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REPORT NO. RN-S-0386
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

ETS-1 SIDE SHIELD INVESTIGATIONS

MARCH 1967
NERVA PROGRAM CONTRACT SNP-1

REON

AEROJET-GENERAL CORPORATION

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CONTRACT SNP-1

ROCKET ENGINE OPERATIONS - NUCLEAR

MARCH 1967

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10 March 1967

ETS-1 SIDE SHIELD INVESTIGATIONS

An Operational Reliability Study for
SPACE NUCLEAR PROPULSION OFFICE
CLEVELAND EXTENSION

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I. INTRODUCTION

Operational experience gained to date with the side shield and ETS-1 Engine Test Compartment (ETC) systems indicates the feasibility of investigating certain modifications that have the potential of significantly improving the operational reliability of the overall system.

On the basis of recently acquired information, Aerojet is proposing a test program that will further identify and define the modifications required to (1) achieve improved side-shield and ETC system reliability and (2) determine the cost of new work. Quality-control efforts that will support this work are presented in Appendix A, and Shielding Cooling requirements are presented in Appendix B.

II. SUMMARY

To increase the reliability of the overall side-shield and ETC system, Aerojet will conduct a test program relating to movement of the S-1 and S-2 side-shield cars and to radiation dosage levels.

The proposed effort will include testing relative to water flow; shield reliability; mechanical, seal, and leakage; removal operation qualifications; and an operational reliability study.

III. TECHNICAL DISCUSSION

A. WATER FLOW TEST

1. Water Flow-Rates

An operational reliability study of the ETC has revealed a problem in the shield water flow distribution. The shield cooling water is supplied to the shields through four Bailey globe valves of 6- and 8-in.-size, with a hydraulic actuation system utilizing process water as the hydraulic

fluid. These cooling water valves are supplied through a 24-in.-diameter header with a normal head pressure of 230 psig. The actuation system is designed to provide pressure control with an average pressure drop across the valve of approximately 200 psig. Cooling water from the shields is discharged into the duct vault through a series of discharge nozzles, which provide cooling to various duct areas and trunnion mounts.

If a failure of the shield cooling water valve actuation system occurs, the valves will go to the full-open position because of the high upstream pressure. The 8-in. side shield cooling water valve in the full-open position is capable of flowing approximately 12,000 gallons/min with the available pressure and would cause a structural failure of the shield. This would necessitate an elaborate method of shield over-pressurization protection. An additional operational problem is protecting the 3/4- and 1/2-in. valve actuation system against freezing.

Since the ETC shield designs were based on criteria for the 3.5 NERVA, the design cooling water flow rates are higher than necessary for the presently scheduled engines to be tested at ETS-1. Because the process water supply is a critical item and could affect both run time and turn-around time, it is desirable to reduce the flow rates as much as possible. Operating the existing valves at a reduced flow rate presents a difficult control problem.

The solution to these problems is to remove the existing shield-cooling water supply valves and replace them with smaller, pneumatically operated valves, sized to provide adequate cooling water flow in the full-open position. This would eliminate the possibility of shield over-pressurization.

The required valve sizes (i.e., flow rates) were determined by calculating the radiation heating effects on the shields and then determining the minimum water flow rates required to prevent overheating.

Figure 1 gives the bulk heating per square inch of surface area at various locations on the intermediate, side, and bottom shields of the

ETS-1 engine test compartment. These data are also given in Table 1, with dimensional information relative to interpretation of the figure.

The data in Table 1 indicate direct gamma heating, heating due to slowing down of the neutrons incident on the shield, and resultant neutron-capture gamma and alpha heating in the shield. This latter category of data is predicated on 2.2 Mev energy release per neutron capture, with no loss due to leakage from the shield. This should be a fairly valid assumption for the following reasons:

a. The alpha particles produced in the boral are absorbed therein.

b. The accompanying gamma capture radiation in boron and hydrogen occurs near the inner portions of the shield, with the concomitant result that leakage is inward and therefore trapped in the engine test compartment. Such leakage gamma rays are most probably absorbed in the ETC shields rather than the engine.

Heating of the boral is approximated by using 50% of that attributable to neutron captures in the sixth column of Table 1.

Using these radiation heating rates, a thermal analysis was made to determine the minimum cooling water flow rates for the facility radiation shields.

Three criteria were used in calculating the minimum cooling water flow rates: (1) enthalpy balance (based on cooling water inlet temperatures of 90°F and maximum outlet temperature of 180°F); (2) boiling suppression on boral plate surfaces; and (3) parallel flow stability. Results of this study are summarized in Table 2. A detailed discussion of the calculation of these cooling rates is presented in Appendix B. Recommendations for additional studies are presented in Section III, Conclusions and Recommendations of Appendix B.

TABLE 1

ETS-1 Intermediate Shield, Side Shield, and Bottom Shield Radiation Heating

Heating Point Location	Station (in)	Radius (in)	Radiation Heating per Unit Surface Area (Btu/in ² -sec)			
			Direct Gamma	Neutron Kinetic Heating	Neutron(n, α) + (n, γ) Capture Heating	Total
ISB-1	157	54	2.6×10^{-2}	7.1×10^{-2}	3.6×10^{-2}	6.9×10^{-2}
ISB-2	157	66	3.9×10^{-2}	8.4×10^{-3}	4.4×10^{-2}	9.1×10^{-2}
ISB-3	157	78	4.5×10^{-2}	8.6×10^{-3}	4.5×10^{-2}	9.9×10^{-2}
ISB-4	157	90	4.6×10^{-2}	8.2×10^{-3}	4.3×10^{-2}	9.7×10^{-2}
ISB-5	157	102	4.5×10^{-2}	7.8×10^{-3}	4.0×10^{-2}	9.3×10^{-2}
SSL-1	157	105	4.2×10^{-2}	8.1×10^{-3}	4.2×10^{-2}	9.2×10^{-2}
SSL-2	170	105	5.1×10^{-2}	9.8×10^{-3}	5.1×10^{-2}	1.1×10^{-1}
SSL-3	182	105	6.5×10^{-2}	1.2×10^{-2}	6.0×10^{-2}	1.4×10^{-1}
SSL-4	194	105	7.1×10^{-2}	1.3×10^{-2}	6.7×10^{-2}	1.5×10^{-1}
SSL-5	206	105	8.0×10^{-2}	1.5×10^{-2}	7.8×10^{-2}	1.7×10^{-1}
SSL-6	218	105	8.6×10^{-2}	1.7×10^{-2}	8.6×10^{-2}	1.9×10^{-1}
SSL-7	230	105	8.8×10^{-2}	1.7×10^{-2}	8.8×10^{-2}	1.9×10^{-1}
SSL-8	242	105	8.5×10^{-2}	1.6×10^{-2}	8.4×10^{-2}	1.9×10^{-1}
SSL-9	253	105	7.8×10^{-2}	1.5×10^{-2}	7.5×10^{-2}	1.7×10^{-1}
SSL-10	263	98	7.6×10^{-2}	1.4×10^{-2}	7.3×10^{-2}	1.6×10^{-1}
SSL-11	273	92	7.2×10^{-2}	1.3×10^{-2}	6.8×10^{-2}	1.5×10^{-1}
SSL-12	284	86	6.4×10^{-2}	1.3×10^{-2}	6.6×10^{-2}	1.4×10^{-1}
SSL-13	294	79	5.3×10^{-2}	1.3×10^{-2}	6.6×10^{-2}	1.3×10^{-1}
SSL-14	304	73	4.1×10^{-2}	1.3×10^{-2}	6.5×10^{-2}	1.2×10^{-1}
SSL-15	316	73	3.1×10^{-2}	1.2×10^{-2}	6.0×10^{-2}	1.0×10^{-1}
BS-1	327	44	2.5×10^{-2}	2.0×10^{-2}	1.0×10^{-1}	1.5×10^{-1}
BS-2	327	58	2.8×10^{-2}	1.5×10^{-2}	7.9×10^{-2}	1.2×10^{-1}
BS-3	327	72	2.6×10^{-2}	1.2×10^{-2}	6.1×10^{-2}	9.9×10^{-2}

Figure 1 - ETS-1 Intermediate Shield, Side Shield,
and Bottom Shield Radiation Heating

TABLE 2

FACILITY SHIELD COOLING WATER FLOW RATES
AS A FUNCTION OF THERMAL/FLOW STABILITY CRITERIA

<u>Shield</u>	<u>Enthalpy Balance</u>	<u>Boiling Suppression</u>	<u>Parallel Flow Stability</u>	
			<u>Re = 2500</u>	<u>Re = 4000</u>
Intermediate	175 gpm	153 gpm	230 gpm	368 gpm
Bottom	112 gpm	(1)	382 gpm	604 gpm
Side	1290 gpm	(1)	(2)	(2)

(1) Flow rate not computed as the heat transfer correlation does not apply to cases where the Reynolds number indicates flow to be laminar.

(2) Flow rate not computed as the Reynolds number for enthalpy balance flow is greater than 4000 and thus the flow stability criterion does not control.

Based on Table 2, the necessary flow rates for the four water lines are as follows:

(1) Line supplying bottom shield - 604 gpm;

(2) Each line supplying one side shield and intermediate shield combined = $\frac{2580 + 368}{2} = 1474$ gpm per line where the flow to the side shield is doubled to provide for uncertainties in the nuclear analysis.

(3) Line supplying top shield--no minimum flow rate.
Radiation heating is negligible.

The valve sizes corresponding to these flow rates are:

(1) bottom shield: 2-in.-dia Annin globe valve; (2) each side and intermediate shield: 3-in., Annin globe valve; (3) top shield: 1-in. Annin globe valve (existing).

2. Piping Modifications

The calculation of heating rates due to radiation effects has revealed a critical area in the intermediate shields. With the current water supply piping to the side and intermediate shields, there is no method of determining the actual flow split between the two systems. Figure 2 shows the proposed piping modification to measure and control the intermediate shield water flow rates.

The two 2-in.-diameter aluminum lines leading to the intermediate shield will be broken and the upstream side capped. The two 2-in. lines will then be connected to a common tee from a 3 in. line, which will contain a flow meter for intermediate shield flow determination. Orifice flanges will be installed in the 8-in. line to allow for orifice insertion if necessary to obtain the desired flow split. Flow meter and orifice stations will be located at an easily accessible elevation. The 3-in.-line will receive flow from the 8 in. main that supplies the two shields.

Figure 2 - Piping Modification Schematic

3. Trough and Seal Cooling Water Requirements

During installation and checkout of the lower eutectic trough by the contractor, several operational problems became apparent. When the molten eutectic solidifies normally, freezing begins on the surface, progresses to the outside edges, and finally the center solidifies. Due to contraction of the eutectic, large depressions form in the center of the trough and remain after the eutectic is solidified, creating an unacceptable sealing surface. This condition will be helped when the sealing blades enter the eutectic. Also, it has been observed that circulation of cooling water through the trough cooling tubes tends to freeze the eutectic from the inside out, resulting in a smooth sealing surface. The existing trough cooling system is designed so that cooling water can be circulated through the cooling tubes only when total cooling water flow through the shields is occurring. Since eutectic cooling will require approximately 30 minutes of cooling water flow, it is desirable to flow only the amount of water necessary for trough cooling to conserve the process water supply. This is a simple modification for the lower trough and will require an additional remote disconnect and supply line for each side shield for top trough cooling.

The upper trough gate design has an elastomer seal in the area where the top trough halves are mated. This elastomer seal is designed to prevent the molten eutectic from flowing downward into the vertical convolute seal area and depends on a small flow of cooling water that freezes eutectic in the immediate area of the seal while the eutectic is being heated. The existing design also requires total side shield cooling water flow to be circulated in the side shields to provide this seal cooling flow. An additional supply line and solenoid valve on the S-2 test car and corresponding remote control will be necessary for this modification.

B. SHIELD RELIABILITY TEST

1. Space Frame Computer Analyses

Pretest structural analysis of the side shield transfer car is based on a model simulating the configuration and conditions of the actual transfer car. The model has been analyzed on an IBM 7094 Mod. II computer, using a space frame program called STRESS, which was developed by the Department of Engineering of M.I.T. Analysis was started using a structural program called FRAN, which was developed by IBM Corp., but because of large unbalanced joint conditions present in the output at numerous points, the program STRESS was substituted for FRAN.

The output of STRESS consists of forces and moments at the ends of each member, joint displacements, support reactions, member stresses (as specified), plus joint loads as back-substituted from the member forces. The latter constitute a useful static check to evaluate the round-off error that occurs in the computation.

The structure will be analyzed for 25 different conditions with varying loading and restraints to simulate actual operating conditions as shown in Table 3. The stresses and displacements calculated will be used to set the range of strain-measuring devices attached to the structure as indicated in Table 3.

2. Instrumentation Program and Provisioning Requirement

The instrument provisioning, installation, check-out and recording will be handled by contract to E.G. & G. This contract is independent to the negotiated ETS-1 work load. Data obtained will be used for checking the reliability, structural integrity, and alignment of the shield transfer carts and for support of a space frame analysis.

TABLE 3

LOAD AND RESTRAINT CONDITONS

1. D.L.* with wheels locked in position (this condition does not occur but because of model makeup it is necessary to combine this condition with condition 2 to get the force in the wheel mounts).
2. D.L.* with front wheels locked in position and rear wheels free to move parallel to the direction of the car travel.
3. D.L. with front wheels locked in direction parallel to car and flanged wheels, front and rear, restrained perpendicular to car.
4. Repeat condition 3 and add a force perpendicular to car at wheels equivalent to the estimated forces created by the car transversing the curve.
5. 700# cable pull to front of car + condition 3.
6. 700# cable pull to rear of car + condition 3.
7. 700# cable pull to front of car + condition 4.
8. 700# cable pull to rear of car + condition 4.
9. 12,000# cable pull to front of car + condition 4.
10. 12,000# cable pull to rear of car + condition 4.

*D.L. = Dead load of structural and shield
**F.L. = Dead load of structural and shield plus the weight of shield contents when the shield is filled with water.

TABLE 3 (CONT.)

LOAD AND RESTRAINT CONDITONS

11, 12, 13, and 14. Repeat conditions 5 through 8 with cable pull at new center location.

15. Impact created by both front wheels hitting wheel stops at a velocity of 6 in./min. when the shield is filled with water. An estimated loading will be applied to the structure to provide pretest information.

16. Impact created by one wheel of car hitting wheel stop at a velocity of 15 ft/min with D.L. conditon.

17. Repeat condition 1; replace D.L. with F.L.**

18. Repeat condition 2; replace D.L. with F.L.

19. 2000# cable pull to front of car + condition 3 with D.L. replaced by F.L.

20. 2000# cable pull to rear of car + condition 3 with D.L. replaced by F.L.

1 and 22. Repeat condition 11 and 12; replace D.L. with F.L.

23. Wind from front to rear and perpendicular to front of car, plus condition 5 with cable pull adjusted to compensate for wind.

24. Wind perpendicular to side of car plus condition 3, with D.L. replaced by F.L.

*D.L. = Dead load of structure and shield

**F.L. = Dead load of structure and shield plus the weight of shield contents when the shield is filled with water

TABLE 3 (CONT.)

LOAD AND RESTRAINT CONDITIONS

25. Wind from front to rear and perpendicular to front of car, plus condition 3, with D.L. replaced by F.L.

*D.L. = Dead load of structure and shield
**F.L. = Dead load of structure and shield plus the weight of shield contents when the shield is filled with water

The stresses in various structural members will be measured. The flexibility of the framework will be checked by measuring the displacement between the wheels of the cart frame and the shield. Vibration will be checked with accelerometers at two locations. Motive forces will be checked by measuring the strain in the drive cable clevis and the current to the drive motor.

The transducers will be wired to a terminal box mounted on the shield cart. Flexible cables will connect the terminal box to a stationary instrumentation trailer located on the test stand pad. The trailer will house the signal conditioning and recording equipment, which will be calibrated and checked out prior to parking at ETS-1.

Balancing, ranging, calibrating and end-to-end checks will be performed prior to the test.

All channels will be recorded on eight-point recorders and the data will be available immediately after each run.

A measurement requirements list and an instrumentation location drawing are included in the test description, Section III.B.3.

3. Reliability Test Description, ETS-1 Shield

a. Introduction

This section defines the basic test plan to conduct a test program with data-recording capability to sufficiently analyze the alignment, loading, and deformation of the S-1 shield and cart under the following conditions:

(1) Normal operation over the straight and curved sections of the tracks with moving forces applied in accordance with the current design.

(2) Normal operation over the straight and curved sections of the tracks with moving forces applied as near as possible through the center of gravity of the shields and carts (Figure 3).

Relocation of the moving force point on the S-1 cart requires the following temporary modifications of the facility:

(a) Borrowing four guide sheaves from the S-3 duct cover drive system. Two of these sheaves will be modified in height to ensure clearance between the lower trough seal blades on the shield and the top of the guide sheave assembly.

(b) Temporarily installing these guide sheaves on the concrete pad at points shown in Figure 4.

(c) Temporarily adding approximately 20 ft of cable to the S-1 drive system by splicing in a new section of 3/4-in.-diameter cable to the existing cable system.

Temporary modifications required on the S-1 cart (Figure 3) are as follows:

(a) Drilling two sets of holes in the lower flange of the side girders at the intersection of the main cross girder to enable installation of two temporary attachment points for the push-pull struts.

(b) Drilling two holes in the gusset plate beneath the rear concrete beam at the intersection of the center line of the beam and the center line of the cart for installation of the temporary pull point connection plate.

(c) Installing and welding in place of the two push-pull struts will complete the temporary modifications of the cart.

Figure 3 - Proposed Location: S-1 Cart Pulling Force

Figure 4 - Proposed Relocation of Shield S-1 Moving Force for ECRS Reliability Tests

The S-1 shield is one-half of a right circular cylinder that forms one side (180°) of the engine test compartment (ETC). This shield and its companion (S-2) are mounted on carts located on rails and are remotely placed into position. An air-tight seal is required, which is achieved by using a eutectic seal between the top shield and the side shields and between the bottom shield and the side shields.

The S-1 track is curved to allow the S-1 shield to be moved out of the way to its "park" position when installing or removing the engine. The engine is installed by using the engine-installation vehicle (EIV), which approaches the test stand on its own rail system. This rail system intersects the northeastern Shield S-1 cart track rail on the northeast side of the test-stand apron.

b. Test Objectives

The test objectives are as follows:

(1) Travel and Alignment Test (Using Present Design)

(a) Series 1A

Demonstrate the ability of the S-1 shield to acceptably traverse the straight portion of track from Station 3 to the straight-track extreme (parallel with east end of shadow wall) and return to Station 3 with lateral and angular displacement deviation no greater than the 3-sigma limit.

(b) Series 1B

Demonstrate the ability of the S-1 shield to acceptably traverse the curve section of the track and return to Station 3

from Station Park with lateral and angular displacement deviation no greater than the 3-sigma limit.

(c) Series 1C

Determine transfer-car loading and deformation when filled with water and moved into the wheel stops under normal operation.

(2) Travel and Alignment Test with Moving Force
Relocated to S-1 Shield Near Center of Gravity
(Figures 3 and 4)

(a) Series 2A

(Same as for Series 1A.)

(b) Series 2B

(Same as for Series 1B.)

(c) Series 2C

(Same as for Series 1C.)

(d) Repeatability and Reliability Effect

Ascertain the repeatability or reliability effect, or both, by relocating the moving force.

(3) S-2 Travel Loading Tests

Determine stresses in the S-2 transfer-car knee brace during normal operation with original contractor-installed wheel bearings.

Correlate specific stresses in the S-2 car with contractor-installed bearings vs S-1 car stresses with new conventionally lubricated bearings.

(4) Data

Obtain data for analysis of alignment, loading, and deformation of the shields under normal operation.

c. Test Description

(1) Series 1A

Prior to initiation of the test program, all wheel bearings in the S-1 car will be replaced with full-roller, conventionally lubricated bearings. Start with S-2 in the "park" position, S-1 at Position 3 (water-fill position), and S-1 drained. Set up two transits to determine shield alignment. One transit is to be located on the S-2 side of the test-stand center line set parallel to the machined track and will be used to sight a target on S-1 to determine lateral displacement. The other transit is to be set parallel to the test-stand center line perpendicular to the track center line to determine angular displacement of the shield. Move S-1 from Station 3 to a point where the back end of the cart is approximately parallel to the eastern end of the test-stand shadow wall (extension of straight track), and return to Station 3. Measure any lateral and angular displacements from the original sightings. Repeat movement and measurements four additional times. Measurements listed in Table 4 must also be recorded, beginning with initial shield movement from Station 3. The measurements taken during this phase will determine S-1 shield repeatability on movement over straight track and will provide a basis for comparative analysis.

TABLE 4

MEASUREMENT RANGES AND ACCURACIES,
SHIELD RELIABILITY TEST,
S-1 TRANSFER CAR

(Use this list in connection with Figure 5.)

<u>Gage Tag Number</u>	<u>Range</u>	<u>Strain, Microinches/in.</u>
A-1x	0.05 - 10g	
A-1y	0.05 - 10g	
A-1z	0.05 - 10g	
A-2x	0.05 - 10g	
A-2y	0.05 - 10g	
A-2z	0.05 - 10g	
C-1	0 - 20 amps (Drive-motor current)	
D-1A	<u>+0.375 in.</u>	
D-1B	<u>+0.375 in.</u>	
D-2A	<u>+0.375 in.</u>	
D-2B	<u>+0.375 in.</u>	
D-3	<u>+0.75 in.</u>	
D-4	<u>+0.50 in.</u>	
D-5	<u>+0.50 in.</u>	
D-6	<u>+0.50 in.</u>	
D-7	<u>+0.25 in.</u>	
D-8	<u>+0.50 in.</u>	
D-9	<u>+0.50 in.</u>	
D-10	<u>+0.50 in.</u>	
D-11	<u>+0.25 in.</u>	
D-12	<u>+0.25 in.</u>	
S-1	<u>+500 psi</u>	<u>+50 Alum.</u>
S-2	<u>+500 psi</u>	<u>+50 Alum.</u>
S-3	<u>+250 psi</u>	<u>+25 Alum.</u>
S-4	<u>-5,000, +15,000 psi</u>	<u>-500, +1500 Alum.</u>
S-5	<u>-3,000, +12,000 psi</u>	<u>-300, +1200 Alum.</u>
S-6	<u>-3,000, +12,000 psi</u>	<u>-300, +1200 Alum.</u>
S-7	<u>+1,000 psi</u>	<u>+100 Alum.</u>
S-8	<u>+1,000 psi</u>	<u>+100 Alum.</u>
S-9	<u>+2,000 psi</u>	<u>+200 Alum.</u>
S-10	<u>+2,000 psi</u>	<u>+200 Alum.</u>
S-11	<u>+15,000 psi</u>	<u>+1500 Alum.</u>
S-12	<u>+15,000 psi</u>	<u>+1500 Alum.</u>

TABLE 4 (Cont.)

<u>Gage Tag No.</u>	<u>Range</u>	<u>Strain, Microinches/in.</u>
S-13	+15,000 psi	+1500 Alum.
S-14	+15,000 psi	+1500 Alum.
S-15	+15,000 psi	+1500 Alum.
S-16	+15,000 psi	+1500 Alum.
S-17	+15,000 psi	+1500 Alum.
S-18	+15,000 psi	+1500 Alum.
S-19	-6,000, +3,000 psi	-200, +100 St1
S-20	-6,000, +3,000 psi	-200, +100 St1
S-21	-6,000, +3,000 psi	-200, +100 St1
S-22	-6,000, +3,000 psi	-200, +100 St1
S-23	-15,000, +5,000 psi	-1500, +500 Alum.
S-24	-15,000, +5,000 psi	-1500, +500 Alum.

$$E = \frac{\text{Stress}}{\text{Strain}}$$

$$1 \text{ in.} = 1 \times 10^6 \text{ microinches}$$

$$\text{Strain} = \frac{\text{Stress} \times 10^6}{E} = \text{Microinches/in.}$$

$$E (\text{steel}) = 30 \times 10^6$$

$$E (\text{alum.}) = 10 \times 10^6$$

1. Strain measurements shall be within +5%.
2. Displacement measurements shall be within +3%.
3. Tension measurements shall be within 5%.
4. Acceleration measurements shall have a frequency-response range of 1 to 1000 cps.
5. Current measurements shall be within 3%.

(2) Series 1B

Start with S-2 in the "park" position and S-1 at Position 3. Move S-1 toward the "park" position. When the rear of the cart reaches the eastern end of the shadow wall, the car will be stopped at regular intervals. All wheels will be visually monitored to determine wheel behavior and to ensure that the car is not allowed to leave the rails. Upon reaching the "park" position, the car will be moved forward in the same manner until the rear of the car has passed the end of the shadow wall. It will then be moved directly to Station 3 and stopped. Measure any lateral and angular displacement from the original sighting. If the initial cycle is acceptable, the test will be repeated four additional times with a stop only at the "park" station and at Station 3. Transit sightings will be taken and recorded on local cycle at Station 3. Measurements listed in Table 5 will also be recorded, beginning with initial shield movement from Station 3.

(3) Series 1C

With Shield S-1 at Station 3 (drained condition), fill the side shield with water and move to the test position; return the shield to Position 3. Record all starting, moving, and stopping measurements as defined in Table 4. (Measure quantity of water put in and taken out of shield, if possible). Move the side shield (full of water) at a velocity of 6 in./min into the wheel stops at the test-stand end of the rail; be sure that both wheel stops butt at the same time. Record measurements defined in Table 4. Move the side shield empty (drained of water) at 6 in./min into the left wheel stop and record the measurements defined in Table 4.

(4) Series 2A

Same as Series 1A, except with moving force relocated (Figures 3 and 4).

TABLE 5

MEASUREMENT RANGES AND ACCURACIES,
SHIELD RELIABILITY TEST,
S-2 TRANSFER CAR

Work this list with Figure 6.

<u>Gage Tag Number</u>	<u>Range</u>	<u>Strain, Microinches/in.</u>
A-1x	0.05 - 10g	
A-1y	0.05 - 10g	
A-1z	0.05 - 10g	
C-1	0 - 20 amps (drive-motor current)	
S-1	+500 psi	+50
S-2	+500 psi	+50
S-3	+250 psi	+25
S-4	-5,000, +15,000 psi	-500, +1500 Alum.
S-5	-3,000, +12,000 psi	-300, +1200 Alum.
S-6	-3,000, +12,000	-300, +1200 Alum.
S-7	-6,000, +3,000 psi	-200, +100 Stl
S-8	-6,000, +3,000 psi	-200, +100 Stl
S-9	-6,000, +3,000 psi	-200, +100 Stl
S-10	-6,000, +3,000 psi	-200, 100 Stl
S-11	+15,000 psi	+1,500 Alum.
S-12	+15,000 psi	+1,500 Alum.
S-13	+15,000 psi	+1,500 Alum.
S-14	+15,000 psi	+1,500 Alum.
S-15	+15,000 psi	+1,500 Alum.
S-16	+15,000 psi	+1,500 Alum.
S-17	+15,000 psi	+1,500 Alum.
S-18	+15,000 psi	+1,500 Alum.
S-19	-15,000, +5,000 psi	-1,500, +500 Alum.
S-20	-15,000, +5,000 psi	-1,500, +500 Alum.

$$E = \frac{\text{Stress}}{\text{Strain}} \quad 1 \text{ in.} = 1 \times 10^6 \text{ microinches.}$$

$$\text{Strain} = \frac{\text{Stress} \times 10^6}{E} = \text{Microinches/in.}$$

$$E (\text{steel}) = 30 \times 10^6$$

$$E (\text{alum.}) = 10 \times 10^6$$

1. Strain measurements shall be within $\pm 5\%$.
2. Displacement measurements shall be within $\pm 3\%$.
3. Tension measurements shall be within 5% .
4. Acceleration measurements shall have a frequency response range of 1 to 1000 cps.
5. Current measurements shall be within 3% .

(5) Series 2B

Same as Series 1B, except with moving force relocated.

(6) Series 2C

Same as Series 1C, except with moving force relocated. Performance of the test involving movement into the left wheel stop will not be performed in this configuration.

(7) S-2 Travel Loading Test

Starting with S-2 in the "park" position, S-2 will be moved forward at 15 ft/min to Station 1 and stopped. S-2 will then be moved forward at 6 in./min to Station 3 and filled. S-2 will then be moved to the test position against the wheel stops at 6 in./min. S-2 will be moved back to Position 3 and drained and then back to Position 1 at 6 in./min. S-2 will then be moved back to the "park" position at a 15-ft/min travel speed. Data will be recorded during all shield movements.

(8) Instrumentation

Measurements recorded will be those listed in Tables 4, and 5, in conjunction with the transit sightings. Transducer locations are identified in Figures 5 and 6.

Chart speeds will be correlated with the shield distance traveled, and recorders will be turned off after the shield stop circuit is energized. The shield stop signal will also be recorded.

Figure 5 - Location of Instrumentation for S-1 Side Shield Transfer Car Reliability Tests

P L A N
S-2

E L E V A T I O N

R E A R V I E W

SECTION A-A

SECTION B-B

SECTION C-C
SECTION C-C

LEGEND
S = STRAIN GAUGE

DETAIL - 1
DETAIL - 2 (OPP)

Figure 6 - Location of Instrumentation for S-2 Side Shield Transfer Car Reliability Tests

(9) Data

Data obtained will be reduced and analyzed to determine deviation from the 3-sigma limits. Data obtained from Test Series IA will be used for comparative analysis.

d. Test Limits

The test will be terminated if, in the opinion of the test conductor, the cart is not able to negotiate the curved section of track, or if further testing will damage the shield.

The test will be delayed or interrupted if a failure occurs in the control or instrumentation system pending resolution of the problem.

During test operations, several critical strain-gage parameters will be monitored. The test will be terminated if gages indicate that stresses are approaching the elastic limit of the material.

e. Safety Requirements

All phases of this test will be in compliance with NTO-A-0022, NTO Health and Safety Manual, where applicable.

The exclusion area will be established by the test conductor, in coordination with the Facility Operations Shift Supervisor (FOSS), during various portions of the test. Specifically, personnel will be restricted during shield movement. The exclusion area will be monitored by operations personnel.

f. Test Schedule

Figure 7, Shield Reliability Test, shows the proposed test schedule.

g. Status Board

No status board required; however, all facility operations will be coordinated through the FOSS.

h. Product Assurance

Product-assurance personnel will follow the conduct of this test and will maintain a discrepancy log of all systems that are activated during testing.

i. Data Requirements

Data requirements are listed in Tables 4 and 5. Only those instruments and controls that are displayed or which require recording are listed. See Paragraph c,(3) for exceptions.

Specific operation of the oscillograph charts and strip recorders will be at the direction of the test conductor.

Television coverage will be required for test observation and surveillance by operating personnel located in the CP and will be on an as-required basis at the direction of the test conductor. The following cameras will be used primarily, although all cameras will be operational and ready for substitution:

<u>Camera Position No.</u>	<u>Location</u>	<u>Observation</u>
1	North side of ditch	S-l movement
3	West side of ditch	Shield movement, mating
5	Northeast end of pad	S-l movement
9	3848-ft level - hot side of shadow wall.	Shield mating

Still photographic coverage will be continually available during test performance. Shots will be taken at the request of the test conductor.

The ETS-1 communications system will be operational.

j. Operational Requirements

(1) Test Direction

Primary operation and test direction will be from the test-stand pad. The test conductor will direct the test activity from the pad, and the shield will be operated primarily with the local control panels.

(2) Control Point

The following consoles will be operational and will be manned during the test period:

Remote-installation console
Lead facility engineer console

k. Report Requirements

Any anomalies, failures, and necessary modifications will be reported in accordance with NTO documentation procedures.

A formal report will be prepared that covers this test plan.

Figure 7 - Shield Reliability Test Schedule

C. MECHANICAL, SEAL AND LEAK TEST DESCRIPTION

1. Introduction

a. General

This section defines the basic test plan for mechanical, seal and leak testing of the engine test compartment (ETC) at ETS-1, NRDS, as well as providing schedules and listing the current instrumentation. The purpose of this test program is to demonstrate that the ETC meets the design, functional, operational, and safety requirements for the planned engine test operation.

b. Engine-Test-Compartment Description

The ETC at ETS-1 has three basic functions: (1) to provide a safe, air- or oxygen-free, operating environment for the engine; (2) to permit reduction in ambient atmospheric pressure around the engine in order to partially simulate the space environment; and (3) to provide radiation shielding for compliance with the requirements of safety, for economy of material selection elsewhere in the facility, and for optimum use of ETS-1 and adjacent NRDS areas.

The ETC consists basically of six components. Top and bottom shields, when mated with two halves of a right circular cylinder, hereafter called side shields, form a closed cylindrical container. A half-doughnut-shaped intermediate shield is attached to each of the side shields, which mate with an engine shield located at the upper end of the thrust chamber when the two side shields are in the test position. The bottom shield contains a nozzle penetration device for the NERVA exhaust-system duct. This area can be covered by a portable duct cover shield when the side shields are in the "parked" position. The side shields and the duct cover shield are remotely

placed into position. Penetrations into the compartment for the fuel line, purge lines, thrust-measuring components, electrical lines, and instrumentation leads are in the top shield. An air-tight seal is required and is achieved by using a eutectic seal between the top shield and the side shields and between the bottom shield and the side shields. Sealing between the vertical faces of the side shields is achieved by pressurizing a convolute metal-to-metal seal system with inert gas. Each of these compartment seals is a double seal with a buffer zone pressurized by inert gas between the seals.

2. Test Objectives

The test objectives are as follows:

a. ETC Makeup, Mechanical and Seal Test

1. Mate the shields by using procedures applicable to engine test operations in preparation for leak testing.
2. Optimize operational procedures.
3. Determine the seal leakage rates at ambient compartment pressure and determine the percentage of leakage external to the compartment.
4. Provide operator training.

b. Shield Water-Flow Tests

1. Determine the flow characteristics of each shield cooling-water system, including system flow-rate calibrations for future reference.
2. Develop optimum operating procedures.
3. Provide operator training.

c. ETC Leak Test

1. Determine the design-condition seal leakage rates with the ETC evacuated.
2. Determine the adequacy of the GN₂ system to handle seal pressure and to buffer the gas flows encountered.
3. Determine optimum seal pressures and buffer-zone pressures.
4. Test for leakage of air into the evacuated ETC.

d. ETC Seal Malfunction Test

1. Determine the minimum number of heaters required to melt the eutectic during a specified period of time.
2. Evaluate the use of steam and hot gas flowing through the cooling coils for emergency melting of the eutectic metal.
3. Determine the methods and the force required for the manual release of the latching mechanism.
4. Develop optimum seal-malfunction operating procedures.
5. Provide operator training.

3. Test Description

a. ETC Makeup, Mechanical and Seal Test

During this portion of the test, the shields will be moved into position, filled with water, mated, and the eutectic seals will be made up. Each operation will be closely scrutinized visually to determine the performance of all mechanical devices, to check for mechanical interfaces, and to check for design deficiencies.

Figure 8 is a simplified flow diagram of the GN₂ system showing the installation of test gas flowmeters. All seals and buffer zones will be pressurized to design conditions with the engine compartment at ambient pressure, and the leakage flow rates will be measured. Also, the amount of leakage flow that goes into the compartment will be measured.

b. Shield Water-Flow Tests

Figure 9 is a simplified flow diagram of the shield cooling-water system and the facility process-water system as modified for this test. Each shield cooling-water system will be made to flow through the maximum flow range attainable, and system calibrations of inlet and discharge line pressures vs flow rate will be established. From these calibrations, each system remote shutoff valve will be adjusted to provide the design cooling-water flow rate. Transfer-car piping will be modified and tests will be run to determine the intermediate-shield water flow rates, and if necessary flow-balance orifices will be installed to obtain the desired split of water flow between the side shield and intermediate shield. During the side-shield water flow tests, pressure measurements in each of the extrusion section will be recorded to determine flow distribution through the shield. A combined-shield water flow test will be conducted to verify valve settings under combined flow conditions and also to verify calibrations by comparing combined flows with the measured total flow.

c. ETC Leak Test

With the use of mechanical vacuum pumps, the ETC will be evacuated to as low a pressure as is attainable (pressure not to be less than 1 psia). With all seals and buffer zones pressurized to design conditions, all pressure and purge flow rates will be measured. Approximate leakage flow rates into the compartment will be obtained by measuring the vacuum-pump exhaust flow rates.

Figure 8 - Shield GN₂ System Flow Diagram:
ETC Mechanical, Seal, and Leak Test

With the ETC evacuated, the effects on leakage rate of increasing and decreasing convolute-seal pressure will be evaluated. The effects of increasing and decreasing buffer purge pressures will also be evaluated, and optimum seal and buffer purge operating pressures will be established. Any areas that exhibit unusually high leakage rates will be thoroughly examined to determine the cause.

With the ETC evacuated and all seals and buffer purges operating at their optimum pressures, a test to determine leakage of outside air into the compartment will be performed. With a helium leak detector connected to the vacuum-pump inlet, helium will be sprayed along all the sealing surfaces of the shields, with particular attention given to the areas where the vertical convolute seals mate with the top and bottom eutectic seals. After all the seals have been tested, helium will be sprayed into the duct to determine the effectiveness of the temporary bottom-shield plug.

After completion of ETC leak testing, the vacuum-pump isolation valves will be closed and data on pressure rise vs time will be recorded. From these data, the rate of leakage into the compartment will be calculated. This calculation will be compared with data obtained by measuring vacuum-pump exhaust flow, and the comparison will be evaluated.

d. ETC Seal Malfunction Test

With the side shields mated, a test series will be conducted on the top and bottom eutectic seals to determine if the eutectic can be melted first with one, and then with two, of the three heaters inoperative. Each seal will be tested to determine the ability of hot gas or steam circulated through the cooling coils to melt the eutectic in the event of total heater or electrical failure.

A test to determine the force required and the optimum method to manually release the side-shield latching mechanism will be performed.

From the ETC seal malfunction tests, optimum emergency operating procedures will be developed to ensure the capability of separating the shields in the event of pneumatic and electrical failure.

After the eutectic and convolute seals have been broken and re-established, the ETC seal leakage test will be repeated at optimum operating conditions, if time and schedule permit, to test the repeatability of the sealing action.

4. Test Limits

During water flow tests, internal shield pressure will not exceed 2 psig. Shield pressures will be monitored in the water discharge manifold as follows (numerical designations indicate pressure parameter numbers).

- a. Top shield - 50-PT-272
- b. Bottom shield - 50-PT-263
- c. Side shield S_1 - 50-PT-279
- d. Side shield S_2 - 50-PT-289

During ETC leak testing, the ETC will not be evacuated to less than 1 psia. ETC pressures will be monitored with 50-PT-292 and 50-PT-293.

ETC leak tests will not be initiated if the GN_2 storage pressure (V-3201, V-3202, V-3203) is less than 1100 psig.

Water flow tests will not be initiated if the process-water storage level is below 20 ft, and the level will not be allowed to drop below 10 ft (to maintain a sufficient quantity for fire protection).

5. Safety Requirements

All phases of this test will be in compliance with NTO-A-0022, NTO Health and Safety Manual, were applicable.

The exclusion area will be established by the test conductor, in coordination with the facility operations shift supervisor, during various portions of the test. Specifically, personnel will be restricted during shield movement. The exclusion area will be monitored by operations personnel.

6. Test Schedule

Figure 10 is the proposed test schedule for the ETC mechanical, seal and leak test.

7. Status Board

No status board is required; however, all facility operations will be coordinated through the FOSS.

8. Product Assurance

Product Assurance personnel will follow the conduct of ETC checkout and will maintain a discrepancy log of all systems that are actuated during testing.

9. Data Requirements

Data requirements are listed in Table 6, Mechanical, Seal and Leak Test Instrumentation List. Only those instruments and controls that are displayed or which require recording are listed in Table 6.

Figure 10 - ETS-1 Detailed Activity Schedule
(Sheet 2 of 2)

TABLE 6

MECHANICAL, SEAL, AND LEAK TEST INSTRUMENTATION LIST

<u>Tag No.</u>	<u>Parameter Title</u>	<u>Meas. Range</u>
50TE 178	S1 through Temp Ind	32-475°F
50TE 179	S1 through Temp Ind	32-475°F
50TE 180	S1 through Temp Ind	32-475°F
50TE 181	S1 through Temp Ind	32-475°F
50TE 182	S1 through Temp Ind	32-475°F
50TE 183	S1 through Temp Ind	32-475°F
50TE 193	S2 in H ₂ O Ind	32-251°F
50TE 235	S2 through Temp Ind	32-475°F
50TE 236	S2 through Temp Ind	32-475°F
50TE 237	S2 through Temp Ind	32-475°F
50TE 238	S2 through Temp	32-475°F
50TE 239	S2 through Temp	32-475°F
50TE 250	Top Shield Water In	32-251°F
50TE 274	BTM Shld H ₂ O Inlet Ind	32-251°F
50TE 295	BTM through Temp Ind.	32-475°F
50TE 296	BTM through Temp Ind	32-475°F
50TE 297	BTM through Temp Ind	32-475°F
50TE 298	BTM through Temp Ind	32-475°F
50TE 299	BTM through Temp Ind	32-475°F
50TE 300	BTM through Temp Ind	32-475°F
50TE 301	BTM through Temp Ind	32-475°F
50TE 302	BTM through Temp Ind	32-475°F
50TE 303	S1 H ₂ O Inlet Temp Ind	32-251°F
50PT 256	Top Shld Blws Vac (Chg. Xducer)	0-15 psia
50PT 258	S2 BTM Seal Bld PGE	0-15 psig
50PT 259	S1 Side Seal Press	0-10 psig
50PT 260	S1 Side + Btm Seal Purge	0-5 psig
50PT 262	BTM Shld H ₂ O in Ind	0-25 psig
50PT 263	BTM Shld H ₂ O out Ind	0-10 psig

Table 6 (cont.)

<u>Tag No.</u>	<u>Parameter Title</u>	<u>Meas. Range</u>
50PT 271	Top Shld H ₂ O In Ind	0-50 psig
50PT 272	Top Shld H ₂ O Out Ind	0-10 psig
50PT 278	S1 Inlet H ₂ O Press	0-25 psig
50PT 279	S1 Outlet H ₂ O Press	0-10 psig
50PT 284	S2 Inlet H ₂ O Press	0-25 psig
50PT 285	S2 Outlet H ₂ O Press	0-10 psig
50FE 30	Water Flow Meter ΔP	0-10 psig
50PT 292	BTM Chamber Press Ind	0-10 psia
50PT 293	BTM Chmbr Press Ind (Change Xducer)	0-20 psia
50PT 340	TP Shld Blws Press Ind	0-25 psig
50PT 342	BTM Shld Bld PGE Ind	0-5 psig
50PT 384	Top Shld Bld - Gsk PGE	0-5 psig
50AT 01	S1/S2 Top Outboard Alignment	0-6-in.
50AT 02	S1/S2 Top Inboard Alignment	0-6-in.
50AT 03	S1/S2 Bottom Outboard Alignment	0-6-in.
50AT 04	S1/S2 Bottom Inboard Alignment	0-6-in.
50AT 05	S1/S5 Alignment	0-6-in.
50AT 06	S2/S5 Alignment	0-6-in.
* 50TE 290	Bottom through Heater Temp	32-475°F
* 50TE 292	Bottom through Heater Temp	32-475°F
* 50TE 294	Bottom through Heater Temp	32-475°F
* 50TE 171	S1 through Heater Temp	32-475°F
* 50TE 172	S1 through Heater Temp	32-475°F
* 50TE 173	S1 through Heater Temp	32-475°F
* 50TE 228	S2 through Heater Temp	32-475°F
* 50TE 229	S2 through Heater Temp	32-475°F
* 50TE 230	S2 through Heater Temp	32-475°F
* 50TE 284	Bottom through Heater Temp	32-475°F

*These channels are normally control channels only, and special arrangements will be necessary for data acquisition.

Table 6 (cont.)

<u>Tag No.</u>	<u>Parameter Title</u>	<u>Meas. Range</u>
* 50TE 286	Bottom through Heater Temp	32-475°F
* 50TE 288	Bottom through Heater Temp	32-475°F
H-5001	Bottom through Heater Trace	Event
H-5002	Bottom through Heater Trace	Event
H-5003	Bottom through Heater Trace	Event
H-5004	Bottom through Heater Trace	Event
H-5005	Bottom through Heater Trace	Event
H-5006	Bottom through Heater Trace	Event
H-5007	S-1 Top through Heater Trace	Event
H-5008	S-1 Top through Heater Trace	Event
H-5009	S-1 Top through Heater Trace	Event
H-5010	S-2 Top through Heater Trace	Event
H-5011	S-2 Top through Heater Trace	Event
H-5012	S-2 Top through Heater Trace	Event

*These channels are normally control channels only, and special arrangements will be necessary for data acquisition.

Specific operation of the oscillograph charts and strip recorders will be at the direction of the test conductor.

Television coverage will be required for test observation and surveillance by operating personnel located at the control point (CP). Television coverage will be on an as-required basis at the discretion of the test conductor. The following cameras will be used primarily, although all cameras will be operational and capable of ready substitution:

<u>Camera Position No.</u>	<u>Location</u>	<u>Observation</u>
1	North side of ditch	S-1 movement
2	South side of ditch	S-2, S-3 movement
3	West side of ditch	Shield movement, mating
4	SW end of pad	S-2, S-3 movement
5	NE end of pad	S-1
9	3848-ft level, hot side of shadow wall	Shield mating

The ETS-1 communications system will be operational.

10. Operational Requirements

a. Test Direction

The test will be primarily operative and directed from the test-stand pad. The test conductor will direct the test activity from the pad, and shield will be operated primarily with the local control panels. Operation of the vacuum pumps and readout of flowmeters will be performed locally.

b. Control Point

The following consoles will be operational and will be manned during the test period:

Gas fill and service console
Remote-installation console
Lead facility engineer
Remote recorder operator
TVC operator

c. Facility Systems

The following systems and their associated equipment will be operational for conduct of the ETC mechanical, seal, and leak test:

Gaseous-nitrogen distribution system
Process-water system
ETC shields

D. REMOTE OPERATION QUALIFICATION TEST

1. Objective

The objective of the remote operation qualification test is to demonstrate the satisfactory remote operation of the complete system.

2. Procedure

With the side shield car in park position the system will be run through a complete cycle remotely.

This operation will include moving the car to the connection position, connecting, moving to test position, sealing, flowing gas and water, disconnecting, and returning to the park position.

If the system performs satisfactorily the engine test compartment will be ready to support the engine tests.

3. Possible Alternative Approaches if Problems Occur

If problems with remote control occur the following alternatives will be investigated:

a. Elimination of all local controls to simplify the control systems and to increase reliability.

b. Changing of binary (on-off) controls or heaters to analog-type controls.

c. Changing of binary closed-loop controls to open-loop manual-type operation.

E. OPERATIONAL RELIABILITY STUDY

1. Wheel-Bearing Problems

a. Radiation Environment Effects

The wheel bearings on the radiation shield transport cart wheels were originally lubricated with a special application of baked-on molybdenum disulfide. A study of the predicted radiation environment substantiates that an industrial bearing grease can be used for lubrication. Potentially, this grease may disintegrate due to radiation or radiation-heating effects. The Shielding Analysis group of NRO calculated an expected maximum radiation level of less than 5×10^5 rad/hr at this position on the cart. Vendor data indicate that industrial greases, such as those produced by Chevron, will perform satisfactorily after a 10^{10} rad dose. Therefore, no problems related to degradation of a standard industrial grease are expected. Also no significant radiation-heating is expected. Since the grease film is thin, the wheels will act as a heat sink.

A complete set of needle-type roller bearings have been procured and are on site. These bearings will be used with conventional grease lubricants.

b. Bearing Side-Loading Effects

The bearings on the transfer cars are affected by side loads by a change in vertical loading. The side thrust is taken out by thrust washers located on either side of the hub of the wheel. Therefore, the existing wheel bearings do not resist lateral loads directly, and the current design is satisfactory. Figure 11, shows the design of the existing wheel bearings.

Figure 11 - Current Design of the Existing Wheel Bearings

2. S-2 Car Movement

a. Interference with Engine Installation Vehicle

Since there may be difficulty in moving the side shields, the best way to increase shield reliability is to eliminate movement of the shields. A study has indicated the feasibility of leaving side shield S-2 in place with some modification of the engine installation vehicle (EIV) and of changing the accompanying engine installation procedures.

With the existing design, there is an interference between the holding lugs of the EIV (EIV horseshoe to engine shield) as shown in Figure 12. The holding lugs can be modified to enable clearance of the EIV during engine installation.

Figure 13 is a drawing of the proposed modification that would enable use of the EIV with the S-2 shield left in place. The vertical blocks that cause the interference (Figure 12) are hinged and operated by pneumatic cylinders. The blocks are tipped back as soon as the engine is within 2 or 3 feet of center position. The drawing includes the air flow system to the pneumatic cylinders.

The estimated schedule to accomplish this modification is 6 weeks design and drawing preparation, and 6 weeks fabrication time. Allowing 2 weeks for preparation of procurement bids and 1 week for load testing, the modified hardware could be shipped 15 weeks after design initiation date. The modified hardware probably can be installed on the EIV in approximately one week.

Although there is no other interference if the S-2 is left in place, there is a chance of damaging the shield or engine during installation or removal if the following operating procedures are not followed.

THIS PLAN VIEW SCHEMATIC OF THE INTERMEDIATE RADIATION SHIELD (ATTACHED TO SIDE SHIELD S-2) SHOWS THE EIV INTERFERENCE WITH THE INTERMEDIATE SHIELD WHEN THE EIV IS IN THE ENGINE-MATING POSITION AND THE S-2 SHIELD IS LEFT IN POSITION

Figure 12 - EIV Interference with S-2 Side Shield

Figure 13 - Proposed Modification Enabling use of the EIV with S-2 Shield Left in Test Position

(1) With a minimum of 3/4-in.-clearance, the engine must be precisely centered during installation in the S-2 shield.

(2) The lateral/azimuth carriage must be retracted when the EIV/Engine is moved into position.

(3) Both manipulators must be retracted and out of the way during engine positioning.

(4) There must be no over-extension of the lateral/azimuth carriage when it is used to center the engine prior to raising the engine into place.

During emergency engine removal, when the manipulators must be used behind the engine to remove the TSA/UTS floating-nut arrangement, there may be insufficient clearance to accomplish this task effectively. To prove that this operation can be accomplished will require testing at NRDS with the WEMU and SETS. It will be necessary to keep the shield filled with water if it is left in place to prevent the shield from leaning toward the engine.

Finally, if it is decided to move the shield, the minimum S-2 shield movement with unmodified EIV hardware is 30 in.

b. Effect of Radiation Dose Rate

If radiation shield S-2 is left in place, it will not be possible to use the S-3 shield in the current configuration to cover the duct opening due to a geometrical interference between the S-2 and S-3 shield. If the S-3 shield is not used (the duct opening is unshielded), the radiation levels in the engine compartment area will be much higher than if the S-3 shield were used. The radiation from the duct is the major contributor of radiation dosage to the engine compartment area.

3. Alignment Problems

a. Wheel Guides

Positioning wheel guides (Figure 14) will be required if the reliability test proves that the shield will not reliably return to test position. These guides will force the flangeless wheels back to a fixed position, ensuring that the shields will always return to the test position with an acceptable lateral offset.

The wheel guides (Figure 15) are designed to ensure that the flangeless wheels will follow the curved track on the S-1 shield only. The guides will force the flangeless wheel to slip laterally. The requirement for the wheel guides will be determined as soon as possible after beneficial occupancy date and, if required, the guides will be installed before the reliability test.

b. Car Reinforcement

There are no data indicating that the transfer cars will require reinforcement. However, if the reliability test indicates a need for added strength, this can be readily accomplished. When the problem areas are defined, a detailed design will be required that includes the change in flexibility of the transfer car, because this change will affect the existing alignment of the shields.

c. Modification of Rails

If it is determined that the side shield mate-up can be improved by eliminating the curved track, there are several feasible methods of straightening the tracks.

Figure 14 - Positioning Wheel Guides Plan: Sections and Details of Side Shield Transfer Cars

SECTION A A

SECTION BB
SECTION CC (SIMILAR)

SECTION DD
SECTION E-E (SIMILAR)

SECTION FF

SECTION G G

DETAIL - 1
DETAIL - 2 (SIMILAR)
DETAIL - 3 (SIMILAR)

DETAIL - 4
DETAIL 5 (SIMILAR)

Figure 15 - Wheel Guides Plan: Sections and Details of S-2 Side Shield Transfer Car

The most feasible method would be to leave the EIV tracks in their present location and run the S-1 cart tracks out straight until the curved EIV tracks clear the S-1 cart tracks (Figure 16). This proposal would require a considerable amount of concrete work, as well as a new cable and cable drum on the drive system, which could be a long lead-time item. Another disadvantage would be the great distance required to move the S-1 side shield to clear the EIV tracks.

The second approach would be to run the S-1 cart tracks straight out and to bend the EIV tracks to the north (Figure 17). A minimum of 90 ft of straight track will be required at the test stand to install the engine. The EIV will negotiate a 250-ft minimum radius, but a 300 ft radius is desirable. A minimum of 70 ft of straight track between points of tangency is required if the EIV has to negotiate inverse curves. Figure 17 (showing no straight tangents between inverse curve and curves are 250-ft radii) shows only the general type of relocation and not the exact distance of track relocation. Increasing the curvature to 300 ft and inserting the minimum tangent length would require a longer relocation length than is indicated.

The third proposal would be to run the S-1 cart track straight out and to bend the EIV tracks to the south (Figure 18). The same minimum curvature and tangent distance for the EIV tracks as those in the preceding method apply to this proposal. This approach would require the least amount of relocation but would require the S-1 cart-drive system to be moved to the south side of the cart.

Relocation of the pull point of the S-1 cart relative to the center of gravity could be accomplished if this would eliminate undesirable stresses in the cart. However, this modification would require some concrete work as well as a means of crossing the EIV tracks with the cable. The estimated time required for a selected approach is 2 months.

Figure 16 - ETS-1 Track Relocation: First Alternative

Figure 17 - ETS-1 Track Relocation: Second Alternative

Figure 18 - ETS-1 Track Relocation: Third Alternative

A variation of the second proposal may be practicable if it is decided to leave the S-2 side shield in place. This could be achieved by using the present S-1 tracks for the S-3 shield. New S-1 tracks would then be run straight out, and the EIV tracks would be curved to the left.

Another possible approach is to use the EIV as the means of locomotion for the S-1 side shield to eliminate the side pull point or the moving of the cable pull to the center of gravity. This means of locomotion could be accomplished in the second and third approaches by leaving the present EIV tracks and the new addition in place and installing a switch at each end where the tracks come together. In the first approach new EIV tracks would have to be installed in the center of the new S-1 cart tracks, with a curvature at the end to mate with the existing EIV tracks.

d. Articulating Trucks

Two articulating truck concepts were developed (Figure 19). The principal of the articulating truck is that the double wheels will rotate as required to follow the curved section of the track. The flangeless wheels will have to be replaced with flanged wheels or the existing wheels could have flanges installed. This concept will require a detailed design and considerable modification of the transfer car.

4. Seal Areas

a. Inflatable Elastomer Seals

Proposed methods of replacing the side shield convolute seals and the top and bottom eutectic troughs with inflatable elastomer seals are presented in Figures 20 and 21. These seals should enable a positive seal with approximately 20 psig inflatable pressure. The collapsible property of these seals will enable mating without seal interference.

SIDE VIEW

SECTION A-A

CASE I

SECTION B-B

SECTION C-C

SIDE VIEW

- NOTE
- 1 KINGPIN MATERIAL IS ALUMINUM; STEEL TO BE USED IF RADIATION REQUIREMENTS ARE LOWERED
 - 2 WHEEL GUIDES OR FLANGES WILL BE REQUIRED FOR FLANGELESS WHEELS & RAIL PROFS WILL REQUIRE MODIFICATION TO ALLOW FLANGES TO ROLL THRU FROG.

CASE II

Figure 19 - Articulated Front Truck Concept for S-1 Side Shield Transfer Car

Figure 20 - Proposed Method of Replacing the Side Shield Convolute Seals

Figure 21 - Proposed Method of Replacing the Top and Bottom Eutectic Troughs

The following companies have been consulted concerning seal fabrication and materials: B. F. Goodrich, Akron, Ohio; Stalwart Rubber Co., Bedford, Ohio; Kirkhill Rubber Co., Brea, California; and Los Angeles Standard Rubber Co., Huntington Park, California. The Stalwart Rubber Co. indicated it could not fabricate the seals and suggested the Kirkhill Rubber Co. The Kirkhill Co. indicated that this seal was considerably larger than its standard product and was not too interested in the job. B. F. Goodrich showed an interest in fabricating the seals but believes there will be material problems. The Los Angeles Standard Rubber Company indicated it had fabricated similar seals for the General Electric Co. to be used on the rear face of the Hanford Reactor. Evidently, General Electric has made extensive studies of radiation damage to high-temperature elastomers. The material used for the Hanford seals was a vinyl silicone polymer produced by General Electric and classified as the 555 series of silastics. This material has retained 50% elongation or better after being subjected to 1×10^8 roentgen. Data will be obtained from personnel at the Hanford Reactor concerning the radiation properties of this material.

The Los Angeles Standard Rubber Co. indicated there would be no major problems in fabricating straight sections or circular seals of the required size. It will also be possible for this company to obtain the 555 series of silastics or any other required material. Approximately 1 month will be required for tooling the die and an additional month for fabrication.

The side shield strip seals can be provided with end plugs for capping the ends of the straight sections. Aluminum tubing inflating lines can be provided as required.

The Los Angeles Standard Rubber Co. believes the seals will have to be reinforced with a temperature-resistant fabric material and suggested using either Dacron or high-temperature nylon. Figure 22 and Table 7 indicates that Dacron has better resistance to radiation than nylon.

Figure 22 - Radiation-Induced Change in Strength of Synthetic Fabrics (Cotton Shown for Comparison): Exposures in Air Less than 95°F

TABLE 7

CHANGE IN STRENGTH OF TIRE CORDS WITH
GAMMA IRRADIATION AT ROOM TEMPERATURE

Type Cord	Atm.	Tensile strength in pounds for given dose in megarads					Change in Strength after 10×10^8 rads
		0	0.09	0.9	2.6	8.7	
Nylon 66	Air		23.7	19.7	16.2	12.7	-59
		26.5					
	Vac		20.9	25.0	20.6	23.1	-15
Nylon 6	Air		21.1	20.5	17.9	10.7	-62
		24.2					
	Vac		22.4	21.0	22.4	21.4	-13
Nylon 66 HT	Air		22.3	20.2	17.2	11.7	-57
		23.6					
	Vac		23.0	22.1	20.2	21.4	-10
Dacron	Air		37.3	33.6	34.7	31.7	-17
		35.0					
	Vac		35.7	36.4	35.1	37.2	+7
Orlon	Air		12.8	11.8	11.4	10.8	-20
		13.2					
	Vac		13.0	12.2	11.4	11.9	-11

IV. ACTIVE ENGINEERING CHANGE REQUESTS, ACTUAL AND POTENTIAL PROBLEMS

Engineering Change Requests have been prepared or are currently being prepared that will enable implementation immediately after ETC B.O.D. Examples of these changes are as follows:

A. ENGINEERING CHANGE REQUEST NO. 379

The GN_2 supply line to the S-2 shield is a 1-1/2-in.-line several hundred feet long. All of the buffer gas to the convolute seals, plus buffer gas to other areas, is supplied through this line. Preliminary calculations indicate that the maximum flow attainable through this line is marginal, based on expected convolute seal leakage. The remote disconnect in the line was 1/2-in.-line size and severely restricted the flow. Because of long material lead time, 1-1/2-in. disconnects were purchased, and brackets were fabricated. The disconnects are now ready for installation.

B. ENGINEERING CHANGE REQUEST NO. 516

The ETC latching mechanism, when operated in the opening cycle, slammed against the unbuffered pneumatic cylinders violently but operated satisfactorily in the closing cycle. A 4-way solenoid valve with dual exhaust ports was obtained, and the exhaust port for the opening cycle will be orificed to slow the opening cycle and to prevent cylinder damage. Concurrently, a hand-operated bleed valve will be installed to vent the closing side of the cylinder in the event pneumatic, electrical, or valve failure requires manual unlatching of the ETC. The bleed valve will be mounted on the back of S-1 to be readily operable by the EIV or personnel with minimum exposure time.

C. ENGINEERING CHANGE REQUEST NO. 392

When the side shields are drained of water, there are 22 compartments, 1-ft high, on the bottom of each shield which cannot be drained. Within each of these compartments is a boron and a lead shield with a 3/8-in.-gap to the shield exterior. In cold weather, freezing could occur that would cause buckling of the boron or lead shielding. A drain header was designed for installation with a drain valve located at the back of the transfer car. This component was also designed to serve as an emergency drain for the S-1 shield if a failure occurs and prevents normal drain-valve opening.

D. ENGINEERING CHANGE REQUEST NO. 316

When the side shields are moved away from the test stand and the water-fill connectors are separated, large quantities of water remain in the fill pipe that are emptied on the pad area. A fill and drain line header was designed to provide draining of the fill pipes from the cold side of the shadow wall prior to shield movement. An alternate method of circulating water through the closed shields for protection against freezing was also incorporated in the design.

Quality Control reports indicate that the as-manufactured lower seal ring was slightly undersized. As a result, when the heated lower trough is raised to engage the lower seal ring, the fit between the inner edge of the expanded trough and the cold seal ring is extremely tight. An ECR is being prepared to provide a trough position indication on the RIC console and controls to stop the lower trough when the seal blade enters the eutectic. The blade can then be allowed to heat and expand prior to further raising of the trough.

V. RADIATION LEVELS AT ETS-1 AFTER A NORMAL XE TEST

Expected radiation levels have a significant effect on the planning of postoperational procedures. Because of time limitations, the information obtained in this study was limited to identifying and determining the approximate magnitude of problem areas. Comparisons have been made with experimental data, including those obtained in the NRX/EST test where feasible, and generally show that the results are reasonable. An internal consistency regarding items such as run time does not exist in this section, since extensive use has been made of data generated when the XE test objectives were 300 sec.

A. ENGINE ON THE TEST STAND

The radiation levels at ETS-1 24 hr after the 300-sec XE test are shown in Figure 23. The variation of gamma dose rate with distance from the axis of the engine is shown with and without the ETC shielding in place. The time variation of the radiation level just outside the ETC is shown in Figure 24. For example, Figure 24 indicates a dose of 440 rem/hr 30 days after shutdown. The time dependence of other points on Figure 23 will be similar. Runs of longer duration will affect the shape of the Figure 24 curve slightly, but the data are adequate to estimate the environment. The distribution of fast neutron flux 24 hr after a 15-min test is shown in Figure 25.

B. ENGINE REMOVED

Radiation levels in the ETC after the engine is removed will be dominated by the activation and contamination of the NERVA Exhaust System (NES). The predicted radiation levels are dependent on the quantity and distribution of fission-product contamination. The dose rate from a uniform deposition of 0.5% of the total fission-product inventory is about 20 R/hr on the test pad 24 hr after a 300-sec firing. The time variation of this quantity is shown in Figure 24. The dose rate from neutron-induced activation of the NES is shown in Figure 26. Evidently the dose rate from this source is much

Figure 23 - ETS-1 Radiation Environment after Shutdown

Figure 24 - Radiation Level on the Outer Surface of the Side Shields

24 HOURS AFTER A 15-MINUTE XE TEST

Figure 25 - Radial Distribution of Fast Neutron Flux

Figure 26 - Neutron Activation of the ETS-1 Duct from Operation of the X-Engine

lower than that from the assumed distribution of fission products. Without shielding, personnel access to the test stand is extremely limited. The addition of shielding equivalent to 6 in. of lead, however, will provide access conditions similar to those attainable with the installation of the duct cover shield.

C. ETC ACTIVATION

With the installation of the duct cover shield or its equivalent the major source of radiation on the test pad is the ETC shields. Radiation from these shields is shown in Figures 27 and 28 for the intermediate and side shields, respectively. These radiation levels should be expected wherever the shields are located, and, if one is in place with the NES shielded, access to the test-pad area will be limited.

Figure 27 - Neutron Activation of the ETS Intermediate Shield from Cyclic Operation of the X-Engine

Figure 28 - Neutron Activation of the ETS Clam Shell from Operation of the X-Engine

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APPENDIX A

QUALITY-CONTROL SUPPORT

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A. ENGINEERING

1. Conduct a quality control program in accordance with AETRON Specification 6914 for the ETS-1 Engine Compartment Radiation Shields and NERVA Test Operations Reliability and Quality Assurance Program Plan, NTO-A-0013.

2. The primary functions and responsibilities are as follows:

- a. Review all drawings, specifications, procurements, modifications, and testing documents for adequate QC requirements.
- b. Monitor all on-site modifications, repairs, and testing activity to ensure conformance to specifications.
- c. Ensure that all proper documentation and records are incorporated as part of end-item report to ensure conformance to specification.
- d. Record all deviations and discrepancies and ensure adequate disposition and corrective action.
- e. Ensure that all personnel are certified in accordance with the applicable NTO standards.

ETC QC Manning Requirements, 1967

<u>March</u>	<u>April</u>	<u>May</u>
2	2	2

B. FINAL ACCEPTANCE PRIOR TO BOD

1. Verify all field tests to approved procedures, No. 1 through 9.2, "Field Tests, WEC/SNPO-C."
2. Verify all field certifications.
 - a. Proof-pressure tests
 - b. Line cleanliness
 - c. Cross check with Catco and WEC QC inspection.
3. Clear all discrepant-apparatus tags (DA's).
 - a. Cross-check with Catco and WEC QC inspection.
4. Close loop on all acceptance tests by confirming all data, records, certifications, nonconformances, waivers, and deviations with NTO, SNPO-N, ETS-1 Shield Task Force, and the SNPO-C QC Site Representative.

C. INSPECTION TEST PLAN AFTER BOD (3-17-67)

1. S-1 transfer car reliability test
 - a. Curved-track problem and remating of shields
 - b. EG&G instrumentation, record and witness
 - c. Verify instrumentation and checkout, witness tests
 - d. Ref. Test Description for ETS-1 Shield Reliability Tests - ETS-1 Facility Operation, dated 1-26-67
2. H₂O flow test, entire ETC shield system
 - a. Record test pressures and flow rates
 - b. Document all leaks and discrepancies
 - c. Witness and record all tests
 - d. Verify instrumentation calibration requirements
 - e. Ref. Field Test Sections 2.7 and 2.8
3. Leak and Seals Test: upper and lower trough, convolutes
 - a. Witness integrity of seal during closure test
 - b. Record all nonconformances
 - c. Record uncompleted tests
 - d. Record any waivers or deviations from test procedure (Ref. Field Test Section 2.9)
4. Purge GN₂ system test
 - a. Record test pressures and flow rates
 - b. Document all leaks and discrepancies
 - c. Witness and record all tests
 - d. Verify instrumentation calibration requirements
 - e. Ref. Field Test Sections 2.4 and 2.8

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APPENDIX B

MINIMUM COOLING-WATER FLOW RATES FOR
FACILITY RADIATION SHIELDS, ETS-1

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I. INTRODUCTION

An analysis to determine the minimum coolant-water flow rates for the facility radiation shields of ETS-1 for XE operation was performed. The design described in Drawings 3350-S101 through 3350-S139 and 3350-P103 was used together with the latest nuclear heating rates.

II. TECHNICAL DISCUSSION

A. ANALYTICAL APPROACH

Two thermal constraints were initially imposed as criteria for computing the minimum water flow rate to the intermediate, side, and bottom shields. These were:

- a. Inlet water temperature of 90°F with a maximum bulk temperature rise (inlet to outlet) of 90°F.
- b. Surface boiling to be suppressed at all points within the system.

The initial analysis, as reported herein, was restricted to thermal considerations, with pressure drop and pressure head not considered except as they affected thermal and flow stability parameters.

1. Enthalpy Balance

The first criterion requires that sufficient water be supplied to remove the total quantity of heat generated in the boral, aluminum, and the water itself for each shield component. The total volumetric heat flux is in terms of a surface heat flux in the engine-test-compartment bounding wall. This flux was therefore integrated over the

heated area to give the total heat rate, which was then set equal to the product of the water flow rate, its heat capacity, and maximum water temperature rise.

$$(Q/A)_{\text{rad}} A_{\text{heated}} = Q, \quad (1)$$

$$\dot{m} = \frac{Q}{C_p \Delta T_b}, \quad (2)$$

where

$(Q/A)_{\text{rad}}$ = total radiation heating per unit surface area, Btu/in.²-sec,

A_{heated} = heated surface area, in.²,

Q = heat generation rate, Btu/sec,

$\dot{m}$ = water flow rate, lbm/sec,

C_p = heat capacity of water, Btu/lbm-°F,

ΔT_b = maximum coolant-water temperature rise, °F.

2. Heat-Transfer Correlations

Examination of the drawings referenced in the Introduction discloses that the basic flow configuration in all cases relative to the boron plates is a rectangular channel of high aspect ratio. The immediate question was then to determine if conventional heat-transfer correlations, as developed for an incompressible fluid for forced-convection flow in tubes of circular cross-section, would apply to this case. A rapid literature review disclosed several pertinent references. Levy, Fuller and Niemi* presented the results of experiments for water flowing vertically in thin rectangular channels (0.1 by 2.5 in.) 18 and 36 in. long and heated electrically around the entire periphery. Their results for heat-transfer coefficients on the 2.5-in. faces

*S. Levy, R. A. Fuller, and R. O. Niemi, "Heat Transfer to Water in Thin Rectangular Channels," J. Heat Transfer, Vol. 81, Series C, No. 2, pps 129-143, May 1959

were 30 to 45% below those predicted by the familiar Sieder-Tate equation, indicating that rectangular channels of high aspect ratio (25:1) exhibit poorer heat-transfer characteristics than a circular tube of the same hydraulic diameter.

Hartnett, Koh, and McComas** reported analytical and experimental studies of both laminar and turbulent flow through rectangular channels, with primary emphasis on pressure drop. It was implied that conventional equations would be satisfactory for rectangular ducts with aspect ratios greater than 5:1.

In later work, however, Sparrow, Lloyd and Hixon*** note that for rectangular channels of aspect ratio of 5:1 with unequal heat flux from opposite sides (e.g., boron side heating vs aluminum side heating), conventional correlations overpredict heat transfer on the order of 10 to 20% at Reynolds numbers above 20,000.

In evaluating these sources, it is apparent that, for rectangular channels, heat transfer may vary from 55 to 100% of the conventional prediction, depending on the Reynolds modulus, aspect ratio, fluid, asymmetries in heating, and probably on the absolute magnitude of the minor dimension (i.e., the ratio of boundary-layer thickness to channel height is a factor). It was concluded that a reasonably conservative analysis based on experiments most closely simulating the shield coolant channel would be based

**J. P. Hartnett, J. C. Y. Koh and S. T. McComas, "A Comparison of Predicted and Measured Friction Factors for Turbulent Flow Through Rectangular Ducts," J. Heat Transfer, Vol. 84, Series C, No. 1, pps 82-88, February 1962

***E. M. Sparrow, J. R. Lloyd, and C. W. Hixon, "Experiments on Turbulent Heat Transfer in an Asymmetrically Heated Rectangular Duct," J. Heat Transfer, Vol. 88, Series C, No. 2, pps 170-174, May 1966

on the data of Levy, Fuller, and Niemi*. Since these workers did not derive a correlation covering the entire span of Reynolds numbers, the low Re range was evaluated to give, for $\sim 7000 < Re < \sim 20,000$, a modification of the Sieder-Tate equation:

$$Nu_b = 0.0061 Re_b^{0.93} Pr_b^{0.4} (\mu_w/\mu_b)^{0.14}. \quad (3)$$

This equation was therefore used to determine local heat-transfer coefficients.

B. INTERMEDIATE SHIELD

1. Enthalpy-Balance, Flow-Rate Criterion

The integrated heat-input rate to the intermediate shield was computed as 2184 Btu/sec. For a maximum temperature rise of 90°F, water at 24.27 lbm/sec (175 gal/min) is required.

2. Boiling-Suppression, Flow-Rate Criterion

The saturation temperature of water at 16 psia is 216°F. This value was assumed to be the maximum boral temperature permissible (i.e., no water superheat was permitted). A calculation was then performed by using Equation 3 to compute the flow rate required to satisfy: (1) the requirements set by the local boral heating rates; (2) an inlet temperature of 90°F; and (3) a wall temperature of 216°F. This flow rate was determined to be 21.22 lbm/sec, or 153 gal/min.

*S. Levy, R. A. Fuller, and R. O. Niemi, "Heat Transfer to Water in Thin Rectangular Channels", J. Heat Transfer, Vol. 81, Series C, No. 2, pps 129-143, May 1959

Since this flow is below that required by the enthalpy-balance calculation, the higher value was then used as the basis for a step-by-step integration down the boron-walled coolant passage to determine the bulk and wall temperature profiles.

However, a new factor appeared in the first of these calculations. The inlet Reynolds number was computed as 1900. This low value is in the laminar-flow regime. Further down the channel, the Reynolds number rises somewhat so that an appreciable portion of the flow would be in the transition region. This condition is highly undesirable, particularly for a parallel-flow network, as adjacent sections can be in either laminar or turbulent flow with significant differences in individual channel flow rates for the same value of plenum-to-plenum pressure drop.

The data of Hartnett, Koh, and McComas* indicate the Reynolds modulus should have a minimum value of 2500 for turbulent flow, whereas a more conservative value may be taken as 4000. This then constitutes a new constraint on the cooling-water flow rate.

3. Parallel-Flow Stability Criterion

For the minimum (optimistic) Reynolds number of 2500, the flow rate required to satisfy this criterion is 32.0 lbm/sec, or 230 gal/min. For the more conservative Re value of 4000, the flow rate is 51.2 lbm/sec, or 368 gal/min.

*op. cit.

C. BOTTOM SHIELD

1. Enthalpy-Balance, Flow-Rate Criterion

The shield area exposed to nuclear heating is less than that of the intermediate shield because of the diagonal lower section on the side shield. This reduced area is reflected in a computed flow requirement of 112 gal/min for a 90° water-temperature rise.

2. Boiling-Suppression, Flow-Rate Criterion

A cooling-water flow rate could not be computed by using Equation 3 because the Reynolds number so obtained was in the laminar region and, thus, the correlation did not apply. Identification and use of a suitable laminar-flow heat-transfer correlation for this case was not warranted.

3. Parallel-Flow Stability Criterion

Two Reynolds-number values were assumed: the optimistic value of 2500 and the more conservative value of 4000. For these values, water flow rates for the total bottom shield were determined as 382 and 604 gal/min, respectively.

D. SIDE SHIELDS

1. Enthalpy-Balance, Flow-Rate Criterion

The local volumetric heat fluxes were integrated over the side-shield exposed area to give a total heating rate of 16,100 Btu/sec. For water entering at 90°F and discharged at 180°F, this heating rate requires a total flow of 1290 gal/min for the side shields.

2. Boiling-Suppression, Flow-Rate Criterion

The minimum flow rate required to maintain boron surface temperatures at 216°F, as computed by using Equation 3, is again so low as to place the flow in the laminar-flow region. The exact flow rate was not computed because this heat-transfer correlation cannot be applied to this case.

An analysis was then made to ensure that boron surface temperatures would remain below the saturation temperature for water flowing at the enthalpy-based rate of 1290 gal/min. Since the side-shield channels are of constant flow area and are relatively long, they are considered most susceptible to possible overheating. However, the maximum bulk temperature was predicted to be 111°F at the channel outlet, whereas the maximum boron surface temperature was computed as about 160°F at the point of maximum heat flux. No overheating is thus anticipated.

3. Parallel-Flow Stability Criterion

The Reynolds number determined for flow in the side shield based on the enthalpy-balance criterion is well into the turbulent regime, and no flow instability typical of transition-region Reynolds numbers is expected.

III. CONCLUSIONS AND RECOMMENDATIONS

Minimum cooling-water flow rates for the three facility shields are summarized in Table 1 of the main text. Recommended flow rates are:

A. INTERMEDIATE SHIELD

The parallel-flow stability criterion controls the flows. The absolute minimum coolant-water flow rate is 230 gal/min; a more conservative recommendation is 368 gal/min.

B. BOTTOM SHIELD

The parallel-flow stability criterion again controls flow rate. The absolute minimum rate is 382 gal/min; 604 gal/min is more conservative.

C. SIDE SHIELD

The enthalpy-balance criterion controls the flow rate, and flow rate of 1290 gal/min is required.

It is recommended that consideration be given to re-evaluating the following items from the standpoint of the above coolant flow rates and the as-built shields:

a. Pressure drop across the forced-convective coolant channels should be evaluated to determine the pressure head necessary. This evaluation appears particularly required for the intermediate and bottom shields, since it appears that such computations have not been made for these components.

b. A sensitivity analysis should be made to determine the effect of off-print fabrication on local flow rates. For example, a variation in width of the intermediate-shield water flow channel from the nominal 0.25 to 0.20 or 0.30 in. could be expected to contribute to maldistribution in flow and could possibly subject local regions to overheating.

c. The problem of gas entrapment within each shield during coolant flow should be examined. Water velocities are low, and any entrapped gas will affect local flow and, thus, heat transfer. This effect will be especially significant in horizontal coolant channels.

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