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14 August 1967

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Westinghouse Astronuclear Laboratory

PRESENTATION TO SNPO - C
NUCLEAR AND RADIATION DEVELOPMENT PROGRAM

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PRESENTATION TO SNPO-C

NUCLEAR AND RADIATION DEVELOPMENT PROGRAM

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OUTLINE

	<u>Page No.</u>
1.0 (U) INTRODUCTION	1
2.0 (C) NUCLEAR DEVELOPMENT PROGRAM	2
3.0 (C) RADIATION & SHIELDING DEVELOPMENT PROGRAM	5
4.0 (C) CRITICAL EXPERIMENT FACILITY DESCRIPTION	7
5.0 (C) DISCUSSION OF UNCERTAINTIES IN THE MEASUREMENT OF PROPELLANT TANK HEATING IN A CRITICAL FACILITY	12
(U) APPENDIX A - COMPARISON OF PROPOSED WANEF TEST CELL WITH ALTERNATE FACILITIES FOR PERFORM- ING SIDE-BY-SIDE NUCLEAR AND RADIATION MEASUREMENTS AND PTX EXPERIMENTS	18

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LIST OF ILLUSTRATIONS

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
1	Outline	19
2	Key Nuclear Subsystem Characteristics	20
3	NR-1 Reactor Conceptual Configuration	21
4	NR and NE Nuclear Characteristics	22
5	Reactivity Shimming Experience in Previous NRX Reactors	23
6	Reactivity Uncertainties	24
7	Uncertainty due to Possible Discrepancies in the Determination of Core Mass	25
8	NR and NE Control Reactivity Characteristics	26
9	Variation of Key Parameters During NR Startup and Operation	27
10	Influence on the NR and NE Power Distribution of Adding Reactivity by Control Drums and Adjusting Flow in Support Stems (C-RD)	28
11	NR Control Drum Nuclear Characteristics	29
12	Nuclear Experimental Information Needs to Support NR Reactors	30
13	Nuclear Experimental Information Needs to Support NE Reactors	31
14	Experimental Facilities to Support PFRT Nuclear Development Program	32
15	FCX Assembly	33
16	FCX (Flexible Critical Experiment for NR-1)	34
17	Nuclear Experimental Information to be Obtained from the FCX NR Mockup	35
18	FCX NR Mockup Schedule	36
19	NCX Assembly	37
20	Nuclear Experimental Information to be Obtained from the NCX	38
21	NCX Schedule	39
22	Nuclear Experimental Information to be Obtained from the PTX	40
23	Nuclear Experimental Information to be Obtained from the Operation of NCX and PTX	41

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
24a	Nuclear Experimental Information Needs to Support NR and NE Reactors and the Experimental Facilities	42
24b	Nuclear Experimental Information Needs to Support NR and NE Reactors and the Experimental Facilities (cont'd.)	43
25	Summary of Nuclear Development Program	44
26	Nuclear, Radiation and Shielding Development Experiment Schedule	45
27	Schematic of Basic Geometric Model	46
28	NR Radiation and Shielding Characteristics (Preliminary)	47
29	Temperature Difference in 1/4" Slab Cooled on Both Sides	48
30	Temperature Rise in Adiabatic Sample	49
31	Present Analytical Uncertainties	50
32	Development of Uncertainty in Experimental Measurement of Propellant Tank Heating	51
33	Comparison of NR-1 Shielded vs. Unshielded Core Gamma Dose Rate at 10 Feet From the Core Center	52
34	Steady State Power of Shutdown Driven Core, Driver Core at Full Power	53
35	Radiation and Shielding Experimental Information Needs to Support NR Program	54
36	Radiation and Shielding Experimental Information Needs to Support NE Program	55
37	Experimental Facilities to Support PFRT Radiation and Shielding Development Program	56
38	Preassembly Reactor Experiment (PAX)	57
39	Radiation and Shielding Experimental Information from PAX	58
40	PAX Radiation and Shielding Schedule	59
41	Radiation and Shielding Experimental Information from FCX NR Mockup	60
42	Radiation and Shielding Experimental Information from NCX	61
43	Ratio of Calculated Gamma Ray Dose Rate Test Environment to Space Environment at a Propellant Tank Mockup	62
44	Ratio of Calculated Fast Neutron Dose Rate Test Environment to Space Environment at a Propellant Tank Mockup	63

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
45	Radiation and Shielding Experimental Information from NCX-PTX	64
46	Schedule for NCX-PTX Radiation and Shielding Measurements	65
47a	Radiation and Shielding Experimental Information Needs to Support NR and NE Program and the Experimental Facilities	66
47b	Radiation and Shielding Experimental Information Needs to Support NR and NE Program and the Experimental Facilities (cont'd.)	67
48	Summary of Radiation and Shielding Development Program	68
49	Critical Experiment Facility Description	69
50	Proposed WANEF Layout	70
51	WANEF Layout Showing a Modification of the Existing Test Cell	71
52	WANEF Critical Reactor Costs	72
53	Proposed WANEF Test Cell Schedule	73
54	Heating Rate vs. Shield Thickness at Actuator Detector Point Location 4, 200 Megawatt NR-1	74
55	Heating Rate vs. Shield Thickness at Drum Actuator and Support System Actuator 4, 200 Megawatt NERVA	75
56	5000 MW Incident Nuclear Heating Rate (Minimum Reactor Weight Increment)	76
57	System Weight Increment vs. Shield Weight with Unshielded Integral Tank Heating as Parameter for Single Module	77
58	Comparison of Alternate Methods of Calculating Neutron Flux Distribution	78
59	Gamma Ray Dose Rate 10 Feet from Center	79
60	Calculated Gamma Dose Rates for LH_2 and CH_2 Media for on-Axis Propellant Tank Centerline	80
61	Comparative Energy Absorption Coefficients Hydrogen and Carbon	81
62	Differential Gamma Energy Flux (Monte Carlo)	82
63	Calculated Neutron Dose Rate on Propellant Tank Centerline	83
64	Comparison of Dose Conversion Factors for Ethylene and Hydrogen	84
65	Demonstration of Reproducibility of Active Measurement Technique at WANEF	85

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
A-1	ETS-1 Possible Side-by-Side Configuration for Nuclear and Radiation Measurements	86
A-2	E/STS-2-3 Possible Side-by-Side Configuration for Nuclear and Radiation Measurements	87
A-3	(ETS-1) Summary of Advantages and Disadvantages of Various Facilities for Side-by-Side Nuclear and Radiation Measurements	88
A-4	(E/STS-2-3) Summary of Advantages and Disadvantages of Various Facilities for Side-by-Side Nuclear and Radiation Measurements	89
A-5	(Proposed WANEF Test Cell) Summary of Advantages and Disadvantages of Various Facilities for Side-by-Side Nuclear and Radiation Measurements	90
A-6	Summary of Advantages and Disadvantages of Various Facilities for Performing PTX Experiments (NRDS - E-MAD)	91
A-7	Summary of Advantages and Disadvantages of Various Facilities for Performing PTX Experiments (Cape Kennedy)	92
A-8	Summary of Advantages and Disadvantages of Various Facilities for Performing PTX Experiments (Proposed WANEF Test Cell)	93

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1.0 INTRODUCTION

- (U) This memo documents the presentation made to SNPO-C on the Nuclear and Radiation Development Program associated with the PFRT Program*.
- (U) Figure 1 gives an overall outline of the presentation.
- (U) Let's begin by briefly reviewing the key characteristics of the nuclear subsystem as shown in Figure 2. It is important to recognize that the PFRT nuclear subsystem differs from the PHOEBUS 2A reactor and will have different nuclear characteristics. The reference nuclear subsystem configuration for the NR-1 is shown in Figure 3.
- (U) With that brief orientation we will now move onto a discussion of the nuclear development program.

*WANL-WP(J)-035 - NERVA Nuclear Subsystem PFRT Development Plan, May 8, 1967.

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2.0 NUCLEAR DEVELOPMENT PROGRAM

- (U) Let's begin the discussion of the nuclear development program by reviewing the nuclear characteristics of the NR and NE subsystems. These characteristics are summarized in Figure 4.
- (C) The experience on NRX initial criticality is given in Figure 5. The uncertainty in initial criticality is related to the adequacy of the nuclear mockup and the tolerances and accuracy of the non-destructive inspection systems as given in Figures 6 and 7, respectively. We now consider the reactivity changes expected in NR (Figure 8). Further illustration of these changes is given in Figure 9. The significance of flow control on power distribution is shown in Figure 10. Some key NR control drum characteristics are shown in Figure 11.
- (U) The requirements for nuclear facilities is determined by the information needs. Therefore, the starting point for development of the critical facility requirements is a definition of the nuclear information needs. The nuclear experimental information needs are given in Figures 12 and 13 for the NR and NE reactors.
- (U) To meet the needs of the nuclear designers for experimental information, a careful review was made of our experience on supplying such information in the NRX program and the availability of facilities, both Westinghouse and the Government. As a result of this review, it was our best judgment that the following experimental assemblies were needed in order to supply the nuclear information for the PFRT program (Figure 14). Appendix A presents a comparison of the proposed WANEF test cell with the use of modified ETS-1 or ETS-2/3 for coupled radiation measurements and PTX experiments.

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- (U) Let's begin with the FCX mockup of the NR reactor. The basic FCX assembly as it presently exists at WANEF is shown in Figure 15. The experiments performed to date indicate that this assembly provides a versatile development tool for both basic experimental information and for information to provide the early verification of nuclear characteristics of new reactors. Figure 16 shows how we intend to utilize the FCX to provide an initial mockup of the NR reactor. From this FCX NR mockup we expect to obtain the experimental information outlined in Figure 17. Figure 18 shows the schedule which we expect to meet on this assembly. It should be noted that we intend to supplement the information from the FCX NR mockup with an intensive analysis of the experimental information available on the Los Alamos experimental assemblies for PHOEBUS 2A. We expect to apply analytical techniques to both assemblies and then use these results to set the initial NR loading and loading distribution.
- (U) Let's now turn to discussion of the NCX. A schematic of the NCX assembly is shown in Figure 19. It has been our experience in the NRX program that close nuclear mockups of the subsystem are required if you are going to have confidence in the nuclear characteristics of the as-shipped reactor. We feel that with adequate nuclear mockups such as NCX we can pretty well guarantee an accurate set of experimental data on the cold reactor and can make important measurements applicable to the operating reactor. We expect to utilize the NCX throughout the entire PFRT program just as the PAX assembly has been utilized in support of the NRX program. The experimental information we expect to obtain from NCX is summarized in Figure 20. It should be noted that this list is only a major summary list, and there are literally hundreds of measurements that will be made in support of specific design and analysis test requests on this assembly during the course of the PFRT program. The schedule for the NCX is shown in Figure 21. Careful mechanical handling studies have indicated to us that it will be impossible to perform a PTX (proof-test experiment) in the existing cell with the NCX reactor present and impossible to perform clustered nuclear measurements in the existing cell. In addition, our analysis indicates that, as we will discuss later, it will be highly desirable to perform the DVT test of the shield for the

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NR and NE reactors in a location other than that presently contemplated for NCX reactor. Dr. Kovacik will describe the overall NCX facility activation schedule and cost in more detail later in the discussion. The configuration of the PTX at WANEF would be very similar to that previously shown for NCX except that it would involve the actual deliverable hardware. It is planned to perform a PTX on NE-3 and on the deliverable engine subsystem NE-8 and NE-10. The PTX on NE-3 would supply early information on the side-by-side operation of the subsystems. The experimental information we expect to obtain in the nuclear area from the PTX is given in Figure 22 and from the NCX and PTX is summarized in Figure 23.

- (U) Figure 24 presents a summary of the experimental information needs and the assembly which will be utilized to perform this experiment. A summary of the Nuclear Development Program is given in Figure 25. A summary schedule for the Nuclear, Radiation and Shielding Program is given in Figure 26.

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3.0 RADIATION & SHIELDING DEVELOPMENT PROGRAM

- (C) Let's begin the discussion of the radiation and shielding development program by review of the reactor shield configurations presently under investigation (Figure 27). A few key radiation and shielding characteristics are summarized in Figure 28. This figure indicates that the maximum internal heating varies from about 2 watts/gram to 800 watts/gram. Figure 29 shows how these heating rates translate into internal temperature rises. Outside of the subsystem the levels are lower and some components are cooled only by conduction and/or radiation. Figure 30 shows the temperature rise rate of adiabatic samples.
- (U) The levels in Figure 28 are calculated and have large uncertainties. The uncertainties are summarized in Figure 31. It should be noted that with an experimental program discussed later the propellant tank heating uncertainty can be reduced as shown in Figure 32. The complexity of the external environment is illustrated by the variation of the dose rate at 10 feet from the core center as shown in Figure 33. One important problem from the operational standpoint for clustered subsystems is the increase in shutdown power of a core adjacent to an operating core (see Figure 34).
- (U) The next important topic is "what are the experimental information needs required to support the radiation and shielding development of the PFRT". These are summarized in Figure 35 for the NR reactor while Figure 36 summarizes the radiation and shielding experimental information needs to support the nuclear subsystem for the NE engines.
- (U) Now let's turn to how we expect to satisfy these experimental information needs in the radiation and shielding area. We intend to use a variety of assemblies making use of those that are now available or will be required to fulfill the nuclear information requirements. Figure 37 summarizes PFRT experimental facilities that will be utilized to supply the radiation and shielding experimental information needs.

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- (U) Let's now review each of these experimental facilities and what experimental information we expect to obtain. The first assembly is the existing pre-assembly experiment (PAX). Figure 38 shows a schematic of this assembly modified for use in providing early information on shield attenuation. Figure 39 shows the experimental information we expect to obtain from this assembly. The schedule for the activation and experiments on the PAX assembly in support of NR is shown in Figure 40. Some important internal radiation information will be obtained from the FCX-NR mockup as shown in Figure 41.
- (U) You have previously seen the proposed configuration for the NCX reactor. We will utilize the NCX reactor to provide experimental information of importance from the radiation and shielding characteristics as shown in Figure 42. The importance of eliminating backscatter on ground measurements of radiation around a nuclear rocket is shown in Figures 43 and 44.
- (U) During the time at which the proof test experiments are performed at WANEF, we expect to make measurements on the coupled reactors. From the combination of the NCX and PTX reactors, we expect to obtain the information as given in Figure 45. You will note that we believe the simultaneous startup of the two reactors in space is a difficult development problem from a control standpoint. We intend to use these reactors in this configuration to ensure that the Leave-Earth stages of the Mars-Mission vehicle can be properly started. Figure 46 shows the schedule for the NCX-PTX measurements.
- (U) The relationship between the information needs on the radiation and shielding development program and the assembly is shown in Figure 47. A summary of the program is given in Figure 48. In Figure 47, the symbol P stands for preliminary while F stands for final.

4.0 CRITICAL EXPERIMENT FACILITY DESCRIPTION

(U) 4.1 Description of Critical Reactor Assemblies and Facility

The preceding presentation has shown the nuclear and radiation information needs and the experimental facilities required. We will discuss the items shown on Figure 49. We will expand upon the descriptions of the various critical assemblies, their flexibility and capabilities and present a few additional words about the experiments that we intend to perform with them and the facility in which they will be performed. We intend to utilize the following critical assemblies and reactors:

PAX

FCX/NR-1 Mockup

NCX

PTX

(U) Figure 38 shows the present PAX reactor adapted for use in mockup shield experiments in support of NR. The NR-1 shield design will be mocked up on the nozzle end of PAX utilizing plates of various materials that make up the shield. Flux and dose measurements will be conducted both in the material and adjacent to the shield. These measurements will provide the first data to be utilized to check the calculational methods and to provide assurance that the shield design for NR-1 is adequate. Measurements will also be made with a realistic type shield which includes cooling holes and other penetrations characteristic of the present designs. Measurements with such a shield will check the effects of this design upon the streaming and attenuation characteristics.

(C) Figure 16 shows the FCX/NR-1 mockup. The FCX stand will be utilized in which an NR-1 type beryllium reflector with control drums will be installed. The reflector will not have the axial and lateral holes of the NR-1. The control drums will be manually adjustable to the desired angle. Actual reactor control will be performed utilizing the seven FCX fuel follower control rods. The core will be made up of NRX type fuel and possible Phoebus or

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Zepo rejects. The lateral support region will be mocked up with graphite slabs. The major purpose of this experiment is to supply necessary input for the NR-1 fuel zoning specification and verification of control and shutdown reactivity capability.

- (C) Figure 19 shows the present concept of the NCX. It represents a close mockup of the NR-1 reactor. The beryllium reflector for the NCX is initially used on the FCX/NR mockup. Following its use on the FCX, the beryllium will be finally machined to the NR-1 specifications. The design will provide a very close nuclear simulation of the lateral support region in the reactor while at the same time maintaining the flexibility required for core changes and modifications. The core will utilize a complete set of NR-1 pre-production fuel elements. The reflector sectors and control drums will be removable. Eighteen of the control drums will be ganged in pairs of two and have single drive units on the remaining six control drums. Two completely separate sets of drive and magnetic supplies will be provided. Each set will drive one-half of the control drums and in the improbable event of uncontrolled drum motion due to drive or power supply failure, the other system will still be operable for the necessary shutdown.
- (U) A control console and control system will be provided to be located in the present control room, which will be expanded to accommodate it.
- (U) Experiments on the NCX, performed in support of all the NR and NE reactors, include:
1. Complete power distribution mapping in the core, including effects of hydrogen and material distribution.
 2. Complete flux and radiation mapping throughout the NSS.
 3. Measurement of the reactivity worths of all materials of interest.
 4. Measurement of control span, shutdown and excess reactivity and poison wire worths.
 5. Measurement of the performance of the flight shield.
 6. Effect of engine system upon NSS.
 7. Measurement of control detector responses and characteristics.

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8. Fuel reactivity checks to verify production fuel.
9. Measurement of facility effects.

(U) The PTX reactor experiment will utilize a final assembled NE reactor that will be shipped to WANEF prior to shipment to Nevada. A separate test stand, drive units, and control console to operate the PTX reactor will be provided. The control system and console for the PTX will be entirely separate from that of the NCX which will permit separate or simultaneous operation, as required.

(U) PTX experiments will accurately check the reactivity and guarantee start of life critical drum angle, shutdown and excess reactivity. Also, power distribution measurements may be performed to verify as-built power distribution. Measurements in support of NRDS startup operations, such as poison wire removal and drum uniformity checks, will be performed.

(U) Necessary reactor clustering experiments will be performed by utilizing the NCX and PTX capabilities. Experiments with the clustered reactors will include:

1. Definition of source-core-detector geometries and resultant detector characteristics.
2. Effects of clustering upon power generation tilting in the adjacent core.
3. Effect of clustering upon radiation patterns affecting NSS.

(U) The NCX and PTX reactors are to be located in a new test cell.

(U) Figure 50 is a floor plan view of this test cell. The dimensions of this cell which is to be located on the south side of the present WANEF facility is approximately 50 feet wide by 100 feet long. Sufficient room is available in the facility in order to perform the necessary experiments and handling of the various reactors and components. A truck dock is also provided in the facility in order that proper cleanliness conditions can be maintained during receipt and utilization of the PTX reactors. Space and motion studies have shown that use

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or even extensive modification of the present test cell will not meet these requirements as illustrated in Figure 51.

- (U) Some of the key features of the proposed facility will now be discussed. The PTX test stand is on rails and is movable which will permit experiments as a function of distance between the two reactors. We are providing a collimator type shield which will be utilized to minimize cell and floor backscatter during specific radiation shielding measurements. The collimator shield essentially simulates the space environment that the NERVA reactor will eventually operate in (see Figures 43 and 44). Shielding measurements will be made with the NCX flight shield located on the nozzle end of the reactor. The collimator shield will only permit radiation from the reactor that passes through the shield to be detected at the points of interest. Background radiation from wall and floor scatter will be trapped within the closure formed by the collimator shield. An engine mockup and propellant tank mockup will be employed to determine the effect of these engine structures upon the nuclear subsystem.

4.2 Schedule of Experiments

- (U) A schedule for performance of the experiments is shown in Figure 26. Before discussing the schedule of the NCX and PTX reactors, let me briefly review the schedule of experiments on the FCX and PAX. Later this contract year we will be performing experiments to develop both nuclear and radiation methods in the FCX reactor. Following these FCX physics studies, we will perform NR shield mockup studies on the PAX through the first two quarters of CY-68. The next major experiment will be the NR-1 mockup in the FCX which will be utilized to provide data for the fuel element specification released for the NR-1. Following the mockup experiment, the beryllium reflector will be removed for final machining to the NR-1 specifications. The NCX reactor will be installed and operated in support of the NR-1 reactor during the last two quarters of CY-69. Experiments in support of the final definition of the NR-3 shield will then be performed. There are literally hundreds of miscellaneous experiments that will be performed for the PFRT program in addition to these major ones.

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- (U) Following the FRC for NR-2, the NR-3 flight shield DVT will be performed. The DVT experiment will utilize the NCX along with the collimator, shield, and the engine mockup. The DVT experiment will utilize the NCX along with the collimator shield and the engine mockup. The DVT experiment occurs prior to the assembly of the NR-3 reactor. FRC experiments are performed on all succeeding reactors and engines from NR-3 through NE-10. In CY-72, the NE-3 fully assembled reactors will be brought to WANEF for proof test experiment for the PTX on NE-3. At this time, cluster engine experiments will be performed utilizing the NCX and the NE-3 PTX. Since the NE-3 is presently scheduled to be a spare, we plan to make extensive use of its availability for cluster type experiments. Then in CY-74 and CY-75, PTX experiments will be performed on the completely assembled NE-8 and NE-10 deliverable hardware units.

4.3 Costs

- (U) The costs of the NCX and PTX reactors are shown in Figure 52 in some detail. The cost of the NCX reactor and control system is approximately 1.95 million dollars. The costs for the PTX are about \$90,000. Ancillary equipment necessary for performance of the NR-3 DVT experiment and experiments to determine the effect of the engine upon the nuclear subsystem amount to \$250,000. A schedule for the proposed new test cell is shown in Figure 53.

5.0 DISCUSSION OF UNCERTAINTIES IN THE MEASUREMENT OF PROPELLANT TANK HEATING IN A CRITICAL FACILITY

- (U) In this section we will review the uncertainties existing in analytical calculations of the radiation environment in the nuclear subsystems and the uncertainties existing in the measurement of propellant tank heating.
- (U) Figure 31 shows the magnitude of these analytical uncertainties at specific locations in and around the nuclear subsystem. It also shows the expected experimental uncertainty that can be obtained with the proposed criticals program. This figure also shows the disagreement of calculations with experiments obtained from previous measurements taken on NRX-A2 and A3 tests at NRDS. The inability to accurately predict the measured parameters illustrates the need for a thorough experimental program to resolve these discrepancies.
- (C) Figure 54 shows a Monte Carlo calculation of the heating rate versus shield thickness at the control drum actuator location based on a preliminary 4200 MW NR design. The calculations were performed for a single module flight configuration and for the actuators located on the center reactor in a clustered module flight configuration. It is seen that for an 8" central shield thickness, the actuator heating rate in the clustered mode is increased by a factor of two from the single module configuration. The need for a reduction of the uncertainty in order to confidently predict actuator performance is illustrated by the factor of three error bars.
- (C) Figure 55 presents the results of a Monte Carlo calculation of the heating rate versus shield thickness at the support system actuator location. A similar increase of a factor of two occurs for the clustered module configuration. This again illustrates the need for a reduction in the analytical uncertainties, plus the need to accurately determine the contribution to the radiation environment at the nuclear system components from the off-axis reactor in a clustered configuration. The radiation heating in the propellant tanks in a clustered configuration is illustrated in Figure 56. This figure shows the incident nuclear heating rate

of the propellant as a function of reactor weight increment for single and clustered configuration. The first curve shows the heating rate for a single module. The second curve shows the heating rate contribution from an on-axis reactor and an off-axis reactor. The third curve shows the heating rate experienced by a central tank in a three module clustered configuration. This curve shows the contribution from the central and two off-axis reactors. As a typical example, for a 2400 lb. shield the on-axis reactor contribution is about 300 KW and the two off-axis reactors contribute about 800 KW. The calculations have an uncertainty factor of 2-3 associated with them. It is also seen from the curves that the off-axis contribution becomes much larger than the on-axis contribution; therefore, any program to determine the reactor shield effect on propellant tank heating must consider the off-axis contribution since this is by far the predominant mode of nuclear propellant tank heating in the clustered configuration.

- (C) Figure 57 illustrates the effect of uncertainties in propellant tank heating for a single module Mars braking stage on the shield and system weight increment. These calculations were performed to determine the effect of system weight penalties due to radiation attenuation uncertainties of the shield. As can be seen, a factor of three uncertainty in radiation attenuation results in approximately a 1000 lb increase in shield weight, but a 5000 lb penalty in system weight per module. For five modules this results in a total system weight penalty of approximately 25,000 lb.
- (U) A further illustration of the need for experimental results to assist in reduction of analytical uncertainties is illustrated in the next two slides. Figure 58 shows a comparison of calculations by Point Kernel and Monte Carlo methods of the fast neutron flux with an energy greater than 0.3 MeV as a function of polar angle at a 10 ft radius. It is seen that there is a spread of a factor of approximately ten between the two calculation methods.

- (U) Figure 59 shows a comparison of the calculational methods of the gamma ray dose as a function of polar angle on a radius of 10 ft. It is seen that there is a disagreement of from 2 to 3. This further illustrates the need for criticals experimental measurements to reduce the uncertainties associated with calculational methods.
- (C) The previous figures have shown the importance of a definitive experimental program to determine the effects of a single module and clustered operation on the nuclear subsystem and associated hardware. Specifically, the determination of propellant heating from clustered nuclear operation is necessary. The possibility of performing this type of experiment in a critical facility was investigated. The ability to mockup the neutron and photon transport of liquid hydrogen with a solid hydrocarbon was examined. The choice of polyethylene was made based on a high H to C ratio, ease of handling, safety and availability. Two material densities were selected for the mockup based upon (a) equating electron densities of polyethylene with that of liquid hydrogen to mockup the photon transport properties, yielding a density of 0.12 gm/cc, (b) equating hydrogen atom densities with LH₂ to mockup the neutron transport properties of liquid hydrogen, yielding a density of 0.48 gm/cc.
- (C) Monte Carlo calculations were performed to determine the adequacy of simulating the neutron and photon properties of LH₂. Figure 60 depicts the calculated gamma dose rates of LH₂ and CH₂ media for an on-axis propellant tank center line. It is seen that the agreement of the gamma dose rate between the two media is very good. The statistical uncertainties associated with each position overlap and one cannot say that there is a difference between the photon transport properties of CH₂ and LH₂. However, the trend is that the 0.12 gm/cc polyethylene over-estimates (or under-attenuates) the gamma dose rate by approximately 10-15%. Therefore, it would be expected that a slightly higher density polyethylene would provide better simulation of the LH₂. A 0.14 gm/cc polyethylene is commercially available. This material should provide an excellent photon simulation of LH₂. Presented too on the curve is a comparison of the dose rate contribution of the secondaries produced in hydrogen. It is noted that the polyethylene simulation over-estimates the secondary dose rate by approximately 30% at distances greater than 50 cm.

- (C) It is also noted that it under estimates the gamma dose by approximately 15% at distances less than 20 cm. The secondaries contribute approximately 10-15% of the direct gamma dose rate. Therefore, the 30% difference in secondary gamma dose rate contribution is a small uncertainty addition to the measurement of the total gamma dose rate at detector locations in polyethylene. It has been shown that polyethylene will adequately simulate the direct and secondary photon transport properties of LH_2 . The next question to ask is how does one measure the energy deposition in LH_2 due to gamma rays with CH_2 simulation? It should be noted that the units of the slide are in rads-carbon per hour. A carbon wall CO_2 filled gas ion chamber will measure energy deposition in carbon. The translation of rads-carbon into rads-hydrogen is illustrated in Figure 61. This figure depicts the comparative energy absorption coefficients of H and C. For a constant ratio of mass energy absorption coefficient of H and C, the relationship depicted in the figure applies. That is, the rads H is equal to 1.93 rads C. It is also seen that at 6 MeV there is an approximate 8% decrease in the ratio of energy absorption coefficient and at 10 MeV, the decrease is approximately 16%. The importance of the decrease in the ratio of the energy absorption coefficients is illustrated in Figure 62 which is a plot of the differential gamma energy flux at 180 cm depth into LH_2 . The contribution to the dose rate for photons with energy greater than six MeV is approximately 20%. Therefore, the 10% deviation of the ratio of energy absorption coefficient of H and C contributes an insignificant amount of uncertainty to the conversion into energy deposition in H.
- (C) The next question to ask is how to measure the neutron kinetic energy distribution in a critical facility with a polyethylene mockup? As was stated previously, a density of 0.48 gm/cc should be a good simulation of the neutron transport of LH_2 .
- (C) Figure 63 shows the results of a Monte Carlo calculation of the neutron dose rate in rads-ethylene on the propellant tank center line as a function of distance into the propellant. Also presented on the slide is a similar calculation with a density of 0.12 gm/cc. The 0.12 gm/cc density polyethylene cannot adequately simulate the neutron transport properties of LH_2 , but the 0.48 gm/cc polyethylene is a moderately good simulation up to approximately

70 cm. A linear scale of density change would predict that a density of approximately 0.42 gm/cc would considerably improve the neutron transport simulation in LH₂. A density of 0.54 gm/cc polyethylene is commercially available.

- (U) The next question to ask is how does one measure the energy deposition in hydrogen by use of detector techniques. It is expected that a Hurst dosimeter will be used to measure the energy deposition in rads-ethylene. Figure 64 shows the comparison of dose conversion factors for ethylene and hydrogen as a function of neutron energy. The ratio of rads H to rad ethylene is within 5% of being independent of neutron energy as shown in the upper curve. Therefore, the direct measurement of energy deposition in terms of rads-ethylene presents a constant conversion to rads H with a minimal amount of error.
- (C) The accuracy with which one can expect to measure the tank heating by use of polyethylene simulation in a critical facility can be estimated from the following. The approximate uncertainties for the primary contributors of nuclear heating are listed in Figure 32. The primary gamma heating is estimated to contribute approximately 67% of total tank heating for an on-axis reactor with an expected component measurement uncertainty of approximately 19% to yield an approximate 12.7 unit uncertainty per 100 total heating units. The component uncertainty of 19% was obtained by adding $\pm 8\%$ (uncertainty in test cell gamma background) to the statistical sum of the following individual uncertainties:
- $\pm 5\%$ power level
 - $\pm 5\%$ gamma transport mockup
 - $\pm 9\%$ instrumentation and conversion of rads C to rads H
- (C) The secondary captures contribute approximately 12% of the total heating with a component uncertainty of approximately 39%. The component uncertainty was obtained by adding $\pm 7\%$ (uncertainty in test cell neutron background) to the statistical sum of the following individual uncertainties.

- (C) $\pm 5\%$ power level
 $\pm 10\%$ instrumentation, gamma transport mockup, and conversion of
rads C to rads H
 $\pm 30\%$ neutron captures
- (U) The neutron K.E. deposition uncertainty of $\pm 50\%$ was obtained by adding $\pm 8\%$ (uncertainty in test cell background) to the statistical sum of the following individual uncertainties:
- $\pm 5\%$ power level
 $\pm 10\%$ instrumentation and conversion of rads-ethylene to rads H
 $\pm 40\%$ neutron transport mockup
- (U) The tank cell uncertainty of $\pm 29\%$ was obtained by adding $\pm 10\%$ (tank shell heat transfer uncertainty) to the 19% uncertainty of the primary gamma heating.
- (U) These results yield a total component heating unit uncertainty per 100 total heating units of approximately 15% on a 1σ basis if they are independent variables, i.e., square root of sum of squares from a statistical weighing of the contribution to the total.
- (U) A maximum uncertainty would be $\sim 25.3\%$ if all components uncertainties are dependent variables. This shows that one can expect to measure tank heating accurately in a critical facility using a CH_2 mockup for LH_2 .
- (U) A further illustration of the critical facility ability to reduce uncertainties is the capability to repeat measurements. An example of this is given in Figure 65 where gamma ray ion chambers and a boron ion chamber were exposed at four different locations for three runs on the PAX assembly at WANEF. The good reproducibility is shown by the repetitive measurements which reduced the uncertainties and increases confidence over that associated with experimentation performed on a one run basis.

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APPENDIX A

COMPARISON OF PROPOSED WANEF TEST CELL WITH ALTERNATE
FACILITIES FOR PERFORMING SIDE-BY-SIDE NUCLEAR
AND RADIATION MEASUREMENTS AND PTX EXPERIMENTS

- (U) As part of the evaluation of available and proposed facilities for performing the experiments necessary to support the nuclear and radiation program, an evaluation was performed of the ETS-1, E/STS-2-3 and the proposed new WANEF test cell for performing side-by-side radiation measurements.
- (U) Figures A-1 and A-2 illustrate the possible configuration for ETS-1 and E/STS-2-3. The configuration in the proposed WANEF test cell is illustrated in Figure 50. A summary of the advantages and disadvantages of ETS-1, E/STS-2-3 and the proposed WANEF test cell are shown in Figures A-3, A-4 and A-5, respectively. The overwhelming advantages of the proposed WANEF test cell and the serious disadvantages associated with the use of ETS-1 and E/STS-2-3 resulted in the recommendation of the proposed WANEF test cell for side-by-side nuclear and radiation measurements.
- (U) Advantages and disadvantages of performing PTX experiments at NRDS, Cape Kennedy and in the proposed WANEF test cell were prepared and are given in Figures A-6, A-7 and A-8, respectively. Here again, the overwhelming advantages of performing the experiments in the WANEF test cell have led to its recommendation.

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OUTLINE

INTRODUCTION

NUCLEAR DEVELOPMENT PROGRAM

RADIATION AND SHIELDING DEVELOPMENT PROGRAM

CRITICAL EXPERIMENT FACILITY DESCRIPTION

611949-1

Figure 1. Outline

PERFORMANCE REQUIREMENTS

THERMAL POWER LEVEL	4200 MW
NOZZLE FLOW RATE	243 lb/sec.
CORE OUTLET TEMPERATURE	4500°R
ALLOWABLE TIME FROM CRITICAL TO FULL POWER	60 sec.
OPERATION IN BOTH SINGLE AND CLUSTERED CONFIGURATIONS	
FULL POWER OPERATING TIME	60 min.
SHIELD MEETS CRITERIA	

GEOMETRICAL CHARACTERISTICS

CORE DIAMETER AND LENGTH	51.8 X 52 INCHES
BERYLLIUM THICKNESS	6.0 INCHES
OVERALL NSS HEIGHT	100 INCHES
NUMBER OF CONTROL DRUMS	24

NUCLEAR

INVENTORY OF URANIUM	244 KG
CONTROL DRUM SPAN	\$9.1

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Figure 2. Key Nuclear Subsystem Characteristics

Figure 3. NR-1 Reactor Conceptual Configuration

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<u>CORE CHARACTERISTICS</u>		<u>NO ADDITIVES</u>	<u>ADDITIVE 2.5 v/o NbC</u>
NUMBER OF FUEL ELEMENTS		3606	3606
TOTAL URANIUM LOADING (KG)		244	296
MAXIMUM U LOADING (MG/CM ³)		300	364
MINIMUM U LOADING (MG/CM ³)		94	114
DESIGN SHIM CONTENT (\$)		3	3
CONTROL DRUM SPAN (\$)		9.1	8.4
DESIGN POWER FACTOR RANGE	0.6 TO 1.1		
CHANGE IN EDGE POWER PER DEGREE DRUM CHANGE	0.7%/θ		

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Figure 4. NR and NE Nuclear Characteristics

REACTOR	AIM DRUM POSITION, DEGREES	ACTUAL DRUM POSITION, DEGREES	REACTIVITY DISCREPANCY, DOLLARS
NRX-A2	90	97.8	-0.59
NRX-A3	90	89.1	0.07
NRX-A4	94	99.1	-0.38
NRX-A5	93	99.4	-0.48
MEAN DISCREPANCY			0.38
ESTIMATED STANDARD DEVIATION*			$\sigma \pm 0.17$
			$3\sigma \pm 0.51$

* BASED UPON THE RELATION (FOR A SMALL SAMPLE OF N ELEMENTS)

$$\sigma_{\bar{X}} \approx \frac{\text{RANGE}}{N}$$

611949-48B

Figure 5. Reactivity Shimming Experience in Previous NRX Reactors

ITEM	XE-2	NR-1
1. SPECIFICATION TOLERANCE ON FUEL CARBON ± 2 PERCENT	$\pm 0.99\%$	$\pm 1.08\%$
2. SPECIFICATION TOLERANCE ON INDIVIDUAL ELEMENT URANIUM CONTENT OF ± 2.5 PERCENT	$\pm 0.58\%$	$\pm 0.60\%$
3. SPECIFICATION TOLERANCE ON INDIVIDUAL ELEMENT NIOBIUM CONTENT OF ± 10 GM	$\pm 0.86\%$	$\pm 0.90\%$
4. TOLERANCE OF MOLYBDENUM ± 1 GM	$\pm 0.17\%$	$\pm 0.22\%$
ARITHMETICAL SUM OF UNCERTAINTIES	$\pm 2.62\%$	$\pm 2.80\%$
STATISTICAL SUM OF UNCERTAINTIES	$\pm 1.44\%$	$\pm 1.55\%$

611949-83

Figure 6. Reactivity Uncertainties

	<u>XE-2</u>	<u>NR-1</u>
<u>URANIUM</u>		
THE QUOTED ACCURACY OF THE GAMMA SCANNER ALLOWS A 1.4 PERCENT DISCREPANCY.	<u>+ 0.33\$</u>	<u>+ 0.33\$</u>
<u>CARBON</u>		
ACCURACY OF SCALE ALLOWS 0.7 GRAMS DISCREPANCY PER ELEMENT.	<u>+ 0.06\$</u>	<u>+ 0.08\$</u>
POSSIBLE DISCREPANCY DUE TO MEASUREMENT OF:		
URANIUM	<u>+ 0.14\$</u>	<u>+ 0.11\$</u>
NIOBIUM	<u>+ 0.09\$</u>	<u>+ 0.09\$</u>
MOLYBDENUM	<u>+ 0.09\$</u>	<u>+ 0.09\$</u>
<u>NIOBIUM</u>		
ACCURACY OF SCALES ALLOWS 1.0 GRAMS DISCREPANCY PER ELEMENT.	<u>+ 0.09\$</u>	<u>+ 0.09\$</u>
ACCURACY OF NIOBIUM PROFILE DETERMINATION	<u>+ 0.10\$</u>	<u>+ 0.10\$</u>
<u>MOLYBDENUM</u>		
ACCURACY OF SCALE ALLOWS 1.0 GRAM DISCREPANCY PER ELEMENT.	<u>+ 0.17\$</u>	<u>+ 0.22\$</u>
ARITHMETICAL SUM	<u>+ 1.07\$</u>	<u>+ 1.11\$</u>
STATISTICAL SUM	<u>+ 0.44\$</u>	<u>+ 0.46\$</u>

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Figure 7. Uncertainty Due to Possible Discrepancies in the Determination of Core Mass

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Figure 8. NR and NE Control Reactivity Characteristics

Figure 9. Variation of Key Parameters During NR Startup and Operation

Figure 10. Influence on the NR and NE Power Distribution of Adding Reactivity by Control Drums and Adjusting Flow in Support Stems

NUMBER OF DRUMS
 TOTAL REACTIVITY SPAN OF BANK
 MAXIMUM WORTH OF BANK
 WORTH OF A SINGLE DRUM
 MAXIMUM WORTH OF SINGLE DRUM

24
 9.0\$
 7.5 ¢/o
 37.5 ¢
 0.31 ¢/o

SENSITIVITY FACTORS

Δ DRUM SPAN/ Δ NUMBER OF DRUMS AT 24 DRUMS	+ 0.25\$/DRUM
Δ DRUM SPAN/ Δ BERYLLIUM THICKNESS AT 6" THICKNESS	+ 2.0\$/IN.
Δ DRUM SPAN/ Δ MG B-10 PER CM ² AT 65 MG/CM ²	+ 0.016\$/MG B-10, PER CM ²
Δ DRUM SPAN/ Δ V/O NbC ADDITIVE AT 0 V/O ADDITIVE	- 0.25\$/V/O NbC
Δ DRUM SPAN/ Δ VANE RADIUS AT 2.12"	+ 4.29\$/IN.

611949-50

Figure 11. NR Control Drum Nuclear Characteristics

1. PROVIDE VARIATION OF FISSION DISTRIBUTION THROUGHOUT REACTOR CORE
2. VERIFICATION OF CONTROL DRUM AND REFLECTOR REACTIVITY CONTROL CAPABILITY
3. PROVIDE INFLUENCE OF SUPPORT STEM AND FUEL CHANNEL HYDROGEN ON FISSION DISTRIBUTION, COLD TO HOT REACTIVITY CHANGE, AND CONTROL CAPABILITY
4. PROVIDE INFLUENCE OF VARIOUS COMPONENTS AND MATERIALS ON FISSION DISTRIBUTION AND REACTIVITY
5. PROVIDE VERIFICATION OF CLUSTER PLATE EFFECT ON INLET POWER PEAKING
6. PROVIDE VERIFICATION OF FLIGHT POISON WIRE SYSTEM CHARACTERISTICS
7. PROVIDE VERIFICATION OF NR FUEL ELEMENT NUCLEAR MATERIAL CONTENT BY REACTIVITY MEASUREMENT OF A SAMPLE OF PRODUCTION FUEL
8. PROVIDE INFLUENCE OF TEST CELL C FACILITY ON FISSION DISTRIBUTION AND REACTIVITY
9. PROVIDE SUPPORT TO APPROACH TO CRITICAL AT TEST CELL C

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Figure 12. Nuclear Experimental Information Needs to Support NR Reactors

1. PROVIDE INFLUENCE OF SUPPORT STEM AND FUEL CHANNEL HYDROGEN (OVER THE OPERATING MAP) ON FISSION DISTRIBUTION AND CONTROL CAPABILITY
2. PROVIDE INFLUENCE OF CLUSTERED ENGINE CONFIGURATION ON NUCLEAR STARTUP AND SOURCE - DETECTOR LOCATION
3. PROVIDE INFLUENCE OF CLUSTERED ENGINE OPERATION ON FISSION DISTRIBUTION AND REACTIVITY
4. PROVIDE VERIFICATION OF NE FUEL ELEMENT NUCLEAR MATERIAL CONTENT BY REACTIVITY MEASUREMENT OF A SAMPLE OF PRODUCTION FUEL
5. VERIFY THE CRITICAL DRUM POSITION OF THE DELIVERABLE ENGINE SUBSYSTEM (NE-8 AND NE-10) PRIOR TO SHIPMENT
6. PROVIDE INFLUENCE OF ETS-1 AND E/STS 2-3 ON FISSION DISTRIBUTION AND REACTIVITY
7. PROVIDE SUPPORT TO ETS-1 AND E/STS 2-3 APPROACH TO CRITICAL

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Figure 13. Nuclear Experimental Information Needs to Support NE Reactors

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1. FLEXIBLE CRITICAL EXPERIMENT (FCX) NR MOCKUP
2. NERVA CRITICAL EXPERIMENT (NCX)
3. PROOF TEST EXPERIMENT (PTX)

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Figure 14. Experimental Facilities to Support PFRT Nuclear Development Program

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Figure 15. FCX Assembly

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Figure 16. FCX (Flexible Critical Experiment for NR-1)

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1. PROVIDE ESTIMATES OF VARIATION OF FISSION DISTRIBUTION THROUGHOUT REACTOR CORE SUITABLE FOR SETTING FUEL ZONING SPECIFICATION.
2. PROVIDE INITIAL VERIFICATION OF CONTROL DRUM AND REFLECTOR REACTIVITY CONTROL CAPABILITY.
3. PROVIDE INFLUENCE OF VARIOUS COMPONENTS AND MATERIALS ON FISSION DISTRIBUTION AND REACTIVITY.

Figure 17. Nuclear Experimental Information to be Obtained from the FCX NR Mockup

	<u>DATE</u>
1. COMPLETE DRAWING RELEASE ON BERYLLIUM	9/67
2. COMPLETE BALANCE OF DRAWINGS	4/68
3. COMPLETE ASSEMBLY AND CHECKOUT OF MOCKUP REFLECTOR	6/68
4. INITIAL CRITICALITY	6/68
5. COMPLETE EXPERIMENTAL PROGRAM	12/68
6. RELEASE BERYLLIUM TO MACHINING FOR NCX	12/68

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Figure 18. FCX NR Mockup Schedule

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~~GROUP 1 - Excluded from automatic downgrading and declassification~~

Figure 19. NCX Assembly

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~~GROUP 1 - Excluded from automatic downgrading and declassification~~

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38

1. PROVIDE FINAL VARIATION OF FISSION DISTRIBUTION THROUGHOUT CORE.
2. PROVIDE FINAL VERIFICATION OF CONTROL DRUM AND REFLECTOR CONTROL CAPABILITY.
3. PROVIDE INFLUENCE OF HYDROGEN IN SUPPORT STEM AND FUEL CHANNELS ON FISSION DISTRIBUTION AND REACTIVITY OVER OPERATING MAP.
4. PROVIDE INFLUENCE OF VARIOUS COMPONENTS AND MATERIALS ON FISSION DISTRIBUTION AND REACTIVITY.
5. PROVIDE VERIFICATION OF CLUSTER PLATE EFFECT ON INLET POWER PEAKING.
6. PROVIDE VERIFICATION OF FLIGHT ANTICRITICALITY POISON SYSTEM CHARACTERISTICS.
7. PROVIDE VERIFICATION OF THE NUCLEAR MATERIAL CONTENT OF A SAMPLE OF PRODUCTION FUEL FOR EACH REACTOR (FRC).
8. PROVIDE INFLUENCE OF TEST CELL C, ETS-1 AND E/STS 2-3 ON FISSION DISTRIBUTION AND REACTIVITY.
9. PROVIDE SUPPORT TO APPROACH TO CRITICAL AT TEST CELL C, ETS - 1 AND E/STS 2-3.

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Figure 20. Nuclear Experimental Information to be Obtained from the NCX

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		<u>DATE</u>
1.	COMPLETE FINAL DRAWING RELEASE ON BERYLLIUM	10/68
2.	COMPLETE BALANCE OF DRAWINGS	2/69
3.	COMPLETE ASSEMBLY AND CHECKOUT OF REFLECTOR	9/69
4.	PERFORM INITIAL CRITICALITY	10/69
5.	COMPLETE EXPERIMENTS IN SUPPORT OF NR-1	1/70
6.	PERFORM COUPLED REACTOR EXPERIMENT DURING PTX ON NE-3	1/73
7.	PERFORM COUPLED REACTOR EXPERIMENT DURING PTX ON NE-8	7/74
8.	PERFORM COUPLED REACTOR EXPERIMENT DURING PTX ON NE-10	1/75

Figure 21. NCX Schedule

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1. PROVIDE VERIFICATION OF THE ACCEPTABLE CRITICAL DRUM POSITION
ON THE DELIVERABLE ENGINE SUBSYSTEM (NE-8 AND NE-9)
AND NE-3 PRIOR TO SHIPMENT
2. VERIFY THE REACTIVITY CONTROL SPAN OF THE CONTROL DRUMS
AND REFLECTOR SYSTEM
3. PROVIDE A CHECKOUT OF THE GANGED CONTROL DRIVE SYSTEM

Figure 22. Nuclear Experimental Information to be Obtained from the PTX

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41

1. PROVIDE INFLUENCE OF CLUSTERED ENGINE OPERATION ON NUCLEAR DETECTOR RESPONSE AND OPTIMUM SOURCE LOCATION DURING STARTUP, SHUTDOWN, AND MANEUVERING
2. PROVIDE INFLUENCE OF CLUSTERED OPERATION OF FISSION DISTRIBUTION AND REACTIVITY
3. PROVIDE INFLUENCE ON REACTIVITY OF ADJACENT PROPELLANT TANK IN CLUSTERED CONFIGURATION
4. PROVIDE VERIFICATION OF AN ACCEPTABLE CRITICAL DRUM POSITION OF THE DELIVERABLE ENGINE SUBSYSTEMS (NE-8 AND NE-10) PRIOR TO SHIPMENT

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Figure 23. Nuclear Experimental Information to be Obtained from the Operation of NCX and PTX

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1. PROVIDE VARIATION OF FISSION DISTRIBUTION THROUGHOUT THE REACTOR CORE.
2. VERIFICATION OF CONTROL DRUM AND REFLECTOR REACTIVITY CONTROL CAPABILITY.
3. PROVIDE INFLUENCE OF SUPPORT STEM AND FUEL CHANNEL HYDROGEN ON FISSION DISTRIBUTION, COLD TO HOT REACTIVITY CHANGE AND CONTROL CAPABILITY OVER THE OPERATING MAP.
4. PROVIDE INFLUENCE OF VARIOUS COMPONENTS AND MATERIALS ON FISSION DISTRIBUTION AND REACTIVITY.
5. PROVIDE VERIFICATION OF CLUSTER PLATE EFFECT ON INLET POWER PEAKING.
6. PROVIDE VERIFICATION OF FLIGHT POISON WIRE SYSTEM CHARACTERISTICS.

FCX-NR	NCX	NCX-PTX	PTX
P	F		
P	F		
	F		
P	F		
	F		
	F		

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Figure 24a. Nuclear Experimental Information Needs to Support NR and NE Reactors and the Experimental Facilities

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43

7. PROVIDE VERIFICATION OF NR AND NE FUEL ELEMENT NUCLEAR MATERIAL CONTENT BY REACTIVITY MEASUREMENT OF A SAMPLE OF PRODUCTION FUEL.
8. PROVIDE INFLUENCE OF TEST CELL C, ETS-1 AND E/STS 2-3 FACILITIES ON FISSION DISTRIBUTION AND REACTIVITY.
9. PROVIDE SUPPORT TO APPROACH TO CRITICAL AT TEST CELL C, ETS-1 AND E/STS 2-3.
10. PROVIDE INFLUENCE OF CLUSTERED ENGINE CONFIGURATION ON NUCLEAR STARTUP AND SOURCE - DETECTOR LOCATION.
11. PROVIDE INFLUENCE OF CLUSTERED ENGINE OPERATION ON FISSION DISTRIBUTION AND REACTIVITY.
12. VERIFY THE CRITICAL DRUM POSITION OF THE DELIVERABLE ENGINE SUBSYSTEM (NE-8 & NE-10) PRIOR TO SHIPMENT.

FCX-NR	NCX	NCX-PTX	PTX
	F		
	F		
	F		
		F	
		F	
			F

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Figure 24b. Nuclear Experimental Information Needs to Support NR and NE Reactors and the Experimental Facilities (cont'd.)

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44

1. UTILIZE AN INTEGRATED ANALYTICAL AND EXPERIMENTAL PROGRAM TO INSURE NSS MEETS NUCLEAR SPECIFICATION
2. EXPERIMENTAL PROGRAM EMPLOYS FCX NR MOCKUP, NCX, AND PTX ASSEMBLIES TO SUPPLY NUCLEAR INFORMATION NEEDS
3. EXPERIMENT PROGRAM PROVIDES THE FOLLOWING NUCLEAR INFORMATION
 - A. FISSION DISTRIBUTION THROUGHOUT CORE
 - B. INFLUENCE OF CONTROL DRUM POSITION, SUPPORT STEM AND FUEL CHANNEL HYDROGEN AND VARIOUS COMPONENTS AND MATERIALS ON FISSION DISTRIBUTION.
 - C. INFLUENCE OF CONTROL DRUM POSITION, SUPPORT STEM AND FUEL CHANNEL HYDROGEN, TEST CELLS, ENGINE AND PROPELLANT TANKS ON REACTIVITY
 - D. INFLUENCE OF CLUSTERED OPERATION ON NUCLEAR STARTUP
 - E. VERIFICATION THAT DELIVERABLE ENGINES HAVE AN ACCEPTABLE COLD CRITICAL DRUM POSITION PRIOR TO SHIPMENT

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611949-13

Figure 25. Summary of Nuclear Development Program

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Figure 26. Nuclear, Radiation and Shielding Development Experiment Schedule

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Figure 27. Schematic of Basic Geometric Model

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1.	THERMAL POWER LEVEL	4200 MW
2.	MAXIMUM HEATING RATE IN:	
	A. UNFUELED ELEMENT	280 WATTS/GM
	B. BERYLLIUM	57 WATTS/GM
	C. SHIELD	101 WATTS/GM
	D. CONTROL VANE	780 WATTS/GM
	E. SUPPORT PLATE	1.9 WATTS/GM
	F. CLUSTER PLATES	271 WATTS/GM
3.	MAXIMUM FAST NEUTRON FLUX ($E > 1.0$ MEV)	1×10^{16} NEUTRONS/CM ² -SEC
4.	<u>RADIATION LEVELS AT 7.0 FEET ABOVE CORE CENTER</u> <u>(ON REACTOR AXIS) (SINGLE MODULE)</u>	<u>SHIELD THICKNESS</u>
		8" 12" 16"
	FAST NEUTRON FLUX ($E > 1.0$ MEV)	4.1×10^{11} 2.2×10^{11} 5.6×10^{10}
	GAMMA DOSE RATE (RADS, C/HR)	1.4×10^7 4.6×10^6 1.7×10^6
	HEATING RATE IN ALUMINUM (WATTS/GM)	0.041 0.013 0.0048
5.	MAXIMUM HEATING RATE IN CONTROL DRUM ACTUATOR (WATTS/GM-AL)	0.066 0.024 0.011
6.	MAXIMUM HEATING RATE IN TIE TUBE COOLANT VALVE ACTUATOR (WATTS/GM-AL)	0.059 0.021 0.011

611949-40

Figure 28. NR Radiation and Shielding Characteristics (Preliminary)

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TEMP DIFFERENCE

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Figure 29. Temperature Difference in 1/4" Slab Cooled on Both Sides

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49

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Figure 30. Temperature Rise in Adiabatic Sample

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<u>COMPONENT</u>	<u>ANALYTICAL UNCERTAINTY (PERCENT)</u>	<u>EXPECTED EXPERIMENTAL (PERCENT)</u>
SUPPORT SYSTEM ACTUATOR HEATING	100-200	10
CONTROL DRUM ACTUATOR HEATING	100-200	10
PROPELLANT HEATING	100-200	15
MIDPLANE NEUTRON FLUX > 2.9 MEV ⁽¹⁾ NRX-A2-A3	30-60*	
GROSS REFLECTOR HEATING, NRX-A2-A3	15*	
THERMAL FLUX-REFLECTOR, NRX-A2-A3	100*	
NRX-A3 CALORIMETER DATA ⁽¹⁾		
NOZZLE	30*	
DOVE	100*	

(1) DATA PRESENTED AT ANS WINTER MEETING, 1966, OCT. 30-NOV. 3

*AMOUNT OF DISAGREEMENT WITH EXPERIMENT

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Figure 31. Present Analytical Uncertainties

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51

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<u>CONTRIBUTOR</u>	<u>APPROXIMATE PERCENTAGE OF TOTAL TANK HEATING</u>	<u>EXPECTED COMPONENT UNCERTAINTY</u>	<u>COMPONENT HEATING UNIT UNCERTAINTY PER 100 TOTAL HEATING UNITS</u>
PRIMARY GAMMA HEATING	67%	$\pm 19\%$	12.7
CAPTURE GAMMA HEATING	12%	$\pm 39\%$	4.8
NEUTRON K. E. HEATING	8%	$\pm 50\%$	4.0
TANK SHELL HEATING TO PROPELLANT	13%	$\pm 29\%$	3.8
TOTAL			14.7

611949-47

Figure 32. Development of Uncertainty in Experimental Measurement of Propellant Tank Heating

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Figure 33. Comparison of NR-1 Shielded vs. Unshielded Core Gamma Dose Rate at 10 Feet From the Core Center

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Figure 34. Steady State Power of Shutdown Driven Core,
Driver Core at Full Power

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54

1. MEASURE RADIATION CHARACTERISTICS* THROUGHOUT THE NSS
2. INFLUENCE OF CONTROL DRUM POSITION AND HYDROGEN DISTRIBUTION ON RADIATION CHARACTERISTICS*
3. INFLUENCE OF VARIOUS COMPONENT AND MATERIALS ON RADIATION CHARACTERISTICS
4. INFLUENCE OF INTERNAL CENTRAL AND SIDE SHIELD MATERIAL AND CONFIGURATION ON RADIATION CHARACTERISTICS
5. VERIFICATION THAT NSS MEETS THE SHIELD CRITERIA (DVT OF SHIELD)
6. INFLUENCE OF TEST CELL C ON RADIATION CHARACTERISTICS
7. RADIATION CHARACTERISTICS OF TEST CELL C SHIELD
8. MEASUREMENTS TO SUPPORT THE NUCLEAR DETECTOR SYSTEM DEVELOPMENT FOR TEST CELL C

*RADIATION CHARACTERISTICS INCLUDE, FOR EXAMPLE, THE FAST NEUTRON FLUX, THERMAL NEUTRON FLUX, GAMMA DOSE RATE AND RADIATION HEATING.

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Figure 35. Radiation and Shielding Experimental Information Needs to Support NR Program

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1934

55

1. MEASURE RADIATION CHARACTERISTICS* THROUGHOUT THE NSS IN THE ENGINE CONFIGURATION.
2. MEASUREMENT OF RADIATION CHARACTERISTICS IN ONE NSS FROM AN ADJACENT NSS IN THE CLUSTERED CONFIGURATION.
3. MEASUREMENTS TO SUPPORT THE NUCLEAR DETECTOR SYSTEM DEVELOPMENT FOR USE IN ETS-1 AND E/STS 2-3.
4. INFLUENCE OF ETS - 1 AND E/STS 2-3 ON RADIATION CHARACTERISTICS.
5. MEASUREMENT OF CHARACTERISTICS OF LOCAL SHIELDS THAT MAY BE REQUIRED TO MEET NSS COMPONENT LIMITATIONS.

* RADIATION CHARACTERISTICS INCLUDE, FOR EXAMPLE, THE FAST NEUTRON FLUX, THERMAL NEUTRON FLUX, GAMMA DOSE RATE AND RADIATION HEATING.

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Figure 36. Radiation and Shielding Experimental Information Needs to Support NE Program

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1954

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1. PRE-ASSEMBLY EXPERIMENT (PAX)
2. FLEXIBLE CRITICAL EXPERIMENT (FCX) NR MOCKUP
3. NERVA CRITICAL EXPERIMENT (NCX)
4. PROOF TEST EXPERIMENTS (PTX)

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Figure 37. Experimental Facilities to Support PFRT Radiation and Shielding Development Program

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1954

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Figure 38. Preassembly Reactor Experiment (PAX)

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1. MEASUREMENT OF RADIATION CHARACTERISTICS* IN AND ADJACENT TO AN NR SHIELD MOCKUP
2. MEASUREMENT OF THE RADIATION CHARACTERISTIC IN AND ADJACENT TO THE NR BACKUP SHIELD MATERIAL
3. MEASUREMENT OF STREAMING EFFECTS OF SHIELD PENETRATIONS IN THE NR SHIELD MOCKUP

*RADIATION MEASUREMENTS INCLUDE, FOR EXAMPLE, THE FAST NEUTRON FLUX, THERMAL NEUTRON FLUX, GAMMA DOSE RATE AND RADIATION HEATING .

Figure 39. Radiation and Shielding Experimental Information from PAX

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	<u>Date</u>
1. ORDER MATERIALS REQUIRED FOR SHIELD MOCKUPS	9/67
2. INITIATE EXPERIMENTS	11/67
3. COMPLETE EXPERIMENTS	4/68

611949-18

Figure 40. PAX Radiation and Shielding Schedule

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60

INITIAL MEASUREMENTS OF RADIATION
CHARACTERISTICS* IN THE CORE AND
REFLECTOR WITH SPECIAL ATTENTION TO
LIMITING COMPONENTS

*RADIATION CHARACTERISTICS INCLUDE, FOR EXAMPLE,
THE FAST NEUTRON FLUX, THERMAL NEUTRON FLUX,
GAMMA DOSE RATE AND RADIATION HEATING.

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Figure 41. Radiation and Shielding Information from FCX NR Mockup

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1954
1. MEASUREMENT OF RADIATION CHARACTERISTICS* THROUGHOUT THE NSS.
 2. MEASUREMENT OF THE RADIATION CHARACTERISTICS THROUGHOUT THE NSS IN THE ENGINE CONFIGURATION.
 3. INFLUENCE OF CONTROL DRUM POSITION AND HYDROGEN DISTRIBUTION ON RADIATION CHARACTERISTICS.
 4. VERIFICATION MEASUREMENTS ON THE CENTRAL AND SIDE SHIELDS (DVT OF SHIELDS).
 5. INFLUENCE OF VARIOUS COMPONENTS AND MATERIALS ON RADIATION CHARACTERISTICS.
 6. MEASUREMENT TO SUPPORT DEVELOPMENT OF NUCLEAR DETECTOR SYSTEMS FOR TEST CELL C, ETS-1 AND E/STS 2-3.
 7. INFLUENCE OF TEST CELL C, ETS-1 AND E/STS 2-3 ON RADIATION CHARACTERISTICS OF NSS.

* RADIATION CHARACTERISTICS INCLUDE, FOR EXAMPLE, THE FAST NEUTRON FLUX, THERMAL NEUTRON FLUX, GAMMA DOSE RATE AND RADIATION HEATING.

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611949-52

Figure 42. Radiation and Shielding Experimental Information from NCX

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Figure 43. Ratio of Calculated Gamma Ray Dose Rate Test Environment to Space Environment at a Propellant Tank Mockup

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Figure 44. Ratio of Calculated Fast Neutron Dose Rate Test Environment to Space Environment at a Propellant Tank Mockup

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64

1. MEASUREMENT OF RADIATION CHARACTERISTICS* IN ONE NSS (PTX) FROM AN ADJACENT NSS (NCX) IN THE CLUSTERED CONFIGURATION.
2. EVALUATION OF THE EFFECT OF ENGINE MOCKUP AND PROPELLANT TANK MOCKUP ON RADIATION CHARACTERISTICS OF NSS COMPONENTS IN THE CLUSTERED CONFIGURATION.
3. MEASUREMENT OF THE SHUTDOWN POWER LEVEL IN ONE NSS FROM AN ADJACENT NSS IN THE CLUSTERED CONFIGURATION.
4. DEMONSTRATION OF THE STARTUP OF CLUSTERED NSS INCLUDING DETERMINATION OF OPTIMUM SOURCE-DETECTOR SYSTEM DESIGN.

*RADIATION CHARACTERISTICS INCLUDE, FOR EXAMPLE, THE FAST NEUTRON FLUX, THERMAL NEUTRON FLUX, GAMMA DOSE RATE AND RADIATION HEATING.

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Figure 45. Radiation and Shielding Experimental Information from NCX-PTX

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PERFORM COUPLED RADIATION MEASUREMENTS DURING PTX ON NE-3 - 1/73
PERFORM COUPLED RADIATION MEASUREMENTS DURING PTX ON NE-8 - 7/74
PERFORM COUPLED RADIATION MEASUREMENTS DURING PTX ON NE-10 - 1/75

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Figure 46. Schedule for NCX-PTX Radiation and Shielding Measurements

	PAX	FCX-NR	NCX	NCX-PTX
1. MEASURE RADIATION CHARACTERISTICS* THROUGHOUT THE NSS.		P	F	
2. INFLUENCE OF CONTROL DRUM POSITION AND HYDROGEN DISTRIBUTION ON RADIATION CHARACTERISTICS*.		P	F	
3. INFLUENCE OF VARIOUS COMPONENT AND MATERIALS ON RADIATION CHARACTERISTICS*.			F	
4. INFLUENCE OF INTERNAL CENTRAL AND SIDE SHIELD MATERIAL AND CONFIGURATION ON RADIATION CHARACTERISTICS*.	P		F	
5. VERIFICATION THAT NSS MEETS THE SHIELD CRITERIA (DVT OF SHIELD).			F	
6. INFLUENCE OF TEST CELL C AND ETS-1 ON RADIATION CHARACTERISTICS*.			F	
7. RADIATION CHARACTERISTICS* ON TEST CELL C SHIELD.			F	
*RADIATION CHARACTERISTICS INCLUDE, FOR EXAMPLE, THE FAST NEUTRON FLUX, THERMAL NEUTRON FLUX, GAMMA DOSE RATE AND RADIATION HEATING.				

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Figure 47a. Radiation and Shielding Experimental Information Needs to Support NR and NE Program and the Experimental Facilities

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67

8. MEASUREMENTS TO SUPPORT THE NUCLEAR DETECTOR SYSTEM DEVELOPMENT FOR TEST CELL C AND ETS-1.
9. MEASUREMENT OF RADIATION CHARACTERISTICS* IN ONE NSS FROM AN ADJACENT NSS IN THE CLUSTERED CONFIGURATION.
10. MEASUREMENT OF CHARACTERISTICS OF LOCAL SHIELDS THAT MAY BE REQUIRED TO MEET NSS COMPONENT LIMITATIONS.
11. EVALUATION OF THE EFFECT OF ENGINE MOCKUP AND PROPELLANT TANK MOCKUP ON RADIATION CHARACTERISTICS* OF NSS COMPONENTS IN THE CLUSTERED CONFIGURATION.
12. MEASUREMENT OF THE SHUTDOWN POWER LEVEL IN ONE NSS FROM AN ADJACENT NSS IN THE CLUSTERED CONFIGURATION.
13. DEMONSTRATION OF THE STARTUP OF CLUSTERED NSS INCLUDING DETERMINATION OF OPTIMUM SOURCE-DETECTOR SYSTEM DESIGN.

* RADIATION CHARACTERISTICS INCLUDE, FOR EXAMPLE, THE FAST NEUTRON FLUX, THERMAL NEUTRON FLUX, GAMMA DOSE RATE AND RADIATION HEATING.

PAX	FCX-NR	NCX	NCX-PTX
		F	
			F
		F	F
		F	
			F
			F

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Figure 47b. Radiation and Shielding Experimental Information Needs to Support NR and NE Program and the Experimental Facilities (cont'd.)

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68

1. UTILIZE AN INTEGRATED ANALYSIS AND EXPERIMENTAL MEASUREMENT PROGRAM TO INSURE NSS MEETS ALL RADIATION AND SHIELDING SPECIFICATIONS.
2. EXPERIMENTAL PROGRAM EMPLOYS PAX/FCX R MOCKUP, NCX, AND PTX ASSEMBLIES TO SUPPLY RADIATION AND SHIELDING INFORMATION NEEDS.
3. EXPERIMENTAL PROGRAM PROVIDES THE FOLLOWING RADIATION AND SHIELDING INFORMATION:
 - A. RADIATION CHARACTERISTICS THROUGHOUT THE NSS IN THE SINGLE AND CLUSTERED CONFIGURATION.
 - B. INFLUENCE OF TEST CELLS C, AND ETS-1, ON NSS RADIATION CHARACTERISTICS.
 - C. INFLUENCE OF CONTROL DRUMS AND HYDROGEN ON RADIATION CHARACTERISTICS.
 - D. VERIFICATION THAT THE SHIELD MEETS ITS DESIGN CRITERIA.
 - E. DEMONSTRATION OF THE STARTUP OF CLUSTERED NSS.

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Figure 48. Summary of Radiation and Shielding Development Program

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69

1. DESCRIPTION OF CRITICAL REACTOR ASSEMBLIES AND FACILITY.
2. UTILIZATION IN PFRT PROGRAM AND SCHEDULE
3. COSTS

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Figure 49. Critical Experiment Facility Description

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Figure 50. Proposed WANEF Layout

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71

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Figure 51. WANEF Layout Showing a Modification of the Existing Test Cell

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72

1.	<u>NERVA CRITICAL EXPERIMENT (NCX)</u>	
	NCX BERYLLIUM MACHINING	\$ 116,240
	DRUM DRIVES	105,000
	TEST STAND AND TOOLS	30,000
	CONTROL SYSTEM	94,600
	NOZZLE MOCKUP	20,000
	PRESSURE VESSEL MOCKUP	20,000
	REFLECTOR COMPONENTS	307,000
	CORE COMPONENTS	768,900
	NCX/NR SHIELD	492,642
	NCX TOTAL	1,953,682
2.	<u>PROOF TEST EXPERIMENT (PTX)</u>	
	CONTROL CONSOLE	69,600
	TEST STAND AND TOOLS	32,000
	DRUM DRIVES	50,000
	TURNING STAND	38,000
	PTX TOTAL	189,600
3.	<u>ANCILLARY EQUIPMENT</u>	
	COLLIMATOR SHIELD	150,000
	HARDWARE MOCKUP	100,000
	ANCILLARY EQUIPMENT TOTAL	250,000

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Figure 52. WANEF Critical Reactor Costs

(Contract Years)

DESIGN TEST CELL

CONSTRUCT TEST CELL

INSTALL NCX CONTROLS AND WIRING

CHECKOUT NCX CONTROL SYSTEM

NCX/NR-1 EXPERIMENTS

NR-1 ASSEMBLY

NCX/NR-3 SHIELD DESIGN MEASUREMENT

NR-3 SHIELD HARDWARE RELEASE

DVT NR-3 SHIELD

CONTINUING NR AND NE EXPERIMENTS

PERFORM PTX ON NE-3

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Figure 53. Proposed WANEF Test Cell Schedule

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Figure 54. Heating Rate vs. Shield Thickness at Actuator Detector Point Location 4, 200 Megawatt NR-1

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Figure 55. Heating Rate vs. Shield Thickness at Drum Actuator and Support System Actuator 4, 200 Megawatt NERVA

611949-33

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Figure 56. 5000 MW Incident Nuclear Heating Rate
(Minimum Reactor Weight Increment)

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Figure 57. System Weight Increment vs. Shield Weight with Unshielded Integral Tank Heating as Parameter for Single Module

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Figure 58. Comparison of Alternate Methods of Calculating Neutron Flux Distribution

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Figure 59. Gamma Ray Dose Rate 10 Feet From Center

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Figure 60. Calculated Gamma Dose Rates for LH₂ and CH₂ Media for
On-Axis Propellant Tank Centerline

Figure 61. Comparative Energy Absorption Coefficients Hydrogen and Carbon

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Figure 62. Differential Gamma Energy Flux (Monte Carlo)

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Figure 63. Calculated Neutron Dose Rate on Propellant Tank Centerline

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Figure 64. Comparison of Dose Conversion Factors for Ethylene and Hydrogen

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<u>RUN NO.</u>	<u>DETECTOR NO. 1</u> <u>10⁺² R/HR/WATTS</u>	<u>DETECTOR NO. 2</u> <u>10⁺² R/HR/WATTS</u>	<u>DETECTOR NO. 3</u> <u>10⁺² R/HR/WATTS</u>	<u>BORON</u> <u>ION CHAMBER</u> <u>10⁹ AMPS/WATTS</u>
1	9.56 X 10 ⁻²	9.13 X 10 ⁻²	5.64 X 10 ⁻²	7.5 X 10 ⁻⁹
2	9.57 X 10 ⁻²	9.57 X 10 ⁻²	5.64 X 10 ⁻²	7.5 X 10 ⁻⁹
3	9.70 X 10 ⁻²	9.61 X 10 ⁻²	5.64 X 10 ⁻²	7.52 X 10 ⁻⁹
AVERAGE	9.61 ± 0.08 (σ = 1%)*	9.44 ± 0.26 (σ = 2.7%)*	5.64 ± 0 *	7.51 ± 0.01 (σ < 1%)*

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*STANDARD DEVIATION OF THE MEAN BASED ON

$$\sigma^2 = \frac{1}{N-1} \sum_{i=1}^N (X_i - \bar{X})^2$$

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Figure 65. Demonstration of Reproducibility of Active Measurement Technique at WANEF

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Figure A-1. ETS-1 Possible Side-by-Side Configuration for
Nuclear and Radiation Measurements

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Figure A-2. E/STS-2-3 Possible Side-by-Side Configuration for Nuclear and Radiation Measurements

ETS-1

ADVANTAGES

1. FACILITY TOTALLY AVAILABLE AFTER COMPLETION OF NE-1 TEST, (JUNE, 1971).

DISADVANTAGES

1. FACILITY SHIELD AND UPPER SUPPORT STRUCTURE WILL HAVE TO BE REMOVED.
2. PRESENT RUN TANK DOES NOT HAVE CORRECT BOTTOM GEOMETRY.
3. REQUIRES RAIL CAR AND TANK.
4. REQUIRES ACTIVATION OF IMPROVED RADIATION MEASUREMENT TECHNIQUES.
5. FACILITY WILL NOT BE WELL SUITED FOR CAREFUL EXPERIMENTAL MEASUREMENTS.
6. CANNOT OPERATE TWO REACTORS SIMULTANEOUSLY.

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Figure A-3. (ETS-1) Summary of Advantages and Disadvantages of Various Facilities for Side-by-Side Nuclear and Radiation Measurements

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89

E/STS-2-3

ADVANTAGES

1. FACILITY AVAILABLE DURING ENGINE TESTS FOR A PERIOD OF TWO WEEKS EVERY SIX MONTHS BEGINNING JUNE, 1972 (NE-2)

DISADVANTAGES

1. PRESENCE OF LARGE PERMANENT TANK SUPPORT STRUCTURE WILL SEVERELY INTERFERE WITH OFF AXIS TANK MEASUREMENTS AND INCREASE FACILITY BACKSCATTER IN TANK MEASUREMENT.
2. REQUIRES SPECIAL RAIL CAR AND TANK.
3. REQUIRES ACTIVATION OF IMPROVED RADIATION MEASUREMENT TECHNIQUES.
4. FACILITY WILL NOT BE WELL SUITED FOR CAREFUL EXPERIMENTAL MEASUREMENTS.
5. LARGE TIME ELEMENT (6 MONTHS) BETWEEN TESTS, AND ANTICIPATE SCHEDULING DIFFICULTIES SHOULD ANY REDO OF DATA BE REQUIRED.
6. CANNOT OPERATE TWO REACTORS SIMULTANEOUSLY.

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Figure A-4. (E/STS-2-3) Summary of Advantages and Disadvantages of Various Facilities for Side-by-Side Nuclear and Radiation Measurements

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90

ADVANTAGES

1. CAN START GETTING DATA JULY, 1969.
2. REPEATED RUNS AND ADVANCED RADIATION MEASUREMENT TECHNIQUES INSURE ACCURATE DATA.
3. SPECIAL FACILITY DESIGN MINIMIZES THE EFFECT OF BACKSCATTER OF RADIATION AND PROVIDES OPTIMUM SIMULATION OF SPACE ENVIRONMENT.
4. AVAILABILITY OF SPECIALLY TRAINED PERSONNEL.
5. OPERATE TWO REACTORS SIMULTANEOUSLY.

DISADVANTAGES

1. REQUIRES PURCHASE OF PROPELLANT TANK MOCKUP AND COLLIMATOR SHIELD, WHOSE ACCOMODATION REQUIRES A NEW TEST CELL.

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Figure A-5. (Proposed WANEF Test Cell) Summary of Advantages and Disadvantages of Various Facilities for Side-by-Side Nuclear and Radiation Measurements (cont'd.)

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91

ADVANTAGES

1. NONE

DISADVANTAGES

1. REQUIRES INSTALLATION OF CONTROLS SYSTEM AND CONSOLE IN E-MAD.
(APPROXIMATE COST - 200K\$)
2. ADVERSE EFFECT UPON SCHEDULE IF RETURN TO MANUFACTURER IS REQUIRED.
3. REQUIRES APPROVAL FOR CRITICALITY MEASUREMENTS IN E-MAD.
4. POSSIBLE SCHEDULAR INTERFERENCE WITH DISASSEMBLY OF HOT REACTORS.

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Figure A-6. Summary of Advantages and Disadvantages of Various Facilities for Performing PTX Experiments (NRDS - E-MAD)

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92

ADVANTAGES

1. NONE

DISADVANTAGES

1. REQUIRES INSTALLATION OF CONTROLS SYSTEM AND CONSOLE IN SAM.
(APPROXIMATE COST - 200K\$)
2. ADVERSE EFFECT UPON SCHEDULE IF RETURN TO MANUFACTURER IS REQUIRED.
3. REQUIRES APPROVAL FOR CRITICALITY MEASUREMENTS IN AN AREA WHERE AN
ACCIDENT WOULD HAVE A SIGNIFICANT EFFECT ON OVERALL SPACE PROGRAM.
4. REQUIRES SPECIALLY TRAINED PERSONNEL.

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Figure A-7. Summary of Advantages and Disadvantages of Various Facilities
for Performing PTX Experiments (Cape Kennedy)

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93

ADVANTAGES

1. EXPERIENCED CRITICALITY STAFF AVAILABLE FOR MEASUREMENTS.
2. PERMITS MEASUREMENT IF REQUIRED OF POWER DISTRIBUTION.
3. PROVIDES A REACTOR FOR USE IN NUCLEAR INTERACTION MEASUREMENTS INCLUDING DEMONSTRATION OF START-UP OF SIDE-BY-SIDE NUCLEAR ROCKET REACTORS.
4. PROVIDES MANUFACTURER WITH NECESSARY ASSURANCE THAT NUCLEAR SUBSYSTEM MEETS NUCLEAR SOL CRITICAL DRUM ANGLE SPECIFICATIONS PRIOR TO SHIPMENT.
5. MINIMUM EFFECT UPON TEST SCHEDULE IF REACTOR TO BE RETURNED FOR CORRECTION.

DISADVANTAGES

1. REQUIRES INSTALLATION OF CONTROLS SYSTEM AND CONSOLE.
(APPROXIMATE COST - 200K\$)

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Figure A-8. Summary of Advantages and Disadvantages of Various Facilities for Performing PTX Experiments (Proposed WANEF Test Cell)