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TEST REPORT

STEAM GENERATOR DEVELOPMENT

TEST PROGRAM

EXPERIMENTAL PLAN IV

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NERVA TEST OPERATIONS

Jackass Flats, Nevada

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EXPERIMENTAL PLAN IV

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I. OBJECTIVES

The objectives of the Experimental Plan IV of the Steam Generator System Development Test Program were:

1. Primary Objectives

- a. Evaluate generator performance when supplied with temperature condition propane to establish:
 - 1) Fuel injection differential pressure as a function of supply temperature.
 - 2) Propane supply temperature conditioning requirements for safe and reliable operation.
- b. Provide data to verify cause of injector weld crack failures.
- c. Evaluate dynamic characteristics of modified facility water supply system.
- d. Confirm calculations in connection with expansion requirements for the three expansion joints.

2. Secondary Objectives

- a. Evaluate performance of modified water injection system.
- b. Establish weight flow of propellants and injection water to produce steam at specified temperatures as measured in the steam pipe.
- c. Evaluate performance of injection bolt-orifices.
- d. Demonstrate compatibility of permanent facility I & C with the steam generator system.
- e. Provide operator training.

II SUMMARY

The ETS-1 Steam Generator System was set up for single module, full-steam operation, and the Development Test Program Experimental Plan IV was conducted between 14 December 1965 and 10 February 1966.

A total of five 60-seconds-duration, full-steam tests were performed using fuel conditioned to temperatures between about 40° F to 68° F; in addition, two water flow, two fuel flow, and two short-duration adjustment tests were made during the EP-IV activities.

The combustion chamber injection water system was modified to minimize the piping pressure losses and to improve flow control. The modified system operated successfully and steam exhaust temperatures up to 950° F were established on the longer full-steam tests.

During the test series no significant change in the injector condition occurred. The combustion chamber initially used developed two cracks in the upper expansion joint on the fourth 60-seconds-duration run, and was replaced for the last full-steam test.

Upon completion of the test series, activities began for the rework, modification, and assembly of the steam generator modules and system, as appropriate, in preparation for the succeeding phase of the Development Test Program.

III CONCLUSTIONS AND RECOMMENDATIONS

1. The injector fuel system operational characteristics were determined and injector pressure drop versus fuel temperature data were successfully obtained. It is recommended that the maximum fuel temperature during SGS testing not exceed 60°F.
2. Data to verify the cause of previous injector weld crack failures was not obtained. There was no significant change in the injector condition as a result of the five 60-seconds-duration test; no cracks developed during the test series.
3. The modified water injection control system operated satisfactorily, and the exhaust steam temperatures were successfully controlled at approximately 700°F and 950°F during the tests. The control valve position was less than 30% open when controlling steam temperatures at the values given here. It is suggested that a control valve plug with a C_v (capacity factor) of 75 be investigated to provide a more sensitive flow control, thereby utilizing more nearly the full range throttling capability of the valve.
4. The injector-to-combustion chamber flange seal, using only a Flexitalic gasket, was satisfactory for single unit, "one-time-only" operation. Following each full-steam test of 15-seconds-duration or more, the flange bolts were always found to have greatly decreased torque, and when pressure checks were made after EP-IV-K-11 and -P-17, considerable leakage occurred past the seal. This seal is not suitable for repeated full-steam tests without servicing, and may be marginal on a multiple-unit test operation where one generator is shutdown from full-steam while another continues to operate at the full-steam condition. Leakage may develop past the flange seal of the unit initially shutdown, while the other generator(s) continue to run. The one attempt to use a flange "spacer ring" for control of the gasket compression, and to obtain high flange-bolt torque, was inconclusive.
5. A satisfactory bleed-in of the generator liquid oxygen system was achieved when the ignitor assembly LO_2 bleed valve was replaced with a small orifice providing a continuous bleed. However, freezing in the small-size water tubing adjacent to the bleed tube caused two test

attempts to be aborted. It is recommended that the continuous LO₂ bleed orifice be reinstalled in the ignitor assembly, together with a new over-board bleed line which will be judiciously located to eliminate the possibility of freezing of other tubing.

In addition, it is suggested that the generator fuel system bleed valve be replaced with a continuous bleed orifice, taking into account the tubing considerations noted above. Replacement of the bleed valves is consistent with the continuing effort for simplification and increasing the reliability of the SGS.

6. The generator module main stage fuel venturi operating characteristics were investigated and analyzed, and it was concluded that the venturi calibration data could not be used to determine the actual fuel flow rate. It is recommended that additional flow calibration tests be conducted to resolve the anomalies.
7. The indicated movement of the combustion chamber expansion joints during the several tests was insignificant. On two tests the upper joint appeared to expand about 0.04 to 0.05 inch; no movement of the center and lower expansion joints was observed on any runs.
8. The water injection "long" bolt-orifices were not affected by the EP-IV. The erosion pattern which was established during earlier tests appeared to be unchanged, and there was no significant dimensional changes in bolt-orifices during this test series.
9. The permanent (ETS-1) Instrumentation and Control System provided satisfactory data and operational control of the SGS. Several minor modifications or changes were made in the console switches and visual displays for improved utilization.
10. Operator and support systems personnel training for steam generator systems testing was satisfactorily achieved. The interchangeability of selected personnel at several control stations was successfully demonstrated.

IV TECHNICAL DISCUSSION

The Steam Generator System (SGS) Development Test Program Experimental Plan IV (EP-IV) was initiated on 14 December 1965 and was completed on 10 February 1966. The test program was conducted in accordance with REON Test Specification 004, and Experimental Plan IV (NTO-M-4742) which is presented as Appendix I.

In preparation for the tests to be preformed, several modifications were made to the Steam Generator System and to the individual modules as described below:

1. Each module combustion chamber water injection piping and valving was modified to reduce the system pressure drop and to simplify the system control valve requirements, as shown in Figures 1 and 2.

The requirement for the injection water shutoff valve (50-RSV-428) was deleted by making the injection water control valve (50-FCV-423) also a shutoff valve. The "two-way" shutoff valve was disassembled and a linear throttling plug with a C_v (capacity factor) of 110 was installed; the Domotor actuator, formerly on the original "three-way" injection water control valve, was then installed on the "two-way" valve body and valve assembly was then installed in the generator modules replacing the former "three-way" valve assembly. The water piping was then re-worked to accomodate the change in the system valves.

2. A by-pass line (2 inch diameter) was installed between the SGS four-inch and six-inch-diameter water manifolds. The by-pass, which included a 60-mesh screen and four-inch check valve, allows the six-inch-diameter manifold to (more) slowly fill upon the initial filling of the four-inch-diameter plenum-water coolant line, thereby minimizing any water-hammer or shock effect of the combustion chamber coolant jackets. The six-inch manifold supply valve (50-RSV-433) is then opened after the larger manifold is filled.
3. A differential pressure switch (50-PDS-404) was installed in the SES control box and connected to the plenum coolant water discharge line on either side of an orifice (2.4 inch diameter). Closure at approximately $7\frac{1}{2}$ psig, as shown by a control console visual display, indicates adequate

plenum coolant water flow rate during tests.

4. The steam generator system pressure switches for the propane, liquid oxygen and water manifolds (50-PS-438, 50-PS-439 and 50-PS-440) were disconnected and capped off from the respective manifolds, and the pressure switches control circuitry was deleted from the SGS sequence control unit. The gaseous nitrogen pressure switches (50-PS-401 and 50-PS-402) control circuitry was deleted from the sequence control unit, but both switches must operate when the 450 psig and 150 psig manifolds are pressurized and indicate adequate pressures by operation of the "GN₂ OK" light on the control console. These modifications were made because there were no provisions for indicator lights on the control console and because actual pressure values are displayed on the console meters. It was considered undesirable to allow the subject switches to remain in the sequence control system without an actual monitor of the switch position.
5. The generator modules main propane shutoff valve control circuitry was modified such that before the propane valve pilot valve opening signal can be initiated, after the one-second delay starting with the main liquid oxygen (LO₂) valve opening control signal, the LO₂ valve "open" position switch must also have been activated. This modification prevents the possibility of the fuel valve opening "early" which could create a hazardous condition during combustion chamber propellant ignition.
6. The steam generator system configuration specified for the test series required the assembly of Generator Module 0016, incorporating Injector 0016 and Combustion Chamber 01. This module was located at the Generator No. 1 position, while the two other plenum stations were closed with 10-inch-diameter blind flanges. At Generators No. 2 and 3 positions, blind flanges were installed in the propane, liquid oxygen and water supply piping (at high point of risers) to eliminate the possibility of leakage from

components in these modules. In addition, the ignitor assembly liquid oxygen supply tubing in these modules was connected to the LO₂ bleed line using a short piece of $\frac{1}{4}$ inch tubing containing a 0.040 inch diameter orifice, thereby providing a small continuous bleed of the amin oxydizer risers to eliminate (or minimize) any gas bubbles which might affect the operation of Generator No. 1.

During the water-injection piping modification, several of the SGS manufacturers piping welds were found to be defective. An "on-the-spot, coarse survey" by X-ray examination of selected piping welds in the three generator modules revealed a large percentage of welds in the water, propane and liquid oxygen systems would not pass minimum code standards.

Defective welds in the water piping being modified (to accomodate the two-way valve) were repaired and the piping was then installed in the modules. In order to insure that a minimum risk of weld failure was present if testing was conducted, a proof test was successfully performed on Generator No. 1 water, propane and liquid oxygen piping and the supply manifolds, and on the risers in Generators No. 2 and 3, all of which would be subject to fluid pressures during module tests. It was then decided that the re-work necessary to correct the many weld defects would be accomplished upon completion of the EP-IV tests.

The Field Action Request (FAR) procedure, established by the NES Project Department to define, specify, detail, and approve all work on or affecting the Steam Generator System, was continued. An index of the FAR's received between 9 July and 10 February 1966 is presented as Appendix II.

The EP-IV tests were conducted from the ETS-1 Control Room, utilizing the control consoles specifically provided for operation of the Steam Generator System and supporting systems and activities. The NERVA Test Operations Document No. NTO-I-0023, titled "Steam Generator System Operating Instructions," describes the SGS testing procedure.

Before beginning the EP-IV tests, work on the SGS and associated facility systems included the following tasks:

1. Instrumentation pressure sensors used on preceeding tests were removed and new transducers, compatible with the permanent instrumentation systems, were calibrated and installed in the module and SGS transducer boxes.
2. The generator injector-to-combustion chamber flanged joint was sealed using a Flexitalic gasket instead of the solid aluminum flat gasket previously specified. The Flexitalic gasket (spiral-wrapped asbestos and thin, chevron-shaped, stainless steel strip) was compressed approximately 0.025 inch in five steps by measuring the gap between the flanges.
3. All of the pressure switches in Generator 0016 and the SGS were checked for operation at specified pressures and were readjusted where necessary.
4. A turbine type, 2-inch-diameter flow meter was installed in the fuel supply piping in order to provide data for comparison to the module venturi flow meter data.
5. Leak tests of the water, propane, liquid oxygen, nitrogen and hot gas system were satisfactorily completed.

The EP-IV test program required that several 60-seconds duration tests at "full-steam" conditions be conducted with the fuel supply temperature being progressively increased, in 10°F increments from 40°F to 80°F, for each run. In addition, the water injection control valve (50-FCV-423) position was to be adjusted to obtain specified steam exhaust temperatures of $700 \pm 100^\circ\text{F}$ ($900 \pm 100^\circ\text{F}$ on last test).

Throughout the test series, the requirement for increasing fuel temperatures from test-to-test to the values nominally specified was very difficult to achieve. The fuel tank was heated and then the warmed fuel was bled into the supply piping and to the steam generator. Because the outside air temperature was usually quite cold (frequently below freezing) and the limitation as to the quantity of propane which could be bled through the piping before the raw fuel was expelled from the flare (burn-off) stack, the fuel temperature during the succeeding run was usually below the nominal value desired. The propane tank was heated by covering it with a large plastic-seal canvas "tent," sand-bagged around the edge on the ground to minimize entrance of outside air,

and then continuously filled with hot air from an oil-fired heater with blower. See Figure 3. With the heater operating around-the-clock, the propane temperature within the tank could be raised approximately 80°F.

The Steam Generator System Test Summary is presented as Table I. The Steam Generator System Test Data Tabulation, Table II, presents the operational data reduced for each of the EP-IV tests, together with calculated fluid flow rates and mixture ratios. The symbols used in the data tabulation are defined in the Steam Generator System Test Nomenclature (NTO-M-4654), presented as Appendix III.

The initial test of the series, EP-IV-A-1 on 14 December 1965, was a water (flow) calibration of the recently modified water injection flow control valve (FCV). Generator No. 2 (Module 0017) injection water system was used for this test. An orifice (1.25 inch diameter) was installed in the overboard pipe downstream of the FCV to create a backpressure simulating the condition which would occur when water is injected into a combustion chamber operating at full steam.

The test was not satisfactory because the FCV opened approximately six-percent of total lift due to the supply water pressure on the bottom of the valve plug. Subsequent discussion with the valve vendor disclosed higher pneumatic pressures were required in the valve operator system to obtain proper operation. A second water flow test, EP-IV-C-3 on 16 December, was satisfactorily completed.

Test EP-IV-B-2, conducted on 15 December, was a propellant bleed-in test performed to verify that the propane and liquid oxygen supply systems would function properly under normal bleed-in conditions. Satisfactory operations of the propellant systems components were observed.

The initial EP-IV generator hot gas run, EP-IV-D-4, was an adjustment test of five-seconds duration at full steam, conducted on 21 December 1965. A second adjustment test, EP-IV-E-5, was performed the following day for a full-steam duration of 15 seconds. The generator operated normally and there was no evidence of overheating during these tests. No attempt was made to adjust the water injection control valve during the short periods of operation; the fuel temperature was approximately 40°F.

As noted earlier, the injector-to-chamber flanged joint was sealed using a Flexitalic gasket compressed about 0.025 inch. Prior to the first full-steam test, the "final" torque required on the flange bolts to obtain required gasket crush as given above was 65 to 100 foot-pounds, with an average bolt torque of

75 foot-pounds. Following Test EP-IV-E-5, a check of the bolts disclosed the torque valves had decreased to 5 to 40 foot-pounds and the average torque was 20 foot-pounds. The injector was removed and a dye penetrant inspection was performed; numerous points of minor porosity and two small cracks were noted in weld areas around the three spud assemblies in the injector face.

The injector was cleaned, reinstalled on the chamber, and because of the low torque of the flange bolts after Test EP-IV-E-5, the Flexitalic gasket compression was increased to 0.035 inch. The installation was accomplished in seven cycles of tightening the bolts to obtain approximately a 0.005 inch "crush" during each bolt-tightening sequence. The ignitor assembly was then installed.

Following completion of leak tests of the SGS propellant piping and hot gas system, and performance of satisfactory pre-test, electromechanical (sequence) checks, a 60-seconds-duration full-steam test, EP-IV-F-6, was conducted on 29 December 1965. During this test, initiated at a nominal fuel temperature of 45°F, the water injection control valve (50-FCV-423-1) was slowly closed, by operation of the control console valve-control "pot", to obtain a steam exhaust temperature of about 700°F before shutdown. The generator operated normally. The post test activities included: a hot-gas system leak test to determine the tightness of the injector-to-chamber seal, and no leakage was found; a check of the injector-to-chamber bolts revealed torque values varied from zero to approximately 80 foot-pounds with the average bolt torque about 15 foot-pounds, as compared to the pre-test torque values of 170 to 345 foot-pounds (average approximately 200 foot-pounds); the injector was removed and a dye penetrant inspection of the injector face was made and the injector condition was not significantly changed from the condition described after Test EP-IV-E-5. The combustion chamber water injection "long" bolt-orifices were removed, inspected for erosion, and measured to determine the minimum diameter. No obvious changes were noted.

Tests EP-IV-G-7 and EP-IV-I-9 (7 January and 14 January 1966, respectively) were performed to obtain fuel venturi calibration data. Comparison of the flow data from the generator module main fuel venturi and the turbine-type flow meter in the facility propane supply, showed a considerable difference in the indicated propane flow rates. During Test EP-IV-G-7, the fuel venturi from Module No. 0016 was installed at the outlet flange of the main

propane shutoff valve in Generator No. 3, with the discharge from the venturi connected by one-inch-diameter tube to the propane-to-flare stack piping. Using the shutoff valve for on-off control, venturi flow data for propane tank supply pressures of 165, 230 and 260 psig were obtained, but it was subsequently determined that excessive backpressure prevented the venturi from operating at cavitating conditions. For the second propane flow test, EP-IV-I-9, the module main shutoff valve together with the venturi section (as normally assembled) was installed in the SGS propane manifold bleed line such that cavitation would occur in the venturi under flow conditions. The facility flow meter (which had been recalibrated on 5 January 1966) was used as the calibration "standard" for these tests. Discussion and analysis of the venturi flow data is presented in Appendix IV.

After the EP-IV-F-6 post-test activities, the injector was cleaned and re-installed in Generator No. 1 with a Flexitalic Gasket seal again compressed 0.035 inch. The ignitor assembly and the "long" bolt-orifices were re-installed, and leak tests were satisfactorily completed on the hot gas system and propellant piping. Electromechanical tests, which were performed before every hot gas test, were also completed.

Test EP-IV-H-8, made on 10 January, was a full-steam run of 60-seconds-duration. The fuel tank temperature was approximately 55°F during this test while the fuel temperature at the SGS manifold was 48°F. A steam exhaust temperature of about 720°F was obtained during the run by manual control of the water injection control valve; there was no evidence of overheating or abnormalities. Post-test dye penetrant inspection of the injector face showed no significant change in the injector condition from the preceeding run. The injector was then cleaned and re-installed. The injector-to-chamber bolt torque prior to the test was 100 to 300 foot-pounds) whereas following the test the torque was estimated to be 5 foot-pounds on three bolts and zero on the remaining bolts. The water injection bolt-orifices were inspected and reinstalled.

A full-steam 60-seconds-duration test, EP-IV-L-12, was conducted on 25 January 1966. During the test, performed with the fuel supply temperature approximately 67°F, the steam exhaust temperature was increased to approximately 700°F by manual control of the water injection control valve. The test operation was completed without indication of abnormalities; however, after the run

it was observed that water had collected at several locations around the generator chamber. All of the injector-to-chamber bolts were loose and could be turned by hand, whereas prior to the run the bolts torque values were 90 to 360 foot-pounds (average 195 foot-pounds). After tightening the injector-chamber flange bolts, a pressure check was made and two cracks were found in the combustion chamber upper expansion joint torus, adjacent to the torus-to-chamber weld on the upper side. A post-test injector face dye penetrant inspection showed no significant change in conditions from the preceeding test.

Combustion chamber S/N 01 was removed from Steam Generator 0016, and chamber 0017 (re-worked after EP-II to incorporate a modified upper expansion joint) was installed in the module. All of the previously used water injection bolt-orifices and the over-temperature switch were transferred to the "new" chamber. The "long" bolt orifices were measured for the smallest diameter and examined for erosion before installation.

In order to investigate the differences between the facility and generator fuel flowmeters indicated flow rates to obtain additional data on the main fuel venturi operational characteristics, the main fuel venturi assembly was removed from the generator and the venturi section was modified to provide for measurement of the throat pressure. A new venturi-section holder was fabricated to incorporate a throat-pressure measurement fitting. The modified venturi assembly was then installed in the module fuel line preparatory to test EP-IV-M-13.

Another change at this time to the generator configuration was the replacement of the generator LO₂ bleed valve (50-RSV-424) with a small orifice, which would provide for continuous low flow rate, overboard bleed. This change was made as part of a general goal to simplify the SGS piping and controls.

When Injector 0016 was installed on Chamber 0017, a spacer ring was placed between the flanges for the purpose of controlling and limiting the compression (crush) of the Flexitalic gasket seal. It was intended that the gasket crush in the tongue and groove joint would be limited to about 0.025 inch, and at the same time the injector-to-chamber bolts could be tightened to reasonably high torque values. The result would be a leak-tight joint with the flange bolts having essentially no change in loading from test-to-test. However, when the initial injector installation was completed, with bolts

torqued to 390 foot-pounds, the flange joint leaked. Subsequent measurements indicated the gasket was compressed as little as (perhaps) 0.006 inch at one point and as much as (perhaps) 0.027 inch at another location. The flanges of the injector and chamber appeared to have considerable variation in flatness; the height of the flange tongue of Chamber 0017 was considerably less than the same dimension of Chamber 01. Because of these factors, and the fact that each injector-combustion chamber combination required a different spacer thickness, the spacer ring was set aside and the injector was installed using the same procedure as on the preceeding tests.

A 12-inch-diameter orifice in the exhaust stack was replaced with a 9.8-inch-diameter orifice so that the steam plenum pressure, with one unit at full steam, would be increased to that value nominally expected when two generators were at full-steam conditions. The operational characteristics of the single module would then more closely approach the SGS design conditions. The steam exhaust temperature specified for the succeeding test was raised to $900 \pm 100^{\circ}\text{F}$.

Tests EP-IV-M-13 and EP-IV-N-14 were made on 4 February and 7 February 1966. The initial test was scheduled to be a full-steam, 60-seconds-duration run with a fuel temperature of $80 \pm 10^{\circ}\text{F}$, and the second test was a repeat attempt at the same conditions. Both tests were aborted prior to actual generator operation because there was no indication of satisfactory water flow and pressure conditions, as evidenced by the failure to actuate the control sonsole "H₂O OK" light when the water supply line shutoff valve was opened. Examination of the module and operational checks of pressure switches and electrical circuits after Test EP-IV-M-13 did not disclose any reason for the trouble. Following the second occurrence of this problem, the post test examination of the water system pressure-sensing tubing to first-and second-stage ignitors coolant water pressure switches (50-PS-422 and 50-PS-423) revealed that icing and freezing in the tube fittings prevented the switches from being actuated. The freezing condition occurred because the ignitor assembly continuous LO₂ bleed tubing passed near-by, and the very-low temperature of the liquid oxygen in the tubing caused the water filled fittings to freeze. The LO₂ bleed valve, which had been removed after Test EP-IV-L-12, was reinstalled in the original configuration, since this had proved to be a workable configuration and would allow testing to be resumed more quickly than if rerouting and insulation of the continuous bleed plumbing was attempted.

On 8 February 1966, a third attempt to operate with the fuel temperature of $80 \pm 10^{\circ}\text{F}$, Test EP-IV-0-15, resulted in a malfunction shutdown during the start-up sequence due to "no second stage ignition." Within minutes a second start-up was attempted, EP-IV-0-16, and again a malfunction occurred because of a lack of combustion pressure in the second-stage ignitor. Examination of the module relay (sequence) control box revealed there were two broken wires in the second-stage ignitor propellant valve control circuit, thereby preventing propellant injection and ignitor operation. The wiring defect, which had occurred during recent electrical work in the box, was repaired. The final test of the series, EP-IV-P-17, was conducted on 10 February 1966. During the 60 seconds at full steam, the water injection control valve was manually controlled to obtain a steam exhaust temperature of approximately 950°F . There was no evidence of overheating or abnormalities during the run. Post-test examination again found a number of the injector-to-chamber bolts to be loose, and when a pressure test was made on the chamber, leakage occurred past the Flexitalic gasket flange seal. The dye penetrant inspection of the injector face showed the condition to be essentially unchanged from the last inspection.

The final measurements on the "long" bolt-orifices, taken after each test of 60-seconds-duration, are tabulated in Table III. As will be noted, no significant change in the diameter measurements is indicated. The erosion pattern established prior to EP-IV was not affected during these runs.

During testing preparations several SGS discrepancies were found, including those described below:

1. When the installation of Combustion Chamber S/N 01 onto the steam plenum was first attempted, it was found that the four chamber stud bolts were misaligned and would not enter the bolt holes in the plenum mating flange. The outer edge of the bolt ends were ground as shown in Figure 4, to obtain the clearance required for installation of the chamber onto the plenum.
2. During the initial leak tests of Generator Module 0016, leakage was noted from a fitting in the body of the LO_2 bleed valve (50-RSV-424) and the valve was replaced by a like item from Module 0017 top works. The valve from

Module 0017 was found to be leaking past the seat at a later time and was replaced by a like-item from Module 0018.

3. The one-inch diameter nitrogen supply tubing from the SGS 450 psig header to the module nitrogen shutoff valve (50-RSV-432), was found to have cracks in the aluminum B-nut sleeves. The line was reworked to eliminate the aluminum fittings and reinstalled.
4. Before the first hot gas test, it was found that the over-temperature switch (50-TS-413) boss in the combustion chamber (S/N 01) bottom flange did not have a spot-face, and consequently a leaktight seal could not be obtained at the boss when the switch was installed in the normal manner. In order to conduct the two short-duration adjustment tests without undue delay, a "quick-fix" was made by substituting a "Toroseal," Teflon-lined jam nut in place of the copper bushing which normally seals the boss and switch base. Upon compression of the Toroseal, the Teflon insert deformed to match and seal against the flange curved surface. Prior to performing 60-seconds-duration runs, the over-temperature switch installation was modified to obtain a more reliable seal by substitution of a specially made stainless steel bushing for the copper bushing; the special bushing was machined on one side to match the curvature of the flange surface, and a seal of the boss and switch base was obtained by utilizing two Teflon O-rings at either side of the bushing I.D. and a "flat" Durabola gasket between the flange and the bushing. This modification was successfully used throughout the remainder of the tests using Combustion Chamber S/N 01.

As part of the EP-IV instrumentation requirements, linear motion potentiometers were installed across the three combustion chamber expansion joints to record any movement of the joints during full-steam tests. The "pots" were originally installed on special brackets which were glued to the chamber wall with epoxy glue, but because the bracket of the upper pot would loosen after nearly every run, the pots were reinstalled on the expansion joints supports using dental cement, as shown in Figure 5. On only two tests was any movement of the upper

expansion joint recorded, and no change or movement was recorded of either the center or lower expansion joints on any test. A plot of the upper joint movement versus time for Test EP-IV-L-12, together with the combustion chamber pressure versus time for comparative purposes, is shown in Figure 6.

The EP-IV inspection requirements specified that the generator injector was to be removed from the chamber following each full-steam test for a dye penetrant inspection of the face area. During these inspections, photographs were taken of the injector face over-all and of each of the three "spud assemblies" separately. Figures 7 and 8 shows the condition of the injector after Tests EP-IV-E-5 and EP-IV-P-17, respectively. The number of points of porosity has increased but no change was observed in the two small cracks found on the initial examination.

One of the objectives of the test series was to investigate the injector fuel system operation characteristics. A summary analysis of the injector fuel system performance is presented below.

During EP-II, cracking of the injector face had occurred, and it was suspected that the elevated propane temperatures, up to and exceeding 90°F, were the cause of the cracking. Six significant tests were performed during the EP-IV test program in which the propane temperature supplied to the Steam Generator varied between 39°F and 68°F. During the EP-IV test program no cracking was observed. However, a change in the injector K_w was observed ranging from 1.46 to 0.725. The K_w value changed radically between Tests H-8 and K-11.

Inspection of the tabulation below indicates that for Test H-8, P_{CU} , the combustion chamber pressure measured directly beneath the injector, was much higher than the vapor pressure of the propane (P_{VP}) at a specific location within the injector manifold supply passage, while in Test K-11 this was not the case. For Tests E-5, F-6, and H-8, it can be said that the propane entered the combustion chamber through the injector orifice as a liquid while in the remaining tests the propane flashed into a gas in the injection orifice passages and caused a considerably higher pressure drop as shown by Figure 9.

For two module operation at a steam plenum pressure of 115 psig, the upper combustion chamber pressure will be approximately 135 psig. If an upper limit of fuel supply temperature of 60°F is chosen, the increase in temperature to the point of measurement in the injector passageway should be approximately 50°F, which means the vapor pressure of the 650°F liquid will be 100 psig. A comfortable margin will exist between P_{cU} and P_{vP} ; flashing should not occur and an injector K_w of 1.38 should be valid.

However, for single module operation the upper combustion chamber pressure will be approximately 92 psig, which is considerably below the vapor pressure of 100 psig and flashing will occur, the K_w will decrease and the injection pressure drop will increase. Unless compensated for by increasing the fuel tank pressure, a drop in fuel flow rate of approximately 0.7 lb/sec. will occur. This will occur because the existing fuel venturi does not appear to be a flow limiting device (see Appendix IV for the fuel venturi discussion).

INJECTOR OBSERVED & CALCULATED DATA TABULATION

TEST NO.	T _{fM} (°F)	T _{fJ} (°F)	Based on T _{fJ}	P _{fJ} (S) (psi)		$\dot{w}_f$ (lb/sec)	K _w	P _{cU} (psig)	P _{vP} (psig)
E-5	39	39	.526	34	4.23	6.17	1.46	83	64
F-6	45	46	.520	44	4.77	6.39	1.34	91	72
H-8	48	51	.515	54	5.25	7.13	1.35	92	79
K-11	55	60	.509	98	7.05	6.97	.99	95	94
L-12	68	71	.499	111	7.45	6.94	.93	98	112
P-17	66	70	.500	101	7.12	6.94	.775	120	110

At the beginning of the EP-IV tests, a "flush-mounted" pressure transducer was installed in the SGS six-inch, coolant and injection water supply manifold. The purpose of the sensor was to record any water pressure surges which may occur and which might cause damage to the generator. Prior to Test EP-IV-J-10, the sensor was removed from the original location and installed in the generator combustion chamber coolant water outlet "yoke" (just upstream of orifice 50-FE-422). Throughout all EP-IV test activities, including water manifold

filling and full-stream operations, no pressure surges or water hammer effects were observed.

At the conclusion of the test series the planned modification and re-work, and piping repair and X-ray, to the steam generator system was initiated. Upon completion of this work, reassembly will proceed in preparation for the beginning of the next series of tests.

TABLE I
STEAM GENERATOR SYSTEM TEST SUMMARY
STEAM GENERATOR MODULE DATA

STEADY STATE OPERATIONAL DATA (1)																	
TEST NUMBER	DATE	TYPE OF TEST	STEAM IDLE sec	FULL STEAM sec	1st STC Press. psig	2nd STC Press. psig	3rd STAGE		STEAM PLENUM		FLUID FLOW RATE				MIXTURE RATIOS		REMARKS
							Press. psig	Temp °F	Press. psig	Temp (5) Ave °F	OXID lb/sec	FUEL lb/sec	WATER lb/sec	TOTAL(2) lb/sec	MR _T (3)	MR _W (4)	
EP-IV-A-1	12-14-65	Water calibration of S.G. No. 0017 water throttle valve.															Unsatisfactory test. Valve 50-FCV-423-2 lifted off seat to about 6% open when water supply manifold pressure was applied. Plenum drain valve automatically closed at simulated "full-steam" condition and plenum and chamber filled with water from main chamber film coolant orifices.
EP-IV-B-2	12-15-65	LO ₂ and C ₃ H ₈ bleed-in facility check.															Satisfactory propellant bleed-in.
EP-IV-C-3	12-16-65	Water calibration of S.G. No. 0017 water throttle valve															Satisfactory test. Calibrated valve 50-FCV-423-2 for water flow rate vs lift.
EP-IV-D-4	12-21-65	Full steam adjustment test on S.G.S. plenum and Gen. No. 1	36	5	165	134	65	290	45	458	18.69	7.95	53.25	79.89	2.35	2.00	Satisfactory test. Combustion chamber upper expansion joint linear motion pot mounting brackets came unglued during test.
EP-IV-E-5	12-22-65	Full steam adjustment test on S.G.S. plenum and Gen. No. 1	43	15	150 ± 3	126	60	265	40	433	18.90	7.85	52.69	79.43	2.41	1.97	Satisfactory test. Combustion chamber upper expansion joint linear motion pot mounting bracket came unglued during test. Post-test injector to combustion chamber bolts torque 5 to 25 foot-pounds. (Pre EP-IV-D4) test torque values 65 to 100 foot-pounds. Post-test injector dye penetrant inspection revealed numerous point of porosity around

(1) End of test data

(2) Flow rates are defined as follows: Oxidizer and Fuel are total of each through all generator stages; Water flow rate is total of 3rd stage film cooling and injection water ($\dot{W}_{WT} = \dot{W}_{W3} + \dot{W}_{WP}$); total flow rate is total of oxidizer, fuel and water discharged from generator into plenum.

(3) MR_T Mixture Ratio; ratio of total oxidizer to total fuel flowing into all generator stages.

(4) MR_W Mixing Ratio; ratio of total water to total fuel plus total oxidizer discharged into the plenum.

(5) Plenum Temperature - Average = average temperature valve of three individual plenum thermocouples.

TABLE I (Continued)
STEAM GENERATOR SYSTEM TEST SUMMARY
STEAM GENERATOR MODULE DATA

STEADY STATE OPERATIONAL DATA (1)																		
TEST NUMBER	DATE	TYPE OF TEST	STEAM IDLE sec	FULL STEAM sec	1st STC Press. psig	2nd STC Press. psig	3rd STAGE		STEAM PLENUM		FLUID FLOW RATE				MIXTURE RATIOS		REMARKS	
							Press. psig	Temp °F	Press. psig	Temp (5) Ave °F	OXID lb/sec	FUEL lb/sec	WATER lb/sec	TOTAL(2) lb/sec	MR _T (3)	MR _W (4)		
EP-IV-E-5	(Continued)																the three injector "spud assemblies", and two very small cracks near the No. 2 "spud assembly".	
EP-IV-F-6	12-29-65	Full steam 60 sec. test on S.G.S. plenum and Gen. No. 1 at fuel temperature of 40 ± 10 F.	87	60	172 ⁺⁰ ₋₃₄	137	67	290	49	704	18.54	8.09	48.76	75.39	2.29	1.83	Satisfactory test. Operated the water injection control valve manually to obtain an exhaust temperature (average) of 700 ± 100° F. Pre-test injector to chamber bolts torque valves of 170 to 345 foot-pounds with average of about 200 foot-pounds; post-test torque values varied from zero to 80 foot-pounds with the average less than 16 foot-pounds. Chamber upper expansion joint linear motion pot bracket came unglued during test. Post-test injector dye penetrant inspection showed injector conditions not significantly changed from that noted above, EP-IV-E-5 remarks.	
EP-IV-G-7	1-7-66	Fuel venturi calibration (in Gen. No. 3 piping)															Made propane flow tests on venturi 50-FE-405 with propane tank pressures of 165, 230 and 260 psig. Determined that venturi was flowing in non-cavitating condition. (Venturi relocation to reduce backpressure required to obtain cavitation condition).	
EP-IV-H-8	1-10-66	Full steam 60 sec. test on S.G.S. plenum and Gen. No. 1 at fuel	33	60	175 ⁺⁹ ₋₂₈	138 ⁺⁹ ₋₂	67	306	49	729	17.97	8.21	50.28	76.49	2.9	1.92	Satisfactory test. Operated water injection control valve manually to obtain exhaust temperature (average) of 700 ± 100° F. Combustion chamber upper	

(1) End of test data

(2) Flow rates are defined as follows: Oxidizer and Fuel are total of each through all generator stages; Water flow rate is total of 3rd stage film cooling and injection water ($W_{wt} = W_{w3} + W_{wF}$); total flow rate is total of oxidizer, fuel and water discharged from generator into plenum.

(3) MR_T Mixture Ratio; ratio of total oxidizer to total fuel flowing into all generator stages.

(4) MR_W Mixing Ratio; ratio of total water to total fuel plus total oxidizer discharged into the plenum.

(5) Plenum Temperature - Average = average temperature valve of three individual plenum thermocouples.

TABLE I (Continued)
STEAM GENERATOR SYSTEM TEST SUMMARY
STEAM GENERATOR MODULE DATA

STEADY STATE OPERATIONAL DATA (1)																	
TEST NUMBER	DATE	TYPE OF TEST	STEAM IDLE sec	FULL STEAM sec	1st STC Press. psig	2nd STC Press. psig	3rd STAGE		STEAM PLENUM		FLUID FLOW RATE				MIXTURE RATIOS		REMARKS
							Press. psig	Temp °F	Press. psig	Temp (5) Ave °F	OXID lb/sec	FUEL lb/sec	WATER lb/sec	TOTAL (2) lb/sec	MR _T (3)	MR _W (4)	
EP-IV-H-8	(Cont.)	temperature of 50 ± 10° F.															expansion joint linear motion pot mounting bracket came unglued during test. The pre-test injector to chamber bolts torque values were 200 ± 5 foot-pounds; post-test torque was zero to 5 foot-pounds on all bolts. Post-test injector dye penetrant inspection showed injector condition not significantly changed from preceding test.
EP-IV-I-9	1-14-66	Fuel venturi calibration (in S.G.S. manifold bleed piping)															Made propane flow test on venturi 50-FE-405 with propane tank pressures of 150 to 290 psig. Venturi flow data obtained under cavitating conditions.
EP-IV-J-10	1-18-66	Full steam 60 sec. test on S.G.S. plenum and Gen. No. 1 at fuel temperature of 60 ± 10° F.															Test aborted. During bleed-in of the propane supply line, spillage of liquid propane from flare stack ignited leaking propane in test stand piping; aborted test to investigate and repair cause of fire.
EP-IV-K-11	1-20-66	Full steam 60 sec. test on S.G.S. plenum and Gen. No. 1 at fuel temperature of 60 ± 10° F.	35	60	178 ⁺¹⁰	148 ⁺⁹	69	342	56	681	18.69	8.60	53.51	80.80	2.17	1.96	Satisfactory test. Operated water injection control valve manually to obtain exhaust temperature (average) of 700 ± 100° F. Combustion chamber center expansion joint linear motion pot mounting bracket came unglued during test. Pre-test injector to chamber bolts torque was 40 to 190 foot-pounds; post-test torque was zero to 10 foot-pounds on all bolts.

(1) End of test data

(2) Flow rates are defined as follows: Oxidizer and Fuel are total of each through all generator stages; Water flow rate is total of 3rd stage film cooling and injection water ($W_{wt} = W_{w3} + W_{wf}$); total flow rate is total of oxidizer, fuel and water discharged from generator into plenum.

(3) MR_T Mixture Ratio; ratio of total oxidizer to total fuel flowing into all generator stages.

(4) MR_W Mixing Ratio; ratio of total water to total fuel plus total oxidizer discharged into the plenum.

(5) Plenum Temperature - Average = average temperature valve of three individual plenum thermocouples.

TABLE I (Continued)
STEAM GENERATOR SYSTEM TEST SUMMARY
STEAM GENERATOR MODULE DATA

STEADY STATE OPERATIONAL DATA (1)																	
TEST NUMBER	DATE	TYPE OF TEST	STEAM IDLE sec	FULL STEAM sec	1st STC Press. psig	2nd STC Press. psig	3rd STAGE		STEAM PLENUM		FLUID FLOW RATE				MIXTURE RATIOS		REMARKS
							Press. psig	Temp °F	Press. psig	Temp (5) Ave °F	OXID lb/sec	FUEL lb/sec	WATER lb/sec	TOTAL (2) lb/sec	MR _T (3)	MR _W (4)	
EP-IV-K-11	(Continued)																Post-test injector dye penetrant inspection showed no significant change in condition from preceding test.
EP-IV-K-12	1-25-66	Full steam 60 sec. test of S.G.S. plenum and Gen. No. 1 at fuel temperature of 70 ± 10°F.	40	60	182	156	72	339	56	699	18.66	8.34	52.68	79.68	2.24	1.95	Satisfactory test. Operated water injection control valve manually to obtain exhaust temperature (average) of 700 ± 100°F. Pre-test injector to chamber bolts torque valves were 90 to 330 foot-pounds; post-test torque was zero on all bolts. Found two points of leakage (cracks) from chamber upper expansion joint; combustion chamber No. 1 replaced with chamber No. 0017. Post-test injector dye penetrant inspection showed no significant change in condition from preceding test.
EP-IV-M-13	2-4-66	Full steam 60 sec. test on S.G.S. plenum and Gen. No. 1 at fuel temperature of 80 ± 10°F.															Test aborted. Upon initiation of water flow in the S.G.S., the "Water OK" light did not come on to indicate adequate water pressure was present; aborted test to investigate and correct cause of problem. Cause of trouble could not be determined.
EP-IV-N-14	2-7-66	Full steam 60 sec. test on S.G.S. Gen. No. 1 at fuel temperature of 80 ± 10°F.															Test aborted. The "Water OK" light did not indicate upon initiation of S.G.S. water flow and the test was aborted. Subsequent inspection of Gen. No. 1 revealed icing in the water-filled pressure sensing lines to injector coolant water pressure switches; the icing was caused by the

(1) End of test date

(2) Flow rates are defined as follows: Oxidizer and Fuel are total of each through all generator stages; Water flow rate is total of 3rd stage film cooling and injection water ($W_{wt} = W_{w3} + W_{wI}$); total flow rate is total of oxidizer, fuel and water discharged from generator into plenum.

(3) MR_T Mixture Ratio; ratio of total oxidizer to total fuel flowing into all generator stages.

(4) MR_W Mixing Ratio; ratio of total water to total fuel plus total oxidizer discharged into the plenum.

(5) Plenum Temperature - Average = average temperature valve of three individual plenum thermocouples.

TABLE I (Continued)
STEAM GENERATOR SYSTEM TEST SUMMARY
STEAM GENERATOR MODULE DATA

STEADY STATE OPERATIONAL DATA (1)																	
TEST NO. & DATE	DATE	TYPE OF TEST	STEAM IDLE sec	FULL STEAM sec	1st STC Press. psig	2nd STC Press. psig	3rd STAGE		STEAM PLENUM		FLUID FLOW RATE				MIXTURE RATIOS		REMARKS
							Press. psig	Temp °F	Press. psig	Temp Ave °F (5)	OXID lb/sec	FUEL lb/sec	WATER lb/sec	TOTAL(2) lb/sec	MR _T (3)	MR _W (4)	
EP-IV-N-14	(Continued)																closeness of a liquid oxygen continuous bleed line to the water pressure sensing line. The continuous bleed system was removed and the original short duration bleed reinstalled.
EP-IV-0-15	2-8-66	Full steam 60 sec. test of S.G.S. plenum and Gen. No. 1 at fuel temperature of 80 ± 10°F.															Malfunction shutdown of ignitor. A "no second stage ignition malfunction" shutdown occurred. Test EP-IV-0-16 immediately followed, see below.
EP-IV-0-16	2-8-66	Full steam 60 sec. test of S.G.S. plenum and Gen. No. 1 at fuel temperature of 80 ± 10°F.															Immediately reinitiated start attempt and again a "no-second stage ignition malfunction" shutdown occurred. Investigation disclosed that a broken wire in the module relay control box prevented the second stage propellant valve pilot valve from receiving an opening signal.
EP-IV-P-17	2-10-66	Full steam 60 sec. test of S.G.S. plenum and Gen. No. 1 at fuel temperature of 80 ± 10°F.	39	60	181	161	98	478	93	960	18.69	9.01	43.50	71.89	2.07	1.57	Satisfactory test. Operated that water injection control valve manually to obtain exhaust temperature (average) of 700 ± 100°F. Pre-test injector to chamber bolts torque was 80 to 350 foot-pounds; post-test torque was zero; made pressurization test on chamber and injector chamber flange leaked at 100 psig internal pressure. Post-test dye penetrant inspection showed slight increase in the number of porous spots around the injector and assemblies.

(1) End of test date

() Flow rates are defined as follows: Oxidizer and Fuel are total of each through all generator stages; Water flow rate is total of 3rd stage film cooling and injection water ($W_{W3} + W_{W1}$); total flow rate is total of oxidizer, fuel and water discharged from generator into plenum.

(3) MR_T Mixture Ratio; ratio of total oxidizer to total fuel flowing into all generator stages.

(4) MR_W Mixing Ratio; ratio of total water to total fuel plus total oxidizer discharged into the plenum.

(5) Plenum Temperature - Average = average temperature valve of three individual plenum thermocouples.

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TABLE II

See Steam Generator System Test Nomenclature
(NTO-M-4654) for definition of symbols
Oscillograph data indicated by /XXX/
Strip-chart data indicated by XXX/
Strip-chart and Oscillograph data indicated by XXX/XXX

NERVA TEST OPERATIONS
Nuclear Rocket Development Station
Engine Test Stand No. 1

STEAM GENERATOR SYSTEM TEST DATA TABULATIONS

Test Number	Date	Data Time, Sec.	PfT 34-PT-118 psig	PfM 50-PT-420 psig	TfT 34-TT-483 °F	TfM 50-TT-478 °F	PfJ1-1 50-PT-407 psig	PfV2-1 50-PT-408 psig	PfV3-1 50-TE-405 psig	ΔPfV3-1 50-PT-571 psid	PfJ3-1 50-PT-409 psig	TfJ (s1) 50-TE-701 °F	TfJ (s2) 50-TE-702 °F	TfJ (s3) 50-TE-703 °F	TfJ (s5) 50-TE-704 °F
EP-IV-D4	12-21-65	41	207/-	199/191	-/48	44/43	-/184	-/185	183/185		/137	/91	/177	/51	45/50
EP-IV-E5	12-22-65	58	186/-	165/168	-/38	41/39	163/163	161/165	-/169		/114	/32	/32	-	40/39
EP-IV-F6	12-29-65	147	200/202	195/196	-/45	45/45	188/189	188/190	192/195		/137	/41	/41	/46	42/46
EP-IV-H8	1-10-66	93	218/218	216/214	-/54	48/48	206/210	207/211	207/211		/149	/99	/46	/51	52/51
EP-IV-K11	1-20-66	95	266/-	255/258	66/66	56/55	245/243	250/249	252/247		198/197	/69	/60	/69	60/60
EP-IV-L12	1-25-66	100	277/275	273/274	81/81	66/68	260/258	265/264	262/265		213/217	/58	/53	/75	71/71
EP-IV-P17	2-10-66	99	314/311	304/311	79/81	66/66	287/290	295/298	295/295	198/201	228/230	/59	/58	/79	69/70
Test Number	PoT 28-PT-49 psig	PoM 50-PT-421 psig	ToM 50-TT-479 °F	PoV2-1 50-PT-414 psig	PoV3-1 50-PT-409 psig	PoJ3-1 50-PT-415 psig	ΔPoJ (s) 50-PT-706 psid	Pc1-1 50-PT-416 psig	Pc2-1 50-PT-417 psig	Pc3-1 50-PT-438 psig	ΔPcC (s) 50-PT-706 psid	PsP1 50-PT-425 psig	PsP2 50-PT-426 psig	ΔPfJ (s) 50-PT-705 psid	PfJ (s) 50-PT-703 psig
EP-IV-D4	283/274	277/283	-284/-	/265	270/263	/224	/137	/165	/134	66/65	-/-	45/45	/47	-/39	135/131
EP-IV-E5	293/288	279/280	-285/-	/265	268/266	/200	/109	/150± 3	/126	61/60	-/-	42/40	/42	32/34	120/117
EP-IV-F6	293/285	271/277	-278/-280	/263	265/266	/200	/105	/179± 34	/137	67/67	-/29	50/49	/48	39/44	130/135
EP-IV-H8	277/280	265/265	-277/-278	/251	255/255	/202	/103	/175± 28	/138± 2	67/67	-/32	49/49	/49	53/54	145/146
EP-IV-K11	283/281	266/272	-283/-286	/254	258/258	/222	/121	/178± 97	/148± 2	69/69	28/28	53/54	/56	89/88	190/193
EP-IV-L12	280/-	278/-	-282/-283	/260	262/263	/227	/123	/182	/156	70/72	28/28	55/56	/55	110/111	209/209
EP-IV-P17	292/289	273/277	-283/-283	/258	265/261	/231	/107	/181	/161	99/98	21/22	93/93	/92	105/107	221/221
Test Number	PwH 50-PT-168 psig	PwM 50-PT-427 psig	PwM (s) 50-PT-704 psig	TwM 50-TT-481 °F	ΔPwV-1 50-PT-406 psid	PwV0-1 (s) 50-PT-701 psig	PwJ-1 50-PT-411 psig	PwC03-1 50-PT-410 psig	PwC0-1 (s) 50-PT-708 psig	TwC0-1 50-TT-434 °F	TwP0 50-TT-431 °F	LM1 (s) 50-DT-701 inches	LM2 (s) 50-DT-702 inches	LM3 (s) 50-DT-703 inches	POTTER 50-FT-701 CPS
EP-IV-D4	/218	186/193		69/72	199/196	/120	/119	/127		76/75	/70	/-	/0	/0	-/170
EP-IV-E5	/230	190/177	/197	57/63	200/193	/119	/110	/122		82/82	/73	/,005	/0	/0	160/155
EP-IV-F6	/214	189/189	/193	62/61	166/177	/163	/107	/120		81/-	/75	/0	/0	/0	170/162
EP-IV-H8	/-	186/190	/185	59/57	193/189	/166	/114	/126		79/80	/74	/0	/0	/0	180/181
EP-IV-K11	/219	200/200		62/62	211/214	/178	/124	/133	/119	100/100	/81	/,040	/0	/0	175/179
EP-IV-L12	/213	201/201		59/60	214/208	/164	/121	/127	/121	98/97	/79	/,051	/0	/0	180/182
EP-IV-P17	/222	210/213		60/61	137/133	/194	/128	/124	/201	89/89	/80	/0	/0	/0	185/186

TABLE II (Continued)

NERVA TEST OPERATIONS
Nuclear Rocket Development Station
Engine Test Stand No. 1

STEAM GENERATOR SYSTEM TEST DATA TABULATION

Test Number	Date	Data Time Sec.	Tc1-1 50-TT-435 °F	Tc2-1 50-TT-436 °F	Tc3-1 50-TT-437 °F	TcAV-1 - °F	TsP1 50-TE-504 °F	TsP2 50-TE-505 °F	TsP3 50-TE-506 °F	TsPAV - °F	TsE1 50-TT-428 °F	TsE2 50-TT-429 °F	TsE3 50-TT-430 °F	TsEAV - °F	LwCV-1 - % Open
EP-IV-D4	12-21-65	41	309/277	301/295	290/304	290/290					456/401	504/509	420/434	-/458	/100
EP-IV-E5	12-22-65	58	290/290	279/295	279/285	265/265					405/412	409/441	394/429	409/433	/100
EP-IV-F6	12-29-65	147	314/305	284/287	293/290	272/290					694/699	715/721	693/714	662/704	/14
EP-IV-H8	1-10-66	93	325/337	306/295	306/298	300/306	350/351	676/676	555/547	-/519	726/726	718/723	732/737	715/729	/21
EP-IV-K11	1-20-66	95	412/459	304/299	314/319	347/342	336/346	596/597	634/611	515/519	673/676	668/672	679/664	679/681	/29
EP-IV-L12	1-25-66	100	371/379	297/299	-/-	-/-	287/284	512/505	455/427	420/404	685/691	674/689	678/699	678/699	/23
EP-IV-P17	2-10-66	99	758/768	339/342	325/315	476/478	426/440	773/763	934/938	711/711	930/934	950/954	975/977	952/960	/17
Test Number	IwCV-1 - % Open	Wol Venturi lb/sec	Wo2 Venturi lb/sec	Wo1 Venturi lb/sec	Wf1 Venturi lb/sec	Wf2 Venturi lb/sec	WfI Venturi lb/sec	Wo3 Venturi lb/sec	WoT Venturi lb/sec	Wf3 Venturi lb/sec	WfT Potter lb/sec	WfT Venturi lb/sec	Ww3 Venturi lb/sec	WwF lb/sec	WwT Venturi lb/sec
EP-IV-D4	/100	.020	.423	.443	.043	.103	.146	18.25	18.69	7.80	6.87	7.95	49.00	4.25	53.25
EP-IV-E5	/100	.020	.425	.445	.045	.104	.149	18.45	18.90	7.70	6.32	7.85	48.60	4.09	52.69
EP-IV-F6	/20	.020	.418	.438	.037	.107	.144	18.10	18.54	7.95	6.53	8.09	44.60	4.16	48.76
EP-IV-H8	/-	.018	.403	.421	.034	.109	.143	17.55	17.97	8.10	7.27	8.21	46.10	4.18	50.28
EP-IV-K11	/45	.021	.421	.442	.029	.118	.147	18.25	18.69	8.45	7.11	8.60	49.20	4.31	53.51
EP-IV-L12	//41	.022	.438	.460	.026	.116	.142	18.20	18.66	8.20	7.08	8.34	48.40	4.28	52.68
EP-IV-P17	/39	.020	.416	.436	.027	.130	.157	18.25	18.69	8.85	7.27	9.01	38.60	3.90	43.50
Test Number	Wt1 Venturi lb/sec	Wt2 Venturi lb/sec	WtI Venturi lb/sec	Wt3 Venturi lb/sec	WtT Potter lb/sec	WtT Venturi lb/sec	MR1 Venturi	MR2 Venturi	MR1 Venturi	MR3 Venturi	MRT Potter	MRT Venturi	MRw-1	C* Potter ft/sec	C* Venturi ft/sec
EP-IV-D4	.063	.526	.589	79.30	78.81	79.89	0.47	4.11	3.03	2.34	2.71	2.35	2.00	2680	2645
EP-IV-E5	.065	.529	.594	78.84	77.90	79.43	0.44	4.09	2.99	2.40	2.99	2.41	1.97	2480	2430
EP-IV-F6	.057	.525	.582	74.81	73.83	75.39	0.54	3.91	3.04	2.28	2.84	2.29	1.83	3060	2995
EP-IV-H8	.052	.512	.564	75.93	75.55	76.49	0.52	3.69	2.94	2.17	2.47	2.19	1.92	2990	2950
EP-IV-K11	.050	.539	.589	80.21	79.31	80.80	0.72	3.56	3.00	2.16	2.63	2.17	1.96	3080	3020
EP-IV-L12	.048	.554	.602	79.08	78.56	79.68	0.85	3.78	3.24	2.22	2.64	2.24	1.95	3200	3155
EP-IV-P17	.047	.546	.693	71.20	70.15	71.89	0.74	3.20	2.78	2.06	2.57	2.07	1.57	3670	3580

TABLE III

STEAM GENERATOR 0016 WATER INJECTION
BOLT-ORIFICE MEASUREMENTS

Following the generator full steam tests noted below, the "long" water injection bolt-orifices (AGC P/N 1115989) were removed for inspection and the minimum diameter was measured.

Following Test No.	BOLT-ORIFICE MINIMUM DIAMETER *				
	Bolt 1	Bolt 2	Bolt 3	Bolt 4	Bolt 5
EP-IV-F-6	0.471	0.465	0.463	0.473	0.461
EP-IV-H-8	0.471	0.464	0.462	0.472	0.460
EP-IV-K-11	0.472	0.463	0.462	0.473	0.461
EP-IV-L-12	0.469	0.463	0.464	0.473	0.463
EP-IV-P-17	0.465	0.463	0.461	0.466	0.462

* Approximately 1/2 to 1/4 inch from end of bolt.

FIGURE 1

STEAM GENERATOR MODULE WATER INJECTION SYSTEM PIPING, FROM
WATER MANIFOLD TO COMBUSTION CHAMBER, BEFORE MODIFICATION

FIGURE 2

STEAM GENERATOR MODULE WATER INJECTION SYSTEM PIPING, FROM
WATER MANIFOLD TO COMBUSTION CHAMBER, AFTER MODIFICATION.

FIGURE 3

ETS-1 PROPANE TANK SHOWN COVERED WITH CANVAS TENT FOR HOT AIR
CONDITIONING OF TANK INVENTORY.

FIGURE 4

COMBUSTION CHAMBER S/N 01 LOWER FLANGE STUD BOLTS SHOWING GRINDING REQUIRED ON OUTSIDE EDGE IN ORDER FOR THE BOLTS TO CLEAR AND ENTER MATING SGS PLENUM FLANGE BOLT HOLES.

FIGURE 5

INSTALLATION OF LINEAR MOTION "POTS" ON THE COMBUSTION CHAMBER EXPANSION JOINTS. (NOTE: SPOTS ON COMBUSTION CHAMBER SURFACE TO LEFT OF EACH POT WHERE POT SUPPORT BRACKETS WERE ORIGINALLY GLUED TO CHAMBER WALL.)

Figure 5

Conduction Chamber Pressure and Upper Expansion Joint Movement vs Time

Test No. IX-5-13, 1-25-46

Steam Generator 015, Chamber 200 N.

NSA, ETO-1, NASC, Jackson Place, Nevada

FIGURE 7

INJECTOR 0016 AFTER TEST EP-IV-E-5 SHOWING RESULTS OF DYE PENETRANT INSPECTION. (NOTE: INJECTOR CONDITION BEFORE INITIATION OF 60-SECONDS-DURATION FULL-STEAM TESTS ON EP-IV).

FIGURE 8

INJECTOR 0016 AFTER TEST EP-IV-P-17 SHOWING RESULTS OF DYE PENETRANT INSPECTION. (NOTE: INJECTION CONDITION AFTER CONCLUSION OF TESTS ON EP-IV).

NERVA TEST OPERATIONS

Nuclear Rocket Development Station

APPENDIX I

TO: Distribution

DATE: 3 December 1965

FROM: W. J. Kurtz

NTC-M-4742:HH:WJK:hdd

SUBJECT: Experimental Plan IV Steam Generator Development Test Series
Title of EP: Full Steam Operation of One Steam Generator Module

DISTRIBUTION:

1.0 OBJECTIVES

1.1 Primary Objectives

- 1.1.1 Evaluate generator performance when supplied with temperature conditioned propane to establish:
 - 1) Fuel injection differential pressure as a function of supply temperature.
 - 2) Propane supply temperature conditioning requirements for safe and reliable generator operation.
- 1.1.2 Provide data to verify cause of injector weld crack failures.
- 1.1.3 Evaluate dynamic characteristics of modified facility water supply system.
- 1.1.4 Confirm calculations in connection with expansion requirements for the three expansion joints.

1.2 Secondary Objectives

- 1.2.1 Evaluate performance of modified injection water system.
- 1.2.2 Establish weight flow of propellants and injection water to produce steam at a temperature of $1200 \pm 50^{\circ}$ F as measured in the steam pipe.
- 1.2.3 Evaluate performance of injection bolt orifices.
- 1.2.4 Demonstrate compatibility of permanent facility I&C with the steam generator system.
- 1.2.5 Provide operator training.

2.0 TEST DESCRIPTION

2.1 Set Up

A Steam Generator (S/N 0016) will be installed at plenum position No. 1, and plenum positions Nos. 2 and 3 will be blanked off.

2.2 Water System Evaluation and Calibration

An evaluation of the injection water system will be performed prior to initiating full steam operation. An orifice, sized to produce a pressure drop of 105 psi at a flow rate of 40 lb/sec, will be installed downstream of the injection water control valve at plenum position No. 2.

A simulated standard run procedure will be followed to provide operator training and to establish initial water flow conditions. Also, the injection water control valve will be operated through the entire range, i.e., closed to full open to closed.

2.3 Full Steam Operation

A series of single module full steam tests will be conducted at propane temperatures varying between 40° and $80^{\circ}\text{F} \pm 10^{\circ}$. The generator will be started and brought to idle operation by following a standard start-up procedure. The injection water control valve will be adjusted to go to the maximum open position on full steam command. The injection water valve will remain in the maximum open position during the adjustment tests. For the duration tests, the injection water valve will be adjusted to provide $1200^{\circ}\text{F} \pm 50^{\circ}$ steam at the steam pipe as indicated by the average of 50 TT-428, 429 and 430.

The full steam portion of this EP will consist of a minimum of seven tests as follows:

<u>Test</u>	<u>Propane Supply Temp.</u>	<u>Fuel Vent. Inlet Pressure (Psig)</u>	<u>Test Duration (Sec.)</u>
1. Adjustment*	$40 \pm 10^{\circ}\text{F}$	170	5
2. Adjustment*	$40 \pm 10^{\circ}\text{F}$	170	15
3.	$40 \pm 10^{\circ}\text{F}$	170	60
4.	$50 \pm 10^{\circ}\text{F}$	194	60
5.	$60 \pm 10^{\circ}\text{F}$	218	60
6.	$70 \pm 10^{\circ}\text{F}$	242	60
7.	$80 \pm 10^{\circ}\text{F}$	268	60

* Additional short duration checkout tests may be conducted if deemed to be desirable by NES Project & NTO.

LO_2 temperature to be $282 \pm 5^{\circ}\text{F}$ for all tests, and the LO_2 supply pressure to be adjusted to provide 257 psig at the venturi inlet during full steam operation. The idle operation will be maintained for 30 seconds prior to full steam for Test No. 3.

2.4 Test Schedule

It is expected that one test will be made on each run day until the

scheduled testing is completed. The tests will be conducted in accordance with the Control Room Procedure which will be available on R-1 Day. The access list will be prepared on R-1 Day. Area control will be initiated at 1700 hours on R-Day.

Operations will commence at 1500 hours on R-Day with the setup of instrumentation and the exercising of valves. After area control (ETS-1 Area Control and Safety Standards for Steam Generator Testing, NTO-SOP-0068) is imposed, the LO₂ system bleed-in will be initiated, followed by bleed-in of the propane system. The propellant tanks will be pressurized and the test will be performed. For the water system evaluation, the propellant systems will not be activated.

After completion of the test, the system will be secured to allow re-entry for visual examination of the steam generator. Strip chart and oscillograph records will be examined and preliminary calculations will be performed.

The planned run schedule is as follows:

13 December	Water System Test
15 December	Full Steam Adjustment
16 December	Full Steam Adjustment
17 December	Full Steam Duration
22 December	Full Steam Duration
30 December	Full Steam Duration
5 January	Full Steam Duration
10 January	Full Steam Duration

3.0 SPECIAL SYSTEM EVALUATION REQUIREMENTS

3.1 Bolt Orifice Evaluation

All bolt orifices (P/N 940030-1) will be removed from the generator after each full steam run and evaluated for erosion. At the first measurable evidence of erosion, the following measurements will be recorded:

- 3.1.1 Diameter at area of maximum erosion (minimum diameter).
- 3.1.2 Distance from end of bolt orifice to centerline of maximum erosion.

Detailed photographs of all eroded areas, showing top and side view, will be taken.

3.2 Injector Evaluation

The main stage injector will be removed after each run for evaluation, starting with Test No. 3. Dye penetrant tests will be performed on the injector face. Prior to removal, torque valves on injector bolts will be checked and documented.

3.3 Expansion Joint Evaluation

Dye penetrant tests will be performed on each of the three combustion chamber expansion joints after each full steam 60-second test.

4.0 PREMATURE TEST TERMINATION CRITERIA

The following are specific conditions which warrant shutdown of the steam generator. However, should any erratic operation occur, the test shall be terminated.

- 4.1 Should any combination of main stage injector fuel pressure, $P_{fJ}(S)$, and temperature, $T_{fJ}(S-5)$, fall below Curve "A", Figure 1, Appendix I immediate shutdown shall be executed.
- 4.2 Should the main stage fuel injector differential pressure, $\Delta P_{fJ}(S)$, increase to a value of 80 psid, immediate shutdown shall be executed.
- 4.3 Should the steam temperature, as measured by the average of 50-TT-435, -436 and -437 exceed 1600°F for a duration greater than two seconds, combined with inability of the injection water valve to reduce steam temperature, execute immediate shutdown.
- 4.4 In event of any apparent runaway steam temperature, execute immediate shutdown.
- 4.5 Should the 28 volt D.C. supply reduce to 19 volts, terminate test. In the event the generator will not shutdown on command, turn off all power to the generator.

5.0 SAFETY REQUIREMENTS

- 5.1 The safety requirements specified in Section 2.0 of NTO-I-0023 shall apply as modified to be compatible with requirements for the permanent facility I&C.
- 5.2 Following each test, gas samples shall be taken from the steam plenum with a combustible gas analyzer to verify that the propane valves are properly seated and not leaking.

5.3 After propane has been bled-in, the special temperature rake, $T_{SP}(3)$, will not be operated to change position of probe except during steady state full steam generator operation.

6.0 QUALITY CONTROL REQUIREMENTS

Prior to the start of EF IV Test Series, it shall be verified that all test equipment has been properly calibrated and documented.

7.0 SUPPORT REQUIREMENTS

7.1 Major Test Participants

Alternates

Facility Manager	B. Bernstein	D. Vander Meer
Test Director	H. Henze	N. E. Erickson
		T. A. Keasling
		J. F. Christensor
		B. A. Bernstein
Assistant Facility Engineer, Left	V. Hill	T. A. Keasling
	J. A. Gaccione	E. M. Shultis
Health & Safety	F. M. Cox	R. E. Benshoof
Security	A. B. Bagwell	J. S. Holt
Support	A. R. Marshall	W. J. Reibel
Advisor	NES Project Representative	

7.2 Facility Conditions

7.2.1 GN_2 System

This system will be charged to a normal operating pressure with a maximum pressure of 2500 psig, and a minimum pressure of 1500 psig.

7.2.2 Process Water System

The level in the process water tank shall not be lower than 10 feet.

7.2.3 LO_2 System

The liquid level in the tank will be maintained consistent with economical scheduling; however, the tank level shall not be permitted to drop below 10,000 gallons. The dewar shall be pressurized to provide 257 psig at the third stage venturi inlet during steady state operation.

7.2.4 Propane System

The tank level shall not be permitted to drop below 7,000 gallons. The tank shall be pressurized to provide third stage venturi inlet

pressures, as specified in Section 2.4 for the various temperature conditions.

7.3 Instrumentation and Data Acquisition Requirements

- 7.3.1 Data requirements are as shown in Appendix 2 for the Water System Evaluation, and Appendix 3 for the Full Steam Tests.
- 7.3.2 The event functions connected to the event recorders are to be operational for all tests.
- 7.3.3 The oscillograph chart speed shall be operated at approximately 10 in/sec during transient condition and reduced to approximately 4 in/sec during steady state operation.

The test title and identification, including date, shall appear on each record. All parameters shall be identified on the record.

- 7.3.4 Photographic coverage for selected tests will be provided and show:

- a) Exhaust Stack (infrared)
- b) Steam Generator Enclosure (color)

The camera will run at 24 FPS and use 16mm film. Locations of cameras to be mutually agreed upon between Test Director and Photographer.

- 7.3.5 Television coverage will be used for test observation and for surveillance of the facility from safety consideration. The following cameras will be used, although all existing cameras (14) will be operational and capable of being substituted.

<u>Monitor No.</u>	<u>Camera Position No.</u>	<u>Location</u>	<u>Primary Observation</u>
1	1	North of Ditch	TS, Pad, Ditch
2	5	North End of Shadow Wall	S.G. Enclosure
3	20	Tripod North of LO ₂ Dewar	Pipe Chase Toward TS
4	6	Atop LH ₂ Dewar	Test Stand
5	7	Atop Fill Station	LO ₂ Dewar and TS
6	13	Northeast of Steam Generator	SG Enclosure
7	15	Tripod Southwest of Propane Tank	Propane Tank
8	3	West of Ditch	Flare Stack

7.4 Area Control

Area control will be in effect from 1700 hours on R-Day and remain in effect until securing operations have been completed as announced by the Test Director. Only personnel listed on the access lists issued on R-1 Day will be permitted in the area.

7.5 Pan American Airways

7.5.1 Operating Technicians

The crew normally assigned to the Steam Generator Operation shall be available. Overtime may be necessary in the event of unforeseen circumstances.

7.5.2 Photographic Services

Camera equipment and photographers are required to provide coverage from two locations. Overtime operation may be necessary.

7.6 EG&G

EG&G support is required to process the oscillograph records produced during the test. These records will be delivered to EG&G as available by NTO personnel.

FIG 1

VENTURI INLET PRESSURE VS. FLOW RATE
OVER PROPELLANT TEMPERATURE RANGE
GENERATOR S/N 0016

VENTURI INLET PRESSURE-PSIG

PROPANE FLOW RATE-LB/SEC

Fig. No. 1

LOX FLOW RATE-LB/SEC

CAF
2-12-65

ENGINE TEST STAND NO. 1
NRDS, NEVADA
NERVA TEST OPERATIONS

ENGINE NO. _____
TEST FACILITY Steam Generator System
SERIES & TEST NO. EP IV Water Flow Tests
W.O. NO. _____

PAGE 1 OF 1
DATE OF REQUEST 22 October 1965
TEST ENGR. H. Hense
INSTR. ENGR. R. Cooper

INSTRUMENTATION REQUEST

		RECORDING METHOD												REMARKS			
FUNCTION	RANGE	OSC.			STRIP CHART						L & N-Rec.	DDS-100 s/s	DDS-50 s/s	DDS-10 s/s	AMPEX	EVENTS-Rec.	
		R1	R2	R3	A	B	C	D	E	F							
P _w V-2	0-250	X									1						50-FT-406-2
P _w M	0-250	X									2						50-PT-427
F _w VO(S)	0-200	X									3						Downstream P _w V-1
F _w J-2(S)	0-200	X									4						Downstream 2 way
I _w V-2		X									5						50-FCV-423-2
L _w CV-2		X									6						50-FCV-423-2
T _w CC-1	460-660	X									7						50-TT-434-1
T _w PC	460-660	X									8						50-TT-431

ENGINE TEST STAND NO. 1
NRDS, NEVADA
NERVA TEST OPERATIONS

LINE NO _____
TEST FACILITY Steam Generator System
SERIES & TEST NO. EP IV
W.O. NO. _____

PAGE 1 OF 3
DATE OF REQUEST 21 October 1965
TEST ENGR. H. Henze
INSTR. ENGR. R. Cooper

INSTRUMENTATION REQUEST

[illegible]

		RECORDING METHOD													REMARKS			
FUNCTION	RANGE	OSC.			STRIP CHART							AFEL/LFE	DDS-100 s/s	DDS-50 s/s	DDS-10 s/s	AMPEX	EVENTS-Rec.	
		MW R1	CEC R2	R3	A	B	C	D	E	Meter on TD								
The following are special parameters for EP IV																		
P _w M(S)	0-250	X															Flush Mounted	
T _s P(S)	460-2460		X				X										Temp. Rake	
T _f J(S1)	460-1460		X														Injector Temp.	
T _f J(S2)	460-1460		X														"	
T _f J(S3)	460-660		X														"	
T _f J(S5)	460-660		X							X	X						"	
P _f J(S)	0-200	X								X	X						Injector Press.	
I _r (S)		X					X										Rake Position	
LM1(S)	0-1/2"	X															C/C Linear Motion	
LM2(S)	0-3/16"	X															"	
LM3(S)	0-3/16"	X															"	
ΔP _o J(S)	0-200	X															P _o J3-1 vs P _c 3-1	
ΔP _f J(S)	0-100	X								X	X						P _f J3-1 vs P _c 3-1	
W _f		X															Potter Flowmeter	
P _w VO(S)	0-200		X														Downstream P _w V-1	

NERVA TEST OPERATIONS

Nuclear Rocket Development Station

TO: Steam Generator System Distribution **DATE:** 30 December 1965
FROM: W. J. Kurtz *W. J. Kurtz* NTO-M-8351: HH:WJK:da
SUBJECT: Experimental Plan IV - Full Steam Operation of One Steam Generator
Module: Supplement No. 2.

Reference: (a) NTO-M-4742: HH:WJK:hdd, dated 3 December 1965.

The purpose of this supplement is to make the following changes to Reference (a).

- 1). Change the fuel flow rate in paragraph 2.3 from 7.1 lb/sec. to 7.7 lb/sec.
- 2). Change paragraph 3.2 to read: "The main stage injector will be removed after each run for evaluation, starting with Test No. 2 (EP-IV-E-5). Dye penetrant....."

NERVA TEST OPERATIONS

Nuclear Rocket Development Station

TO: Steam Generator System Distribution DATE: 10 January, 1966
 FROM: W. J. Kurtz *WJK* NTO-M-8358: HH:WJK:dsa
 SUBJECT: Experimental Plan IV - Full Steam Operation of One Steam Generator
 Module: Supplement No. 3

Reference: (a) NTO-M-4742: HH:WJK:hdd, dated 3 December 1965.

The purpose of this supplement is to make the following changes to Reference (a).

1. Change paragraph 2.3 to read:
 "...between 40° and 80° F $\pm$ 10°. The Propane Tank Temperature (34-TT-483) will be monitored for four minutes after each full steam test. The generator..."

"...the average of 50-TT-428, -429, - 430. These three temperature transducers will be moved from their present position to the exhaust stack exit. An additional three temperature transducers will be installed in the plenum exit flange."

2. Delete from Page 2 of 3, Appendix 3:

<u>FUNCTION</u>	<u>RANGE</u>	<u>OSC.</u>	<u>STRIP CHART</u>	<u>REMARKS</u>
TsP1	500-2260	X	X	50-TT-428
TsP2	500-2260	X	X	50-TT-429
TsP3	500-2260	X	X	50-TT-430
TsPAV	500-2260	X	X	

3. Add to Page 3 of 3, Appendix 3:

<u>FUNCTION</u>	<u>RANGE</u>	<u>OSC.</u>	<u>STRIP CHART</u>	<u>REMARKS</u>
TsP1	492-2760°R	X	X	50-TE-504
TsP2	492-2760°R	X	X	50-TE-505
TsP3	492-2760°R	X	X	50-TE-506
TsPAV	492-2760°R	X	X	
TsE1	492-2760°R	X	X	50-TT-428
TsE2	492-2760°R	X	X	50-TT-429
TsE3	492-2760°R	X	X	50-TT-430
TsEAV	492-2760°R	X	X	

4. Add to Paragraph 7.1

Instrumentation and controls

R. D. Cooper

P. D. Zaremba

NERVA TEST OPERATIONS

Nuclear Rocket Development Station

TO: Steam Generator System Distribution

DATE: 28 January, 1966
NTO-M-8363: HH:WJK:dsa

FROM: W. J. Kurtz *W. J. Kurtz*

SUBJECT: Experimental Plan IV - Full Steam Operation of One Steam Generator
Module: Supplement No. 4

Reference: (a) NTO-M-4742: HH:WJK:hdc, dated 3 December 1965.

The purpose of this supplement is to make the following additions to Reference (a):

1. Additional tests requested by NES Project:

A) Special Water Flow Test of Plenum Coolant Passage.

The purpose of this test is to determine the water pressure drops across various points within the plenum coolant passage while simulating plenum flow only. Pressures will be recorded from five temporary visual gauges. The ambient water temperature will be recorded before and after the test.

B) Main Stage Fuel Venturi Recalibration.

Main stage fuel flow rates from Thiokol's venturi calibration do not correspond to potter flow meter data. The purpose of this test is to establish propane flow rates through the venturi as a function of upstream pressures for a given propane temperature (ambient) using the potter flow meter as a calibration standard in series with the venturi.

The pressure upstream of the fuel venturi will be adjusted in four steps to approximate flow rates of 6.0, 7.0, 8.0 and 9.0 lb/sec.

The following data will be taken:

Pft, Propane tank pressure
Tft, Propane tank temperature
Pfm, Propane manifold pressure
Tfm, Propane manifold temperature
Pfv3, Propane venturi inlet pressure
Pfv03, Propane venturi outlet pressure
Pfi3, Propane injector inlet pressure

2. Enclosed is Appendix 3, revision a).

NERVA TEST OPERATIONS

W.O. NO. _____

INSTR. ENGR. R. Cooper

Revision a) 18 January 1966

[illegible]

[illegible]

		RECORDING METHOD												REMARKS			
FUNCTION	RANGE	OSC.			STRIP CHART						L & N	Meter, T.D.	DDS-50 s/s	DDS-10 s/s	AMPEX	EVENTS-Rec.	
		R1	R2	R3	A	B	C		E	CSCR "A"							
LO ₂ VALVE PILOT*			X	X												X	S.G. Module #1
FUEL VALVE PILOT*			X	X												X	"
All S.G. Module #1 Events on Standard Setup																	
*These functions to be on the same galvo.																	
The following are special parameters for EP-IV																	
P _w CO3-1 (S) 0-227 psig			X														50-PT-708
T _f J (S1) 32-885°F			X														50-TE-701
T _f J (S2) 32-885°F			X														50-TE-702
T _f J (S3) 32-251°F			X														50-TE-705
T _f J (S5) 32-251°F			X							6		X					50-TE-704
P _f J (S) 0-300 psig				X						7		X					50-PT-703
LM1 (S) 1/4"				X													50-DT-701
LM2 (S) 1/4"				X													50-DT-702
LM3 (S) 1/4"				X													50-DT-703
ΔP _o J (S) 0-200 psid				X													50-DT-706
ΔP _f J (S) 0-200 psid				X						8		X					50-PT-705
W _f				X			6										50-FT-701
P _w VO (S) 0-200 psig			X														50-PT-701
ΔP _c C (S) 0-50 psid				X			8										50-PT-707
T _f T (S) 32-142°F											X						

NERVA TEST OPERATIONS

Nuclear Rocket Development Station

TO: Steam Generator System Distribution

DATE: 18 February, 1966

FROM: W. J. Kurtz *W. J. Kurtz*

NTO-M-8366: HH:WJK:dsa

SUBJECT: Experimental Plan IV - Full Steam Operation of One Steam Generator
Module: Supplement No. 5

Reference: (a) NTO-M-4742: HH:WJK:hdd, dated 3 December 1965.

The purpose of this supplement is to make the following addition to Reference (a):

Beginning with test EP-IV-H-8, the steam temperature (as measured by the average 50-TT-428, -429, and -430) shall be controlled at 700 ± 100 °F.

Appendix II

STEAM GENERATOR DEVELOPMENT PROGRAM

FIELD ACTION REQUESTS INDEX

(FAR's Received July 9 thru February 10, 1966)

<u>FAR NO.</u>	<u>TITLE</u>	<u>Date Received</u>	<u>Date Completed</u>
S 080	MODIFICATION OF GENERATOR	8-8-65	Cancelled
S 081	SHIPMENT OF S/N 0017 COMBUSTION CHAMBER TO THIOKOL	8-19-65	8-20-65
S 082	REMOVAL OF S/N 0016 COMBUSTION CHAMBER FROM S. G. ASSEMBLY	8-26-65	9-3-65
S 083	RECEIVING INSPECTION ON S.G. INJECTOR ASSEMBLY S/N 01 (SPARE)	8-26-65	Cancelled
S 084	COMPLETE RECEIVING INSPECTION ON PO/NP 000308 SPARE PARTS (REFER TO FAR's 083)	9-3-65	Cancelled
S 085	SHIPMENT OF S.G. MODULE ASSEMBLY (FRAME AND ASSOCIATED VALVING) S/N 0019	9-2-65	Cancelled
S 086	SIMPLIFY THE WATER INJECTION CIRCUIT	9-9-65	Cancelled
S 087	PROVIDE BYPASS LINES FOR FACILITY VALVES 50-RSV-433 & 434	9-9-65	Cancelled
S 088	REMOVAL OF FILTER ELEMENT (50-LF-428) FROM FACILITY H ₂ O SUPPLY	9-9-65	9-14-65
S 089	MODIFY VALVE PLUG & SEAT IN WATER INJECTION VALVE	9-9-65	Cancelled
S 090	MACHINING OFF SERRATIONS FROM SPARE COMBUSTION CHAMBER	9-9-65	Cancelled
S 091	HIGH TEMPERATURE SHUTDOWN, ACTIVATION OF JUMPER TERMINALS 2 AND 4 OF RELAY R13	9-10-65	Cancelled
S 092	SHIPMENT OF STEAM GENERATOR COMBUSTION CHAMBER SPARE	9-17-65	9-23-65
S 093	PREFILLING OF STEAM GENERATOR WATER SUPPLY MANIFOLD	9-17-65	10-28-65
S 094	MODIFICATION OF THE WATER INJECTION SYSTEM	9-27-65	12-1-65

Appendix II (Continued)

<u>FAR NO.</u>	<u>TITLE</u>	<u>Date Received</u>	<u>Date Completed</u>
S 095	INSTALLATION OF 50-PS-404 (PLENIUM COOLANT WATER OUTLET ΔP)	9-29-65	10-28-65
S 096	SHIPMENT OF IGNITOR ASSEMBLY SPARE TO AGC-SACTO	9-29-65	10-7-65
S 097	FLOW METER INSTALLATION	9-5-65	11-18-65
S 098	TRANSDUCER INSTALLATION, STATHAM MODEL - PL280	9-4-65	11-16-65
S 099	INSTALLATION OF GREYRAD CALORIMETRIC PROBE	10-4-65	12-21-65
S 100	INTERCHANGING OF FUEL AND LOX VENTURIS FROM S.G. UNIT #19 TO #16 S/N	10-12-65	OPEN
S 101	REPAIR WELD OF GENERATOR MODULE INJECTION WATER SUPPLY LINE (MOD 0016, 0017, 0018)	10-11-65	10-12-65
S 102	REMOVAL OF HI TEMPERATURE SWITCH PROBES & WATER INJECTION PINTLES	10-14-65	10-19-65
S 103	WATER INJECTION SYSTEM CONTROL	10-20-65	12-15-65
S 104	DELETION OF THE GASEOUS NITROGEN, LIQUID OXYGEN, PROPANE & WATER MANIFOLD PRESSURE CONTROL SWITCH CIRCUITRY	10-20-65	10-28-65
S 105	CHECK ALL EQUIPMENT ON THE STEAM GENERATOR FOR PROPER OPERATION	10-21-65	12-3-65
I 106	MODIFICATION OF PLENUM DRAIN VALVE CONTROL CIRCUIT	10-21-65	11-4-65
S 107	FIELD X-RAY OF DESIGNATED S.G. PIPES	10-22-65	10-27-65
S 108	DISPLACEMENT XDUCER MTG. & HARDWARE	10-27-65	12-20-65
S 109	DELETE THE AUTOMATIC BLEED SYSTEM ON LOX AND PROPANE VALVE 436 & 435	10-27-65	11-3-65
S 110	FIELD X-RAY OF DESIGNATED S.G. PIPES	11-1-65	11-24-65
S 111	REPAIR OF STUD MISMATCH ON C.C. S/N 101	11-5-65	11-12-65

Appendix II (Continued)

<u>FAR NO.</u>	<u>TITLE</u>	<u>Date Received</u>	<u>Date Completed</u>
S 112	FIELD X-RAY OF DESIGNATED S.G. PIPES FOR POSITION 2 & 3	11-8-65	11-24-65
S 113	WATER CONTROL VALVE SUPPORT BRACKETS	11-10-65	12-8-65
I 114	MANUAL PURGE MODIFICATION	11-18-65	1-10-66
I 115	REMOVAL OF LOX & PROPANE BLEED PRESSURE SWITCHES	11-18-65	12-15-65
I 116	MAIN STAGE LOX VALVE LIMIT SWITCH	11-18-65	12-1-65
S 117	RECEIVING PROCEDURE FOR STEAM GENERATOR PARTS	11-18-65	1-15-66
S 118	INJECTOR INSTALLATION I INSTRUCTION FLEX GASKETS	11-18-65	12-18-65
I 119	THERMOCOUPLE CALIBRATION	11-22-65	12-6-65
I 120	INJECTOR PERFORMANCE MONITOR (TEMPORARY)	11-22-65	12-20-65
S 121	PROOF TEST OF S.G.S. PIPING	11-24-65	11-26-65
S 122	REMOTE COMBUSTIBLE GAS SAMPLING SYSTEM INST.	12-2-65	12-3-65
S 123	CHILL DOWN OF LO2 SUPPLY LINES TO SG#2 & SG#3	12-3-65	12-3-65
S 124	PRESSURE TRANSDUCERS, STEAM GENERATOR SYSTEM	12-3-65	12-20-65
S 125	CHANGE TO FAR I 120	12-3-65	12-15-65
I 126	FAR 116, CHANGE TO	12-3-65	12-15-65
S 127	PERFORM DYE PENETRANT INSPECTION OF S/N 18 INJECTOR	12-8-65	12-10-65
S 128	REPLACEMENT OF GN2 LINE	12-8-65	12-9-65
S 129	REPLACEMENT OF SOFT SEALS IN MAIN LOX PROP. VALVE	12-8-65	12-15-65
S 130	SHIPMENT OF DAMAGED THERMOCOUPLES	12-10-65	12-15-65
S 131	ADDENDA, FLEXITALLIC GASKET INSTALLA- TION PROCEDURE FAR 118	12-14-65	CANCELLED

Appendix II (Continued)

<u>FAR NO.</u>	<u>TITLE</u>	<u>Date Received</u>	<u>Date Completed</u>
S 132	FACILITY WATER SAMPLES FROM PROCESS WATER SYSTEM	12-16-65	1-3-66
S 133	DYE PENETRANT INSPECTION OF S/N 01 & S/N 0019 S.G. INJECTIONS	12-16-65	12-20-65
S 134	FLEXITALLIC GASKET INSTALLATION PROCEDURE AMENDMENT	12-27-65	1-25-66
S 135	SGS CLEANLINESS LEVELS	12-27-65	1-4-66
S 136	HI-TEMPERATURE SWITCH LEAK, SG-1	12-17-65	12-20-65
S 137	GREYRAD CALORIMETRIC PROBE	12-28-65	1-15-65
S 138	EP-IV TEST OF 30 DECEMBER '65	12-30-65	12-29-65
139	PROPANE SAMPLES	12-30-65	OPEN
140	POTTER FLOWMETER, CALIBRATION	12-30-65	1-10-66
141	FLOW TEST, SGS PROPANE SYSTEM	12-30-65	1-14-66
142	EXHAUST PIPE T/C AMENDMENT	1-3-66	1-10-66
143	COMPLETE DISASSEMBLY & INSPECTION OF SG #19 PIPING	1-5-66	1-13-66
144	OVERHAUL OF MAIN PROP. VALVE	1-10-66	3-1-66
145	RELAY UNIT & EQUIPMENT BOX ELECTRICAL CONNECTOR REWIRING	1-20-66	1-20-66
146	DISASSEMBLY & INSPECTION OF SG #16, 17 & 18 PIPING	1-11-66	2-21-66
147	FABRICATION OF LOX & WATER SUPPLY & PROPANE HEADERS	1-11-66	3-18-66
148	(REV. A) RELOCATION OF LINEAR MOTION TRANSDUCER, 50-DT-701	1-12-66	1-24-66
149	RELOCATION OF SPECIAL FLUSH DIAPHRAGM PRESS. TRANSDUCER	1-12-66	1-13-66
150	RETERMINATION OF STANDBY RELAYS R-107, 108, 109	1-12-66	1-12-66
151	INSTALLATION OF S/N 0017 COMBUSTION CHAMBER	1-26-66	2-2-66

Appendix II (Continued)

<u>FAR NO.</u>	<u>TITLE</u>	<u>Date Received</u>	<u>Date Completed</u>
152	(REV. A) REWORK OF THE FUEL VENTURI FOR S/N 16,17,18 & 19 S G.	1-26-66	3-16-66
153	REMOVAL OF LO2 BLEED VALVE	1-27-66	2-3-66
154	INSTALLATION OF WATER INJECTION AND BLANK PINTLES INTO COMBUSTION CHAMBER S/N 0017	2-1-66	2-4-66
155	INSTALLATION OF JACKET SQUEEZE GASKET ON S.G. S/N 0017 COMBUSTION CHAMBER	1-27-66	Recinded 2-3-66
156	PROVIDE READY-TO-START CIRCUITRY DEPENDENT ON TDR-& RELAY	2-1-66	2-2-66
157	INSTALLATION OF WATER PINTLES IN S.G. MODULE S/N 0017 COMBUSTION CHAMBER	2-2-66	2-4-66
158	RE-INSTALL LOX BLEED VALVE	2-8-66	2-8-66
159	ELONGATION OF BOLT HOLES IN EACH S.G. MODULE SKID TOP SUPPORT	2-8-66	2-15-66
160	REMOVAL OF WATER RETURN LINES (WAS USED AS A SUPPORT FOR THE ORIGINAL 3-WAY WATER INJECTION LINE)	2-8-66	3-1-66
161	SHIPMENT OF S/N's 0019 AND 01 S.G. COMBUSTION CHAMBERS TO AGC-SACTO	2-9-66	2-18-66

STEAM GENERATOR SYSTEM TEST NOMENCLATURE

NOMENCLATURE	TAG NO.	DESCRIPTION
P _O T	28-PT-49	LO ₂ Tank Pressure
P _O TR	28-PT-440	LO ₂ Tank Pressure Regulator Dome Pressure
P _g H	32-PT-02	GN ₂ Header Pressure
P _f T	34-PT-118	Propane Tank Pressure
P _f TR	34-PT-439	Propane Tank Pressure Regulator Dome Pressure
P _w H	50-PT-168	Process Water Header Pressure
P _f M	50-PT-420	Propane Manifold Pressure
P _O M	50-PT-421	LO ₂ Manifold Pressure
P _g M1	50-PT-574	150# GN ₂ Manifold Pressure
P _w M	50-PT-427	Process Water Manifold Pressure
P _g M2	50-PT-428	450# GN ₂ Pressure
P _w PO	50-PT-424	Plenum Coolant Water Outlet Pressure
P _s P1	50-PT-425	Plenum Steam Pressure #1
P _s P2	50-PT-426	Plenum Steam Pressure #2
P _f J1-1, -2, -3	50-PT-407	1st Stage Propane Injector Pressure
P _f V2-1, -2, -3	50-PT-408	2nd Stage Propane Venturi Inlet Pressure
P _f J3-1, -2, -3	50-PT-409	3rd Stage Propane Injector Pressure
P _f V3-1, -2, -3	50-FT-405	3rd Stage Propane Venturi Inlet Pressure
ΔP _f V3-1, -2, -3	50-PT-571	3rd Stage Propane Venturi Differential Pressure
P _O V2-1, -2, -3	50-PT-414	2nd Stage LO ₂ Venturi Inlet Pressure
P _O J3-1, -2, -3	50-PT-415	3rd Stage LO ₂ Injector Pressure
P _O V3-1, -2, -3	50-FT-409	3rd Stage LO ₂ Inlet Venturi Pressure

STEAM GENERATOR SYSTEM TEST NOMENCLATURE

NOMENCLATURE	TAG NO.	DESCRIPTION
P_w C01-1, -2, -3	50-PT-422	1st Stage Coolant Water Outlet Pressure
P_w C02-1, -2, -3	50-PT-423	2nd Stage Coolant Water Outlet Pressure
P_w C03-1, -2, -3	50-PT-410	3rd Stage Coolant Water Outlet Pressure
P_w J-1, -2, -3	50-PT-411	Water Injector Pressure
ΔP_w V-1, -2, -3	50-FT-406	Water Venturi Differential Pressure
P_w V0-1, -2, -3	50-PT-701	Water Venturi Outlet Pressure
P_c 1-1, -2, -3	50-PT-416	1st Stage Chamber Pressure
P_c 2-1, -2, -3	50-PT-417	2nd Stage Chamber Pressure
P_c U3-1, -2, -3	50-PT-709	3rd Stage Chamber Upper Pressure
P_c L3-1, -2, -3	50-PT-438	3rd Stage Chamber Lower Pressure
T_f T	34-TT-483	Propane Tank Temperature
T_s E1	50-TT-428	Exhaust Stack Steam Temperature #1
T_s E2	50-TT-429	Exhaust Stack Steam Temperature #2
T_s E3	50-TT-430	Exhaust Stack Steam Temperature #3
T_s EAV		Exhaust Stack Steam Average Temperature
T_s P1	50-TE-504	Plenum Steam Temperature #1
T_s P2	50-TE-505	Plenum Steam Temperature #2
T_s P3	50-TE-506	Plenum Steam Temperature #3
T_s PAV		Plenum Average Steam Temperature
T_w PO	50-TT-431	Plenum Coolant Water Outlet Temperature
T_w C0-1, -2, -3	50-TT-434	Coolant Water Outlet Temperature
T_c 1-1, -2, -3	50-TT-435	Main Chamber Exit Temperature #1
T_c 2-1, -2, -3	50-TT-436	Main Chamber Exit Temperature #2

STEAM GENERATOR SYSTEM TEST NOMENCLATURE

NOMENCLATURE	TAG NO.	DESCRIPTION
T_c 3-1, -2, -3	50-TT-437	Main Chamber Exit Temperature #3
T_c AV-1, -2, -3		Main Chamber Exit Average Temperature
T_M T_f	50-TT-478	Propane Manifold Temperature
T_M T_o	50-TT-479	LO ₂ Manifold Temperature
T_M T_w	50-TT-481	Process Water Manifold Temperature
T_o H	50-TT-480	LO ₂ Transfer Line Temperature
I_w CV	50-FC-423	Injection Water Valve Current
L_w CV	50-FC-423	Injection Water Valve Position
T_f J1-1, -3	50-TE-701	Injector Propane Temperature #1
T_f J2-1, -3	50-TE-702	Injector Propane Temperature #2
T_f J3-1, -3	50-TE-703	Injector Propane Temperature #3
T_f J4-1, -3	50-TE-704	Injector Propane Temperature #4
P_f J-1, -3	50-PT-703	Injector Propane Pressure
ΔP_f J3-1, -3	50-PT-705	Injector Propane Differential Pressure
ΔP_o J3-1, -3	50-PT-706	Injector LO ₂ Differential Pressure
T_o B-1	50-TE-707	LO ₂ Bleed Temperature
$\dot{W}_f$	50-FT-701	Propane Potter Flow Rate
P_w CQ3-1 (S)	50-PT-708	Special 3rd Stage Coolant Water Outlet Pressure
P_w M (S)	50-PT-704	Special Water Manifold Pressure
ΔP_c C	50-PT-707	3rd Stage Chamber Differential Pressure
LM ₁	50-DT-701	Upper Torus Expansion
LM ₂	50-DT-702	Middle Torus Expansion
LM ₃	50-DT-703	Lower Torus Expansion

STEAM GENERATOR SYSTEM TEST NOMENCLATURE

NOMENCLATURE	DESCRIPTION
$\dot{W}_{O1-1, -2, -3}$	1st Stage Oxidizer Flow
$\dot{W}_{O2-1, -2, -3}$	2nd Stage Oxidizer Flow
$\dot{W}_{OI-1, -2, -3}$	Idle Unit Oxidizer Flow ($\dot{W}_{O1} + \dot{W}_{O2}$)
$\dot{W}_{O3-1, -2, -3}$	3rd Stage Oxidizer Flow
$\dot{W}_{Ot-1, -2, -3}$	Total Oxidizer Flow ($\dot{W}_{OI} + \dot{W}_{O3}$)
$\dot{W}_{f1-1, -2, -3}$	1st Stage Fuel Flow
$\dot{W}_{f2-1, -2, -3}$	2nd Stage Fuel Flow
$\dot{W}_{fI-1, -2, -3}$	Idle Unit Fuel Flow ($\dot{W}_{f1} + \dot{W}_{f2}$)
$\dot{W}_{f3-1, -2, -3}$	3rd Stage Fuel Flow
$\dot{W}_{fT-1, -2, -3}$	Total Fuel Flow ($\dot{W}_{fI} + \dot{W}_{f3}$)
$\dot{W}_{WC-1, -2, -3}$	Jacket Coolant Water Flow
$\dot{W}_{w3-1, -2, -3}$	Injection Water Flow
$\dot{W}_P$	Plenum Coolant Water Flow
$\dot{W}_{wF-1, -2, -3}$	3rd Stage Film Cooling Water Flow
$\dot{W}_{wt-1, -2, -3}$	$\dot{W}_w3 + \dot{W}_wF$
$\dot{W}_{T1-1, -2, -3}$	$\dot{W}_O1 + \dot{W}_f1$
$\dot{W}_{T2-1, -2, -3}$	$\dot{W}_O2 + \dot{W}_f2$
$\dot{W}_{TI-1, -2, -3}$	$\dot{W}_OI + \dot{W}_{fI}$ or $\dot{W}_{T1} + \dot{W}_{T2}$
$\dot{W}_{T3-1, -2, -3}$	$\dot{W}_O3 + \dot{W}_f3 + \dot{W}_{wF} + \dot{W}_w3$
$\dot{W}_{TT-1, -2, -3}$	$\dot{W}_{TI} + \dot{W}_{T3}$
$\dot{W}_T$	$\sum \dot{W}_{TT}$

STEAM GENERATOR SYSTEM TEST NOMENCLATURE

NOMENCLATURE	DESCRIPTION
$MR_1-1, -2, -3$	$\dot{W}_O 1 / \dot{W}_F 1$
$MR_2-1, -2, -3$	$\dot{W}_O 2 / \dot{W}_F 2$
$MR_I-1, -2, -3$	$\dot{W}_O I / \dot{W}_F I$
$MR_3-1, -2, -3$	$\dot{W}_O 3 / \dot{W}_F 3$
$MR_t-1, -2, -3$	$\dot{W}_O T / \dot{W}_F t$
MR_T	$\sum \dot{W}_O t / \sum \dot{W}_F T$
MR_W	$\sum \dot{W}_W t / (\sum \dot{W}_O t + \sum \dot{W}_F t)$
$MR_W-1, -2, -3$	$\dot{W}_W t / (\dot{W}_O t + \dot{W}_F t)$
C^*_I	$(P_C 2 \times A_t 2 \times g) / \dot{W}_T I$
C^*	$(P_s P \times A_t P \times g) / \dot{W}_T$

Notes:

1. Dash numbers refer to Steam Generator System module numbers.
2. $P_C 2$ and $P_s P$ for C^* calculations are psia.

APPENDIX IV

ANALYSIS OF MAIN STAGE VENTURI PERFORMANCE

1. FUEL SYSTEM

1.1 Introduction

Prior to the initiation of EP-IV, a two inch rotating-vane flow meter (Potter) was installed in the facility line between the filter (50-LF-436) and the shutoff valve 50-RSV-482; the purpose was to determine if and when the venturi decavitated during the scheduled injector development tests. Comparison of the Potter and venturi flow rates during the first 15 seconds full-steam test indicated a 1.53 lb/sec variation with the Potter indicating 6.17 lb/sec and the venturi indicating 7.70 lb/sec. The venturi flow rate was obtained from Thiokol supplied curves. The Potter meter was calibrated and the factor of 12.86 changed insignificantly to 12.91.

A vapor pressure determination was made from a propane sample drawn from storage tank V-3401 and the following data was obtained:

Temp °F	Vapor Pressure Experimental psia	Vapor Pressure Reference psia
102.2	201	—
101.1	197	—
98.2	194	181.7
73.4	135	129.0
72.8	134	127.9
68.6	126	121.3
32.2	72	68.2

Reasonably good correlation exists between the experimental and published data.

All other instrumentation was checked and verified to be operating correctly. The remaining full-steam tests evidenced the same discrepancy in fuel flow rates. Prior to the last test, EP-IV-P-17, the fuel venturi was modified by incorporating a throat tap and in this test the venturi to throat differential pressure was measured.

1.2 Analysis of Data

For the first five tests in which the throat pressure tap was not available a series of calculations were performed assuming a C_d of unity and utilizing the Bernoulli energy equation.

The results of this analysis (see Table 1) indicated non-cavitating flow through the venturi (the calculated throat pressure exceeding the vapor pressure).

A venturi inlet to throat K_w and inlet to outlet K_w as then calculated,

$$\text{the } K_w = \frac{\dot{w}}{\sqrt{\Delta P \rho}} \quad \text{where}$$

$\dot{w}$ = propane flow rate, lb/sec
 ρ = specific gravity
 ΔP = pressure differential, psi

The throat pressure used is the calculated value determined in Table 1.

Table 2 shows the results of this determination. It appears that the inlet to throat K_w is consistent and has a value of 0.885 while the overall K_w is a variable ranging from 1.15 to 1.42. For a non-cavitating venturi the overall K_w should also remain constant.

A review of both Thiokol and NTO fuel venturi flow calibration test data indicated that, under cavitation conditions, the inlet to throat K_w is also 0.885, assuming unity for C_d .

On test EP-IV-P-17 it was determined that the throat pressure was 97 psig and that vapor pressure for the propane supplied at 66°F was 102 psig which indicated that cavitation in fact existed. Again using the Bernoulli energy equation, it was determined that these conditions exist if the C_d at the throat was 0.8. Table 3 is calculations in which the C_d was determined.

Assuming vapor pressure at the throat for all tests conducted during EP-IV, the C_d and percent recovery were determined and this data is presented in Table 4. Figure 1 presents a curve of C_d vs percent recovery in which the trend indicates a higher C_d with higher percent recovery. Included in this figure is shown the fuel venturi flow calibration data obtained at NRDS.

1.3 Interpretation of Analysis

The data indicates that cavitation probably existed during all full steam tests with the flow rate dependent upon the system backpressure. During the flow tests a C_d of approximately unity was achieved with low recovery pressures. As the recovery pressure was increased, the effective flow area was reduced, decreasing the fuel flow rate. A point will eventually be reached where cavitation will no longer exist and at this point the C_d should be minimum. As the recovery pressure is further increased, the flow rate will be further reduced but the C_d should again approach unity. Because of the varying effective throat area, the differential pressure drop across the venturi is not a measure of the flow rate. Review of the venturi design drawings indicates an abrupt convergence section (74° included angle) and a discharge section with a 12° included angle. Further, the venturi inlet and outlet diameter is

approximately 1.15 inches while the inside diameter of the pipe is 2.07 inches, which should both distort the flow and create turbulence losses.

Further testing will be performed with water to determine whether the above phenomenon is a function of venturi design or the propellant used.

2. OXIDIZER MEASURING SYSTEM

2.1 Introduction

As a result of the analysis made in the fuel system, an analysis was made on the oxidizer system. The oxidizer system does not contain Potter or similar type flow meter as a check on the venturi flow rate nor does the venturi have a throat tap incorporated for differential pressure measurements. The flow rate is determined using the inlet pressure and temperature and the Thiokol supplied calibration curve. The venturi is designed similar to the fuel venturi.

2.2 Analysis

Table 5 presents the results of calibrations using the Bernoulli energy equation in which the effective area of the throat of the venturi was determined. The effective area was determined to be 88% of the actual area.

2.3 Interpretation of Analysis Based on the Results of the Propane.

Based on the results of the Propane system, one would expect the C_d to be unity instead of 0.91. Installation of a flow meter upstream of the venturi and the modification of the venturi to include a throat tap would confirm the calculated value of C_d . The LO_2 flow rate could be in error by approximately 12%.

Test No.	T _{fM} °F	$\dot{w}_f$ lb/sec	$(\dot{w}_f)^2$	ρ	$(w_f)^2$	$(\dot{w}_f)^2 (1.27)$ psi	P _{fV3} psig	P _{thr} psig	P _{vP} psig	P _{fV3} psig
E5	39	6.17	38.07	.526	72.37	91.91	169	77	63	114
F6	45	6.39	40.83	.520	78.52	99.72	195	95	71	137
H8	48	7.13	50.84	.518	98.14	124.64	211	86	74	149
K11	55	6.97	48.58	.512	94.88	120.50	247	127	84	197
L12	68	6.94	48.16	.502	95.94	121.85	265	143	107	217
P17	66	6.44	47.0	.504	95.20	121.00	295	174	102	230

$$K_w = \frac{w}{\sqrt{\rho \Delta P}}$$

TABLE 2

Test No	VENTURI THROAT K_w					VENTURI OVERALL K_w					% Rec. P _{fJ3} P _{fV3}
	$\frac{\Delta P}{P_{fV3}-P_{thr}}$ psid	ρ	$\sqrt{\rho \Delta P}$	$\dot{w}_f$ lb/sec	K_w	$\frac{\Delta P}{P_{fV3}-P_{fJ3}}$ psid	ρ	$\sqrt{\rho \Delta P}$	$\dot{w}_f$ lb/sec	K_w	
E5	92	.526	6.94	6.17	.890	55	.526	5.36	6.17	1.15	67.5
F6	100	.520	7.20	6.39	.887	58	.520	5.49	6.39	1.16	70.2
H8	125	.518	8.14	7.13	.876	62	.518	5.66	7.13	1.25	70.6
K11	120	.512	7.84	6.97	.890	50	.512	5.06	6.97	1.38	79.8
L12	122	.502	7.84	6.94	.885	48	.502	4.90	6.94	1.42	82.0
P17	121	.504	7.82	6.94	.886	65	.504	5.71	6.94	1.21	78.0

Avg K_w .885

TABLE 3

ANALYSIS OF DATA FROM EP-IV-P-17

$$\begin{aligned}
 H_1 + \frac{v_1^2}{2g} &= H_2 + \frac{v_2^2}{2g} \\
 (P_1 - P_2) \frac{(144)}{\rho(62.4)} &= H_1 - H_2 = \frac{v_2^2 - v_1^2}{2g} \\
 (\Delta P) \frac{(144)(2g)}{\rho(62.4)} &= v_2^2 - v_1^2 = v_2^2 - \left[\frac{\dot{w}_f}{\rho(62.4) / (3.36 / 144)} \right]^2 \\
 \Delta P \frac{(144)(2g)}{(\rho)(62.4)} + \dot{w}_f^2 &= \left[\frac{144}{(\rho)(62.4)(3.36)} \right]^2 = \dot{w}_f^2 \left[\frac{144}{(\rho)(62.4) C_d A .21} \right]^2 \\
 \Delta P \frac{148}{\rho} + \frac{\dot{w}_f^2}{\rho} (.46) &= \frac{\dot{w}_f^2}{\rho} \left[5.32 \right] \left[\frac{1}{C_d A} \right]^2
 \end{aligned}$$

For Test EP-IV-P-17

$$\begin{aligned}
 \Delta P &= 198 \\
 \dot{w}_f &= 6.94 \\
 \rho &= .504
 \end{aligned}$$

$$(198)(148) + \frac{48.0}{.504} \times .46 = \left(\frac{48.0}{.504} \right) (5.32) \left[\frac{1}{C_d A} \right]^2$$

$$\frac{(29400 + 44)}{510} = \left[\frac{1}{C_d A} \right]^2$$

$$\left[C_d A \right]^2 = \frac{510.00}{29400} = .0174$$

$$C_d A = .132$$

$$C_d = \frac{.132}{\frac{\pi}{4} (.461)^2} = \frac{.132}{.165} = .8$$

$$\text{Eff Throat} = \frac{\pi}{4} d^2 = .132 ; \quad d^2 = \frac{.132}{.786} = ; \quad d = .41''$$

TABLE 4

Analysis of Fire Test Data
Based on Results of EP-IV-P-17

P-17 results indicate that cavitation exists but that effective area is less than area at throat. See sheet on P-17 analysis for sample reduction.

Test No.	P _F V3 psig	P _V P psig	ΔP psid	(ΔP)(148)	T _F M °F	w _F lb/sec	w _F ²	ρ	$\frac{w_F^2}{\rho}$	$\frac{w_F^2}{\rho}^{5.32}$	$\frac{w_F^2}{\rho}^{5.32}$ ^② ①
E5	169	63	106	157x10 ²	39	6.17	38.2	.526	72.4	386	2.36x10 ⁻²
F6	195	71	124	184x10 ²	45	6.39	40.4	.520	78.5	419	2.28x10 ⁻²
H8	211	74	137	203x10 ²	48	7.13	51.1	.578	98.1	523	2.58x10 ⁻²
K11	247	84	163	241x10 ²	55	6.97	48.1	.512	94.9	502	2.09x10 ⁻²
L12	265	107	158	234x10 ²	68	6.94	48.0	.502	95.9	510	2.19x10 ⁻²
P17	295	102	193	285x10 ²	66	6.94	48.0	.504	95.2	509	1.78x10 ⁻²
	C _d A	A	C _d	P _F J3	Recovery P _F V3-P _V P	P _F J3-P _V P	%	K _w	$\frac{K_w}{C_d}$		
E5	.158	.165	.958	114	106	51	48.3	.82	.86		
F6	.152	.165	.920	137	124	66	53.2	.788	.86		
H8	.161	.165	.975	149	137	75	54.8	.848	.87		
K11	.145	.165	.88	191	163	113	69.0	.740	.84		
L12	.148	.165	.895	217	158	110	69.0	.78	.87		
P17	.134	.165	.815	230	193	128	66.4	.702	.865		

TABLE 5

TEST NO	P ₁ psig	P ₂ [*] psig	ρ	ρ[P ₁ - P ₂]	$\dot{w}_o$ lb/sec	($\dot{w}_o$) ²	① $\left[\frac{144 \rho [P_1 - P_2]}{(\dot{w}_o)^2} \right] + 0.7$	② $\frac{2.95}{①}$	③ $d = \sqrt{②}$	P _o J3 psig	Percent Recovery	C _d
E-5	266	14	1.11	280	18.45	342	11.7	.252	.508	200	75.3	0.88
F-6	266	24	1.09	265	18.10	329	11.6	.254	.504	200	75.3	0.87
H-8	255	29	1.08	245	17.55	309	11.5	.256	.505	202	79.3	0.87
K-11	258	14	1.11	270	18.25	334	11.6	.254	.504	222	86.0	0.87
L-12	263	17	1.10	272	18.20	332	11.7	.252	.508	227	86.3	0.88

*Vapor Pressure