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LIQUID ROCKET PLANT

MASTER

FINAL TEST REPORT NO. 1.9.5-1E

VOLUME II

MECHANICAL IRRADIATION TEST

No. 1/LOO1

TANK SHUT-OFF VALVE, CONFIGURATION NO. 1

February 1964

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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MASTER

FINAL TEST REPORT NO. 1.9.5-1E

VOLUME II

MECHANICAL IRRADIATION TEST

No. 1/LOOL

TANK SHUT-OFF VALVE, CONFIGURATION NO. 1

Reviewed By:

for J. L. Smith
R M Beattie, Manager
Radiation Test System Dept.
NERVA Rocket Operations
Liquid Rocket Plant

Prepared BY:

M. H. Warner
M H Warner
Radiation Test System Dept.
NERVA Rocket Operations
Liquid Rocket Plant

Approved By:

P W Rowe
P W Rowe
Assistant Technical Manager
NERVA Rocket Operations
Liquid Rocket Plant

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I. ABSTRACT

The test was designed to provide preliminary information as to the suitability of a first configuration NERVA Tank Shut-off Valve (TSOV, P/N 259300, S/N 0000004) and its associated pilot valve and position indicator for operation in a combined cryogenic and radiation environment. The test was conducted on the Aerospace Test Reactor at General Dynamic's Nuclear Aerospace Research Facility in Fort Worth, Texas.

The TSOV was immersed in low pressure liquid hydrogen and operated five times during the 327 second test while receiving an integrated dose of between 8×10^{12} to 9×10^{12} fast neutrons per cm^2 and a gamma dose of between 2.9×10^7 and 4.0×10^7 ergs per gram (carbon).

From a comparison for pre- and post-irradiation test inspections, there was no apparent permanent deformation of the valve body or seat due to radiation effects and the valve seal was not functionally affected by the radiation received.

II. INTRODUCTION

The NERVA component radiation effects test program is designed to obtain early preliminary information regarding the effects of radiation on NERVA engine non-nuclear components under conditions representative of engine operations, including typical actuations and cryogenic environments.

The first test of a NERVA Tank Shut-Off Valve was to evaluate the operability of the valve, its springs, seat, seals, actuator, pilot valve, and position indicator. The TSOV was designed to mount on the bottom of the Reactor In-Flight Test propellant tank and to initiate or stop the flow of propellant to the NERVA engine. Proper operation of this valve in a radiation environment is vital to the functioning of the engine.

III.

EXPERIMENT IDENTIFICATION

A. Test Plan Reference Number

1/L001 - Tank Shut-Off Valve, Configuration No. 1, P/N 259300

B. Sponsor -

NERVA Rocket Operations

Liquid Rocket Plant

Aerojet-General Corporation

Sacramento, California

C. Test Facilities -

1. Pre-Irradiation Tests:

Liquid Rocket Plant

Aerojet-General Corporation

Sacramento, California

2. Irradiation Tests:

NARF (ASTR)

General Dynamics Corporation

Fort Worth, Texas

3. Post-Irradiation Tests:

Liquid Rocket Plant

Aerojet-General Corporation

Sacramento 13, California

D. Test Dates -

LRP Pre-Irradiation - 13 March 1963

GD/FW Irradiation - 17 July 1963

LRP Post Irradiation - October 1963

IV. PURPOSE OF THE EXPERIMENT

The purpose of this experiment was to determine what effects radiation in combination with a cryogenic environment would have on the operation of a NERVA Tank Shut-Off Valve. The valve was to be operated several times during checkout and pre-irradiation control runs while immersed in liquid hydrogen. During the irradiation test, these same cryogenic conditions were to be provided in addition to the radiation field provided by the ASTR. Comparison of pre- and post-irradiation test inspections would determine any physical effects and a position indicator would be monitored during the test to determine operational characteristics.

V. TEST DESCRIPTION

The TSOV, its pilot valve and its position indicator were mounted on Radiation Effects Test Pallet #901, P/N 255802-19, (See Figure A-1) and functionally checked at the Test Zone G-7 (See Figure A-2) Liquid Rocket Plant, Aerojet-General Corporation, Sacramento, California on 13 March 1963. During this checkout, the TSOV was actuated twice, but due to an electrical malfunction no position information was recorded.

After the checkout, the TSOV and the Pallet were cleaned and shipped to General Dynamics, Fort Worth, Texas. GD/FW personnel performed functional and leak checks, installed the pallet on the ASTR dolly, and conducted a 10 second pre-irradiation control run prior to the irradiation test. The TSOV was actuated twice during the coast-down period immediately following the 10 second run while the LH_2 flow continued. (See Figures C-2 to C-4)

The irradiation test was conducted on 17 July 1963, for a duration of 327 seconds at 10 MW reactor power, during which time the TSOV was cycled (closed-open-closed) five times. From the 750 gallon LH_2 Dewar (See Figure A-3),

liquid hydrogen was supplied to the test pallet. The LH_2 passed through a six-flange seal test assembly and an orifice before entering the TSOV cryostat. (See Figure C-1). A slight positive pressure was maintained in the cryostat by the boil-off of the LH_2 . The cold GH_2 was then directed to the facility burn stack. Liquid level sensors were used to maintain the LH_2 level above the TSOV seat and seal. A rectilinear potentiometer, linked to the TSOV poppet, indicated position. It may be seen in Figure D-1 that the position trace showed consistency in valve operation times except for the second cycle. This anomaly was caused by a malfunction of the GH_2 pressure switch, which closed the GH_2 supply valve momentarily at about +65 seconds, reducing actuation gas pressures accordingly. (See Figure D-2).

Following the irradiation test, the TSOV was removed from the pallet and returned intact to LRP where it was disassembled and inspected. An annular groove was found in the sealing surface of the seat caused by contact with a ridge on the poppet seal ring. This is normal in valves using ridged poppet seal rings. No other damage to the seal surfaces was noted.

A detailed description of the test pallet and special test equipment provided for this test is given in Volume V of this report. Briefly, the test pallet consisted of an aluminum structural portion designed to support the test component in the desired position relative to the radiation field of the adjacent reactor.

The pallet contained the necessary valves, regulators, filters, relief-systems and instrumentation to control the fluid and electrical supplies to the test component. (See Figure A-1). Liquid hydrogen pressure at the test pallet was controlled at the liquid hydrogen storage dewar. The liquid hydrogen dewar with its pressurization, vent, and deluge system are shown in Figure A-3.

The gas distribution system shown in Figure A-4 supplied gaseous helium to the pallet regulation system. Helium was to purge the container housing the Tank Shut-Off Valve throughout the test.

Control of the test equipment was accomplished through the use of a master sequencer checker and associated control rack. (See Figure A-5). The master sequencer checker contained switches for control of all manual control functions on the test pallet, the liquid hydrogen dewar, the motor generator set and the electrical control rack. The unit also contained run and emergency warning lights. The electrical control rack included a sequencer unit, power panel, event recorder, output amplifier and a signal conditioning unit.

The data acquisition system for this test consisted of an analog magnetic tape system, video tape system, visual meter panels and four four-channel Sanborn recorders. Critical parameters were monitored visually during the test by use of the meter panels. All critical and "kill" parameters were wired directly to the Sanborn recorders and all test measurement parameters were recorded on analog tape. The analog magnetic tape system had twenty-four tape channels and each tape channel had the capacity to record six separate parameters.

VI. TEST PROCEDURES

Report No. 9440-1SA, Test Procedure No. 1.9.5-1, Mechanical Irradiation Test No. 901 presents the data handling requirements and the detailed pre-test, irradiation test, and post-test operating procedures. Briefly, the following sequence of major events was adhered to: The test pallet and associated control equipment was set up and functionally tested prior to its installation at the reactor site. Once the test equipment was installed at ASTR, leak checks, functional tests and a liquid nitrogen flow test were performed to ascertain

that all systems were operational. At this point, the liquid hydrogen dewar was loaded with liquid hydrogen, a cooldown sequence was followed and when the cooldown by-pass liquid level sensor indicated that LH₂ was flowing, a 10 second control run was initiated. The TSOV was not cycled during the 10 second run, but was cycled twice during the subsequent coast-down period.

Following the 10 second non-nuclear run, the irradiation test was started. During the irradiation test, the system was cooled down, the reactor was elevated into position, and activated to 10 megawatts full power. The TSOV was cycled every 60 seconds, for a total of five cycles, during the 327 seconds that the reactor was at full power. At this time, the reactor was shut-down and the test shut-down procedures were initiated.

A complete electrical checkout and calibration was made of all electrical controls and instrumentation prior to the irradiation test. At the conclusion of the irradiation test, all pressure transducers were recalibrated using the same Heise gage that was used for the original calibrations. All irradiation test parameters were plotted using the post-test calibration data because the conditions existing during post-calibration were more nearly like those extant during the irradiation test. Appendix E presents the calibration curves used in conjunction with the oscillograph charts.

VII. NUCLEAR MEASUREMENTS

Dosimetry was supplied by GD/FW at 19 locations on the pallet as shown in Tables B-I and B-II, Appendix B. All foils were counted and data reduced by an IBM 7090 digital computer.

A. Neutron flux was monitored through use of sulphur threshold detectors for neutrons with energies > 2.9 Mev, aluminum for energies > 8.1 Mev, and phosphorous pellets (bare and cadmium

plated) for thermal fluxes.

B. Gamma - The gamma dose measurements were made with nitrous oxide (N_2O) dosimeters, chemical dosimeters, and cobalt glass.

1. Nitrous Oxide Dosimeters

The nitrous oxide dosimeters used at GD/FW consist of a quartz shell forming a volume of about 24 cc which is filled with a measured quantity of N_2O gas before the dosimeter is flame-sealed. Upon exposure to gamma radiation, the following reaction is produced in the gas:

The dose is determined by measuring the moles of $N_2 + O_2$ produced per mole of original N_2O , and relating this quantity to dose on a calibration curve.

Energy dependence of the N_2O system is air-equivalent (within 10%) from 150 kev to 5 Mev. The dosimeters are usable in the dose and temperature ranges of from 10^8 to 10^{12} ergs/gm(C) and -90° to $+120^\circ C$, respectively. The dosimeters have a reproducibility of 7% to 9%.

2. Chemical Dosimeters

The chemical dosimeters are the chlorinated hydrocarbon type developed originally by Taplin-Sigaloff and modified at GD/FW. They consist of 0.8 ml of tetrachloroethylene overlaid with 0.2 ml of water. The dosimeters, sensitive to gamma energies from 65 kev to 10 Mev, have a usable gamma dose range from 10^5 to 10^8 ergs/gm(C), a temperature range from 5 to $50^\circ C$, and a precision of 5 to 6% at the 95% confidence level.

3. Cobalt Glass Dosimeters -

These dosimeters are cobalt-activated borosilicate glass plates, 15 by 6 by 1.5 mm, manufactured by Bausch and Lomb Inc. Exposure to ionizing radiation darkens the glass. The change in optical density measured at 390 nm versus dose was plotted and the plot was compared with similar plots of calibrated glass plates to obtain the dose. The recommended range of the dosimeters is from 10^6 to 2.6×10^8 ergs/gm(C).

These dosimeters were enclosed in a 1/16 inch-thick thermal neutron shield of the following composition: 33% by weight B_4C (92% enriched B^{10}), 33% Epon 828, and 33% Versamid¹⁴⁰.

VIII. TEST RESULTS

Analyses of the 60 second checkout test, 10 second control run, and 327 second irradiation test of the TSOV show no serious effects due to the combined cryogenic and radiation environment. The operation times of the valve were consistent as shown in Figure D-5 and there was no apparent material damage or deterioration beyond that expected from normal operation of this type valve. The indicated temperatures within the cryostat ranged from -300°F to -340°F (See Figure D-3) at pressures from 6.6 psig to 9.0 psig (See Figure D-4). The integrated neutron flux for energies greater than 2.9 Mev was from 8.6×10^{12} to 9.0×10^{12} n/cm² and the gamma dose ranged from 2.9×10^7 to 4.0×10^7 ergs per gram of carbon. (See Tables B-I and B-II).

IX. DISCUSSION OF TEST RESULTS

The irradiation test on the TSOV and associated pilot valve and position indicator showed that the operation was not adversely affected by

radiation and that the design philosophies concerning radiation effects resistance were adequate.

The performance of liquid level sensors in two-phase hydrogen is questionable at best, therefore, the level of liquid hydrogen may not have been positively established. However, the temperatures and pressures in the cryostat were such as to insure that cryogenic conditions were prevalent, and that the valve was subjected to temperatures which satisfied the purpose of the test. Several instrumentation malfunctions were experienced during the test, but were not critical as to the determination of valve design adequacy. Insufficient dimensional and hardness information was derived in pre- and post-irradiation inspection to isolate the effects of radiation from other environmental effects.

X. CONCLUSIONS AND RECOMMENDATIONS

A. It is concluded:

1. That the TSOV (P/N 259300) and its pilot valve operated satisfactorily in a combined cryogenic and radiation environment.
2. That valve opening and closing times were repeatable.
3. That the materials of fabrication of valve body, seat, springs, and seals were not adversely affected by the radiation.
4. That the temperature of the propellant in the TSOV was elevated by the heat gained in the Static Flange Seal Assembly.

B. It is recommended:

1. That irradiation tests of succeeding configurations of the TSOV be of extended duration to accumulate radiation dosage and operations more representative of expected engine operations.

2. That more control or reference tests prior to and after the irradiation test be conducted such that the effects of radiation could be isolated from the effects due to other concurrent test conditions.
3. That in future TSOV irradiation tests an LH_2 flow be maintained through the valve and that design of the pallet insure that the temperature of the hydrogen in the valve be as nearly that expected in actual operations as possible.
4. Conduct more thorough pre- and post-irradiation inspections oriented toward determination of the possible affects of radiation on the proper functioning of the TSOV and pilot valve.

XI. APPENDICES

APPENDIX A

PHOTOGRAPHS

LIST OF FIGURES

Appendix A

<u>Figure No.</u>	<u>Title</u>
A-1	Radiation Effects Pallet, TSOV Cryostat Cover Removed
A-2	G-7 Test Area Showing Radiation Effects Pallet Connected to Supply and Purge Lines
A-3	LH ₂ Supply Dewar, Vacuum Pump and Valves
A-4	Gas Distribution System at GD/FW
A-5	Sequencer - Checker Panel

Radiation Effects Pallet, TSOV Cryostat Cover Removed

Figure A-1

Figure A-2

G-7 Test Area Showing Radiation Effects Pallet Connected
to Supply and Purge Lines

L1262 602

Figure A-3

LH₂ Supply Dewar, Vacuum Pump and Valves

Figure A-4

Gas Distribution System at GD/FW

Sequencer — Checker Panel

Figure A-5

APPENDIX B

DOSIMETRY

LIST OF TABLES

Appendix B

<u>Table No.</u>	<u>Title</u>
B - I	Dosimetry Results
B - II	Dosimetry Locations

DOSIMETRY

Nineteen dosimetry packets were attached to the various components on the test pallet to measure the integrated dose received by each component. Table I contains the dose measured by each of the dosimetry packets. Table II contains the location description and number of the dosimetry packets for each of the components.

TABLE B-I

Dosimetry Results

Packet	Gamma ergs/gm(C)	Neutrons/cm ² E>8.1 Mev	Neutrons/cm ² E>2.9 Mev	Thermal Neutrons/cm ² E<0.48 ev
1.	8.1 (7)*	6.2 (11)	1.8 (13)	2.8 (12)
2.	3.8 (7)	3.5 (11)	1.1 (13)	2.5 (12)
3.	1.3 (7)	1.3 (12)	3.7 (13)	
4.	1.4 (8)	2.3 (12)	8.3 (13)	
5.	2.1 (6)	2.5 (12)	9.2 (13)	
6.	3.8 (8)	2.4 (12)	8.1 (13)	
7.	1.8 (8)	1.1 (12)	3.5 (13)	
8.	1.7 (7)	1.8 (11)	5.2 (12)	3.2 (12)
9.	1.4 (7)	1.8 (11)	5.2 (12)	3.1 (12)
10.	1.7 (7)	1.0 (11)	3.6 (12)	2.7 (12)
11.	8.1 (6)	6.0 (10)	1.7 (12)	2.1 (12)
12.	5.4 (6)	1.3 (10)	6.0 (11)	1.6 (12)
13.	7.4 (7)	7.9 (11)	2.5 (13)	
14.	2.2 (7)	3.2 (11)	1.0 (13)	2.4 (12)
15.	8.1 (7)	7.9 (11)	2.5 (13)	
17.	5.4 (7)	8.0 (11)	2.8 (13)	
18.	7.0 (6)	2.6 (11)	1.3 (12)	2.1 (12)
19.	4.0 (7)	1.7 (11)	9.0 (12)	2.5 (12)
20.	2.9 (7)	2.7 (11)	8.6 (12)	2.8 (12)

*8.1 (7) denoted 8.1×10^7

TABLE B-II

Dosimetry Locations

Static Flange Seal Assembly

Packet No. 1	On horizontal centerline, 6 inches from left end, on front face.
Packet No. 3	On horizontal centerline, 12 inches from left end, on front face.
Packet No. 19	On horizontal centerline, $8\frac{1}{2}$ inches from left end, on back face.

Tank Shut-Off Valve

Packet No. 19	On vertical centerline, front face, directly behind Static Flange Seal Assembly.
Packet No. 20	Directly behind No. 19 on back face of TSOV.

Bearing Tester

Packet No. 4	On front face, vertical and horizontal centerlines.
Packet No. 17	Mounted on rear surface of flange at top.
Packet No. 18	Mounted on rear surface of Bearing Tester Motor

Turbine Pump Control Valve Actuator

Packet No. 13	On front face
Packet No. 14	On rear face

Turbine Pump Control Valve

Packet No. 15	On front face
Packet No. 2	On rear face

Shroud (outside dosimetry 6" up from base)

Front face left to right distance from left side of shroud

$18\frac{1}{2}$ " 25" 34"

APPENDIX C

TEST DATA - 10 SECOND RUN

LIST OF FIGURES

Appendix C

<u>Figure No.</u>	<u>Title</u>
C-1	Flow Diagram MIT 901 Pallet
C-2	Voltage Output, Tank Shut-Off Valve Position Indicator
C-3	Pressure of LH_2 in Tank Shut-Off Valve Cryostat
C-4	Temperature Inside Tank Shut-Off Valve Actuator and Cryostat

REVISIONS		
SYM	ZONE	DESCRIPTION
A		SEE "A" CHANGE DCN

NOTES:

1. SYMBOLS PER MIL-STD-18.
2. ALL SECONDARY LINES ARE .25 INCH DIA.
3. TO BE USED IN CONJUNCTION WITH ASSY DWG. P258002 & P255830.
4. FOR CONTROL SYSTEM SCHEMATIC SEE DWG NO. P255830.
5. FOR ACI RADIATION EFFECTS PALLET ELECTRICAL SCHEMATIC SEE DWG NO. P255811.
6. FOR AGE ELECTRICAL HARNESS INTERFACE SEE DWG NO. P255815.

⚠ DENOTES NERVA ENGINE COMPONENT TO BE TESTED (NOT PART OF TEST PALLET).

HYDRAULIC DATA	
SYMBOL	DESCRIPTION
TURBINE POWER CONTROL VALVE
TANK SHUT-OFF VALVE
MARMION FLANGE COUPLING
HYDROGEN GAS LINE, PRIMARY
HELIUM LINE, PRIMARY
VENT RETURN LINE
LIQUID HYDROGEN LINE, PRIMARY
EXPANSION BEND
HELIUM LINE, SECONDARY
HYDROGEN GAS LINE, SECONDARY
LIQUID HYDROGEN LINE, SECONDARY
FLEX HOSE LINE
VENT PORT
DENOTES LINE SIZE
MAJOR THREADED TUBE CONNECTION
DENOTES APPROX CONNECTING FOR PARAMETRIC DATA
COMPONENT LOCATION
ORIFICE
TPCV & TSOV 3 WAY PILOT VALVE
MINOR THREADED TUBE CONNECTION

PARAMETRIC DATA		
SYMBOL	DESCRIPTION	FUNCTION
T1	TEMPERATURE, LIQUID HYDROGEN INLET TO BEARING TESTER	TLH ₂₁
T2		TBH ₁
T3		TBH ₂
T4		TRB
T5		TSB ₁
T6		TSB ₂
T7		TPBM
T8		TSFSA
T9		TSOV _a
T10		TSOV
T12		TGH ₂₁
T13		TGH _{2a}
T18		T ₁
T15		T _c
T16	TEMPERATURE	T ₃
P1	PRESSURE, LIQUID HYDROGEN INLET OF BEARING TESTER	PLH ₂₁
P2		P _{ab}
P3		PTPB
P9		PSFSA
P5		PTSOV
P7		P _{g1} TPCV
P8		P _{g0} TPCV
P6		P _{g1} TPCV
P10	PRESSURE, TURBINE POWER CONTROL VALVE ACTUATOR GAS OUTLET	P _{g0} TPCV
VP1	VALVE POSITION, TSOV	LTSOV
VP2	VALVE POSITION, TPCV	LTPCV
M	MOTOR SPEED	NTPB

[illegible]

Flow Diagram MIT 901 Pallet
Figure C-1, Sheet 2 of 2

Figure C-2

Voltage Output, Tank Shut-Off Valve Position Indicator

Figure C-3

Pressure of LH_2 in Tank Shut-Off Valve Cryostat

Figure C-4

Temperature Inside Tank Shut-Off Valve Actuator and Cryostat

APPENDIX D

TEST DATA - 300 SECOND IRRADIATION TEST

LIST OF FIGURES

Appendix D

<u>Figure No.</u>	<u>Title</u>
D-1	Voltage Output from Tank Shut-Off Valve Actuator
D-2	Pressure of GH_2 at the Inlet and Outlet of the Turbine Power Control Valve
D-3	Temperature Inside the Tank Shut-Off Valve Actuator and Cryostat
D-4	Pressure of LH_2 in the Tank Shut-Off Valve Cryostat
D-5	Opening and Closing Times TSOV

Figure D-1

Voltage Output from Tank Shut-Off Valve Actuator

Figure D-2

Pressure of GH_2 at the Inlet and Outlet of the Turbine Power Control Valve

Figure D-3

Temperature Inside the Tank Shut-Off Valve Actuator and Cryostat

Figure D-4

Pressure of LH_2 in the Tank Shut-Off Valve Cryostat

Valve Operating Times Are as Listed Below:

Cycle No.	Opened - Closed Seconds	Closed - Opened Seconds	Remarks
1	$< .5 \leq 1.5$	$< 1.0 \leq 2.0$	Normal
2	$< .0 \leq 1.0$	$< .0 \leq 1.0$	Partial cycle due to temporary loss of actuating GH ₂ pressure
3	$< .5 \leq 1.5$	$< .5 \leq 1.5$	Normal
4	$< 1.0 \leq 1.5$	$< .5 \leq 1.5$	Normal
5	$< .5 \leq 1.5$	$< .5 \leq 1.5$	Normal

Opening and Closing Times TSOV

APPENDIX E

CALIBRATION DATA

LIST OF FIGURES

Appendix E

<u>Figure No.</u>	<u>Title</u>
E-1	Calibration Curve - TSOV Actuator GH_2 Temperature Transducer
E-2	Calibration Curve - TSOV Cryostat LH_2 Temperature Transducer
E-3	Calibration Curve - TSOV Cryostat LH_2 Pressure Transducer

Figure E-1

Calibration Curve — TSOV Actuator GH₂ Temperature Transducer

Figure E-2

Calibration Curve — TSOV Cryostat LH₂ Temperature Transducer

Figure E-3

Calibration Curve — TSOV Cryostat LH₂ Pressure Transducer

REFERENCES

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Aerojet-General Corporation Reports 9440-1S and 9440-1SA.
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3. Preliminary Report ASTR-1 Irradiation Test 17 July 1963. General
Dynamics - Fort Worth.
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5. NERVA Turbopump Bearing and Tester MIT901 Test Report Radiation
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