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PRELIMINARY OUTLINE OF FTR
NUCLEAR SYSTEMS START-UP TESTS

August 1971

HANFORD ENGINEERING DEVELOPMENT LABORATORY

UNITED STATES ATOMIC ENERGY COMMISSION

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PRELIMINARY OUTLINE OF FTR
NUCLEAR SYSTEMS START-UP TESTS

R. M. Fleischman

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PRELIMINARY OUTLINE OF FTR
NUCLEAR SYSTEMS START-UP TESTS

R. M. Fleischman

ABSTRACT

Preliminary outlines of anticipated FFTF start-up tests related to Nuclear Systems are presented. For each test brief sections on Purpose, Test Description, Plant Status, and Special Equipment are provided. The test outlines, as given, are intended to serve as a "working" outline for the development of a more detailed FFTF start-up testing program.

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PRELIMINARY OUTLINE OF FTR NUCLEAR SYSTEMS

START-UP TESTS

R. M. Fleischman

INTRODUCTION

A preliminary outline of nuclear systems start-up tests for the FTR has been prepared. The primary purpose of this outline is to provide a basis for making initial start-up schedule estimates for the FFTF and to serve as a starting point for more detailed test descriptions and special equipment requirements.

The preliminary nature of this outline should be emphasized. It is fully expected that tests may be added and removed as the FFTF Start-up program evolves.

The tests are organized into three categories as follows:

- A. Systems Tests
- B. Nuclear Start-up Tests
- C. Power Ascension and Full Power Tests

For each proposed test, a section on Purpose, Test Description, Plant Status and Special Equipment is provided.

ST-1

CHECKOUT OF FFTF CRITICALITY MONITORING SYSTEM

I. PURPOSE

The purpose of this test is to determine the operability of the criticality monitoring equipment and calibrate its response to electronically simulated and actual gamma or neutron signals prior to bringing fuel into the building and/or fuel storage area.

II. TEST DESCRIPTION

- A. Test the electronics associated with each detector with a calibrated electronic signal which simulates a chamber output.
- B. Test the proper operation of all detection devices by exposure to a gamma or neutron source.
- C. Test proper operation of all alarms and trips.

III. PLANT STATUS

Criticality monitoring system installed.

IV. SPECIAL EQUIPMENT

- A. Calibrated signal generator which will simulate chamber output conditions.
- B. Portable gamma or neutron source strong enough to trip circuit.

ST-2

PREOPERATIONAL CHECKOUT OF NUCLEAR SYSTEMS

I. PURPOSE

The purpose of this test is to:

- A. Determine the integrity of the low, intermediate and high-level neutron detection systems.
- B. Determine the integrity of all gamma detection systems.
- C. Test the proper operation of all safety circuit trips associated with these nuclear systems.
- D. Provide initial calibration of power levels derived from calculations.

II. TEST DESCRIPTION

- A. Test the electronics of each neutron or gamma detection circuit with a calibrated electronic signal which simulates chamber output under all conditions.
- B. Test the proper operation of each neutron or gamma detection system with a portable neutron or gamma source. Compare readings with calculated predictions.
- C. Test proper operation of safety circuit and alarm trips during (A) and (B).
- D. Use calculated results to relate neutron flux level to power level.

III. PLANT STATUS

- A. Safety and alarm circuits installed.
- B. Neutron and gamma detection equipment installed and ready for fuel loading.

IV. SPECIAL EQUIPMENT

- A. Calibrated signal generator which simulates detector output for steady-state and rising-period conditions.
- B. Portable neutron and gamma source.

ST-3

CONTROL AND SAFETY ROD INSERTION AND WITHDRAWAL BEHAVIOR

I. PURPOSE

The purpose of this test is to insure that operating safety limits are met with regard to:

A. Maximum rate of reactivity insertion,

B. Rate of reactivity removal during scram,

by combining the measured withdrawal, insertion, and scram times with calculated control and safety rod worth curves.

II. TEST DESCRIPTION

Measure the rod position vs. time for manual insertion, manual withdrawal, and scram for all control rods and during withdrawal and scram for safety rods.

III. PLANT STATUS

A. Installation of control and safety rod systems complete.

B. Sodium coolant status.

1. No sodium in reactor

2. Low sodium flow conditions

3. High sodium flow conditions

C. No fuel in reactor.

D. Computer acceptance tests complete.

IV. SPECIAL EQUIPMENT

A. High-speed position indicating device which may be moved from rod to rod or one for each rod.

B. High-speed time marker for computer input.

C. Individual rod scram switch and indicator.

D. Computer interfacing for position indicator, timer, and scram switch.

NST-1

APPROACH TO CRITICAL

I. PURPOSE

The purpose of this test is to monitor the fuel loading process to assure compliance with operating safety limits and achieve criticality in a safe manner.

II. TEST DESCRIPTION

Direct the loading of the FTR with periodic assessment of the degree of subcriticality and predictions of critical using the reactivity output from the RMAAS* system. Monitor the first rising period to the desired power level.

III. PLANT STATUS

All systems go for zero power operation.

IV. SPECIAL EQUIPMENT

- A. Ability to scram individual rods to perform subcritical inverse kinetics measurements using the on-line computer.
- B. Special neutron detector in in-core position to achieve a high detector efficiency.
- C. Cooled thimble for special neutron detector.
- D. RMAAS.

*RMAAS - Reactivity Monitoring and Anomaly System

NST-2

CONTROL AND SAFETY ROD CALIBRATIONS DURING APPROACH TO CRITICAL

I. PURPOSE

The purpose of this test is to obtain an early measurement of control strength and total shutdown reactivity during approach to critical to assure continuous compliance with operating safety limits.

II. TEST DESCRIPTION

As criticality is approached, use the various options in RMAAS to measure the total worth of each control rod as it is withdrawn in each subcritical assembly.

III. PLANT STATUS

All systems go for zero power operation.

IV. SPECIAL EQUIPMENT

A. RMAAS.

B. Control rod position indicator interface with on-line computer.

NST-3

POSITIVE PERIOD Δk CALIBRATIONS

I. PURPOSE

The purpose of this test is to provide data for comparison of positive period reactivity measurements and inverse kinetics techniques (RMAAS). The test will insure that the proper technique is used in the final control rod calibrations.

II. TEST DESCRIPTION

Measure the worth of increments of a selected control rod using asymptotic positive periods and compare with similar measurements using inverse kinetics.

III. PLANT STATUS

Zero power operation

IV. SPECIAL EQUIPMENT

- A. Positive period algorithm for on-line computer.
- B RMAAS.

NST-4

CONTROL AND SAFETY ROD CALIBRATIONS

I. PURPOSE

The purpose of this test is to provide accurate calibrations of control and safety rods and selected control rod calibration curves for later reactivity worth measurements and to assess the accuracy of measuring reactivity changes with a calibrated control rod.

II. TEST DESCRIPTION

- A. Use the inverse kinetics algorithm in RMAAS to measure control rod calibration curves for selected rods (slow-run technique).
- B. Use the inverse kinetics algorithm to measure the total worth of all safety and control rods (rod-drop technique).
- C. Measure the reproducibility of control rod positioning and infer the uncertainty it introduces into reactivity measurements.

III. PLANT STATUS

Zero power operation

IV. SPECIAL EQUIPMENT

- A. RMAAS
- B. Control rod position indicator interface with on-line computer.
- C. Special inverse kinetics algorithm for slow calibrations.

NST-5

REACTIVITY RATE OF INSERTION

I. PURPOSE

The purpose of this test is to measure the reactivity rate of insertion and withdrawal during material insertion of control rods and manual withdrawal and scram for both control and safety rods. This provides a direct measurement of compliance with operating safety limits with regard to:

- A. Maximum rate of reactivity insertion.
- B. Rate of reactivity removal during scram.

II. TEST DESCRIPTION

Using the inverse kinetics algorithm measure the reactivity vs. time function for the following conditions:

- A. Manual insertion of control rods.
- B. Manual withdrawal of control and safety rods.
- C. Scram of the total safety system.

III. PLANT STATUS

- A. Zero power operation.
- B. Flow conditions.
 - 1. Low flow
 - 2. High flow

IV. SPECIAL EQUIPMENT

- A. High-speed position indicating device which may be moved from rod to rod or one for each rod.
- B. High-speed time marker for computer input.
- C. Individual rod scram switch and indicator.
- D. Computer interfacing for position indicator, timer, and scram switch.

NST-6

ZERO POWER STABILITY

I. PURPOSE

The purpose of this test is to measure the reactor transfer function at zero power to use as a basis for determining possible instabilities at higher power levels.

II. TEST DESCRIPTION

The measurement can be made using one or more of several alternative techniques:

- A. Special oscillator device.
- B. Control rod as an oscillator.
- C. Rod Drops.
- D. Noise analysis.

III. PLANT STATUS

- A. Zero power operation.
- B. Flow conditions variable.

IV. SPECIAL EQUIPMENT

- A. If a special oscillator is used, it will be furnished as part of the system.
- B. Control rod as oscillator.
 - 1. Special control rod drive.
 - 2. High-efficiency detector in core.
- C. Rod drops.
 - 1. High-speed rod-drop and position indicator.
 - 2. Special high-efficiency detector.
 - 3. RMAAS and special algorithms.
- D. Complete noise analysis system.

NST-7

ZERO POWER REACTIVITY FLUCTUATIONS

I. PURPOSE

The purpose of this test is to record a power trace for several sodium flow conditions. The power trace will be converted to a reactivity fluctuation record through the use of an on-line computer. The reactivity traces will be used as a diagnostic tool for comparison with reactivity traces taken later in FFTF design life.

II. TEST DESCRIPTION

Under steady-state power conditions, record the reactor power level as a function of time for several sodium flow conditions.

III. PLANT STATUS

Zero power operation.

IV. SPECIAL EQUIPMENT

- A. Special high-efficiency, short-time constant neutron detector.
- B. Special computer algorithm.

NST-8

NUCLEAR POWER CALIBRATION

I. PURPOSE

The purpose of this test is to make a low-power (~100 w) calibration of the FTR neutron detection systems.

II. TEST DESCRIPTION

Measure the fission rate in a fission counter with known detector efficiency near the reactor mid-plane and near the core center. Measure the chamber output from all on-scale FTR neutron detectors and special startup detectors at the same power level. Convert the measured absolute fission rate to reactor power through an analytical determination of the sensitivity of the absolute fission counter per unit power.

III. PLANT STATUS

Zero power operation.

IV. SPECIAL EQUIPMENT

A. Special fission counter ^{239}Pu .

B. Cooled access thimble.

NST-9

ASSEMBLY WORTH DETERMINATIONS

I. PURPOSE

The purpose of this test is to measure the worth of various reactivity shimming options and other key full element exchanges for comparison with calculations and to verify nuclear design parameters.

II. TEST DESCRIPTION

Use calibrated control rods and subcritical reactivity measuring techniques to measure the worth of element substitutions of the following general categories:

- A. Inner driver and outer driver for sodium
- B. Inner driver and outer driver for material test
- C. Inner driver for outer driver
- D. Outer driver for inner driver
- E. Outer driver for reflector
- F. Reflector for outer driver
- G. Fixed shim rod for peripheral control rod
- H. Peripheral control rod for fixed shim rod
- I. Reflector for peripheral control rod and fixed shim rod
- J. Fixed shim rod and peripheral control rod for reflector
- K. Test assembly installation

III. PLANT STATUS

Zero power operation

IV. SPECIAL EQUIPMENT

none

NST-10

VARIANCE OF FUEL ELEMENT WORTHS

I. PURPOSE

The purpose of this test is to measure the statistical distribution of fuel element worths in a single core position to assess the variance in fuel element composition.

II. TEST DESCRIPTION

At a selected high-worth location substitute a statistically significant number of inner core and outer core fuel elements. Measure the reactivity worth associated with each substitution using a calibrated control rod.

III. PLANT STATUS

Zero power operation

IV. SPECIAL EQUIPMENT

none

NST-11

SPATIAL DEPENDENCE OF SELECTED MATERIAL WORTHS

I. PURPOSE

The purpose of this test is to measure the worth of selected material samples at the axial mid-plane for several radii and axial material worth distributions at selected reactor and test locations. Comparisons will be made with calculations and calculational performance will be compared with that of similar measurements in the EMC. Test position measurements will be factored into future test assembly design.

II. TEST DESCRIPTION

Remotely insert samples into the desired position and measure the reactivity change associated with the insertion. The method of reactivity measurement will depend on the magnitude of the sample worth. Possibilities to be considered include:

- A. Positive period measurements
- B. Inverse kinetics measurements
- C. Calibrated control rod measurements

III. PLANT STATUS

Zero power operation.

IV. SPECIAL EQUIPMENT

- A. Remote sample changer (may overlap with fission counter traverse mechanism NST-13).
- B. Special duct to accommodate sample (may overlap with fission counter duct in NST-13).
- C. Samples of:
 - 1. Fissile isotopes ^{239}Pu , ^{235}U
 - 2. Fertile isotope ^{238}U
 - 3. Structural materials, S/S, Fe

NST-12

REACTIVITY EFFECTS OF REPOSITIONING CORE RESTRAINT MECHANISM

I. PURPOSE

The purpose of this test is to measure the reproducibility of core reactivity after repositioning core restraint mechanism to assess its effect on the measurement of reactivity worths.

II. TEST DESCRIPTION

Using a core configuration having a known reactivity, activate and release the core restraint mechanism several times and infer the variance in reactivity associated with its repositioning.

III. PLANT STATUS

- A. Zero power operation
- B. Core restraint mechanism operable.

IV. SPECIAL EQUIPMENT

Special position indicator on the core restraint mechanism or the normal mechanical monitoring device if provided.

NST-13

FLUX MAPPING

I. PURPOSE

The purpose of this test is to determine the spatial flux distributions in the reactor using experimental techniques for comparison with calculated results.

II. TEST DESCRIPTION

Measure selected axial reaction rate distributions at specific locations using one or more of the following methods:

- A. Chamber traverses
- B. Flux wire irradiation
- C. Foil packet irradiation

III. PLANT STATUS

Zero power operation

IV. SPECIAL EQUIPMENT

- A. Chamber traverses
 - 1. Chambers and associated electronics
 - 2. Special thru-tube element as in NST-11
 - 3. Traverse mechanism as in NST-11
- B. Flux wire irradiation
 - 1. Flux wires in special fuel element(s)
 - 2. Counting facilities
- C. Foil packet irradiation
 - 1. Foil holder fuel element
 - 2. Counting facilities

NST-14

LOW-POWER SHIELD SURVEYS

I. PURPOSE

The purpose of this test is to assure that the shield system is adequate with regard to:

- A. Protection of personnel
- B. Protection of in-vessel equipment
- C. Agreement with design calculations for low-power operation

II. TEST DESCRIPTION

- A. Using normal plant monitors and hand instruments, measure the intensity of reactor leakage radiation in all personnel areas during the initial operation and in all access areas following initial operation.
- B. Install retractable foil packets in positions which will measure the incident radiation on all important in-vessel equipment with radiation damage life limiting factors.
- C. Install retractable foil packets to determine the attenuation characteristics of all shield regions in the immediate vicinity of the core for comparison with design parameters and calculations.

Steps B and C may be done as part of NST-13.

III. PLANT STATUS

Perform test A at initial critical and tests B and C during steady-state low-power runs.

IV. SPECIAL EQUIPMENT

- A. Foil packets
- B. Access tubes to in-vessel shield and equipment regions with retractable mechanism for foil irradiation.
- C. Counting equipment.

NST-15

NEUTRON ENERGY SPECTRUM

I. PURPOSE

The purpose of this test is to measure the neutron energy spectrum at selected locations for comparison with calculations. Selected locations will include typical test locations and control rod locations.

II. TEST DESCRIPTION

Measure the neutron energy spectrum in selected test, control rod, and driver locations using one of the following techniques:

- A. Proton recoil techniques at very low power levels
- B. Foil packet irradiation using spectrum unfolding techniques

III. PLANT STATUS

Zero power operation

IV. SPECIAL EQUIPMENT

A. Proton Recoil

- 1. Cooled counter thimbles in core, test, and control rod locations
- 2. Counters and special electronics
- 3. Computer algorithms for analysis

B. Foil irradiations

- 1. Foil packets
- 2. Counting facilities
- 3. Special foil holding assembly

NST-16

TEMPERATURE COEFFICIENT OF REACTIVITY

I. PURPOSE

The purpose of this test is to measure reactivity as a function of average core temperature for use in correcting reactivity measurements to a standard core temperature.

II. TEST DESCRIPTION

Measure the reactivity and average temperature of the reactor using a calibrated control rod while the temperature is allowed to increase isothermally due to pump heat input. The minimum temperature range should be 50°F. The measurement should be made for both heat-up and cool-down conditions and should be repeated to assess reproducibility.

III. PLANT STATUS

Zero power operation

IV SPECIAL EQUIPMENT

A. Supplementary RTD's necessary to obtain accurate temperature monitoring.

B. Quick RDT sampler (computer interface)

NST-17

FLOW COEFFICIENT OF REACTIVITY

I. PURPOSE

The purpose of this test is to measure the reactivity as a function of bulk coolant flow rate for correction of reactivity measurements to a standard coolant flow rate.

II. TEST DESCRIPTION

Measure the reactivity of the reactor using a calibrated control rod to maintain a constant power level as the coolant flow rate is increased in increments and then decreased in the same increments. If there is a measurable effect repeat to assess reproducibility.

III. PLANT STATUS

- A. Zero power operation
- B. Flow conditions variable
- C. Compatible with NST-7

IV. SPECIAL EQUIPMENT

None

NST-18

COVER GAS PRESSURE COEFFICIENT OF REACTIVITY

I. PURPOSE

The purpose of this test is to measure reactivity as a function of cover gas pressure for correction of reactivity measurements to a standard cover gas pressure.

II. TEST DESCRIPTION

Measure the reactivity of the reactor using a calibrated control rod to maintain a constant power level as the cover gas pressure is increased in increments and then decreased in the same increments. If there is a measurable effect repeat to assess reproducibility.

III. PLANT STATUS

- A. Zero power operation
- B. Cover gas pressure variable

IV. SPECIAL EQUIPMENT

None

NST-19

SODIUM VOID EFFECTS

I. PURPOSE

The purpose of this test is to measure the worth of voiding selected driver elements and closed loop test positions of sodium. The test will provide a direct measurement of pinned sodium void effects and closed loop loss of coolant effects.

II. TEST DESCRIPTION

A. Measure the worth of substituting a special fuel element which excludes all sodium flow for a regular fuel element at selected core locations.

B. Measure the worth of substituting a series of special fuel elements which simulate sodium bubble formation, expansion, and axial motion for a fuel element at the calculated location of maximum sodium void effects.

III. PLANT STATUS

Zero power operation

IV. SPECIAL EQUIPMENT

Special fuel elements with voiding regions, to be later designated, designed for use without sodium at $\sim 400^{\circ}\text{F}$ ambient temperature.

PAFPT-1

THERMAL POWER CALIBRATION

I. PURPOSE

The purpose of this test is to measure the thermal power production in the reactor through heat balance techniques and to cross compare the results with other power indications to insure proper operation of the power calculator.

II. TEST DESCRIPTION

At prescribed power levels (10%, 50%, and 100% of full power) use the on-line computer to calculate the thermal power generation in the reactor using measured temperature changes and flows and calculated heat losses. Compare the calculated power level with power indications from the neutron flux level and design calculations.

III. PLANT STATUS

- A. All process instrumentation interfaces with computers complete.
- B. Computer heat balance program debugged and operable.

IV. SPECIAL EQUIPMENT

None

PAFPT-2

POWER REACTIVITY COEFFICIENT

I. PURPOSE

The purpose of this test is to measure the change in core reactivity as a function of reactor power (ρ /Mwt). These measurements will be necessary for use in kinetic analyses of the reactor to verify that adequate reactivity margins for full-power operation are available.

II. TEST DESCRIPTION

Measure the reactivity of the reactor using a calibrated control rod for a given reactor configuration at discrete power levels of $\sim 10\%$, 25% , 50% , and 100% of full power. From this determine the power reactivity coefficient for each range. Assess the effect of changing sodium flow and inlet temperatures and observe any hysteresis effects.

III. PLANT STATUS

A. Power calibration made

B. Approach to full power

IV. SPECIAL EQUIPMENT

None

PAFPT-3

POWER STABILITY

I. PURPOSE

The purpose of this test is to measure the reactor transfer function on manual and automatic control at discrete power levels in order to search for indications of possible instabilities at higher power levels.

II. TEST DESCRIPTIONS

Using the test method or methods selected for NST-6, measure the reactor transfer function at 10%, 25%, 50%, 75%, and 100% of full power. Assess the stability of the reactor at each power level before the power is increased any further.

III. PLANT STATUS

10%, 25%, 50%, 75%, and 100% of full power

IV. SPECIAL EQUIPMENT

- A. If a special oscillator is used, it will be furnished as part of the system.
- B. Control rod as oscillator.
 - 1. Special control rod drive.
 - 2. High-efficiency detector in core.
- C. Rod drops.
 - 1. High-speed rod-drop and position indicator.
 - 2. Special high-efficiency detector.
 - 3. RMAAS and special algorithms.
- D. Complete noise analysis system.

PAFPT-4

HIGH-POWER REACTIVITY FLUCTUATIONS

I. PURPOSE

The purpose of this test is to record the power trace at several power levels and for several coolant flow rates. The power trace will be converted to a reactivity fluctuation record through the use of an on-line computer. The reactivity traces will be used as a diagnostic tool for comparison with reactivity traces taken later in FFTF design life.

II. TEST DESCRIPTION

Under steady-state power conditions on both manual and automatic control, record the reactor power level as a function of time for several sodium flow conditions at 10%, 25%, 50%, and 100% power.

III. PLANT STATUS

Approach to full power

IV. SPECIAL EQUIPMENT

- A. Special high-efficiency, short-time constant neutron detector.
- B. Special computer algorithm.

PAFPT-5

SETBACK TESTS

I. PURPOSE

The purpose of this test is to measure the neutronic performance (reactivity vs. time and power vs. time) of the automatic setback mechanism and to assure compliance with design specification and operating safety limits.

II. TEST DESCRIPTION

Purposely allow the setback circuit to be tripped and measure reactor power and reactivity vs. time. The test should be performed at 50% and 90% of full power on both automatic and manual control.

III. PLANT STATUS

Approach to power at 50% and 90% of full power.

IV. SPECIAL EQUIPMENT

None

PAFPT-6

HIGH-POWER SHIELD SURVEYS

I. PURPOSE

The purpose of this test is to assure that the shield system is adequate with regard to:

- A. Protection of personnel.
- B. Protection of ex-vessel equipment from radiation damage.
- C. Agreement with design calculations for high-power operation.

II. TEST DESCRIPTION

- A. Using normal plant monitors and hand instruments, measure the intensity of reactor leakage radiation in all personnel areas during operation and in all access areas following operation.
- B. Install retractable foil packets in positions which will measure the incident radiation on all important ex-vessel equipment with radiation damage life limiting factors.
- C. Install retractable foil packets to determine attenuation characteristics of shield regions for comparison with design parameters and calculations.

III. PLANT STATUS

Perform tests at 1, 10, 40, 100, 200, 400 Mwt power levels.

IV. SPECIAL EQUIPMENT

- A. Foil packets
- B. Access tubes to shield and equipment regions with retractable mechanism for foil irradiations.
- C. Counting equipment.

PAFPT-7

RMAAS CALIBRATION FOLLOWING HIGH-POWER OPERATION

I. PURPOSE

The purpose of this test is to recalibrate the RMAAS system after high-power operation in order to compensate for any effective source changes due to increased gamma background and/or fuel burnup.

II. TEST DESCRIPTION

Immediately after shutdown or during power descent, take the reactor to a specified low-power level and do a rod-drop experiment with a peripheral control rod. Use the power history and the inverse kinetic algorithm to recalibrate the RMAAS system for monitoring subsequent fuel loading changes.

III. PLANT STATUS

During shutdown.

IV. SPECIAL EQUIPMENT

Operating RMAAS system.