REON **MASTER**

SACRAMENTO PLANT

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TO
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CFDTS PRE-TEST PREDICTIONS
APRIL 1965

NERVA PROGRAM

CONTRACT SNP-1

VOLUME I

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CFDTS PRE-TEST PREDICTIONS.

VOLUME I

ROCKET ENGINE OPERATIONS - NUCLEAR

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CFDTS PRETEST PREDICTIONS REPORT

ABSTRACT

The CFDTS Pretest Analysis provides analytical predictions of the CFDTS performance for use in the planning of the test program and the interpretation of test data. These predictions provide the most current information prior to the actual tests, and form the guidelines for the final CFDTS test planning.

The analyses presented were conducted for Blocks 1, 2 and 3 of the CFDTS test plan. While Block 1 involves general engine chillsdowns, the objectives of Blocks 2 and 3 are directed toward providing information for NRX/EST startup. Supplements will be published at regular intervals to provide pretest predictions of the other test blocks.

The agreement between pretest predictions and the actual test results cannot be expected to be better than the data used in the analysis. Large variations in the apparent performance of the turbopump have resulted from small variations in turbopump test measurements. Therefore, the uncertainty in the test predictions is high but is representative of the best data available at the time the calculations were performed.

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1.0 Introduction

The Cold Flow Development Test System, (CFDIS), shown schematically in Figure 1, is the first test system to incorporate all major NEFVA engine components. It is an unfueled, cold-flow prototype of the NRX/EST and X-Engine systems.

The function of the CFDIS test program (Reference RECN Report RN-S-0148) is to provide data related to the behavior of the NEFVA hot bleed engine system during chillover and bootstrap startup. A bootstrap startup implies that the engine system has sufficient thermal capacitance to initiate and maintain operation of the turbo-pump until the reactor is able to supply adequate nuclear power to continue operation. Specifically, the CFDIS tests will provide information regarding the ability of the thermal energy of the engine components to accomplish a successful bootstrap start-up. The CFDIS tests will also investigate the effects of back pressure, tank pressure and turbine power control valve (TPCV) position on startup. These tests will help define the startup procedures for the NRX/EST and X-Engine systems. Table I presents the complete proposed schedule of CFDIS tests.

Although the basic CFDIS configuration is similar to that of the NRX/EST and X-Engine, differences exist in facilities lines and certain engine components because of time and facility limitations. The differences are to be expected with the continuous development of component and system design for the NRX/EST and X-Engines. The CFDIS run tank propellant line essentially duplicates (in diameter) that of the X-Engine at ET3-1 but is much shorter than the NRX/EST line at Test Cell A. This means that tank pressures must be increased when extrapolating from CFDIS to NRX/EST but the tank pressure will closely match that of the XE system. The CFDIS turbine inlet line contains a jacketed section which acts as a counter-current heat exchanger, while the diluent in NRX/EST system, as a result of a recent design change, has removed the jacket from above the elbow in the turbine inlet line. Also, the CFDIS bleed port has a higher impedance to flow than that for the other systems. These two differences in the hot bleed systems result in the CFDIS having a larger resistance for diluent flow and, therefore, for a given pressure drop between the dome and the hot bleed port, a smaller diluent flow is

obtained. This must be kept in mind when using CFDTIS hot bleed system data to provide information on analogous NRX/EST and XE behavior.

Another difference is the turbopump and turbine exhaust system. Recent design changes to improve performance for the NRX/EST system have not been incorporated in the CFDTIS turbopump in order to maintain delivery schedules.

The CFDTIS pretest analyses are analytical investigations of chillover and startup using a transient mathematical model of the CFDTIS. Until the CFDTIS test data are properly analyzed and the test results made available, the CFDTIS pretest analyses will compose the best information on the chillover and bootstrap startup phenomena of the NRX/EST and X-Engine systems. They will be used in the planning and conducting of analytical NRX/EST bootstrap startup studies to be completed prior to the NRX/EST tests. Therefore, the CFDTIS pretest analyses will also be useful as a significant contribution to the understanding of the startup characteristics of the NRX/EST system, and in turn the X-Engine.

Table 1 is a summary of the test planned for Cold Flow Development Test System, RN-S-0191, March 1965.

TABLE I

CFDTS TEST PROGRAM

BLOCK	SPECIAL CONDITIONS	TEST NO.	PUMP START	T.P. PSIA	B.P. PSIA	D.V. POSITION	TPCV POSITION
I.	System and facility checkout. Chillo down with wet and dry pump. Confirm valve sequencing for wet and dry pump starts.	(a)	D	70	Min.	0	C
		(b)	D	70	Min.	0	C
		(c)	W	70	Min.	0	C
		(d)	W	70	Min.	0	C
II	Establish start program for NRX/EST. Wet pump start, TPCV programmed as indicated. ① TPCV programmed on basis of previous tests and supporting analysis.	(a)	W	70	Min.	0	90° @ FS _L
		(b)	W	70	12.7	0	90° @ FS _L
		(c)	W	70	12.7	0	45° @ FS _L
		(d)	W	70	12.7	0	①
III	Refine start program for NRX/EST. Wet pump starts. ② Minimum tank pressure based on three previous tests. ③ Program based on block II tests and supporting analysis.	(a)	W	70	12.7	0	③
		(b)	W	55	12.7	0	III (a)
		(c)	W	40	12.7	0	III (a)
		(d)	W	②	12.7	0	III (a)
IV	Establish start program for XE-Engine. Determine minimum tank pressure for dry pump start at ETS-1 conditions. ④ Minimum estimated tank pressure based on previous tests. ⑤ TPCV program optimum per analysis.	(a)	D	62.7	ETS-1	0	90° @
		(b)	D	62.7	ETS-1	0	⑤
		(c)	D	50	ETS-1	0	IV (b)
		(d)	D	④	ETS-1	0	IV (b)
V	Continue development of start program for XE-Engine. To minimize chillo down time, investigate effect of reducing time from PSOV to TPCV opening. ⑥ Program based on previous tests and supporting analysis.	(a)	D	IV (d)	ETS-1	0	⑥
		(b)	D	IV (d)	ETS-1	0	V (a)
		(c)	D	IV (d)	ETS-1	0	V (a)
		(d)	D	IV (d)	ETS-1	0	V (a)

TABLE I (cont.)

BLOCK	SPECIAL CONDITIONS	TEST NO.	PUMP START	T.P. PSIA	B.P. PSIA	D.V. POSITION	TPCV POSITION
VI	Refine start program for XE-Engine. Minimize tank pressure and investigate effect of minimum back pressure using dry pump start. ⑦ Reduced tank pressure at ETS-1 conditions based on block IV tests. ⑧ Minimum possible tank pressure. ⑨ Minimum tank pressure at minimum back pressure.	(a)	D	⑦	ETS-1	0	V (d)
		(b)	D	⑧	ETS-1	0	V (d)
		(c)	D	VI (b)	Min.	0	V (d)
		(d)	D	⑨	Min.	0	V (d)
VII	Determine effect of wet pump on start-up characteristics of system. Establish minimum tank pressures for wet pump start.	(a)	W	⑦	ETS-1	0	V (d)
		(b)	W	⑧	ETS-1	0	V (d)
		(c)	W	VII (b)	Min.	0	V (d)
		(d)	W	⑨	Min.	0	V (d)
VIII	Confirm optimum start program Remove 4" flowmeter from supply line. Investigate effect of diluent valve position for wet pump and dry pump starts. ⑩ Optimum program based on previous tests and supporting analysis.	(a)	D	VII (d)	ETS-1	0	10
		(b)	D	VII (d)	ETS-1	C	VIII (a)
		(c)	W	VII (d)	ETS-1	0	VIII (a)
		(d)	W	VII (d)	ETS-1	C	VIII (a)
IX	Start-up conditions on optimum TP, TPCV program. Investigate closing of pressure loop of sequencer at various times after fire switch. Perform other system tests based on analysis studies of previous tests.	(a)	⑩	Opt.	ETS-1	⑩	Opt.
		(b)	⑩	Opt.	ETS-1	⑩	Opt.
		(c)	⑩	Opt.	Min.	⑩	Opt.
		(d)	⑩	Opt.	Min.	⑩	Opt.

Reference: Test Specifications for Cold Flow Development Test System, RN-S-0191, March 1965, pp. 5c, 5d.

2.0 Summary of Analyses

The CFDIS test program is extended over more than eight months. Since this is the first engine systems test and since it is confined to operation in the low speed region where component data are limited, pretest predictions will be continuously upgraded throughout the test program. Test results will affect the descriptions and conditions of succeeding tests, and because component descriptions will change over such a length of time as newer data become available, the pretest CFDIS analyses will be performed in several series. Between each series of pretest analyses, the system description will be updated where necessary to make it consistent with the best current data. Also, changes in test specifications as the series proceeds will be incorporated into future pretest analyses. At intervals during the test program, and prior to a series of tests, supplements to this report will be issued. These supplements will present pretest analyses of the next test series based on the best component description and test definitions available prior to the analyses.

This report presents pretest predictions for Blocks 1, 2 and 3 of the CFDIS test program based on component data of 19 March 1965. Included in these blocks are the tests designed to provide information on NRX/EST startup. Basically, these test blocks may be defined as follows:

Block 1 - System and facility checkout; chilldown to investigate valve sequencing for wet or dry pump starts.

Block 2 - Wet pump starts; investigate scheduling of the turbine power control valve, IPCV, on startup with a 12.7 psia back pressure for NRX/EST.

Block 3 - Wet pump starts; investigate the effect of tank pressure on startup at 12.7 psia back pressure to establish a minimum tank pressure for NRX/EST startup.

Because of the nature of the necessary limitations in the present analyses, it is difficult to make definitive conclusions concerning the performance of the CFDTS. However, it appears that the performance of the CFDTS will be lower than that predicted by earlier analysis (Reference REON Report RN-S-0150). This lower performance results primarily from lower turbopump efficiencies now projected during low speed operation. Not only will the peak values reached during a test be reduced, but the response times will be lengthened beyond those previously expected. Hence the final definition of NRX/EST startup procedures will depend entirely upon the CFDTS tests themselves. The reduced performance now anticipated suggests that a minimum tank pressure of 70 psia, with the TPCV at 90°, may compose a realistic NRX/EST startup schedule to ensure maximum bootstrap capability. The possibility of using a preheated core to improve CFDTS performance and NRX/EST bootstrap capabilities appears promising. However, further analytical work on NRX/EST with improved turbopump data is required to evaluate more completely the advantages of this approach.

3.0 CFDIS Model

The digital model used in the CFDIS pretest analyses contains descriptions of the nozzle, reflector, shield, core, hot bleed port, lines and turbopump. For each component, the best estimate of available information from design and test data was used. A detailed presentation of the component data used to describe the CFDIS appears in Volume II of this report. The section below will be concerned only with a qualitative description of the model.

Fluid inlet temperature and pressure were assumed to be constant throughout any given run. The line from the tank to the pump inlet consists of several flow impedances, namely:

1. Tank shutoff valve (TSOV)
2. Two flowmeters, one 8-in. and the other 4-in. in diameter
3. Filter screen
4. Propellant shutoff valve (PSOV)

All of the above impedances were represented by constant loss coefficients. A sufficient equivalent length of line was also included to simulate the line pressure loss.

The Mark III Mod 4 turbopump was used for all pretest analyses. This turbopump description included the extrapolation of data into the low speed range. The complete pump operating and efficiency maps were stored internally in the computer in the form of tables.

The pump discharge line included the pump discharge valve, simulated by a constant loss coefficient, and a check valve with a constant pressure drop of 1.7 psi for all flow rates. Also an equivalent length of line sufficient to account for line and bend losses was included in the model.

The CFDTS nozzle model was based on the small U-tube nozzle, S/N-23. Heat transfer coefficients for both the hot and cold sides of the coolant passages, and friction factors for the coolant passages were based on calibration of nozzle data with in-house firings of the S/N-21 nozzle. Coolant flow areas were equivalent to those measured for the S/N-23 nozzle.

The descriptions of the reflector, shield and core of the CFDTS model were identical to those for the NRX system and were compatible with the models of these components presented by WANL in TME-483. These components were modeled by single channels for the CFDTS analyses.

The heat exchanger and hot bleed port sections of the CFDTS model were based primarily on design data. However, experimental data were used where available. A mixing ring was also included in this portion of the system.

The turbine inlet line contains the following:

1. Turbine power control valve (TPCV), whose loss coefficient is calculated as a function of gate position.
2. Venturi with a constant loss coefficient.
3. Turbine overspeed valve with a constant loss coefficient.

In addition, an equivalent length of line was included to account for line losses.

The diluent bleed line included:

1. Diluent valve with a constant loss coefficient
2. 30.17 inches of 1.76-in. ID line
3. 39 inches of 2.00-in. ID corrugated line.

The turbine exhaust nozzles of the CFDTIS were located at the turbine exhaust manifold exits, eliminating any need for simulation of a turbine exhaust line. The throat diameter of each nozzle was 3.09 inches.

The CFDTIS model described above is consistent with both the system design and the best component data available prior to the pretest analyses.

4.0 Effects of Untested System Components

The CFDTS is the initial engine test system. However, as a result of NRX-A1 and -A2 tests, an accurate definition of the reflector, shield and core behavior is available prior to the CFDTS tests. Also, NRX-A2 provided system test data on a steel U-tube nozzle. Although the nozzle with a hot bleed port has not been previously tested under an environment analogous to that which will exist during the CFDTS tests, it has been possible to undertake sufficient component testing to eliminate many uncertainties concerning its performance.

The performance of the CFDTS system is strongly dependent upon the performance of the turbopump. The flow rates, pressures, and speeds attained during a test are strong functions of the turbopump operational capabilities, especially pump efficiency. The CFDTS is the first test system to incorporate a complete turbopump assembly and to investigate pump operation primarily in the low speed range. During a typical CFDTS test, the turbopump speed will be in the range from 0 to 10,000 rpm. To accurately predict such a test, the turbopump performance must be well described in this speed range. Because of the experimental difficulties in obtaining data to evaluate low speed turbopump operation, and in particular, low speed turbopump efficiencies, pretest data available in this speed range are sparse and uncertain. The ability to predict confidently the CFDTS performance is therefore severely hampered by the lack of accurate experimental data describing low speed turbopump operation.

The difficulty of the turbopump simulation problem can be seen by comparing pump efficiency maps that are generated with the same test data by considering measurement inaccuracies. The deviation is most prominent from 0 to 10,000 rpm, the speed range of concern in the CFDTS. A one-degree error in the measurement of fluid temperatures into and out of the pump at low speeds results in a pump efficiency variation of as much as 20 percent. This uncertainty in the low speed pump efficiencies makes accurate predictions of CFDTS performance extremely difficult. The results of the analyses which employed these data must therefore be interpreted in this light.

5.0 Nuclear Engine Transient Program (12013)

The digital program used in the present analyses was the Nuclear Engine Transient Program (12013) (Reference REON Report RN-S-0114). The 12013 computer program is a transient explicit finite-difference formulation of the heat transfer and fluid flow phenomena related to the NERVA hot bleed system. Temperature, pressure and flow rate histories throughout the complete system are calculated by separate analyses of the turbopump, hot bleed port, reflector, shield, core, core support plate, nozzle and various lines.

The turbopump assembly analytical model consists of a complete performance map of the pump, as well as an energy balance that accounts for the storage of energy as angular momentum of the rotating shaft.

Each of the nuclear components (reflector, two-pass shield, core support plate and core with tie rod) is analytically represented as a single flow channel, single-pass, heat exchanger. The nozzle, however, is modeled as a counter-current heat exchanger. For each of the above components, friction factors are input as constants, heat transfer coefficients are calculated as functions of the fluid properties, and entrance and exit pressure losses are evaluated from constant loss coefficients. In addition, the nozzle pressure drop calculations account for losses caused by turning of the fluid.

The hot bleed jacketed line is also modeled as a counter-current heat exchanger. Friction factors for this line are input as constants and heat transfer coefficients are calculated from fluid properties. Analyses of the hot bleed port also consider the effects of the vena contracta and the angle of the diluent injection.

The 12013 program does not account for two-phase heat transfer in any of the system components. Throughout the program, the LASL TAB H parahydrogen properties deck is used to obtain the fluid properties.

6.0 Discussion of Analyses

6.1 Block I

The predictions of the Block I CFDTS tests appear in Figures 2 through 8. These figures contain the time plots of major plenum temperatures, pressures, and flow rates as well as conditions at the tank, pump inlet, and pump discharge. Turbopump parameters such as shaft speed, and turbine and diluent flow rates also appear on the figures, but their values are zero for the present chilldown analyses since the TPCV is closed.

The profiles as shown are jagged rather than smoothly varying contours. This jaggedness results primarily from the convergence tolerances used in the finite difference approximation to the system. Smaller tolerances could be employed but the gain in accuracy would not be commensurate with the increased computer time required for a solution. Most of the larger oscillations are caused by inaccurate hydrogen properties data obtained from the LASL TAE H deck. The variations have been amplified visually by using a computer plotting routine which connects the calculated time points by straight lines rather than an approximated curve. The use of computer plotting routines, however, considerably reduces cost and time in preparing computer output for engineering use.

Block I tests involve wet and dry pump chilldowns of the CFDTS with 70 psia tank pressure, 1 psia back pressure, and the TPCV closed. Strictly speaking, these predictions apply to chilldown with a wet pump. However, chilldown with a dry pump makes available only a negligible amount of additional energy, namely that associated with the thermal capacitance of the pump inlet line and turbopump assembly. The analytical programs do not represent the engine in sufficient detail to show the difference between a wet and dry pump chilldown. Therefore, these predictions may be applied to all Block I tests.

Figures 2 and 3 are summary plots presenting profiles of major system parameters, while figures 4 through 8 contain plots of the inlet and exit conditions

for the reflector, first and second passes of the shield, core support plate, and core. The core inlet temperature reaches 90°R at 52 seconds. Therefore, the chilldown test duration appears to be of the order of 50 seconds. At 52 seconds, the chamber temperature is 180°R , and the pump flow rate is 20 lb/sec, while the chamber pressure is at its peak of 33 psia.

Figure 2: Since the tank pressure is held constant at 70 psia and the resistances of the pump and pump inlet line are thought to be relatively small at chilldown flow rates, the pump inlet and discharge pressures are essentially 70 psia. Figure 2 also shows essentially no temperature rise across the pump. The chamber temperature remains above 500°R for 23 seconds. However, as the core inlet temperature continues to drop, the chamber temperature decreases rapidly. At the calculational limit of 80 seconds, it has reached 60°R , 30°R below the core inlet temperature limit.

Figure 3: The pump flow rate increases as the system temperatures decrease and therefore the resistance to flow falls. At 52 seconds the flow rate is 20 lb/sec. This is the point where the core inlet temperature reaches the limit of 90°R .

Figure 4: The reflector inlet temperature reaches the region of the nozzle inlet temperature (equal to the pump discharge temperature of Figure 2) in 5 seconds, implying that the nozzle capacitance energy has rapidly been removed and the temperature rise across the nozzle from then on is due to heat transfer from the hot side gases. However, during this initial 5-sec period, when relatively low density fluid is flowing through the nozzle tubes, the nozzle pressure drop (essentially from pump discharge, Figure 2, to reflector inlet, Figure 4) is by far the major system pressure loss. As the nozzle jacket and tubes are cooled, the nozzle pressure drop rapidly decreases.

The reflector has considerable thermal energy, as manifested by the slow decrease in reflector exit temperature even though the inlet temperature rapidly falls to 50°R . During this period the reflector pressure drop is

considerable. The energy is completely depleted at 54 seconds, since there is no longer any temperature rise across the reflector. At this point, the reflector temperatures have fallen sufficiently to reduce the flow impedance, and the reflector pressure drop therefore decreases significantly.

Figure 5: Figure 5 shows the first pass of the shield from the reflector outlet to the dome. It indicates that there is only a small flow resistance and little thermal capacitance.

Figure 6: This figure shows the shield from the dome to the core support plate. The flow resistance and thermal capacitance are both small.

Figure 7: The core support plate pressure drop and the temperature change is also small.

Figure 8: The reactor core contains significant thermal energy. The core has sufficient thermal energy to sustain a considerable system temperature rise for the proposed 52-second chilldown duration. In fact, the analyses showed that it would take approximately 80 seconds to completely remove the thermal energy of the core. Figure 8 also shows that, once the nozzle is cooled (at 5 seconds), the core pressure drop becomes the predominant system pressure loss.

6.2 Block II

The predictions of Block II tests appear in Figures 9 through 29. This block involves investigations of TPCV programming at 70 psi tank pressure for wet pump starts. Time zero corresponds to simultaneous opening of the pump discharge valve and setting of the TPCV to the desired program.

Figures 9 through 15 present the predictions for test IIa. The predictions are based on a test plan of tank pressure 70 psia, back pressure 1 psia and TPCV open to 90 degree at start of pump discharge valve opening. They show that peak values of chamber pressure (P_c) = 78 psia, pump flow rate ($\dot{W}_p$) = 30 lb/sec

and shaft speed (N) = 8300 rpm are reached at 8 seconds after opening the PDV. Although these values are lower than previously predicted (Reference FEON Report RN-S-0150) they indicate that at these conditions, the thermal energy of the CFDTs is capable of producing a considerable turbopump response.

Figures 16 through 22 present the predictions for test IIb. It is for a tank pressure of 70 psia, back pressure of 12.7 psia and TPCV wide open. The change in back pressure causes a severe degradation in the performance of the system. The peak value of $\dot{W}_p$ has fallen to 8.6 lb/sec and P_c to 25 psia, both appearing at 6 seconds. Shaft speed reaches a reduced peak of 2000 rpm at 2 seconds. Comparison of tests IIa and IIb show that system response has been reduced by the higher back pressure to such a level that successful engine bootstrap may be jeopardized at these tank conditions.

The predictions for test IIc are presented in Figures 23 through 29. The run conditions are: tank pressure of 70 psia, back pressure of 12.7 psia, TPCV open to 45 degrees. They show that a step in the TPCV to 45° gives reduced performance and slower response than a 90° step. Peak values, reached at 16 seconds, are $\dot{W}_c = 8.5$ lb/sec, $N = 550$, and $P_c = 23$ psia. It should be noted that, while a reduction in shaft speed would be expected, the actual magnitude predicted is somewhat questionable because of the low speed turbopump simulation problems discussed previously. However, it is evident that, since the response in test IIb is in the region of the minimum now thought to be required for engine bootstrap, the conditions of IIc appear less desirable than those of IIb.

From the results of analyses of tests IIb and IIc, ramping the TPCV, and thereby reducing performance while extending the length of the response, appeared to be undesirable. Therefore, the feasibility of conducting test IIId as stated in the Test Plan was questionable and no analysis was made at those conditions. The actual conditions of test IIId appear now to be dependent on results from Tests IIb and IIc.

6.3 Block III

The series of tests which compose Block III are wet pump tests designed to determine the minimum tank pressure for the optimum TPCV setting. Previous to the pretest analyses, it was felt that tank pressures below 70 psia would be possible for a successful bootstrap startup. However, as a result of the analyses, it appears that 70 psia tank pressure may be a realistic minimum and that a higher pressure may be even more desirable to insure NRX/EST startup. Thus Block III as originally proposed may be unfeasible. The actual composition of Block III appears now to depend heavily on results from Block II. If the experimental results support pretest analysis, a major redefinition of Block III will be necessary.

It appears from pretest analysis that a step 90° in TPCV is the most desirable programming for NRX/EST. Therefore, Figures 16 through 22 may be used as predictions for test IIIa as it now stands. Because of the uncertainty in the desirability of investigating reduced tank pressures, tests IIIb and IIIc were not analyzed. Instead, an additional test at 90 psia tank pressure, 45° TPCV and 12.7 psia back pressure was analyzed to show the performance gain in going to an increased tank pressure. Peak values of $\dot{w}_c = 11$ lb/sec, $P_c = 29$ psia and $N = 1700$ rpm appear at 5 seconds. Comparing these data with those from test IIb, one finds that there has been a small rise in peak flow rate and chamber pressure, but a slight decrease in peak shaft speed. The response time is relatively unchanged. With a back pressure of 12.7 psia, there appears to be no significant gain in going to a tank pressure of 90 psia with the TPCV at 45°. Opening the TPCV to 90° would improve the performance (as shown in tests IIb and IIc)

NOTE VALVES 1, 3, 8 & 11 ARE FACILITY VALVES

SCHEMATIC DIAGRAM
CFDTS ENGINE VALVES AND
PURGE FLOW PATTERN

FIGURE 1

CFDTS CHILLDOWN

CFDTS CHILLDOWN

Figure 3

- 1 WDOTP Pump Weight Flow, lb/sec
- 2 WDOTN Nozzle Throat Weight Flow, lb/sec
- 3 WDOTT Turbine Flow Rate, lb/sec
- 4 WDOTL Diluent Flow Rate, lb/sec
- 5 GT POS TPCV Position, degrees
- 6 NTRB Turbopump Speed, rpm

REF 0

CFDTS CHILLDOWN

Figure 4
Reflector

1 P IN	Inlet Pressure, psia
2 P OUT	Outlet Pressure, psia
3 T IN	Inlet Temperature, °R
4 T OUT	Outlet Temperature, °R
5 W IN	Inlet Weight Flow, lb/sec
6 W OUT	Outlet Weight Flow, lb/sec

SH 0.0

CFDTS CHILLDOWN

$4T OUT \times 10^2$ $5W IN \times 10^1$ $6W OUT \times 10^1$
 $1P IN \times 10^1$ $2P OUT \times 10^1$ $3T IN \times 10^2$

SHI

CFDTS CHILLDOWN

Figure 6
Shield Two

1P IN	Inlet Pressure, psia
2P OUT	Outlet Pressure, psia
3T IN	Inlet Temperature, °R
4T OUT	Outlet Temperature, °R
5W IN	Inlet Weight Flow, lb/sec
6W OUT	Outlet Weight Flow, lb/sec

SUPP α

CFDTS CHILLDOWN

Figure 7

Core Support Plate

- 1P IN Inlet Pressure, psia
- 2P OUT Outlet Pressure, psia
- 3T IN Inlet Temperature, $^{\circ}$ R
- 4T OUT Outlet Temperature, $^{\circ}$ R
- 5W IN Inlet Weight Flow, lb/sec
- 6W OUT Outlet Weight Flow, lb/sec

CORE 9

CFDTS CHILLDOWN

Figure 8

Reactor Core

- 1P IN Inlet Pressure, psia
- 2P OUT Outlet Pressure, psia
- 3T IN Inlet Temperature, °R
- 4T OUT Outlet Temperature, °R
- 5W IN Inlet Weight Flow, lb/sec
- 6W OUT Outlet Weight Flow, lb/sec

CFDTS STARTUP TP070 BP01

GP090

CFDTS STARTUP TP070 BP01 GP090

Figure 10

1. WDOTP	Pump Weight Flow, lb/sec
2. WDOTN	Nozzle Throat Weight Flow, lb/sec
3. WDOTT	Turbine Flow Rate, lb/sec
4. WDOTL	Diluent Flow Rate, lb/sec
5. GT POS	TPCV Position, degrees
6. NTRB	Turbopump Speed, rpm

REFL TR

CFDTS STARTUP TP070 BP01

GP090

Figure 11

Reflector

- 1 P IN Inlet Pressure, psia
- 2 P OUT Outlet Pressure, psia
- 3 T IN Inlet Temperature, $^{\circ}$ R
- 4 T OUT Outlet Temperature, $^{\circ}$ R
- 5 W IN Inlet Weight Flow, lb/sec
- 6 W OUT Outlet Weight Flow, lb/sec

SHLD 1 a

CFDTS STARTUP TP070 BP01

GP090

Figure 12

Shield One

$1^P IN$	Inlet Pressure, psia
$2^P OUT$	Outlet Pressure, psia
$3^T IN$	Inlet Temperature, $^{\circ}R$
$4^T OUT$	Outlet Temperature, $^{\circ}R$
$5^W IN$	Inlet Weight Flow, lb/sec
$6^W OUT$	Outlet Weight Flow, lb/sec

SHLD 2

CFDTS STARTUP TP070 BP01

GP090

Figure 13

Shield Two

1P IN	Inlet Pressure, psia
2P OUT	Outlet Pressure, psia
3T IN	Inlet Temperature, °R
4T OUT	Outlet Temperature, °R
5W IN	Inlet Weight Flow, lb/sec
6W OUT	Outlet Weight Flow, lb/sec

SUPT 0

CFDTS STARTUP TP070 BP01

GP090

Figure 14

Core Support Plate

- 1^P IN Inlet Pressure, psia
- 2^P OUT Outlet Pressure, psia
- 3^T IN Inlet Temperature, °R
- 4^T OUT Outlet Temperature, °R
- 5^W IN Inlet Weight Flow, lb/sec
- 6^W OUT Outlet Weight Flow, lb/sec

CORE

CFDTS STARTUP TP070 BP01

GP090

CFDTS TP070 BP012.7 GP090

CFDTS TP070 BP012.7 GP090

Figure 17

- 1 WDOTP Pump Weight Flow, lb/sec
- 2 WDOTN Nozzle Throat Weight Flow, lb/sec
- 3 WDOTT Turbine Flow Rate, lb/sec
- 4 WDOTL Diluent Flow Rate, lb/sec
- 5 GT POS TPCV Position, degrees
- 6 NTRB Turbopump Speed, rpm

REF

CFDTS TP070 BP012.7 GP090

SH

CFDTS TP070 BP012.7 GP090

SUPP

CFDTS TP070 BP012.7 GP090

CORE

CFDTS TP070 BP012.7 GP090

Figure 22

Reactor Core

- 1P IN Inlet Pressure, psia
- 2P OUT Outlet Pressure, psia
- 3T IN Inlet Temperature, °R
- 4T OUT Outlet Temperature, °R
- 5W IN Inlet Weight Flow, lb/sec
- 6W OUT Outlet Weight Flow, lb/sec

CFDTS TP070 BP012.7 GP045

CFDTS TP070 BP012.7 GP045

REF 0

CFDTS TP070 BP012.7 GP045

SH 0

CFDTS TP070 BP012.7 GP045

Figure 26

Shield One

1P IN	Inlet Pressure, psia
2P OUT	Outlet Pressure, psia
3T IN	Inlet Temperature, °R
4T OUT	Outlet Temperature, °R
5W IN	Inlet Weight Flow, lb/sec
6W OUT	Outlet Weight Flow, lb/sec

SHI

CFDTS TP070 BP012.7 GP045

Figure 27

Shield Two

- 1 P IN Inlet Pressure, psia
- 2 P OUT Outlet Pressure, psia
- 3 T IN Inlet Temperature, $^{\circ}$ R
- 4 T OUT Outlet Temperature, $^{\circ}$ R
- 5 W IN Inlet Weight Flow, lb/sec
- 6 W OUT Outlet Weight Flow, lb/sec

SUPP 0 CFDT5 TP070 BP012.7 GP045

CORE 0 CFDT5 TP070 BP012.7 GP045

Figure 29

Reactor Core

- 1P IN Inlet Pressure, psia
- 2P OUT Outlet Pressure, psia
- 3T IN Inlet Temperature, °R
- 4T OUT Outlet Temperature, °R
- 5W IN Inlet Weight Flow, lb/sec
- 6W OUT Outlet Weight Flow, lb/sec

CFDTS TP 90 GP 45 BP 12.7

CFDTS TP 90 GP 45 BP 12.7

Figure 31

- 1 WDOTP Pump Weight Flow, lb/sec
- 2 WDOTN Nozzle Throat Weight Flow, lb/sec
- 3 WDOTT Turbine Flow Rate, lb/sec
- 4 WDOTL Diluent Flow Rate, lb/sec
- 5 GT POS TPCV Position, degrees
- 6 NTRB Turbopump Speed, rpm

REFLE 0

CFDTS

TP 90 GP 45 BP 12.7

SHIEL

CFDTS

TP 90 GP 45 BP 12.7

Figure 33

Shield One

1^P IN	Inlet Pressure, psia
2^P OUT	Outlet Pressure, psia
3^T IN	Inlet Temperature, $^{\circ}\text{R}$
4^T OUT	Outlet Temperature, $^{\circ}\text{R}$
5^W IN	Inlet Weight Flow, lb/sec
6^W OUT	Outlet Weight Flow, lb/sec

SHIELD

CFDTS

TP 90 GP 45 BP 12.7

CORE

CFDTS

TP 90 GP 45 BP 12.7

CORE

CFDTS

TP 90 GP 45 BP 12.7