REON

ROCKET ENGINE OPERATIONS — NUCLEAR

REPORT NO. 2652 AGC--2652

TO

AEC-NASE SPACE NUCLEAR PROPULSION OFFICE

ANALYSIS OF THE FAST NEUTRON AND GAMMA RAY SPECTRUM FOR LRP MECHANICAL TEST 901

NERVA PROGRAM, CONTRACT SNP-1

30 SEPTEMBER 1963

AEROJET GENERAL TIRE GENERAL

AEROJET-GENERAL CORPORATION

AZUSA, CALIFORNIA

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AEROJET-GENERAL CORPORATION

A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

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Report No. 2652

ABSTRACT

The gamma ray and fast neutron fluxes and the gamma ray heating rates produced by the ASTR in the LRP Mechanical Radiation Test No. 901 were calculated and are herein reported. The Los Alamos QAD Code was used for the calculations.

for W. D. Stinnett
NERVA Technical
Systems Manager

Prepared by

[illegible] Fogg

30 August 1963

SECTION I

INTRODUCTION

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I. INTRODUCTION

The analytical results reported herein are a description of the nuclear environment produced by the Aerospace Systems Test Reactor at General Dynamics/Ft. Worth in the LRP Mechanical Radiation Test No. 901. The gamma ray and fast neutron fluxes and the gamma ray heating rates were calculated for selected points throughout the test components using the Los Alamos QAD Code.

The test components from the NERVA Propellant Feed System include a tank shut-off valve, a turbine power control valve, the turbopump bearings, and assorted flanges and seals.

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SECTION II

GENERAL

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II. GENERAL

A. OBJECTIVES OF ANALYTIC PROGRAM

A radiation analysis program, executed concurrently with the Radiation Effects Testing program, will provide necessary information in the following areas:

Prior to the test:

Analysis will provide an evaluation of the radiation fluxes and integrated doses expected in the test components during the test. It can then be established whether the intended levels will be attained in the components during the test. Analysis will further provide an evaluation of the nuclear activation so that pre-estimates may be made of handling problems and evaluation of possible structural failure of any part of the test or support structure due to radiation damage or excessive localized nuclear heating.

After the test:

The results of the analysis will allow interpolation of values in areas of the test where no experimental data are available. Comparison of the experimental data with the analytical results will allow evaluation of the analytical technique. Such evaluations will lead to improvement of the technique and induce confidence in it, which will be essential later, when reliance must be placed almost entirely on analytical techniques for a description of the NERVA engine nuclear environment.

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SECTION III

DISCUSSION OF ANALYSIS
LRP MECHANICAL RADIATION TEST 901

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III. DISCUSSION OF ANALYSIS, LRP MECHANICAL RADIATION TEST 901

The analytical results are used in this report to predict the radiation environment of LRP Mechanical Radiation Test 901. This test is the first of a series which will expose components of the NERVA Engine propellant-feed system to a radiation environment which will closely approximate the NERVA environment.

It should be noted that the analysis was performed without the benefit of a measured gamma source term for the test reactor* or the results of the radiation distribution mapping of the test volume performed for the same reactor in April 1963. It was therefore necessary to approximate the source gamma ray and neutron spectra with reasonable assumptions.

The detail of the analysis is sufficient to satisfy the requirements of II,A, but the primary value will be the evaluation of the analytical technique. Comparison of the experimental data of the test with the analytical results will permit normalization of the analytical results for interpolation purposes. However, when the experimentally determined source term and the mapping run data are available, the results can be re-evaluated to determine the extent of the error introduced by using the source spectra approximations. After these known errors have been removed from the analytical results, a critical evaluation may be made of the use of the code to approximate experimental data by comparison of the two sources of data.

*The Modified Aerospace Systems Test Reactor (ASTR) operated by General Dynamics/Fort Worth, Texas.

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SECTION IV

LRP MECHANICAL RADIATION TEST NO. 901

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IV. LRP MECHANICAL RADIATION TEST NO. 901

The series of which this is the first test is of special interest to the NERVA program because it investigates some of the problems unique to the use of nuclear power for rocket propulsion. In particular, the effects of a combined cryogenic and high intensity radiation environment on the materials and operation of mechanical and electromechanical components are little known. In addition, the process of hydrogen embrittlement with all its implications relative to the reliability of components will be aggravated by intense neutron radiation. The apparent inability of petroleum-based and other types of lubricants to function properly in cryogenic environments has required that a search be initiated for means of lubricating high-speed bearing surfaces. The problem of structural damage to metals and electric components caused by high intensity radiation must also be solved for the NERVA application.

Test No. 901 attempts to approach some specific examples of these problems. In this context, the primary objectives of the test are to investigate:

> The effects of the environment on metal-to-metal seals of such components as line connections and valves.
>
> The lubricating ability of glass-impregnated Teflon (called "Armalon") when used as a caging material for bearings rotating in the vicinity of 20,000 rpm while exposed to cryogenic hydrogen and high intensity radiation.
>
> The feasibility of operating typical components containing these features in a cryogenic and radiation environment.

The particular components to be tested are described, in the following pages, together with a general discussion of the nuclear and non-nuclear aspects of the test. Greater detail concerning the nuclear aspects of these components is contained in the Radiation Effects Data Book, REON Report 2277. Further details of the non-nuclear aspects are contained in the relevant test requests, test plans, and specifications contained in Radiation Effects Testing Data Book, REON Report 2510.

A. RADIATION EFFECTS TEST 1/L001

Radiation Effects Test 1/L001 involves Configuration 1 of the Tank Shutoff Valve (TSOV).

Figure 1 shows the TSOV in the NERVA context. This valve is a GH_2-operated poppet valve designed for operation at settings of completely open or completely closed, and functioning to control LH_2 propellant flow from the propellant tank into the propellant feed line.

In this test the TSOV will be immersed in LH_2 with the fluid present on both sides of the valve. The liquid flow rate when the valve is open will be relatively small, approximately 0.05 lb/sec. During irradiation the valve will be periodically cycled from closed, to open, to closed; and will operate in (expected) flux levels of 1×10^{11} to 1×10^{12} nv for fast neutrons, and 1×10^{5} to 1×10^{6} ergs/gm(C)-sec for gamma rays.

The effect of the environment on the metal-to-metal seal of the valve is of primary interest in the test. Hydrogen embrittlement of the sealing surfaces and other metal parts, as aggravated by radiation, may cause structural failure of the seal as well as the actuating components. Visual examination of the sealing surfaces and records of the leak rate through the valve during the test will provide the basis for evaluation of possible damage, and consequent implications relative to reliability.

In addition, the valve-position-sensing transducer is being tested for reliability. Exposure of the device to the environment of the valve in the NERVA application may cause structural or electrical failure, resulting in a loss of control of the valve position, which would be a critical parameter during engine operation.

In addition to the test factors previously mentioned, structural failure of the non-moving parts of the valve, sticking of the moving parts due to damage or contraction, or changes in the actuating gas because of the cryogenic temperature, may all contribute to possible overall failure of the valve.

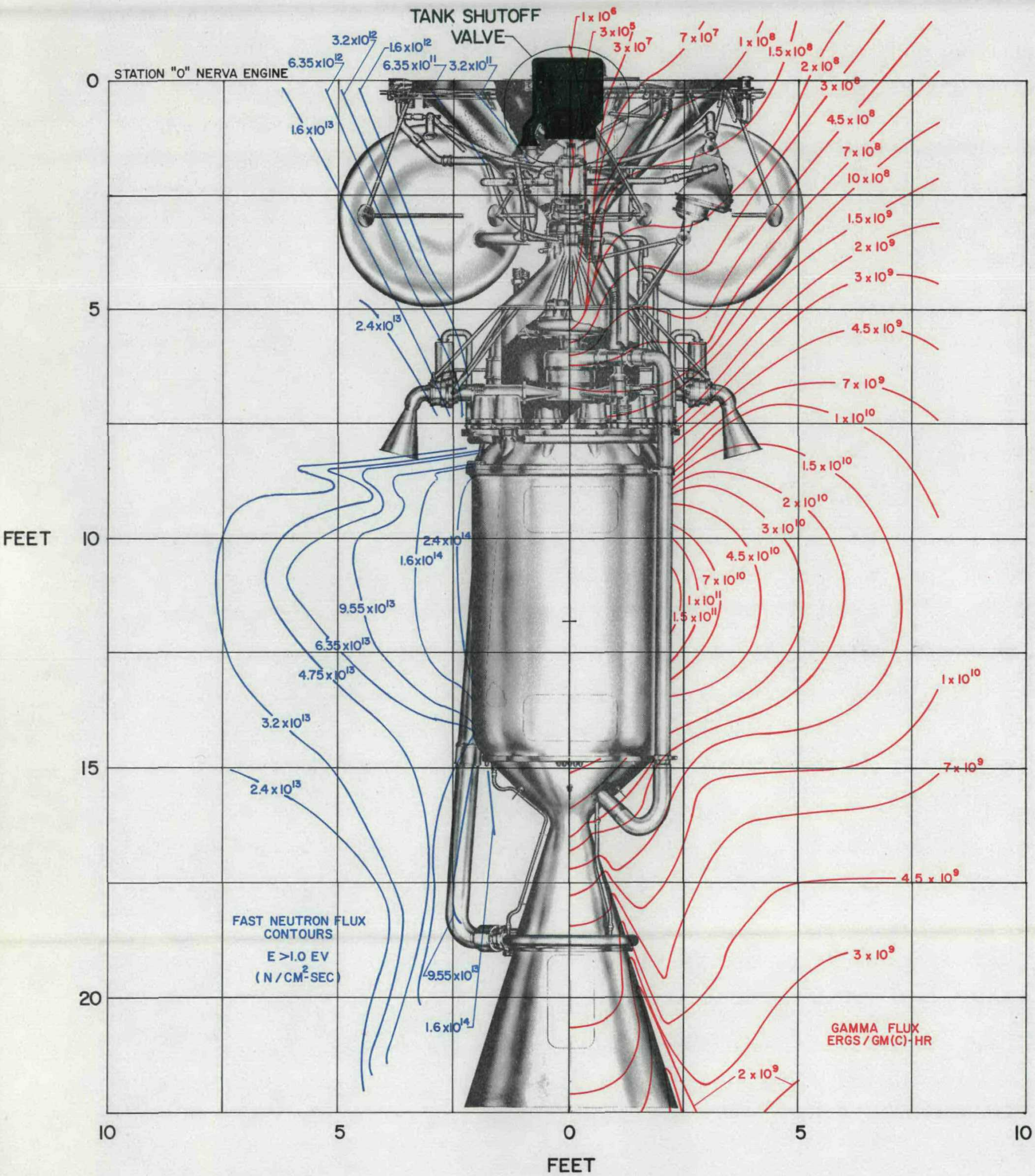

Figure 1

Location of the TSOV on the NERVA Engine

Figure 2 shows the TSOV in the context of Test 901. The position transducer with its mechanical linkage is visible at the left side of the valve, the actuating gas line is on the right, and the LH_2 reservoir is below. The static flange and seal tester with its multiple Marman clamp configuration, and the bearing tester support are in the foreground.

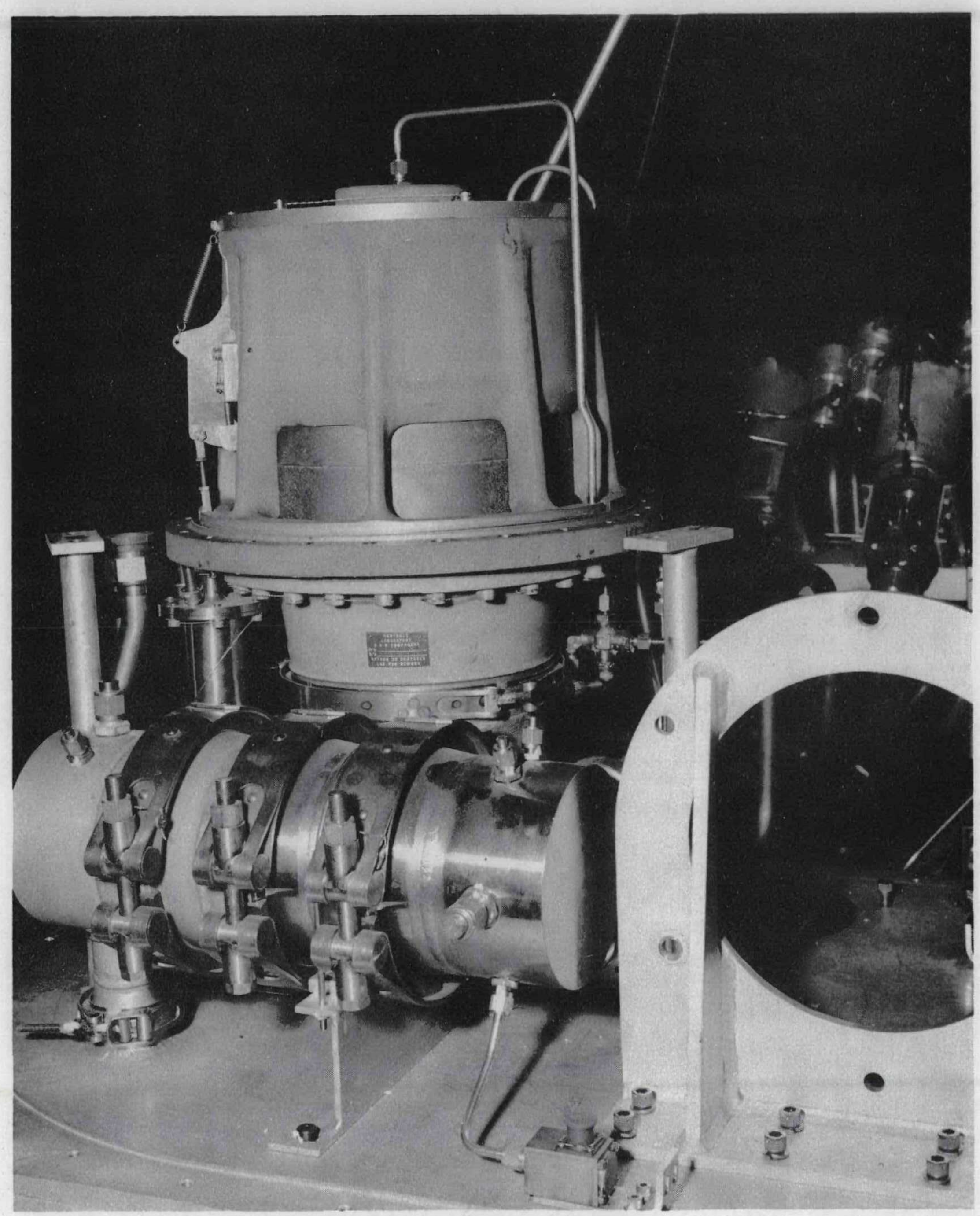

Figure 2

Uncovered LRP Mechanical Radiation
Test 901 Pallet Showing the TSOV in the Background

B. RADIATION EFFECTS TEST 3/L001

Radiation Effects Test 3/L001 involves the Turbopump Bearing Assembly, which is shown by Figure 3 in the NERVA context.

This assembly includes the turbopump shaft with its bearing sets and bearing spacers, the housing, and the shaft RPM transducer. An actuating electric motor to drive the shaft from the turbine end at approximately 21,000 rpm, and a closure at the pump end are provided.

No attempt is being made to approximate the axial loads of the NERVA application. During the test LH_2 will flow through the assembly at about 0.1 lb/sec. The assembly is expected to be exposed to irradiation levels of approximately 1×10^{11} to 1×10^{12} nv for fast neutrons, and 1×10^{5} to 1×10^{6} ergs/gm(C)-sec for gamma rays.

The caging material and lubrication of the bearings are of primary importance in this test. Liquid hydrogen is to be used as the coolant for the bearing assembly, but, since petroleum-based lubricants become brittle and extremely inefficient when exposed to cryogenic temperatures, a satisfactory substitute lubricant must be found. Teflon is known to have the property of remaining pliable when exposed to cryogenic temperatures, and would provide a good lubricating surface for the bearing, but it is easily damaged by radiation. Teflon impregnated with glass (under the trade name of "Armalon") will be used in this test as the bearing caging material, in an attempt to solve this problem.

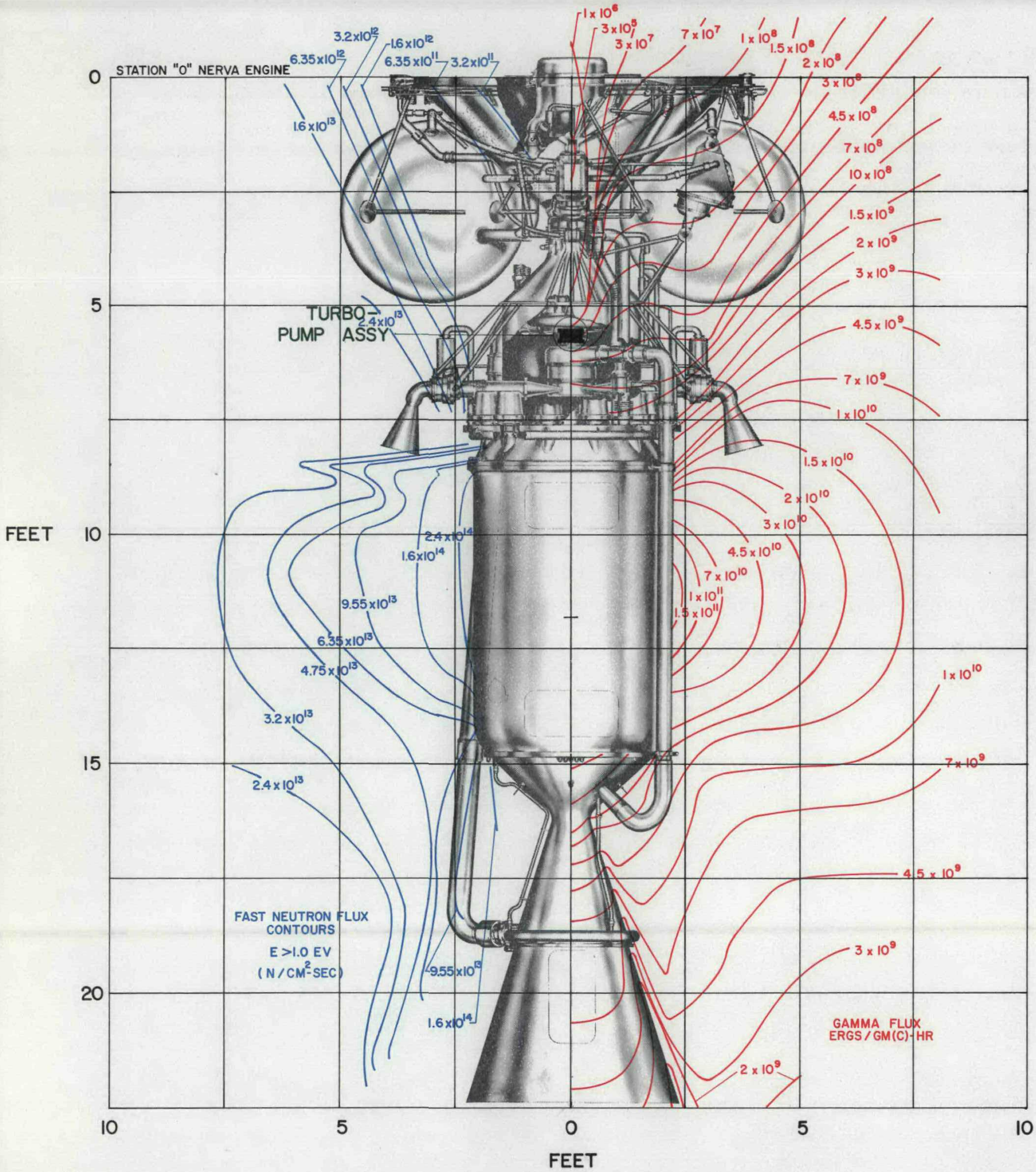

Figure 3

Location of Turbopump on the NERVA Engine

Figure 4 shows the bearing test assembly. The section from the middle to the right end is the electric motor drive; the turbine-end bearing-temperature transducer connections are seen in the center of the picture. The connection to the left of center is the rpm transducer connection. The support flange is seen at the left.

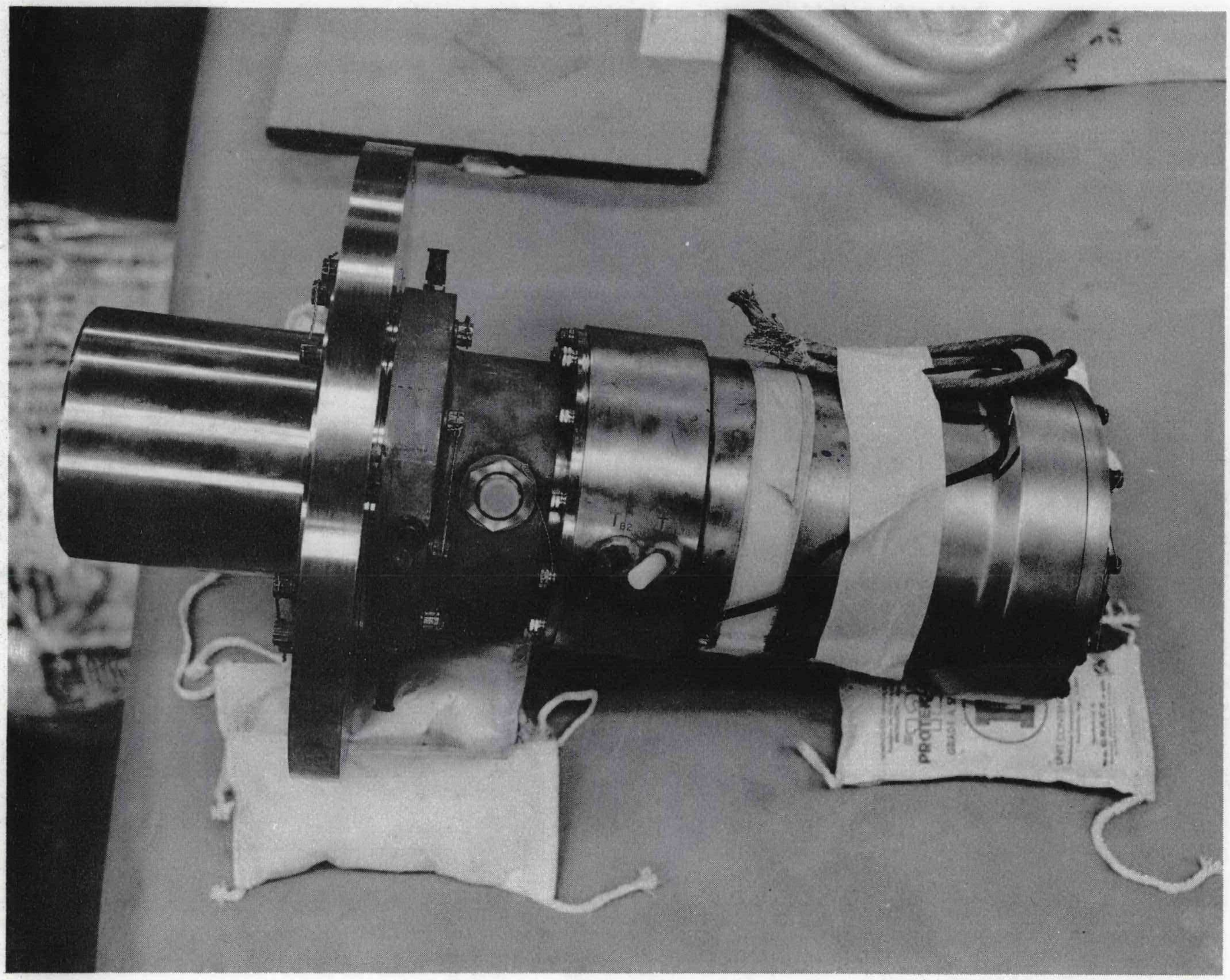

Figure 4

Turbopump Bearing Assembly Tester

C. RADIATION EFFECTS TEST 8/L001

Radiation Effects Test 8/L001 involves static flanges and metal-to-metal seal combinations, typical examples of which are located on the NERVA engine in Figure 5. The test configuration includes three seal combinations; aluminum-to-aluminum, aluminum-to-steel, steel-to-steel; and end covers secured by Marman clamps to form an enclosure.

During irradiation, LH_2 will flow under 250 psia at a rate of 0.05 lb/sec through the enclosure. It is anticipated that the assembly will be exposed irradiation of 1×10^{11} to 1×10^{12} nv for fast neutrons, and 1×10^{5} to 1×10^{6} ergs/gm(C)-sec for gamma rays. The reliability of the seals is of primary concern in the test. On the NERVA engine, warping of the sealing surfaces due to the cryogenic temperature, embrittlement and possible resultant structural failure due to exposure to cryogenic hydrogen and intense neutron radiation, and structural damage due to neutrons alone, may all result in intolerable leakage in critical systems.

Reference is again made to Figure 2. The seal and flange test configuration is mounted on the test pallet with the aluminum seals to the left, and the steel flanges to the right. The LH_2 pressure transducer is located in the lower center foreground.

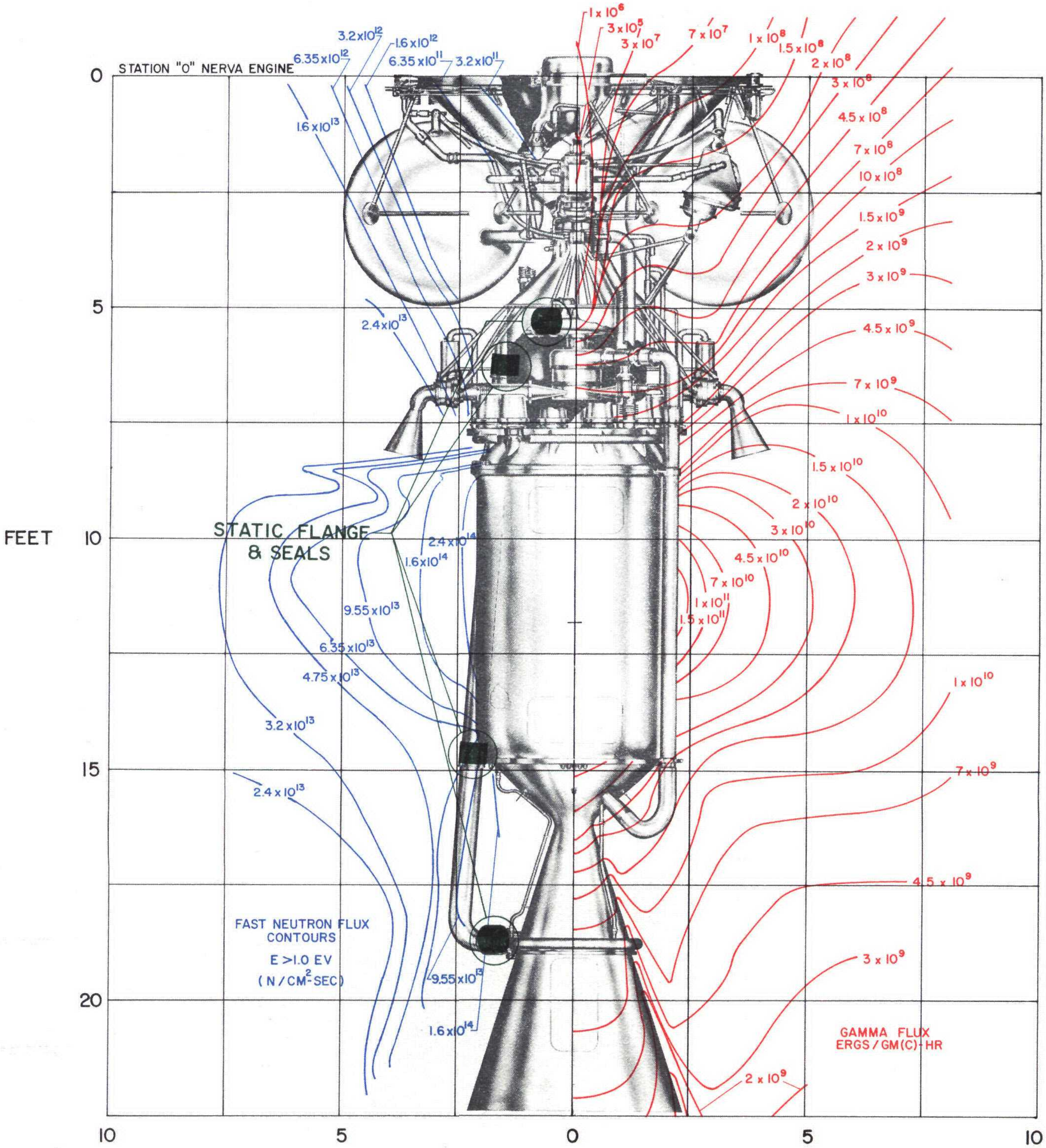

Figure 5

Typical Flange and Seal Locations on the NERVA Engine

D. RADIATION EFFECTS TEST 4/L001

Radiation Effects Test 4/L001 involves the Turbine Power Control Valve (TPCV) which is located on the NERVA engine in Figure 6. The TPCV is a butterfly-type valve designed to regulate the flow of high temperature GH_2 to the turbopump turbine, thus controlling the turbine power. The loss of the valve or knowledge of its position during NERVA operation would be most serious for engine operation, making imperative the design of a reliable valve.

The test configuration includes a pneumatic linear actuator which will position the valve blade during the test to regulate the flow of ambient temperature GH_2. The test actuator is not intended for NERVA application. The operational actuator is being developed under a different program, and will be mated to the TPCV in a later radiation effects test.

It is anticipated that the assembly will be exposed to irradiation of 1×10^{11} to 1×10^{12} nv for fast neutrons, and 1×10^{5} to 1×10^{6} ergs/gm(C)-sec for gamma rays.

As with the TSCV, the metal-to-metal seal is of primary interest in this test. However, cryogenic temperature LH_2 will not be present in the TPCV test, but the controlled gas may still produce hydrogen embrittlement in the valve materials. The problem of structural damage due to neutron radiation alone resulting in failure of the valve and/or the position sensing transducer is also to be investigated in this test.

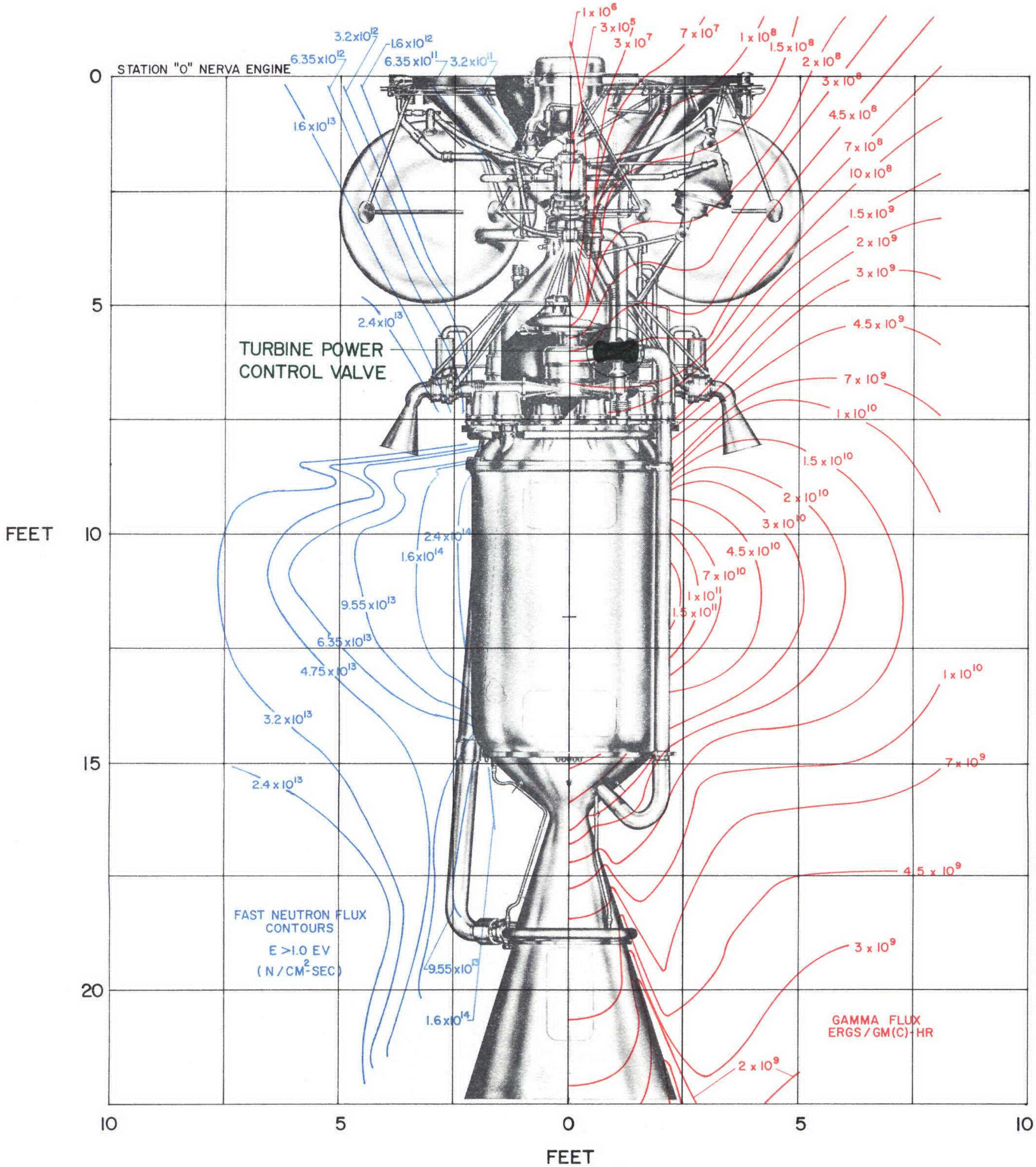

Figure 6

Location of TPCV on the NERVA Engine

Figure 7 shows the TPCV with its actuator, and other test components, mounted in their relative positions on the test pallet. The light colored box on top of the actuator is the position sensing transducer. The valves which will regulate the environmental gases and liquids can be seen in the background, as can some of the necessary piping. The TSOV is enclosed in a cryostat to contain the LH_2 bath. The remainder of the components will be enclosed by a cover (as shown by Figure 8), which will contain an inert atmosphere of helium to prevent an explosion if leaking GH_2.

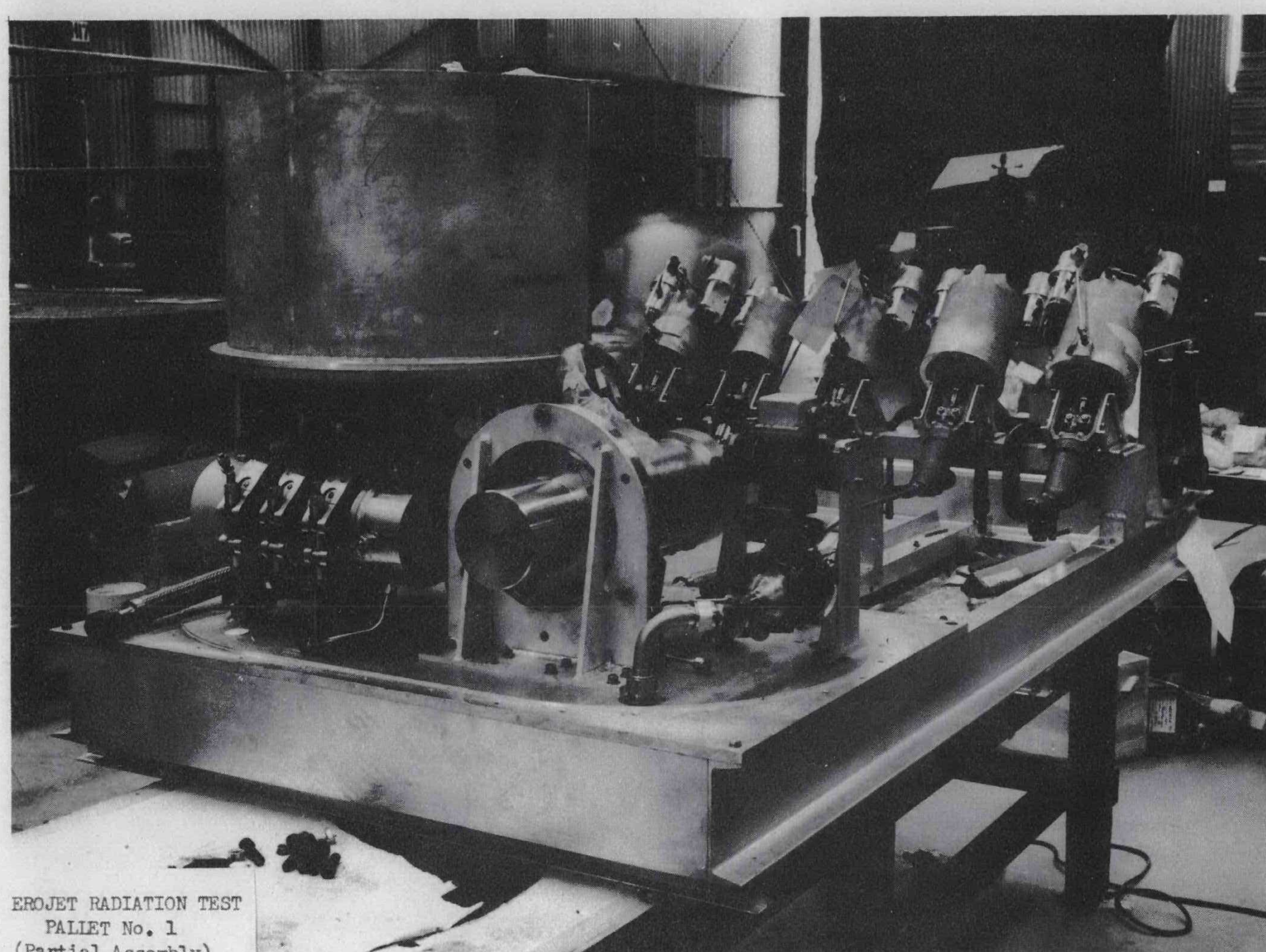

Figure 7

Uncovered LRP Mechanical Radiation Test 901 Pallet

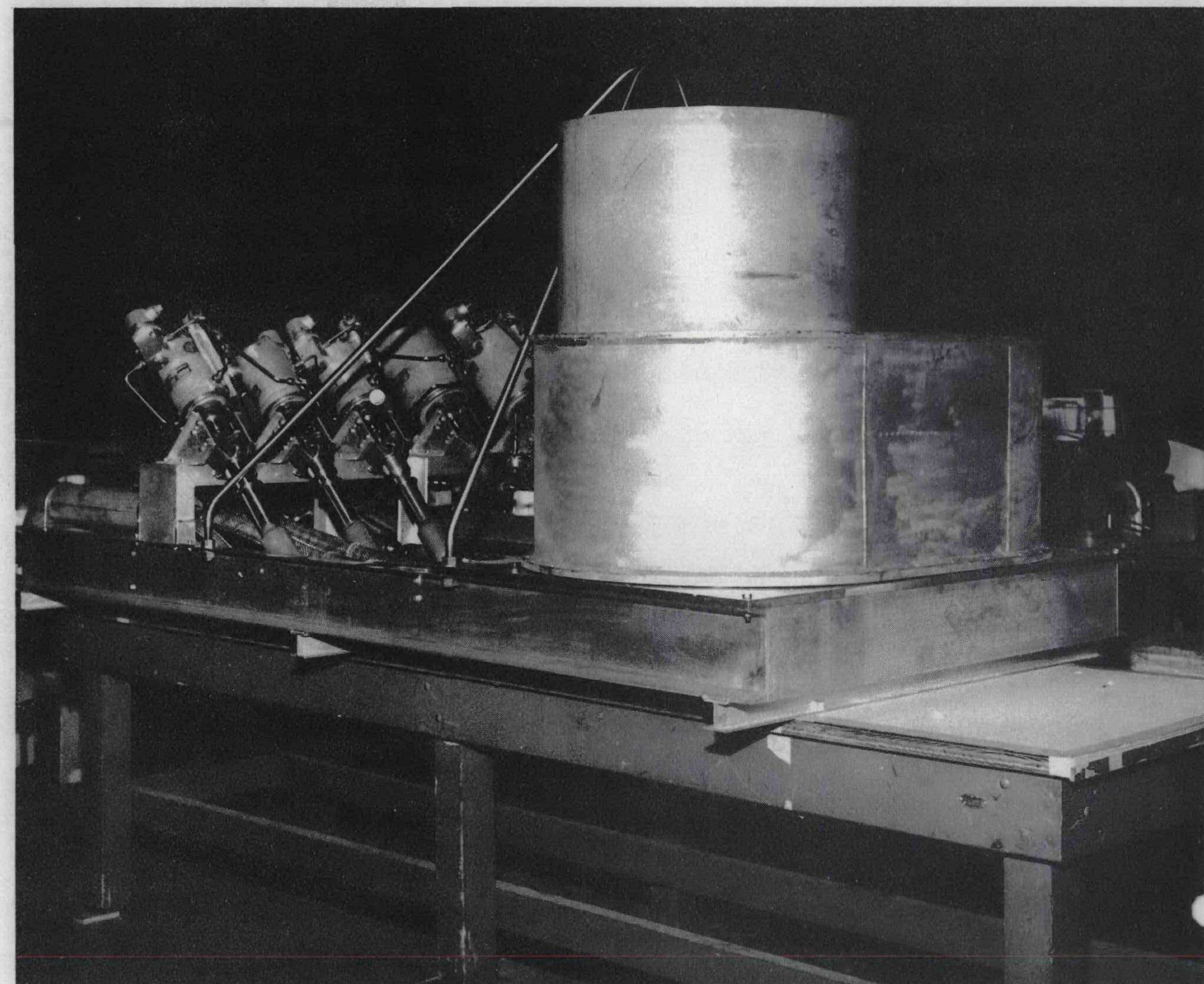

Figure 8

Covered LRP Mechanical Radiation Test 901 Pallet

SECTION V

THE TEST REACTOR
ASTR

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V. THE TEST REACTOR - ASTR

The test series for propellant-feed system components will be conducted at the Aerospace Systems Test Reactor, General Dynamics/Fort Worth, Texas. This facility was selected because of the following considerations:

> The ASTR and the necessary support functions and facilities are available for the program.
>
> The ASTR and other facilities are capable of modification to produce a radiation environment in excess of the NERVA operational environment with a comparable spatial radiation distribution.
>
> The ASTR power is capable of being increased from 3 megawatts thermal to the necessary 10 Mw.
>
> The minimal construction necessary to make the ASTR facility compatible with the test requirements.

To produce the necessary compatibility, the following modifications and additions were made to the ASTR facility.

> Two aluminum air voids were fabricated, one being placed inside the reactor pressure vessel next to the core, and the other attached to the outside of the pressure vessel opposite the internal void.
>
> An indentation was constructed in the Outside ASTR Tank, within an inch of the measure-vessel void location. The rear wall of the indentation closest to the reactor is composed of an aluminum plate and a plate made of an aluminum and boral sandwich. The combined effect of the air voids and boral plate is to "harden" the spectrum of the leakage neutron flux. The air voids essentially remove water (which is used as moderator and shielding for the reactor) from the intended irradiation direction, resulting in exposure of the test volume to the fast neutrons of the bare core. The boral further removes thermal neutrons from the leakage flux which then is primarily composed of fast neutrons.

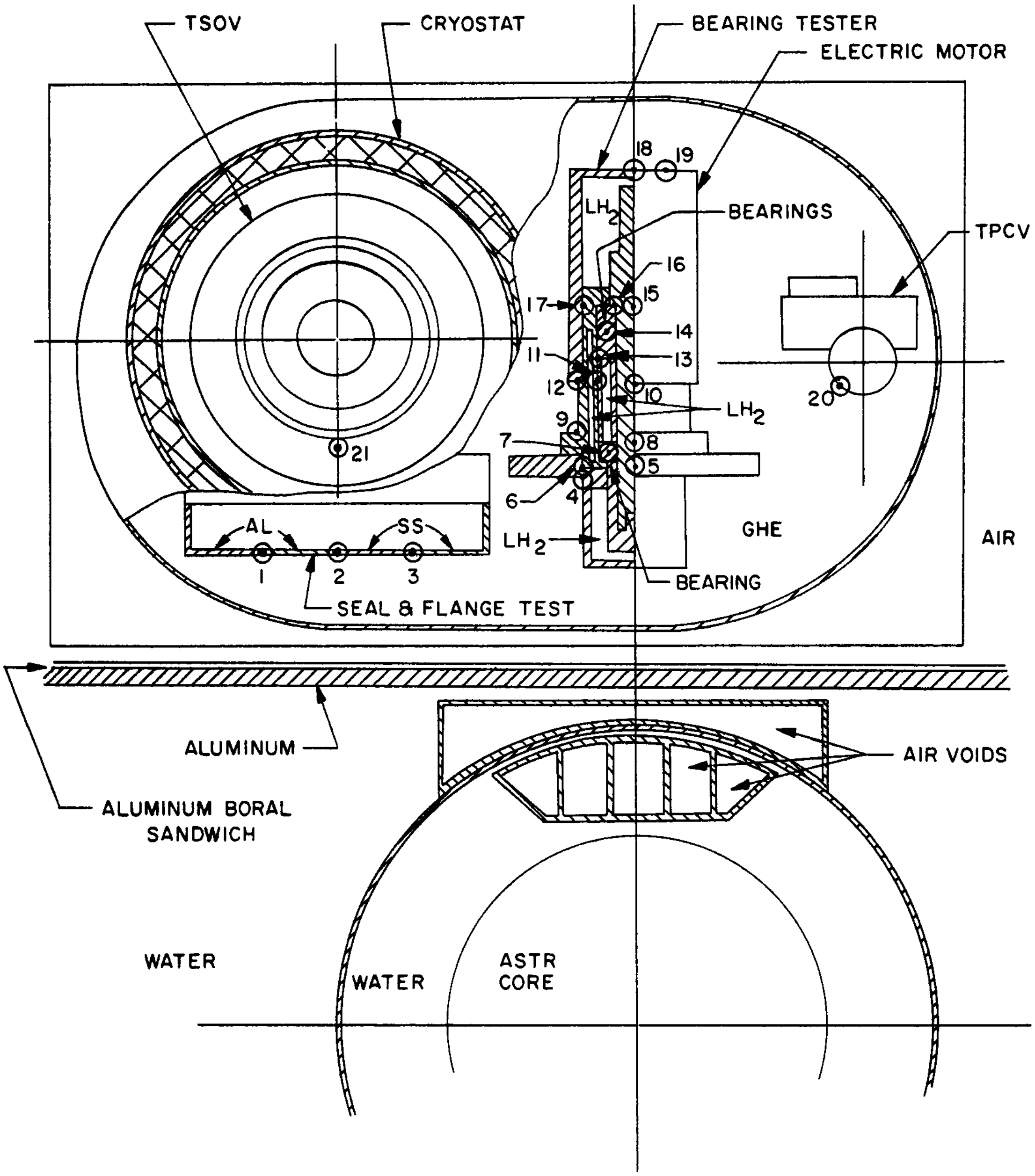

Figure 9

ASTR - LRP Pallet Test 901
Top View

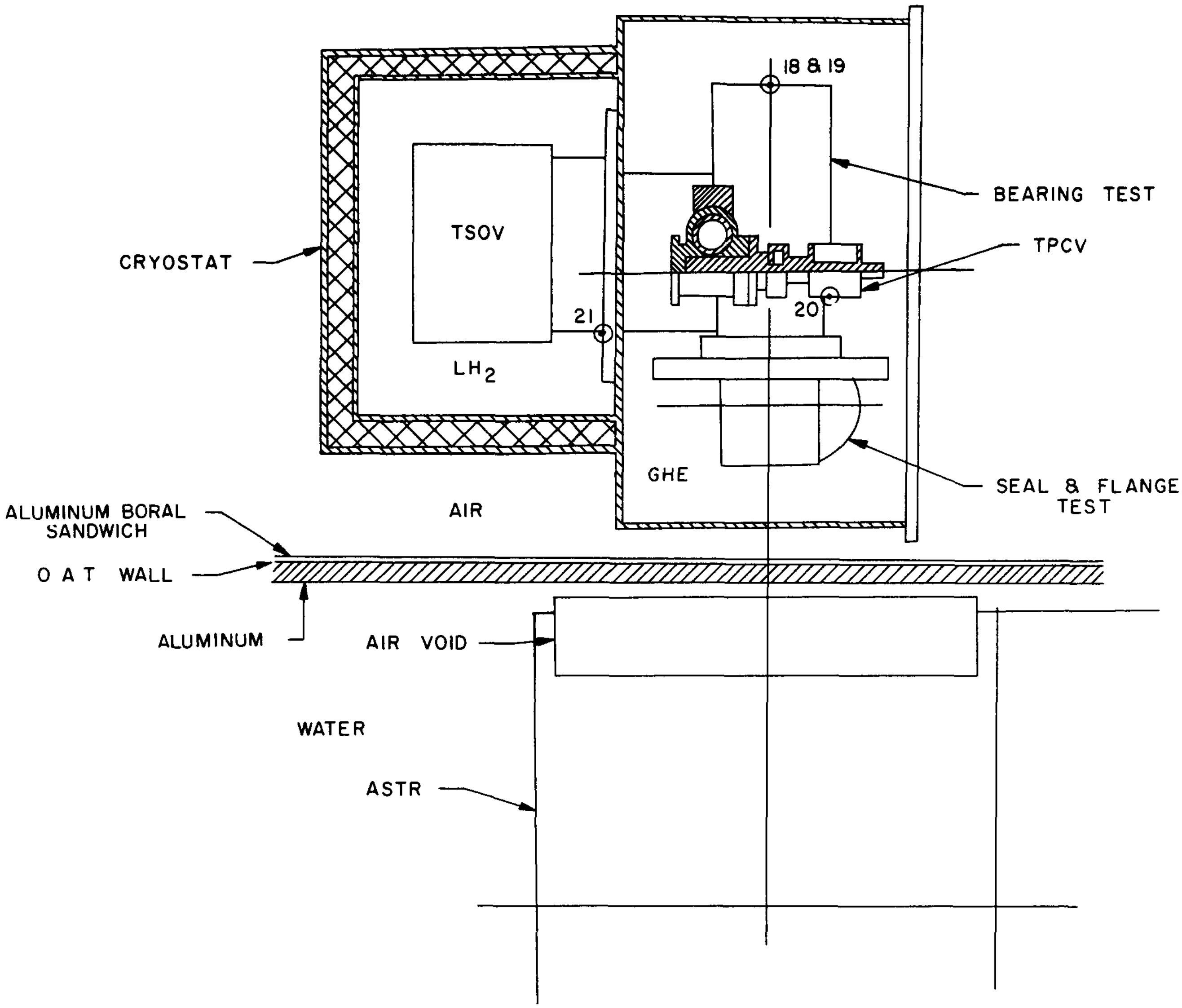

Figure 10

ASTR - LRP Pallet Test 901
Side View

A movable carriage was constructed for positioning the pallet, LH_2 stowage facilities, and the necessary facilities and equipment to provide other gases, electric power, and instrumentation to the test area.

Figures 9 and 10 illustrate the analytical representation of the ASTR and the relative position of Test 901.

SECTION VI

THE ANALYSIS

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VI. THE ANALYSIS

A. ANALYTICAL OBJECTIVES

The analytical objectives for Test 901 are:

To calculate the perturbed fast neutron and gamma ray fluxes and integrated doses experienced by the test components. These values will be used to evaluate the nuclear activation produced in the test components and to compare the test environment with the NERVA application.

To calculate the radiation induced heating rates and heat distribution for evaluation of the cooling requirements, for anticipation of mechanical failure as a result of excessive localized heating, and for comparison purposes.

To establish an analytical model of the test to permit interpolation in those areas where no experimental data will be available.

To compare the calculated values with the experimental data for evaluation of the analytical technique — the major objective of this analysis.

Evaluations thus based will contribute to the necessary development of an analytical technique, by use of which the NERVA nuclear environment can be confidently predicted with increasing accuracy.

B. THE CALCULATION

The gamma ray and neutron fluxes were calculated through use of the Point Kernel Approximation of Removal theory. This method calculates the flux produced at a distance, R, from a volume distribution of point sources by means of the equation

$$I = K \sum_i S_i \, B(R)_i \frac{e^{-R\Sigma_{ij}}}{4\pi R^2} \qquad (1)$$

where

i = i th energy group

S_i = source strength

Σ_{ij} = the homogeneous macroscopic absorption cross section for the j th material when the equation is used to calculate gamma flux

or the fast-neutron removal cross section when the equation is used to calculate fast neutron flux.

The computer code, called "QAD," developed by the Los Alamos Scientific Laboratory, was used for these calculations.

It should be noted that R in Equation (1) is defined as

$$R = \sum_j r \qquad (2)$$

where

r = distance through the j th material.

As an integral part of the calculation, the source volume is divided into a large number of incremental volumes to approximate point sources. The source strength, S_i, is determined by the reactor power, the distribution of relative power level in space, and the group-dependent energy spectrum.

When Equation (1) is used for neutron calculations, one energy group is used and B(R) is taken to be 1.

By insertion of the proper factor for K, gamma heating rates or doses can be calculated directly.

Figures 9 and 10 have been referenced as illustrations of the analytical model used to represent the test. The surfaces were described to QAD by expressing them in the equation

$$Ax^2 + Bx + Cy^2 + Dy + Ez^2 + Fz - K = 0 \qquad (3)$$

or one of its simplifications. It will be noted that all piping, structural members, wiring, and instrumentation have been omitted from the representation. Evaluation of the contribution of these items showed that they will produce localized perturbations of the incident flux, but not of sufficient magnitude in the gross flux distribution to justify increasing the complexity of the geometry.

C. INPUT PARAMETERS

The nuclear input parameters for the calculation are

1. Reactor Power

10 megawatts

2. Relative Power Distribution

Presented in cylindrical coordinates - tabulated in Table 1.

TABLE 1

INPUT PARAMETERS
RELATIVE POWER DISTRIBUTION

Radial and Azimuthal Coordinates	Axial Coordinate: Distance from Reactor Upper End	Axial Coordinate: Relative Power
Assumed flat	0 cm	0.583
	1.75	0.518
	3.5	0.500
	5.25	0.532
	10.0	0.660
	20.0	0.880
	30.0	1.000
	40.0	0.853
	50.0	0.650
	56.0	0.520
	58.5	0.460
	59.75	0.471
	60.0	0.500

3. Energy Spectrum

a. Gamma

The gamma energy spectrum used is the result of a choice between spectrums calculated by REON, and General Dynamics/Fort Worth, and the measured spectrum of the Bulk Shielding Reactor (BSR) at ORNL. The REON calculated spectrum was based on computations of the gamma source strength from the fission of U235 after steady-state operation of 100 hours. These calculations omitted the capture-gamma contribution from the reactor structure and supports. Evaluation of this contribution proved to be unnecessarily involved, and estimates were substituted.

The calculated spectrum furnished by General Dynamics proved to be a reasonable approximation up to gamma energies of about 4 Mev. However, above that energy the spectrum exceeds the fission spectrum by an amount greater than could be attributed to capture gammas.

The measured leakage gamma spectrum of the BSR provides the best approximation of ASTR due to the nuclear similarities of the two cores. The added advantage of the use of this spectrum is that it includes some capture gamma contribution. The gamma spectrum derived from this reactor is tabulated in Table 2.

TABLE 2

BSR GAMMA SPECTRUM FOR ASTR

Energy Group Mev	Energy $Mev\text{-}watt^{-1}\text{-}sec^{-1}$	Energy Group Mev	Energy $Mev\text{-}watt^{-1}\text{-}sec^{-1}$
0 → 0.4	6.775×10^{10}	2.6 → 3.0	3.66×10^{10}
0.4 → 0.9	8.87	3.0 → 4.0	5.60
0.9 → 1.35	7.40	4.0 → 5.0	3.10
1.35 1.8	7.35	5.0 → 6.0	1.50
1.8 2.2	7.90	6.0 → 7.0	1.15
2.2 2.6	5.38	7.0 → 8.0	1.10

While the choice between these alternatives admittedly results in a compromise, this is necessitated by the fact that no experimental measurement has been made by General Dynamics of the ASTR gamma spectrum.

Since these calculations were completed, measurements have been made of the unperturbed fluxes produced by ASTR in the irradiation volume, but the data has not yet been used to derive a spectrum.

b. Neutron

Calculated U235 fission prompt-neutron flux per watt of reactor power used for the neutron removal calculation of fast neutron flux was calculated in this manner:

$$3.09 \times 10^{10} \frac{\text{fission}}{\text{watts} \cdot \text{sec}} \times 2.56 \frac{\text{neutrons}}{\text{fission}} \tag{4}$$

$$= 7.9 \times 10^{6} \frac{\text{neutrons}}{\text{watt} \cdot \text{sec}} \qquad (E > 0.1 \text{ Mev})$$

SECTION VII

RESULTS OF THE CALCULATIONS

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VII. RESULTS OF THE CALCULATIONS

Table III is a tabulation of the gamma-ray and fast neutron fluxes and the gamma-ray heating rates at the detector points shown on Figures 9 and 10. Table 4 compares the analytical environments of the test and NERVA with respect to gamma-ray flux.

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TABLE 3

FLUXES AND HEATING RATES AT DETECTOR POINTS

Detector Point	Detector Location	Material/Density at Detector Point (gm/cm^3)		Gamma Flux (ergs/gm(C)-sec)	Gamma Heating Rates for Pure Iron at Detector Point ($Btu/in.^3$-sec)	Fast Neutron Flux (N/cm^2-sec)
1	Flange and seal test - Al to Al flange	Al 6061-T6	2.71	2.9×10^5	3×10^{-4}	1.98×10^{11}
2	Flange and seal test - Al to SS flange	Al SS	2.71 8.04	4.15×10^5	4.3×10^{-4}	4.3×10^{11}
3	Flange and seal test - SS to SS flange	SS 347	8.04	6.16×10^5	6.5×10^{-4}	8.5×10^{11}
4	Bearing test	SS 302	7.92	2.32×10^5	2.4×10^{-4}	4.23×10^{11}
5	Bearing test	Inconel X	8.42	2.1×10^4	2.1×10^{-5}	1.1×10^{11}
6	Bearing test	SS 302	7.92	1.37×10^5	1.4×10^{-4}	3.02×10^{11}
7	Bearing test - pump end bearing	SS 302	7.92	7.5×10^4	7.6×10^{-5}	1.84×10^{11}
8	Bearing test	Inconel X	8.42	1.4×10^4	1.4×10^{-5}	8.0×10^{10}
9	Bearing test	H Monel	8.44	7.4×10^4	7.6×10^{-5}	2.26×10^{11}
10	Bearing test	Inconel X	8.42	3.78×10^3	3.8×10^{-6}	2.9×10^{10}
11	Bearing test	A 286	7.92	6.8×10^3	6.8×10^{-6}	3.65×10^{10}
12	Bearing test	Inconel X	8.42	3.3×10^4	3.3×10^{-5}	1.06×10^{11}
13	Bearing test - turbine end bearings	SS 302	7.92	7.4×10^3	7.4×10^{-6}	3.57×10^{10}
14	Bearing test - turbine end bearings	SS 302	7.92	3.52×10^3	3.5×10^{-6}	2.11×10^{10}
15	Bearing test	Inconel X	8.42	9.1×10^2	9.1×10^{-7}	1.07×10^{10}
16	Bearing test - turbine end bearing	SS 302	7.92	1.30×10^3	1.4×10^{-6}	1.24×10^{10}
17	Bearing test	H Monel	8.44	6.1×10^3	6.1×10^{-6}	2.9×10^{10}
18	Bearing test	Inconel X	8.42	5.0×10^2	5.0×10^{-7}	4.0×10^9
19	Bearing test	Inconel X	8.42	2.76×10^3	2.8×10^{-6}	1.15×10^{10}
20	TPCV	Hastelloy B	9.17	3.7×10^5	3.8×10^{-3}	5.4×10^{11}
21	TSOV	Al 356-T6	2.71	1.2×10^5	1.2×10^{-4}	1.35×10^{11}

TABLE 4

Component		Test Gamma Flux (ergs/gm(c)-sec)	NERVA Gamma Flux (ergs/gm(c)-sec)
ISOV		1.2×10^5	$5 \times 10^5 \rightarrow 3 \times 10^7$
Turbopump Bearings	Turbine end	- 3.4×10^3	7×10^7
	Pump end	- 7.5×10^4	3×10^7
Static Seals and Flanges		$3 \times 10^5 \rightarrow 6 \times 10^5$	$1 \times 10^8 \rightarrow 3 \times 10^{10}$
TPCV		3.7×10^5	7×10^8

It is apparent that the flux predictions of the test fall several factors of 10 short of the predictions of NERVA application. The gross effects will be even further divergent when the 5-minute exposure of the test is compared with the NERVA operating period.

An important limitation of QAD should be noted. QAD does not directly evaluate the contribution to the gamma-ray flux due to (n, γ) reactors of thermalized neutrons. The modification of ASTR is intended to produce a "hard" leakage spectrum, but large reservoirs of LH_2 in the test components will produce thermalization of the incident flux. Thermal neutrons will be scattered from the thermalization volumes and may interact at random locations. The effect will be to produce gamma rays in areas shielded from the direct gamma rays of the reactor. For the present calculations this contribution to the gamma ray flux has been neglected. As a result, predictions of the gamma ray fluxes in (or in the immediate vicinity of) the larger reservoirs of LH_2 may be low.