethyl-siloxane (77-018)	Tensile strength (920 psi)	1×10^8	Not reached at 2×10^9	
	Elongation (375%)	1×10^8	8×10^8	1.4×10^9
	Shore hardness (H=78)	1×10^8	Not reached at 2×10^9	
Methyl-vinyl-siloxane (SE 750)	Tensile strength (750 psi)	2×10^7	7×10^9	Not reached at 7×10^9
	Elongation (140%)	9×10^7	7×10^8	1.6×10^9
	Short hardness (H=54)	7×10^7	1.4×10^9	4×10^9
Methyl-phenyl-siloxane (Y-1668)	Tensile strength (800 psi)	1×10^8	3×10^9	Not reached at 8×10^9
	Elongation (330%)	1×10^8	6×10^8	1×10^9
	Shore hardness (H=52)	1×10^8	1.1×10^9	4×10^9
Nitrile-silicone (NSR-X-5602)	Tensile strength (980 psi)	No test	8×10^8	1×10^{10}
	Elongation (280%)	No test	2×10^8	8×10^8
	Compression set (16%)	No test	$<1\times10^8$	$<1\times10^8$

*Ref. 6, p. B-90.

4. Irradiation of nitrile-silicone rubber at -65°F and testing at 80°F yielded data similar to that for specimens irradiated and tested at 80°F.

5. Silastic 950, a high-phenyl, high-strength, extreme-low-temperature silicone rubber, showed a 30% decrease in both tensile strength and elongation when irradiated to 6.7 x 10^9 ergs/gm(C) in LN_2 and tested at LN_2 temperatures (Ref. 15, p. 295).

Gaskets, Seals and O-Rings. The recommended radiation tolerance for silicone rubber gaskets, seals, and O-rings, 8 x 10^8 ergs/gm(C), is based upon a less than 50% reduction in elongation. At this exposure the compression set of nitrile-silicone rubber would have increased from an initial value of 16% to over 60%; therefore, nitrile-silicone rubber should not be used for these applications.

Electrical Insulation, Tape, and Inserts. The recommended radiation tolerance for silicone rubber employed as electrical insulation, electrical tape, or inserts in electrical connectors is 1 x 10^9 ergs/gm(C). At this exposure the electrical insulating properties of silicone rubber have not degraded; however, the degradation in its mechanical properties, i.e., reduction in tensile strength and elongation to about 40% of their preirradiation values, limits its usefulness at higher exposures.

Sealants and Packing. The recommended radiation tolerance for silicone rubber sealants and packing is 1 x 10^9 ergs/gm(C). This is the exposure at which all types of silicone rubber retain at least 40% of their preirradiation values of both elongation and tensile strength.

Spacers, Grommets, Sleeves, Tubing, Liners, Thermal Insulation, and Molding. The recommended radiation tolerance for these applications of silicone rubber, 2 x 10^9 ergs/gm(C), is the exposure at which many chemical formulations of silicone rubber begin to physically deteriorate.

Potting. The recommended radiation tolerance for silicone rubber potting compounds used for encapsulating electrical components, 2 x 10^9 ergs/gm(C), is the exposure at which many chemical formulations of silicone rubber begin to physically deteriorate.

4.3.18.2 Silicone Resin

Silicone resins which are used in conjunction with coatings are not seriously degraded at exposures of 1 x 10^{10} ergs/gm(C) and, with the proper filler, are satisfactory to 1 x 10^{11} ergs/gm(C) (Ref. 5, p. 99). The presence of phenyl groups in the silicone chain increases radiation stability, whereas the addition of methyl groups increases flexibility.

Coatings and Primers. The recommended radiation tolerance for silicone resin base coatings and primers is 1 x 10^{10} ergs/gm (C). At this exposure, the material will only be slightly affected.

4.3.19 Teflon

Teflon is employed for numerous applications in the S-II and S-IVB stages of the Saturn V vehicle. Establishing radiation tolerance limits for these applications is complicated by many factors. First, there are two chemical compositions for Teflon: Téflon TFE (tetrafluoroethylene) and Teflon FEP (fluorinated copolymer of ethylene and propylene). Secondly, tests indicate that the effects of radiation are dependent upon the test environment, i.e., temperature, atmosphere, and test specimen thickness.

Kerlin and Smith (Ref. 15, p. 218) irradiated Teflon TFE and Teflon FEP of varying thickness ranging between 2 and 40 mils to exposures up to 9.7×10^9 ergs/gm(C) in both air and vacuum and subsequently tensile tested the specimens in air. Their data indicate:

1. The thickness of the material affects the ultimate values in both air and vacuum by a factor of two, the thicker specimens being affected less by radiation.
2. In vacuum, 10-mil-thick Teflon FEP film retains its elongation property at radiation exposures ten times higher than does Teflon TFE.
3. In air, Teflon FEP is a factor of 16 more resistant than Teflon TFE.
4. Teflon FEP retains its elongation property to a factor of 2 higher dose in vacuum than in air.

The irradiation temperature strongly influences the radiation tolerance of Teflon, as is evidenced by experimental data at an exposure of 2.6×10^7 ergs/gm(C) in which Teflon TFE showed decreases in tensile strength of 40% and 60% at 70°F and 350°F, respectively, but exhibited only negligible changes at -350°F (Ref. 5, p. 105).

Since there is a significant difference in the radiation stability of Teflon TFE and Teflon FEP, recommended radiation tolerances are presented for both types of Teflon. These recommendations are based upon tests performed in air at room temperature (Ref. 10, p. 25, Ref. 19, p. 43, and Ref. 23, p. 677). These data are presented below.

Type Of Teflon	Property Affected	Damage at Dose in Ergs/gm(C) Incipient	25%	50%
TFE	Tensile strength	2.1×10^6	1.2×10^7	9.1×10^7
FEP	Tensile strength	Not measured	4.0×10^7	1.0×10^9
TFE	Elongation	1.5×10^6	3.4×10^6	7.3×10^6
FEP	Elongation	Not measured	1.2×10^7	7.0×10^8
TFE	Shear strength	1.8×10^7	4.0×10^7	1.5×10^8
TFE	Impact strength	1.8×10^7	3.6×10^7	5.0×10^7

Experimental data indicate that Teflon should not be adversely affected by an environment of cryogenic temperatures and vacuum, as its radiation stability increases in vacuum and at cryogenic temperatures.

Hoses. Hydraulic hoses which contain an inner lining of Teflon TFE impregnated with carbon black should only be employed in environments in which the integrated exposure is less than 3×10^6 ergs/gm(C). This limit is based upon tests performed by Collins (Ref. 5, p. 151) who demonstrated that failure of Teflon TFE hoses occurs at about 1×10^8 ergs/gm(C) for static pressure tests and 1×10^7 ergs/gm(C) for intermittent pressure tests. Since hydraulic hoses will be flexed and pressurized periodically throughout the RNS mission, the recommended radiation tolerance limit is 3×10^6 ergs/gm(C).

Gaskets, Valve Seats, and Seals. The primary concern for these applications is radiation damage resulting in leakage of gases and fluids as well as physical deterioration of the gasket and subsequent contamination of the fluids which could cause malfunction of valves or increased system pressure due to plugging of filters. The recommended radiation tolerances for Teflon TFE and Teflon FEP gaskets, seals, and valve seats are 7×10^6 ergs/gm(C) and 7×10^8 ergs/gm(C), respectively. Physical deterioration should not occur below these levels.

Retainer Rings. Radiation causes Teflon retainer rings to harden and become brittle; however, they should be usable as long as neither elongation nor tensile strength degrades below 50% of its preirradiation value. Therefore, the recommended radiation tolerance for Teflon TFE and Teflon FEP retainer rings are 7×10^6 ergs/gm(C), and 7×10^8 ergs/gm(C), respectively, the exposure at which elongation decreases by 50%.

Packing and O-Rings. Teflon packings and O-rings are used in the construction of valves and transducers. In these applications, Teflon should function satisfactorily as long as its tensile strength and elongation maintain a reasonable value and the material does not physically deteriorate. The recommended tolerance for Teflon TFE packings and O-rings is 7×10^6 ergs/gm(C), the exposure at which its elongation and tensile strength have decreased to 50% and 85%, respectively, of their preirradiation values. The recommended radiation tolerance for Teflon FEP packings and O-rings, 7×10^8 ergs/gm(C), is the exposure at which its tensile strength and elongation have decreased by approximately 50%. Physical deterioration is not anticipated at these exposures.

Tape. Teflon TFE tape is used for identification purposes and to hold thermal insulation on pipes containing cryogenic fluids or hot gasses. The recommended limit for these noncritical applications is 2×10^7 ergs/gm(C), the exposure at which its elongation and tensile strength have decreased to 25% and 70%, respectively, of their preirradiation values.

Bearings and Bushings. The recommended radiation tolerance for Teflon TFE bearings and bushings, 3×10^7 ergs/gm(C), is the exposure at which its impact strength has decreased by 25%. The recommended radiation tolerance for Teflon FEP bearings, 7×10^8 ergs/gm(C), is the exposure at which its mechanical properties begin to degrade rapidly.

Inserts. The recommended radiation tolerance for Teflon TFE inserts, which are used to pin parts on shafts and perform functions similar to shear pins, 3×10^7 ergs/gm(C), is the exposure at which the shear strength has decreased 10% from its pre-irradiation value; however, shear strength decreases very rapidly at exposures greater than 4×10^7 ergs/gm(C).

Backing for Explosives. Teflon TFE is employed as backing for the linear shaped charge assembly explosive materials. The recommended radiation tolerance, 5×10^7 ergs/gm(C), is based upon a conservative estimate of the radiation exposure at which the backing material begins to physically deteriorate.

Face-Coated Seals. Teflon TFE face-coated seals of a design similar to MC252C4TA (corrosion resistant steel coated with 0.0005 in. of Teflon primer and 0.0010 in. of black Teflon enamel) are used throughout the propellant management and pneumatic systems. Since the mass of material is small, physical deterioration has been used to establish the radiation tolerance for these seals. Although the forces holding the seals in position should prevent contamination of the fluids if the Teflon coating deteriorates, the recommended radiation tolerance for Teflon TFE face-coated seals, 1×10^8 ergs/gm(C), is slightly below the exposure at which physical deterioration begins.

Electrical Insulation. Teflon insulated wires have been tested while being irradiated and after irradiation to exposures of up to 8.7×10^{10} ergs/gm(C) (Ref. 6, p. 627). These tests indicate that good insulation properties are retained even though the mechanical properties are severely degraded and physical deterioration has occurred. The recommended radiation limits for Teflon TFE and Teflon FEP insulated wires are 1×10^8 and 1×10^9 ergs/gm(C), respectively. These limits, which are slightly below the exposures at which physical deterioration occurs, are recommended since wires may be subjected to mechanical strain.

Sleeves. The recommended radiation tolerance for Teflon TFE sleeves, which are used to bundle wiring harnesses and facilitate harness routing as well as to protect the wires from physical damage, 1×10^8 ergs/gm(C), is based upon physical deterioration limiting its usefullness.

Adapters, Pads, and Spacers. The recommended radiation tolerance for Teflon adapters, pads, and spacers, which are utilized to separate components and maintain them in fixed positions relative to one another, is based upon physical deterioration limiting its usage. The recommended limits for Teflon TFE and Teflon FEP in these applications are 1×10^8 and 1×10^9 ergs/gm (C), respectively.

Grommets. The recommended radiation tolerances for Teflon TFE and Teflon FEP grommets are 1×10^8 and 1×10^9 ergs/gm(C), respectively, based upon physical deterioration limiting their usefullness.

4.3.20 Teflon, Filled

4.3.20.1 Teflon, Fiberglass Filled

Armalon, which is a trade name for fiberglass reinforced Teflon (either TFE or FEP) manufactured by DuPont, has been tested in a radiation environment at both room temperature and LH_2 temperature. The results of these tests are summarized below (Ref. 23, p. 673):

1. The incipient damage threshold for tensile strength is approximately 1×10^9 ergs/gm(C) for both FEP and TFE Teflon type Armalon at both room and LH_2 temperatures. The 25% damage threshold is approximately 5×10^9 ergs/gm(C) for specimens irradiated in LH_2 and air. The 50% damage threshold is about 1×10^{10} ergs/gm(C).

2. The elongation of both FEP and TFE Teflon type Armalon at room temperature ($<1.5\%$) is relatively unaffected at exposures up to 2×10^{10} ergs/gm(C)).

3. The elongation of FEP Teflon type Armalon, when tested at LH_2 temperature, starts to decrease at 1×10^9 ergs/gm(C), and the 25% damage threshold is 5×10^9 ergs/gm(C).

4. Armalon delaminates at exposures greater than 1×10^{11} ergs/gm(C).

In addition to Armalon, several other fiberglass reinforced Teflon materials are used in Saturn V components. These include: Rulon, which is a trade name of the Dixon Corporation for Teflon TFE reinforced with inorganic fillers such as fiberglass; Fluorogold, which is 25% by weight fiberglass filled Teflon TFE manufactured by the Fluorocarbon Co.; and Fluorocomp #105, which is also 25% by weight fiberglass filled Teflon TFE manufactured by Liquid Nitrogen Co. The effects of radiation on these materials are assumed to be similar to those for Armalon.

Seals, Gaskets, and Valve Seats. The recommended radiation tolerance for fiberglass filled Teflon TFE seals, gaskets, and valve seats is 5×10^9 ergs/gm(C), the exposure at which Teflon TFE type Armalon begins to degrade rapidly.

Bearings and Inserts. The recommended radiation tolerance for fiberglass filled Teflon TFE bearings is 8×10^9 ergs/gm(C), the exposure at which the impact and compressive strengths of Armalon begin to decrease.

Retainer Rings, Pads, Spacers, and Sleeves. The recommended radiation tolerance for these applications is 1×10^{10} ergs/gm(C), the exposure at which the tensile strength of Armalon decreases to 50% of its preirradiation value.

4.3.20.2 Teflon, Asbestos Filled

The addition of fillers such as asbestos and fiberglass can significantly improve the radiation stability of Teflon. Duroid 5600, fiberglass filled Teflon, was unaffected at an exposure of 1.1×10^{10} ergs/gm(C) when tested in a vacuum at cryogenic temperature (Ref. 15, p. 236). Although no radiation effects test data could be located for asbestos filled Teflon, it is believed to have properties similar to fiberglass filled Teflon.

Spacers. The recommended radiation tolerance for this non-critical application of asbestos filled Teflon is 1×10^{10} ergs/gm(C).

4.3.21 Viton A

Viton A, a copolymer of hexafluoropropylene and vinylidene fluoride, is employed as O-rings throughout the propellant feed system. Viton A, both with and without antirad compounds, has been tested in air and vacuum at exposures of up to 1×10^{10} ergs/gm(C) yielding the following results:

1. Seven different chemical formulations (Viton A-12 through A-18) were tested in air at room temperature after an exposure of 8.7×10^9 ergs/gm(C). Hardness increased between 15% and 45%; elongation decreased between 85% and 94%; and tensile strength varied between -20% and +38% (Ref. 5, p. 135).

2. Carbon black as well as five different antirad materials were compounded with Viton A; however, no improvement was noted for any mixture at an exposure of 8.7×10^9 ergs/gm(C) (Ref. 5, p. 134).

3. The exclusion of air (oxygen) increases the apparent radiation resistance of Viton A (Ref. 5, p. 136). In vacuum there was no significant change in tensile strength at an exposure of 1×10^{10} ergs/gm(C) at room temperature; however, the elongation decreased by about 50% (Ref. 7, p. 244).

4. After irradiation in air at 75^{o}F, Viton A-HV showed a 100% compression set at an exposure of 1×10^{10} ergs/gm(C) (Ref 6, p. 46).

5. In air, Viton A reaches the damage threshold point at an exposure of 5×10^8 ergs/gm(C) and a 25% damage point at 6×10^9 ergs/gm(C) (Ref. 6, p. 58).

O-Rings and Ring Seals. The recommended radiation tolerance for Viton A O-rings and ring seals, 6×10^9 ergs/gm(C), is the exposure at which elongation begins to decrease very rapidly. No data were found regarding irradiation at cryogenic temperature as this material is normally used at elevated temperatures.

4.4 Data Summary for Adhesives

Various types of adhesives are employed for bonding metals, gaskets, and insulation materials. The effects of radiation on the shear strength of adhesives at room temperature are presented in Table 4-6 for materials irradiated in both air and in vacuum. In addition to these data, radiation effects test experience indicates:

1. Adhesives developed for high-temperature use, such as the phenolic-epoxy types, have better resistance to radiation than the thermoplastic and general-purpose types.

2. Lap-shear specimens prepared with epoxy, epoxy-phenolic, vinyl-phenolic, nitrile-phenolic, and glass-supported epoxy-film adhesives were irradiated in air and in vacuum (10^{-6} torr) to an exposure of 1×10^9 ergs/gm(C) at a temperature of 100°F. The specimens were then tested for shear strength at a temperature of -300°F. In all cases, the loss in shear strength was small and the original strength of the adhesive bond specimens could be considered adequate for the design of parts to be subjected to the above conditions.

3. Epoxy, epoxy-phenolic, vinyl-phenolic, nitrile-phenolic, and glass-supported epoxy-film adhesives were irradiated to 1.7×10^9 ergs/gm (C) in vacuum at ambient temperature. Results indicate that the cryogenic temperature and

Table 4-6

EFFECTS OF RADIATION ON THE SHEAR STRENGTH OF ADHESIVES*

Adhesive	Type	Gamma Exposure (ergs/gm(C)	Change (%) from Preirrad Value Irrad in Air	Irrad in Vac
Epox 929	Epoxy	2.9×10^{10}	+10	-10
Epon 934	Epoxy	2.9×10^{10}	0	-10
Epon VIII	Epoxy	1.7×10^{10}	no test	-10
FB-1000	Epoxy-Nylon	2.9×10^{10}	0	0
Metlbond	Epoxy-Nylon	1.1×10^{10}	+20	no test
Metlbond	Epoxy-Nylon	4.9×10^{10}	-85	no test
HT-424	Epoxy-Phenolic	2.9×10^{10}	-25	-10
Hexcell-422J	Epoxy-Phenolic	3.9×10^{10}	no test	+5
Narmco A	Modified Epoxy	2.9×10^{10}	-10	+20
Metlbond 408	Modified vinyl-epoxy-nylon	3.9×10^{10}	no test	-75
FM-47	Vinyl-Phenolic	3.9×10^{10}	-15	-45
Metlbond 4021	Nitrile-Phenolic	2.9×10^{10}	-25	-25
AF-6	Nitrile-Phenolic	3.9×10^{10}	no test	-5
APCO 1252	Polyurethane	2.9×10^{10}	+10	+10
Narmco C	Polyurethane	2.9×10^{10}	-90	-50
Aerobond 430	Phenolic-Epoxy	1.1×10^{10}	-10	no test
EC-1469	Modified Epoxy	6×10^{10}	0	no test
AF-31	Elastomer-Phenolic	4×10^{10}	-25	no test
AF-32	Elastomer-Phenolic	4×10^{10}	-25	no test
EC 1639	Modified Phenolic	9×10^{10}	0	no test

*Refs. 6 and 23

and vacuum environment had no effect on lap-shear strength. Specimens prepared with epoxy-phenolic, glass-supported epoxy-film, and vinyl-phenolic appeared to be only slightly affected by vacuum. The effect was small enough that the original strength of the adhesive-bonded specimens could be considered in the design of parts for the above conditions. Specimens bonded with epoxy and nitrile-phenolic adhesives showed no indication of deterioration (Ref. 6).

4. One polyurethane-adhesive-bonded (APCO 1219) and three epoxy-adhesive-bonded (Narmco 3135, Lefkoweld 109, and 3M 1469/1968) test specimens were irradiated and tested in LN_2. No significant changes were noted in single lap shear or flatwise ultimate strengths at exposures up to 1.7×10^9 ergs/gm(C) (Ref. 6).

5. In general, fillers improve the radiation stability of an adhesive, although in some cases at a sacrifice of the overall shear strength. The curing agent and reactive diluent used in epoxy adhesives will also influence the radiation stability of the adhesive. Aromatic curing agents generally produce more radiation resistant compositions than do the aliphatic curing agents.

6. Nitrile rubber/phenolic adhesives which have basic ingredients similar to Buna N maintain good strength properties after exposures up to 5×10^{10} ergs/gm(C) when irradiated and tested in air at room temperature (Ref. 6).

7. No data were found regarding the effects of radiation on polysulfide base adhesives; however, since polysulfide rubber has poor radiation stability (both elongation and tensile strength decrease by 50% at 1×10^{10} ergs/gm(C)) (Ref. 6, p. 67), polysulfide base adhesives are not recommended for exposures greater than 6×10^9 ergs/gm(C).

The recommended radiation tolerance, based on the exposure at which the shear strength begins to decrease, is 1×10^{10}

ergs/gm(C) for polyurethane, epoxy, Buna N, and silicone adhesives. The recommended radiation tolerance for polysulfide base adhesives is 6×10^9 ergs/gm(C).

4.5 Data Summary for Fiberglass Laminates

Fiberglass laminated with various thermosetting resins is used primarily for spacers and doublers. The selection of the binding resin is dependent upon the mechanical properties desired and the anticipated environment.

Radiation effects test experience with organic binders and laminates is summarized below:

1. The mechanical properties of silicone, phenolic, polyester, polyurethane, and epoxy binders were not significantly degraded when irradiated to doses through 8.3×10^{10} ergs/gm(C) (Ref. 5, p. 153).

2. The effect of fiberglass fillers on the radiation stability of polyester and silicone resins is illustrated by the following data (Ref. 19, p. 83):

Binder Material	Fiber	Damage at Dose in Ergs/gm(C) Incipient	25%	50%
Polyester	Unfilled	6×10^7	1×10^8	5×10^9
	Glass Fiber	6×10^{10}	5×10^{11}	1×10^{12}
Silicone	Unfilled	1×10^8	4×10^8	2×10^{11}
	Glass Fiber	2×10^{11}	1×10^{12}	8×10^{12}

3. No changes were detected in either the tensile strength or elongation of the following structural laminates when they were irradiated in a vacuum to exposures in excess of 7.5×10^9 ergs/gm(C): DC-2106 (silicone resin), CTL-91-LD (phenolic resin), Conolon 506 (phenolic resin), Mobiloy AH-81 (phenolic resin), and Epon 828 (epoxy resin)

(Ref. 7, p. 90).

4. The ultimate tensile strength of Conolon 506 and Epon 828 increased by approximately 25% when irradiated in a vacuum to an exposure of 1.3×10^{10} ergs/gm(C). The ultimate strength increased by approximately 50% at an exposure of 2×10^{10} ergs/gm(C) (Ref. 6, p. A-37).

Spacers and Doublers. The recommended radiation tolerances for structural laminates of fiberglass and various organic binders are:

Binder	Recommended Tolerance (ergs/gm(C))
Polyester	6×10^9
Phenolic	2×10^{10}
Epoxy	2×10^{10}
Polyurethane	2×10^{10}
Silicone	2×10^{11}

The recommended limits, which are based upon exposures at which tensile strength begins to decrease, are very conservative since the laminated spacers and doublers are not designed to meet rigid structural requirements.

4.6 Data Summary for Fluids and Lubricants

4.6.1 Hydraulic Fluid

MIL-H-5606, a petroleum-base fluid specified for the S-II and S-IVB hydraulic systems, is relatively radiation sensitive. The rather limited irradiation data shows the material to decrease in viscosity and increase in neutralization number and oxidation corrosion. Considerable gas evolution has been observed in some tests. Bolt and Carrol (Ref. 24, p. 398) state that degradation becomes measurable at 5 x 10^8 ergs/gm(C) and excessive at 5 x 10^9 ergs/gm(C).

In a pump loop test at Convair, a MIL-H-5606A fluid operated successfully in a radiation field for 50 hours. After an exposure of about 2 x 10^8 ergs/gm(C) the viscosity at -65°F had decreased from 1904 cs to 1304 cs, and at 100°F it was 10.2 cs compared to the preirradiation 14.5 cs. The neutralization number increased from 0.07 to 0.22. Statically irradiated samples showed less change in these properties after a similar exposure.

Oronite 8515, a blend of MIL-0-8200 (a disiloxane) and 15% di(2-ethylhexyl)sebacate, has better radiation stability than MIL-H-5606. Oronite 8515 is a higher temperature fluid (400°F), but otherwise has specifications (MIL-H-8446A) similar to MIL-H-5606. In a pump loop test at Convair, Oronite 8515 was exposed at a rate of 1.8 x 10^9 ergs/gm(C)-h. The system operated for 13.6 h (2 x 10^{10} ergs/gm(C)) but the fluid was out of specification on many points. It was concluded, however, that the fluid would probably be satisfactory to about 10^{10} ergs/gm(C). At this exposure, viscosity changes were not large except at -65°F (3522 cs vs preirradiation 2300 cs). The flash point had decreased to 310°F from 375°F (and 180°F at the end of the test).

In a latter test at a much lower dose rate (concurrent with the test of MIL-H-5606 cited above), Oronite 8515 was operated in a pump loop for 50 hours to a dose of about 2 x 10^8 ergs/gm(C).

Changes in properties were slight except that the flash point changed from 380°F to 330°F.

Hydraulic Fluid. The recommended radiation tolerance of MIL-H-5606 type fluid is 5×10^{8} ergs/gm(C) based on moderate property changes in pump-loop tests. The recommended tolerance for Oronite 8515 is 5×10^{9} ergs/gm(C). These or other fluids to be considered for use on the RNS should be evaluated under conditions specifically related to the requirements.

4.6.2 Lubricants

4.6.2.1 Silicones

The radiation sensitivity of the various silicones varies over a rather wide range. DC-510, which is used as a lubricant in several Saturn V components, appears to be one of the least satisfactory for use in a radiation environment. Data from tests at Convair show an increase in 100°F viscosity of 48% for DC-510 irradiated to 7.4×10^{8} ergs/gm(C); after a dose of 7.0×10^{9} ergs/gm(C) the material had solidified.

DC-710, a methylphenyl silicone, was also tested at Convair. After a dose of 7.0×10^{9} ergs/gm(C) the 100°F viscosity had increased 22%; after an exposure of 2.5×10^{10} ergs/gm(C) the 100°F viscosity had increased 840% but the material had not solidified. DC-710 also has a much lower gas evolution rate than does DC-510, less than 0.5 ml/ml vs 2 ml/ml at a dose of 1×10^{10} ergs/gm(C). Data given in Reference 25 for copper phthalocyanine thickened DC-710 indicates the grease to be only moderately affected after an exposure of 1 x 10^{10} ergs/gm(C).

Silicone Lubricant. The recommended radiation tolerance of DC-510 is 8 x 10^{8} ergs/gm(C) based on a 50% increase in viscosity at 100°F.. The recommended radiation tolerance for DC-710, which would probably be an acceptable substitute for DC-510, is 1 x 10^{10} ergs/gm(C) based on an estimated 50% increase in viscosity at 100°F.

4.6.2.2 Halocarbons

Several chlorofluorocarbons (Kel-F 90, Fluorolube Gd 362, Halocarbon 2S-10M) of the Kel-F type are used as lubricants. These are low-molecular weight polymers of chlorotrifluorethylene which are separated into fractions by vacuum distillation. Kel-F brand oils and waxes have been reported (Ref. 26) to have minor changes in viscosity after an exposure of 2 x 10^{10} ergs/gm(C). However, acid numbers had increased markedly. Fluorocarbons have been observed to produce strong, corrosive acids under irradiation (Ref. 24, p. 14); this is in agreement with results reported for Kel-F plastic (Ref. 5, p. 91).

No specific data were found for the Teflon-base lubricants. It should be assumed, however, that the lubricant would have a low radiation tolerance as does the plastic, i.e., 1 x 10^{8} ergs/gm(C).

Halocarbon Grease. The recommended radiation tolerance of Kel-F-base grease is 1 x 10^9 ergs/gm(C). The lubricant is probably usable to higher doses, but the lack of data, particularly on the formation of corrosive products, requires caution in the use of this material in long-duration applications in a radiation environment.

The recommended radiation tolerance for Teflon-base grease is 1 x 10^8 ergs/gm(C) based solely on the low radiation tolerance of Teflon plastic.

4.7 Data Summary for Miscellaneous Materials

4.7.1 Leather

Leather backup rings, similar to those employed in Saturn V applications, performed satisfactorily in an electro-hydraulic servo loop when exposed to 5 x 10^9 ergs/gm(C) (Ref. 5, p. 157). Although leather backup rings can most probably function adequately at higher doses, the recommended radiation tolerance is 5 x 10^9 ergs/gm(C), since experimental data do not exist at higher exposures.

4.7.2 Cork

Two laminated cork board insulation samples were irradiated to an exposure of 6.9 x 10^{10} ergs/gm(C). No physical deterioration was observed at this exposure (Ref. 27, p. 31).

A corkboard material (Insulcork 7326) was irradiated and tested as compression and lap-shear specimens (Ref. 21). The results of tests performed in air after exposures of 5-6 x 10^{10} ergs/gm(C) in air and LH_2 show:

1. Strength at 10% deflection was 46.5% and 89.7% of the air control value for specimens irradiated in air and LH_2, respectively.

2. The shear strength with several different adhesives was 56% to 64% of the air control value for specimens irradiated in air, and 102% to 130% of the air control value for specimens irradiated in LH_2.

Insulcork 7326 tested as a composite with several types of vapor barriers retained from 54% to 67% of its flatwise tensile strength after irradiation to a dose of 7.5 x 10^{10} ergs/gm(C) in air, and from 92% to 106% after an exposure of 8.3 x 10^{10} ergs/gm(C) in LH_2 (Ref. 21).

However, in an irradiation test in which a corkboard laminate was used as insulation on a liquid hydrogen filled dewar (Ref. 21), a detonation occurred in the cork after an exposure of about 1.5 x 10^{10} ergs/gm(C). The rather extensive damage to the insulation was attributed to a detonation of a hydrogen-oxygen mixture initiated by the pressure-induced rupture of a vapor barrier. Hydrogen gas is a radiolytic decomposition product and oxygen (air) is trapped in the cork or any voids.

Based upon this experience, the recommended radiation tolerance of cork is 1 x 10^{10} ergs/gm(C).

V. RADIATION ENVIRONMENT

The cumulative doses required for the Saturn V analyses were calculated by methods which provide a degree of accuracy appropriate to the requirements of this study and which allow the generation of rather extensive and detailed data as economically as possible. The gamma-ray source terms were obtained by representing the Aerojet Nuclear reference data for the full-flow engine (Ref. 4) in terms of a few nonisotropic point sources. Attenuation in liquid hydrogen was calculated by the use of infinite-medium buildup factors derived from moments method data; this method was checked and monitored for accuracy by comparison with calculations based on single scattering with infinite-medium buildup on the second leg.

5.1 Unattenuated Gamma Dose Rates

The Aerojet data on unattenuated gamma dose rates were extended by locating a small set of nonisotropic source points in the vicinity of the reactor core, which, given appropriate directional strengths, reproduced the given isodose curves. The dose rate was assumed to fall off as distance squared along a given direction relative to a source point. A differential analysis shows that for detector positions lying more than 250 in. from the core center the unattenuated dose rate can be attributed to a single nonisotropic source at the core center, with an accuracy of about 20% or better. The unattenuated gamma dose rate ranges from about 6 x 10^7 ergs/gm(C)-h at the tank bottom to about 1 x 10^6 ergs/gm(C)-h at the top of a typical configuration. Figure 5-1 shows isodose rate curves out to several hundred inches from the full-flow NERVA.

5.2 Mission-Integrated Gamma-Ray Doses

5.2.1 Method of Calculation

5.2.1.1 Gamma-Ray Attenuation in LH_2

Figure 5-2 shows a set of arbitrarily normalized points taken from SHADRAC results on gamma-ray attenuation in liquid hydrogen. The squares correspond to a plane fission source. The circles represent the experimentally measured distance-squared weighted dose rate from the reactor (ASTR) situated only 134 cm below the hydrogen surface. The two sets of data are essentially exponential and have nearly the same effective removal coefficient. This comparison shows that gamma-ray dose rate attenuation in an infinite liquid hydrogen medium is rather insensitive to the detailed shape of the incident spectrum, which result is supported by transport-theory considerations for a case where pair production is absent and where the gamma spectrum decreases with increasing energy but is nonvanishing over a fairly extensive range of energy. On the basis of estimated gamma spectra from NERVA at various emergence intervals, it is concluded that the indicated removal coefficient should give

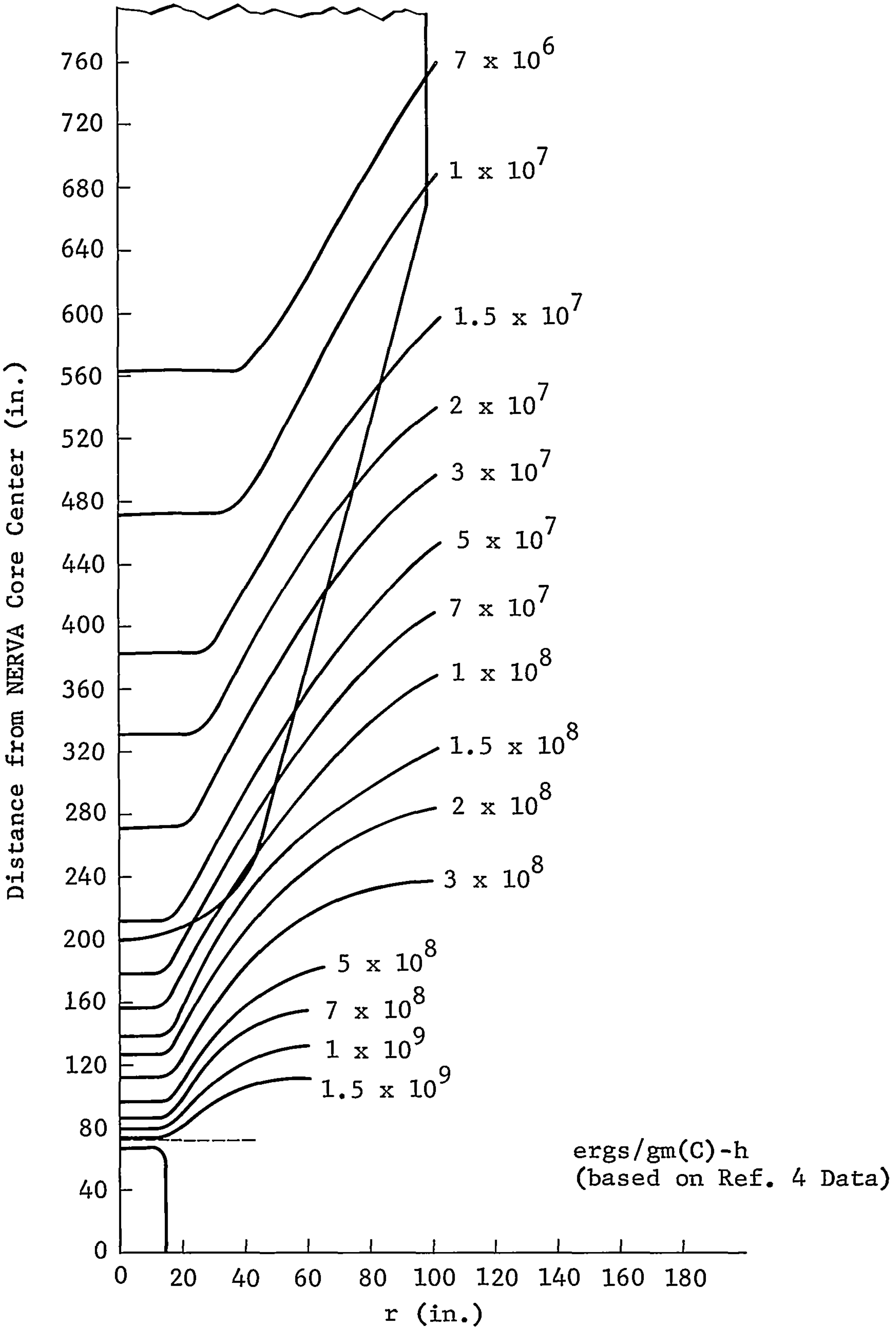


Figure 5-1 Unattenuated Gamma Dose Rates for NERVA Full-Flow Engine

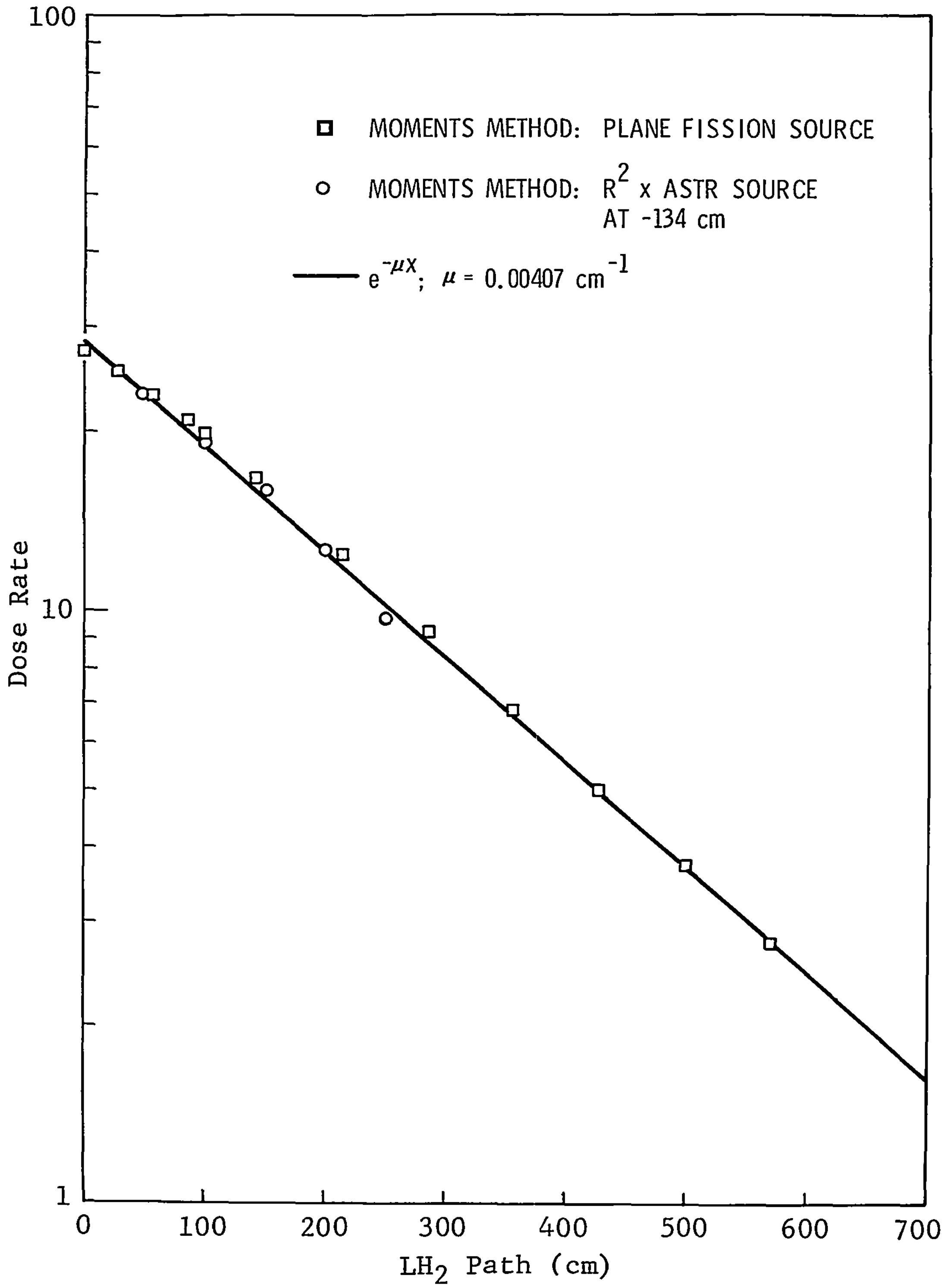


Figure 5-2 Gamma-Ray Attenuation in an Infinite LH_2 Medium

dose rate accuracy to 30% over two decades of gamma attenuation in an infinite medium of liquid hydrogen.

The limitation on the validity of constant removal cross sections in liquid hydrogen derives less from spectral hardening than from the fact that the infinite-medium assumption is not necessarily applicable to large penetrations through small-angle conical volumes. In the case of hydrogen propellant tanks, unattenuated gamma rays reaching the wall at points well above the tank bottom may be scattered in the direction of an on-axis detector-point thereby contributing more dose at that point than would be inferred on the basis of infinite-medium attenuation. However, at detector points not far above the bottom of the tank this "short-circuit" effect is small since the large scattering angles involved imply low differential cross sections and low scattered gamma-ray energies. Calculations based on single scattering with infinite-medium buildup on the second leg show that the under-estimate resulting from the infinite-medium buildup assumption does not exceed 15% in the propellant regions where the cumulative dose is considered to be significant. Hence, the SHADRAC results have been used to describe gamma-ray dose buildup in this study.

5.2.1.2 Mission-Dose Calculation

The derivation of full-flow NERVA radiation levels in the absence of hydrogen attenuation and the application of moments method data to obtain dose rates at a given point in a propellant tank has been described in Section 5.1. In the case of the Saturn V analysis, the essential feature of the cumulative mission-dose calculation is that one must consider the continuous decrease in the amount of hydrogen between the engine and the material location of interest. In general, the accumulated dose depends upon the drain rate and the residual mass. All of the calculations have been based upon an assumed drain rate of 90 lb/sec and an LH_2 residual of 7500 lb. Neutron contributions to material damage appear to be insignificant and will not be discussed here.

It is convenient to divide the mission dose received at a given point into (1) a component accrued before the liquid level drops to the point in question and (2) a component accrued after the liquid level drops below the point. These components are designated, respectively, as the "pre-emergence" dose and the "post-emergence" dose. The pre-emergence dose at a point which is a distance r_o from the vehicle axis and a distance z_o above the core center is given by

$$D_1(r_o,z_o) = \dot{D}_o(r_o,z_o)e^{-\mu s_o}\Delta t_1$$

where $\dot{D}_o$ is the unattenuated dose rate, μ is the effective removal cross section for gamma rays, s_o is the slant path through hydrogen, and Δt_1 is the time required for the liquid to drop from its initial level to the point at z_o. Although the above expression is only valid at points low enough in the tank for infinite medium buildup factors to apply, it has been shown to be adequate for prediction of doses in the range of interest. The dependence of D_1 on drain rate is contained in the pre-emergence exposure time, which is given by

$$\Delta t_1 = t_f - \frac{\rho(LH_2)}{\dot{m}} \int_{z_f}^{z_o} \pi R^2 \, dz$$

where t_f is the total time required for the tank to drain to its residual level, $\rho(LH_2)$ is the density of liquid hydrogen, $\dot{m}$ is the drain rate, z_f is the final residual level, and R is the tank radius at height z.

The post-emergence dose at (r_o, z_o) is given by

$$D_2(r_o,z_o) = D_o(r_o,z_o) \int_{z_o}^{z_f} e^{-\mu s} \frac{dt}{dz} \, dz$$

where dt/dz is the reciprocal of the rate of descent of the LH_2 surface at a given instant, and s is the hydrogen slant path which varies with time according to

$$s(z) = s_o - (z_o - z) \sec \theta \, (r_o, z_o)$$

where z is the level height at a given time and θ is the angle between the vehicle axis and a vector from the core center to (r_o, z_o). The integration is obviated by a transformation that replaces time by distance as the variable of integration. The mass-balance relation

$$\rho(LH_2)\,\pi R^2\,\frac{dz}{dt} = -\,\dot{m}$$

yields

$$\frac{dt}{dz} = \frac{-\rho(LH_2)}{\dot{m}}\,\pi R^2$$

Since R^2 can always be expressed as a polynominal in z, the integral required for the evaluation of $D_2(r_o,z_o)$ can be expressed in closed form. The total dose received at (r_o,z_o) in a single mission is the sum of the pre- and post-emergence doses:

$$D(r_o,z_o) = D_1(r_o,z_o) + D_2(r_o,z_o)\ .$$

Contributions from hydrogen capture gammas and extra-PVRA sources (e.g., the nozzle skirt) have been considered in the calculations, but these rarely account for more than 15% of the total dose.

5.2.2 Mission Dose for 8.5° Tank Configuration

Isodose contours for a 8.5° conical aft bulkhead configuration are shown in Figure 5-3. The values correspond to a single mission in which the initial propellant mass is 290,000 lb, the drain rate is 90 lb/sec and the residual mass is 7,500 lb. The assumed separation between the core center and the tank bottom is 200 in. The mission gamma dose is seen to vary from 5.3×10^7 ergs/gm(C) at the tank bottom to 1×10^4 ergs/gm(C) at an on-axis point 800 in. above the core center. The 8.5° configuration

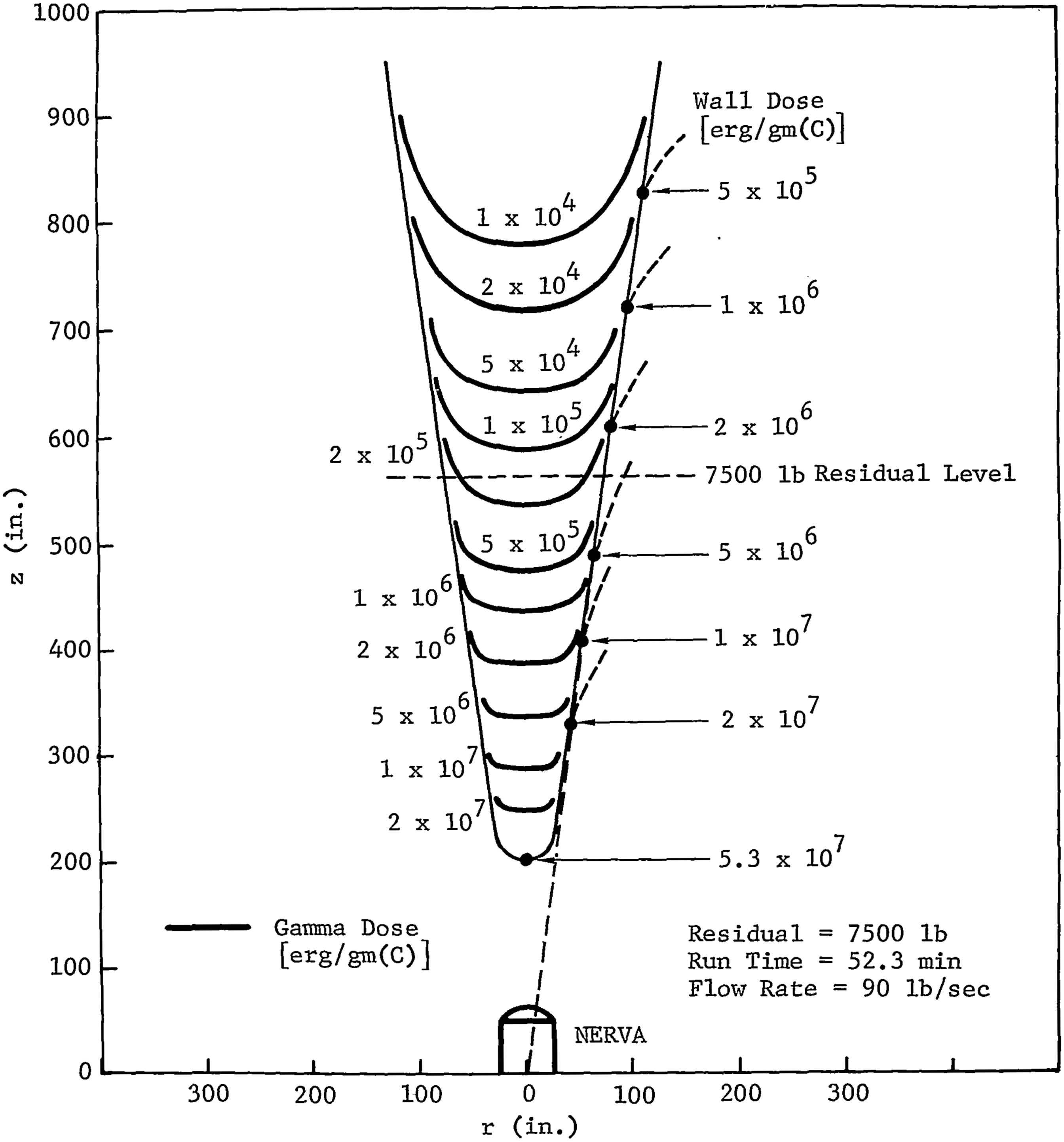


Figure 5-3 Mission Gamma Dose for 8.5-Degree Conical Tank

has the peculiarity that gamma rays from the core impinge on the conical portion of the tank wall without traversing liquid hydrogen. This effect results in a rapid ascent of the isodose curves at interior points near the tank wall. For example, the 2×10^6 ergs/gm(C) isodose contour intersects the axis near z = 400 in. but would intersect the wall near z = 600 in. Because of the relatively strong scattering densities along the wall, the infinite-medium buildup method tends to underestimate the dose at on-axis points. It is estimated that the on-axis dose shown in Figure 5-3 is low by about 20% at z = 800 in. because of this effect.

5.2.3 Mission Dose for 15° Tank Configuration

Isodose contours for a 15° conical aft bulkhead configuration are shown in Figure 5-4. The assumed mission parameters are 290,000-lb propellant mass, 90-lb/sec drain rate, and 7,500-lb residual. The on-axis mission dose at z = 650 in. is about 1.2×10^5 ergs/gm(C) which is twice the corresponding dose for the 8.5° configuration shown in Figure 5-3. The difference is due to the longer post-emergence exposure time in the case of the 15° configuration.

5.2.4 Mission Dose for Hybrid Configuration

Figure 5-5 shows isodose contours for a hybrid configuration in which the engine-module tank has an LH_2 capacity of 10,179 lb. The assumed mission parameters are 290,000-lb propellant mass,

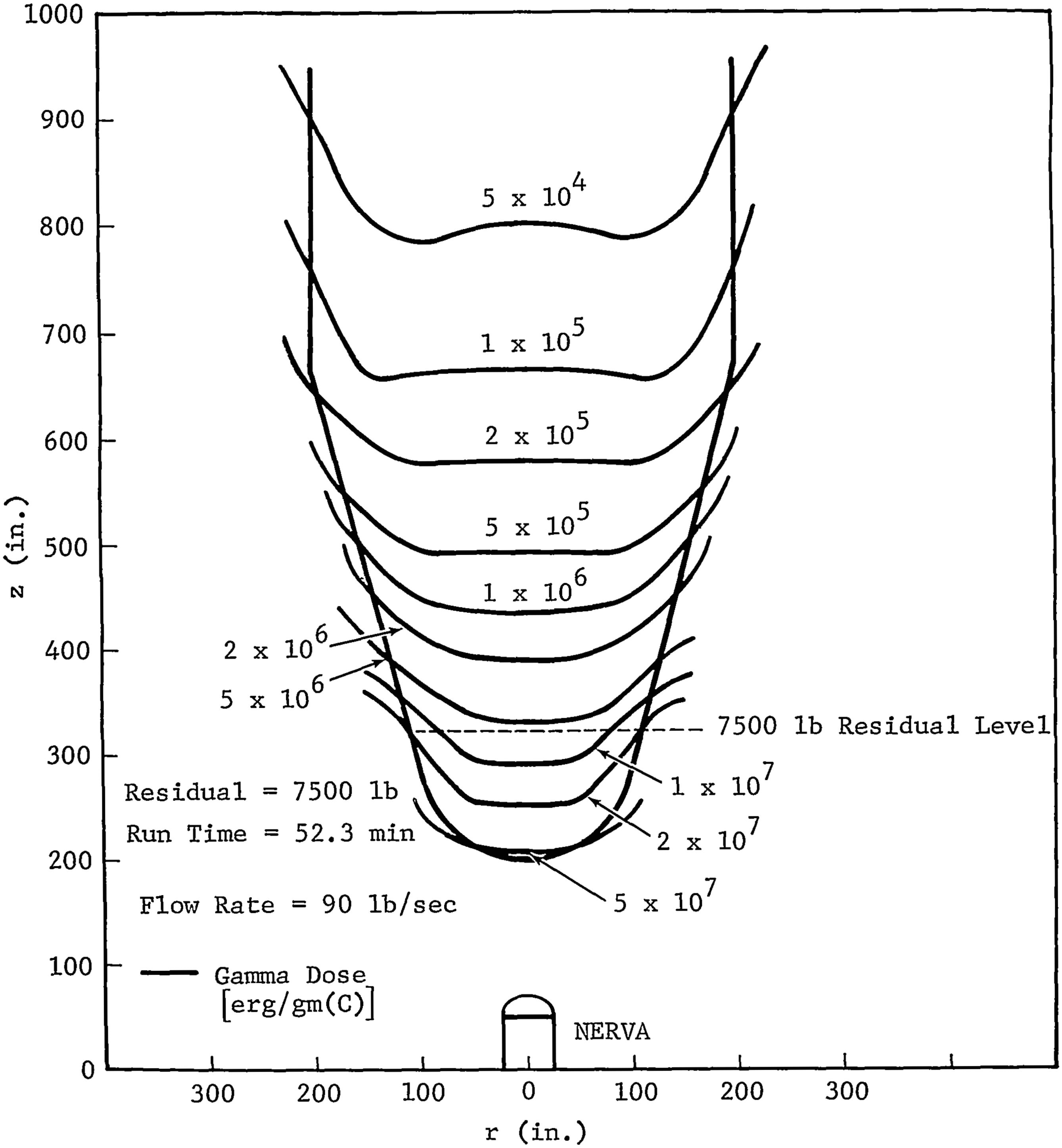


Figure 5-4 Mission Gamma Dose for 15-Degree Conical Tank

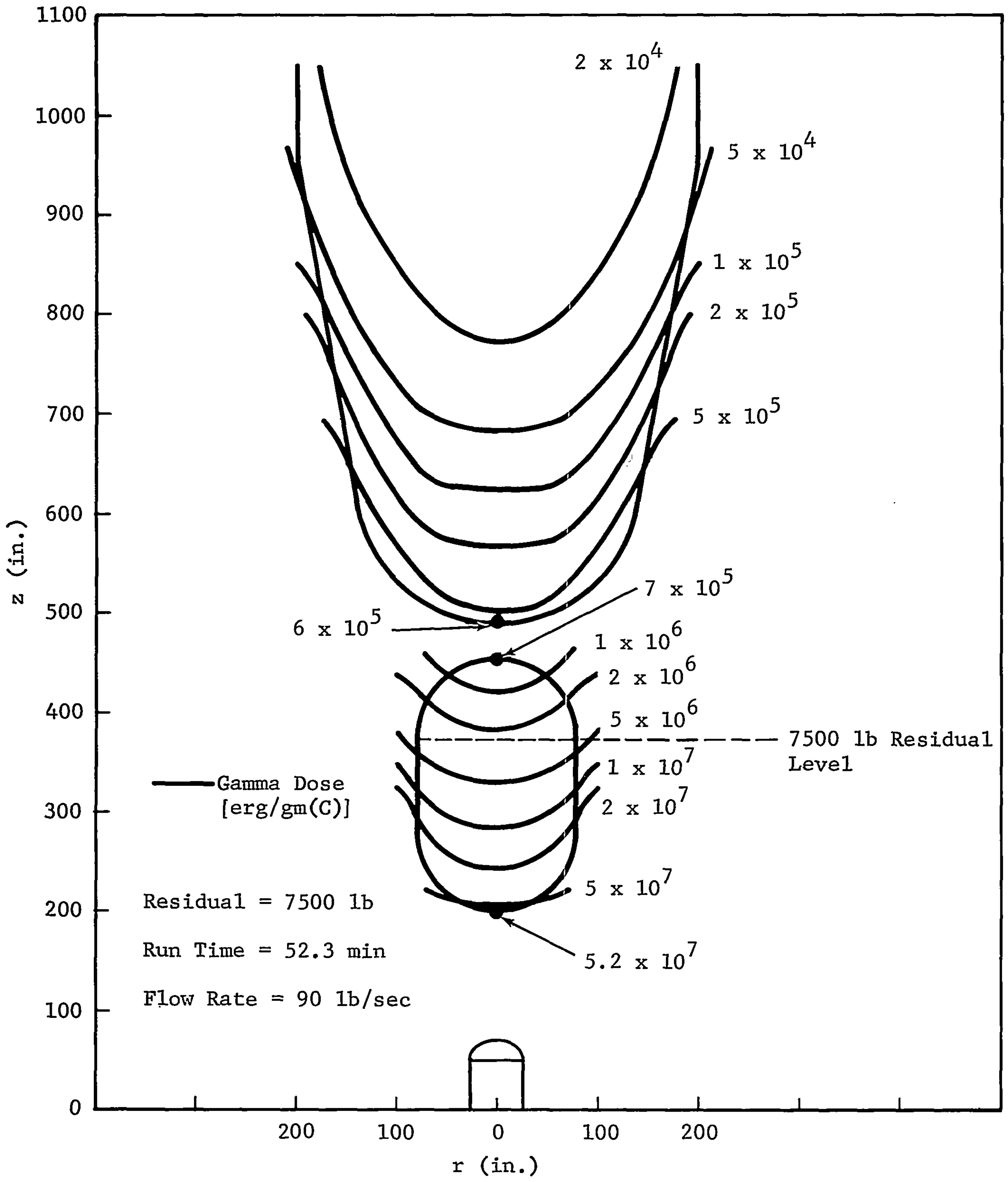


Figure 5-5 Mission Gamma Dose for Hybrid Configuration

90-lb/sec drain rate, and 7,500-lb residual. The on-axis mission dose at z = 650 in. is about 0.8×10^5 ergs/gm(C), which value is greater than the z = 650 in. on-axis dose for the 8.5^o conical configuration (0.5×10^5 ergs/gm(C)) and less than the z = 650 in. on-axis dose for the 15^o conical configuration (1.2×10^5 ergs/gm(C)). However, the z = 650 in. wall dose for the hybrid configuration is 2.5 times as large as the z = 650 in. wall dose for the 15^o conical configuration.

5.2.5 Mission Dose for Propulsion Module

Figure 5-6 shows isodose contours for a 174-in.-diam propulsion module with a liquid hydrogen capacity of 38,380 lb. The assumed drain rate is 90 lb/sec. Since a number of such modules would be employed in a typical mission, two sets of isodose curves have been calculated. The solid curves on the right in Figure 5-6 represent the dose that would be received in a module whose bottom is 200 in. above the core center during the time required for that module to drain from its full liquid hydrogen capacity to a residual mass of 7,500 lb. The dashed curves on the left represent the dose that would be received in a full module located at the same position during the time required for an identical module to drain completely. For a mission involving a total propellant mass of 290,000 lb, eight propulsion modules would be required. The corresponding mission dose at r = 0, z = 650 in. is $2 \times 10^4 + 7(5 \times 10^3) = 5.5 \times 10^4$ ergs/gm(C), an

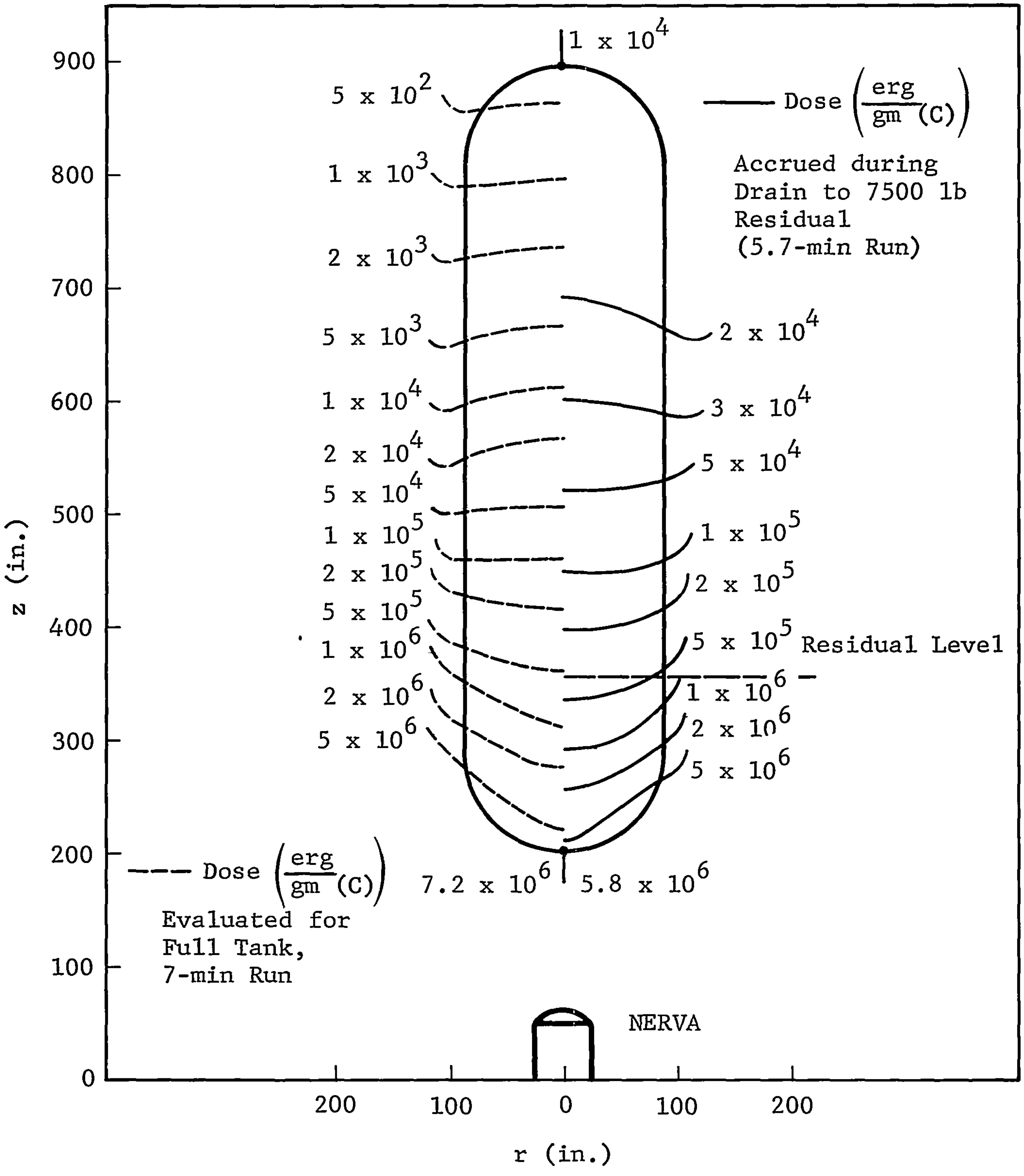


Figure 5-6 Full Tank and Drain-Time-Integrated Doses for Propulsion Module

exposure similar to that obtained in the case of the 8.5° conical configuration.

VI. ANALYSIS OF S-IVB STAGE

The S-IVB stage, which is the third booster stage of the Saturn V system, is approximately 59 feet in length with a stage weight at liftoff of approximately 262,150 pounds. It is powered by a single J-2 engine and is designed with a multiple restart capability, providing 232,000 pounds of thrust at first burn and 211,000 pounds during second burn.

Table 6-1 lists the major systems analyzed and notes the subsection in which the analysis of each appears.

Table 6-1

S-IVB SYSTEMS ANALYZED

System	Drawing	Subsection
Hydraulic	1B62563-505	6.1
Auxiliary Propulsion	1A83918-535	6.2
Propulsion	1A39318-551	6.3
J-2 Engine	103826-2035	6.4
Structures	1A39301-527	6.5
Thermoconditioning	1B38426-539	6.6
Support	1A95641-513	6.7

From the radiation effects standpoint, most of the S-IVB components and subsystems can readily be modified and/or adapted for RNS applications. The recommended substitute materials must also be examined with regards to system compatibility and the specific design requirements of each system or component. It should be noted that all radiation dosages used in the subsequent analyses are based on the unattenuated gamma doses (Fig. 5-1, Sec. V) for 10 hours of engine operation.

In addition to the procedures described in Section III, these additional comments pertaining to the following analyses may be helpful.

Generally, the discussion of each system is in four subsections containing (a) a brief description of the system and the assumed location on the RNS, (b) a summary, usually containing a table giving the evaluation of each subsystem, (c) the main data tables, i.e., the system breakdown to radiation sensitive materials and the recommended modifications, and (d) the discussion of each subsystem.

The tables giving the radiation sensitive components, e.g., Table 6-3, contains a column headed "Critical Application." If the entry in this column is "no," the corresponding entry under "Tolerance" is enclosed in parentheses; the value given, however, is the same as if the application were considered critical. If all radiation sensitive materials listed for a component (or subsystem) are considered noncritical, an asterisk appears under "Tolerance."

The tables giving the recommended modifications, e.g., Table 6-4, have in some cases been shortened by listing only a representative item for material applications which may appear many times in the subsystem. It should be understood that the modification applies to all similar items.

6.1 Hydraulic System

6.1.1 Description and Location

The potential application of S-IVB hydraulic system components to the RNS is unknown since neither the actuation system nor the gimbal system have been defined. In addition, either a hydraulic or pneumatic system may be required for the actuation of various valves.

The hydraulic system (Drawing 1B62563-505) is composed of the main engine pump, two hydraulic actuators, an accumulator, a reservoir, and an auxiliary electric motor pump (in parallel with the main engine pump). The assumed locations of these components are shown in Figure 6-1. The main engine pump receives its oil (MIL-H-5606) from a prepressurized (pneumatic and bootstrap) reservoir through a 3/4-in. steel braid Teflon lined flexible line. The pump output flow to the system is through a 5/8-in. flex line.

The primary function of the hydraulic system is to power two servoactuators which gimbal the J-2 engine. Engine gamballing is accomplished by an independent closed-loop hydraulic system. Gimbal position is proportional to the magnitude of an electrical input to the electrohydraulic servovalve located on each actuator. Mechanical feedback from the actuator to the servovalve completes the closed engine-position loop. During S-IC and S-II stage burns, the actuators hold the engine position to null. This is

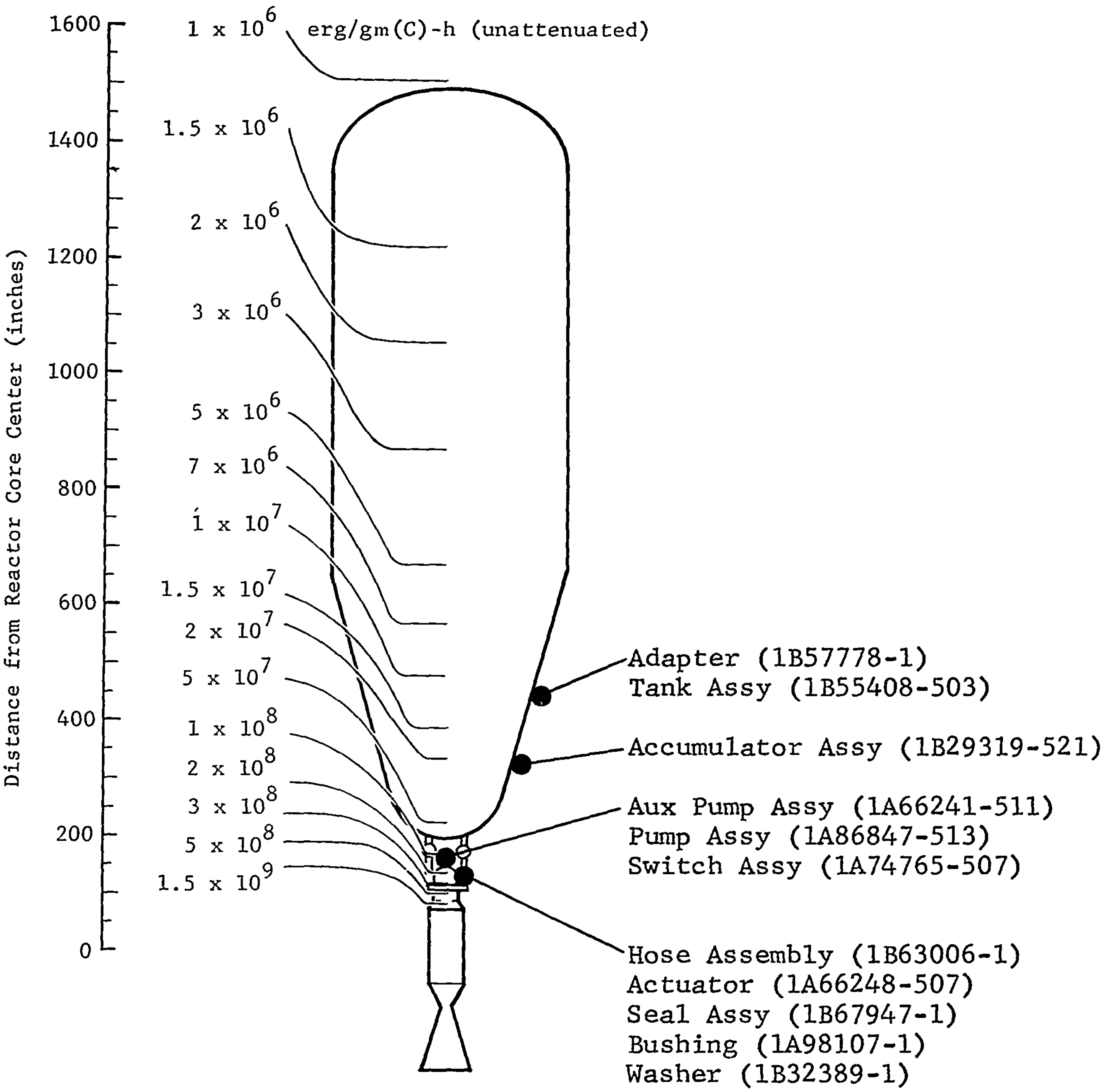


Figure 6-1 Assumed Location of (S-IVB) Hydraulic System Components

accomplished by utilizing the electrically driven auxiliary hydraulic pump. The auxiliary hydraulic pump is also used during orbit to periodically circulate the hydraulic fluid to prevent freezing. During the S-IVB burn, the main hydraulic pump, which is driven by the engine, provides the necessary pressure and circulation for actuator operation (pitch and yaw control). Roll control is provided by the auxiliary propulsion system.

6.1.2 Summary

Based upon analyses presented in Section 6.1.4, it is believed that each of the major components and subsystems of the hydraulic system can be radiation hardened to levels greater than those predicted at the assumed component locations shown in Figure 6-1 Table 6-2 summarizes the predicted nuclear environment and the recommended radiation tolerances of both the basic, i.e., as designed, system and the modified configuration of each subsystem. The recommended modifications and a discussion of resulting improvements are described in Section 6.1.4.

6.1.3 System Breakdown and Recommended Modifications

Drawings, specifications, and parts lists were examined to determine radiation sensitive materials whose performance characteristics might degrade due to the influence of radiation. Table 6-3 lists these materials, describes their applications, and presents for comparative purposes the recommended tolerance for each application and the predicted nuclear environment. Table 6-4

Table 6-2

RADIATION HARDENING SUMMARY — S-IVB HYDRAULIC SYSTEM

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C)) As Designed	Recommended Tolerance (ergs/gm(C)) As Modified	Remarks
Tank assembly	1B55408-503	$3x10^8$	$1x10^9$	$6x10^9$	
Pump assembly	1A86847-513	$1.5x10^9$	$1x10^8$	$1x10^{10}$	
Aux hydraulic pump	1A66241-511	$1.5x10^9$	$1x10^9$	$1x10^{10}$	
Switch assembly	1A74765-507	$1.5x10^9$	$1x10^8$	$1x10^{10}$	
Adapter	1B57778	$3x10^8$	Not critical	--	Modification does not contain organics
Accumulator-Reservoir	1B29319-521	$7x10^8$	$1x10^9$	$1x10^{10}$	
Hose assemblies	1B63006-1 (Typ)	$4x10^9$	$3x10^6$	--	Modification does not contain organics
Actuator assembly	1A66248-507	$4x10^9$	$7x10^6$	Unknown	Dwgs not available for complete analysis
Seal assembly	1B67947-1	$4x10^9$	--	Not required	All metal
Bushing	1A98107-1	$4x10^9$	--	Not required	All metal
Thermal washer	1B32389-1	$4x10^9$	--	Not required	All metal
Hydraulic fluid	MIL-H-5606A	$4x10^9$	$5x10^8$	$5x10^9$	

Table 6-3

RADIATION SENSITIVE COMPONENTS - S-IVB HYDRAULIC SYSTEM (1B62563-505)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
1B55408-503	Tank Assy		--	yes	$3x10^8$	$1x10^9$	
MC266J-xxx		Packing	Silicone rubber	yes		$1x10^9$	
1B31295-1		Valve	--	yes		$1x10^{10}$	P/N 238128-1; TAVCO Inc.
600448		Washer-seal	Teflon TFE	no		$(7x10^6)$	
MC266B-xxx		O-ring seal	Buna N	yes		$1x10^9$	
1B55647-1		Gage	N/R	yes	$3x10^8$	N/R	P/N 6914-760; American Standard
1A86847-513	Pump Assy		--	yes	$1.5x10^9$	$1x10^8$	
MC266B-xx		Packing	Buna N	yes		$1x10^{10}$	
MS28875		Packing	Synthetic rubber	yes		$1x10^{10}$	MIL-P-25732
MS28774		Retainer	Teflon TFE	no		$(7x10^6)$	
MS28777		Backup ring	Leather	no		$(5x10^9)$	
1A92754-501		Valve	--	yes		$1x10^9$	
MS28778		Packing	Synthetic rubber	yes		$1x10^9$	MIL-G-5510
1A74764-501		Switch	--	yes		$1x10^8$	P/N 2627-1-4; United Controls Corp.
--		Wire	Teflon FEP insul.	yes		$1x10^9$	MIL-W-16878/4
--		Potting	Epoxy base	no		$(2x10^{10})$	Stycast 2651
--		Wire	Teflon TFE insul.	yes		$1x10^8$	MIL-W-7139
1A62245-501		Valve	--	yes		$1x10^9$	P/N 2630328; Parker Hannifin
MC266B-xx		O-ring seal	Buna N	yes		$1x10^9$	
MS28775		O-ring seal	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
MS28774		Backup ring	Teflon TFE	no		$(7x10^6)$	
1A66240-505		Pump	--	yes		$8x10^8$	P/N AA-65365-L-S699; Vickers Inc.
331615		Press. control assy	--	yes		$1x10^9$	
151120		Packing	Synthetic rubber	yes		$1x10^{10}$	MIL-P-25732
250196		Backup ring	Teflon TFE	no		$(7x10^6)$	
321712		Pilot valve	N/A	yes		N/A	
151116		Ring seal	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
196168		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
196170		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
195543		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
202933		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
205838		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
206847		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
206851		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
206854		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
206858		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
206861		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
206898		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
206906		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
206915		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
207792		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
215008		Ring seal	Rubber	yes		$5x10^9$	
215034		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
218121		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
218122		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
218123		Ring seal	Synthetic rubber	yes		$1x10^9$	NAS 1593
234918		Ring seal	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
271724		Backup ring	Buna N	no		$(1x10^9)$	
277442		Sealing ring	Buna N	yes		$1x10^9$	
293332		Ring seal	Silicone rubber	yes		$8x10^8$	P/N L-308-8; Parker Seal
297431		Washer	Polyimide	no	$1.5x10^9$	$(3x10^{10})$	VESPEL

Table 6-3 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB HYDRAULIC SYSTEM (1B62563-505)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
297436		Packing	Polyimide	no	1.5×10^9	(2×10^{10})	VESPEL
297437		Packing	Polyimide	no	1.5×10^9	(2×10^{10})	VESPEL
1A66241-511	Hydraulic Pump		--	yes	1.5×10^9	1×10^9	P/N EA 1565-530-11; Vickers Inc.
313952		RF Filter	N/A	yes		N/A	P/N 3545-1; General Design Inc.
MC266B-xx		Packing	Buna N	yes		1×10^{10}	
MC266J-xx		Packing	Silicone rubber	yes		1×10^9	
328440		Pump Assy	--	yes		1×10^9	
MS28774		Retainer	Teflon TFE	no		(7×10^6)	
205595		Packing	Synthetic rubber	yes		6×10^9	NAS 1593
MC266B-xx		Packing	Buna N	yes		1×10^{10}	
MC266J-xx		Packing	Silicone rubber	yes		1×10^9	
612586		Seal, shaft	Synthetic rubber	yes		6×10^9	MIL-R-25897;type 1, class 1
612705		Valve, check	--	yes		1×10^9	P/N 9317; Pneu-draulics
--		O-ring seal	Buna N	yes		1×10^9	MIL-P-25732
612707		Valve, check	--	yes		1×10^9	P/N 9316-1; Pneu-draulics
--		O-ring seal	Buna N	yes		1×10^9	MIL-P-25732
612706		Valve, check	--	yes		1×10^9	P/N 9315; Pneu-draulics
--		Seal	Buna N	yes		1×10^9	MIL-P-25732
612708		Valve, relief	--	yes		1×10^9	P/N 1610; Pneu-draulics
--		Seal	Buna N	yes		1×10^9	MIL-P-25732
612709		Detector, metal	--	no		*	P/N CD7S; Lisle Corp.
--		Seal	Synthetic rubber	no		6×10^9	MIL-R-25897
612887		Valve, relief	--	yes		6×10^9	P/N 402097; Pneu-hydro Valve Corp.
--		Packing	Synthetic rubber	yes		6×10^9	MIL-R-25897
612888		Valve, relief	--	yes		1×10^9	P/N A-63248-1; Vinson Div-Gen Metal Corp.
--		Packing	Silicone rubber	yes		1×10^9	MIL-P-25988
612889		Valve, check	--	yes		1×10^9	P/N A-63245-1; Vinson Div-Gen Metal Corp.
--		Seal	Buna N	yes		1×10^9	MIL-P-25732
612890		Regulator, press.	N/A	yes		N/A	P/N 302073; Pneu-hydro Valve Corp.
612924		Valve, hyd. bleed	--	yes		1×10^9	P/N 1A92754-501; Douglas Acft.
MS28778		Packing	Synthetic rubber	yes		1×10^9	MIL-G-5510
322385		Valve Plate Controls	--	no		*	
MC266B-xx		Packing	Buna N	no	1.5×10^9	(1×10^{10})	
1A74765-507	Switch Assy		--	yes	1.5×10^9	1×10^8	P/N 2627-1-7; United Controls
--		Wire, electrical	Teflon TFE Insul.	yes		1×10^8	MIL-W-7139
--		Wire, electrical	Teflon FEP Insul.	yes		1×10^9	MIL-W-16878/4
--		Potting	Epoxy base	no	1.5×10^9	(2×10^{10})	Stycast 2651
1B57778	Adapter		Teflon TFE	no	3×10^8	(1×10^8)	
1B63006-1(typ.)	Hose Assy		Teflon TFE	yes	4×10^9	3×10^6	
1B29319-521	Accumulator Assy		--	yes	7×10^8	1×10^9	
MC266B-xx		Packing	Buna N	yes		1×10^{10}	
MS28774		Retainer	Teflon TFE	no		(7×10^6)	
MS28775		Packing	Synthetic rubber	yes		1×10^9	
MS28782		Retainer	Teflon TFE	no		(7×10^6)	
Q441-523A		Seal	Rubber	yes		5×10^9	P/N Q-441-523A; Minnesoto Rubber Co.
SR6144-xxx		Backup ring	Teflon TFE	no	7×10^8	(7×10^6)	P/N SR6144-xxx; W. S. Shamban Co.

Table 6-3-(continued)

RADIATION SENSITIVE COMPONENTS - S-IVB HYDRAULIC SYSTEM (1B62563-505)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
1A66244-1		Filter	--	yes	$7x10^8$	$1x10^9$	P/N AC-6543E-5; Aircraft Porous Media Co.
--		O-ring	Silicone rubber	yes		$8x10^8$	
1A88359-1		Retainer	Teflon TFE	no		$(7x10^6)$	
1A92754-501		Valve	--	yes		$1x10^{10}$	
MC266B-xx		Packing	Buna N	yes		$1x10^{10}$	
1B31295-1		Valve	--	yes		$1x10^9$	P/N 238128-1; TAVCO
6000448		Washer - seal	Teflon TFE	no		$(7x10^6)$	
MC266B-xx		O-ring seal	Buna N	yes		$1x10^9$	
1A78153-501		Potentiometer	N/R	no		(N/R)	P/N 9781; Markite Corp.
1B74437-1		Seal	Buna N	yes		$1x10^9$	P/N 523A; Minnesoto Rubber Co.
63856-7/16		Seal	Rubber	yes		$5x10^9$	
1A86746-1		Valve, Relief	--	yes		$1x10^9$	P/N P34-352; James, Pond & Clark
--		Seal	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
1B31296-1		Gage	N/R	yes	$7x10^8$	N/R	P/N 6914-753; American Standard
1A66248-507	Actuator Assy		N/R	yes	$4x10^9$	N/R	P/N 010-49232; Moog Servoactuator
--	Hydraulic Fluid		Petroleum base	yes	$4x10^9$	$5x10^8$	MIL-H-5606A

Table 6-4

RECOMMENDED MODIFICATIONS — S-IVB HYDRAULIC SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Tank Assy							
	MC266J-xx	Packing	Desired	Silicone rubber	1x10^{9}	Polyimide	2x10^{10}
	600448	Washer-seal	Not critical	Teflon TFE	7x10^{6}	Kynar coated metal*	3x10^{10}
	MC266B-xxx	O-ring seal	Desired	Buna N	1x10^{9}	Viton A	6x10^{9}
Pump Assy							
	MS28774 (Typ)	Retainer ring	Not critical	Teflon TFE	7x10^{6}	Polyimide*	3x10^{10}
	MS28778 (Typ)	Packing	Required	Silicone rubber	1x10^{9}	Polyimide	2x10^{10}
	MIL-W-16878/4	Wire, electrical	Required	Teflon FEP insul.	1x10^{9}	Polyimide	1x10^{10}
	MIL-W-7139	Wire, electrical	Required	Teflon TFE insul.	1x10^{8}	Polyimide	1x10^{10}
	151116 (Typ)	Seal	Required	Buna N	1x10^{9}	Kynar	3x10^{10}
	196168 (Typ)	Seal	Desired	Viton A	6x10^{9}	Kynar	3x10^{10}
	215008	Seal	Desired	Rubber	5x10^{9}	Kynar	3x10^{10}
	293332	Seal	Required	Silicone rubber	8x10^{8}	Kynar	3x10^{10}
Hydraulic Pump							
	205595	Packing	Desired	Viton A	6x10^{9}	Polyimide	2x10^{10}
	MC266J-xx (Typ)	Packing	Required	Silicone rubber	1x10^{9}	Polyimide	2x10^{10}
	MS28774	Retainer ring	Not critical	Teflon TFE	7x10^{6}	Polyimide*	3x10^{10}
	612705-x (Typ)	Seal	Required	Buna N	1x10^{9}	Kynar	3x10^{10}
	612586 (Typ)	Seal	Desired	Viton A	6x10^{9}	Kynar	3x10^{10}
Switch Assy							
	MIL-W-7139	Wire, electrical	Required	Teflon TFE insul.	1x10^{8}	Polyimide	1x10^{10}
	MIL-W-16878/4	Wire, electrical	Required	Teflon FEP insul.	1x10^{9}	Polyimide	1x10^{10}
Adapter							
	1B57778	Adapter	Not critical	Teflon TFE	1x10^{8}	Aluminum 2024	--
Hose Assy							
	1B63006 (Typ)	Hose assy	Required	Teflon TFE	3x10^{6}	Aluminum**	--
Accumulator Assy							
	MS28774 (Typ)	Retainer ring	Not critical	Teflon TFE	7x10^{6}	Polyimide*	3x10^{10}
	MS28775	Packing	Desired	Silicone rubber	1x10^{9}	Polyimide	2x10^{10}
	Q441-523A	Seal	Desired	Rubber	5x10^{9}	Kynar	3x10^{10}
	1A66244-x	O-ring	Desired	Silicone rubber	8x10^{8}	Polyimide	2x10^{10}
	600448	Washer-seal	Not critical	Teflon TFE	7x10^{6}	Kynar coated metal*	3x10^{10}
	MC266B-xx	O-ring seal	Desired	Buna N	1x10^{9}	Polyimide	2x10^{10}
	1A86746-1	Seal	Desired	Buna N	1x10^{9}	Kynar	3x10^{10}
Hydraulic Fluid							
	MIL-H-5606A	Hydraulic fluid	Required	Petroleum base	5x10^{8}	Oronite 8515	5x10^{9}

*Use soft metal if possible.
**Weld metal tubing.

gives the modifications recommended to achieve a radiation tolerance level of 1×10^{10} ergs/gm(C).

6.1.4 Radiation Hardening Analysis

6.1.4.1 Tank Assembly

The tank assembly (Drawing 1B55408-503), which contains compressed air for pressurizing the hydraulic fluid accumulator, is considered flight critical since leakage of gas pressurant can degrade the functional response of the actuators, thus compromising the mission.

Although the recommended radiation tolerances for all components and parts considered critical to the functional performance of the tank assembly, with the possible exception of the dial indicator tank pressure gage, are greater than the predicted environment, 3×10^{8} ergs/gm(C), the material replacement modifications described in Table 6-4 are recommended to increase the reliability of the tank assembly, thus providing a more radiation resistant system in the event location in a higher radiation environment is necessary. The recommended modifications increase the recommended radiation tolerance to 1×10^{10} ergs/gm(C).

The dial indicator tank pressure gage (American Standard; P/N 6914-760), which is used during prelaunch ground checks, could not be analyzed due to unavailability of vendor drawings. If the actuation diaphragm (material unknown) develops a leak, the mission could be compromised. Therefore, it might be desirable to incorporate the gage into the ground support equipment and cap this line as well as the charging valve prior to launching the RNS.

6.1.4.2 Hydraulic Pump and Thermal Isolator Assembly

The engine-driven hydraulic pump (Vickers Inc.; P/N AA-65365-L-S699) is incorporated into the thermal isolator assembly (Drawing 1A86847-513). It is mounted on the rocket engine and is driven directly from a main engine turbopump. In order to prevent the extreme temperatures encountered during launch from freezing the pump case oil, thermal isolation of the system is provided between the pump mounting flange and the turbine exhaust manifold dome. Heat is supplied to the main pump by means of the hydraulic fluid circulated by the auxiliary pump.

The recommended radiation tolerance of the engine driven hydraulic pump and thermal isolation assembly, 1×10^8 ergs/gm(C), is well below the predicted gamma environment, 1.5×10^9 ergs/gm(C). The material substitutions described in Table 6-4 increase the recommended limit to 1×10^{10} ergs/gm(C). Drawings and specifications for all components except a pilot valve (P/N 321712) contained in the main pump pressure control assembly were examined in this analysis. No problems can be foreseen in radiation hardening the main hydraulic pump assembly for use in locations where the integrated gamma exposure during its mission lifetime is less than 1×10^{10} ergs/gm(C).

6.1.4.3 Auxiliary Hydraulic Pump

The battery-powered motor-driven auxiliary hydraulic pump assembly (Drawing 1A66241) is utilized in conjunction with the gimbal actuators during S-IC and S-II stage burns to hold the S-IVB engine to null. In addition, it is also used during preflight checkout operations and during orbit to periodically circulate the hydraulic fluid to prevent freezing. It is connected in parallel with the main pump, thus providing a degree of emergency backup for the main pump.

With the exception of the RF filter (General Design Inc.; P/N 3545-1), which minimizes conduction or radiation of radio frequency interference, and the pressure regulator (Pneu-hydro Valve Corp.; P/N 302073), which reduces the pressure of air supplied to the motor, all parts contained in the auxiliary hydraulic pump assembly were analyzed for radiation sensitive materials and applications. Based on this analysis, the recommended radiation tolerance is 1×10^9 ergs/gm(C), which is slightly less than the predicted gamma environment, 1.5×10^9 ergs/gm(C). The modifications described in Table 6-4 increase the recommended tolerance to 1×10^{10} ergs/gm(C).

6.1.4.4 Switch Assembly

The hydraulic system temperature control switch assembly (Drawing 1A74765-507), which is typical of various switch assemblies used throughout the hydraulic system, is a hermetically sealed switch actuated by temperature changes. These thermal switch assemblies are used to sense hydraulic fluid temperature and cycle the auxiliary pump which circulates the hydraulic fluid. The heat rejected from the motor is transferred to the recirculating hydraulic fluid thus preventing it from freezing.

The recommended radiation tolerance of the switch assembly, 1×10^8 ergs/gm(C), is well below the predicted environment of 1.5×10^9 ergs/gm(C). The modifications recommended in Table 6-4, which are required if these switches are to be employed in the RNS environment, increase the recommended radiation tolerance to 1×10^{10} ergs/gm(C).

6.1.4.5 Adapter

The Teflon TFE adapter (Drawing 1B57778) which is used to secure the tank assembly to the structure is not considered critical; however, an aluminum adapter is recommended for this application. This modification would eliminate any potential radiation problem with regards to restraining motion of the tank assembly.

6.1.4.6 Hose Assemblies

Hose assemblies 1B63006-1, 1B63007-1, 1B63008-1, 1B63009-1, 1B63010-1, 1B63071-1, 1B63072-1, and 1B63073-1 transport hydraulic fluid to and from the hydraulic pumps, servovalves, accumulator, etc. These hose assemblies contain an inner tube of Teflon TFE impregnated with carbon black. The recommended radiation tolerance,

3×10^6 ergs/gm(C), which is well below the predicted environment, 4×10^9 ergs/gm(C), is based upon radiation effects tests of similar hoses (Ref. 5, p. 151) in which the hoses failed at exposures of 1×10^7 ergs/gm(C) when pressurized intermittently during irradiation. No elastomeric hoses have been tested that will provide reliable service in the predicted environment. Therefore, it is recommended that hydraulic system components be assembled and welded together with rigid aluminum lines containing expansion joints and bellows to allow the necessary motion between components during transition from earth to space environment. Hydraulic lines should be attached securely to the vehicle structure to minimize flexure and subsequent failure. This modification eliminates any potential problems resulting from irradiation.

6.1.4.7 Accumulator Reservoir

The accumulator reservoir assembly (Drawing 1B29319-521) is basically two systems — a reservoir for collecting hydraulic fluid returned from the hydraulic servoactuator and an accumulator for smoothly actuating the servovalves. During orbit, the accumulator is pressurized whenever the main engine-driven pump or the auxiliary pump is operated.

The radiation hardening analysis for the accumulator reservoir assembly could not be completed due to the unavailability of vendor drawings for the following parts:

Component	P/N	Vendor
Potentiometer, piston position	9781	Markite Corp.
Gage	6914-753	American Standard

The piston position potentiometer is for data instrumentation; therefore, it is not deemed critical to this analysis. The tank pressure gage is used during prelaunch ground test operations when pressurizing the accumulator; therefore, since it is not required for flight operations, the system could be redesigned such that the gage could be incorporated into ground support equipment and the pressurization port could be closed and sealed prior to launch. The modifications recommended in Table 6-4, when coupled with those noted above, results in a subsystem with a recommended radiation tolerance of 1×10^{10} ergs/gm(C), which far exceeds the predicted environment of 7×10^{8} ergs/gm(C).

6.1.4.8 Actuator Assembly

The actuator assembly for gimballing the engines, Moog Servocontrols P/N 010-49232, was not analyzed since vendor drawings could not be obtained. The Specification Control Drawing for this flight-critical assembly, 1A66248, indicates:

1. Each actuator assembly consists of the following subassemblies and components
   a. Hydraulic cylinder
   b. Servovalve
   c. Feedback potentiometer
   d. Fluid filter element
   e. Pre-filtration valve
   f. Piston by-pass valve
   g. Piston position indicator
   h. Bleed and sample valve

2. Elastomeric seals conform to MS28775 (e.g., Buna N), MS28778 (e.g., silicone rubber), MIL G-5510 (e. g., silicone rubber) or MIL-P-25732 (e.g., Buna N). The least radiation stable seal could be silicone rubber which has a radiation tolerance of 8 x 10^8 ergs/gm(C).

3. Teflon backup rings, which have a radiation tolerance of 7 x 10^6 ergs/gm(C), may be used with elastomeric seals.

4. The hydraulic fluid for use in the actuator and in the potentiometer conforms to MIL-H-5606A, which has a radiation tolerance of 5 x 10^8 ergs/gm(C).

5. All wiring conforms to DAC Drawing 7869679 which specifies Teflon TFE insulation. Its radiation tolerance is 1 x 10^8 ergs/gm(C).

Based on this information, the recommended radiation tolerance is no higher than 1 x 10^8 ergs/gm(C) and could be as low as 7 x 10^6 ergs/gm(C). Therefore, it will be required to analyze the vendor drawings and radiation harden this assembly if it is to be employed for RNS applications.

6.1.4.9 Hydraulic Fluid

The hydraulic fluid, which conforms to MIL-H-5606, has a relatively low radiation tolerance, 5 x 10^8 ergs/gm(C). The hydraulic fluid, although satisfactory for a single RNS mission, will not provide the required confidence for the 10-mission life. The recommended replacement fluid, Oronite 8515, conforms to specification MIL-H-8446 and has a radiation tolerance of 5 x 10^9 ergs/gm(C). More recently developed fluids might be more radiation resistant; however, radiation effects testing will be required to establish their recommended limits and their influence upon the design of hydraulic components.

The system should be modified to incorporate a bleed valve in the accumulator-reservoir to vent the radiolytic gases resulting from radiation damage to the hydraulic fluid. The system could be redesigned to include a recirculating system with a storage reservoir in a low radiation environment such that the integrated exposure of the fluid would be less than 2×10^8 ergs/gm(C). Consideration should also be given to a system flushed of all contaminants as part of the periodic maintenance program.

6.2 Auxiliary Propulsion System

6.2.1 Description and Location

The RNS system will include an auxiliary propulsion system (APS) capable of performing functions analogous to those of the S-IVB APS, i.e., attitude control during powered flight in the roll axis, attitude control during coast periods in the pitch, yaw, and roll axes, velocity and course corrections, and possibly for settling of the propellant in the tank before, during, and after each engine operation through the use of a thrust ullage motor.

The S-IVB APS engines are located on the aft end of the S-IVB stage in two modules 180^{o} apart. Each module contains four engines — three 150-lb thrust engines for attitude control and one 70-lb thrust ullage engine. Each APS module contains its own propellant supply and pressurization system. The hypergolic propellants used by the engines are monomethyl hydrazine (MMH) for the fuel and nitrogen tetroxide (N_2O_4) for the oxidizer. Helium is the pressurant in the system.

As shown in Figure 6-2, most of the S-IVB APS components are assumed to be located on the aft skirt where the radiation environment is quite severe. The APS reaction motors might be located on the aft end of the nuclear reactor for more efficient control. If so, the motors will require components with very high radiation tolerances as well as radiation resistant electrical wiring

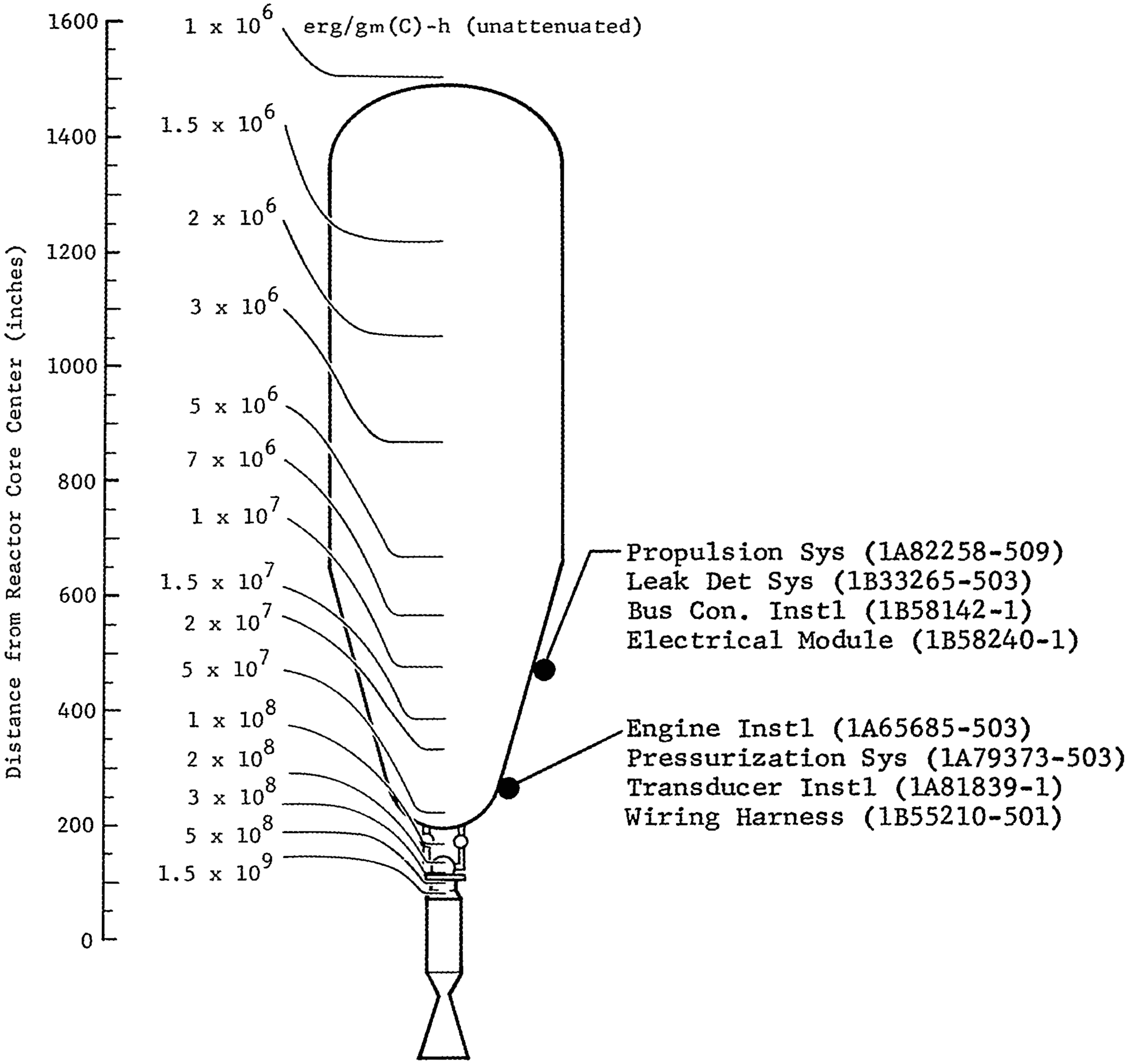


Figure 6-2 Assumed Location of (S-IVB) Auxiliary Propulsion System Components

and propellant piping for connecting control equipment and propellant storage with the motors.

6.2.2 Summary

All APS subsystems and components analyzed can be radiation hardened by material substitution and/or minor design changes, thus providing a high degree of confidence in their performance in the assumed environment. Table 6-5 summarizes the recommended radiation tolerance of both the basic and modified configurations. These limits can readily be compared with the predicted environment which is also presented in Table 6-5.

Radiation tolerances must be determined for both the propellant and oxidizer if they are to be stored in the vicinity of the APS engines. The test program recommended to obtain these data is discussed in Section II.

6.2.3 System Breakdown and Recommended Modifications

The radiation sensitive materials and components contained in the S-IVB auxiliary propulsion system are listed in Table 6-6. The recommended modifications for radiation hardening these components and subsystems and the resulting improvements are presented in Table 6-7. The basis for these recommendations and the radiation effects analyses for each subsystem are discussed in detail in Section 6.2.4.

Table 6-5

RADIATION HARDENING SUMMARY — S-IVB AUXILIARY PROPULSION SYSTEM

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))		Remarks
			As Designed	As Modified	
Engine installation	1A65686-503	$1x10^9$	$7x10^6$	Unknown	Dwgs not available for complete analysis
Pressurization	1A74373-503	$1x10^9$	$7x10^6$	$2x10^{10}$	
Transducer instl	1A81839-1	$1x10^9$	$7x10^6$	$1x10^{10}$	
Transducer instl	1A81840-1	$1x10^9$	$7x10^6$	$1x10^{10}$	
Propulsion	1A82258-509	$2x10^8$	$7x10^6$	$1x10^{10}$	
Leak detection	1B33265-503	$2x10^8$	$7x10^6$	Not required	Not considered critical
Bus connector	1B58142-1	$2x10^8$	$1x10^8$	$1x10^{10}$	
Electrical module	1B58240-1	$2x10^8$	$1x10^{10}$	Not required	
Wiring harness	1B55210-501 (Typ)	$1x10^9$	$1x10^8$	$1x10^{10}$	

Table 6-6

RADIATION SENSITIVE COMPONENTS - S-IVB AUXILIARY PROPULSION SYSTEM (1A83918-535)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
1A65685-503	Engine Instl		--	yes	$1x10^9$	$7x10^6$	
1B63088-1		Retainer	Epoxy laminate	yes		$2x10^{10}$	MIL-R-9300, Type I
210005		Engine Assy	--	yes		N/R	
19-557131-2		O-ring	N/R	yes		N/R	P/N 19-557131-2; Plastic & Rubber Prod.
2-432-V377-9		O-ring	Buna N	yes		$1x10^9$	P/N 2-432-V377-9; Parker Seal
1A39597-513		Engine	N/R	yes		N/R	P/N 700800-06; TRW Inc.
S0046T260		Gasket	Teflon TFE	yes		$7x10^6$	
S0139T4		Gasket	Teflon TFE	yes		$7x10^6$	
1P20056		Lubricant	Perfluorinated aliphatic	no		$(1x10^8)$	1P20056
1P20040		Primer	Silicone base	no		$(1x10^{10})$	1P20040
9709143		Sealant	Silicone base	yes		$8x10^8$	
--		Tape	Polyester backing	no	$1x10^9$	$(2.3x10^9)$	STD L-T-100
1A79373-503	Pressurization Sys		--	yes	$1x10^9$	$7x10^6$	
MS28778		Packing	Synthetic rubber	yes		$1x10^9$	MIL-G-5510
S0046T-xx		Gasket	Teflon TFE	yes		$7x10^6$	
S0139T-xx		Gasket	Teflon TFE	yes		$7x10^6$	
1A49998-xxx		Module	N/R	yes		N/R	P/N A62445-xxx; Vinson Mfg.
1A67912		Valve	--	yes		$7x10^6$	P/N A-63077; Vinson Mfg.
D63077-7		Poppet seal	N/A	yes		N/A	
D63077-9		Seal	N/A	yes		N/A	
S-10055		Tefloc insert	Teflon TFE	no		$(3x10^7)$	
MGC60778C-2A		Face coated gasket	Teflon TFE coated	no		$(1x10^8)$	
2118-016		O-ring	Teflon TFE	yes		$7x10^6$	P/N 2118-016; Parco
1B33382-1		Gasket	Synthetic rubber	yes		$1x10^9$	MIL-STD 417; Type R; class RS
1B51334-1		Insulator	Phenolic laminate	no		$(2x10^{10})$	
1B54601-505		Regulator	N/A	yes		N/A	P/N 65-185-5; Fairchild Hiller
1B58239-1		Vent seal	Kel-F	yes		$1x10^9$	
1B66755-xxx		Spacer	Phenolic laminate	no	$1x10^9$	$(2x10^{10})$	MIL-R-79; Form R; Type FBG
1A81839-1	Transducer Instl		--	no	$1x10^9$	*	
S0139T4		Gasket	Teflon TFE	no		$(7x10^6)$	
1A88035-505		Transducer	N/R	no		(N/R)	P/N PS601A-5; Genisco Tech. Corp.
1P20056		Lubricant	Perfluorinated aliphatic	no	$1x10^9$	$(1x10^8)$	1P20056
1A81840-1	Transducer Instl		--	no	$1x10^9$	*	
S0046T-xx		O-ring	Teflon TFE	no		$(7x10^6)$	
1B31377-1		Transducer	--	no		*	P/N 2091-3701; Servionic Instr.
--		Insulation, electrical	Diallyl phthalate	no		$(2x10^{10})$	
--		Potting	Epoxy base	no		$(2x10^{10})$	Stycast 2651; Emerson & Cuming
--		Wire, electrical	Teflon TFE insul.	no		$(1x10^8)$	
--		Lubrication	Silicone oil	no		$(8x10^8)$	DC510; Dow Corning
1A67863-xxx		Transducer	N/R	no		(N/R)	P/N 2448-xx; Genisco Tech Corp.
1A72913-567		Transducer	N/R	no		(N/R)	P/N 451319L-1; Giannini Controls Corp.
1B31413-1		Transducer	--	no		*	P/N 2091-4001; Servionic Instr.
--		Insulation, electrical	Diallyl phthalate	no		$(2x10^{10})$	
--		Potting	Epoxy base	no		$(2x10^{10})$	Stycast 2651; Emerson & Cuming
--		Wire, electrical	Teflon TFE insul.	no		$(1x10^8)$	
--		Lubrication	Silicone oil	no	$1x10^9$	$(8x10^8)$	DC510; Dow Corning

Table 6-6 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB AUXILIARY PROPULSION SYSTEM (1A83918-535)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
1A82258-509	Propulsion Sys Instl		--	yes	$2x10^8$	$7x10^6$	
S0046S333		O-ring	Silicone rubber	yes		$8x10^8$	
S0046T-xx		O-ring	Teflon TFE	yes		$7x10^6$	
S0139T-xx		Gasket	Teflon TFE	yes		$7x10^6$	
S0513-4-08-38		Spacer	Nylon	no		$(3x10^9)$	Mil-P-17091
1A49422-xxx		Module	N/R	yes		N/R	P/N 219040-xx; Wallace O. Leonard Co.
1B33382-xxx		Gasket	Synthetic rubber	yes		$1x10^9$	MIL-STD-417; Type R; Class RS
1P20056		Lubricant	Perfluorinated ali.	no		$(1x10^8)$	1P20056
--		Tape	Teflon TFE backing	no		$(2x10^7)$	MIL-T-23594
1B30493-xxx		Bracket	Phenolic laminate	no		$(2x10^{10})$	
1B30494-xxx		Bracket	Phenolic laminate	no		$(2x10^{10})$	
1B61416-xxx		Bracket	Phenolic laminate	no		$(2x10^{10})$	
1B61417-1		Bracket	Phenolic laminate	no	$2x10^8$	$(2x10^{10})$	
1B33265-503	Leak Detector Sys		--	no	$2x10^8$	*	
S0139T2		Gasket	Teflon TFE	no		$(7x10^6)$	
1B58239-1		Vent seal	Kel-F	no		$(1x10^9)$	
		Lubricant	Perfluorinated aliphatic	no	$2x10^8$	$(1x10^8)$	1P20056
1B58142-1	Bus Connector Instl		--	yes	$2x10^8$	N/R	
1B29862-1		Module	N/R	yes	$2x10^8$	N/R	
1B58240-1	Electrical Module		--	yes	$2x10^8$	$1x10^{10}$	
1B57771-559		Connector	--	yes		$1x10^{10}$	P/N 46011-22-55P-2; Deutsch
1P20016		Potting	Polyurethane	yes		$1x10^{10}$	1P20016
1P20066		Primer	Synthetic rubber base	no	$2x10^8$	$(1x10^{10})$	1P20066
1B55210-501	Wiring Harness		--	yes	$1x10^9$	$1x10^8$	
1B58284-1		Wiring Harness	--	yes		$1x10^8$	
MS3116E8-45		Connector	--	yes		*	
MS3420		Bushing	Rubber	no		$(1x10^{10})$	MIL-STD-417; Class RN
PT060E12-8S		Connector	--	yes		$1x10^9$	P/N PT060E12-8S; Bendix Corp.
--		Insert	Silicone rubber	yes		$1x10^9$	
S0286Exx (Typ)		Connector	--	yes		$1x10^9$	
--		Insert	Silicone rubber	yes		$1x10^9$	
--		Tubing	Irradiated polyolefin	no		$(3x10^9)$	MSFC-SPEC-276; Type 1, class 1
--		Tape	Reinforced polyester	no		$(2x10^9)$	PPP-T-66; Type 1, class B
--		Tape	Waxed nylon	no		$(3x10^9)$	
7869679		Wire	Teflon TFE insul.	yes		$1x10^8$	
1B67267-1		Wiring Harness	--	yes		$1x10^8$	
MS3116E8-4S		Connector	--	yes		*	
MS3420		Bushing	Rubber	no		$(1x10^{10})$	MIL-STD-417; Class RN
S0280Exx (Typ)		Connector	--	yes		$1x10^9$	
--		Insert	Silicone rubber	yes		$1x10^9$	
1B54522-501		Module	--	yes		$1x10^8$	
MSFC-SPEC-222		Potting	Epoxy base	no		$(2x10^{10})$	MSFC-SPEC-222 (type IV)
7869679		Wire	Teflon TFE insul.	yes		$1x10^8$	
MSFC-SPEC-276		Tubing	Irradiated polyolefin	no		$(3x10^9)$	MSFC-SPEC-276 (type I, class 2)
MIL-T-713		Tape	Waxed nylon	no		$(3x10^9)$	
7869679		Wire	Teflon TFE insul.	yes	$1x10^9$	$1x10^8$	

Table 6-7

RECOMMENDED MODIFICATIONS — S-IVB AUXILIARY PROPULSION SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Engine Installation							
	19-557131-2	O-ring	Desired	Unknown	?	Polyimide	$2x10^{10}$
	S0046T260	Gasket	Desired	Teflon TFE	$7x10^{6}$	Kynar*	$3x10^{10}$
	S0139T4	Gasket	Desired	Teflon TFE	$7x10^{6}$	Kynar*	$3x10^{10}$
	9709143	Sealant	Required	Silicone rubber	$8x10^{8}$	Polyimide	$2x10^{10}$
	--	Tape	Not critical	Polyester backing	$2x10^{9}$	Rubber/glass	$1x10^{10}$
	1P20056	Lubricant	Not critical	Perfluorinated aliphatic	$1x10^{8}$	Dry film MoS_2	$1x10^{11}$
Pressurization System							
	MS28778	Packing	Required	Silicone rubber	$1x10^{9}$	Polyimide	$2x10^{10}$
	S0046T-xx	Gasket	Desired	Teflon TFE	$7x10^{6}$	Kynar*	$3x10^{10}$
	S0139T-xx	Gasket	Desired	Teflon TFE	$7x10^{6}$	Kynar*	$3x10^{10}$
	D63077-x	Seal	Required	Unknown	?	Kynar	$3x10^{10}$
	S-10055	Insert	Not critical	Teflon TFE	$3x10^{7}$	Polyimide*	$3x10^{10}$
	2118-016	O-ring	Required	Teflon TFE	$7x10^{6}$	Polyimide	$2x10^{10}$
	1B33382	Gasket	Required	Silicone rubber	$1x10^{9}$	Kynar*	$3x10^{10}$
	1B58239	Vent seal	Required	Kel-F	$1x10^{9}$	Kynar	$3x10^{10}$
	MGC60778C-2A	Face coated gasket	Not critical	Teflon TFE coated	$1x10^{8}$	Kynar coated*	$3x10^{10}$
Transducer Installations							
	S0139T4	Gasket	Desired	Teflon TFE	$7x10^{6}$	Kynar*	$3x10^{10}$
	S0046T-xx	O-ring	Desired	Teflon TFE	$7x10^{6}$	Polyimide	$2x10^{10}$
	1P20056	Lubricant	Not critical	Perfluorinated aliphatic	$1x10^{8}$	Dry film MoS_2	$1x10^{11}$
	--	Wire	Not critical	Teflon TFE	$1x10^{8}$	Polyimide	$1x10^{10}$
	DC510	Lubricant	Not critical	Silicone base	$8x10^{8}$	DC710	$1x10^{10}$
Propulsion System Installation							
	S0046S333	O-ring	Desired	Silicone rubber	$8x10^{8}$	Polyimide	$2x10^{10}$
	S0046T-xx	O-ring	Desired	Teflon TFE	$7x10^{6}$	Polyimide	$2x10^{10}$
	S0139T-xx	Gasket	Desired	Teflon TFE	$7x10^{6}$	Kynar*	$3x10^{10}$
	1B33382	Gasket	Desired	Silicone rubber	$1x10^{9}$	Kynar*	$3x10^{10}$
	--	Tape	Not critical	Teflon TFE	$2x10^{7}$	Rubber/glass	$1x10^{10}$
	1P20056	Lubricant	Not critical	Perfluorinated aliphatic	$1x10^{8}$	Dry film MoS_2	$1x10^{11}$
Leak Detection System							
	S0139T2	Gasket	Not critical	Teflon TFE	$7x10^{6}$	Kynar*	$3x10^{10}$
	1B58239	Vent seal	Not critical	Kel-F	$1x10^{9}$	Kynar	$3x10^{10}$
	1P20056	Lubricant	Not critical	Perfluorinated aliphatic	$1x10^{8}$	Dry film MoS_2	$1x10^{11}$
Wiring Harness							
	PT060E12	Connector, insert	Required	Silicone rubber	$1x10^{9}$	Vitreous glass**	--
	--	Tape	Not critical	Waxed nylon	$1x10^{9}$	Rubber/glass	$1x10^{10}$
	MSFC-SPEC-276	Tubing	Not critical	Irrad. polyolefin	$3x10^{9}$	Rulon	$1x10^{10}$
	786979	Wire	Required	Teflon TFE	$1x10^{8}$	Polyimide	$1x10^{10}$
	--	Tape	Not critical	Polyester	$2x10^{9}$	Rubber/glass	$1x10^{10}$

*Use soft metal if possible.
**Specify connectors with glass inserts.

6.2.4 Radiation Hardening Analysis

6.2.4.1 Engine Installation

The radiation tolerance of the engine installation subsystem, which includes the engine assemblies (Dwg 1A65685-503), could not be accurately determined due to the unavailability of drawings, specifications, and list of materials pertaining to the bipropellant reaction motors (Thompson-Ramo-Woolridge Inc.; P/N 700800-06). Information was requested of the vendor; however, data were not received during the preparation of this report. Examination of the Specification Control Drawing for these engines (Drawing 1A39597) indicates:

1. Wiring conforms to Douglas Specification 7869679, i.e., Teflon TFE insulated wire which has a recommended tolerance of 1×10^8 ergs/gm(C).
2. The potting compound is Scotchcast XR-5038, an epoxy base material which has a recommended tolerance of 2×10^{10} ergs/gm(C).
3. Lubricants used are in accordance with specification 1P20112 for antigalling grease.

Therefore, the recommended radiation tolerance of the basic system can be no higher than 1×10^8 ergs/gm(C) and it will require radiation hardening. Although the engine assembly drawings could not be analyzed, it is believed that it can be radiation hardened to 1×10^{10} ergs/gm(C) by specifying (1) polyimide insulated wire, (2) electrical connectors with ceramic inserts, and (3) usage of Kynar seals, gaskets, etc. The other components included in the engine installation can readily be hardened to tolerances greater than 1×10^{10} by utilizing Kynar gaskets and O-rings.

6.2.4.2 Pressurization System

All of the components of the pressurization system (Dwg 1A79373-503) could not be analyzed due to the unavailability of drawings, specifications, and list of materials for the pressurization control module (Vinson Manufacturing Co.; P/N A62445) and regulator assembly (Fairchild Hiller; P/N 65-185-5). The other components contained in this system have a very low recommended tolerance, 7×10^6 ergs/gm(C), and will require radiation hardening.

Examination of the Specification Control Drawing for the low pressure helium module (Drawing 1A49998) indicates:

1. The module contains a double-coil, solenoid operated dump valve and a relieve valve.

2. Wiring conforms to Douglas Specification 7869679, i.e., Teflon TFE insulation which has a recommended radiation tolerance of 1×10^8 ergs/gm(C).

3. Connectors conform to Bendix Corp. P/N PT1H-8-3P which have a silicone rubber O-ring; this does not limit its usage in a radiation environment.

Assuming that the pressurization control module and the pressure regulator assemblies can be radiation hardened by techniques similar to those outlined for analogous components of the J-2 engine pressurization system (Sec. 6.4.4.4), the modifications described in Table 6-7 will increase the recommended radiation tolerance from 7×10^6 ergs/gm(C) to 1×10^{10} ergs/gm(C); this is a factor of ten higher than the predicted environment.

6.2.4.3 Transducer Installations

Transducer installation 1A81839-1, which measures pressure in the APS engines, and transducer installation 1A81840-1, which measures both temperature and pressure, are employed primarily as diagnostic instrumentation.

Vendor drawings could not be obtained for the following transducers:

P/N	Manufacturer	S.C.D.	Description
PS601A-5	Genisco Tech. Corp.	1A88035	Pressure Transducer
2448	Genisco Tech. Corp.	1A67863	Variable Resistance Temperature Transducer
451319-L	Giannini Controls Corp.	1A72913	Absolute Pressure Transducer

Examination of the Specification Control Drawing for the high-frequency DC-DC pressure transducer, 1A88035, indicates:

1. The pressure transducer system consists of a strain-gage sensor and a solid-state amplifier connected by a cable assembly.

2. The cable assembly uses Teflon FEP insulated wire (Specification MIL-W-16878/4) which has a recommended tolerance of 1×10^9 ergs/gm(C). The cable jacket is Teflon TFE.

3. The electrical connectors, Bendix Corp. P/N PT06-12-10S, contain a silicone rubber insert which has a recommended tolerance of 1×10^9 ergs/gm(C).

Since the solid state amplifier probably has a low radiation tolerance and material substitutions will not suffice, it cannot be located near the sensor; therefore, this transducer design is not recommended for RNS applications.

Examination of the Specification Control Drawing for the potentiometer-type absolute pressure transducer, 1A72913, indicates:

1. The pressure transducer consists of a pressure sensitive bellows which actuates a precision potentiometer.

2. The electrical connectors, Bendix Corp. P/N PT06E-8-4S, contain a silicone rubber insert which has a radiation tolerance of 1×10^9 ergs/gm(C).

Based on the above information, it is believed that material substitutions can improve the radiation tolerance of this transducer to at least 1×10^{10} ergs/gm(C).

Examination of the Specification Control Drawing for the variable-resistance temperature transducer, 1A67863, indicates that the sensing element is pure platinum wire wound on a ceramic bobbin. The electric connections are made through a Bendix Corp. connector, P/N PT1H-8-4P, having a silicone rubber O-ring which does not limit its usage in a radiation environment. Based on this information, the RTT is believed to be radiation resistant and can readily be used at exposures below 2×10^{10} ergs/gm(C).

The modifications recommended in Table 6-7, when coupled with the above recommendations should result in a system capable of reliable operation in gamma environments of up to 1×10^{10} ergs/gm(C).

6.2.4.4 Propulsion System Installation

The performance of the components required for the propulsion system installation (Dwg 1A82258-509) is critical to the operation of the APS. The recommended radiation tolerance of the as-designed system could not be accurately determined due to the unavailability of drawings, etc. of the propellant control module (Wallace O. Leonard; P/N 219040), which is the nucleus of the propulsion system installation. Review of the Specification Control Drawings for the propellant control module indicates:

1. The module, which controls the fill and purge of oxidizer and fuel, contains two check valves, one filter, and two solenoid valves.

2. The connectors for the solenoid operated valves are manufactured by Deutsch Company (P/N DTKIH-8-3P-034).

3. Wiring is in accordance with Douglas Specification 7869678, i.e., Teflon TFE insulated wire which has a recommended tolerance of 1×10^8 ergs/gm(C).

Based on the above information, it is believed that the propellant control module can be radiation hardened by material substitutions such that it can reliably function in nuclear environments up to exposures of 1×10^{10} ergs/gm(C).

The recommended radiation tolerance of the basic propulsion system installation appears to be limited to 1×10^8 ergs/gm(C) by the Teflon TFE insulated wire used in the propellant control module. The modifications described in Table 6-7 for the interfacing gaskets and O-rings in conjunction with hardening the propellant control module should result in a system with a recommended tolerance of 1×10^{10} ergs/gm(C), which is well above the predicted environment, 2×10^{8} ergs/gm(C).

6.2.4.5 Leak Detection System Installation

The components required for the installation of the leak detection system installation (Dwg 1B33265-503) which contain organic materials are not considered critical to the auxiliary propulsion system. Although the recommended radiation tolerance of these components is greater than the predicted environment, 2×10^{8} ergs/gm(C), the modifications described in Table 6-7 are recommended to increase the reliability of the system.

6.2.4.6 Bus Connector Installation

The recommended radiation tolerance of the bus connector installation (1B58142-1) could not be determined due to the unavailability of drawings, etc. of the bus connector module (Dwg. 1B29862). However, it is believed to contain Teflon TFE insulated wires which would limit its recommended tolerance to 1×10^{8} ergs/gm(C), which is less than the predicted environment of 2×10^{8} ergs/gm(C). Substitution of polyimide insulated wires should increase the recommended tolerance of the bus connector installation to 1×10^{10} ergs/gm(C).

6.2.4.7 Electrical Module

The electrical module, which is basically a mounting plate containing a connector, has a radiation tolerance of 1×10^{10} ergs/gm(C). Since this recommended limit is far in excess of the predicted environment, 2×10^{8} ergs/gm(C), this subsystem can be utilized for RNS application without modification.

6.2.4.8 Wiring Harnesses

The recommended radiation tolerance of wiring harness installations, similar to Drawing 1B55210-501, are limited by the usage of Teflon TFE insulated wire which has a recommended tolerance of only 1×10^{8} ergs/gm(C). The modifications described in Table 6-7, which include usage of polyimide insulated wires and electrical connectors with ceramic inserts, increases the tolerances of wiring installations to 1×10^{10} ergs/gm(C).

6.3 Propulsion System

6.3.1 Description and Location

The propulsion system is the heart of the S-IVB, and all systems function in support of its successful operation. The propulsion system for the AS-512 vehicle, i.e., the one selected for analysis in this study, is of the configuration defined by Drawing 1A39318-551. It contains the subsystems listed in Table 6-8 as well as the J-2 engine described in Section 6.4. A description of each subsystem and its radiation effects analysis are contained in Section 6.3.4. Many of the S-IVB propulsion system components and subsystems have potential for RNS use.

The assumed locations for each subsystem are shown in Figure 6-3.

6.3.2 Summary

Based upon analyses presented in Section 6.4.4 for the J-2 engine and the analyses presented in Section 6.3.4 for all other subsystems of the S-IVB propulsion system, it is believed that each of the major components and subsystems can be radiation hardened to reliably function in nuclear environments more severe than those predicted at the assumed component locations shown in Figure 6-3. Table 6-8 summarizes the predicted nuclear environment and the recommended tolerances for both the basic system and the modified configuration of each subsystem. The recommended modifications and the resulting improvements are discussed in Section 6.3.4.

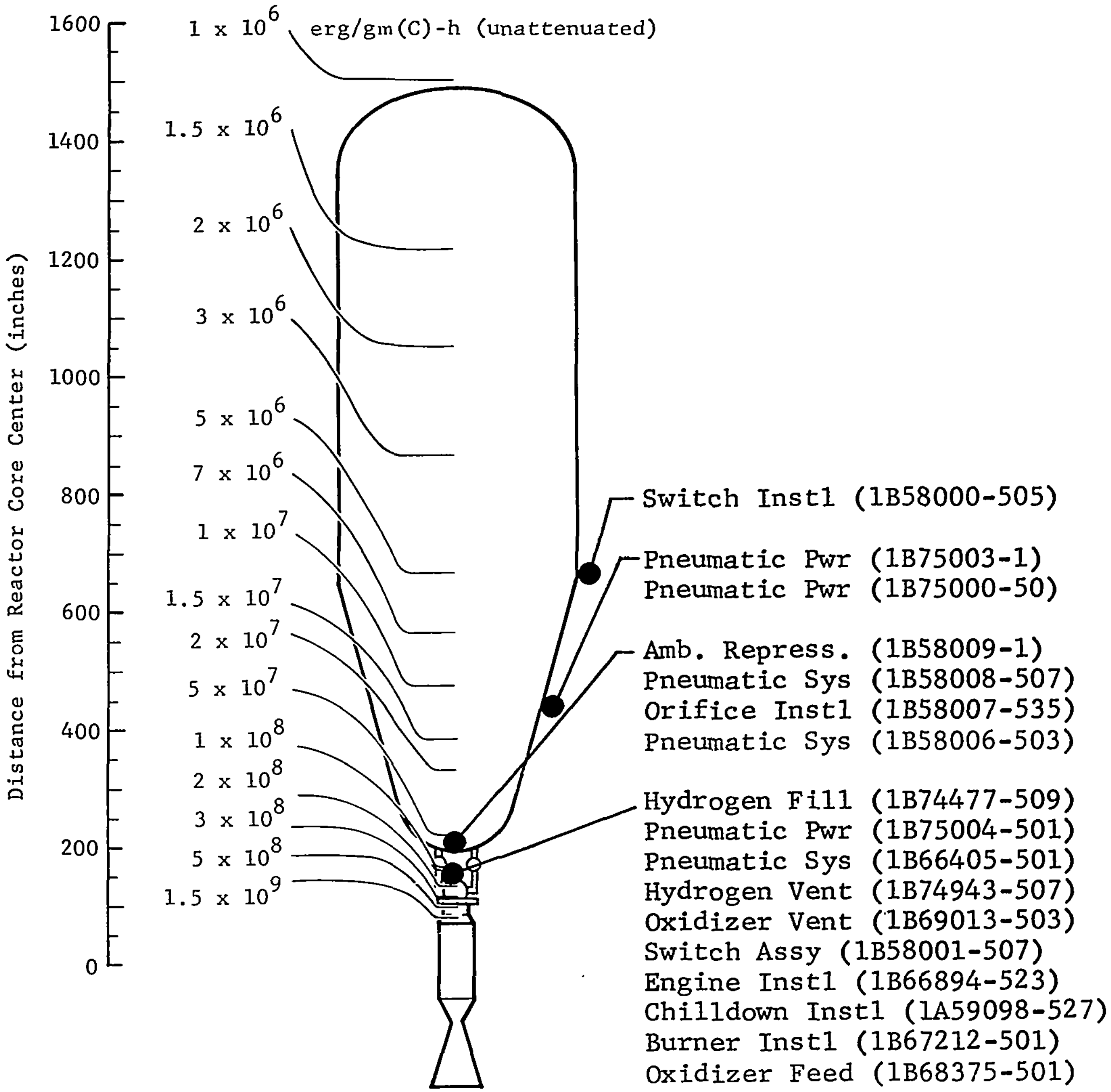


Figure 6-3 Assumed Location of (S-IVB) Propulsion System Components

Table 6-8

RADIATION HARDENING SUMMARY — S-IVB PROPULSION SYSTEM

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))		Remarks
			As Designed	As Modified	
Chilldown instl	1A59098-527	$1.5x10^9$	$7x10^6$	$1x10^{10}$	
Engine instl	1B66894-523	$1.5x10^9$	See Table 6-11	See Table 6-11	J-2 engine assy is described in Sec. 6.4
Switch instl	1B58000-505	$1x10^8$	Unknown	Unknown	Dwgs not available for detailed analysis
Orifice instl	1B58007-535	$6x10^8$	$7x10^6$	$2x10^{10}$	
Pneumatic system	1B58008-507	$6x10^8$	$7x10^6$	$6x10^9$	Can be radiation hardened to higher exp
Ambient repressurization	1B58009-1	$6x10^8$	$7x10^6$	$6x10^9$	Can be radiation hardened to higher exp
Oxidizer vent	1B69013-503	$1.5x10^9$	$7x10^6$	$1x10^{10}$	
Gaseous hydrogen vent	1B74943-507	$1.5x10^9$	$7x10^6$	$1x10^{10}$	
Pneumatic power	1B75000-501	$3x10^8$	$7x10^6$	$1x10^{10}$	
Pneumatic system	1B58006-503	$6x10^8$	$7x10^6$	$6x10^9$	Can be radiation hardened to higher exp
Pneumatic power	1B75003-1	$3x10^8$	$7x10^6$	$1x10^{10}$	

Table 6-8 (continued)

RADIATION HARDENING SUMMARY — S-IVB PROPULSION SYSTEM

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))		Remarks
			As Designed	As Modified	
Pneumatic system	1B66405-501	$1.5x10^9$	$7x10^6$	$1x10^{10}$	
Pneumatic power	1B75004-501	$1.5x10^9$	$7x10^6$	$2x10^{10}$	
Burner instl	1B67212-501	$1.5x10^9$	$7x10^6$	$1x10^{10}$	
LH_2 fill	1B74477-509	$1.5x10^9$	$7x10^6$	$1x10^{10}$	
Switch instl	1B58001-507	$1.5x10^9$	$1x10^8$	$1x10^{10}$	
Oxidizer feed	1B68375-501	$1.5x10^9$	$7x10^6$	$2x10^{10}$	

6.3.3 System Breakdown and Recommended Modifications

Drawings, specifications, and parts lists for all components were examined to determine radiation sensitive materials whose performance characteristics might degrade due to the influence of nuclear radiation. Table 6-9 summarizes these materials, describes their applications, and presents, for comparative purposes, the recommended tolerance and the predicted environment. Table 6-10 gives the recommended modifications and the resulting improvements in radiation tolerance.

6.3.4 Radiation Hardening Analysis

6.3.4.1 Chilldown Installation

The S-IVB chilldown installation (Dwg 1A59098-527) includes all the necessary ducting, valves, and pumps for chilling J-2 engine components to operating temperature prior to their operation. The major components are the chilldown system shutoff valves (Fairchild-Hiller; P/N 64-400-09) which are pneumatically actuated valves used for regulating both liquid oxygen and liquid hydrogen during chilldown operations, and the liquid oxygen pump (Pesco Products; P/N 14466-114) which is an electric motor driven pump assembly used in the liquid oxygen chilldown circulation system.

Although the RNS chilldown system will differ significantly in design from the S-IVB system in that it will use only liquid hydrogen and will also be required for afterheat removal after

Table 6-9

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
1A59098-527	Childown Installation		--	yes	1.5x10^9	7x10^6	
MC252C4TA		Face coated seal	Teflon TFE coated	no		(1x10^8)	
1B58239-1		Vent seal	Kel-F	yes		1x10^9	
VD261-0037		Face coated seal	Teflon TFE coated	no		(1x10^8)	P/N 261-0037; Navan Prod.
1B38511-501(typical)		Insulation	Polyurethane foam	no		(5x10^9)	
1A49423-509		Pump	--	yes		7x10^6	P/N 144666-114; Pesco Prod.
MC252C4TA		Face coated seal	Teflon TFE coated	no		(1x10^8)	
14-526		Wire, electrical	Teflon TFE insul.	yes		1x10^8	
14-449		Bearing, ball	Teflon TFE/glass	yes		8x10^9	Rulon
14-450		Bearing, ball	Teflon TFE/glass	yes		8x10^9	Rulon
121-1032		Rotor, motor windings	Polyimide varn. imprg.	yes		1x10^{10}	P/N RK-692; Pyre M.L. Varnish; DuPont
114-100-02		Balanced Assy windings	Polyimide varn. imprg.	yes		1x10^{10}	P/N RK-692; Pyre M.L. Varnish; Dupont
22-7066		Wire, electrical	Teflon TFE insul.	yes		1x10^8	MIL-W-7139B class 2
22-7069		Insulation tubing	Teflon TFE	no		(1x10^8)	MIL-I-22129C
EE-410		Tape	N/A	no		(N/A)	
99-4444		Seal, ring	Teflon TFE	yes		7x10^6	
99-4326		Grease, antigalling	N/A	no		(N/A)	P/N DPM-3329-1; McDonnell Douglas Co.
121-1095		Stator, motor windings	Polyimide varn. imprg.	yes		1x10^{10}	P/N RK-692; Pyre M.L. Varnish; Dupont
121-1035		Core, stator	Polyimide varn. imprg.	yes		1x10^{10}	P/N RK-692; Pyre M.L. Varnish; Dupont
21-1047		Insulator, slot	Polyimide	yes		1x10^{10}	P/N 6508 - Pyre M.L.; Dupont
21-1048		Insulator, leader	Polyimide	yes		1x10^{10}	P/N 6507 - Pyre M.L.; Dupont
22-7061		Wire, electrical	Silicone insul.	yes		1x10^9	
21-1049		Seperator	Polyimide	yes		3x10^{10}	P/N 6508 - Pyre M.L.; Dupont
21-1050		Wedge	Teflon/glass	yes		1x10^{10}	Similar to Armalon
22-7047		Tape, insulating	Polyimide	yes		1x10^{10}	P/N 6508 - Pyre M.L.; Dupont
114-136		Valve, relief	N/A	yes		N/A	DAC Spec 7696938
S0046T-xx		O-ring	Teflon TFE	yes		7x10^6	
1A87736-501		Duct Assy	--	no		*	
S0139T2		O-ring	Teflon TFE	no		(7x10^6)	
1A87741-503		Duct Assy	--	no		*	
--		Tape	Teflon TFE	no		(2x10^7)	MIL-T-22742
S0046T10		O-ring	Teflon TFE	no		(7x10^6)	
S0139T2		O-ring	Teflon TFE	no		(7x10^6)	
1A49965-535		Valve Assy Shutoff	--	yes		1x10^8	P/N 64-400-09; Fairchild Hiller
MGC61085C275		Face coated gasket	Teflon TFE coated	no		(1x10^8)	P/N MGC61085C275; Aeroquip Corp.
1A82714-535		Receptacle	N/A	yes		N/A	P/N 46019-14-19P; Deutsch Co.
1HM25		Switch	N/A	yes		N/A	P/N 1HM25; Microswitch Co.
67-091		Actuator	N/A	yes		N/A	
66-502		Seal, ring	Teflon TFE/glass	yes		5x10^9	Fluorogold
64-476		Wire, electrical	Teflon TFE insul.	yes		1x10^8	
65-214		Gasket	Teflon TFE/glass	yes		5x10^9	Armalon
PR-1939		Sealant	Silicone base	yes		1x10^9	P/N PR-1939; Precision Prod. Research
66-028		Gasket	Teflon TFE/glass	yes		5x10^9	Armalon
22651-14-19P		Receptacle	N/A	yes		N/A	P/N 22651-14-19P; Deutsch Co.
65-334		Actuator	N/A	yes		N/A	
64-406		Seal	Teflon FEP	yes	1.5x10^9	7x10^8	
1A66894-523	Engine Installation		--	yes	1.5x10^9	7x10^6	
1B58239-1		Vent seal	Kel-F	yes		1x10^9	
1B67912-505		Face coated seal	Teflon TFE coated	no		(1x10^8)	P/N VD261-0046-004; Navan Prod.
1A49958-xxx		Disconnect Assy	N/R	yes		N/R	P/N 1264004; Purolator Prod.
103826		Engine Assy	--	yes	1.5x10^9	7x10^6	See Table 6-11

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
1B58000-505	Switch Instl.		--	yes	$1x10^8$	N/R	
1B52624-513		Switch, pressure	N/R	yes	$1x10^8$	N/R	P/N 72215-501; Hydra-Electric Co.
1B58007-535	Orifice Instl.		--	yes	$6x10^8$	$7x10^6$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
1B58239-1		Vent seal	Kel-F	yes		$1x10^9$	
1A58347-513		Module, control, pump purge	--	yes		$7x10^6$	P/N 38170-1; Sterer Mfg. Co.
AR10105-017A1Q		Omni-seal	Teflon TFE	yes		$7x10^6$	P/N AR10105-017A1Q; Aeroquip Corp.
24798		Packing	Silicone rubber	no		$(1x10^9)$	
23825-1		Solenoid Assy	N/A	yes		N/A	
24955		Packing	Silicone rubber	yes	$6x10^8$	$1x10^9$	
1B58008-507	Pneumatic System		--	yes	$6x10^8$	$7x10^6$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
1B58239-1		Vent seal	Kel-F	yes		$1x10^9$	
1B65813-1		Diffuser	--	yes		$1x10^9$	
1B65813-3 (typical)		Fabric	Nylon	yes		$1x10^9$	
1B65813-7		Cord	Nylon	no		$(1x10^9)$	
1B65673-1		Valve, Helium check	--	yes		$6x10^9$	P/N 670-012; Calmec Mfg. Co.
670-5		Seat	Mylar	yes		$6x10^9$	
670-4		Gasket	Mylar	no		$(6x10^9)$	
S0046T-xx		O-ring	Teflon TFE	yes	$6x10^8$	$7x10^6$	
1B58009-1	Ambient Repressurization System		--	yes	$6x10^8$	$7x10^6$	
S0046T26		O-ring	Teflon TFE	yes		$7x10^6$	
1B40824-507		Valve	--	yes		$1x10^9$	P/N 60192; J. C. Carter Co.
25901		Seat	Kel-F	yes		$1x10^9$	
No. 48		Seal	Teflon TFE	no		$(7x10^6)$	
1B58239-1		Vent seal	Kel-F	yes		$1x10^9$	
1B69550-501		Module Assy	--	yes		$7x10^6$	
FID10031-01		Filter Assy	--	yes		*	P/N FID10031-01; Vacco Industries
62575-A		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
1B43660-511		Solenoid Valve	--	yes		$7x10^6$	P/N 548-515; Calmec Mfg. Co.
659-51		Seat	Polyimide	yes		$2x10^{10}$	Vespel
622-139		Seal	Teflon TFE	yes		$7x10^6$	
CMS-101K-2		Plug	Kel-F	no		$(3x10^9)$	
548-42		Gasket	Mylar	no		$(6x10^9)$	
548-41		Gasket	Mylar	no		$(6x10^9)$	
548-46		Seat	Mylar	yes		$6x10^9$	
548-48		Solenoid Assy	N/A	yes		N/A	
PT1H-8-4P		Connector	--	yes		*	P/N PT1H-8-4P; Bendix Corp.
--		O-ring	Silicone rubber	no	$6x10^8$	$(1x10^9)$	
1B69013-503	Oxidizer Vent System		--	yes	$1.5x10^9$	$7x10^6$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
AR10205-040A1H		Seal	Teflon TFE	yes		$7x10^6$	P/N AR10205-040A1H; Aeroquip Corp.
S0046T161		O-ring	Teflon TFE	yes		$7x10^6$	
1B58239-1		Vent seal	Kel-F	yes		$1x10^9$	
1A48312-517		Valve Assy, Vent & Relief					
		Oxidizer Tank	--	yes		$7x10^6$	P/N 528-519; Calmec Mfg. Co.
171-153		Gasket	Kel-F	no		$(1x10^9)$	
1031-4		Switch assy	N/A	yes	$1.5x10^9$	N/A	P/N 1031-4; Microswitch

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
TVM-1-8		Face coated seal	Teflon TFE coated	yes	$1.5x10^{9}$	$1x10^{8}$	P/N TVM-1-8; Tetrafluor Co.
528-98		Gasket	Kel-F	no		$(1x10^{9})$	
528-91		Seal	Teflon TFE/glass	yes		$5x10^{9}$	Armalon
VD261-0003-0004		Face coated seal	Teflon TFE coated	no		$(1x10^{8})$	P/N VD261-0003-0004; Navan Prod.
519-19		Gasket	Kel-F	no		$(1x10^{9})$	
AN6290-4		O-ring	Teflon TFE	yes		$7x10^{6}$	
519-66		Gasket	Kel-F	no		$(1x10^{9})$	
--		Tubing	Teflon TFE	no		$(1x10^{8})$	
528-93		Seal	Teflon TFE/glass	yes		$5x10^{9}$	Armalon
519-135		Insulator	Mylar	no		$(1x10^{10})$	
931-27		Switch	N/A	yes		N/A	Microswitch
931-21		Receptacle	N/A	yes		N/A	Deutsch
171-52		Gasket	Kel-F	no		$(1x10^{9})$	
519-124-5		Seal	Teflon TFE	yes		$7x10^{6}$	
528-55		Gasket	Kel-F	no		$(1x10^{9})$	
528-19		Gasket	Kel-F	no		$(1x10^{9})$	
528-59		Ring, retainer	Kel-F	no		$(5x10^{9})$	
528-92		Seal	Teflon TFE	yes		$7x10^{6}$	
519-127		Insert	Teflon TFE/glass	no		$(8x10^{9})$	Fluorogold
519-124-2		Seal	Teflon TFE	yes		$7x10^{6}$	
528-24		Gasket	Kel-F	no		$(1x10^{9})$	
528-32		Gasket	Kel-F	no		$(1x10^{9})$	
528-88		Seal	Teflon TFE	yes		$7x10^{6}$	
528-30		Seat	Teflon TFE	yes		$7x10^{6}$	
528-89		Seal	Teflon TFE/glass	yes		$5x10^{9}$	Armalon
528-8		Gasket	Teflon TFE/glass	no		$(5x10^{9})$	Fluorogold
528-45		Seat	Kel-F	yes		$1x10^{9}$	
528-76		Ring	Teflon TFE/glass	no		$(1x10^{10})$	Fluorogold
528-78		Ring	Teflon TFE/glass	no		$(1x10^{10})$	Fluorogold
528-21		Seal	Teflon TFE	yes		$7x10^{6}$	
528-26		Ring	Teflon TFE/glass	no		$(1x10^{10})$	Fluorogold
528-27		Spacer	Kel-F	no		$(8x10^{9})$	
519-85		Plug	Kel-F	no		$(8x10^{9})$	
528-110		Seal	Teflon TFE	yes		$7x10^{6}$	
171-112		Seat	Teflon TFE	yes		$7x10^{6}$	
1B69030-505		Valve Assy, Relief LO_2 Latching	--	yes		$7x10^{6}$	P/N 931-505; Calmec Mfg. Co.
528-110		Seal	Teflon TFE	yes		$7x10^{6}$	
519-135		Insulator	Mylar	no		$(1x10^{10})$	
MS9068		O-ring	Viton A	yes		$6x10^{9}$	
519-124-4		Seal	Teflon TFE	yes		$7x10^{6}$	
519-85		Plug	Kel-F	no		$(8x10^{9})$	
931-11		Gasket	Kel-F	no		$(1x10^{9})$	
TVM-1-8		Face coated seal	Teflon TFE coated	yes		$1x10^{8}$	P/N TVM-1-8; Tetrafluor Co.
528-98		Gasket	Kel-F	no		$(1x10^{9})$	
528-91		Seal	Teflon TFE/glass	yes		$5x10^{9}$	Armalon
VD261-0003-0004		Face coated seal	Teflon TFE coated	no		$(1x10^{8})$	P/N VD261-0003-0004; Navan Products
931-9		Ring seal	Teflon TFE	no		$(7x10^{6})$	
519-19		Gasket	Kel-F	no		$(1x10^{9})$	
AN6290		O-ring	Teflon TFE	yes		$7x10^{6}$	
519-66		Gasket	Kel-F	no		$(1x10^{9})$	
1031-3		Switch assy	N/A	yes	$1.5x10^{9}$	N/A	P/N 1031-3; Microswitch

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Appli- cation	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
171-153		Gasket	Kel-F	no	$1.5x10^9$	$(1x10^9)$	
528-93		Seal	Teflon TFE/glass	yes		$5x10^9$	Armalon
--		Tubing	Teflon TFE	no		$(1x10^8)$	
931-27		Switch	N/A	yes		N/A	Microswitch
171-52		Gasket	Kel-F	no		$(1x10^9)$	
528-55		Gasket	Kel-F	no		$(1x10^9)$	
528-19		Gasket	Kel-F	no		$(1x10^9)$	
528-59		Ring, retainer	Kel-F	no		$(1x10^9)$	
528-92		Seal	Teflon TFE	yes		$7x10^6$	
519-127		Insert	Teflon TFE/glass	no		$(8x10^9)$	Fluorogold
931-7		Spacer	Kel-F	no		$(3x10^9)$	
528-24		Gasket	Kel-F	no		$(1x10^9)$	
528-32		Gasket	Kel-F	no		$(1x10^9)$	
528-88		Seal	Teflon TFE	yes		$7x10^6$	
528-30		Seat	Teflon TFE	yes		$7x10^6$	
528-89		Seal	Teflon TFE/glass	yes		$5x10^9$	Armalon
528-8		Gasket	Teflon TFE/glass	no		$(5x10^9)$	Fluorogold
528-45		Seat	Kel-F	yes		$1x10^9$	
528-16		Ring	Teflon TFE/glass	no		$(1x10^{10})$	Fluorogold
528-78		Ring	Teflon TFE/glass	no		$(1x10^{10})$	Fluorogold
931-21		Receptacle	N/A	yes		N/A	Deutsch
528-21		Seal	Teflon TFE	yes		$7x10^6$	
528-26		Ring	Teflon TFE/glass	no		$(1x10^{10})$	Fluorogold
528-27		Spacer	Kel-F	no		$(3x10^9)$	
931-2		Gasket	Kel-F	no		$(1x10^9)$	
171-112		Seat	Teflon TFE	yes		$7x10^6$	
1A89487-1		Gasket	Teflon TFE/glass	no	$1.5x10^9$	$(5x10^9)$	Armalon
1B74943-507	GH2 Vent System		--	yes	$1.5x10^9$	$7x10^6$	
ASF200		Seal	Teflon TFE	yes		$7x10^6$	P/N ASF 200; Creavey Seal
AS100		Seal	Teflon TFE	yes		$7x10^6$	P/N AS100; Creavey Seal
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
1B58239-1		Vent Seal	Kel-F	yes		$1x10^9$	
S0046T-xx (typical)		O-ring	Teflon TFE	yes		$7x10^6$	
1A93730-1		Gasket	Teflon TFE/glass	no		$(5x10^9)$	Armalon
1A94469-511		Duct	--	no		*	
1A94469-5		Sleeve	Nylon fabric	no		$(1x10^9)$	
1A94469-7		Sleeve	Aclar sheet	no		$(2x10^9)$	
1A49988-513		Valve Assy Dir. Control Vent	--	yes		$7x10^6$	P/N 511-513; Calmec Mfg. Co.
511-96		Switch assy	N/A	yes		N/A	
VD261-0003-0004		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	P/N VD261-0003-0004; Navan Prod.
511-88		Ring seal	Teflon TFE	no		$(7x10^6)$	
511-79		Dampener	Leather	no		$(5x10^9)$	
--		Tubing	Teflon TFE	no		$(1x10^8)$	
511-80		Backup ring	Mylar	no		$(1x10^{10})$	
511-61		Gasket	Silicone rubber	no		$(8x10^8)$	
511-60		Gasket	Teflon TFE/glass	no		$(5x10^9)$	Fluorogold
511-51		Seal	Teflon TFE	yes		$7x10^6$	
511-48		Gasket	Teflon TFE/glass	no		$(5x10^9)$	Fluorogold
1A82714-533		Connector	N/A	yes		N/A	Deutsch
511-38		Gasket	Silicone rubber	no		$(8x10^8)$	
511-37		Baffle	Phenolic	no	$1.5x10^9$	$(1x10^{10})$	MIL-P-3115

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
931-27		Switch	N/A	yes	$1.5x10^9$	N/A	Microswitch
519-124-3		Seal	Teflon TFE	yes		$7x10^6$	
511-20		Seat	Teflon TFE	yes		$7x10^6$	
511-78		Seal	Teflon TFE/glass	yes		$5x10^9$	Armalon
511-13		Seal	Teflon TFE	yes		$7x10^6$	
511-77		Seal	Teflon TFE	yes		$7x10^6$	
511-92		Seal	Teflon TFE	yes		$7x10^6$	
511-5		Gasket	Kel-F	no		$(1x10^9)$	
1A48257-525		<u>Valve Assy, Vent & Relief</u>	--	yes		$7x10^6$	P/N 519-529; Calmec Mfg. Co.
519-108		Gasket	Kel-F	no		$(1x10^9)$	
TVM-2-8		Face Coated seal	Teflon TFE coated	no		$(1x10^8)$	P/N TVM-2-8; Tetrafluor Co.
519-100		Seal	Teflon TFE/glass	yes		$5x10^9$	Armalon
519-97		Seal	Teflon TFE	yes		$7x10^6$	
519-96		Seal	Teflon TFE/glass	yes		$5x10^9$	Armalon
161-39		Seat	Teflon TFE	yes		$7x10^6$	
519-56		Gasket	Kel-F	no		$(1x10^9)$	
519-54		Gasket	Kel-F	no		$(1x10^9)$	
519-127		Insert	Teflon TFE/glass	no		$(8x10^9)$	Fluorogold
519-67		Switch Assy	N/A	yes		N/A	
2-15S604-7		O-ring	Silicone rubber	yes		$1x10^9$	P/N 2-15S604-7; Parker Seal Co.
519-135		Insulator	Mylar	no		$(1x10^{10})$	
519-117		Seal	Mylar	yes		$6x10^9$	
519-66		Gasket	Kel-F	no		$(1x10^9)$	
519-47		Ring	Kel-F	no		$(1x10^9)$	
519-22		Gasket	Kel-F	no		$(1x10^9)$	
519-45		Gasket	Kel-F	no		$(1x10^9)$	
519-64		Gasket	Kel-F	no		$(1x10^9)$	
519-63		Gasket	Teflon TFE/glass	no		$(5x10^9)$	Fluorogold
519-62		Seat	Kel-F	yes		$1x10^9$	
519-71		Switch assy	N/A	yes		N/A	
931-27		Switch	N/A	yes		N/A	Microswitch
--		Tubing	Teflon TFE	no		$(1x10^8)$	
931-21		Receptacle	N/A	yes		N/A	
171-153		Gasket	Kel-F	no		$(1x10^9)$	
171-52		Gasket	Kel-F	no		$(1x10^9)$	
519-19		Gasket	Kel-F	no		$(1x10^9)$	
519-40		Seal	Teflon TFE	yes		$7x10^6$	
519-85		Spacer	Kel-F	no		$(8x10^9)$	
519-115		Seal	Teflon TFE	yes		$7x10^6$	
171-112		Seat	Teflon TFE	yes		$7x10^6$	
519-39		Spacer	Kel-F	no		$(8x10^9)$	
519-37		Ring	Teflon TFE/glass	no		$(1x10^{10})$	Fluorogold
519-124-1		Seal	Teflon TFE	yes		$7x10^6$	
519-61		Ring	Teflon TFE/glass	no		$(1x10^{10})$	Fluorogold
519-105		Seal	Teflon TFE/glass	yes		$5x10^9$	Armalon
519-99		Seal	Teflon TFE	yes		$7x10^6$	
1B74535-1		<u>Valve Assy, Relief, LH_2, Latching</u>	--	yes		$7x10^6$	P/N 1031; Calmec Mfg. Co.
519-135		Insulator	Mylar	no		$(1x10^{10})$	
2-15S604-7		O-ring	Silicone rubber	yes		$8x10^8$	P/N 2-15S604-7; Parker Seal
519-124-x		Seal	Teflon TFE	yes		$7x10^6$	
528-xxx		Seal	Teflon TFE	yes	$1.5x10^9$	$7x10^6$	

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
519-85		Plug	Kel-F	no	1.5×10^{9}	(3×10^{9})	
931-14		Bearing	Teflon TFE	yes		3×10^{7}	
931-11		Gasket	Kel-F	no		(1×10^{9})	
TVM-1-8		Face coated seal	Teflon TFE coated	no		(1×10^{8})	P/N TVM-1-8; Tetrafluor Co.
528-xx		Gasket	Kel-F	no		(1×10^{9})	
528-xx		Seal	Teflon TFE/glass	yes		5×10^{9}	Armalon
--		Lubricant	Teflon base spray	yes		1×10^{8}	Dri-lube
931-9		Ring, retainer	Teflon TFE	no		(7×10^{6})	
519-xx		Gasket	Kel-F	no		(1×10^{9})	
AN6290-4		O-ring	Teflon TFE	yes		7×10^{6}	
528-30		Seat	Teflon TFE	yes		7×10^{6}	
171-xxx		Gasket	Kel-F	no		(1×10^{9})	
519-xx		Switch assy	N/A	yes		N/A	
528-8		Gasket	Teflon TFE/glass	no		(5×10^{9})	Fluorogold
--		Tubing	Teflon TFE	no		(1×10^{8})	
528-45		Seat	Kel-F	yes		1×10^{9}	
931-27		Switch	N/A	yes		N/A	Microswitch
528-xx		Ring, retainer	Teflon TFE/glass	no		(1×10^{10})	Fluorogold
931-21		Receptacle	N/A	yes		N/A	
528-27		Spacer	Kel-F	no		(3×10^{9})	
931-2		Gasket	Kel-F	no		(1×10^{9})	
528-59		Ring, retainer	Kel-F	no		(1×10^{9})	
171-112		Seat	Teflon TFE	yes		7×10^{6}	
519-127		Insert	Teflon TFE/glass	no		(8×10^{9})	Fluorogold
931-7		Spacer	Kel-F	no	1.5×10^{9}	(3×10^{9})	
1B75000-501	Pneumatic Power		--	yes	3×10^{8}	7×10^{6}	
MC252C4TA		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
S0046T18		Gasket	Teflon TFE	yes		7×10^{6}	
1B58239-1		Seal	Kel-F	yes		1×10^{9}	
1B67843-xx		Spacer	Epoxy laminate	no		(2×10^{10})	
1B66692-501		Module, actuation control	--	yes		7×10^{6}	P/N 31850-3; Sterer Mfg. Co.
24798		Packing	Silicone rubber	no		(1×10^{9})	
S-1-022W		Packing	Silicone rubber	no		(1×10^{9})	
AR10105-017A1Q		Seal	Teflon TFE	yes		7×10^{6}	P/N AR10105-017A1Q; Aeroquip Corp.
23825-1		Solenoid Assy	--	yes		1×10^{8}	
--		Wire, electrical	Teflon TFE insulated	yes		1×10^{8}	MIL-W-7139
--		Connector insert	Silicone rubber	yes		1×10^{9}	P/N PT1H-8-3S; Bendix Corp.
1B67481-1		Valve Assy, Check	--	yes		8×10^{8}	P/N P36-673; James, Pond, Clark, Inc.
--		Seal	Silicone rubber	yes	3×10^{8}	8×10^{8}	Mil-R-5847
1B58006-503	Pneumatic System		--	yes	6×10^{8}	7×10^{6}	
MC252C4TA		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
MGC60778C12		Face coated gasket	Teflon TFE coated	no		(1×10^{8})	P/N MGC60778C12; Aeroquip Corp.
MGC61085C125		Face coated gasket	Teflon TFE coated	no		(1×10^{8})	P/N MGC61085C125; Aeroquip Corp.
55666-150AE4		Face coated gasket	Teflon TFE coated	no		(1×10^{8})	P/N 55666-150AE4; Aeroquip Corp.
1B40824-507		Valve	--	yes		1×10^{9}	P/N 60192; J. C. Carter Co.
25901		Seat	Kel-F	yes		1×10^{9}	
No. 48		Seal	Teflon TFE	no		(7×10^{6})	
5045-002		Isolator	--	no		*	P/N 5045; Robinson Tech Prod.
5045-002-0-02		Liner	Teflon TFE	no		(1×10^{8})	
1B58239-1		Seal	Kel-F	yes		1×10^{9}	
1B57781-511		Module- He Dump & Fill	--	yes		7×10^{6}	P/N 659-511; Calmec Mfg. Co.
VD261-0003		Face coated seal	Teflon TFE coated	no	6×10^{8}	(1×10^{8})	P/N VD261-0003-0004; Navan Prod.

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
MS28775		O-ring	Buna N	yes	6×10^{8}	1×10^{9}	
622-139		Seal	Teflon TFE	yes		7×10^{6}	
659-19		Gasket	Mylar	no		(6×10^{9})	
622-123		Seal	Teflon TFE/glass	yes		5×10^{9}	Fluorogold
659-41		Gasket	Mylar	no		(6×10^{9})	
MS29512		O-ring	Silicone rubber	yes		1×10^{9}	
622-64		Diaphram	Mylar	yes		6×10^{9}	
622-67		Gasket	Mylar	no		(6×10^{9})	
659-8		Seal	Mylar	yes		6×10^{9}	
659-7		Gasket	Mylar	no		(6×10^{9})	
622-68		Gasket	Mylar	no		(6×10^{9})	
622-63		Seat	Mylar	yes		6×10^{9}	
622-69		Gasket	Mylar	no		(6×10^{9})	
622-115		Seal	Teflon TFE/glass	yes		5×10^{9}	Fluorogold
622-127		Spacer	Kel-F	no		(3×10^{9})	
622-125		Plug	Kel-F	no		(3×10^{9})	
659-51		Seat	Polyimide	yes		2×10^{10}	Vespel
659-52		Seat	Polyimide	yes		2×10^{10}	Vespel
P36-673		Relief valve	N/A	yes		N/A	P/N P36-673; Circle Seal
PT1H-8-3P		<u>Connector</u>	--	yes		*	P/N PT1H-8-3P; Bendix Corp.
--		O-ring	Silicone rubber	no		(1×10^{9})	
622-30-2		Solenoid Assy	N/A	yes		N/A	
1B42290-511		<u>Module, Tank Pressurization</u>	--	yes		7×10^{6}	P/N 622-513; Calmec Mfg. Co.
622-139		Seal	Teflon TFE	yes		7×10^{6}	
622-68		Gasket	Mylar	no		(6×10^{9})	
MS28775		O-ring	Silicone rubber	yes		1×10^{9}	
622-71		Gasket	Mylar	no		(6×10^{9})	
622-64		Diaphram	Mylar	yes		6×10^{9}	
622-67		Gasket	Mylar	no		(6×10^{9})	
622-87		Gasket	Mylar	no		(6×10^{9})	
622-69		Gasket	Mylar	no		(6×10^{9})	
622-123		Seal	Teflon TFE/glass	yes		5×10^{9}	Fluorogold
622-127		Spacer	Kel-F	no		(3×10^{9})	
659-51		Seat	Polyimide	yes		2×10^{10}	Vespel
622-93		Gasket	Mylar	no		(6×10^{9})	
622-115		Seal	Teflon TFE/glass	no		(5×10^{9})	Fluorogold
622-114		Seal	Teflon TFE/glass	no		(5×10^{9})	Fluorogold
622-113		Seal	Teflon TFE/glass	no		(5×10^{9})	Fluorogold
622-63		Seat	Mylar	yes		6×10^{9}	
622-125		Plug	Kel-F	no		(3×10^{9})	
622-30-2		Solenoid Assy	N/A	yes		N/A	
622-80		Regulator Assy	N/A	yes		N/A	
P36-673		Relief valve	N/A	yes		N/A	P/N P36-673; Circle Seal
622-116		Control valve assy	N/A	yes		N/A	
622-3-2		Solenoid assy	N/A	yes		N/A	
PT1H-8-3P		<u>Connector</u>	--	yes		*	P/N PT1H-8-3P; Bendix
--		O-ring	Silicone rubber	no	6×10^{8}	(8×10^{8})	

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
S0139T8		O-ring	Teflon TFE	yes	$6x10^8$	$7x10^6$	
S0046T26		O-ring	Teflon TFE	yes	$6x10^8$	$7x10^6$	
1B75003-1	Pneumatic Power		--	yes	$3x10^8$	$7x10^6$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
1B67843-xx		Spacer	Laminated epoxy	no		$(2x10^{10})$	
1B68776-1		Spacer	Laminated phenolic	no		$(2x10^{10})$	
1B66692-501		Module, actuation control	--	yes		$7x10^6$	P/N 31850-3; Sterer Mfg. Co.
24798		Packing	Silicone rubber	no		$(1x10^9)$	
S-1-022W		Packing	Silicone rubber	no		$(1x10^9)$	
AR10105-017A1Q		Seal	Teflon TFE	yes		$7x10^6$	P/N AR10105-017A1Q; Aeroquip Corp.
23825-1		Solenoid Assy	--	yes		$1x10^8$	
--		Wire, electrical	Teflon TFE insul.	yes		$1x10^8$	MIL-W-7139
10414087		Valve	--	yes		*	P/N 15600; Benton Corp.
--		Packing	Teflon TFE	no		$(7x10^6)$	
7851823-503		Disconnect	N/R	yes	$3x10^8$	N/R	P/N 1198004-02; Purolator
1B66405-501	Pneumatic System		--	yes	$1.5x10^9$	$7x10^6$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
MGC60778C12		Face coated gasket	Teflon TFE coated	no		$(1x10^8)$	P/N MGC 60778C12; Aeroquip Corp.
S0046T26		O-ring	Teflon TFE	yes		$7x10^6$	
S0139T4		O-ring	Teflon TFE	yes		$7x10^6$	
1B58239-1		Seal, vent	Kel-F	yes		$1x10^9$	
1B40824-507		Valve	--	yes		$1x10^9$	P/N 60192; J. C. Carter Co.
25901		Seat	Kel-F	yes		$1x10^9$	
No. 48		Seal	Teflon TFE	no		$(7x10^6)$	
1B62778-xxx		Valve Assy	--	yes		$7x10^6$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
S0046T26		O-ring	Teflon TFE	yes		$7x10^6$	
1B58239-1		Seal	Kel-F	yes		$1x10^9$	
1B43660-xx		Valve, solenoid, cold He	--	yes		$7x10^6$	P/N 548-515; Calmec Mfg. Co.
548-43		Seat	Mylar	yes		$6x10^9$	
548-xx		Gasket	Mylar	no		$(6x10^9)$	
PT1H-8-4P		Connector	--	yes		*	P/N PT1H-8-4P; Bendix Corp.
--		O-ring	Silicone rubber	no		$(8x10^8)$	
548-46		Solenoid assy	--	yes		$1x10^8$	
--		Wire, electrical	Teflon TFE insul.	yes		$1x10^8$	
CMS-101K-2		Plug	Kel-F	no		$(3x10^9)$	
622-139		Seal	Teflon TFE	yes		$7x10^6$	
659-51		Seat	Polyimide	yes	$1.5x10^9$	$2x10^{10}$	Vespel
1B75004-501	Pneumatic Power		--	yes	$1.5x10^9$	$7x10^6$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
S0046T-xx		O-ring	Teflon TFE	yes		$7x10^6$	
1A48857-503		Tank	N/R	yes		N/R	P/N 4425002; Airtec Dynamics
1B58239-1		Vent seal	Kel-F	yes		$1x10^9$	
1B29290-1		Strap Assy	--	no		*	
1B29290-xx		Pads	Teflon TFE	no		$(1x10^8)$	
1A57350-507		Module Assy, He fill	--	yes		$1x10^9$	P/N 64-820-04; Fairchild Hiller
PRP568-902		Gasket	N/A	no		(N/A)	P/N PRP568-902-1005-75; Precision Rubber
PRP568-020		O-ring	N/A	yes		N/A	P/N PRP568-020-1005-75; Precision Rubber
65-234		Poppet seal	Polyimide	yes		$2x10^{10}$	P/N SP-1; Dupont
PRP568-013		O-ring	N/A	yes	$1.5x10^9$	N/A	P/N PRP568-013-1005-75; Precision Rubber

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
PRP568-003		O-ring	N/A	yes	$1.5x10^9$	N/A	P/N PRP568-003-1005-75; Precision Rubber
PRP568-016		O-ring	N/A	yes		N/A	P/N PRP568-016-1005-75; Precision Rubber
64-790		Solenoid	N/A	yes		N/A	
64-809		Seat	Kel-F	yes		$1x10^9$	AMS-3650
PRP568-906		Gasket	N/A	no		(N/A)	P/N PRP568-906-1005-75; Precision Rubber
MS28774		Backup ring	Teflon TFE	no		$(7x10^6)$	
1B65857-1		Spacer	Laminated epoxy	no		$(2x10^{10})$	
1B66692-1		Module Actuation Control	--	yes		$7x10^6$	P/N 31850-3; Sterer Manufacturing Co.
24798		Packing	Silicone rubber	no		$(1x10^9)$	
S-1-022W		Packing	Silicone rubber	no		$(1x10^9)$	
AR10105-017A1Q		Seal	Teflon TFE	yes		$7x10^6$	P/N AR10105-017A1Q; Aeroquip Corp.
1B67481-1		Valve Assy, check	--	yes		$8x10^8$	P/N P36-673; James, Pond, Clark, Inc.
--		Seal	Silicone rubber	yes		$8x10^8$	
1B67700-505		Module Assy Pneu. Pwr.Cont	--	yes		$7x10^6$	P/N A-62390-531; Adel
PT1H-8-3P		Connector	--	yes		*	P/N PT1H-8-3P; Bendix Corp.
--		O-ring	Silicone rubber	no		$(8x10^8)$	
D-62390-24		Solenoid	N/A	yes		N/A	
MS28774		Backup ring	Teflon TFE	no		$(7x10^6)$	
S-20000-006AG		O-ring	N/R	yes		N/R	
S-21000-2AG		O-ring	N/R	yes		N/R	
MGC-60778C-12A		Face coated gasket	Teflon TFE coated	no		$(1x10^8)$	P/N MGC60778C-12A; Aeroquip Corp.
PRP2118-026		O-ring	Teflon TFE	yes		$7x10^6$	P/N PRP2118-026; Precision Rubber
1B67843-xx		Spacer	Laminated epoxy	no		$(2x10^{10})$	
1B68835-1		Spacer	Laminated epoxy	no		$(2x10^{10})$	
10414087		Valve	--	yes		*	P/N B-15600; Benton Corp.
--		Packing	Teflon TFE	no		$(7x10^6)$	
1B77000-1		Pneu. Control Assy	--	yes		*	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
1B67713-1		Regulator	N/A	yes		N/A	P/N 679000; Fairchild Hiller
1B67715-1		Valve, Pneu. control	--	yes		$1x10^8$	P/N 72552; Adel
62390-6		Thread lock	Nylon	no		$(3x10^9)$	MIL-P-17091
42272-4		Packing	N/R	yes		N/R	P/N 42272-4; Plastic & Rubber Co.
85134		Solenoid	--	yes		$1x10^8$	
--		Wire, electrical	Teflon TFE insul.	yes		$1x10^8$	
MGC60778C-12		Face coated gasket	Teflon TFE coated	yes		$1x10^8$	
42271-x		Packing	N/R	yes		N/R	P/N 42271-x; Plastic & Rubber Co.
MS28774		Retaining ring	Teflon TFE	no	$1.5x10^9$	$(7x10^6)$	
1B67212-501	Burner Instl		--	yes	$1.5x10^9$	$7x10^6$	
K2319-40		Isolation Mount	--	no		*	P/N K2319-40; Robinson Tech Prod.
--		Liner	Teflon TFE	no		$(1x10^8)$	
S0046T37		O-ring	Teflon TFE	yes		$7x10^6$	
S0139T2		O-ring	Teflon TFE	yes		$7x10^6$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
1B59008-501		Filter	--	yes		$1x10^8$	
--		Liner	Teflon TFE	yes		$1x10^8$	
1B67212-xx (typical)		Insulation	Polyurethane foam	no		$(1x10^{10})$	
1B62600-533		Burner	--	yes		$7x10^6$	
VD261-0003-0008		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	P/N VD261-0003-0008; Navan Prod.
1A35427-501		Gasket	N/A	no		(N/A)	
1B66639-1		Actuator Assy	--	yes		$7x10^6$	
1P20056		Lubricant	Perfluorinated aliphatic	no		$(1x10^8)$	
1B66627-1		Gasket	Teflon FEP	no		$(7x10^8)$	
1B66798-1		Seat	Teflon TFE	yes	$1.5x10^9$	$7x10^6$	

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
1B67211-1		Gasket	Teflon FEP	no	$1.5x10^9$	$(7x10^8)$	
1HM-1		Switch	N/A	yes		N/A	P/N 1HM-1; Honeywell Microswitch
101-004		Seal	Teflon TFE	yes		$7x10^6$	P/N 101-004; Balseal Engr. Co.
7869679		Wire, electrical	Teflon TFE insul.	yes	$1.5x10^9$	$1x10^8$	
1B74477-509	<u>LH_2 Fill System</u>		--	yes	$1.5x10^9$	$7x10^6$	
S0046T-xx		O-ring	Teflon TFE	yes		$7x10^6$	
S0046S-xx		O-ring	Silicone rubber	yes		$8x10^8$	
1A48240-511		Valve	N/A	yes		N/A	P/N 402000-2; Fairchild Hiller
1A49320		Duct assy	N/R	no		(N/R)	P/N 1303426-103; Stainless Steel Prod.
1A49968-519		Valve	N/R	yes		N/R	P/N 527510; Snaptite Inc.
1A77906-1		<u>Fill assy</u>	--	yes		$1x10^9$	
--		Sealant	Silicone rubber	yes		$1x10^9$	1P20057
--		Tape	Fiberglass	no		$(1x10^{10})$	
1B39067-1		Insulation	Polyurethane foam	no		$(5x10^9)$	
1B58239-1		Vent seal	Kel-F	yes		$1x10^9$	
1B66932-501		<u>Disconnect</u>	--	yes		$1x10^9$	
1B66935-1		Seal	Kel-F	yes		$1x10^9$	
1A78053-1		<u>Fill assy</u>	--	yes		*	
--		Tape	Mylar	no		$(1x10^{10})$	
1P20057		Sealant	Silicone rubber	no		$(1x10^9)$	
--		Sleeve	Nylon fabric	no		$(3x10^9)$	
--		Insulation	Polyurethane	no	$1.5x10^9$	$(5x10^9)$	
1B58001-507	<u>Switch Installation</u>		--	yes	$1.5x10^9$	$1x10^8$	
MC252C4TA		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
1B52624-515		<u>Switch Assy</u>	--	yes		$1x10^8$	P/N 21SN22; Consolidated Controls
JGE-121		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	MC252C4TA
MAE57-11		Shrinkable tube	Silicone rubber	no		$(2x10^9)$	
SF278		Potting	Epoxy base	no		$(2x10^{10})$	Stycast 2651; Emerson and Cuming
JEG182		Switch	N/A	yes		N/A	Microswitch
--		Wire, electrical	Teflon TFE insul.	yes		$1x10^8$	
JEB330B		Receptacle	N/A	yes		N/A	P/N 22690-8-4P; Deutsch
JGD121		Seal, ring	Viton A	yes		$6x10^9$	MIL-R-25897
1B52624-519		<u>Switch Assy</u>	--	yes		$1x10^8$	P/N21SN25; Consolidated Controls
MAE57-12		Shrinkable tube	Silicone rubber	no		$(2x10^9)$	
PT1H -x		<u>Receptacle</u>	--	yes		*	P/N PT1H; Bendix Corp.
--		O-ring	Silicone rubber	no		$(8x10^8)$	
JGE121		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
JEB330A		Receptacle	N/A	yes		N/A	P/N 22690-8-4P; Deutsch
--		Wire, electrical	Teflon TFE insul.	yes		$1x10^8$	
JEG-182		Switch	N/A	yes		N/A	Microswitch
SF278		Potting	Epoxy base	no		$(2x10^{10})$	Stycast 2651; Emerson and Cuming
JGD121B		Seal, ring	Viton A	yes		$6x10^9$	MIL-R-25897
1A49958-517		Disconnect Assy	N/R	yes		N/R	P/N 1265004-06; Purolator Prod.
1B52623-515		Switch Assy	N/R	yes	$1.5x10^9$	N/R	P/N 72214-513; Hydra Electric Co.

Table 6-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-IVB PROPULSION SYSTEM (1A39318-551)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
1B68375-501	Oxidizer Feed System		--	yes	1.5×10^9	7×10^6	
FC6511002-x		Seal	N/R	yes		N/R	P/N FC6511002-x; Fluorocarbon Co.
S0046T-x		O-ring	Teflon TFE	yes		7×10^6	
1B66932-501		Disconnect Assy	--	yes		1×10^9	
1B66935-1		Seal	Kel-F	yes		1×10^9	
1A48240-511		Valve	--	yes		1×10^9	P/N 402000-2; Fairchild Hiller
1A49968-521		Valve	N/R	yes		N/R	P/N 527511; Snaptite Inc.
1A49969-503		Duct Assy	N/R	no		(N/R)	P/N 1303349-102; Stainless Steel Co.
1B58239-1		Vent Seal	Kel-F	yes	1.5×10^9	1×10^9	

Table 6-10

RECOMMENDED MODIFICATIONS - S-IVB PROPULSION SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed: Material	As Designed: Tolerance (ergs/gm(C))	Modified: Recommended Material	Modified: Tolerance (ergs/gm(C))
Childown Installation							
	1A82714-535	Receptacle	Required	Unknown	?	Vitreous glass**	--
	MC252C4TA (Typ)	Face coated seal	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
	1B58239	Vent seal	Required	Kel-F	1×10^{9}	Kynar	3×10^{10}
	14-449 (Typ)	Bearing	Desired	Teflon TFE/glass	8×10^{9}	Polyimide*	2×10^{10}
	22-7066 (Typ)	Wire, electrical	Required	Teflon TFE insul.	1×10^{8}	Polyimide	1×10^{10}
	22-7069	Sleeve, tubing	Not critical	Teflon TFE	1×10^{8}	Teflon/glass	1×10^{10}
	99-4444	Seal	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	--	Tape	Not critical	Teflon TFE	2×10^{7}	Rubber/glass	1×10^{10}
	S0046T-xx (Typ)	O-ring	Required	Teflon TFE	7×10^{6}	Polyimide	2×10^{10}
	66-502	Seal, ring	Desired	Teflon TFE/glass	5×10^{9}	Kynar	3×10^{10}
	65-214	Gasket	Desired	Teflon TFE/glass	5×10^{9}	Kynar*	3×10^{10}
	64-406	Seal	Required	Teflon FEP	7×10^{8}	Kynar	3×10^{10}
	PR-1939	Sealant	Required	Silicone rubber	1×10^{9}	Polyimide	2×10^{10}
	22-7061	Wire, electrical	Required	Silicone insul.	1×10^{9}	Polyimide	1×10^{10}
	MGC61085C275	Face coated gasket	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
Engine Installation							
	1B58239	Vent seal	Required	Kel-F	1×10^{9}	Kynar	3×10^{10}
	1B67912	Face coated seal	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
	103826	Engine assy (see Table 6-11)				See Table 6-11	
Orifice Installation							
	MC252C4TA	Face coated seal	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
	1B58239	Vent seal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	AR10105-017A1Q	Seal	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	24798 (Typ)	Packing	Desired	Silicone rubber	1×10^{9}	Polyimide	2×10^{10}
Pneumatic System (1B58008)							
	MC252C4TA	Face coated seal	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
	1B58239	Vent seal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	1B65813-x	Fabric and cord	Not critical	Nylon	1×10^{9}	Polyimide	3×10^{10}
	S0046T-xx	O-ring	Required	Teflon TFE	7×10^{6}	Polyimide	2×10^{10}
Ambient Repression System							
	S0046T26	O-ring	Required	Teflon TFE	7×10^{6}	Polyimide	2×10^{10}
	25901	Valve seat	Desired	Kel-F	1×10^{9}	Polyimide	2×10^{10}
	No. 48	Seal	Not critical	Teflon TFE	7×10^{6}	Polyimide*	2×10^{10}
	62575-A	Face coated seal	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
	622-139	Seal	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	--	O-ring, connector	Not critical	Silicone rubber	1×10^{9}	Vitreous glass**	2×10^{10}
	1B58239	Vent seal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
Oxidizer Vent System							
	MC252C4TA (Typ)	Face coated seal	Not critical	Teflon TFE	1×10^{8}	Kynar coated*	3×10^{10}
	528-92 (Typ)	Seal or seat	Required	Teflon TFE	7×10^{6}	Polyimide	2×10^{10}
	S0046T161	O-ring	Required	Teflon TFE	7×10^{6}	Polyimide	2×10^{10}
	1B58239	Vent seal	Required	Kel-F	1×10^{9}	Kynar	3×10^{10}
	171-153 (Typ)	Gasket	Not critical	Kel-F	1×10^{9}	Kynar*	3×10^{10}
	931-21	Receptacle	Required	Unknown	?	Vitreous glass**	--

Table 6-10 (cont'd)

RECOMMENDED MODIFICATIONS - S-IVB PROPULSION SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Oxidizer Vent System (cont'd)							
	528-91 (Typ)	Seal	Desired	Teflon TFE/glass	5×10^{9}	Kynar	3×10^{10}
	AN6290	O-ring	Required	Teflon TFE	7×10^{6}	Polyimide	2×10^{10}
	--	Tubing	Not Critical	Teflon TFE	1×10^{8}	Teflon/glass	1×10^{10}
	528-59	Retainer ring	Not critical	Kel-F	1×10^{9}	Polyimide*	3×10^{10}
	519-127	Insert	Not critical	Teflon TFE/glass	8×10^{9}	Polyimide*	3×10^{10}
	528-45	Valve seat	Required	Kel-F	1×10^{9}	Kynar	3×10^{10}
	519-85	Spacer	Not critical	Kel-F	3×10^{9}	Laminated epoxy*	2×10^{10}
	528-110	Plug	Not critical	Kel-F	3×10^{9}	Polyimide*	3×10^{10}
	MS9068	O-ring	Desired	Viton A	6×10^{9}	Polyimide	2×10^{10}
GH_2 Vent System							
	ASF 200 (Typ)	Seal or seat	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	MC252C4TA (Typ)	Face coated seal	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
	1B58239	Vent seal	Required	Kel-F	1×10^{9}	Kynar	3×10^{10}
	S0046T-xx	O-ring	Required	Teflon TFE	7×10^{6}	Polyimide	2×10^{10}
	1A93730	Gasket or seal	Not critical	Teflon TFE/glass	5×10^{9}	Kynar*	3×10^{10}
	1A94469-x	Sleeve	Not critical	Nylon or Aclar	1×10^{9}	Teflon/glass	1×10^{10}
	--	Tubing	Not critical	Teflon TFE	1×10^{8}	Teflon/glass	1×10^{10}
	511-61 (Typ)	Gasket	Not critical	Silicone rubber	8×10^{8}	Kynar*	3×10^{10}
	511-5 (Typ)	Gasket or valve seat	Not critical	Kel-F	1×10^{9}	Kynar*	3×10^{10}
	519-127	Insert	Not critical	Teflon TFE/glass	8×10^{9}	Polyimide*	3×10^{10}
	2-15S604	O-ring	Required	Silicone rubber	8×10^{8}	Polyimide	2×10^{10}
	519-117	Seal	Desired	Mylar	6×10^{9}	Kynar	3×10^{10}
	519-47	Retainer ring	Not critical	Kel-F	1×10^{9}	Polyimide*	3×10^{10}
	519-85 (Typ)	Spacer or plug	Not critical	Kel-F	3×10^{9}	Polyimide*	3×10^{10}
	931-14	Bearing	Required	Teflon TFE	3×10^{7}	Polyimide*	3×10^{10}
	931-9	Retainer ring	Not critical	Teflon TFE	7×10^{6}	Polyimide*	3×10^{10}
	AN6290	O-ring	Required	Teflon TFE	7×10^{6}	Polyimide	2×10^{10}
	931-21	Receptacle	Required	Unknown	?	Vitreous glass**	--
	Dri-lube	Lubricant	Required	Teflon base spray	1×10^{8}	MoS_2	--
Pneumatic Power (1B75000)							
	MC252C4TA	Face coated seal	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
	S0046T18	Gasket	Required	Teflon TFE	7×10^{6}	Kynar*	3×10^{10}
	1B58239	Vent seal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	24798 (Typ)	Packing	Not critical	Silicone rubber	1×10^{9}	Polyimide	2×10^{10}
	--	Wire, electrical	Required	Teflon TFE insul.	1×10^{8}	Polyimide	1×10^{10}
	AR10105-017A1Q	Seal	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	1B67481-xx	Seal	Desired	Silicone rubber	8×10^{8}	Kynar	3×10^{10}
	--	Connector	Desired	Silicone rubber insert	1×10^{9}	Vitreous glass**	--
Pneumatic System (1B58006)							
	MC252C4TA (Typ)	Face coated seal	Not critical	Teflon TFE coated	1×10^{8}	Kynar coated*	3×10^{10}
	25901	Valve seat	Desired	Kel-F	1×10^{9}	Polyimide	2×10^{10}
	No. 48	Seal	Not critical	Teflon TFE	7×10^{6}	Polyimide*	2×10^{10}
	5045-002-0-2	Liner	Not critical	Teflon TFE	1×10^{8}	Asbestos/rubber	3×10^{10}
	1B58239	Seal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}

Table 6-10 (cont'd)

RECOMMENDED MODIFICATIONS - S-IVB PROPULSION SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Pneumatic System (1B58006) (cont'd)							
	MS28775	O-ring	Desired	Buna N	1x10^{9}	Polyimide	2x10^{10}
	622-139	Seal	Required	Teflon TFE	7x10^{6}	Kynar	3x10^{10}
	622-123	Seal	Desired	Teflon TFE/glass	5x10^{9}	Kynar	3x10^{10}
	S0139T8 (Typ)	O-ring	Desired	Teflon TFE	7x10^{6}	Polyimide	2x10^{10}
	MGC60778C12	Face coated gasket	Not critical	Teflon TFE coated	1x10^{8}	Kynar coated*	3x10^{10}
	PT1H-8-3P	O-ring, connector	Desired	Silicone rubber	1x10^{9}	Vitreous glass**	--
Pneumatic Power (1B75003)							
	MC252C4TA	Face coated seal	Not critical	Teflon TFE coated	1x10^{8}	Kynar coated*	3x10^{10}
	24798 (Typ)	Packing	Not critical	Silicone rubber	1x10^{9}	Polyimide	2x10^{10}
	AR10105-017A1Q	Seal	Required	Teflon TFE	7x10^{6}	Kynar	3x10^{10}
	--	Wire, insulated	Required	Teflon TFE	1x10^{8}	Polyimide	1x10^{10}
	10414087-x	Packing	Not critical	Teflon TFE	7x10^{6}	Polyimide	2x10^{10}
Pneumatic System (1B66405)							
	MC252C4TA	Face coated seal	Not critical	Teflon TFE coated	1x10^{8}	Kynar coated*	3x10^{10}
	MGC60778C12	Face coated gasket	Not critical	Teflon TFE coated	1x10^{8}	Kynar coated*	3x10^{10}
	S0046T26 (Typ)	O-ring	Required	Teflon TFE	7x10^{6}	Polyimide	2x10^{10}
	1B58239 (Typ)	Seal	Required	Kel-F	1x10^{9}	Kynar	3x10^{10}
	25901	Valve seat	Required	Kel-F	1x10^{9}	Polyimide	2x10^{10}
	No. 48	Seal	Not critical	Teflon TFE	7x10^{6}	Polyimide*	2x10^{10}
	548-43	Valve seat	Desired	Mylar	6x10^{9}	Polyimide	2x10^{10}
	548-xx	Gasket	Not critical	Mylar	6x10^{9}	Polyimide*	2x10^{10}
	--	O-ring, connector	Not critical	Silicone rubber	1x10^{9}	Polyimide**	2x10^{10}
	CMS-101-K2	Plug	Not critical	Kel-F	3x10^{9}	Polyimide*	3x10^{10}
	622-139	Seal	Required	Teflon TFE	7x10^{6}	Kynar	3x10^{10}
	548-46-xx	Wire, electrical	Required	Teflon TFE insul.	1x10^{8}	Polyimide	1x10^{10}
Pneumatic Power (1B75004)							
	MC252C4TA	Face coated seal	Not critical	Teflon TFE coated	1x10^{8}	Kynar coated*	3x10^{10}
	S0046T-xx	O-ring	Required	Teflon TFE	7x10^{6}	Polyimide	2x10^{10}
	1B58239	Vent seal	Required	Kel-F	1x10^{9}	Kynar	3x10^{10}
	1B29290-xx	Pads	Not critical	Teflon TFE	1x10^{8}	Asbestos/rubber	3x10^{10}
	PRP568-902 (Typ)	Gasket	Not critical	Unknown	?	Polyimide*	2x10^{10}
	PRP568-020 (Typ)	O-ring	Required	Unknown	?	Polyimide	2x10^{10}
	64-809	Valve seat	Required	Kel-F	1x10^{9}	Polyimide	2x10^{10}
	MS28774	Backup ring	Not critical	Teflon TFE	7x10^{6}	Polyimide	3x10^{10}
	24798	Packing	Not critical	Silicone rubber	1x10^{9}	Polyimide	2x10^{10}
	AR10105-017A1Q	Seal	Required	Teflon TFE	7x10^{6}	Kynar	3x10^{10}
	--	O-ring	Not critical	Silicone rubber	1x10^{9}	Polyimide**	2x10^{10}
	S-20000-006AG	O-ring	Required	Unknown	?	Polyimide	2x10^{10}
	S-21000-2AG	O-ring	Required	Unknown	?	Polyimide	2x10^{10}
	MGC60778C-12A	Face coated gasket	Not critical	Teflon TFE coated	1x10^{8}	Kynar coated*	3x10^{10}
	PRR2118-026	O-ring	Required	Teflon TFE	7x10^{6}	Polyimide	2x10^{10}
	10414087-x	Packing	Not critical	Teflon TFE	7x10^{6}	Polyimide	2x10^{10}
	42272	Thread lock	Not critical	Nylon	3x10^{9}	Polyimide*	3x10^{10}
	1B67481-xx	Seal	Required	Silicone rubber	8x10^{8}	Kynar	3x10^{10}

Table 6-10 (cont'd)

RECOMMENDED MODIFICATIONS - S-IVB PROPULSION SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Burner Installation							
	K2319-40-x	Liner for mount	Not critical	Teflon TFE	$1x10^8$	Asbestos/rubber	$3x10^{10}$
	S0046T37	O-ring	Required	Teflon TFE	$7x10^6$	Polyimide	$2x10^{10}$
	MC252C4TA (Typ)	Face coated seal	Not critical	Teflon TFE coated	$1x10^8$	Kynar coated*	$3x10^{10}$
	1P20056	Lubricant	Not critical	Perfluorinated aliphatic	$1x10^8$	MoS_2	--
	1B59008-x	Filter liner	Required	Teflon TFE	$1x10^8$	Metal	--
	1A35427	Gasket	Not critical	Unknown	?	Kynar*	$3x10^{10}$
	1B66627	Gasket	Not critical	Teflon FEP	$7x10^8$	Kynar*	$3x10^{10}$
	1B66798	Valve seat	Required	Teflon TFE	$7x10^6$	Polyimide	$2x10^{10}$
	101-004	Seal	Required	Teflon TFE	$7x10^6$	Kynar	$3x10^{10}$
	7869679	Wire, electrical	Required	Teflon TFE insul.	$1x10^8$	Polyimide	$1x10^{10}$
LH_2 Fill System							
	S0046T-xx	O-ring	Required	Teflon TFE	$7x10^6$	Polyimide	$2x10^{10}$
	S0046S-xx	O-ring	Required	Silicone rubber	$8x10^8$	Polyimide	$2x10^{10}$
	1A77906-x (Typ)	Sealant	Required	Silicone rubber	$1x10^9$	Polyimide	$2x10^{10}$
	1B66935	Seal	Required	Kel-F	$1x10^9$	Kynar	$3x10^{10}$
	1A78053-x	Sleeve	Not critical	Nylon fabric	$3x10^9$	Teflon/glass	$1x10^{10}$
Switch Installation							
	MC252C4TA	Face coated seal	Not critical	Teflon TFE coated	$1x10^8$	Kynar coated*	$3x10^{10}$
	MAE57	Sleeve	Not critical	Silicone rubber	$2x10^9$	Teflon/glass	$1x10^{10}$
	--	Wire, electrical	Required	Teflon TFE insul.	$1x10^8$	Polyimide	$1x10^{10}$
	JGD121	Ring seal	Desired	Viton A	$6x10^9$	Kynar	$3x10^9$
	--	O-ring	Not critical	Silicone rubber	$1x10^9$	Polyimide	$2x10^{10}$
	JEB330B	Receptacle	Required	Unknown	?	Vitreous glass**	--
Oxidizer Feed System							
	FC6511002	Seal	Required	Unknown	?	Kynar	$3x10^{10}$
	S0046T-xx	O-ring	Required	Teflon TFE	$7x10^6$	Polyimide	$2x10^{10}$
	1B66935 (Typ)	Seal	Required	Kel-F	$1x10^9$	Kynar	$3x10^{10}$

*Use soft metal if possible
**Specify connectors with glass inserts

each reactor operation, similar components might be required.

The radiation sensitive materials contained in the S-IVB propulsion system and a description of their applications are summarized in Table 6-9. With the exception of the following components, all chilldown system components were reviewed:

Component Description	Part Number	Manufacturer
Grease	DPM-3329-1	McDonnell Douglas
Relief valve	7696938	McDonnell Douglas
Electrical receptical	46019-14-19P	Deutsch Co.
Switch	1HM25	Microswitch Co.
Actuator	67-091	McDonnell Douglas
Electrical receptical	22651-14-19P	McDonnell Douglas

The DPM-3329-1 anti-galling grease is used to lubricate bolts and is not considered critical. Usage of dry film non-organic lubricants such as MoS_2 will facilitate disassembly. Specifying electrical connectors and recepticals with ceramic inserts will permit their usage in environments greater than $1x10^{10}$ ergs/gm(C). Polyimide insulated wiring and Kynar seals, gaskets, and valve seats will permit usage of the relief valves and actuators to exposures greater than 1×10^{10} ergs/gm(C).

The above modifications in conjunction with those recommended in Table 6-10 increase the recommended tolerance of the basic design from 7×10^6 ergs/gm(C) to 1×10^{10} ergs/gm(C) for the modified design, which is in excess of the predicted environment, 1.5×10^9 ergs/gm(C).

6.3.4.2 Engine Installation

The engine system installation (Dwg 1B66894-523) includes the J-2 engine and the interfacing seals and disconnects for installing the J-2 engine into the S-IVB vehicle. The modifications described in Table 6-10 increase the recommended tolerance of the supporting components to 3×10^{10} ergs/gm(C). The J-2 engine system is discussed in detail in Section 6.4.

6.3.4.3 Forward and Tunnel Section Switch Installation

The forward and tunnel section switch installation (Dwg 1B58000-505) could not be analyzed due to the unavailability of vendor drawings for the pressure switch (Hydra-Electric Co.; P/N 72215-501) which is the only radiation sensitive component contained in this subsystem. The switch assemblies are high performance calibratable pressure switches which are employed in the controls circuit for operations such as controlling the LH_2 ground fill valve, first and second burn flight controls, and during prepressurization and repressurization of the LH_2 tank. Analysis of other pressure switches manufactured to the same specification as Dwg 1B52624 (Consolidated Controls Corp.; P/N 21SN25, discussed in conjunction with the aft section switch installation, Dwg 1B58001-507) indicates that it can be radiation hardened to reliably function in nuclear environments up to 1×10^{10} ergs/gm(C).

6.3.4.4 Calibrated Orifice Installation

The calibrated orifice installation, Dwg 1B58007, is a flight critical system containing the necessary seals, etc. for the installation of calibrated orifices into the following S-IVB propulsion subsystems:

1. LOX tank pressurization system
2. Ambient helium repressurization system
3. LH_2 tank pressurization system
4. Engine pump purge control system

In addition to the seals, the only component of the calibrated orifice installation containing radiation sensitive materials is the engine pump purge control module (Sterer Manufacturing Company; P/N 38170-1), which contains a two-way solenoid valve and uses helium for engine pump purge control. The radiation hardening analysis could not be completed due to the unavailability of drawings for the two-way solenoid valve. The Specification Control Drawing for this module, 1A58347, indicates:

1. The electrical connector for the solenoid valve is a Bendix Corp. P/N PT1H-8-3P having a silicone rubber insert with a radiation tolerance of $1x10^9$ ergs/gm(C).

2. Wiring between connectors and internal components of the solenoid valve conforms to Douglas Specification 7869679, which specifies Teflon TFE insulation (radiation tolerance of $1x10^8$ ergs/gm(C)), or to MIL-W-16878 which specifies either Teflon TFE or Teflon FEP insulated wires.

3. Diodes are used in parallel with the coils of the solenoid.

Based on this information, it is believed that the solenoid assembly can be radiation hardened for reliable operation in nuclear environments of 1 x 10^{10} ergs/gm(C) by specifying connectors with glass inserts, using polyimide insulated wiring, and judiciously selecting diodes. These modifications coupled with those described in Table 6-10 increase the recommended tolerance of the basic design from 7 x 10^{6} ergs/gm(C) to 1 x 10^{10} ergs/gm(C) for the modified configuration, which is greater than the predicted environment, 6 x 10^{8} ergs/gm(C).

6.3.4.5 Main Fuel Tank Pneumatic System Installation

The components required for the installation of the main fuel tank pneumatic system (Dwg 1B58008-507) include the necessary piping, seals, and valves for providing pneumatic pressure to the propellant tank from the helium storage bottles. The radiation sensitive materials and components of the basic design can be radiation hardened by the modifications recommended in Table 6-10 such that reliable performance of the main fuel tank pneumatic system can be expected at nuclear exposures of 1 x 10^{10} ergs/gm(C), which exceeds the predicted environment, 6 x 10^{8} ergs/gm(C).

6.3.4.6 Ambient Repressurization System

The ambient repressurization system for the oxygen and hydrogen propellant tanks and the dual repressurization system installation are flight critical systems which contain the necessary piping, valves, seals, and control functions for connecting the helium storage bottles with the propellant tanks and regulating the tank pressure. With the exception of the solenoid assembly (Calmec Mfg. Co.; P/N 548-48) contained in the repressurization control module, all ambient repressurization system components were examined for radiation sensitive materials and applications. The solenoid assembly can be radiation hardened by replacing the Teflon wire insulation with polyimide insulation. This modification in conjunction with those recommended in Table 6-10 results in a system with a recommended tolerance of 6×10^9 ergs/gm(C). If necessary, this limit could be increased to 1×10^{10} ergs/gm(C) by replacing the Mylar gaskets with a more radiation resistant material.

6.3.4.7 Oxidizer Tank Vent System

The RNS will not contain an oxidizer tank; however, many of the components of the S-IVB oxidizer tank vent system (Dwg 1B69013-503) might be employed in other RNS systems. This system contains all the necessary seals, gaskets, pipes, and vent and relief valve assemblies for venting the oxidizer tank and preventing excessive pressure buildup. These components can be radiation hardened to 1×10^{10} ergs/gm(C) by performing the modifications recommended in Table 6-10.

6.3.4.8 GH_2 Vent System

A gaseous hydrogen vent system, similar to the S-IVB system (Dwg 1B74943-507), will be required for the RNS to control the pressure in the LH_2 tank assembly and prevent excessive pressures throughout the propellant feed system. All components, except the following, were examined for radiation sensitive materials:

Component Description	Part Number	Manufacturer
Switch assembly	511-96	Calmec Mfg Co.
Connector	1A82714-533	Deutsch Co.
Switch	931-27	Microswitch Co.
Switch assembly	519-67	Calmec Mfg Co.
Electrical receptical	931-21	Calmec Mfg Co.

Although the drawings and specifications for these components were not available for analysis, it is believed they can be radiation hardened by:

1. Specifying electrical connectors and recepticals with ceramic inserts.
2. Using polyimide insulated wiring.
3. Replacing all other organic materials required for their construction with Kynar or other radiation resistant materials.

The recommended radiation tolerance of the basic system, 7×10^6 ergs/gm(C), can be increased to 1×10^{10} ergs/gm(C) by the material substitution and minor design modifications recommended in Table 6-10.

6.3.4.9 Main Oxidizer Tank Pneumatic System

The RNS design does not include an oxidizer tank; however, it could incorporate the design and functional philosophy of the S-IVB main oxidizer tank pneumatic system (Dwg 1B58006-503) for controlling the transfer of gaseous helium between the helium storage bottles and the liquid hydrogen propellant tank. In addition to the gaskets and seal materials recommended for the modified design, many of the valves and actuation control modules could be employed in the RNS pneumatic system. The check valve used in the cold helium fill line (J. C. Carter Co.; P/N 60192) can be radiation hardened to exposures of 3×10^{10} ergs/gm(C) by replacing the Kel-F valve seat with Kynar. The cold helium dump control module (Calmec Mfg. Co.; P/N 659-511) contains a solenoid valve and a relief valve that can be radiation hardened to 1×10^{10} ergs/gm(C) by the modifications recommended in Table 6-10. The tank pressurization control module (Calmec Mg. Co.; P/N 622-513), which contains two filters, a pressure regulator, and three solenoid valves, can be radiation hardened to 1×10^{10} ergs/gm(C) by the modifications recommended in Table 6-10.

6.3.4.10 Pneumatic System Installation

Although the RNS design will most probably not contain a system directly analogous to the liquid oxygen and hydrogen burner pneumatic system installation (Dwg 1B66405-501), many of the valve assemblies might be incorporated into the design of the

RNS pneumatic system.

Repressurization of the propellant tanks, prior to J-2 engine restart, is attained by passing cold helium, from the helium spheres in the LH_2 tank, through the O_2/H_2 burner. The heated helium is then routed to the propellant tanks. Should the O_2/H_2 burner fail, ambient repressurization ensures propellant tank pressure for engine restart. The solenoid actuated cold helium control valve (Calmec Mfg. Co.; P/N 548-515), which is the major component in this system, can be radiation hardened to 1×10^{10} ergs/gm(C) by the modifications described in Table 6-10. All supporting seals, gaskets, and check valves can be hardened to this level by the modifications described in Table 6-10.

6.3.4.11 Pneumatic Power Installation

The S-IVB pneumatic control system, which controls pressure to all pneumatically actuated valves in the propulsion fill, vent, and chilldown systems, consists of three basic installations:

1. The forward skirt and tunnel installation (Dwg 1B75000)
2. The aft skirt installation (Dwg 1B75003)
3. The thrust structure installation (Dwg 1B75804)

The RNS pneumatic power system will be quite similar and encompass many of the same functions and components.

6.3.4.11.1 Forward Skirt and Tunnel Installation

Detailed analysis were performed for all components except the ¼-in. vent port check valve assembly (James, Pond, Clark, Inc.; P/N P36-673) which prevents contamination by back flow and cryo-pumping of dirt and moisture laden air or gaseous nitrogen into the system during periods of ground operation. The Specification Control Drawing for this check valve, Dwg 1B67481, specifies silicone rubber seals which have a recommended radiation tolerance of 8×10^8 ergs/gm(C). The modifications recommended in Table 6-10 increase the recommended limit to 6×10^9 ergs/gm(C), which exceeds the predicted environment, 3×10^8 ergs/gm(C).

6.3.4.11.2 Aft Skirt Installation

Detailed analyses were performed on all components except the disconnect assembly (Purolator Co.; P/N 1198004-02); however, it is believed that it can be radiation hardened to exposures greater than 1×10^{10} ergs/gm(C) through material substitution. The primary component in this system, the actuation control module (Sterer Mfg. Co.; P/N 31850-3), as well as the supporting seals, gaskets, valves, etc. can be radiation hardened to exposures of 1×10^{10} ergs/gm(C) by the modifications described in Table 6-10.

6.3.4.11.3 Thrust Structure Installation

The thrust structure installation consists of the helium fill module assembly (Fairchild Hiller; P/N 64-820-04), an actuation control module (Sterer Mfg. Co.; P/N 31850-3), a pneumatic control module (Adel Mfg. Co.; P/N A-62390-531), a pneumatic control valve assembly (Adel Mfg. Co.; P/N 72552), and miscellaneous valves, gaskets, and seals.

The helium fill module assembly contains a check valve, a solenoid actuated dump valve, and a relief valve which can be radiation hardened, by the modification noted in Table 6-10, to exposures of 1 x 10^{10} ergs/gm(C). Although many of the gasket and seal materials contained in the actuation control module, the pneumatic control module, and the control valve assemblies could not be identified, the substitution materials recommended in Table 6-10 will permit usage of these components at nuclear exposures of up to 1 x 10^{10} ergs/gm(C).

6.3.4.12 Burner Installation

The liquid hydrogen-liquid oxygen burner system (Dwg 1B67212-501) will not be required for the RNS; however, many of the components contained in this system might be incorporated into various RNS systems. Modifications described in Table 6-10 will be required for hardening these components for RNS applications.

6.3.4.13 Liquid Hydrogen Fill System

The RNS will require a liquid hydrogen fill system quite similar to the S-IVB system (1B74477-509). The two major components, i.e., the fill-and-drain valve (Fairchild Hiller; P/N 402000-2) and the prevalve (Snaptite, Inc.; P/N 527510) could not be analyzed in detail due to the unavailability of vendor drawings.

The Specification Control Drawing for the prevalve, Dwg 1A49968, indicates:

1. The valve is a normally open pneumatic operated shutoff valve which shuts off the propellant flow from the propellant tank during chilldown operation and also during an emergency.

2. It consists of a valve body, a butterfly gate, a pneumatic actuator, several position indicating switches, and a relief valve.

3. The electrical connectors have glass inserts.

4. Teflon TFE insulated wiring conforming to Douglas Specification 7869679 is used between the connector and the internal electrical components.

Usage of polyimide insulated wiring and substitution of Kynar gaskets and seals for the synthetic rubber components should result in a system radiation hardened to 1×10^{10} ergs/gm(C).

The Specification Control Drawing for the fill-and-drain valve, Dwg 1A48240, indicates:

1. The valve assembly consists of a valve body, two position indicator switches, a helium pressure actuator, several shaft seals, and a check valve to prevent flow into the vent ports.

2. The electrical connectors have glass inserts.

3. Teflon TFE insulated wiring conforming to Douglas Specification 7869679 is used for actuator and switch circuits.

4. Lubricants and sealants are dry film types in accordance with Douglas Specification 7696938.

5. Kel-F seals and gaskets, in accordance with Specification AMS-3650, are used throughout the valve assembly.

Usage of polyimide insulated wiring and replacement of the Kel-F seals and gaskets with Kynar should result in a valve assembly capable of reliable operations at dosages of up to 1×10^{10} ergs/gm(C).

The above recommendations coupled with those described in Table 6-10 should result in a liquid hydrogen fill system with a recommended tolerance of 1×10^{10} ergs/gm(C).

6.3.4.14 Switch Installation

The aft section switch installation, Dwg 1B58001-507, employs many components having potential application in the RNS. Detailed analyses were performed for all components except the following:

Component Description	Part Number	Manufacturer
Switch	JEG-182	Microswitch
Receptical	22690-8-4P	Deutsch Co.
Disconnect assy	1265004-06	Purolator Products
Switch assy	72214-513	Hydra Electric Co.

The Specification Control Drawing for the calibratable pressure switch assembly, 1B52623-515, indicates that the electrical connector is a Bendix Corp. P/N PT06E-8-4S configuration which has a silicone rubber insert. The specification control drawing describing the requirements of the switch specifies Teflon TFE insulated wiring. Usage of polyimide insulated wiring, ceramic inserts in the electrical connectors and recepticals, Kynar gaskets and seals in the disconnect assembly, coupled with the modifications recommended in Table 6-10, increases the recommended tolerance of this switch installation to 1×10^{10} ergs/gm(C).

6.3.4.15 Oxidizer Feed System

The RNS does not have an oxidizer feed system; however, many of the components required for the S-IVB oxidizer feed system (Dwg 1B68375-501), e.g., the fill-and-drain valve (Fairchild Hiller; P/N 402000-2), might be incorporated into the RNS propulsion system. The modifications recommended for radiation hardening these components are described in Table 6-10.

6.4 Engine System

6.4.1 Description and Location

The J-2 engine system, which is the primary subsystem of the S-II and S-IVB propulsion systems, is capable of multiple restarts. It is a high-performance, high-altitude engine utilizing liquid hydrogen and liquid oxygen as propellants. The engine system selected for this analysis, which is defined by North American Rockwell Drawing 103826-2035, is representative of both S-II and S-IVB engine assemblies. Support equipment and components unique to each stage are discussed in Sections 6.3 and 7.6.

Although the J-2 engine itself will not be utilized in the RNS, many of the materials, components, and subsystems contained in the J-2 engine assembly have potential application in the RNS.

For the purposes of this analysis, the predicted nuclear environment for each of the major subsystems (Table 6-11) is assumed to be 1.5×10^9 ergs/gm(C).

6.4.2 Summary

Based upon analyses presented in Section 6.4.4, it is believed that each of the major components and subsystems of the J-2 engine assembly can be radiation hardened to levels greater than 1×10^{10} ergs/gm(C), thus resulting in subsystems that can reliably function at exposures greater than the predicted exposure of 1.5 x 10^9 ergs/gm(C). Table 6-11 summarizes the predicted nuclear environment and the recommended radiation tolerance of both the basic, i.e. as designed, system and the modified configuration of each subsystem.

6.4.3 System Breakdown and Recommended Modifications

Drawings, specifications, and parts lists were examined to determine radiation sensitive materials whose performance characteristics might degrade due to the influence of radiation. Table 6-12 summarizes these materials, describes their applications, and presents for comparative purposes the recommended tolerance and predicted nuclear environment. The recommended modifications and the resulting improvements are described in Table 6-13.

6.4.4 Radiation Hardening Analysis

6.4.4.1 Thrust Chamber and Gimbal Installation

The J-2 engine thrust chamber and gimbal installation (Dwg 206276) will not be utilized in the RNS. However, some of the components might be incorporated into RNS systems. Since some leakage of gases from the thrust chamber can be tolerated, most of the organic seals are not considered critical to the engine performance. Metal seals and gaskets should be used wherever possible; however, the modifications recommended in Table 6-13 should result in a system that can reliably operate at nuclear exposures greater than 1 x 10^{10} ergs/gm(C).

Table 6-11

RADIATION HARDENING SUMMARY — J-2 ENGINE SYSTEM

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C)) As Designed	Recommended Tolerance (ergs/gm(C)) As Modified	Remarks
Thrust chamber	206276	$1.5x10^9$	$1x10^{10}$	Not required	
Start system	303927	$1.5x10^9$	$1x10^8$	$1x10^{10}$	
Gas generator	303926	$1.5x10^9$	$1x10^9$	$1x10^{10}$	
Propellant feed	406651	$1.5x10^9$	$7x10^6$	$1x10^{10}$	
Flight instrumentation	702527	$1.5x10^9$	$1x10^8$	$1x10^{10}$	
Customer connections	103850	$1.5x10^9$	$1x10^9$	$2x10^{10}$	
Control system	404665	$1.5x10^9$	$7x10^6$	$1x10^{10}$	

Table 6-12

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
206276	Thrust Chamber & Gimbal Instl		--	yes	1.5×10^9	1×10^{10}	
404659		Face coated seal	Teflon TFE coated	no		(1×10^8)	
404669		Face coated seal	Teflon TFE coated	no		(1×10^8)	
NA5-260053		Boot	Synthetic rubber	no		(2×10^9)	Material not specified (assumed silicone)
206280-11		Igniter Assy	--	yes		1×10^{10}	
651388		Igniter	--	yes		1×10^{10}	
4420		Tape, insulation	Rubber	yes		1×10^{10}	P/N 4420; Conn. Hard Rubber Co.
206606-21		Thrust Chamber	--	yes		*	
404638-3		Face coated seal	Teflon TFE coated	no		(1×10^8)	
404656-87		Face coated seal	Teflon TFE coated	no		(1×10^8)	
404659		Face coated seal	Teflon TFE coated	no	1.5×10^9	(1×10^8)	
303927	Start System		--	yes	1.5×10^9	1×10^8	
404656		Face coated seal	Teflon TFE coated	yes		1×10^8	
309020-11		Valve Assy	--	yes		1×10^8	
MS28778		Packing	Synthetic rubber	no		(1×10^9)	MIL-G-5510
MS29513		Packing	Synthetic rubber	no		(6×10^9)	MIL-P-5315
303472		Lipseal	Kel-F	yes		1×10^9	
303473		Lipseal	Kel-F	yes		1×10^9	
303474		Lipseal	Kel-F	yes		1×10^9	
308946		Face coated seal	Teflon TFE coated	yes		1×10^8	
404657-5		Face coated seal	Teflon TFE coated	yes		1×10^8	
553372-11		Valve, vent	--	yes		6×10^9	
RD262-4006		O-ring	Viton A	yes		6×10^9	
404659		Face coated seal	Teflon TFE coated	no		(1×10^8)	
557756		Valve Assy	--	yes		7×10^8	
MS29512		Gasket	Synthetic rubber	no		(6×10^9)	MIL-P-5315
404630		Face coated seal	Teflon TFE coated	no		(1×10^8)	
406119		Seal	Teflon FEP	yes		7×10^8	RB0130-007
553842		Seal	Teflon FEP	yes		7×10^8	
NA5-27291		Pressure Switch	--	yes		1×10^9	
MS33682		Connector	--	yes		1×10^9	MIL-C-5015
--		Insert	Silicone rubber	yes		1×10^9	
--		End plug	Nylon	no		(3×10^9)	
404657-15		Face coated seal	Teflon TFE coated	no		(1×10^8)	
404673-33		Face coated seal	Teflon TFE coated	no		(1×10^8)	
407909		Face coated seal	Teflon TFE coated	yes		1×10^8	
307599-41		Manifold Assy	--	yes		7×10^8	
309050		Valve	--	yes		7×10^8	
308935		Poppet seal	Teflon FEP	yes		7×10^8	RB0130-007
304386-21		Valve Assy	--	yes		1×10^8	
MS29513		Packing	Synthetic rubber	no		(6×10^9)	MIL-P-5315
303474		Lipseal	Kel-F	yes		1×10^9	
304378		Sleeve	Teflon TFE/glass	no		(1×10^{10})	Rulon
304381		Seal	N/R	yes		N/R	
401204		Face coated seal	Teflon TFE coated	yes		1×10^8	
304398		Gasket	N/R	no		(N/R)	
309299-3		Lipseal	N/R	yes		N/R	
557998-41		Valve Assy	--	yes		1×10^8	
MS29512		Packing	Synthetic rubber	no		(6×10^9)	MIL-P-5315
558301-21		Valve	--	yes	1.5×10^9	1×10^8	

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
638-2-3-TC-2030V		Face coated seal	Teflon TFE coated	yes	1.5×10^9	1×10^8	P/N 638-2-3-TC-2030V; Advanced Prod.
558312-21		Solenoid assy	--	yes		1×10^8	
--		Sleeving	N/R	no		(N/R)	RB0150-009
558308		Receptacle	N/R	yes		N/R	
558311		Coil	--	yes		1×10^8	
--		Wire, elec.	Teflon TFE insul.	yes		1×10^8	
406119		Seal	Teflon FEP	yes		7×10^8	RB0130-007
410870		Face coated seal	Teflon TFE coated	no		(1×10^8)	
553842		Seal	Teflon FEP	yes		7×10^8	
307570-11		Start System	--	yes		1×10^8	
NA5-27215		Transducer	--	yes		1×10^9	
MS33680-3		Receptacle	--	yes		1×10^9	
--		Packing	Synthetic rubber	yes		1×10^9	AMS-3209
404656		Face coated seal	Teflon TFE coated	no		(1×10^8)	
404657-5		Face coated seal	Teflon TFE coated	no		(1×10^8)	
404659		Face coated seal	Teflon TFE coated	no		(1×10^8)	
404666-7		Face coated seal	Teflon TFE coated	no		(1×10^8)	
404673		Face coated seal	Teflon TFE coated	no		(1×10^8)	
306875		Valve Assy	--	yes		1×10^9	
MS28778		Packing	Synthetic rubber	no		(1×10^9)	MIL-G-5510
MS29513		Packing	Synthetic rubber	no		(6×10^9)	MIL-P-5315
303472		Lipseal	Kel-F	yes		1×10^9	
303474		Lipseal	Kel-F	yes		1×10^9	
404657-5		Face coated seal	Teflon TFE coated	no		(1×10^8)	
553372		Valve	--	yes		6×10^9	
RD262-4006		O-ring	Viton A	yes		6×10^9	
557998		Valve Package	--	yes		1×10^8	
MS29512		Packing	Synthetic rubber	no		(6×10^9)	
406119		Seal	Teflon FEP	yes		7×10^8	RB0130-007
410870		Face coated seal	Teflon TFE coated	no		(1×10^8)	
553842		Seal	Teflon FEP	yes		7×10^8	
558301-21		Valve Assy	--	yes		1×10^8	
638-2-3-TC-2030V		Seal	Teflon TFE coated	yes		1×10^8	P/N 638-2-3-TC-2030V; Advanced Prod.
558312-21		Solenoid	--	yes		1×10^8	
--		Sleeving	N/R	no		(N/R)	RB0150-009
558308		Receptacle	N/A	yes		N/A	
558311		Coil	--	yes		1×10^8	
--		Wire, elec.	Teflon TFE insul.	yes	1.5×10^9	1×10^8	
303926	Gas Generator		--	yes	1.5×10^9	1×10^9	
409940		Valve Assy	--	yes		1×10^9	
MS29512		Packing	Synthetic rubber	no		(6×10^9)	MIL-P-5315
405916		Seal	Mylar	yes		6×10^9	
405827		Seal	Mylar	yes		6×10^9	
404579		Seal	Mylar	yes		6×10^9	
553364		Valve, Relief	--	yes		6×10^9	
553153		Poppet seal	Viton A	yes		6×10^9	
13-1806		Seal	N/R	yes		N/R	P/N 13-1806; Hydrodyne
405913		Seal	Mylar	yes		6×10^9	RB0130-039
405922		Spacer	Asbestos/rubber	no		(3×10^{10})	MIL-A-17472A
408012		Resistor Assy	--	yes		1×10^9	
--		Potting	Silicone rubber	no	1.5×10^9	(2×10^9)	RA0106-035

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
NA5-27285		Resistor Switch	--	yes	1.5×10^9	1×10^9	
--		Wire, elec.	Teflon FEP insul.	yes	1.5×10^9	1×10^9	MIL-W-16878/4
406651	Propellant Feed		--	yes	1.5×10^9	7×10^6	
458175-61		Turbopump	--	yes		7×10^6	
AR-10105-253AIM		Seal	Teflon TFE	yes		7×10^6	P/N AR-10105-253A1M; Aeroquip Corp.
RD262-4006		Packing	Viton A	yes		6×10^9	
11-1473		Seal	N/R	yes		N/R	P/N 11-1473; Hydrodyne
11-1730		Seal	N/R	yes		N/R	P/N 11-1730; Hydrodyne
1100-35-0101		Seal	N/R	yes		N/R	P/N 1100-35-0101; Hydrodyne
404664		Seal Assy	--	yes		1×10^8	
--		Face coated seal	Teflon TFE coated	no		(1×10^8)	
0500-3-3-TC		O-ring	Teflon TFE coated	yes		1×10^8	P/N 0500-3-3-TC; Advanced Prod.
410864		Face coated seal.	Teflon TFE coated	yes		1×10^8	
456260		Gasket	Mylar	no		(6×10^9)	
456289		Grommet	Silicone rubber	no		(2×10^9)	AMS-3302
308880		Valve assy	--	yes		7×10^8	
--		Potting	Silicone rubber	no		(2×10^9)	RB0120-005; Type V
308412		Poppet Assy	--	yes		7×10^8	
--		Seal	Teflon FEP	yes		7×10^8	RB0130-007
308414		Insulator	Kel-F	no		(2×10^9)	
308424		Ring	Kel-F	no		(1×10^9)	RB0130-009
NA5-27286T18		Receptacle	--	yes		1×10^9	
--		Insert	Silicone rubber	yes		1×10^9	
308409		Ring	Kel-F	no		(1×10^9)	RB0130-009
--		Wire, elec.	Teflon FEP insul.	yes		1×10^9	MIL-W-16878/4
--		Sleeve	N/R	no		(N/R)	RB0150-009
NA5-10577-068		Spacer	N/R	no		(N/R)	
404656		Face coated seal	Teflon TFE coated	no		(1×10^8)	
459000-101		Turbopump Assy	--	yes		1×10^8	
NA5-260070		Seal	Epoxy resin coated	yes		2×10^{10}	P/N C33223; Sealol Inc.
456183		Gasket	Asbestos/rubber	no		(5×10^9)	MIL-A-7021; Class 1
406348		Face coated seal	Teflon TFE coated	no		(1×10^8)	
303862		Face coated seal	Teflon TFE coated	no		(1×10^8)	
NA5-27328		Transducer	--	yes		1×10^9	
NA5-27286T1		Receptacle	--	yes		1×10^9	
--		Insert	Silicone rubber	yes		1×10^9	
404664		Seal Assy	--	yes		1×10^8	
--		Face coated seal	Teflon TFE coated	no		(1×10^8)	
0500-3-3-TC		O-ring	Teflon TFE coated	yes		1×10^8	P/N 0500-3-3-TC; Advanced Prod.
AR-105C0-2318AIM		Face coated seal	Teflon TFE coated	no		(1×10^8)	
457440		Spacer/seal	Teflon TFE coated	no		(1×10^8)	
309040		Valve Assy	--	yes		1×10^8	
MS28778		Packing	Synthetic rubber	yes		1×10^9	MIL-G-5510
MS29513		Packing	Synthetic rubber	yes		6×10^9	MIL-P-5315
NA5-27307		Potentiometer	--	yes		1×10^8	
--		Wire, elec.	Teflon TFE insul.	yes		1×10^8	
--		Connector	--	yes		1×10^9	MIL-C-5015
--		Insert	Silicone rubber	yes		1×10^9	
		End plug	Nylon	no		(3×10^9)	
302557		Gasket	Kel-F	no	1.5×10^9	(1×10^9)	RB0130-005

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
553372		Valve	--	yes	1.5×10^{9}	6×10^{9}	
RD262-4006		O-ring	Viton A	yes		6×10^{9}	
404657-9		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
NA5-27323T3		Transducer	--	yes		1×10^{9}	
MS3106		Receptacle	--	yes		1×10^{9}	
MS28900		Packing	Synthetic rubber	yes		1×10^{9}	AMS-3209
251351		Valve Assy	--	yes		7×10^{8}	
MS29512		Packing	Synthetic rubber	yes		6×10^{9}	MIL-P-5315
408767		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
459719-3		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
459760-5		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
553364		Valve	--	yes		6×10^{9}	
553153		Poppet seal	Viton A	yes		6×10^{9}	
NA5-26726T4		Actuator	--	yes		7×10^{8}	
--		Servo-motor	N/A	yes		N/A	Not specified
--		Potentiometer	N/A	yes		N/A	Not specified
251401		Seal	Mylar	yes		6×10^{9}	
251373		Seal	Teflon FEP	yes		7×10^{8}	RB0130-007
409969		Valve Assy	--	yes		1×10^{9}	
407089		Seal	Kel-F	yes		1×10^{9}	RB0130-005
MS29512		Gasket	Synthetic rubber	no		(6×10^{9})	MIL-P-5315
MS29513		Packing	Synthetic rubber	yes		6×10^{9}	MIL-P-5315
404561		Seal	Mylar	yes		6×10^{9}	
553364		Valve	--	yes		6×10^{9}	
553153		Poppet seal	Viton A	yes		6×10^{9}	
404562		Spacer	Asbestos/Teflon	no		(1×10^{10})	RB0130-064
405817		Position Indicator	--	yes		1×10^{9}	
NA5-27285		Switch	--	yes		1×10^{9}	
--		Wire, elec.	Teflon FEP insul.	yes		1×10^{9}	MIL-W-16878/4
NA5-27286		Receptacle	--	yes		1×10^{9}	
--		Insert	Silicone rubber	yes		1×10^{9}	
--		Potting	Silicone rubber	no		(2×10^{9})	RA0106-035
405818		Lipseal	Mylar	no		(6×10^{9})	
NA5-27285		Switch Assy	--	yes		1×10^{9}	
--		Wire	Teflon FEP insul.	yes		1×10^{9}	MIL-W-16878/4
404576		Seal	Mylar	yes		6×10^{9}	
406707		Lipseal	Mylar	yes		6×10^{9}	RB0130-039
404658-3		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
405827		Lipseal	Mylar	yes		6×10^{9}	
407408		Lipseal	Kel-F	yes		1×10^{9}	
407406		Lipseal	Mylar	yes		6×10^{9}	
404673		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
404657		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
404700		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
404659		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
404675		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
404666		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
459709		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
459767		Face coated seal	Teflon TFE coated	no		(1×10^{8})	
459765		Face coated seal	Teflon TFE coated	no	1.5×10^{9}	(1×10^{8})	

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
309031		Valve Assy	--	yes	$1.5x10^9$	$1x10^9$	
308739		Switch assy	--	yes		$1x10^9$	
--		Wire, elec.	Teflon FEP insul.	yes		$1x10^9$	MIL-W-16878/4
--		Sleeve	N/R	no		(N/R)	RB0150-009
--		Potting	Silicone rubber	no		$(2x10^9)$	RA0106-035
NA5-27286		Receptacle	--	yes		$1x10^9$	
--		Insert	Silicone rubber	yes		$1x10^9$	
308737		Insulator	Epoxy laminate	no		$(2x10^{10})$	MIL-P-18177; Type GEE
308736		Insulator	Epoxy laminate	no		$(2x10^{10})$	MIL-P-18177; Type GEE
411619-21		Valve Assy	--	yes		N/R	
309029		Valve	N/R	yes		N/R	
309036		Valve Assy	--	yes		$1x10^9$	
308737		Insulator	Epoxy laminate	no		$(2x10^{10})$	MIL-P-18177; Type GEE
308739		Switch Assy	--	yes		$1x10^9$	
--		Wire, elec.	Teflon FEP insul.	yes		$1x10^9$	MIL-W-16878/4
--		Sleeve	N/R	no		(N/R)	RB0150-009
--		Potting	Silicone rubber	no		$(2x10^9)$	RA0106-035
NA5-27286		Receptacle	--	yes		$1x10^9$	
--		Insert	Silicone rubber	yes		$1x10^9$	
MS28778		Packing	Synthetic rubber	yes		$1x10^9$	MIL-G-5510
553373		Valve Assy	--	yes		$6x10^9$	
RD262-4006		O-ring	Viton A	yes		$6x10^9$	
558127-11		Valve Assy	--	yes		$1x10^9$	
556973		Back-up ring	Mylar	no		$(1x10^{10})$	
555782		Seal	Kel-F	yes		$1x10^9$	RB0130-009
553372		Valve	--	yes		$6x10^9$	
RD262-4006		O-ring	Viton A	yes		$6x10^9$	
MS28778		Packing	Synthetic rubber	yes		$1x10^9$	MIL-G-5510
MS29513		Packing	Synthetic rubber	yes		$6x10^9$	MIL-P-5315
555781		Seal	Kel-F	yes		$1x10^9$	
556962		Diaphragm	Mylar	yes		$6x10^9$	
557817-11		Valve Assy	--	yes		$1x10^9$	
556973		Backup ring	Mylar	no		$(1x10^{10})$	
555782		Seal	Kel-F	yes		$1x10^9$	
MS28778		Packing	Synthetic rubber	yes		$1x10^9$	MIL-G-5510
MS29513		Packing	Synthetic rubber	yes		$6x10^9$	MIL-P-5315
555781		Seal	Kel-F	yes		$1x10^9$	
556962		Diaphragm	Mylar	yes		$6x10^9$	
553948		Ring, retainer	N/R	no		(N/R)	
146005 (typ)		Insulation	Polyurethane foam	no		$(5x10^9)$	
503110 (typ)		Insulation	Silicone foam	no	$1.5x10^9$	$(2x10^9)$	RB0130-068
702527	Flight Instrumentation		--	yes	$1.5x10^9$	$1x10^8$	
NA527321		Transducer	--	yes		*	
--		Insulator	Cotton phenolic	yes		$3x10^9$	MIL-P-15035; Type FBM
404666-7		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
408795		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
404659		Face coated seal	Teflon TFE coated	no	$1.5x10^9$	$(1x10^8)$	

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
NA5-27215T-X		Transducer	--	yes	$1.5x10^9$	$1x10^9$	
MS33680-3		Receptacle	--	yes		$1x10^9$	
--		Insert	Synthetic rubber	yes		$1x10^9$	AMS-3209
121238-3		Face coated seal	Teflon TFE coated	yes		$1x10^8$	P/N 121238-3; Technical Industries
19-501745		Boot	Silicone rubber	no		$(2x10^9)$	
19-501743		Boot	Silicone rubber	no		$(2x10^9)$	
702626		Wiring Harness	--	yes		$1x10^9$	
--		Wire, elec.	Teflon FEP insul.	yes		$1x10^9$	MIL-W-16878/4
NA5-27316T2		Transducer	--	yes		$1x10^9$	
--		Potting	N/R	no		(N/R)	Unspecified
NA5-27286		Receptacle	--	yes		$1x10^9$	
--		Insert	Silicone rubber	yes		$1x10^9$	
703953		Spacer	Cotton phenolic	no		$(3x10^9)$	MIL-P-15035; Type FBM
NA5-27323T3		Transducer	--	yes		$1x10^9$	
MS3106		Receptacle	--	yes		$1x10^9$	
MS28900		Insert	Synthetic rubber	yes		$1x10^9$	AMS-3209
704121		Cable, Jumper	--	yes		$1x10^8$	
--		Cable, jacket	Teflon TFE insul.	no		$(1x10^8)$	AB0150-007-22-3; Type II
--		Wire, elec.	Teflon TFE insul.	yes		$1x10^8$	RB0150-028
--		Potting	Epoxy, silica filled	no		$(2x10^{10})$	RA0106-004
RD414-1009		Connector	--	yes		$1x10^9$	
MS28900		O-ring	Synthetic rubber	no		$(1x10^9)$	AMS-3209
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
RD414-1010		Connector	--	yes		$1x10^9$	MIL-C-5015
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
PA534-30		Transducer	N/R	yes		N/R	P/N PA 534-30; Statham Instruments
704120		Cable, Jumper	--	yes		$1x10^8$	
--		Cable, jacket	Teflon TFE insul.	no		$(1x10^8)$	AB0150-007
--		Wire, elec.	Teflon TFE insul.	yes		$1x10^8$	RB0150-028
--		Potting	Epoxy, silica filled	no		$(2x10^{10})$	RA0106-004
RD414-1011		Connector	--	yes		$1x10^9$	MIL-C-5015
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
704114 (typ)		Harness Assy	--	yes		$1x10^8$	
--		Cable, jacket	Teflon FEP	no		$(1x10^9)$	RB0150-015 (RB0150-029)
--		Wire, elec.	Teflon TFE insul.	yes		$1x10^8$	RB0150-019
--		Insulation	Mylar film	yes		$1x10^{10}$	MIL-I-631; Type G
501727-41		Plug Assy	--	yes		$1x10^9$	
RD414-1009		Connector	--	yes		$1x10^9$	
MS28900		O-ring	Synthetic rubber	no		$(1x10^9)$	AMS-3209
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
RD414-1011		Connector	--	yes		$1x10^9$	MIL-C-5015
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
--		Tubing	Silicone rubber	no	$1.5x10^9$	$(2x10^9)$	

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
704124		Harness Assy	--	yes	$1.5x10^9$	$1x10^8$	
704124-xx		Tubing	Silicone rubber	no		$(2x10^9)$	
--		Cable, jacket	Teflon FEP	no		$(1x10^9)$	RB0150-015
--		Wire, elec.	Teflon TFE insul.	yes		$1x10^8$	RB0150-019
--		Insulation, elec.	Mylar film	yes		$1x10^{10}$	MIL-I-631; Type G
501740-131		Receptacle	--	yes		$1x10^9$	RD414-1010 (less sleeve)
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
19-704550-2		Tubing	Silicone rubber	no		$(2x10^9)$	RB0130-065
19-704549		Molding	Silicone rubber	no		$(2x10^9)$	RB0130-065
501727-41 (typ)		Plug Assy	--	yes		$1x10^9$	
RD414-1009		Connector	--	yes		$1x10^9$	
MS28900		O-ring	Synthetic rubber	no		$(1x10^9)$	AMS-3209
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
701696		Sensor Assy	--	yes		$1x10^9$	
MS3100E10SL-3P		Receptacle	--	yes		$1x10^9$	MIL-C-5015
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
--		Tubing	Teflon TFE	no		$(1x10^8)$	MIL-I-22129
P2650		Tape	Silicone rubber	no		$(1x10^9)$	
10-40861-3		Grommet	Neoprene	no		$(1x10^9)$	P/N 10-40861-3; Bendix Corp.
10-60712-4		Grommet	Neoprene	no	$1.5x10^9$	$(1x10^9)$	P/N 10-60712-4; Bendix Corp.
103850	Customer Connections		--	yes	$1.5x10^9$	$1x10^9$	
404657		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
404700		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
MS28777		Backup ring	Leather	no		$(5x10^9)$	MIL-R-5521
MS28778		Packing	Synthetic rubber	yes		$1x10^9$	MIL-G-5510
404673		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
404659		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
19-501743		Boot	Silicone rubber	no		$(2x10^9)$	
19-501745		Boot	Silicone rubber	no	$1.5x10^9$	$(2x10^9)$	
556101	Control System		--	yes	$1.5x10^9$	$7x10^6$	
404665		Seal Assy	--	yes		*	
--		Adhesive	Silicone rubber base	no		$(1x10^{10})$	RTV-112; General Electric
556948		Regulator Assy	--	yes		$7x10^6$	
NA5-27273		Valve	--	yes		$1x10^{10}$	
--		Wire, elec.	Polyimide film insul.	yes		$1x10^{10}$	MIL-W-583; Class 220 M
S11052-250		Seal, piston	Teflon TFE	yes		$7x10^6$	P/N S11052-250; W. S.Shamban Co.
2012		Packing	Asbestos/Teflon	yes		$1x10^{10}$	P/N 2012; Johns Manville Co.
404655-3		Face coated seal	Teflon TFE coated	no		$(1x10^8)$	
404659		Face coated seal	Teflon TFE coated	no	$1.5x10^9$	$(1x10^8)$	

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
553364		Valve Assy	--	yes	1.5x10^{9}	6x10^{9}	
553153		Poppet seal	Viton A	yes		6x10^{9}	
553372		Valve Assy	--	yes		6x10^{9}	
RD262-4006		O-ring	Viton A	yes		6x10^{9}	
553375		Valve Assy	--	yes		6x10^{9}	
RD262-4006		O-ring	Viton A	yes		6x10^{9}	
553842		Seal	Teflon FEP	yes		7x10^{8}	
554018		Poppet	N/R	yes		N/R	
554019		Guide	N/R	yes		N/R	
554863		Seal	Nylon	yes		5x10^{8}	MIL-I-17091; Type I
554867		Diaphragm	Mylar	yes		6x10^{9}	
554868		Diaphragm assy	Mylar	yes		6x10^{9}	
554927		Diaphragm	Mylar	yes		6x10^{9}	
555797		Diaphragm	Mylar	yes		6x10^{9}	
556501		Diaphragm	Mylar	yes		6x10^{9}	
404673		Face coated seal	Teflon TFE coated	no		(1x10^{8})	
MS28778		Packing	Synthetic rubber	yes		1x10^{9}	MIL-G-5510
RD262-4006		O-ring	Viton A	yes		6x10^{9}	
404657		Face coated seal	Teflon TFE coated	no		(1x10^{8})	
404666		Face coated seal	Teflon TFE coated	no		(1x10^{8})	
404658		Face coated seal	Teflon TFE coated	no		(1x10^{8})	
404659		Face coated seal	Teflon TFE coated	no		(1x10^{8})	
19-501750		Probe	--	yes		1x10^{9}	
--		Insert	Silicone rubber	yes		1x10^{9}	
MS33682		Connector	--	yes		1x10^{9}	MIL-C-5015
--		Insert	Silicone rubber	yes		1x10^{9}	
--		End plug	Nylon	no		(3x10^{9})	
651387		Spark Igniter	--	yes		1x10^{10}	
4420		Tape insulation	Rubber	yes		1x10^{10}	P/N 4420; Conn. Hard Rubber Co.
121314-2		Face coated seal	Teflon TFE coated	yes		1x10^{8}	P/N 121314-2; Technical Industries
459724		Face coated seal	Teflon TFE coated	no		(1x10^{8})	
MS28778		Packing	Synthetic rubber	no		(1x10^{9})	MIL-G-5510
12100CR-x		Face coated seal	Teflon TFE coated	yes		1x10^{8}	P/N 12100CR-x; Technical Industries
19-501743		Boot	Silicone rubber	no		(2x10^{9})	
19-501745		Boot	Silicone rubber	no		(2x10^{9})	
459709		Face coated seal	Teflon TFE coated	no		(1x10^{8})	
RD421-5001		Insulator, thermal	Silicone rubber	no		(2x10^{9})	
408767		Face coated seal	Teflon TFE coated	no		(1x10^{8})	
209741		Insulator, thermal	Silicone rubber	no		(2x10^{9})	RB0130-068
503109		Insulator, thermal	Silicone rubber	no		(2x10^{9})	RB0130-068
MS29513		Packing	Synthetic rubber	no		(6x10^{9})	MIL-P-5315
501744		Receptacle	--	yes		1x10^{9}	
--		Wire, elec.	Teflon FEP insul.	yes		1x10^{9}	MIL-W-16878/4
RD414-1010		Connector	--	yes	1.5x10^{9}	1x10^{9}	MIL-C-5015

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
--		Insert	Silicone rubber	yes	$1.5x10^{9}$	$1x10^{9}$	
--		End plug	Nylon	no		$(3x10^{9})$	
500750		Probe Assy	--	yes		$1x10^{9}$	
19-501750		Probe	--	yes		$1x10^{9}$	
--		Insert	Silicone rubber	yes		$1x10^{9}$	
MS33682		Connector	--	yes		$1x10^{9}$	MIL-C-5015
--		Insert	Silicone rubber	yes		$1x10^{9}$	
--		End plug	Nylon	no		$(3x10^{9})$	
553364		Valve Assy	--	yes		$6x10^{9}$	
553153		Poppet seal	Viton A	yes		$6x10^{9}$	
553372		Valve Assy	--	yes		$6x10^{9}$	
RD262-4006		O-ring	Viton A	yes		$6x10^{9}$	
RD284-1001		Valve Assy	--	yes		N/R	
AN6227		Packing	N/R	no		(N/R)	MIL-P-5316
47A1562		O-ring	N/R	yes		N/R	
558272		Valve Assy	--	yes		*	
MS29513		Packing	Synthetic rubber	no		$(6x10^{9})$	MIL-P-5315
AN6227		Packing	N/R	no		(N/R)	MIL-P-5316
502951		Wiring Harness	--	yes		$1x10^{8}$	
502951-xxx		Tubing	Silicone rubber	no		$(2x10^{9})$	
--		Wire, elec.	Teflon TFE insul.	yes		$1x10^{8}$	RB0150-019
--		Cable Jacket	Teflon FEP	no		$(1x10^{9})$	RB0150-015
--		Insulation	Mylar film	yes		$1x10^{10}$	MIL-I-631; Type G
RD262-4006		O-ring	Viton A	no		$(6x10^{9})$	
404673		Face coated seal	Teflon TFE coated	no		$(1x10^{8})$	
408776		Face coated seal	Teflon TFE coated	no		$(1x10^{8})$	
501727-41 (typ)		Plug Assy	--	yes		$1x10^{9}$	
RD414-1009		Connector	--	yes		$1x10^{9}$	
MS28900		O-ring	Synthetic rubber	no		$(8x10^{8})$	AMS-3209
--		Insert	Silicone rubber	yes		$1x10^{9}$	
--		End plug	Nylon	no		$(3x10^{9})$	
558126-11		Valve Assy	--	yes		$1x10^{9}$	
MS28778		Packing	Synthetic rubber	no		$(1x10^{9})$	MIL-G-5510
MS29513		Packing	Synthetic rubber	no		$(6x10^{9})$	MIL-P-5315
553364		Valve, Relief	--	yes		$6x10^{9}$	
553153		Poppet seal	Mylar	yes		$6x10^{9}$	
555781		Seal	Kel-F	yes		$1x10^{9}$	
556962		Diaphram	Mylar	yes		$6x10^{9}$	
557191		Seal	Kel-F	yes		$1x10^{9}$	
557213		Backup ring	Mylar	no		$(1x10^{10})$	
556947-31		Regulator Assy	--	yes		$7x10^{6}$	
MS28778		Packing	Synthetic rubber	no		$(1x10^{9})$	MIL-G-5510
NA5-27273		Valve	--	yes		$1x10^{10}$	
--		Wire, elec.	Polyimide film insul.	yes		$1x10^{10}$	MIL-W-583; Class 220 M
S11052-250		Seal, piston	Teflon TFE	yes		$7x10^{6}$	P/N S11052-250; W. S. Shamban Co.
2012		Packing	Asbestos/Teflon	yes		$1x10^{10}$	P/N 2012; Johns Manville Co.
404655		Face coated seal	Teflon TFE coated	no		$(1x10^{8})$	
404659		Face coated seal	Teflon TFE coated	no		$(1x10^{8})$	
553364		Valve, Relief	--	yes	$1.5x10^{9}$	$6x10^{9}$	

Table 6-12 (cont'd)

RADIATION SENSITIVE COMPONENTS - J-2 ENGINE SYSTEM (103826; ENGINE 2035)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
553153		Poppet seal	Viton A	yes	$1.5x10^9$	$6x10^9$	
553372		Valve Assy	--	yes		$6x10^9$	
RD262-4006		O-ring	Viton A	yes		$6x10^9$	
553375		Valve Assy	--	yes		$6x10^9$	
RD262-4006		O-ring	Viton A	yes		$6x10^9$	
553842		Seal	Teflon FEP	yes		$7x10^8$	
554018		Poppet	N/R	yes		N/R	
554019		Guide	N/R	yes		N/R	
554863		Seal	Nylon	yes		$5x10^8$	MIL-I-17091; Type I
554867		Diaphragm	Mylar	yes		$6x10^9$	
554868		Diaphragm assy	Mylar	yes		$6x10^9$	
554927		Diaphragm	Mylar	yes		$6x10^9$	
555797		Diaphragm	Mylar	yes		$6x10^9$	
556501		Diaphragm	Mylar	yes		$6x10^9$	
558069		Valve Assy	--	yes		N/R	
558065		Solenoid	N/R	yes		N/R	
502670		Control Assy	--	yes		N/R	
RD284-1001		Valve Assy	--	yes		N/R	
AN809-1		Valve core	N/R	yes		N/R	P/N 302-D; Dill Mfg. Co.
47A1562		O-ring	N/R	yes		N/R	
AN6227		Packing	N/R	no		(N/R)	MIL-P-5316
MS35489		Grommet	Synthetic rubber	no		$(2x10^9)$	MIL-G-3036
MS29512		Packing	Synthetic rubber	no		$(6x10^9)$	MIL-P-5315
--		Potting	Silicone rubber	no		$(2x10^9)$	RB0120-005; Type V
502274		Wiring Assy	--	yes		$1x10^9$	
--		Wire, elec.	Teflon FEP insul.	yes		$1x10^9$	MIL-W-16878/4
--		Tubing	Teflon TFE	no		$(1x10^8)$	MIL-I-22129
NA5-27383		Ignition Exciter	--	yes		$1x10^9$	
MS29513		O-ring	Synthetic rubber	no		$(1x10^9)$	MIL-P-5315
MS3367B		Connector	--	yes		$1x10^9$	MIL-C-5015
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
502699		Isolation Assy	--	no		*	
--		Tubing	Teflon TFE	no		$(1x10^8)$	
19-502958		Receptacle	--	yes		$1x10^9$	
--		Insert	Silicone rubber	yes		$1x10^9$	MIL-R-5847; Class II
MS29513		Packing	Synthetic rubber	no		$(6x10^9)$	MIL-P-5315
MS9021		Packing	Silicone rubber	no		$(1x10^9)$	AMS 7271
501854		Insulator	Mylar	no		$(1x10^{10})$	
502692		Insulator	Mylar	no		$(1x10^{10})$	
--		Wire, elec.	Teflon FEP insul.	yes		$1x10^9$	MIL-W-16878/4
--		Cable, jacket	Teflon TFE insul.	no		$(1x10^8)$	AB0150-006; Type IV
--		Cable, jacket	Teflon TFE insul.	no		$(1x10^8)$	AB0150-007
--		Tubing	Teflon TFE	no	$1.5x10^9$	$(1x10^8)$	AB0150-001

Table 6-13

RECOMMENDED MODIFICATIONS — J-2 ENGINE SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Thrust Chamber							
	404659 (Typ)	Face coated seal	Not critical	Teflon TFE coated	$1x10^{8}$	Kynar coated*	$3x10^{10}$
	NA5-260053	Boot	Not critical	Silicone rubber	$2x10^{9}$	Teflon/glass	$1x10^{10}$
Start System							
	404656 (Typ)	Face coated seal	Required	Teflon TFE coated	$1x10^{8}$	Kynar coated*	$3x10^{10}$
	MS28778	Packing	Not critical	Silicone rubber	$1x10^{9}$	Polyimide	$2x10^{10}$
	MS29513	Packing	Not critical	Viton A	$6x10^{9}$	Polyimide	$2x10^{10}$
	303472 (Typ)	Lipseal	Required	Kel-F	$1x10^{9}$	Kynar	$3x10^{10}$
	RD262-4006	O-ring	Desired	Viton A	$6x10^{9}$	Polyimide	$2x10^{10}$
	MS29512	Gasket	Not critical	Viton A	$6x10^{9}$	Kynar*	$3x10^{10}$
	406119 (Typ)	Seal	Required	Teflon FEP	$7x10^{8}$	Kynar	$3x10^{10}$
	MS33682	Insert, connector	Required	Silicone rubber	$1x10^{9}$	Vitreous material**	--
	308935	Poppet seal	Required	Teflon FEP	$7x10^{8}$	Kynar	$3x10^{10}$
	--	Wire, electrical	Required	Teflon TFE insul	$1x10^{8}$	Polyimide	$1x10^{10}$
	558308	Insert, receptacle	Required	Unknown	?	Vitreous material**	--
	RB0150-009	Sleeving	Not critical	Unknown	?	Teflon/glass	$1x10^{10}$
	309299	Lipseal	Required	Unknown	?	Kynar	$3x10^{10}$
	304398	Gasket	Not critical	Unknown	?	Kynar*	$3x10^{10}$
	304381	Seal	Required	Unknown	?	Kynar	$3x10^{10}$
Gas Generator							
	MS29512	Packing	Not critical	Viton A	$6x10^{9}$	Polyimide	$2x10^{10}$
	405916 (Typ)	Seal	Required	Mylar	$6x10^{9}$	Kynar	$8x10^{10}$
	--	Wire, electrical	Required	Teflon FEP insul	$1x10^{9}$	Polyimide	$1x10^{10}$
	13-1806	Seal	Required	Unknown	?	Kynar	$3x10^{10}$
	408012-xx	Potting	Not critical	Silicone rubber	$2x10^{9}$	Epoxy	$2x10^{10}$
Propellant Feed							
	AR10105-253 AIM	Seal	Required	Teflon TFE	$7x10^{6}$	Kynar	$3x10^{10}$
	410864 (Typ)	Face coated seal	Required	Teflon TFE coated	$1x10^{8}$	Kynar	$3x10^{10}$
	456260 (Typ)	Gasket	Desired	Mylar	$6x10^{9}$	Kynar*	$3x10^{10}$
	456289	Grommet	Desired	Silicone rubber	$2x10^{9}$	Polyimide	$3x10^{10}$
	308880-x	Potting	Not critical	Silicone rubber	$2x10^{9}$	Epoxy	$2x10^{10}$
	308412-x	Poppet seal	Required	Teflon FEP	$7x10^{8}$	Kynar	$3x10^{10}$
	308414	Insulator	Not critical	Kel-F	$2x10^{9}$	Laminated epoxy	$2x10^{10}$
	308424	Retainer ring	Not critical	Kel-F	$1x10^{9}$	Polyimide	$3x10^{10}$
	NA5-27286 (Typ)	Insert, receptacle	Required	Silicone rubber	$1x10^{9}$	Vitreous material**	--
	--	Wire, electrical	Required	Teflon FEP insul	$1x10^{9}$	Polyimide	$1x10^{10}$
	456183	Gasket	Not critical	Asbestos/rubber	$5x10^{9}$	Kynar*	$3x10^{10}$
	RD262-4006	O-ring	Desired	Viton A	$6x10^{9}$	Polyimide	$2x10^{10}$
	MS28778	Packing	Required	Silicone rubber	$1x10^{9}$	Polyimide	$2x10^{10}$
	MS29513	Packing	Required	Viton A	$6x10^{9}$	Polyimide	$2x10^{10}$
	--	Wire, electrical	Required	Teflon TFE insul	$1x10^{8}$	Polyimide	$1x10^{10}$
	302557	Gasket	Not critical	Kel-F	$1x10^{9}$	Kynar*	$3x10^{10}$

Table 6-13 (continued)

RECOMMENDED MODIFICATIONS — J-2 ENGINE SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed Material	As Designed Tolerance (ergs/gm(C))	Modified Recommended Material	Modified Tolerance (ergs/gm(C))
Propellant Feed (cont'd)							
	407089	Seal	Required	Kel-F	$1x10^{9}$	Kynar	$3x10^{10}$
	404561	Seal	Desired	Mylar	$6x10^{9}$	Kynar	$3x10^{10}$
	556962	Diaphragm	Desired	Mylar	$6x10^{9}$	Polyimide	$2x10^{10}$
	11-1473	Seal	Required	Unknown	?	Kynar	$3x10^{10}$
	11-1730	Seal	Required	Unknown	?	Kynar	$3x10^{10}$
	1100-35-0101	Seal	Required	Unknown	?	Kynar	$3x10^{10}$
	0500-3-3-TC	O-ring	Required	Teflon TFE coated	$1x10^{8}$	Kynar coated*	$3x10^{10}$
	RB0150-009	Sleeve	Not critical	Unknown	?	Teflon glass	$1x10^{10}$
	553948	Ring, retainer	Not critical	Unknown	?	Polyimide	$3x10^{10}$
Control System							
	404655 (Typ)	Face coated seal	Not critical	Teflon TFE coated	$1x10^{8}$	Kynar coated*	$3x10^{10}$
	RD262-4006 (Typ)	O-ring	Desired	Viton A	$6x10^{9}$	Polyimide	$2x10^{10}$
	553842 (Typ)	Seal	Required	Teflon FEP	$7x10^{8}$	Kynar	$3x10^{10}$
	554863 (Typ)	Seal	Required	Nylon	$5x10^{8}$	Kynar	$3x10^{10}$
	554867 (Typ)	Diaphragm	Desired	Mylar	$6x10^{9}$	Polyimide	$2x10^{10}$
	MS28778	Packing	Required	Silicone rubber	$1x10^{9}$	Polyimide	$2x10^{10}$
	MS33682 (Typ)	Connector, insert	Required	Silicone rubber	$1x10^{9}$	Vitreous glass**	--
	1200CR-x	Seal	Required	Teflon TFE	$7x10^{6}$	Kynar	$3x10^{10}$
	19-501743 (Typ)	Boot	Not critical	Silicone rubber	$2x10^{9}$	Teflon/glass	$1x10^{10}$
	RD421-5001 (Typ)	Insulator, thermal	Not critical	Silicone rubber	$2x10^{9}$	Asbestos/rubber	$3x10^{10}$
	MS29513	Packing	Not critical	Viton A	$6x10^{9}$	Polyimide	$2x10^{10}$
	--	Wire, electrical	Required	Teflon FEP insul.	$1x10^{9}$	Polyimide	$1x10^{10}$
	502951-xxx	Tubing	Not critical	Silicone rubber	$2x10^{9}$	Teflon/glass	$1x10^{10}$
	55781 (Typ)	Seal	Required	Kel-F	$1x10^{9}$	Kynar	$3x10^{10}$
	MS35489	Grommet	Not critical	Silicone rubber	$2x10^{9}$	Polyimide	$3x10^{10}$
	--	Wire, electrical	Required	Teflon TFE insul.	$1x10^{8}$	Polyimide	$1x10^{10}$
	S11052-250	Seal	Required	Teflon TFE	$7x10^{6}$	Kynar	$3x10^{10}$
	553153	Poppet seal	Required	Mylar	$6x10^{9}$	Kynar	$3x10^{10}$
	AN6227	Packing	Not critical	Unknown	?	Polyimide	$2x10^{10}$
	47A1562	O-ring	Required	Unknown	?	Polyimide	$2x10^{10}$
	--	Potting	Desired	Silicone rubber	$2x10^{9}$	Epoxy	$2x10^{10}$
Flight Instrumentation							
	NA5-27321-x	Insulator/spacer	Desired	Cotton/phenolic	$3x10^{9}$	Polyimide	$1x10^{10}$
	404666 (Typ)	Face coated seal	Not critical	Teflon TFE coated	$1x10^{8}$	Kynar coated*	$3x10^{10}$
	MS33680 (Typ)	Receptacle, insert	Required	Silicone rubber	$1x10^{9}$	Vitreous material**	--
	19-501745 (Typ)	Boot	Not critical	Silicone rubber	$2x10^{9}$	Teflon/glass	$1x10^{10}$
	--	Wire, electrical	Required	Teflon FEP insul.	$1x10^{9}$	Polyimide	$1x10^{10}$
	703953	Spacer	Not critical	Cotton/phenolic	$3x10^{9}$	Asbestos/rubber	$3x10^{10}$
	--	Wire, electrical	Required	Teflon TFE insul.	$1x10^{8}$	Polyimide	$1x10^{10}$
	121238	Seal	Required	Teflon TFE coated	$1x10^{8}$	Kynar coated*	$3x10^{10}$
	704124-x (Typ)	Tubing	Not critical	Silicone rubber	$2x10^{9}$	Teflon/glass	$1x10^{10}$
	19-704549	Molding	Not critical	Silicone rubber	$2x10^{9}$	Polyimide	$3x10^{10}$
	P2650	Tape	Not critical	Silicone rubber	$1x10^{9}$	Rubber/glass	$1x10^{10}$
	10-40861 (Typ)	Grommet	Not critical	Neoprene	$1x10^{9}$	Polyimide	$3x10^{10}$
	--	Potting	Not critical	Unknown	?	Epoxy	$2x10^{10}$
	MS28900	O-ring	Not critical	Silicone rubber	$1x10^{9}$	Polyimide	$2x10^{10}$

Table 6-13 (continued)

RECOMMENDED MODIFICATIONS — J-2 ENGINE SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Customer Connections							
	404657 (Typ)	Face coated seal	Not critical	Teflon TFE coated	$1x10^8$	Kynar coated*	$3x10^{10}$
	MS28777	Backup ring	Not critical	Leather	$5x10^9$	Aluminum*	--
	MS28778	Packing	Required	Silicone rubber	$1x10^9$	Polyimide	$2x10^{10}$
	19-501743 (Typ)	Boot	Not critical	Silicone rubber	$2x10^9$	Teflon/glass	$1x10^{10}$

*Use saft metal if possible
**Specify connectors with glass inserts

6.4.4.2 Start System

The start system, Dwg 303927, is part of the propellant management control system. It includes the necessary valve assemblies, seals, etc. for controlling and sequencing valve operations and flow from the start tank during each engine startup operation. Similar components will be required for the RNS propellant management system. The radiation tolerance of this system, 1×10^8 ergs/gm(C), can be increased to 1×10^{10} ergs/gm(C) through the modifications recommended in Table 6-13.

6.4.4.3 Gas Generator

The gas generator and exhaust system described in Dwg 303926 contains the necessary valve assemblies and switches for controlling the flow of GH_2 for acceleration of the turbopumps. The design philosophy for the RNS includes bootstrap turbopump operation; therefore, a gas generator system is not envisioned for RNS usage, although many of the valve components might be employed elsewhere in the RNS propellant management system. The modifications recommended in Table 6-13 will allow usage of these components in nuclear environments of up to 1×10^{10} ergs/gm(C).

6.4.4.4 Propellant Feed System

The RNS propellant feed system will be similar to the S-IVB propulsion system described in Dwg 406651, except only LH_2 is used in the RNS and the propellant bleed-off system is different.

The S-IVB stage propellant feed system is composed of integral LOX/LH_2 tanks, propellant lines, control valves, vents, and supporting control equipment for regulating flow of both LH_2 and LOX to the turbopumps. Loading of the propellant tanks and propellant flow are also controlled by the propellant feed system. Due to the larger requirements of LH_2 propellant, the size of the turbopump and associated plumbing will be different; however, the materials employed will be similar to those recommended in Table 6-13 for the modified configuration. With the exception of the actuator for the propellant utilization valve assembly (Dwg 251351), all components of the propellant feed system were analyzed for radiation sensitive materials.

The specification for the electromechanical actuator for the propellant utilization valve assembly (North American Rockwell Specification NA5-26726) indicates:

1. The use of packings, gaskets, and O-rings is prohibited.

2. Seal materials are not specified for all applications.

3. The actuator consists of a two-phase servomotor, gear train, and position measuring elements.

4. The resistance element of the position measuring potentiometer is made of conductive plastic.

5. Some of the electrical connectors contain silicone rubber inserts.

6. Insulation for electrical wiring is not specified.

Based on this information, it is believed that the actuator can be radiation hardened to 1×10^{10} ergs/gm(C) by:

1. Specifying Kynar seals
2. Using polyimide insulated electrical wire
3. Requiring ceramic inserts for all electrical connectors
4. Using potentiometers with wire wound resistance elements

The modifications recommended in Table 6-13 coupled with the above recommendations for the actuator should result in a propellant feed system capable of operating in nuclear environments as high as 1×10^{10} ergs/gm(C).

6.4.4.5 Flight Instrumentation

The components contained in the flight instrumentation system (Dwg 702527) are designed specifically to measure the J-2 engine operating parameters and, therefore, will only have limited application in the RNS. Temperature and pressure transducers similar to those required to measure RNS engine and propellant feed system parameters have demonstrated their reliability in nuclear environments greater than 1×10^{10} ergs/gm(C) (Ref. 28). Therefore, a high degree of confidence can be placed in this system if the modifications described in Table 6-13 are performed for the electrical harnesses, seals, and other support equipment.

6.4.4.6 Customer Connections

The seals, electrical harnesses, and other miscellaneous components required for integrating the propellant feed system and the J-2 engine system are described in Dwg 103850. Similar components as required for the RNS propellant feed system can be radiation hardened by modifications similar to those described in Table 6-13.

6.4.4.7 Control System

The control system for the S-IVB propellant management system (Dwg 556101) contains all the required valves, seals, regulators, solid-state printed circuit logic boards, etc. for controlling and monitoring propellants during fill-and-drain operations, powered flight, and engine shutdown. A control system analogous to this will be required for the RNS.

The solid-state electronics required for signal conditioning and telemetry of engine operating data to ground stations are contained in the Instrumentation Unit which is located in the forward skirt region where the predicted nuclear exposure is less than 1×10^7 ergs/gm(C). Since this study was directed toward organic materials, neither the electronic components contained on the printed circuit boards nor the supporting electronics equipment were analyzed. These electronic equipments require detailed analysis of their specific design before any recommendation regarding their radiation tolerance can be put forth.

The recommendations described in Table 6-13 radiation hardens each of the control system components to nuclear exposures greater than 1×10^{10} ergs/gm(C). Many of these components can be hardened to even higher levels by minor design modifications.

6.5 Structures Assembly

6.5.1 Description and Location

The S-IVB structures assembly (Dwg 1A39301-527) contains the load supporting members of the S-IVB vehicle and the necessary seals, fittings, etc. for interfacing each segment of the stage structure. Since the S-IVB and the RNS structures differ radically, it is doubtful if any of the S-IVB subassemblies will have application in the RNS design.

Since many of the S-IVB structure assembly components are fairly large, the assumed locations of each subassembly shown in Figure 6-4 is referenced to the highest nuclear environment to which it is exposed.

6.5.2 Summary

All S-IVB structures assembly subsystems can be radiation hardened by material substitution, thus providing a high degree of confidence in their performance in their assumed locations. Table 6-14 summarizes the recommended radiation tolerance of both the basic, i.e., as designed, and modified configurations. These limits can readily be compared with the predicted nuclear environment which is also presented in Table 6-14.

6.5.3 System Breakdown and Recommended Modifications

The radiation sensitive materials and components contained in the S-IVB structures assembly are summarized in Table 6-15.

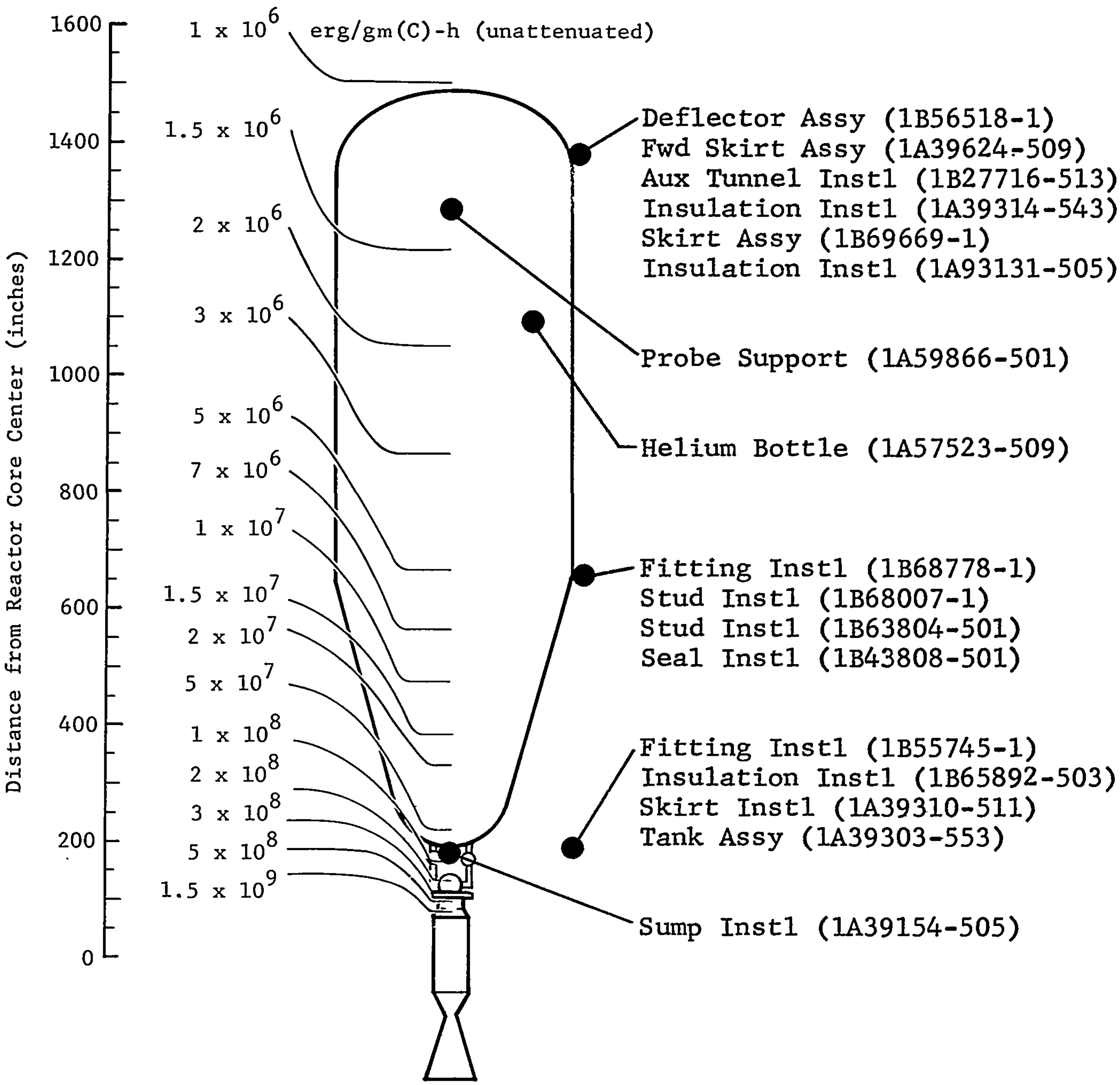


Figure 6-4 Assumed Location of (S-IVB) Structures Assembly Components

Table 6-14

RADIATION HARDENING SUMMARY — S-IVB STRUCTURES ASSEMBLY

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C)) As Designed	As Modified	Remarks
Insulation instl	1A93131-505	$1.4x10^7$	--	Not required	Not considered critical
Seal instl	1B43808-501	$1x10^8$	--	Not required	Not considered critical
Probe support	1A59866-501	$1.4x10^7$	$1x10^9$	Not required	
Tank assembly	1A39303-503	$5x10^9$	--	Not required	Does not contain critical organic comp.
Skirt assembly	1B69669-1	$1.4x10^7$	--	Not required	Does not contain critical organic comp.
Insulation instl	1A39314-543	$1.4x10^7$	--	Not required	Not considered critical
Tunnel instl	1A39313-507	$1x10^8$	--	Not required	Not considered critical
Aux tunnel instl	1B27716-513	$1.4x10^7$	--	Not required	Not considered critical
Forward skirt assy	1A39624-509	$1.4x10^7$	--	Not required	Not considered critical
Skirt instl	1A39310-511	$5x10^9$	--	Not required	Not considered critical
Helium bottle	1A57523-509	$1.9x10^7$	$7x10^6$	$2x10^{10}$	
Deflector assy	1B56518-1	$1.4x10^7$	--	Not required	Not considered critical
Stud instl	1B63804-501	$1x10^8$	--	Not required	Not considered critical
Insulation instl	1B65892-503	$5x10^9$	--	Not required	

Table 6-14 (continued)

RADIATION HARDENING SUMMARY — S-IVB STRUCTURES ASSEMBLY

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))		Remarks
			As Designed	As Modified	
Fitting instl	1B55745-1	$5x10^9$	--	Not required	All metal
Stud instl	1B68007-1	$1x10^8$	--	Not required	All metal
Fitting instl	1B68778-1	$1x10^8$	--	Not required	All metal
Sump instl	1A39154-505	$1.5x10^9$	--	Not required	All metal

Table 6-15

RADIATION SENSITIVE COMPONENTS — S-IVB STRUCTURES ASSEMBLY (1A39301-527)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
1A93131-505	Insulation Installation		--	no	$1.4x10^7$	*	
1A93131-29 (Typical)		Liner	Al polyethylene	no	$1.4x10^7$	$(1x10^9)$	
--		Adhesive	Polysulfide base	no	$1.4x10^7$	$(6x10^9)$	1P20098
1B43808-501	Seal Installation		--	no	$1x10^8$	*	
1B43388-501		Seal	Neoprene	no		$(6x10^8)$	
1B44621-507		Boot	Nylon fabric	no		$(3x10^9)$	
1B56752-1		Seal	Neoprene	no	$1x10^8$	$(6x10^8)$	
1A59866-501	Probe Support		--	yes	$1.4x10^7$	$1x10^9$	
1A57821-1		Support assembly	--	yes		$1x10^9$	
--		Insulation	Polyurethane foam	yes		$5x10^9$	1P20011
--		Sealant	Synthetic rubber	yes		$1x10^9$	1P20057
--		Adhesive	Polyurethane base	yes		$1x10^{10}$	1P20075
--		Resin	Epoxy resin	yes	$1.4x10^7$	$2x10^{10}$	MIL-R-9300
1A39303-553	Tank Assembly		--	yes	$5x10^9$	*	
1A72911-1		Insulation	Polyurethane foam	no	$5x10^9$	$(5x10^9)$	
1B69669-1	Skirt Assembly		--	yes	$1.4x10^7$	*	
1B32995-507		Seal assembly	--	no		*	
9709143		Sealant	Silicone	no		$(1x10^9)$	
--		Sealant	Polysulfide rubber	no		$(5x10^9)$	MIL-S-8802
1B33150-1		Seal assembly	--	no		*	
--		Sealant	Polysulfide rubber	no		$(5x10^9)$	MIL-S-8802
--		Sealant	Polysulfide rubber	no		$(5x10^9)$	MIL-S-8784
1B52342-1		Seal	Silicone rubber	no		$(8x10^8)$	P/N S-1387637-1126
1B69669-857		Seal	Silicone rubber	no		$(8x10^8)$	
--		Adhesive	Silicone base	no		$(1x10^{10})$	1P20014
--		Sealant	Polysulfide rubber	no	$1.4x10^7$	$(5x10^9)$	MIL-S-8802
1A39314-543	Insulation Installation		--	no	$1.4x10^7$	*	
1A39314-3		Doubler	Plastic laminate	no		$(2x10^{10})$	
1A39296-527		Dome insulation installation	--	no		*	
1B56481-503		Pad	Polyurethane/glass	no		$(2x10^{10})$	
1B67832-1		Pad	Polyurethane/glass	no		$(2x10^{10})$	
--		Adhesive	Epoxy base	no		$(1x10^{10})$	1P20001
--		Adhesive	Polyurethane base	no		$(1x10^{10})$	1P20075
--		Adhesive	Polyurethane base	no		$(1x10^{10})$	MMM-A-188
1A89613-509 } 1A78175-523 }		Insulation Installation	--	no		*	
--		Adhesive	Epoxy base	no		$(1x10^{10})$	1P20001
--		Adhesive	Polyurethane base	no		$(1x10^{10})$	1P20075
--		Adhesive	Polyurethane base	no	$1.4x10^7$	$(1x10^{10})$	MMM-A-188
1A39313-507	Tunnel Installation		--	no	$1x10^8$	*	
1A39313-13		Gasket	Asbestos/rubber	no		$(5x10^9)$	
1A39313-33 (Typical)		Gasket	Silicone rubber	no		$(8x10^8)$	
1A39313-43		Doubler	Plastic laminate	no		$(2x10^{10})$	
--		Adhesive	Polyurethane base	no		$(1x10^{10})$	1P20075
--		Primer	Silane base	no		$(1x10^{10})$	1P20111
9709139		Primer	Silicone base	no	$1x10^8$	$(1x10^{10})$	

Table 6-15 (continued)

RADIATION SENSITIVE COMPONENTS — S-IVB STRUCTURES ASSEMBLY (1A39301-527)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
9709143		Sealant	Silicone rubber	no	$1x10^8$	$(1x10^9)$	
1B27716-513	Auxiliary Tunnel Installation		--	no	$1.4x10^7$	*	
1B27716-3 (Typical)		Gasket	Asbestos/rubber	no		$(5x10^9)$	
--		Adhesive	Polyurethane base	no		$(1x10^{10})$	1P20075
--		Primer	Silane base	no		$(1x10^{10})$	1P20111
9709139		Primer	Silicone base	no		$(1x10^{10})$	
9709143		Sealant	Silicone rubber	no	$1.4x10^7$	$(1x10^9)$	
1A39264-509	Forward Skirt Assembly		--	no	$1.4x10^7$	*	
1B52342-1		Seal	Silicone rubber	no		$(8x10^8)$	P/N S-1387637-1126
--		Adhesive	Silicone base	no		$(1x10^{10})$	1P20014
--		Sealant	Polysulfide rubber	no	$1.4x10^7$	$(5x10^9)$	MIL-S-8802
1A39310-511	Skirt Installation		--	no	$5x10^9$	*	
1B39505-507		Seal assembly	--	no		*	
--		Adhesive	Polyurethane base	no		$(1x10^{10})$	1P20075
--		Sealant	Polysulfide rubber	no		$(5x10^9)$	MIL-S-8802
9709143		Sealant	Silicone rubber	no	$5x10^9$	$(1x10^9)$	
1A57523-509	Helium Bottle		--	yes	$1.9x10^7$	$7x10^6$	
S0046T239		O-Ring	Teflon TFE	yes	$1.9x10^7$	$7x10^6$	
55666-400AE4		Face coated gasket	Teflon TFE coated	yes	$1.9x10^7$	$1x10^8$	
1B56518-1	Deflector Assembly		--	no	$1.4x10^7$	*	
1B56518-3 (Typical)		Cord	Nylon	no		$(3x10^9)$	
1B56518-5		Tape fastener	Nylon	no		$(3x10^9)$	P/N V12-1 (80)-200; Velcro Nylon, Corp.
--		Adhesive	Epoxy base	no		$(1x10^{10})$	1P20025
--		Lubricant	Perfluorinated aliphatic	no	$1.4x10^7$	$(1x10^8)$	1P20056
1B63804-501	Stud Installation		--	no	$1x10^8$	*	
--		Adhesive	Epoxy base	no	$1x10^8$	$(1x10^{10})$	1P20001
--		Adhesive	Polyurethane base	no	$1x10^8$	$(1x10^{10})$	1P20075
1B65892-503	Insulation Installation		--	no	$5x10^9$	*	
1B65892-7		Liner	Al Polyethylene	no	$5x10^9$	$(1x10^9)$	
--		Adhesive	Polysulfide base	no	$5x10^9$	$(6x10^9)$	1P20098

The recommended modifications for radiation hardening these components are presented in Table 6-16. The radiation effects analysis, which provides the basis for these recommended modifications, is discussed in detail in Section 6.5.4.

6.5.4 Radiation Hardening Analysis

6.5.4.1 Fitting Installation (1B55745-1); Fitting Installation (1B68778-1); and Stud Installation (1B68007-1)

Fitting installation 1B55745-1, fitting installation 1B68778-1, and stud installation 1B68007-1 only contain metal components and therefore are not affected by the radiation environment.

6.5.4.2 Insulation Installation (1A39314-543); Insulation Installation (1A93131-505); Probe Support Installation (1A59866-501); Auxiliary Tunnel Installation (1B27716-513); Forward Skirt Assembly (1A39264-509); Deflector Assembly (1B56518-1); Skirt Assembly (1B69669-1); and Stud Installation (1B63804-501)

None of these installations contain radiation sensitive materials - either in critical or non-critical applications. All recommended radiation tolerances exceed the predicted exposure level by more than a factor of ten. Therefore, no material replacement or design modifications are recommended for these subsystems.

6.5.4.3 Seal Installation (1B3808-1) and Tunnel Installation (1A39313-507)

Neither of these installations contain radiation sensitive materials in critical applications. For this reason no design

Table 6-16

RECOMMENDED MODIFICATIONS — S-IVB STRUCTURES ASSEMBLY

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Seal Installation							
	1B43388	Seal	Not critical	Neoprene	$6x10^8$	Kynar	$3x10^{10}$
Tunnel Installation							
	1A39313-33 (Typ)	Gasket	Desired	Silicone rubber	$8x10^8$	Kynar*	$3x10^{10}$
	9709143	Sealant	Not critical	Silicone rubber	$1x10^9$	Polyimide	$2x10^{10}$
Skirt Installation							
	--	Sealant	Not critical	Polysulfide rubber	$5x10^9$	Polyimide	$2x10^{10}$
	9709143	Sealant	Not critical	Silicone rubber	$1x10^9$	Polyimide	$2x10^{10}$
Helium Bottle							
	S0046T239	O-ring	Desired	Teflon TFE	$7x10^6$	Polyimide	$2x10^{10}$
	55666-400AE4	Face coated gasket	Desired	Teflon TFE	$1x10^8$	Kynar coated*	$3x10^{10}$
Insulation Installation							
	1B65892	Liner	Not critical	Al polyethylene	$1x10^9$	Al polyimide	$3x10^{10}$
	--	Adhesive	Not critical	Polysulfide	$6x10^9$	Epoxy	$1x10^{10}$

*Use soft metal if possible

modifications are recommended even though some of the non-critical applications utilize organic materials whose radiation tolerances do not exceed the predicted environment, 1×10^8 ergs/gm(C), by the desired factor of ten.

6.5.4.4 Tank Assembly

The recommended radiation tolerance of the polyurethane foam insulation lining the tank assembly (Dwg 1A39303-553), 1×10^{10} ergs/gm(C), does not exceed the predicted nuclear environment, 5×10^9 ergs/gm(C), by the desired factor of ten. However, no design modifications are recommended since the performance of the insulation does not limit mission success.

6.5.4.5 Aft Skirt Installation

Although the aft skirt seal assembly of the skirt installation (Dwg 1A39310-511) does not contain any radiation sensitive materials in critical applications, the modifications described in Table 6-16 are recommended to increase the tolerance of the individual components.

6.5.4.6 Helium Bottle

Helium bottles (Dwg 1A57523-504), which are employed for storage of the pressurant for pneumatically actuated valves, are physically located internal to the propellant tank. The recommended radiation tolerance of the gaskets and O-rings, which interface with the pressurization system, do not exceed the predicted exposure, 1.9×10^7, by the desired factor of ten.

Therefore, the modifications described in Table 6-16 are recommended to improve system reliability.

6.5.4.7 Insulation Installation (1B65892-503)

Although the components of the insulation installation (1B65892-503) do not contain radiation sensitive materials in applications where degradation in material properties might compromise mission success, the modifications described in Table 6-16 are recommended to increase their recommended tolerances to above the predicted exposure levels.

6.6 Thermoconditioning System

6.6.1 Description and Location

The thermoconditioning system (Dwg 1B384260-539) maintains an acceptable operating environment for the S-IVB equipment located in the forward interstage area during preflight and in-flight operations. It maintains electronic equipment at their optimum operating temperature by circulating a methanol-water coolant which has a temperature of $59^{o} \pm 1^{o}F$. A similar system might be required for the RNS; however, its requirements are not known.

The S-IVB thermoconditioning system is assumed to be located in a position where it will be subjected to a nuclear radiation exposure of 1×10^9 ergs/gm(C) during 10 hours of engine operation.

6.6.2 Summary

All of the thermoconditioning components can be radiation hardened by the material substitution and design modifications recommended in Section 6.6.4 such that reliable operation can be expected at nuclear exposures of up to 2×10^{10} ergs/gm(C), which exceeds the predicted environment by more than a factor of ten.

6.6.3 System Breakdown and Recommended Modifications

The radiation sensitive materials and components contained in the S-IVB thermoconditioning system are listed in Table 6-17. The recommended modifications are given in Table 6-18.

Table 6-17

RADIATION SENSITIVE COMPONENTS — S-IVB THERMOCONDITIONING SYSTEM (1B38426-539)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
1B38426-539	Thermoconditioning System		--	yes	$1x10^9$	$3x10^6$	
MS28778		O-Ring	Synthetic rubber	yes		$1x10^9$	MIL-G-5510
1A97549-1		Spacer	Laminated phenolic	no		$(2x10^{10})$	MIL-P-15035, Type FBE
1A97550-1		Spacer	Laminated phenolic	no		$(2x10^{10})$	MIL-P-15035, Type FBE
1B38429-501		Hose	Teflon TFE tube	yes		$3x10^6$	P/N R 25684; Resistoflex Corp.
1B38430-501		Coupling assembly	--	yes		$1x10^9$	P/N 26M02D; General Connectors Corp.
--		Packing	Neoprene	yes		$1x10^9$	
1B76047-1 (Typical)		Isolator	--	no		*	P/N 90847-1; Barry Controls
--		Pads	Silicone rubber	no	$1x10^9$	$(2x10^9)$	

Table 6-18

RECOMMENDED MODIFICATIONS — S-IVB THERMOCONDITIONING SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Thermoconditioning							
	MS28778	O-ring	Required	Silicone rubber	$8x10^8$	Polyimide	$2x10^{10}$
	1B38429 (Typ)	Hose assy	Required	Teflon TFE tube	$3x10^6$	Aluminum*	--
	1B38430-x	Packing	Required	Neoprene	$1x10^9$	Polyimide	$2x10^{10}$
	1B76047-x	Pads	Not critical	Silicone rubber	$2x10^9$	Asbestos/rubber	$3x10^{10}$

*Weld metal tubing

6.6.4 Radiation Hardening Analysis

The least radiation stable component, i.e., the hose assembly which contains an inner lining of Teflon TFE impregnated with carbon black, limits the recommended radiation tolerances of the thermoconditioning system to 3×10^{6} ergs/gm(C). Replacement of these hose assemblies with welded aluminum tubing and usage of polyimide packing and O-rings, as recommended in Table 6-17, increases the recommended tolerance of the thermoconditioning system to 2×10^{10} ergs/gm(C).

6.7 Support System

The support system defined in Drawing 1A95641-513 can best be described as being part of the S-IVB structure. The support system, which consists of the forward dome, forward skirt, aft dome, aft skirt, and tunnel support systems is uniquely designed for the S-IVB. Therefore, it is doubtful if any could be adapted to RNS applications. The assumed locations and predicted nuclear environments are shown in Figure 6-5.

As noted in Table 6-19, most of the subsystems are metal and do not contain any radiation sensitive materials. The only organic material contained in any support subsystem is the electrical feedthru O-ring/grommet which prevents damage to electrical wires penetrating the forward and aft dome support structure. Since these are not considered critical applications, radiation hardening is not required.

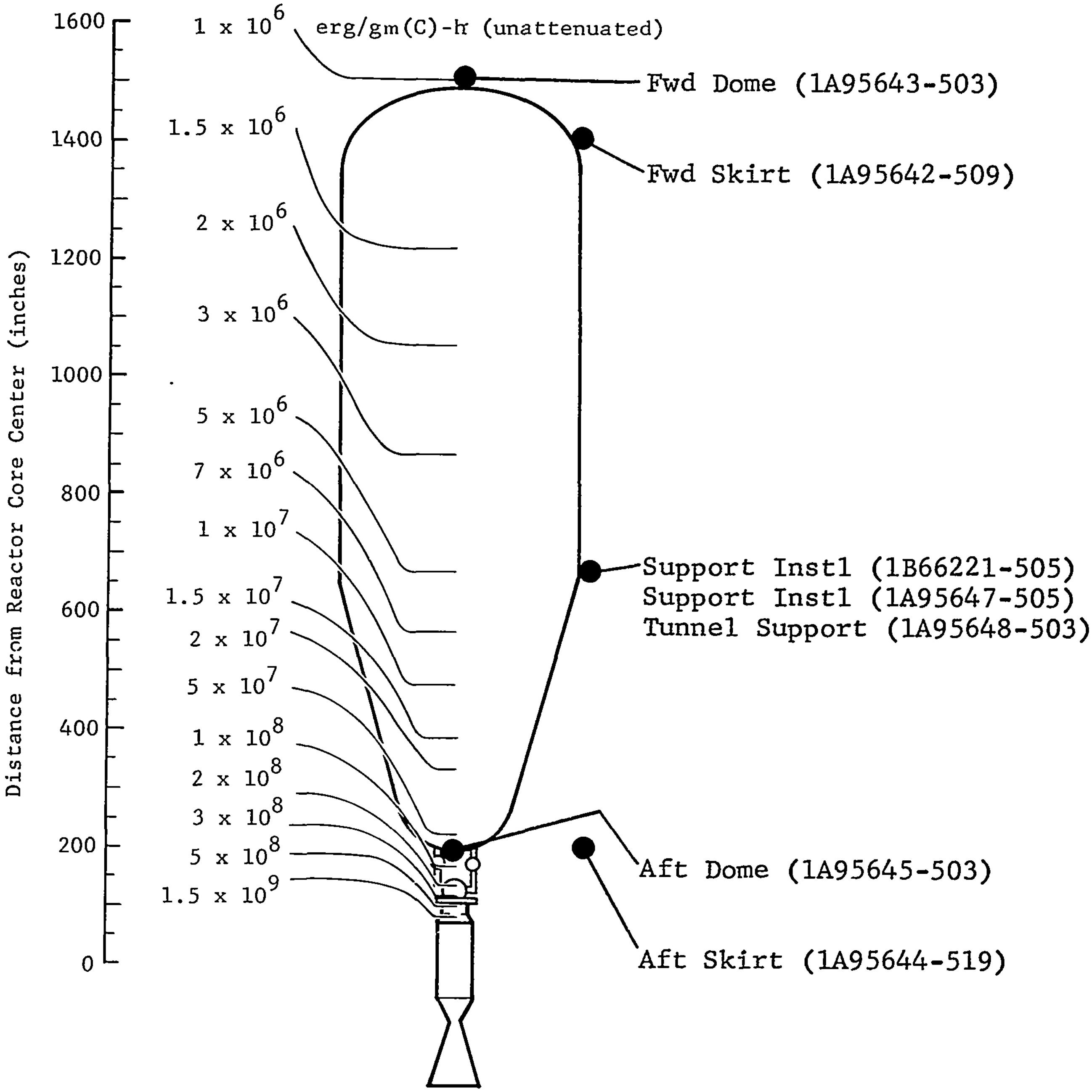


Figure 6-5 Assumed Location of (S-IVB) Support Assembly

Table 6-19

RADIATION HARDENING SUMMARY — S-IVB SUPPORT ASSEMBLY

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))		Remarks
			As Designed	As Modified	
Forward skirt support	1A95642-509	$1.3x10^7$	--	Not required	All metal
Forward dome support	1A95643-503	$1x10^7$	--	Not required	
Aft skirt support	1A95644-519	$5x10^9$	--	Not required	All metal
Aft dome support	1A95645-503	$1x10^9$	--	Not required	
Support instl	1A95647-505	$1x10^8$	--	Not required	All metal
Tunnel support	1A95648-503	$1x10^8$	--	Not required	All metal
Support instl	1B662221-505	$1x10^8$	--	Not required	All metal

VII. ANALYSIS OF S-II STAGE

The S-II stage, which is the second booster stage of the Saturn V system, is approximately 81 feet in length and 33 feet in diameter. It is powered by five J-2 rocket engines using liquid hydrogen and liquid oxygen as propellant to develop a total thrust of 1,150,000 pounds in a single burn. Stage weight at ignition is approximately 1,059,900 pounds of which approximately 158,250 pounds is liquid hydrogen.

Table 7-1 lists the major systems analyzed and notes the subsection in which the analysis of each appears.

Table 7-1

S-II SYSTEMS ANALYZED

System	Drawing	Subsection
Hydraulic	V7-580032	7.1
Propellant Feed	V7-480002	7.2
Pressurization	V7-490800	7.3
Leak Detection and Purge	V7-532501	7.4
Electrical, General	V7-540378	7.5
Engine Installation	V7-417005	7.6
Insulation and Heat Shields	--	7.7
Structure	V7-300011	7.8

As described under the analyses, most of the S-II components and subsystems can be modified and/or adapted for RNS application from the standpoint of withstanding the radiation dosages. It should be noted that all radiation levels used in the subsequent analysis are based on unattenuated gamma doses for 10 hours of engine operation as shown in Figure 5-1 of Section V.

In addition to the procedures described in Section III, these additional comments pertaining to the following analyses may be helpful.

Generally, the discussion of each system is in four subsections containing (a) a brief description of the system and the assumed location on the RNS, (b) a summary, usually containing a table giving the evaluation of each subsystem, (c) the main data tables, i.e., the system breakdown to radiation sensitive materials and the recommended modifications, and (d) the discussion of each subsystem.

The tables giving the radiation sensitive components, e.g., Table 7-3, contains a column headed "Critical Application." If the entry in this column is "no," the corresponding entry under "Tolerance" is enclosed in parentheses; the value given, however, is the same as if the application were considered critical. If all radiation sensitive materials listed for a component (or subsystem) are considered noncritical, an asterisk appears under "Tolerance."

The tables giving the recommended modifications, e.g., Table 7-4, have in some cases been shortened by listing only a representative item for material applications which may appear many times in the subsystem. It should be understood that the modification applies to all similar items.

7.1 Hydraulic System

7.1.1 Description and Location

As mentioned earlier, the application of hydraulic system components to the RNS is unknown; however, some type of engine gimballing device will be required and a hydraulic system will probably be considered.

The S-II thrust vector control system consists of four independent closed-loop hydraulic control subsystems which provide power for gimballing the four outboard engines. The primary components of each subsystem are a main pump, an auxiliary pump (used only during prelaunch checkout), an accumulator-reservoir manifold assembly (ARMA), and two servoactuators. Interconnecting flexible hoses are Teflon lined with a steel outer braid. The hydraulic-fluid is MIL-H-5606A. The assumed locations of these components are shown in Figure 7-1.

The main pump is mounted to and driven by the engine LOX turbopumps. The ARMA consists of a high-pressure accumulator which receives high-pressure fluid from the pump and a low-pressure reservoir which receives return fluid from the servoactuators. The servoactuators convert electrical signals and hydraulic power into mechanical outputs that gimbal the engine. After S-IC/S-II separation, an S-II switch selector command unlocks the accumulator lock-up valves, thereby releasing high-pressure ($\sim$2350 psia) fluid to each of the servoactuators.

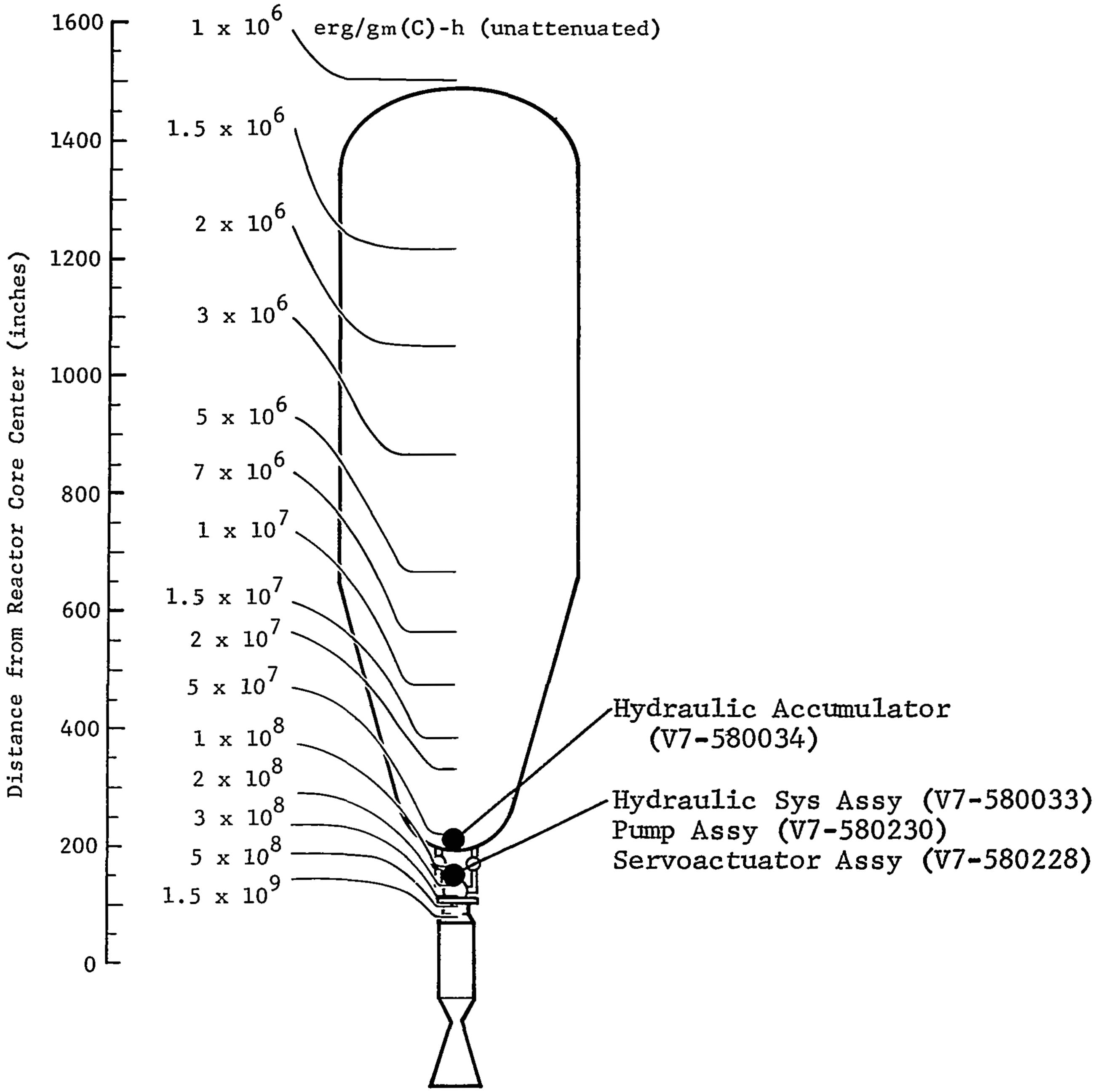


Figure 7-1 Assumed Location of (S-II) Hydraulic System Components

The accumulators provide gimballing power prior to the main hydraulic pump operation. During S-II mainstage operation, the main hydraulic pump supplies high-pressure (~3500 psig) fluid to the servoactuators. The return fluid from the actuators (~17 psig) is routed to the reservoir which stores it at sufficient pressure (~88 psig) to supply a positive pressure at the main pump inlet.

7.1.2 Summary

Based upon the analyses presented in Section 7.1.4, it is believed that each of the major components and subsystems of the hydraulic system can be radiation hardened to levels greater than those predicted at the assumed component locations shown in Figure 7-1. Table 7-2 summarizes the predicted nuclear environment and the recommended radiation tolerances of both the basic system and the modified configuration of each subsystem. The recommended modifications and a discussion of the resulting improvements are given in Section 7.1.4.

7.1.3 System Breakdown and Recommended Modifications

Drawings, specifications, and part lists were examined to determine radiation sensitive materials whose performance characteristics might degrade due to the influence of radiation. Table 7-3 lists these materials, describes their applications, and presents for comparative purposes the recommended tolerance for each application and the predicted nuclear environment.

Table 7-2

RADIATION HARDENING SUMMARY — S-II ENGINE ACTUATION SYSTEM, HYDRAULIC

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))	
			As Designed	As Modified
Hydraulic assy	V7-580033	1.5×10^9	3×10^6	5×10^9
Hydraulic accumulator	V7-580034	6×10^8	7×10^6	1×10^{10}
Pump assy	V7-580230	1.5×10^9	7×10^6	1×10^{10}
Servoactuator assy	V7-580228	1.5×10^9	1×10^8*	1×10^{10}

*Based on partial information; tolerance could be lower.

Table 7-3

RADIATION SENSITIVE COMPONENTS - S-II ENGINE ACTUATION SYSTEM, HYDRAULIC (V7-580032)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
V7-580033	Hydraulic Sys Assy		--	yes	1.5×10^9	3×10^6	
V7-580243		Hose Assy	--	yes		3×10^6	
V7-580243		Sleeve	Teflon, heat shrink	no		(1×10^8)	
ME271-0030		Hose	Teflon (C blk impreg)	yes		3×10^6	P/N R11659; Resistoflex
--		Hydraulic fluid	Petroleum base	yes	1.5×10^9	5×10^8	MIL-H-5606A
V7-580034	Hydraulic Accumulator		--	yes	6×10^8	7×10^6	
V7-580229		ARMA Assy	--	yes		7×10^6	
MC266B		Packing	Synthetic rubber	yes		1×10^{10}	MIL-P-5516
MS9058		Ring, backup	Teflon TFE	no		(7×10^6)	AMS 3651
5631696		Packing	Synthetic rubber	yes		1×10^{10}	MIL-P-25732
ME449-0009		Sensor, temperature	--	no		*	P/N 134-FT; Rosemount Engr. Co.
--		Element support	Teflon	no		(1×10^8)	
--		Potting	Epoxy resin	no		(2×10^{10})	
--		Wire, elec.	Teflon FEP insul.	no		(1×10^9)	
ME449-0043		Transducer, pressure	--	no		*	P/N 3201-0101 and -0102; Servionic Div.
--		Insulation, elec.	Diallyl phthalate	no		(2×10^{10})	MIL-M-14; type SDG
--		Potting compound	Epoxy	no		(2×10^{10})	Emerson & Cuming, Inc.
--		Wire, elec.	Teflon FEP insul.	no		(1×10^9)	
--		Wire, magnet	Teflon FEP insul.	no		(1×10^9)	
--		Lubricant	Silicone oil	no		(8×10^8)	
ME284-0102		Valve, bleed, hydraulic	--	no		*	
		O-ring	Synthetic rubber	no		(1×10^9)	MIL-P-25732 or MIL-R-25897
ME282-0028		ARMA	--	yes		7×10^6	P/N 5630087-M1; Parker Hannifin
5641679		Barrel & piston	--	yes		1×10^9	
5631696		O-ring	Synthetic rubber	yes		1×10^9	MIL-P-25732
5631709		Ring, backup	Teflon TFE, 25% glass	no		(1×10^{10})	Fluorocomp 105
5641334		Piston seal, backup	Teflon TFE, 25% glass	yes		5×10^9	Fluorocomp 105
5651063		Omniseal, backup	Teflon TFE, 25% glass	yes		5×10^9	Fluorocomp 105
5631655		Ring, backup	Teflon TFE, 25% glass	yes		1×10^{10}	Fluorocomp 105
5631654		Ring, guide	Teflon TFE, 25% glass	yes		1×10^{10}	Fluorocomp 105
5641447		Valve, N_2	--	yes		*	
MS28774		Ring, backup	Teflon TFE	no		(7×10^6)	
5631696		Ring, packing	Synthetic rubber	no		(1×10^{10})	MIL-P-25732
5631754		Ring, gasket	Synthetic rubber	no		(1×10^9)	MIL-P-25732
5631696		O-ring, end cap	Synthetic rubber	yes		1×10^9	MIL-P-25732
5631655		Ring, backup	Teflon TFE, 25% glass	no		(1×10^{10})	Fluorocomp 105
5631696		O-ring	Synthetic rubber	yes		1×10^9	MIL-P-25732
5631696		O-ring	Synthetic rubber	yes		1×10^9	MIL-P-25732
5631640		Pressure filter	--	yes		1×10^9	
5631696		O-ring	Synthetic rubber	yes		1×10^9	MIL-P-25732
MS28774		Ring, backup	Teflon TFE	no		(7×10^6)	
MS28774		Ring, backup	Teflon TFE	no		(7×10^6)	
5631696		O-ring	Synthetic rubber	yes		1×10^9	MIL-P-25732
5641227		Return filter	--	yes		1×10^9	
5631696		O-ring	Synthetic rubber	yes		1×10^9	MIL-P-25732
MS28774		Ring, backup	Teflon TFE	no		(7×10^6)	
5631644		Valve, L.P. relief	--	yes		1×10^9	
5631754		O-ring gasket	Synthetic rubber	yes		1×10^9	MIL-P-25732
5631754		O-ring gasket	Synthetic rubber	yes	6×10^8	1×10^9	MIL-P-25732

Table 7-3 (cont'd)

RADIATION SENSITIVE COMPONENTS - S-II ENGINE ACTUATION SYSTEM, HYDRAULIC (V7-580032)

Part Number	Subsystem	Component	Material	Critical Appli- cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
5631973		<u>Valve, H.P. relief</u>	--	yes	$6x10^8$	$1x10^9$	
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
MS28774		Ring, backup	Teflon TFE	no		$(7x10^6)$	
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
MS28774		Ring, backup	Teflon TFE	no		$(7x10^6)$	
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5631696		O-ring - tube	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5631696		O-ring, res. piston	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5631924		Ring, backup	Teflon TFE, 25% glass	no		$(1x10^{10})$	Fluorocomp 105
--		Switch, thermal	N/A	yes		N/A	
5631754		O-ring, gasket	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5631659		Ring, seal	Teflon TFE	yes		$7x10^6$	AMS 3651
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
MS28774		Ring, backup	Teflon TFE	no		$(7x10^6)$	
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
MS28774		Ring, backup	Teflon TFE	no		$(7x10^6)$	
5631668		<u>Pilot valve assy</u>	--	yes		$1x10^9$	
5631671		Gasket, connector	Teflon, Viton A	no		$(7x10^6)$	
--		Sleeving	Silicone rubber	no		$(2x10^9)$	MIL-I-18057
--		Potting compound	N/A	no		(N/A)	Hysol RTV
5631678		Washer, insulation	Silicone glass laminate	no		$(2x10^{11})$	MIL-P-997
--		Tape, insulation	Teflon TFE	no		$(2x10^7)$	MIL-T-22742
--		Insulation, wire	Teflon FEP	yes		$1x10^9$	MIL-W-16878/4A
--		Varnish, insul.	Polyimide	yes		$1x10^{10}$	MIL-I-002707; DC997
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
MS28774		Ring, backup	Teflon TFE	no		$(7x10^6)$	
5631754		O-ring, gasket	Synthetic rubber	no		$(1x10^9)$	MIL-P-25732
5631696		O-ring	Synthetic rubber	yes		$1x10^9$	MIL-P-25732
5693208		Quad-ring	Buna-N	yes		$1x10^9$	MIL-P-25732
5693207		Ring, backup	Teflon TFE	no	$6x10^8$	$(7x10^6)$	AMS 3651
V7-580230	<u>Pump Assy</u>		--	yes	$1.5x10^9$	$7x10^6$	
MC266B		Packing	Synthetic rubber	yes		$1x10^{10}$	MIL-P-5516
MS9058		Ring, backup	Teflon TFE	yes		$7x10^6$	AMS 3651
--		Packing	Synthetic rubber	yes		$1x10^{10}$	NAS 1593
ME449-0009		<u>Sensor, temperature</u>	--	no		*	P/N 134FT; Rosemount Engr. Co.
--		Element support	Teflon	no		$(7x10^6)$	
--		Potting	Epoxy resin	no		$(2x10^{10})$	
--		Wire, elec.	Teflon insul.	no		$(1x10^8)$	
ME281-0009		<u>Main Pump</u>+	--	yes		$1x10^8$	P/N 57177; Abex Corp.
57640		O-rings (various)	Viton A	yes		$6x10^9$	MIL-R-25897, Class 1
57700		Gasket, flange	Asbestos & NBR	yes		$5x10^9$	Armstrong Accopac, Type AN 859
5622		<u>Solenoid</u>	--	yes		$1x10^8$	Rocker Solenoid Co.
--		Potting compound	Silicone rubber	no		$(2x10^9)$	Dow Corning RTV 881
--		Sleeving	Silicone rubber	no		$(2x10^9)$	
--		Insulation, coil	Teflon	yes	$1.5x10^9$	$1x10^8$	No. 60 tape; 3M

+ Detailed parts breakdown not received.

Table 7-3 (cont'd)

RADIATION SENSITIVE COMPONENTS - S-II ENGINE ACTUATION SYSTEM, HYDRAULIC (V7-580032)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
V7-580228	Servoactuator Assy		--	yes	$1.5x10^9$	$1x10^8$	
MC266B		Packing	Synthetic rubber	no		$(1x10^{10})$	MIL-P-5516
080-42502		O-ring	Synthetic rubber	yes		$1x10^9$	MS28775 (MIL-P-25732)
ME449-0043		ΔP Transducer	--	yes		$1x10^8$	P/N 2131-0701; Servonic Div.
--		Insulation, elec.	Diallyl phthalate	yes		$2x10^{10}$	MIL-M-14, type SDG
--		Potting compound	Epoxy	no		$(2x10^{10})$	Stycast 2651; Emerson & Cuming, Inc.
--		Wire, elec.	Teflon	yes		$1x10^8$	
--		Wire, magnet	Polyimide varnish insul	yes		$1x10^{10}$	du Pont ML
--		Lubricant	Silicone oil	yes		$8x10^8$	DC-510, Dow Corning
V7-580252		Servoactuator Assy	--	yes		N/R	
ME287-0004		Servoactuator	N/R	yes		N/R	P/N 010-50485; Moog Servo-controls
ME284-0102		Valve, bleed	--	yes		$1x10^9$	
		O-ring	Synthetic rubber	yes	$1.5x10^9$	$1x10^9$	MIL-P-25732

Table 7-4 gives the modifications recommended to achieve a radiation tolerance level of 5×10^9 ergs/gm(C).

7.1.4 Radiation Hardening Analysis

7.1.4.1 Hydraulic System Assembly

The general assembly (V7-580033) includes, in addition to the major subsystems discussed below, the hose assemblies (V7-580243) and the hydraulic fluid (MIL-H-5606A).

The hose assemblies specified by ME271-0030 are fabricated with a seamless inner liner of Teflon impregnated with carbon black throughout the wall thickness. Interlayers may be used between the Teflon and the outer steel reinforcing braids. The outer Teflon sleeve, when used, is not considered critical to the application. The recommended radiation tolerance, 3×10^6 ergs/gm(C), for these hoses is based upon radiation effects tests of similar hoses (Ref. 5, p. 151) in which failures occurred at exposures of 1×10^7 ergs/gm(C) with the hoses intermittently pressurized during irradiation. Since the recommended radiation tolerance is far below the predicted environment, it is recommended that the hydraulic system components be connected with welded aluminum or steel lines containing expansion joints and bellows to provide the nonrigidity required for vibration and thermal effects. Where possible, the lines should be attached securely to the vehicle structure to minimize flexure and subsequent failure.

Table 7-4

RECOMMENDED MODIFICATIONS - S-II ENGINE ACTUATION SYSTEM, HYDRAULIC

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Hydraulic System Assy							
	V7-580243	Sleeve	Not critical	Teflon	1×10^{8}	Polyimide	1×10^{10}
	ME271-0030	Hose	Required	Teflon TFE	3×10^{6}	Metal*	--
	--	Hydraulic fluid	Required	Petroleum base	5×10^{8}	Oronite 8515	5×10^{9}
Hydraulic Accumulator							
	MS9058 (Typ)	Ring, backup	Not critical	Teflon TFE	7×10^{6}	Mylar	1×10^{10}
	5631696 (Typ)	O-ring	Desired	Buna N	1×10^{9}	Polyimide	2×10^{10}
	5651063 (Typ)	Seal, backup	Desired	Teflon, glass filled	5×10^{9}	Kynar	3×10^{10}
	5631659	Seal, ring	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	--	Sleeving	Not critical	Silicone rubber	2×10^{9}	Polyimide	3×10^{10}
	--	Tape, insulation	Not critical	Teflon TFE	7×10^{6}	Polyimide	1×10^{10}
	--	Wire, elec.	Desired	Teflon FEP insul.	1×10^{9}	Polyimide	1×10^{10}
	5631754	Gasket, ring	Desired	Buna N	1×10^{9}	Kynar	3×10^{10}
	5631671	Gasket, connector	Not critical	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	--	Potting	Not critical	Unknown	--	Epoxy	2×10^{10}
Pump Assy							
	MS9058	Ring, backup	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	--	Element support	Not critical	Teflon	7×10^{6}	Ceramic	--
	--	Wire, elec.	Not critical	Teflon TFE insul.	1×10^{8}	Polyimide	1×10^{10}
	57640 (Typ)	O-ring	Desired	Viton A	6×10^{9}	Polyimide	2×10^{10}
	57700	Gasket, flange	Desired	Asbestos & NBR	5×10^{9}	Kynar	3×10^{10}
	--	Potting compound	Desired	Silicone rubber	2×10^{9}	Epoxy	2×10^{10}
	--	Insulation, coil	Required	Teflon	1×10^{8}	Polyimide	1×10^{10}
	--	Sleeving	Not critical	Silicone rubber	2×10^{9}	Polyimide	3×10^{10}
Servoactuator Assy							
	080-42502 (Typ)	O-ring	Required	Buna N	1×10^{9}	Polyimide	2×10^{10}
	--	Wire, elec.	Required	Teflon	1×10^{8}	Polyimide	1×10^{10}
	DC-510	Lubricant	Required	Silicone oil	8×10^{8}	Silicone oil (DC-710)	1×10^{10}

*Use welded metal tube.

MIL-H-5606A type hydraulic fluid is relatively radiation sensitive; the recommended radiation tolerance is 5×10^8 ergs/gm(C). The earliest indications of radiation damage are changes in viscosity, gassing (decomposition products), and increases in oxidation corrosion. This fluid, while probably satisfactory for a single RNS mission, is not considered suitable for a 10-mission life. A possible substitute fluid of the MIL-H-8446 type, Oronite 8515, has a recommended tolerance of 5×10^9 ergs/gm(C). However, more recently developed fluids for which little or no radiation effects data are available might provide greater radiation stability but possibly at the expense of redesigning the system components to be compatible with the fluid. In any event, it seems that a satisfactory fluid can be selected, but further experimentation is required, particularly in regards to the formation of corrosive products that would produce long-term degradation of the system. The system should be modified to incorporate a bleed valve in the reservoir to vent, upon command, the gaseous radiolytic products. Consideration should also be given to a system in which the fluid could be drained and replaced as part of the periodic maintenance.

7.1.4.2 Hydraulic Accumulator

The ME282-0028 combination accumulator-reservoir manifold assembly (ARMA) is a Type II, Class 3500 hydraulic system component as defined in Specification MIL-H-8775. The main components are the accumulator, reservoir, high- and low-pressure filters, lock-up valve, bypass valve, and thermal switch. Pressure, temperature, and position transducers and a bleed valve are added to the basic commercial part as specified in Drawing V7-500229. Of the transducers, information was not received for the following:

ME478-0004 transmitter, linear position (G. L. Collins Corp.)

ME449-0042 transducer, absolute pressure, potentiometric (vendor unknown)

The ME449-0042 transducer is probably similar to the ME449-0043 transducer listed under the servoactuator assembly. The piston position transmitter is for data instrumentation and, therefore, is not considered critical to the RNS mission. Radiation hardening would proceed in a manner similar to that in Table 7-4.

The high- and low-pressure filter elements (MIL-F-8815) contain wire mesh filter media, welded end caps, and dual O-rings. The lock-up valves are normally open, spring-return solenoid valves.

Of the organic materials used in the ARMA, only the Teflon TFE is considered critical at the predicted dose of 6×10^8 ergs/gm(C). Replacement of the Teflon and other organics, as indicated in Table 7-4, results in a subsystem with a recommended radiation tolerance of 1×10^{10} ergs/gm(C).

7.1.4.3 Pump Assembly

A detailed parts breakdown was not received for the ME281-0009 variable-delivery hydraulic pump (Abex Corp.; P/N 57177). The main components of the subassembly are the pump, high-pressure check valve, case-drain check valve, filter, and solenoid valve. Vendor information states that the only non-metallics used in the pump are various Viton A O-rings, the flange gasket, and solenoid materials as listed in Table 7-3.

A barrier is provided to thermally isolate the subassembly and provide protection for the pump shaft seal area from the heat of the LOX pump exhaust gases. An ME449-0009 temperature sensor is added to the basic pump unit.

The recommended radiation tolerance of the hydraulic pump, 7×10^6 ergs/gm(C), is well below the predicted radiation dose of 1.5×10^9 ergs/gm(C). This low level is based on a Teflon TFE ring used in the pump outlet line. The next lowest radiation tolerance is for Teflon used as wire insulation. The material substitutions indicated in Table 7-4 increase the recommended limit to 1×10^{10} ergs/gm(C).

7.1.4.4 Servoactuator Assembly

Drawings and parts data were not received for the servo-actuator assembly (Moog Servocontrols; P/N 010-50485). However, the Specification Control Drawing, MC287-0004, for this flight-critical component indicates:

1. The actuator is of the linear, double-acting, equal-area type conforming to MIL-H-8775.

2. The actuator includes the following components:

   a. Servovalve
   b. Hydraulic lock valve
   c. Cylinder bypass valve
   d. Prefilteration bypass valve
   e. Filter
   f. Piston bypass valve
   g. Actuator piston
   h. Feedback potentiometer
   i. Actuator body
   j. Seal plate assembly

3. All O-ring packings and gaskets conform to MIL-P-25732 (e.g., Buna N) or MIL-R-25897 (Viton A). The least radiation stable of these, Buna N, has a radiation tolerance of 1×10^9 ergs/gm(C).

4. Spring-loaded Teflon scraper rings may be utilized in lieu of Specification MIL-S-5049 types.

5. Teflon capped O-ring seals may be utilized; the tolerance for this application is 7×10^6 ergs/gm(C).

6. A reinforced bearing liner of polytetrafluoroethylene (e.g., Teflon TFE) may be used in lieu of dry-film bearing lubricant on the actuator end bearings.

7. Electrical wire is specified by MIL-W-16878/4, which has Teflon FEP insulation with a radiation tolerance of 1×10^9 ergs/gm(C).

Based on this information, the recommended radiation tolerance of the servoactuator is no higher than 1×10^9 ergs/gm(C) and could be as low as 7×10^6 ergs/gm(C) if Teflon TFE seals are used. It will therefore be required to perform a further analysis of this assembly if it is to be employed for RNS applications. The tolerance of the V7-580228 servoactuator assembly given in Table 7-3, 1×10^8 ergs/gm(C), is based on the use of Teflon TFE electrical insulation in the differential pressure transducer.

7.2 Propellant Feed System

7.2.1 Description and Location

The S-II stage propellant system is composed of integral LOX/LH_2 tanks, propellant lines, control valves, vents, and pre-pressurization subsystems. The system provides 80 lb/sec of LH_2 at 88 psig. The analysis in this section is based on Drawing V7-480002, System Installation - Propellant Feed, and includes line and prevalve installations for engine feed and lines and valves for fill and drain. The assumed locations of these components are shown in Figure 7-2.

7.2.2 Summary

Based upon the analyses presented in Section 7.2.4, it is believed that each of the major components and subsystems of the propellant feed system can be radiation hardened to a level of at least 8×10^9 ergs/gm(C). This is about a factor of ten higher than the predicted requirement. Table 7-5 summarizes the predicted nuclear environment and the recommended radiation tolerances of both the basic system and the modified configuration of each subsystem. The recommended modifications are discussed in Section 7.2.4.

7.2.3 System Breakdown and Recommended Modifications

Radiation sensitive materials and their applications identified in the examination of drawings, specifications, and part lists are given in Table 7-6 along with the recommended radiation

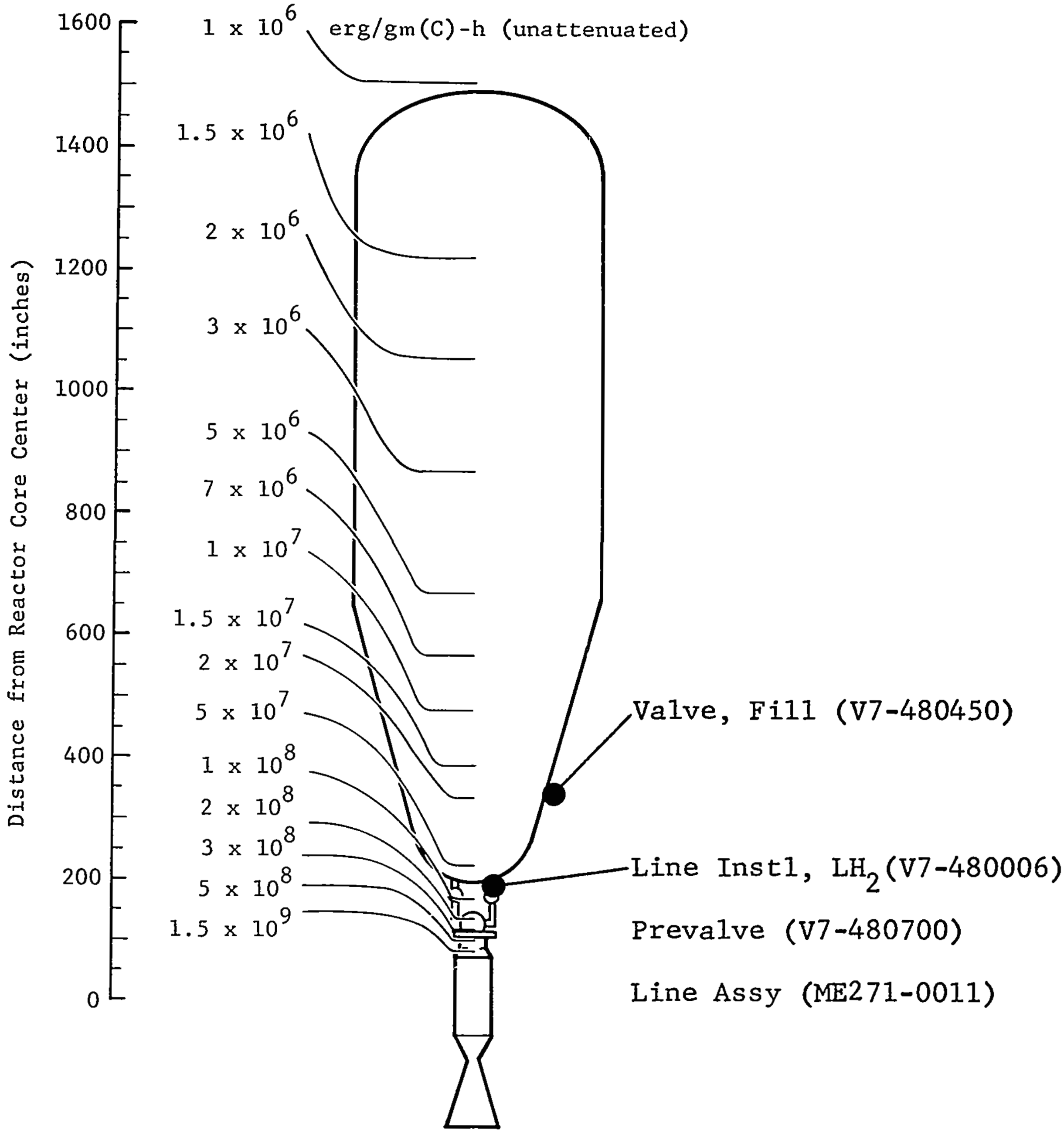


Figure 7-2 Assumed Location of (S-II) Propellant Feed System Components

Table 7-5

RADIATION HARDENING SUMMARY — S-II PROPELLANT FEED SYSTEM

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))	
			As Designed	As Modified
LH_2 line instl	V7-480006	$7x10^8$	$1x10^8$	$8x10^9$
LOX line instl	V7-480005	$7x10^8$	$1x10^8$	$8x10^9$
Fill & drain instl	V7-480008	$6x10^8$	$1x10^8$	$8x10^9$

Table 7-6

RADIATION SENSITIVE COMPONENTS — S-II PROPELLANT FEED SYSTEM (V7-480002)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
V7-480006	Line Instl, Engine Feed, LH_2 (Typical)		--	yes	$6x10^{8}$	$1x10^{8}$	
ME261-0003		Face coated seal	Teflon coated	yes	$7x10^{8}$	$1x10^{8}$	NAVAN; TFE & FEP per VA0621-003
--		Tape	Teflon TFE	no	$6x10^{8}$	$(2x10^{7})$	MIL-T-23594, type I
ME261-0011		Line Assy	--	yes	$7x10^{8}$	$1x10^{9}$	
--		O-ring	Kel-F	yes	$7x10^{8}$	$1x10^{9}$	P/N 35837; Solar
--		Mount, resilient	Silicone rubber	no	$7x10^{8}$	$(2x10^{9})$	P/N SCE90850; Barry Controls
V7-480700		Prevalve	--	yes	$6x10^{8}$	$1x10^{8}$	
V7-480485		Seal	Mylar	yes		$6x10^{9}$	MB 0130-060, Type D7.5
V7-480713		Lipseal	Mylar	yes		$6x10^{9}$	MB 0130-060, Type D7.5
V7-480715		Seal	Mylar	yes		$6x10^{9}$	MB 0130-060, Type A-10
V7-480738		Seal, check	Mylar	yes		$6x10^{9}$	MB 0130-060, Type A-10
V7-480742		Lipseal	Kel-F	yes		$1x10^{9}$	MB 0130-053
V7-480721		Bearing	Kel-F	yes		$1x10^{9}$	AMS 3650
V7-480722		Bearing	Kel-F	yes		$1x10^{9}$	AMS 3650
V7-480727		Bearing	Kel-F	yes		$1x10^{9}$	AMS 3650
MS29512		Packing	Synthetic rubber	no		$(6x10^{9})$	MIL-P-5315
MS29513		Packing	Synthetic rubber	no		$(6x10^{9})$	MIL-P-5315
ME261-0036		Seal	Teflon TFE jacket	yes		$1x10^{8}$	TEC Seal Corp.
V7-480607		Bearing	Teflon FEP	yes		$7x10^{8}$	MB 0130-052
V7-480716		Bearing	Teflon FEP	yes		$7x10^{8}$	
V7-480717		Bearing	Teflon FEP	yes		$7x10^{8}$	
V7-480718		Bearing	Teflon FEP	yes		$7x10^{8}$	
V7-480723		Bumper	Teflon FEP	no		$(1x10^{9})$	MB 0130-052
V7-480547		Valve	--	yes		$6x10^{9}$	
V7-480546		Seal, body	Viton A	yes		$6x10^{9}$	SR277-70; Stillman Seal
MS29512		Packing	Synthetic rubber	no		$(6x10^{9})$	MIL-P-5315
V7-480640		Indicator	--	no		*	
V7-480394		Spacer	Teflon FEP	no		$(1x10^{9})$	MB 0130-052
V7-480322		Washer	Kel-F	no		$(3x10^{9})$	MB 0130-053
--		Potting Compound	Polyurethane	no	$6x10^{8}$	$(1x10^{10})$	MB 0120-024
V7-480005	Line Instl, Engine Feed, LOX (Typical)		--	yes	$6x10^{8}$	$1x10^{8}$	
ME271-0010		Line Assy	--	yes	$6x10^{8}$	$1x10^{9}$	P/N 36371; Solar
--		O-ring	Kel-F	yes	$7x10^{8}$	$1x10^{9}$	
ME261-0003		Face coated seal	Teflon coated	yes	$7x10^{8}$	$1x10^{8}$	NAVAN
ME261-0036		Seal	Teflon TFE jacket	yes	$7x10^{8}$	$1x10^{8}$	TEC Seal Corp.
V7-480500		Prevalve	--	yes	$6x10^{8}$	$1x10^{8}$	
V7-480302		Seal	Mylar	yes		$6x10^{9}$	MB 0130-060, Type A-10
V7-480391		Lipseal	Mylar	yes		$6x10^{9}$	
V7-480411		Lock element, seat	Nylon	yes		$3x10^{9}$	NYLOK locking element
V7-480485		Lipseal	Mylar	yes		$6x10^{9}$	MB 0130-060
V7-480531		Lipseal	Mylar	yes		$6x10^{9}$	MB 0130-060, Type D-7.5
V7-480614		Seal, piston	Mylar	yes		$6x10^{9}$	MB 0130-060, Type A-10
MS29512		Packing	Synthetic rubber	no		$6x10^{9}$	MIL-P-5315
MS29513		Packing	Synthetic rubber	no		$6x10^{9}$	MIL-P-5315
ME261-0028		Face coated seal	Teflon coated	yes		$1x10^{8}$	
ME261-0036		Seal	Teflon TFE jacket	yes		$1x10^{8}$	TEC Seal Corp.
V7-480660		Lipseal	Kel-F	yes		$1x10^{9}$	MB 0130-053
V7-480473		Bushing	Teflon FEP	yes		$7x10^{8}$	MB 0130-052
V7-480607		Bearing	Teflon FEP	yes		$7x10^{8}$	MB 0130-052
V7-480623		Bearing	Teflon FEP	yes	$6x10^{8}$	$7x10^{8}$	MB 0130-052

Table 7-6

RADIATION SENSITIVE COMPONENTS — S-II PROPELLANT FEED SYSTEM (V7-480002) (cont'd)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
V7-480651		Bearing	Teflon FEP	yes	$6x10^8$	$7x10^8$	MB 0130-052
V7-480308		Bushing	Teflon FEP	yes		$7x10^8$	MB 0130-052
V7-480547		Valve	--	yes		$6x10^9$	
V7-480546		Body, seal	Viton A	yes		$6x10^9$	SR277-70; Stillman Seal
V7-480370		Indicator	--	no		*	
ME444-0054		Wire, electrical	Teflon FEP insul.	no		$(1x10^9)$	MIL-W-16878/4A
--		Clamp, cable	Teflon	no	$6x10^8$	$(1x10^8)$	
V7-480008	Line Instl, Fill and Drain, LOX and LH_2		--	yes	$6x10^8$	$1x10^8$	
ME261-0003		Face coated seal	Teflon coated	yes	$6x10^8$	$1x10^8$	NAVAN
V7-480450		Valve	--	yes	$4x10^8$	$1x10^8$	
V7-480391		Lipseal	Mylar	yes		$6x10^9$	MB 0130-060, Type D-7.5
V7-480453		Lipseal	Mylar	yes		$6x10^9$	MB 0130-060, Type D-7.5
V7-480474		Ring	Teflon FEP	yes		$7x10^8$	MB 0130-052
V7-480614		Seal	Mylar	yes		$6x10^9$	MB 0130-060
MS29512		Packing	Synthetic rubber	no		$(6x10^9)$	MIL-P-5315
ME261-0028		Seal	Teflon coated	yes		$1x10^8$	
V7-480743		Lipseal, gate	Kel-F	yes		$1x10^9$	MB 0130-053
ME261-0036		Seal	Teflon TFE jacket	yes		$1x10^8$	
V7-480492		Spacer	Teflon, 25% asbestos	no		$(1x10^{10})$	
V7-480607		Bearing	Teflon FEP	yes		$7x10^8$	MB 0130-052
ME261-0027		Face coated seal	Teflon coated	yes		$1x10^8$	
V7-480643		Bearing	Kel-F	yes		$1x10^9$	AMS 3650
V7-480731		Retainer	Nylon	no		$(3x10^9)$	NYLOK
V7-480732		Retainer	Nylon	no		$(3x10^9)$	NYLOK
V7-480485		Lipseal	Mylar	yes		$6x10^9$	MB 0130-060
V7-480594		Valve	--	yes		$6x10^9$	
V7-480590		Body, seal	Viton A	yes		$6x10^9$	SR277-70; Stillman Rubber
V7-480640		Indicator	--	no	$4x10^8$	*	
V7-480394		Spacer	Teflon FEP	no	$6x10^8$	$(1x10^9)$	MB 0130-052
V7-480322		Washer	Kel-F	no	$6x10^8$	$(3x10^9)$	MB 0130-053
--		Potting compound	Polyurethane	no	$6x10^8$	$(1x10^{10})$	MB 0120-024

tolerance for each application and the predicted nuclear environment. Table 7-7 gives the recommended modifications which should result in a tolerance level of 8 x 10^9 ergs/gm(C).

7.2.4 Radiation Hardening Analysis

7.2.4.1 LH_2 Line Installation

The LH_2 line installations, of which Drawing V7-480066 is typical, includes the prevalves, the vacuum-jacketed 8-in. line extending from the tank to the engine installation, and the supporting brackets and fixtures. All-metal seals (ME261-0033) as well as the Teflon-coated ME261-0003 seals are used in the assembly. The ME261-0011 type line assemblies employ Kel-F O-rings. The replacement of the coated seals and the O-rings with more radiation resistant materials or all-metal seals will readily harden the lines to the RNS requirements. The resiliant mounts and Teflon tape, while not considered to be critical items, can easily be radiation hardened. A vacuum service valve (similar to Cryolab P/N SVL-84-FX or SV14-84-5E2) and thermocouples (for checking the vacuum in the jacket) are provided. However, they have not been analyzed since they would not be a requirement in the space environment.

The V7-480700 propellant prevalve was superseded by the ME284-0358 valve in products 16 and subsequent. However, a detailed parts breakdown was not received for the latter valve (Parker Hannifin; P/N 5670024-102) so the information in Table 7-6

Table 7-7

RECOMMENDED MODIFICATIONS — S-II PROPELLANT FEED SYSTEM

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Line Instl, LH_2 (typ)							
	ME261-0003	Seal	Required	Teflon coated	1×10^{8}	Kynar coated*	3×10^{10}
	--	Tape	Not critical	Teflon TFE	2×10^{7}	Polyimide	1×10^{10}
	--	O-ring	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	--	Mount, resiliant	Not critical	Silicone rubber	2×10^{9}	Polyurethane	5×10^{9}
	V7-480742	Lipseal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	V7-480721 (typ)	Bearing	Desired	Kel-F	1×10^{9}	Teflon/glass	8×10^{9}
	ME261-0036	Seal	Required	Teflon TFE	1×10^{8}	Kynar	3×10^{10}
	V7-480607 (typ)	Bearing	Desired	Teflon FEP	7×10^{8}	Teflon/glass	8×10^{9}
	V7-480394	Spacer	Not critical	Teflon FEP	1×10^{9}	Kynar	3×10^{10}
Line Instl, LOX (typ)							
	--	O-ring	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	ME261-0003 (typ)	Seal	Required	Teflon coated	1×10^{8}	Kynar coated*	3×10^{10}
	ME261-0036	Seal	Required	Teflon TFE	1×10^{8}	Kynar	3×10^{10}
	V7-480411	Lock element, seat	Desired	Nylon	3×10^{9}	Polyimide	3×10^{10}
	V7-480660	Lipseal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	V7-480607 (typ)	Bearing/bushing	Desired	Teflon FEP	7×10^{8}	Teflon/glass	8×10^{9}
	--	Insulation, wire	Not critical	Teflon FEP	1×10^{9}	Polyimide	1×10^{10}
	--	Clamp, cable	Not critical	Teflon	1×10^{8}	Polyimide	3×10^{10}
Line Instl, Fill and Drain							
	ME261-0003 (typ)	Seal	Required	Teflon coated	1×10^{8}	Kynar coated*	3×10^{10}
	V7-480474	Ring	Desired	Teflon FEP	7×10^{8}	Kynar	3×10^{10}
	V7-480743	Lipseal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	ME261-0036	Seal	Required	Teflon TFE	1×10^{8}	Kynar	3×10^{10}
	V7-480607	Bearing	Desired	Teflon FEP	7×10^{8}	Teflon/glass	8×10^{9}
	V7-480643	Bearing	Desired	Kel-F	1×10^{9}	Teflon/glass	8×10^{9}
	V7-480394	Spacer	Not critical	Teflon FEP	1×10^{9}	Kynar	3×10^{10}

*Use soft metal if possible.

is based on the V7-480700 valve. As may be seen, with the exception of the ME261-0036 seal (3 required) having a Teflon TFE jacket, all materials are relatively radiation resistant. Although several material substitutions are desirable (Table 7-7), only the seal is considered a required modification. The position indicating switches (ME452-0103; Teledyne Kinetics; P/N 992-1004) contain no organic materials.

It is believed that the ME284-0358 valve is similar, if not identical to, the V7-480700 valve. The specification (MC284-0358) gives the following components:

1. Valve body with mounting provisions
2. Pneumatic actuator
3. Position indicator switches
4. Closed position lock actuator
5. Relief valve

Although different organic materials could be used, the materials recommended in Table 7-7 would apply to either valve.

With the modifications indicated in Table 7-7, the radiation tolerance of the basic subsystem, 1×10^8 ergs/gm(C), should be increased to 8×10^9 ergs/gm(C), which is well in excess of the predicted exposure of 7×10^8 ergs/gm(C).

7.2.4.2 LOX Line Installation

The RNS will not, of course, require a propellant oxidizer. However, it was felt to be worthwhile to investigate the S-II LOX feedlines to determine the organic materials used. As seen from Tables 7-6 and 7-7, the organic materials used and the recommended substitutions are not significantly different from those for the LH_2 line installation.

7.2.4.3 LOX and LH_2 Fill and Drain

The LOX and LH_2 fill-and-drain installations are specified by Drawing V7-480008. Information was not received for the ME271-0012 LOX line assemblies (Stainless Steel Products; P/N 1803735-102 and 1803736-101) but Specification MC271-0012 indicates them to have the following components:

1. Tubing
2. Flanges
3. Bellows joints
4. Bosses
5. Supports and saddle clamps

The bellows in joints exposed to flow media at fill flow rates are provided with an internal liner to isolate the bellows convoluter from direct flow impingement. The liner material is unknown, but the specification of "multi-ply" construction indicates it could be at least in part organic. If a line of this type were to be considered for RNS LH_2 application, the liner should be removed or replaced if there were any possibility of deterioration that would produce loose material during tank refill.

The only other organic materials which might appear in the line installation, other than the ME261-0003 seals, would apparently be seals or O-rings similar to those used in the feed lines.

The V7-480450 valve (8-in. line size) is used for both the LOX and LH_2. In the LH_2 installation the valve is attached almost directly to the tank near the bottom. On the RNS, the LH_2 fill may be near the forward end of the vehicle as proposed by NAR (Ref. 3). However, the valve could be modified as indicated in Table 7-7 to withstand the doses near the aft end of the vehicle if such a location proved to be most desirable.

7.3 Pressurization System

7.3.1 Description and Location

The S-II stage pressurization system (V7-490800) includes many subsystems performing a variety of functions. These subsystems are located generally in the areas of the forward skirt, the aft end of the LH_2 tank, and the aft skirt. The subsystems examined are all located on the aft skirt since comparable locations (Fig. 7-3) on the RNS are assumed; further, these subsystems should be representative of the components and materials used throughout the system. The subsystems for which information was obtained are:

- V7-490003 - Pressure Sys Instl - External, LOX Tank
- V7-490004 - Vent Sys Instl - External, LOX Tank
- V7-490005 - Pressure Sys Manifold Instl - LOX and LH_2 Tank
- V7-490008 - Actuation & Checkout Sys Instl - LOX and LH_2 Tank Pressure Components
- V7-490052 - Helium Pressurization Sys Instl - LOX Tank Ullage
- V7-490990 - Pneumatic Actuation Sys Instl - Engine Propellant Valves
- V7-490830 - Helium Injection Sys Instl - In-Flight LOX Recirculation

7.3.2 Summary

Based on the analyses presented in Section 7.3.4, it is believed that the major components and subsystems of the pressurization

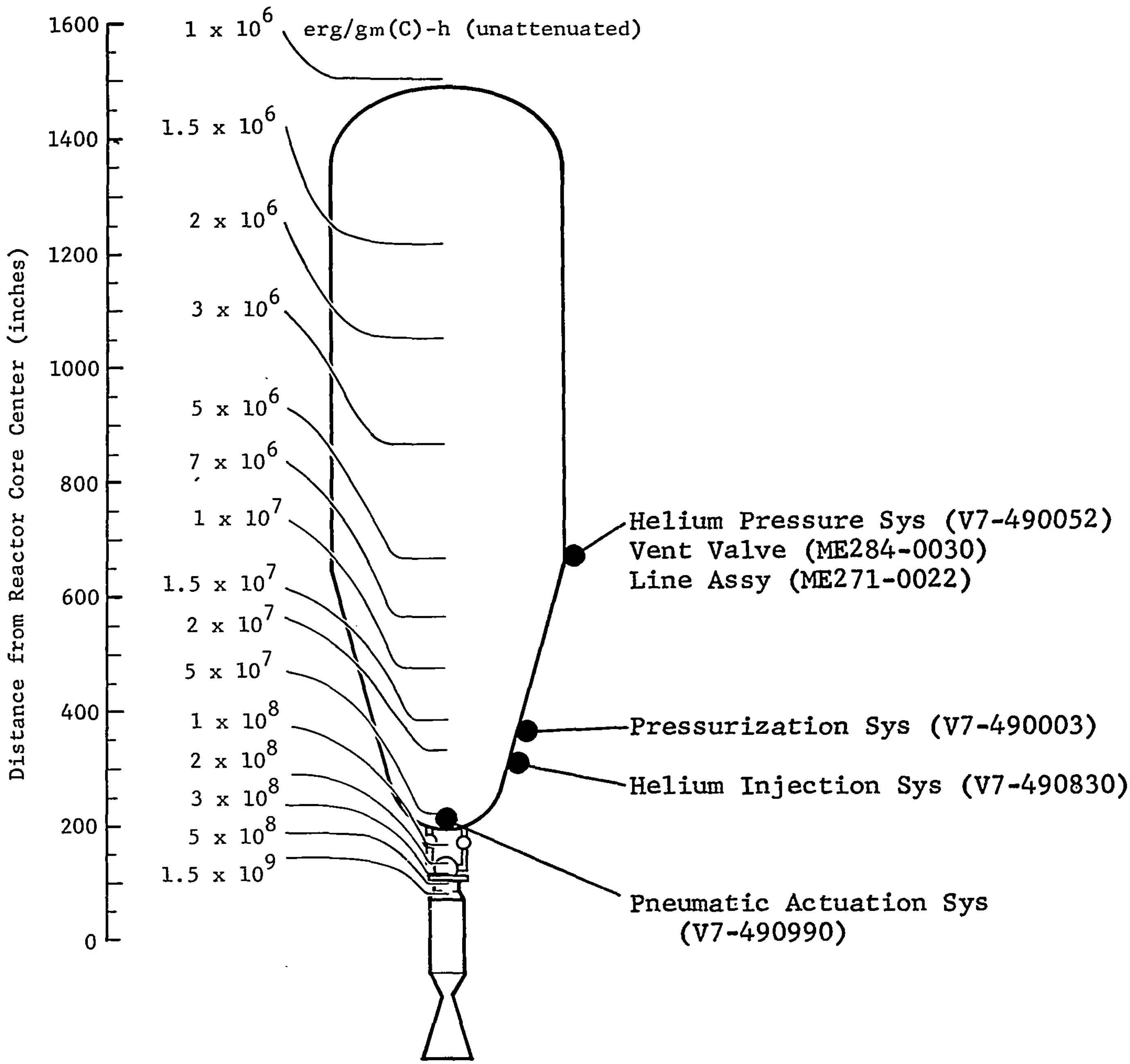


Figure 7-3 Assumed Location of (S-II) Pressurization System Components

system are either usable without modification or can be modified to meet the RNS nuclear requirement. Table 7-8 summarizes the predicted radiation environment and the recommended radiation tolerances of the basic and modified subsystems. The recommended modifications, which are discussed in Section 7.3.4, should increase the radiation tolerances to at least 8×10^9 ergs/gm(C) as compared to a maximum predicted radiation level of 7×10^8 ergs/gm(C).

7.3.3 System Breakdown and Recommended Modifications

Radiation sensitive materials and their applications identified in the examination of drawings, specifications, and part lists are given in Table 7-9 along with the recommended radiation tolerance for each application and the predicted nuclear environment. Table 7-10 gives the recommended modifications.

7.3.4 Radiation Hardening Analysis

7.3.4.1 Pressurization System, LOX Tank

The LOX tank pressurization system (V7-490003) consists of lines, tubes, a regulator, and mounting fixtures. A number of all metal seals (ME261-0033) are used in addition to the Teflon coated seal (ME261-0003). Numerous tubes (V7-490874) having all-metal fittings (MS33584 tube, MC124 nut, and MS20819 sleeve) are used, as is an all-metal flexible hose (ME271-0017). This hose, which is suitable for use in high- and low-pressure oxygen, helium, and hydrogen systems, consists of a convoluted metal

Table 7-8

RADIATION HARDENING SUMMARY — S-II PRESSURIZATION SYSTEM

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))	
			As Designed	As Modified
Pressurization, LOX	V7-490003	$5x10^{8}$	$1x10^{8}$	$3x10^{10}$
Vent, LOX	V7-490004	$1x10^{8}$	$7x10^{6}$	$6x10^{9}$
Helium press.	V7-490052	$1x10^{8}$	$7x10^{6}$	$1x10^{9}$
Pneumatic actuation	V7-490990	$6x10^{8}$	$7x10^{6}$	$6x10^{9}$
Helium injection	V7-490830	$7x10^{8}$	$7x10^{6}$	$8x10^{9}$

Table 7-9

RADIATION SENSITIVE COMPONENTS - S-II PRESSURIZATION SYSTEM, LH_2 AND LOX TANKS (V7-490800)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
V7-490003	Pressurization Sys, External, LOX Tank		--	yes	$5x10^{8}$	$1x10^{8}$	
ME261-0003		Face coated seal	Teflon coated	yes		$1x10^{8}$	NAVAN; TFE and FEP per VA0621-003
V7-490965		Regulator	--	yes		--	
ME284-0161		Regulator	N/R	yes	$5x10^{8}$	N/R	P/N 5640012; Parker Hannefin
V7-490004	Vent Sys, External, LOX Tank		--	yes	$1x10^{8}$	$7x10^{6}$	
ME261-0003		Face coated seal	Teflon coated	yes		$1x10^{8}$	See above
ME271-0022		Line assy	--	yes		$1x10^{9}$	P/N 41082; Solar
--		O-ring	Kel-F	yes		$1x10^{9}$	
ME284-0030		Valve, vent & relief, 7" line	--	yes		$7x10^{6}$	P/N 738-557; AMETEK/Calmec
--		Seal	N/R	no		(N/R)	P/N 10057; Raco Engr.
--		Seal	N/R	no		(N/R)	P/N 10057; Raco Engr.
--		Bearing	Teflon	no		$(3x10^{7})$	
737-93		Ring	Teflon, glass filled	yes		$1x10^{10}$	Fluorogold
737-95		Bearing	Teflon, glass filled	yes		$8x10^{9}$	Fluorogold
737-99		Seal	Teflon, glass filled	yes		$5x10^{9}$	Armalon 406-116
--		Seal	N/R	no		(N/R)	P/N 10057; Raco Engr.
737-64		Seat	Kel-F	yes		$1x10^{9}$	
737-96		Seal	Kel-F	no		$(1x10^{9})$	
737-75		Bearing	Teflon, glass filled	yes		$8x10^{9}$	Fluorogold
737-78		Piston ring	Teflon	yes		$7x10^{6}$	
737-135		Strip	Kel-F	no		$(3x10^{9})$	
737-85		Seal	Kel-F	yes		$1x10^{9}$	
737-137		Gasket	Kel-F	yes		$1x10^{9}$	
737-136		Gasket	Kel-F	yes		$1x10^{9}$	
737-77		Bearing	Teflon, glass filled	yes		$8x10^{9}$	Fluorogold
737-91		Gasket	Kel-F	no		$(1x10^{9})$	
738-32		Piston ring	Teflon	yes		$7x10^{6}$	
737-76		Gasket	Kel-F	no		$(1x10^{9})$	
737-15		Gasket	Kel-F	no		$(1x10^{9})$	
737-193		Tubing	Teflon	yes		$1x10^{8}$	
737-204		Gasket	Kel-F	no		$(1x10^{9})$	
737-51		Bumper	Teflon, glass filled	no		$(1x10^{10})$	Fluorogold
737-72		Gasket	Kel-F	no		$(1x10^{9})$	
--		Potting compound	Silicone rubber	no		$(2x10^{9})$	Silastic RTV601
737-54		Seal	Teflon	yes		$7x10^{6}$	
737-55		Seal	Teflon glass filled	yes		$5x10^{9}$	Armalon 410-128
737-59		Seat	Teflon	yes		$7x10^{6}$	
737-138		Gasket	Kel-F	no		$(1x10^{9})$	
737-63		Seal	Teflon, glass filled	yes		$5x10^{9}$	Fluorogold
737-24		Ring	Teflon, glass filled	yes		$1x10^{10}$	Fluorogold
737-25		Strip	Kel-F	yes		$3x10^{9}$	
737-29		Gasket	Kel-F	no		$(1x10^{9})$	
737-21		Seal	Teflon	yes		$7x10^{6}$	
737-18		Gasket	Mylar A	no		$(6x10^{9})$	
737-43		Seat	Mylar D	yes		$6x10^{9}$	
CMS-101K-2		Plug	Kel-F	no		$(3x10^{9})$	
737-17		Gasket	Mylar A	no		$(6x10^{9})$	
--		Face coated seal	Teflon coated	yes		$1x10^{8}$	P/N 8823-2003-0118; Parker
--		Seal	N/R	yes	$1x10^{8}$	N/R	P/N 10060; Raco Engr.

Table 7-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-II PRESSURIZATION SYSTEM, LH_2 AND LOX TANKS (V7-490800)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
V7-490990	Pneumatic Actuation Sys, Engine Propellant Valves			yes	$6x10^8$	$7x10^6$	
ME284-0159		Solenoid valve, 3-way	--	yes		$1x10^9$	P/N 26530; Sterer Engr. & Mfg. Co.
100-10		Seal	Kel-F	yes		$1x10^9$	Bal Seal
--		Potting compound	N/R	no		(N/R)	Coast Pro Seal 777
--		Connector		yes		$1x10^9$	MIL-C-5015
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no		$(3x10^9)$	
		Wire, elec.	Teflon FEP insul.	yes		$1x10^9$	MIL-W-16878/4
ME284-0158		Regulator-relief valve	--	yes		$7x10^6$	P/N 12078; Royal Industries
153032		Gasket, housing	Mylar A	yes		$6x10^9$	
153060		Retainer assy	--	yes		*	
--		Insert	Kel-F	no		$(3x10^9)$	Long-Lok Corp.
--		Sensor	--	yes		$7x10^6$	
153074		Seal	Teflon TFE	yes		$7x10^6$	AMS 3651
153021		Diaphragm	Mylar A	yes		$6x10^9$	
153094		Seal	Teflon TFE	yes		$7x10^6$	AMS 3651
--		Metering assy	--	yes		$7x10^6$	
153064		Seal	Mylar A	yes		$6x10^9$	
153067		Seat	Mylar A	yes		$6x10^9$	
153072		Seal	Teflon TFE	yes		$7x10^6$	AMS 3651
--		Relief valve	--	yes		$7x10^6$	
153076		Seal	Teflon TFE	yes		$7x10^6$	AMS 3651
153097		Seat	Mylar A	yes		$6x10^9$	
153098		Gasket	Mylar A	yes		$6x10^9$	
1530102		Guide assy	--	yes		*	
--		Pellet	Kel-F	no		$(3x10^9)$	Loc-King Corp.
153092		Plug assy	--	no		*	
--		Insert	Kel-F	no		$(8x10^9)$	Loc-King Corp.
153024		Diaphragm	Mylar A	yes		$6x10^9$	
V7-490849		Solenoid assy	--	yes		$7x10^6$	
ME284-0356		Solenoid valve, 3-way	--	yes		$7x10^6$	P/N 6969-2; J. C. Carter Co.
--		Gasket	N/R	yes		N/R	MS90484 (incorrect number)
--		Tubing	Silicone rubber	no		$(2x10^9)$	FIT-221; Alpha Wire Corp.
--		Potting compound	N/R	yes		N/R	
24312		Bobbin	Diallyl phthalate	yes		$2x10^{10}$	MIL-M-19833, Type GDI-30F
--		Wire, elec.	Synthetic fiber insul.	yes		$3x10^9$	MIL-W-583, Class F
--		Sealant	Silicone rubber	yes		$1x10^9$	Dow Corning RTV-504
		Lubricant	Halocarbon	yes		$1x10^9$	Hooker Chemical Fluorolube Gd-362
24281		Seal	Teflon, glass filled	yes		$5x10^9$	TEC Fluorfil B; Thermech Engr. Corp.
24283		Seat, poppet	Kel-F	yes		$1x10^9$	
24289		Gasket	Teflon, glass filled	yes		$5x10^9$	TEC Fluorfil B; Thermech Engr. Corp.
24298		Gasket	Teflon TFE	yes		$7x10^6$	AMS 3651
--		Connector	--	yes		$1x10^9$	MIL-C-5015
--		Insert	Silicone rubber	yes		$1x10^9$	
--		End plug	Nylon	no	$6x10^8$	$(3x10^9)$	

Table 7-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-II PRESSURIZATION SYSTEM, LH_2 AND LOX TANKS (V7-490800)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
737-130		Gasket	Kel-F	no	1x10^{8}	(1x10^{9})	
737-231		Seat	Teflon	yes		7x10^{6}	
--		Wire	Teflon FEP	yes		1x10^{9}	MIL-W-16878/4A, Type E
737-102		Gasket	Kel-F	no		(1x10^{9})	
737-205		Gasket	Kel-F	yes		1x10^{9}	
737-206		Gasket	Kel-F	no		(1x10^{9})	
737-152		Gasket	Kel-F	no		(1x10^{9})	
--		Sleeve, wire	Teflon	no		(1x10^{8})	
737-270		Pad	Teflon	no		(1x10^{8})	
737-271		Grommet	Teflon	no		(1x10^{8})	
737-167		Gasket	Kel-F	no		(1x10^{9})	
737-273		O-ring	Silicone	no		(8x10^{8})	
737-221		Gasket	Teflon	yes		7x10^{6}	
737-293		Plug, sealing	Polycarbonate	no		(5x10^{9})	
737-258		Seal	Teflon	yes		7x10^{6}	
737-262		Sleeve	Teflon	yes		1x10^{8}	
--		Tape	Teflon	no		(2x10^{7})	Permacel P-421
--		Lacing cord	Nylon	no		(3x10^{9})	MIL-T-713A, Type P, Class 2
737-277		Spacer	Nylon	no		(3x10^{9})	
--		Jacket	Teflon	no		(1x10^{8})	
737-284		Insulator	Mylar	yes		1x10^{10}	
--		Seal	N/R	yes		N/R	P/N 11958; Raco Engr.
--		Lubricant	Teflon base spray	yes		1x10^{8}	Drilube 842
--		Potting compound	Silicone	no	1x10^{8}	(2x10^{9})	Silastic RTV601
V7-490052	Helium Press Sys,	LOX Tank Ullage	--	yes	1x10^{8}	7x10^{6}	
ME261-0003		Face coated seal	Teflon coated	yes		1x10^{8}	NAVAN
ME284-0155		Solenoid valve	--	yes		7x10^{6}	P/N 26540; Sterer Engr. & Mfg. Co.
100-20		Seal	Teflon	yes		7x10^{6}	Bal Seal Engr. Co.
19374		Insert	Kel-F	yes		3x10^{9}	AMS 3650
20702		Gasket	Teflon	yes		7x10^{6}	MB0295-009
12120CR4		K seal, face coated	Teflon coated	yes		1x10^{8}	Harrison Mfg. Co.
20571		Gasket	Kel-F	yes		1x10^{9}	AMS 3650
--		Grease	Kel-F oil & wax	no		(1x10^{10})	Kel-F No. 90; 3M
V7-490629		Pressure switch	--	yes		1x10^{8}	
ME452-0021		Pressure switch	--	yes		1x10^{8}	P/N 8438; Rusha Precision Corp.
4402		Wire, elec.	Teflon FEP insul.	yes		1x10^{9}	MIL-W-16878/4, Type EE
15215		Sleeving	Irrad. polyolefin	no		(3x10^{9})	P/N FIT-270; Alpha Wire Corp.
15243		Sleeving	Teflon TFE	no		(1x10^{8})	AMS 3653
--		Sealant	Synthetic rubber	yes		1x10^{9}	MIL-S-22473, Class C
15386		Rod	Kel-F	yes		3x10^{9}	
--		Potting	Epoxy	no		(2x10^{10})	Emerson & Cuming, Inc.
--		Lubricant	Halocarbon	yes	1x10^{8}	1x10^{9}	Fluorolube Gd-362; Hooker Chemical

Table 7-9 (continued)

RADIATION SENSITIVE COMPONENTS - S-II PRESSURIZATION SYSTEM, LH_2 AND LOX TANKS (V7-490800)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
V7-490830	Helium Injection Sys, LOX Recirculation		--	yes	$7x10^8$	$7x10^6$	
V7-490864		Regulator assy	--	yes		$7x10^6$	
ME284-0158		Regulator	--	yes		$7x10^6$	P/N 12078; Royal Industries
		See above					
V7-490849		Solenoid assy	--	yes		$7x10^6$	
ME284-0356		Solenoid valve, 3-way	--	yes		$7x10^6$	P/N 6969; J. C. Carter Co.
--		See above					
ME284-0159		Solenoid valve, 3-way	--	yes		$1x10^9$	P/N 26530; Sterer Eng. & Mfg. Co.
--		See above					
ME284-0158		Regulator-relief valve	--	yes		$7x10^6$	P/N 12078; Royal Industries
--		See above					
V7-490906		Valve assy	--			*	
ME284-0270		Safety-relief valve	N/R	no		(N/R)	P/N 193800; Wallace O. Leonard, Inc.
ME284-0189		Valve	N/R	yes	$7x10^8$	N/R	

Table 7-10

RECOMMENDED MODIFICATIONS — S-II PRESSURIZATION SYSTEM (V7-490800)

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Pressurization Sys, LOX Tank							
	ME261-0003	Face coated seal	Required	Teflon coated	1×10^{8}	Kynar coated*	3×10^{10}
Vent Sys, LOX Tank							
	ME261-0003 (typ)	Face coated seal	Desired	Teflon coated	1×10^{8}	Kynar coated*	3×10^{10}
	--	Bearing	Not critical	Teflon	3×10^{7}	Teflon/glass	8×10^{9}
	737-78 (typ)	Piston ring	Required	Teflon	7×10^{6}	Kynar composite	1×10^{10}
	737-193	Tubing	Desired	Teflon	1×10^{8}	Aluminum*	--
	737-54 (typ)	Seal	Required	Teflon	7×10^{6}	Mylar	6×10^{9}
	737-59 (typ)	Seat	Required	Teflon	7×10^{6}	Kynar	3×10^{10}
	--	Sleeve, wire	Not critical	Teflon	1×10^{8}	Polyimide	1×10^{10}
	737-270	Pad	Not critical	Teflon	1×10^{8}	Kynar	3×10^{10}
	737-271	Grommet	Not critical	Teflon	1×10^{8}	Teflon FEP	1×10^{9}
	737-221	Gasket	Required	Teflon	7×10^{6}	Kynar composite	1×10^{10}
	--	Tape	Not critical	Teflon	2×10^{7}	Polyimide	1×10^{10}
	--	Jacket	Not critical	Teflon	1×10^{8}	Polyimide	1×10^{10}
	--	Lubricant	Desired	Teflon base	1×10^{8}	Solid film	1×10^{11}
	--	O-ring	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
Helium Pressurization Sys							
	ME261-0003 (typ)	Face coated seal	Desired	Teflon coated	1×10^{8}	Kynar coated*	3×10^{10}
	100-20	Seal	Required	Teflon	7×10^{6}	Kynar	3×10^{10}
	20702	Gasket	Required	Teflon	7×10^{6}	Kynar composite*	1×10^{10}
	15243	Sleeving	Not critical	Teflon TFE	1×10^{8}	Polyimide	1×10^{10}
Pneumatic Actuation Sys							
	100-10	Seal	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	153074 (typ)	Seal	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	--	Tubing	Not critical	Silicone rubber	2×10^{9}	Teflon/glass	1×10^{10}
	--	Insulation, wire	Desired	Synthetic fiber	3×10^{9}	Polyimide	1×10^{10}
	--	Sealant	Desired	Silicone rubber	1×10^{9}	Buna N	8×10^{9}
	--	Lubricant	Desired	Halocarbon	1×10^{9}	MoS_2	--
	24281	Seal	Desired	Teflon, glass filled	5×10^{9}	Kynar composite*	1×10^{10}
	24283	Seat, poppet	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	24289	Gasket	Desired	Teflon, glass filled	5×10^{9}	Kynar composite*	1×10^{10}
	24298	Gasket	Required	Teflon TFE	7×10^{6}	Kynar*	3×10^{10}
	--	Insert	Desired	Silicone rubber	1×10^{9}	Ceramic**	--
	--	End plug	Not critical	Nylon	3×10^{9}	Ceramic**	--
	ME261-0028	Face coated seal	Required	Teflon coated	1×10^{8}	Kynar coated	3×10^{10}
	--	Potting	Not critical	Unknown	?	Epoxy	2×10^{10}
Helium Injection Sys							
	153074 (typ)	Seal	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	--	Tubing	Not critical	Silicone rubber	2×10^{9}	Teflon/glass	1×10^{10}
	--	Insulation, wire	Desired	Synthetic fiber	3×10^{9}	Polyimide	1×10^{10}
	--	Sealant	Desired	Silicone rubber	1×10^{9}	Buna N	8×10^{9}
	--	Lubricant	Desired	Halocarbon	1×10^{9}	Solid film	1×10^{11}
	24281	Seal	Desired	Teflon, glass filled	5×10^{9}	Kynar	3×10^{10}
	24283	Seat, poppet	Desired	Kel-F	1×10^{9}	Kynar	3×10^{10}
	24289	Gasket	Desired	Teflon, glass filled	5×10^{9}	Kynar composite	1×10^{10}
	24298	Gasket	Required	Teflon TFE	7×10^{6}	Kynar	3×10^{10}
	--	Potting	Not critical	Unknown	--	Epoxy	2×10^{10}

*Use soft metal if possible
**Specify connectors with ceramic inserts

bellows covered by a metal braid. The LOX tank pressure line, for which specific information was not requested, is specified (MC271-0025) to be of corrosion resistant alloys and probably does not contain any organic material.

A detailed parts breakdown was not received for the ME284-0161 pressure regulator valves (Parker Hannefin; P/N 5640011 for gaseous hydrogen and P/N 5640012 for gaseous oxygen). The regulators are used to control the ullage pressure in the propellant tanks. Since these valves contain a number of components, e.g., position switch, potentiometer, solenoid valve, shuttle valves, and electrical fittings, it almost certainly contains organic parts similar to those identified elsewhere. If this valve is to be considered for use on the RNS at any location near the aft end, an analysis will be required.

7.3.4.2 <u>Vent System, LOX Tank</u>

The main components of the LOX tank vent system are metal lines (V7-490874), the ME271-0022 vent lines, and the ME284-0030 vent valves. The vent lines (Solar Division of International Harvester; P/N 41082) utilize a Kel-F O-ring. The line sections are assembled with ME261-0003 Teflon coated seals.

The ME284-0030 vent valves (7-in. line size) are specified (MC284-0030) in three types:

Type I - gaseous hydrogen
Type II - gaseous oxygen
Type III - step vent - gaseous hydrogen
Type IIIA - step vent and cryoproof - gaseous hydrogen

The main components are:

1. Vent and relief valves (main valve)
2. Actuation solenoid valves (2)
3. Step vent solenoid valve (Type III and IIIA only)
4. Electrical switches (4)
5. Backup relief valve (Type I and II only)
6. Step vent relief valve (Type III and IIIA only)

It was a design objective to make the Types I, II, III, and IIIA valves identical in every respect, except in relief pressure and installation detail. An examination of drawings for Types II and IIIA valves (Ametek/Calmec; P/N 738-557 and 737-561) indicate that this is the case; therefore the parts breakdown given in Table 7-9 can be considered typical for both oxygen and hydrogen vent valves covered by Specification ME284-0030.

All organic materials in the vent valve were identified except those possibly used in the Raco Engineering seals; no information concerning these parts or this company could be found. However, even assuming the seals to contain Teflon TFE, this would not lower the radiation tolerance, 7×10^{6} ergs/gm(C), of the basic valve. The modifications indicated in Table 7-10 will increase the tolerance to at least 6×10^{9} ergs/gm(C), or well above the assumed environment of 1×10^{8} ergs/gm(C).

7.3.4.3 Pressure System Manifold Installation

The V7-490005 manifold installations employ ME272-0005 (gaseous oxygen) and ME272-0006 (gaseous helium) manifold assemblies. These manifolds consist of bellows, elbows, tubing, flanges, and bosses. These parts (AMETEK/Straza; P/N 8-030087 (GOX), P/N 8-030536 (GH_2), and others) contain no organic materials. The installation is assembled with ME261-0003 Teflon coated seals. Engine isolation check valves (used on some models) use metal seals and appear to be all metal with the possible exception of the poppet seat for which no information was obtained. The radiation tolerance of this subsystem is limited by the Teflon coated seals (1×10^8 ergs/gm(C)) and can be increased to greater than 10^{10} ergs/gm(C) if Kynar coated or metal seals are used and polyimide is used as the poppet seat (if required).

7.3.4.4 Actuation and Checkout System Installation

The V7-490008 actuation and checkout system for the LOX and LH_2 tank pressurization components consists of manifolds, numerous lines, metal seals (ME261-0023 and ME261-0033) and the support fittings. Typical line assemblies (V7-490107, V7-490781) and manifolds (V7-490311) which were examined are all metal. Teflon TFE gaskets are used on the forward umbilical disconnect, but these could be replaced with Kynar if required on the RNS.

7.3.4.5 Purge System, LH_2 Tank Pressure Lines

The V7-490013 LH_2 tank pressure line purge system consists of metal lines (V7-490585, V7-490875) and fittings, metal seals (ME261-0033), and ME284-0074 valves. The helium check valves (Sterer Engr. and Mfg. Co.; P/N 26610) are of welded all-metal construction. This subsystem is therefore satisfactory for use without modification.

7.3.4.6 Helium Pressurization System, LOX Tank Ullage

The main components of the V7-490052 pressurization system aside from metal lines (e.g., V7-490874) and fittings are listed in Table 7-9. The radiation tolerance of the basic system is limited to 7×10^6 ergs/gm(C) by the Teflon (assumed to be TFE) seals in the solenoid valve (Sterer Engr. and Mfg. Co.; P/N 26540). This pilot-operated, two-way, normally open solenoid valve is specified (MC284-0155) for use with helium, nitrogen, oxygen, and hydrogen gases. The wiring, not listed in Table 7-9, conforms to MIL-W-16878/4 which specifies Teflon FEP insulation; this would be satisfactory at the assumed exposure level.

The ME452-0021 absolute pressure actuated switch is used for both LOX and LH_2 tanks. The materials listed in Table 7-9 apply to both type switches (Ruska Precision Corp.; P/N 8438 and 8148). Aside from the Teflon TFE sleeving, which is not considered critical, the materials have recommended tolerances of 1×10^9 ergs/gm(C) or higher.

An ME452-0024 fill overpressure switch (Frebank Co.; P/N 8438) is also used, but information was not received on this part.

The modifications recommended in Table 7-10 will increase the radiation tolerance to about 1 x 10^9 ergs/gm(C). Additional material substitutions could be made to increase this still further.

7.3.4.7 Pneumatic Actuation System, Engine Propellant Valves

The propellant valve actuation system (V7-490990) includes the following components which were investigated and found to contain no organic materials:

Line assemblies (e.g., V7-490306)

Seals (ME261-0023, ME261-0033)

Flex hose (ME271-0017)

Helium receivers (ME282-0036)

Check valves (ME284-0074)

The organic materials contained in the solenoid valves and regulator are shown in Table 7-9. The ME284-0159 3-way solenoid valve (Sterer Engr. and Mfg. Co.; P/N 26530) has a radiation tolerance of 1 x 10^9 ergs/gm(C), or somewhat above the predicted environment. The ME284-0158 high-flow regulator-relief valve (Royal Industries; P/N 12078) has a radiation tolerance, 7 x 10^6 ergs/gm(C), limited by the Teflon TFE seals. The ME284-0356

3-way cryogenic solenoid valve (J. C. Carter Co.; P/N 6969), which is used to actuate the prevalve, has a tolerance set by the Teflon TFE gasket.

As indicated in Table 7-10, the required modifications are replacement of Teflon TFE seals and gaskets. However, with the other suggested modifications, the radiation tolerance of this subsystem could be increased to 8×10^9 ergs/gm(C).

7.3.4.8 Helium Injection System

The main components contained in the helium injection system are metal lines (V7-490831, V7-490881), a metal hose (V7-417852), metal seals (ME261-0023, ME261-0033), a regulator, and several valves. Of the valves, information was not in the MSFC files on the ME284-0189 valve, and information was not received on the ME284-0270 safety relief valve (Wallace O. Leonard; P/N 193800). The ME284-0074 check valve is of all-metal welded construction.

The ME284-0158 high-flow regulator-relief valve has an internal pressure sensing device for maintaining the outlet pressure at specified gauge pressure. It is used to control the actuation pressure for the LH_2 and LOX recirculation systems and the helium injection system. The radiation tolerance of this valve, 7×10^6 ergs/gm(C), is limited by several Teflon TFE seals.

The ME284-0356 3-way cryogenic solenoid valve has a Teflon TFE gasket which sets the limit on the radiation tolerance, i.e., 7×10^6. The other organic materials have tolerances above the predicted exposure.

The ME284-0159 3-way solenoid valve is used to provide helium actuation pressure in the recirculation system and to vent helium pressure from the system. The radiation tolerance should be at least 1×10^9 ergs/gm(C), or somewhat above the predicted requirement.

As indicated in Table 7-10, the required modifications are the replacement of Teflon TFE seals and gaskets. However, with the other suggested modifications, the radiation tolerance of this subsystem could be increased to 8×10^9 ergs/gm(C), or a factor of ten above the predicted environment.

7.4 Leak Detection and Purge System

7.4.1 Description and Location

The S-II stage leak detection and purge system (V7-532501) is located on the aft skirt and around the LOX tank. The assumed location for an RNS installation is along the sidewall of the conical aft tank section. The foam-filled honeycomb material used as outside insulation on the LH_2 tank has helium gas forced through it for purging and leak detection. Although the insulation used on the RNS will be of different material, a system for purging and leak detection will probably be required; the requirement for such a system when in space, however, is unknown.

7.4.2 Summary

The major components of this system contain few or no organic materials, and none of the applications are considered critical to the functioning of the system. Therefore, no modifications are considered to be necessary.

7.4.3 System Breakdown and Recommended Modifications

This system consists primarily of metal lines and fittings, expansion joints, couplings, and metal seals. Some sealants and organic seals are used. The radiation sensitive materials and their applications identified from drawings and part-lists are given in Table 7-11 along with the recommended radiation tolerances and the predicted environment.

Table 7-11

RADIATION SENSITIVE COMPONENTS — S-II LEAK DETECTION AND PURGE SYSTEM (V7-532501)

Part Number	Subsystem	Component	Material	Critical Application	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
V7-530702	Sys Instl, Discharge, Flange Seals, LH_2 Tank		--	no	$7x10^8$	*	
--		Sealant	Silicone rubber	no		$(1x10^9)$	MB0130-019, Type II
--		Sealant	Polyurethane resin	no		$(1x10^{10})$	MB0120-024
--		Laminate	Nylon	no	$7x10^8$	$(3x10^9)$	
V7-530707	Sys Instl, Common Bkd & J-Ring		--	no	$2x10^8$	*	
V7-530638		Flange & seal	Teflon TFE	no	$2x10^8$	$(7x10^6)$	AMS 3651
ME261-0003		Seal	Teflon coated	no	$2x10^8$	$(1x10^8)$	NAVAN

7.4.4 Radiation Hardening Analysis

The following drawings were examined and concluded to be free of organics:

V7-430701 - Sys Instl - Discharge, Common Bulkhead and J-Ring

V7-432403 - Leak Check Instl - Seals, Bolted Flange Joints, Insulated

V7-532590 - Instl - Leak Check Fittings, LOX Sump Flanges

The V7-430702 installation consists of metal lines (e.g., V7-530709) and fittings, metal seals (ME261-0023, ME261-0033), and an expansion joint (ME273-0059). Mounting hardware includes ME127-0014 clamps which have a cushion of glass impregnated Teflon. Some of the attaching hardware is sealed with a laminate of nylon and silicone rubber. Some of the fittings, i.e., nuts and unions, are sealed with polyurethane resin. All of the materials have radiation tolerances higher than the predicted environment, and none of the applications are critical to the operation of the system. However, the use of a fiberglass/silicone laminate would increase the radiation tolerance significantly.

In addition to lines, fittings, metal expansion joints, etc., the V7-530707 installation employes a number of Teflon coated seals (ME261-0008) and a bellows seal assembly (V7-530638) of Teflon TFE sheet. Replacement of these seals with Kynar coated or metal seals and Mylar, respectively, would increase the radiation tolerance of the individual components to 1×10^{10}

ergs/gm(C).

7.5 Electrical System, General Installation

7.5.1 Description and Location

Electrical and electronic systems *per se* are not a part of this study. Installation components and fixtures have been examined, however, since similar items will be required on the RNS. The harness, electrical, and other installations examined are located on the forward skirt, aft skirt, thrust cone, and lower propellant tank. The installations included in the analysis are fairly typical insofar as usage and application of organic materials. The assumed locations are shown in Figure 7-4.

7.5.2 Summary

None of the organic material applications are considered critical to the operation of the systems associated with the installations. With the exception of grommets of Teflon TFE, the materials have radiation tolerances of at least 1×10^9 ergs/gm(C), which are higher than the predicted exposure levels. Since several of the applications are for the physical protection of wiring, it would be a simple matter to use more radiation resistant materials for an added margin of safety.

7.5.3 System Breakdown and Recommended Modifications

Table 7-12 gives the materials and applications for several typical installations. Table 7-13 gives the recommended modifications.

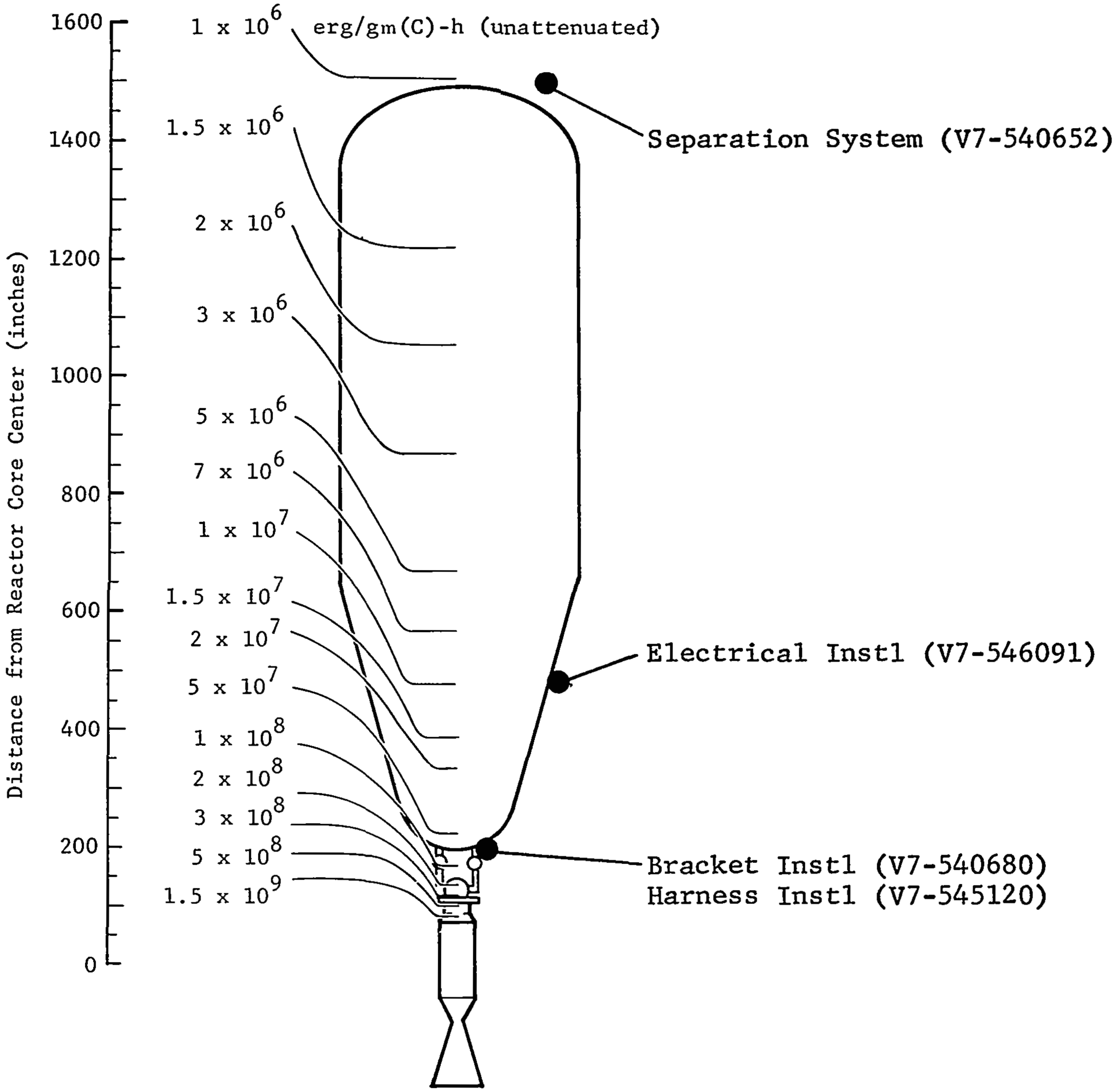


Figure 7-4 Assumed Location of (S-II) Electrical System General Components

Table 7-12

RADIATION SENSITIVE COMPONENTS — S-II ELECTRICAL SYSTEM, GENERAL (V7-540378)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
V7-540680	Bracket Installation (Typical)		--	no	$6x10^8$	*	
--		Grommet	Teflon TFE	no	$6x10^8$	$(1x10^8)$	MS21266
MP154-0001		Grommet	Silicone rubber	no	$6x10^8$	$(2x10^9)$	ZZ-R-765, Cl 3, Gr 50
V7-545120	Harness Installation (Typical)		--	yes	$6x10^8$	*	
MS043-3564		Grommet	Silicone rubber	no		$(2x10^9)$	ZZ-R-765, Cl 3, Gr 50
MP154-0001		Grommet	Silicone rubber	no		$(2x10^9)$	ZZ-R-765, Cl 3, Gr 50
--		Adhesive	Silicone rubber	no		$(1x10^{10})$	MB0130-019, Type III
--		Adhesive	Polyurethane	no		$(1x10^{10})$	MB0120-024
--		Tape	Teflon TFE	no		$(2x10^7)$	MIL-T-23594, Type I
--		Sleeving	Irrad polyolefin	no	$6x10^8$	$(3x10^9)$	
V7-546091	Electrical Installation		--	yes	$2x10^8$	*	
--		Adhesive	Polyurethane	no		$(1x10^{10})$	MB0120-024
V7-545622		Seal	Silicone rubber	no		$(8x10^8)$	MIL-R-5847, Cl 3
MS35490		Grommet	Synthetic rubber	no		$(2x10^9)$	MIL-R-003065A, Gr SB-512-ABF_2
MS043-3564		Grommet	Silicone rubber	no		$(2x10^9)$	ZZ-R-765, Cl 3, Gr 50
--		Fabric	Nylon	no		$(3x10^9)$	MB0135-021, Type II
--		Sealant	Silicone rubber	no	$2x10^8$	$(1x10^9)$	MB0130-019, Type 3
V7-540652	Separation System		--	yes	$1x10^7$	*	
--		Adhesive	Silicone rubber	no	$1x10^7$	$(1x10^{10})$	MB0130-019, Type III
MD175-9007		Tape	Polyester	no	$1x10^7$	$(2x10^9)$	MIL-T-9906

Table 7-13

RECOMMENDED MODIFICATIONS — S-II ELECTRICAL SYSTEM, GENERAL

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Bracket Installation (typ)							
	--	Grommet	Not critical	Teflon TFE	$1x10^8$	Buna N	$1x10^{10}$
	MP154-0001	Grommet	Not critical	Silicone rubber	$2x10^9$	Buna N	$1x10^{10}$
Harness Installation (Typ)							
	MS043-3564	Grommet	Not critical	Silicone rubber	$2x10^9$	Buna N	$1x10^{10}$
	--	Tape	Not critical	Teflon TFE	$2x10^7$	Polyimide	$1x10^{10}$
	--	Sleeving	Not critical	Polyolefin	$3x10^9$	Polyimide	$1x10^{10}$
Electrical Installation							
	V7-545622	Seal	Not critical	Silicone rubber	$8x10^8$	Viton A	$6x10^9$
	--	Sealant	Not critical	Silicone rubber	$1x10^9$	Buna N	$8x10^9$

7.5.4 Radiation Hardening Analysis

The organic materials are used as sealants, adhesives, or for abrasion protection and are only required to maintain their physical integrity. While the installations are considered to be satisfactory as is, the substitution of more radiation resistant materials as noted in Table 7-13 would increase the radiation tolerance of the individual parts.

7.6 Engine Installation

7.6.1 Description and Location

The J-2 engine is analyzed in Section 6.4; the discussion here is of installations associated with the S-II stage engines (V7-417005). These are the service line installations and the LOX and LH_2 recirculation (temperature conditioning) systems. The assumed locations of these components are shown in Figure 7-5.

7.6.2 Summary

Based upon the analyses in Section 6.4.4 for the J-2 engine and in Section 7.6.4 for the S-II stage subsystem installations, it is believed that each of the major components and subsystems can be radiation hardened to reliably function in nuclear environments more severe than those predicted at the assumed component locations. Table 7-14 summarizes the predicted nuclear environment and the recommended tolerances for both the basic and modified configurations. The recommended modifications, discussed in Section 7.6.4, should result in a radiation tolerance of at least 8×10^9 ergs/gm(C).

7.6.3 System Breakdown and Recommended Modifications

Drawings, specifications, and part lists of the service line installation and the LH_2 recirculation system were examined to determine radiation sensitive materials whose performance might degrade due to irradiation. Table 7-15 lists these

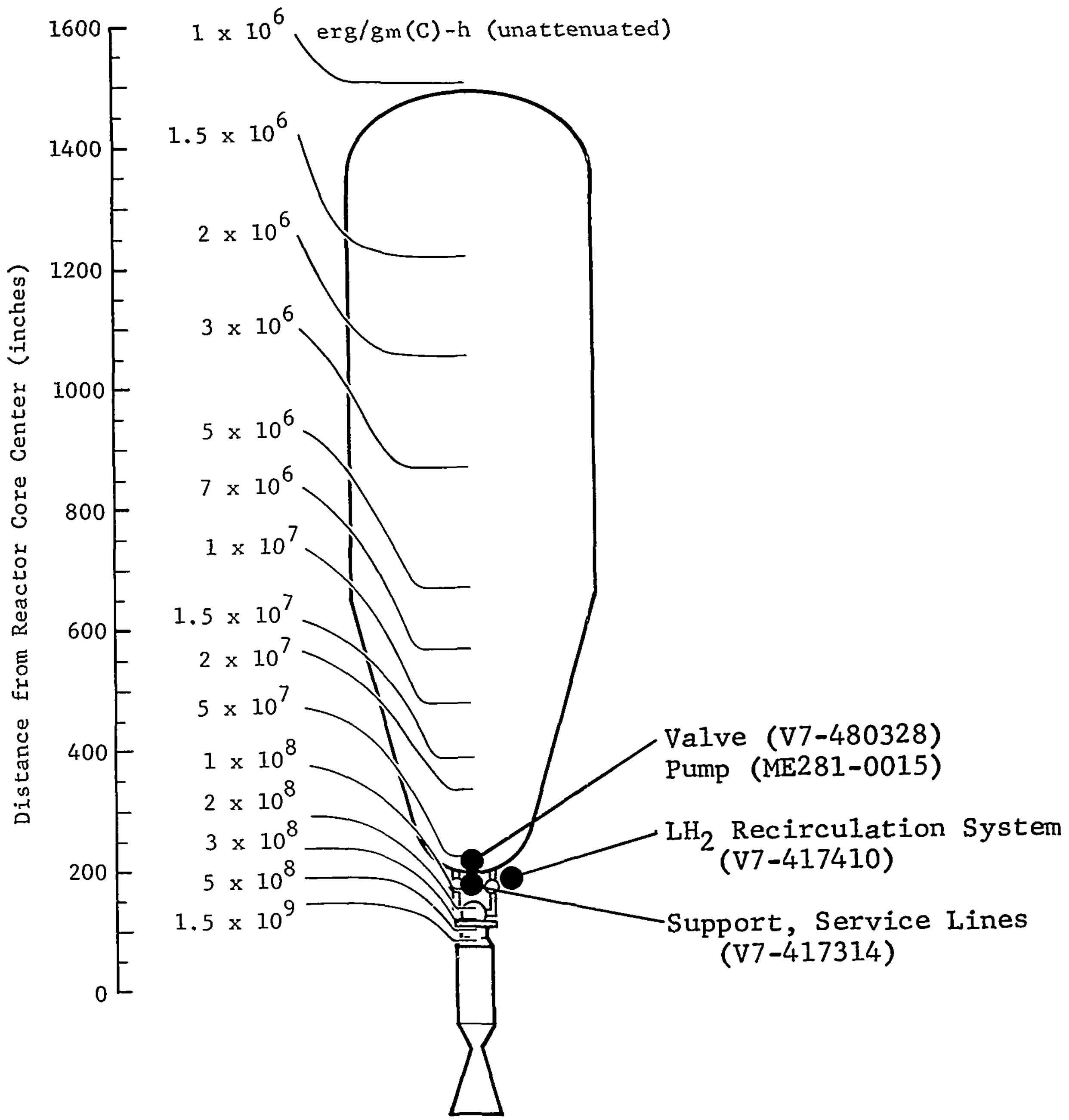


Figure 7-5 Assumed Location of (S-II) Engine Installation Components

Table 7-14

RADIATION HARDENING SUMMARY — S-II ENGINE INSTALLATION

Subsystem	Drawing Number	Predicted Gamma Environment (ergs/gm(C))	Recommended Tolerance (ergs/gm(C))	
			As Designed	As Modified
Support	V7-540652	1.5×10^9	1×10^8	3×10^{10}
LH_2 recirculation	V7-417410	1×10^9	1×10^8	8×10^9

Table 7-15

RADIATION SENSITIVE COMPONENTS — S-II ENGINE INSTALLATION (V7-417005)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Gamma Environment (ergs/gm(C)) Tolerance	Specification or Vendor
V7-417314	Support, Center Engine Service Lines		--	yes	1.5x10^{9}	1x10^{8}	
ME261-0003		Face coated seal	Teflon coated	yes	1.5x10^{9}	1x10^{8}	NAVAN: TFE & FEP per VA 0621-003
V7-417410	LH_2 Recirculation Sys		--	yes	1x10^{9}	1x10^{8}	
ME261-0003		Face coated seal	Teflon coated	yes	1x10^{9}	1x10^{8}	NAVAN
--		Tape	Teflon TFE	no	6x10^{8}	(2x10^{7})	MIL-T-23594, Type I
V7-480328		Valve	--	yes		1x10^{8}	
V7-480555		Bearing	Teflon FEP	yes		7x10^{8}	MB0130-052
V7-480556		Bearing	Teflon FEP	yes		7x10^{8}	MB0130-052
V7-480557		Spacer	Teflon & asbestos	yes		1x10^{10}	75% Teflon, 25% asbestos
V7-480558		Seal	Kel-F	yes		1x10^{9}	MB0130-053
V7-480563		Bearing	Teflon FEP	yes		7x10^{8}	MB0130-052
V7-480564		Bearing	Teflon FEP	yes		7x10^{8}	MB0130-052
V7-480565		Seal	Mylar	yes		6x10^{9}	MB0130-060, Type D-7.5
V7-480568		Retainer locking element	Nylon	no		(3x10^{9})	NYLOK
V7-480570		Seal	Mylar	yes		6x10^{9}	MB0130-060, Type D-7.5
V7-480588		Seal	Mylar	no		(6x10^{9})	MB0130-060, Type D-7.5
ME261-0003		Face coated seal	Teflon coated	no		(1x10^{8})	See above
ME261-0028		Face coated seal	Teflon coated	yes		1x10^{8}	
MS29512		Packing	Synthetic rubber	no		6x10^{9}	MIL-P-5315
V7-480594		Valve Relief	--	yes		*	
V7-480590		Seal, body (integral)	Viton A	no		(6x10^{9})	
V7-480583		Valve, Relief	--	yes		7x10^{8}	
V7-480413		Poppet seat	Teflon FEP	yes		7x10^{8}	MB0130-052
V7-480630		Indicator, Position	--	no		*	
V7-480394		Spacer	Teflon FEP	no		(1x10^{9})	
ME281-0015		Pump, Centrifical	--	yes		1x10^{8}	P/N 144668-130; Pesco Products
99-4326		Grease, anti-galling	Halocarbon	no		(1x10^{9})	No. 25-10M; Halocarbon Co.
121-1095		Stator, Motor	--	yes		1x10^{10}	
--		Varnish impregnated	Polyimide	yes		1x10^{10}	
21-1047		Insulator, slot	Polyimide	yes		1x10^{10}	Pyre-M.L. No. 6508; Du Pont
21-1048		Insulator, leader	Polyimide	yes		1x10^{10}	Pyre-M.L. No. 6507; Du Pont
21-1049		Separator	Polyimide	yes		3x10^{10}	Pyre-M.L. No. 6508; Du Pont
21-1050		Wedge, top	Teflon-glass	yes		1x10^{10}	Similar to Armalon
22-7047		Tape, insulating	Polyimide	no		(1x10^{10})	Pyre-M.L. No. 6508; Du Pont
22-7066		Wire, electrical	Teflon TFE insul.	yes		1x10^{8}	MIL-W-7139B, Cl 2
22-7044		Varnish	Polyimide	yes		1x10^{10}	Pyre-M.L. No. KK-692; Du Pont
22-7067		Insulation sleeving	Teflon	yes		1x10^{8}	RT-1001; Rayclad
MC252C4TA		Seal, boss	Teflon coated	yes		1x10^{8}	
114-129-02		Balanced assy	--	yes		1x10^{10}	
--		Varnish impregnated	Polyimide	yes		1x10^{10}	
121-1038		Rotor, Motor	--	yes		1x10^{10}	
--		Varnish impregnated	Polyimide	yes		1x10^{10}	
14-545		Bearing, ball	--	yes		1x10^{10}	
--		Cage	Teflon/glass	yes		1x10^{10}	Rulon
14-449		Bearing, ball	--	yes		1x10^{10}	
--		Cage	Teflon/glass	yes		1x10^{10}	Rulon
14-526		Counter	--	no		*	
--		Wire, electrical	Teflon insul.	no		(1x10^{8})	
22-7069		Insulation, tubing	Teflon TFE	no	6x10^{8}	(1x10^{8})	MIL-I-22129C
ME284-0184		Valve, check	N/R	yes	1x10^{9}	N/R	P/N 63-1362; Fairchild Hiller

materials and their applications and gives the predicted environment and the recommended tolerances. Table 7-16 shows the recommended modifications.

7.6.4 Radiation Hardening Analysis

7.6.4.1 J-2 Engine Installation

The J-2 engine system installation (V7-417005) includes the engines (V7-417008and 103826) and the subsystems discussed below. Line seals at the stage and engine interface are Teflon coated (ME261-0003). The low radiation tolerance of Teflon coated seals (1×10^8 ergs/gm(C)) requires their replacement by metal seals or Kynar coated seals.

7.6.4.2 Service Line Installation

The service line support installation for the center engine (V7-417314) consists of mounting hardware (clamps, brackets, etc.) and seals (ME261-0003) used at the flex hose connect panels. Replacement of the Teflon coated seals with Kynar coated or metal seals will increase the radiation tolerance of this installation from 1×10^8 to at least 3×10^{10} ergs/gm(C). The cushion clamps (ME127-0034), while not a critical item, should be specified to have a cushion material of polyurethane or Buna N.

7.6.4.3 LH_2 Recirculation System

The main components of the recirculation system are rigid line assemblies, flexible lines (ME271-0017), valves (ME284-0184

Table 7-16

RECOMMENDED MODIFICATIONS — S-II ENGINE INSTALLATION (V7-417005)

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Support, Engine Service Lines	ME261-0003	Face coated seal	Required	Teflon coated	$1x10^8$	Kynar coated*	$3x10^{10}$
LH_2 Recirculation Sys							
	ME261-0003 (typ)	Face coated seal	Required	Teflon coated	$1x10^8$	Kynar coated*	$3x10^{10}$
	--	Tape	Not critical	Teflon TFE	$2x10^9$	Polyimide	$1x10^{10}$
	V7-480555 (typ)	Bearing	Desired	Teflon FEP	$7x10^8$	Teflon/fiberglass	$8x10^9$
	V7-480558	Seal	Desired	Kel-F	$1x10^9$	Kynar	$3x10^{10}$
	V7-480568	Locking element	Not critical	Nylon	$3x10^9$	Polyimide	$1x10^{10}$
	V7-480413	Poppet	Desired	Teflon FEP	$7x10^8$	Polyimide	$2x10^{10}$
	V7-480394	Spacer	Desired	Teflon FEP	$1x10^9$	Polyimide	$3x10^{10}$
	22-7066	Insulation, wire	Required	Teflon TFE	$1x10^8$	Polyimide	$1x10^{10}$
	22-7067	Insulation, sleeving	Required	Teflon	$1x10^8$	Polyimide	$1x10^{10}$
	99-4326	Grease, antigalling	Not critical	Unknown	--	Solid film	$1x10^{11}$

*Use soft metal if possible

and V7-480328), motor-driven chilldown pumps (ME281-0015), and mounting hardware. Seals used are all metal (ME261-0033) and Teflon coated (ME261-0003).

Information was not requested for the line assemblies since they are not expected to contain organic materials except for use in seals. The flexible lines (ME271-0017) are all metal (bellows and braid). Information was requested but not received for the ME284-0184 helium injection check valve (Fairchild Hiller, P/N 63-1362). However, this is a 3/4-in. straight in-line poppet-type check valve so the only organic material would probably, but not necessarily, be used as the poppet seat. The specification of Kynar or polyimide for the seat would assure a sufficiently high radiation tolerance.

The other major components are broken down by material and application in Table 7-15. The modifications recommended in Table 7-16 will increase the radiation tolerance from 1×10^8 ergs/gm(C) for the basic system to 8×10^9 ergs/gm(C) for the modified system.

7.7 Insulation and Heat Shields

7.7.1 Description and Location

Thermal insulation materials are used over the propellant tanks, on lines and valves, and at some locations in the frame structure. Although multilayer high-performance insulations are being developed for use on the RNS, it is possible that some requirements for foams and cork will exist. Heat shields will probably not be required for the RNS. The assumed locations for maximum radiation exposure of the various components are shown in Figure 7-6.

7.7.2 Summary

With the exception of Teflon sleeving, all of the materials have radiation tolerance levels greater than the maximum predicted radiation levels. Because none of the applications are considered to be critical to the successful performance of a mission, no modifications are necessary. Some modifications are suggested, however, that would increase the reliability of the individual components.

7.7.3 System Breakdown and Recommended Modifications

Radiation sensitive materials and their applications identified from drawings and part lists are given in Table 7-17. Table 7-18 gives the recommended modifications.

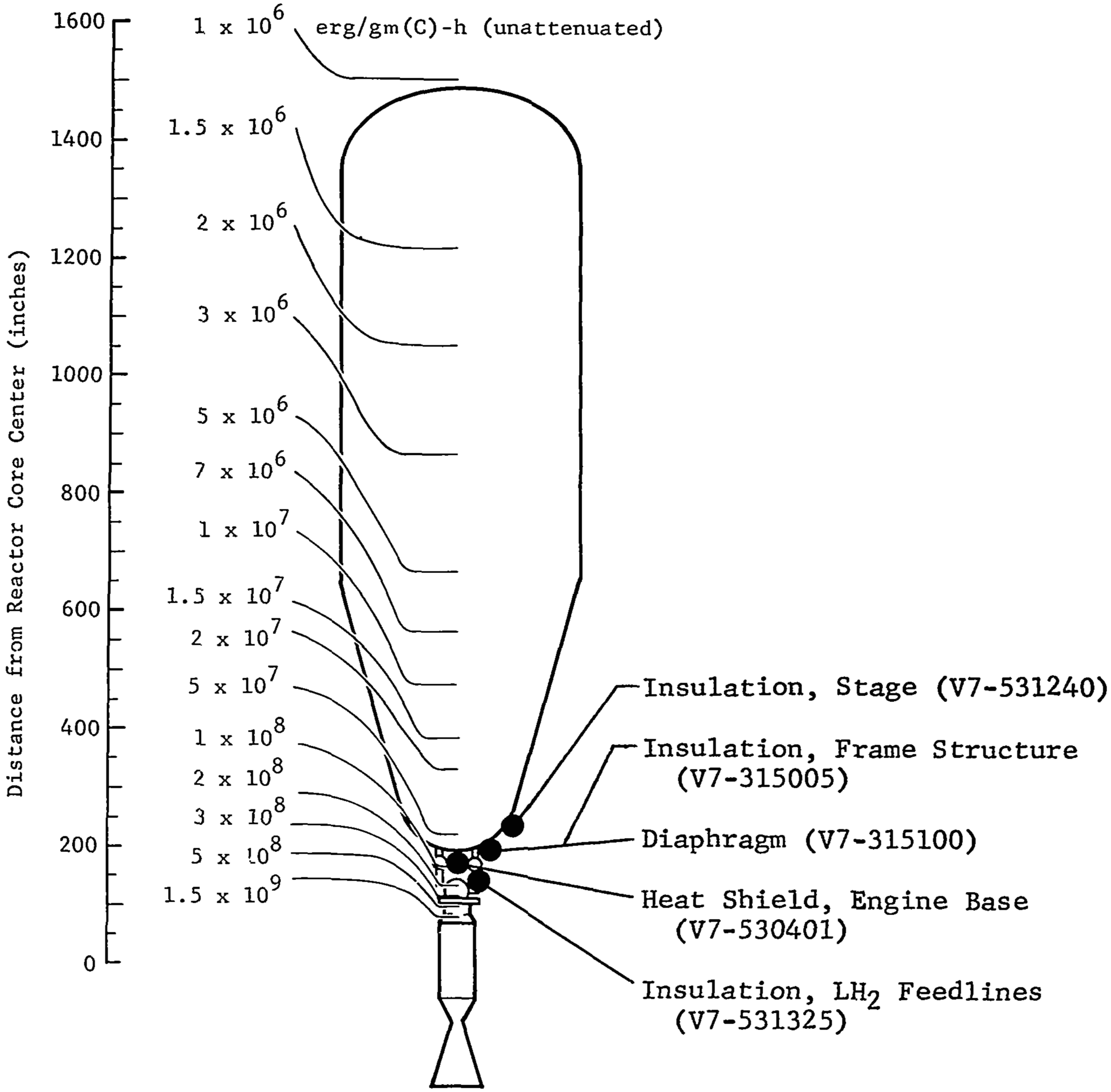


Figure 7-6 Assumed Location of (S-II) Insulation and Heat Shields

Table 7-17

RADIATION SENSITIVE COMPONENTS — S-II INSULATION AND HEAT SHEILDS

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C))		Specification or Vendor
					Predicted	Tolerance	
V7-530401	Heat Shield, Engine Base		--	no	$7x10^8$	*	
V7-530468		Sleeving	Teflon	no	$7x10^8$	$(1x10^8)$	MB0150-025 Class I (heat shrinkable)
V7-530566		Sleeving	Teflon	no	$7x10^8$	$(1x10^8)$	MB0150-025 Class I (heat shrinkable)
V7-531240	Insulation, Stage		--	no	$1x10^9$	*	
--		Insulation	Cork	no		$(1x10^{10})$	
--		Insulation	Polurethane foam	no		$(5x10^9)$	MB0130-077
--		Adhesive	Modified epoxy	no		$(1x10^{10})$	MB0120-023
--		Coating	N/R	no		(N/R)	MB0125-046
--		Fabric	Nylon	no		$(3x10^9)$	MB0135-021
--		Adhesive	Epoxy base	no		$(1x10^{10})$	MB0120-008
--		Adhesive	Polyurethane	no	$1x10^9$	$(1x10^{10})$	MB0120-024
V7-531325	Insulation, Flanges, LH_2 Feedlines		--	no	$1.5x10^9$	*	
--		Adhesive	Natural rubber	no	$1.5x10^9$	$(1x10^{10})$	MIL-A-5092, Type I
--		Insulation	Polyurethane, rigid	no	$1.5x10^9$	$(5x10^9)$	MB0130-069, low density, foam in place
V7-315005	Insulation, Thermal, Frame Structures		--	no	$7x10^8$	*	
--		Insulation, adhesive	Silicone rubber	no	$7x10^8$	$(2x10^9)$	MB0130-034 (RTV-90) or MB0130-019, Type III. (RTV-577)
--		Insulation	Cork	no	$7x10^8$	$(1x10^{10})$	MB0130-020, Type II
V7-315100	Diaphragm, Temperature Control		--	no	$7x10^8$	*	
V7-315318		Diaphragm	Teflon, glass filled	no	$7x10^8$	$(5x10^9)$	Armalon 406A-116

Table 7-18

RECOMMENDED MODIFICATIONS — S-II INSULATION AND HEAT SHIELDS

Subsystem	Part Number	Application	Assigned Category of Modification	As Designed		Modified	
				Material	Tolerance (ergs/gm(C))	Recommended Material	Tolerance (ergs/gm(C))
Heat Shield, Engine Base	V7-530468 (typ)	Sleeving	Not Critical	Teflon	$1x10^{8}$	Polyimide	$1x10^{10}$
Insulation, Stage	--	Coating	Not critical	Unknown	--	Silicone resin	$1x10^{10}$
	--	Fabric	Not critical	Nylon	$3x10^{9}$	Fiberglass	$1x10^{11}$
Insulation, Frame	--	Insulation	Not critical	Silicone rubber	$2x10^{9}$	Polyurethane	$5x10^{9}$
Diaphragm, Temp Control	V7-315318	Diaphragm	Not critical	Teflon/fiberglass	$5x10^{9}$	Polyimide	$2x10^{10}$

7.7.4 Radiation Hardening Analysis

The engine base heat shield (V7-530401) is a fiberglass curtain laced with fiberglass rope. Heat-shrinkable Teflon is used as sleeving on the rope. Fiberglass has a sufficiently high radiation tolerance to be used on the RNS.

The insulation materials used are cork, polyurethane foam, and, to a minor extent, silicone rubber. The cork is cemented in place and the polyurethane is both cemented and foamed in place. The materials defined by the MB specifications are as follows:

- MB0130-007 - flame retardant polyurethane foam, 2-lb density, for spray applications
- MB0120-023 - modified epoxy low-temperature curing adhesive for cryogenic use
- MB0125-046 - coating (no information received)
- MB0135-021 - woven nylon fabric for reinforcing phenolic and epoxy resins
- MB0120-008 - room temperature curing, mineral filled epoxy
- MB0120-024 - low-temperature curing polyurethane resin for cryogenic use
- MB0130-069 - low-density foam-in-place polyurethane
- MB0130-034 - room-temperature vulcanizing silicone rubber paste
- MB0130-020 - resin bonded cork insulation, 8 lb/ft^3, 78 $\pm$ 3% by weight of ground cork mixed with a thermosetting resin binder

The use of sealed cork insulation in areas near the nuclear engine should probably be discouraged because of a demonstrated ability of this material to form and ignite an explosive hydrogen-oxygen mixture under irradiation. Hydrogen formed as a decomposition product along with oxygen trapped in the cork was ignited by energy from the radiation field in a test of a cork insulated hydrogen dewar (Ref. 26). This incident occurred after an exposure of about 1.5×10^{10} ergs/gm(C), but under other circumstances it could conceivably occur at a lower level, or not at all. Also, a marked increase in the thermal conductivity of the cork was noted prior to the explosion.

7.8 Stage Structure

7.8.1 Description and Location

The S-II stage structure (V7-300011) includes the LH_2 tank (V7-332002), the LOX tank (V7-333002), the forward skirt, and the aft skirt and thrust structure. Few applications for organic materials were found, as would be expected, and there will probably be limited number of requirements for organics in the RNS structure, except that composite materials (e.g., boron-epoxy or graphite-epoxy) may be used in skirts and thrust structure. The composite materials are being investigated separately.

With the exception of a Teflon coated seal used on the forward end of the LH_2 tank, all of the components are assumed to be located around the aft end of the tank.

7.8.2 Summary

In all cases the radiation tolerance of the materials is near or exceeds the predicted nuclear environment. With the exception of the seal in the forward LH_2 tank bulkhead, which is in a low radiation field, the applications are not considered to be critical. The stage structure and its subassemblies would therefore be satisfactory for use without modification.

7.8.3 System Breakdown

The radiation sensitive components identified in the S-II stage structure are listed in Table 7-19.

Table 7-19

RADIATION SENSITIVE COMPONENTS — S-II STAGE STRUCTURE (V7-300011)

Part Number	Subsystem	Component	Material	Critical Appli-cation	Gamma Environment (ergs/gm(C)) Predicted	Tolerance	Specification or Vendor
V7-300011	Stage Structure		--	yes	$1x10^9$	$1x10^8$	
ME261-0003		Face coated seal	Teflon coated	yes	$1x10^7$	$1x10^8$	NAVAN
--		Insulation	Polyurethane foam	no	$1x10^9$	$(5x10^9)$	MB0130-069
--		Sealant	Silicone rubber	no	$1x10^9$	$(1x10^9)$	MB0130-019
--		Filler	Polyurethane/nylon	no	$1x10^9$	$(1x10^9)$	MB0120-024 resin/nylon fiber
V7-335900	Aft Skirt to Thrust Structure Assy		--	yes	$1x10^9$	*	
V7-335500		Assembly	--	yes		*	
--		Sealant	Silicone rubber	no		$(1x10^9)$	MB0130-019
V7-335505		Moisture Barrier	--	no		*	
V7-335507		Plug	Polyurethane foam	no		$(1x10^{10})$	MB0130-015
--		Adhesive	Silicone rubber	no		$(1x10^{10})$	MB0130-019
V7-335516		Cover	Silicone rubber	no		$(2x10^9)$	ZZ-R-765, Cl 3
V7-335506		Cover	Silicone rubber	no	$1x10^9$	$(2x10^9)$	ZZ-R-765, Cl 3

7.8.4 Radiation Hardening Analysis

Organic material applications from Drawing V7-300011, Stage Structure Assy - Complete, Less Interstage, are as fillers (polyurethane with nylon fibers), cavity insulation (polyurethane foam), and nut and bolt sealer (silicone rubber). None of these are critical applications. The ME261-0003 seal is used in the forward bulkhead of the LH_2 tank where it is entirely satisfactory.

No organic materials are used in the assembly of the LH_2 tank stage structure (V7-332002). The LH_2 tank structure itself was not investigated since, with the exception of the common bulkhead, it is assumed to be of all metal construction. The common bulkhead, which is an adhesive-bonded assembly of aluminum alloy and fiberglass/phenolic honeycomb core, will not have a counterpart on the RNS.

The aft skirt to thrust structure assembly (V7-335900 and V7-335500) and the interstage structure (V7-337001) have a silicone sealant between fairings and stringers. The moisture barrier if required on the RNS for control of the ground environment would not be a critical to completion of vehicle mission.

If a sealant is required on the RNS in applications similar to these, the use of polyurethane in place of silicone rubber would give added radiation resistance.

VIII. S-IC LOX PREVALVE

8.1 Description and Location

The 17-in. rotary shutoff valve (Whittaker Corporation; P/N 138025A), which was specifically designed to function as the LOX prevalve for Stage S-IC of the Saturn V, was analyzed and radiation hardened by the Whittaker Corporation for potential application as the RNS liquid hydrogen tank shutoff valve and for use as a test vehicle for potential radiation resistant seal materials. The valve is a spring-opened, pneumatically-closed shutoff valve with a nominal line size of 17 inches. It is assumed to be flange-mounted between the LH_2 propellant tank and the suction side of each NERVA engine turbopump. In this location the predicted nuclear exposure is 1 x 10^9 ergs/gm(C) for missions involving a total of 10 hours of engine operation.

The valve was modified for liquid hydrogen use and radiation hardened by Whittaker Corporation under contracts NAS8-20784 and NAS8-20955. The radiation effects analysis and a description of these modifications are summarized in Section 8.3. Upon completion of the valve modifications and functional checkout, the valve was forwarded to Convair Aerospace Division of General Dynamics for irradiation. Test plans and supporting test equipment have been prepared for irradiation testing in Dec. 1971 under contract NAS8-18024. The test will consist of several irradiation cycles at increasing reactor power levels with the valve filled with LH_2. After each cycle, leakage measurements will be made at various test points, after which the valve will be allowed to warm before the next cycle. The test arrangement is to be such that the actuator and a part of the main seal will receive a dose (if all cycles are completed) of at least 2×10^{10} ergs/gm(C). Pre- and post-irradiation data will be used in the evaluation of the valve performance.

8.2 Summary

Based upon analyses presented in References 29 and 30 and Section 8.4, it is believed that the modified LH_2 valve can reliably function in nuclear environments up to 1×10^{10} ergs/gm(C), which is greater than the predicted RNS exposure and comparable to that anticipated during the irradiation test. The predicted improvements resulting from the design modifications described in Section 8.3 are summarized in Table 8-1. The results of testing this valve will be included in test reports for contract NAS8-18024.

8.3 Radiation Hardening Analysis

The effort expended at Whittaker Corporation (Contract NAS8-20784) in modifying this valve for liquid hydrogen service and radiation hardening it for nuclear environments is typical of the effort anticipated in radiation hardening other Saturn V components and systems for RNS applications. A description of the modified valve and the research and development required to

Table 8-1

RADIATION SENSITIVE COMPONENTS — MODIFIED 17-INCH S-IC LOX PREVALVE

Subsystem	Component	Predicted Gamma Environment (ergs/gm(C))	As Designed			As Modified		
			Part Number	Material	Tolerance ergs/gm(C)	Material	Tolerance (ergs/gm(C))	New Part Number
Servoactuator		1×10^{9}	--	--	7×10^{6}	--	1×10^{10}	--
	Seal		110189-21	Teflon	7×10^{6}	NARMCO 7343[a]	1×10^{10}	110189A-21
	Seal		110189-22	Teflon	7×10^{6}	NARMCO 7343[a]	1×10^{10}	110189A-22
	Seal		134387	e	e	Composite[b]	1×10^{10}	NR357-65
	Seal		135128	e	e	Composite[b]	1×10^{10}	NR357-67
	Gasket		136472	Teflon	7×10^{6}	Kynar	3×10^{10}	136472A
	Gasket		136477	Teflon	7×10^{6}	Kynar	3×10^{10}	136477A
	Seal		136517	Teflon	7×10^{6}	Kynar	3×10^{10}	136517A
	Gasket		136638	Teflon	7×10^{6}	Kynar	3×10^{10}	136638A
	Seal		136639	Teflon	7×10^{6}	Kynar	3×10^{10}	136639A
	Gasket		136959	Teflon	7×10^{6}	Kynar	3×10^{10}	136959A
	Seal		136962	e	e	Kynar	3×10^{10}	136962A
	Seal		200500-9	e	e	Composite[b]	1×10^{10}	NR357-39
	Seal		200500-10	e	e	Composite[b]	1×10^{10}	NR357-41
	Seal		200500-12	e	e	Composite[b]	1×10^{10}	NR357-43
	O-ring		200506-2-147	Teflon	7×10^{6}	Kynar	3×10^{10}	200506A-2-14
	O-ring		200506-3-27	Teflon	7×10^{6}	Kynar	3×10^{10}	200506A-3-2
	Seal		200529-313	e	e	Kynar	3×10^{10}	200529A-313
	Seal		200529-342	e	e	Kynar	3×10^{10}	200529A-342
	Ring, wear		134410	Teflon	7×10^{6}	Kynar	3×10^{10}	134410A
	Ring, wear		134370	Teflon/glass	1×10^{10}	Kynar	3×10^{10}	13437A
	Ring, wear		136967	Teflon/glass	1×10^{10}	Kynar	3×10^{10}	136967A
	Ring	1×10^{9}	136968	Teflon	7×10^{6}	Kynar	3×10^{10}	136968A
Position Indicator Assy		1×10^{9}	--	--	7×10^{6}	--	1×10^{10}	--
	Seal		136457	e	e	Composite[b]	1×10^{10}	NR357-33
	Seal		136457-1	e	e	Composite[b]	1×10^{10}	NR357-35
	Seal		200500-33	e	e	Composite[b]	1×10^{10}	NR357-47
	O-ring		200506-2-019T	Teflon	7×10^{6}	Kynar	3×10^{10}	20050EA-2-019
	Seal		200529-9	Teflon	7×10^{6}	Kynar	3×10^{10}	200529A-9
	Insulation		100147-1	e	e	Kynar	1×10^{10}	100147A-1
	Insulation		127139	e	e	Kynar	1×10^{10}	127139A
	Packing		137482	e	e	Kynar	3×10^{10}	137482A
	Sleeve		SS379-12-6	e	e	Kynar	3×10^{10}	SS379A-12-6
	Sleeve		SS379-14-10	e	e	Kynar	3×10^{10}	SS379A-14-10
	Position indicator		136700	e	e	c	--	c
	Connector		100140-100	e	e	c	--	c
	O-ring		d	d	d	Kynar	3×10^{10}	100140A-200
	O-ring	1×10^{9}	d	d	d	Kynar	3×10^{10}	100140A-300
Valve Body								
	O-ring	1×10^{9}	10011AJ14	e	e	Kynar	3×10^{10}	100111A
	Washer		134501	e	e	Kynar	3×10^{10}	134501A-1
	Washer		d	d	d	Kynar	3×10^{10}	134501A-2
	Seal		135129	e	e	Kynar	3×10^{10}	135129A
	Gasket		135707	Teflon	7×10^{6}	Asbestos	$>1 \times 10^{10}$	135707A
	Seal		136719	e	e	Kynar coated	3×10^{10}	136719A
	Seal		136767	e	e	Kynar	3×10^{10}	136767A
	Seal		136769	e	e	Kynar	3×10^{10}	136769A
	Seal		200500-4	e	e	Composite[b]	1×10^{10}	NR357-37
	Seal	1×10^{9}	200500-25	e	e	Composite[b]	1×10^{10}	NR357-47

Table 8-1 (continued)

RADIATION SENSITIVE COMPONENTS — MODIFIED 17-INCH S-IC LOX PREVALVE

Subsystem	Component	Predicted Gamma Environment (ergs/gm(C))	As Designed			As Modified		
			Part Number	Material	Tolerance ergs/gm(C)	Material	Tolerance (ergs/gm(C))	New Part Number
	Seal	$1x10^{9}$	200500-34	e	e	Composite[b]	$1x10^{10}$	NR357-49
	Seal		200500-36	e	e	Composite[b]	$1x10^{10}$	NR357-57
	Seal		200500-38	e	e	Composite[b]	$1x10^{10}$	NR357-51
	Seal		137500	e	e	Composite[b]	$1x10^{10}$	NR357-53
	Seal		200500-40	e	e	Composite[b]	$1x10^{10}$	NR357-55
	Seal		200518-10	e	e	Kynar	$3x10^{10}$	200518A-10
	Seal		200518-11	e	e	Kynar	$3x10^{10}$	200518A-11
	Seal, face coated		MC252S2TA	Teflon TFE coated	$1x10^{8}$	Kynar coated	$3x10^{10}$	MC252S2-A
	Seal, face coated		MC252S4TA	Teflon TFE coated	$1x10^{8}$	Kynar coated	$3x10^{10}$	MC252S4-A
	Seal, face coated		MC252S6TA	Teflon TFE coated	$1x10^{8}$	Kynar coated	$3x10^{10}$	MC252S6-A
	Shim		136960	e	e	Kynar	$3x10^{10}$	136960A
	Shim		136961	e	e	Kynar	$3x10^{10}$	136961A
	Bushing		137069	Teflon/glass	$8x10^{9}$	Kynar	$3x10^{10}$	137069A
	Pad		137328	Teflon/glass	$1x10^{10}$	Kynar	$3x10^{10}$	137328A
	Lubricant		129358-1	e	e	MoS_2	$>1x10^{10}$	129358A-1
	Washer		136317	Teflon/glass	$1x10^{10}$	Kynar	$3x10^{10}$	136317A
	Ring	$1x10^{9}$	MS9058-06	e	e	Kynar	$3x10^{10}$	MS9058A-06

[a]NARMCO 7343 is a polyurethane base material fabricated by Whittaker Corp.

[b]Composite material is mixture of Kynar, Teflon, and fiberglass.

[c]Component eliminated in modified configuration.

[d]Component added in design of modified configuration.

[e]Component is part of an assembly and specific material is not identified in the maintenance manual for this valve.

radiation harden this valve is presented in References 24 and 25. The results of their efforts are summarized in the following paragraphs.

The objective of this program was the replacement of all existing radiation sensitive seals, insulators, lubricants, etc. with radiation resistant materials that would conform to the existing valve geometry envelope.

The initial work was directed toward investigating potential materials for each required application, examining process techniques, and testing candidate designs. The modified valve was subjected to testing at ambient and cryogenic temperatures to determine its conformance to functional and leakage requirements as set forth in the procurement specifications for the LH_2 shutoff valve.

A total of eleven different materials and/or material combinations were investigated for gaskets and seal applications. Several of the candidates were eliminated from further study since it was felt that considerable process technology and development would be required for either polyimide or polybenzimadazole (PBI) cryogenic sealing applications. (Since that time, additional research and development work indicates that polyimide and PBI should be considered.) Gaskets were fabricated from each of the remaining candidate material for preliminary leak, energy absorption, and stress relaxation testing. The results of this test program indicated:

1. Filled or unfilled Kynar showed the greatest promise for use as wear pads and in noncritical sealing applications.

2. The addition of filler materials to the Kynar molding material decreases its sealing capability, primarily because of its noncompressibility and uneveness.

3. Improved processing techniques enhance the reliability and sealing capability of molded Kynar seals.

4. A composite seal of Kynar, Teflon TFE, and fiberglass showed evidence of cracking and crazing. This was attributed to differences in the thermal expansion coefficients of the Kynar encapsulating material and the laminated composite of Teflon TFE and fiberglass. Changing the processing techniques eliminated the thermal stress problem and resulted in a composite material with satisfactory sealing chracteristics at both ambient and cryogenic temperatures.

5. Kynar and Kynar composite materials were selected as the best materials for gaskets, seals, etc.

The Whittaker Corporation 17-in. prevalve (P/N 138025) was modified by substitution of Kynar and Kynar composite materials and subsequently subjected to temperature compatibility and leakage tests. The results of these tests are summarized below:

1. Leakage tests at ambient conditions indicated several seals had to be reworked and thicknesses increased to provide the same sealing capability provided by the original seal materials.

2. The main seal assembly requires a redesign for long-term storage applications.

3. The valve visor did not open completely or in the required time. This was attributed to the increased stiffness of the Kynar seal as compared to the Teflon employed in the original seal design. This can be

corrected by either using a more flexible seal material or by increasing the spring pressure on the visor.

Upon completion of these tests at ambient and liquid nitrogen temperatures, a second phase of radiation hardening and valve modification was performed by Whittaker Corporation under Contract NAS8-20955. The second generation modified valve corrected all deficiencies noted in the initial modification through the substitution of a polyurethane base material for O-rings and special seals, elimination of the position potentiometers with a switch assembly, and by reworking several valve assemblies. The valve was then subjected to leakage and compatibility tests at liquid hydrogen temperature. The results of this test program are summarized below:

1. A Kynar seal in the main seal area which had numerous close-through bolt holes shattered due to excessive thermal stresses. A Garlock 900 asbestos mat seal was substituted for the remainder of the program.

2. At liquid hydrogen temperature, the valve visor did not open completely. This was due to an interference between the inner and outer shells of the spring capsule. This problem was eliminated by increasing the inner diameter of the outer shell.

3. The thickness of several seals had to be increased to prevent leakage caused by the increased thermal contraction that was not compensated for by the compressibility of the seal.

Upon correction of the above design deficiencies, the modified valve successfully demonstrated its ability to meet the leakage and functional operation requirements for liquid hydrogen valves. Table 8-1 lists the modifications incorporated into the valve submitted to Convair Aerospace Division for testing in a combined nuclear/liquid hydrogen environment. As noted, the recommended radiation tolerance of the modified valve is 1×10^{10} ergs/gm(C). Since this limit is comparable to the planned nuclear exposure at General Dynamics, 2×10^{10} ergs/gm(C), its ability to successfully operate under the combined nuclear/liquid hydrogen environment is viewed with optimism. The predicted improvements resulting from these modifications are also presented in Table 8-1.

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