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FFTF REACTOR CHARACTERIZATION PROGRAM

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Abstract

Preparations are under way for the initial startup and testing of the Fast Flux Test Facility (FFTF). The FFTF Reactor Characterization Program is that part of the startup test plan that deals with the determination of the neutron, gamma ray and thermal hydraulic characteristics of the reactor. This program encompasses measurements and calculations of:

- Neutron spectra, flux and fluence.
- Gamma-ray spectra, dose and heating.
- Fission rate distributions.
- Capture rate distributions.
- Other reaction rates of interest.
- Fission product yields.
- Thermal hydraulic data.

Measurements of these parameters will be made in the reactor core and reflectors, will extend vertically downward to the vicinity of the core support structure and upward to the top of the sodium pool, and will extend radially outward to include in-vessel fuel storage locations and the cavity between the reactor vessel and the concrete wall.

The objective of the program is to improve the accuracy of neutron, gamma ray and thermal hydraulic information for operation, safety and irradiation testing by means of systematic comparisons of calculated and measured parameters.

Characterization data, within the scope of this program, will be obtained primarily in three steps:

(1) Measurements in a controlled-environment thimble prior to full power operation.
(2) An irradiation at one percent power for one day.
(3) An irradiation at full power for eight days.

These measurements will be supplemented by gamma dose, gamma heating and thermal hydraulic measurements during first plant operation at full power and by a few samples to be retrieved from fuel assemblies after the first operating cycle. It is anticipated that additional characterization measurements will be made periodically throughout the life of the reactor.

Introduction

Construction of the FFTF on the Energy Research and Development Administration (ERDA) Hanford reservation is nearing completion. Plans for initial startup and testing are being developed by the prime contractor, Westinghouse Hanford Company. The FFTF Reactor Characterization Program (RCP) is that part of initial testing concerned with determination of the neutron, gamma ray and thermal hydraulic environment in the reactor.

The FFTF-RCP consists of measurements and calculations of the following parameters:

- ° Neutron flux and spectra.
- ° Fission rates and distributions.
- ° Capture rates and capture-to-fission ratios.
- ° Other neutron reaction rates.
- ° Fission product yields.
- ° Gamma-ray spectra, dose and heating.
- ° Thermal hydraulic data.

The objective of the RCP is to obtain environmental information early in the life of the reactor for:

- ° Design and interpretation of irradiation experiments.
- ° Improving the accuracy of safety assessments.
- ° More efficient reactor operation.
- ° Better fuel and test management.
- ° Setting follow-on fuel enrichment specifications.
- ° Future FFTF design modifications.
- ° Validation of analytical methods for breeder reactor design.

This paper will provide a brief description of the FFTF, explain how access to the reactor is obtained for the measurements, outline the measurements that will be made, and indicate in general terms how the results can be used to satisfy the program objective.

Reactor Description

The Fast Test Reactor (FTR) is the primary component of the FFTF. It is a sodium-cooled reactor with mixed PuO_2-UO_2 fuel. It was designed to provide a high neutron flux with a spectrum approximating that of a fast breeder reactor for testing fuels, materials and components. General information about the plant is provided in Table I.

TABLE I

FFTF GENERAL INFORMATION

LOCATION: Richland, Washington
PRIME CONTRACTOR: Westinghouse Hanford Company
ARCHITECT-ENGINEER: Bechtel Corporation
FUEL: Mixed PuO_2-UO_2
COOLANT: Sodium
REFLECTORS: Inconel
CLADDING AND STRUCTURAL MATERIAL: 316 Stainless Steel
ABSORBER MATERIAL: B_4C (Natural Boron)
SAFETY RODS: Three
CONTROL RODS: Six
CLOSED LOOPS: Two (Initially)
TOTAL POWER OUTPUT: 400 MW (th)
PEAK FLUX: 7×10^{15} n/cm^2-sec.
ENRICHMENT ZONES: Two
FUEL CYCLE PERIOD: 100 Full Power Days

Figure 1 is a cutaway drawing showing the reactor elevation. The closed loops provide instrumented test channels within the FTR core with independent sodium cooling. Three instrument trees, each servicing one-third of the core, have thermocouples and flowmeters to provide subassembly outlet temperatures and flow rates. The FTR is designed to operate at a constant thermal power of 400 MW throughout each 100 full-power-day irradiation cycle, with about 30% of the core replaced at refueling shutdowns between cycles. Figure 2 is a core map showing the relative locations of safety rods (SR), control rods (CR), closed loops and other special assemblies in the two-fuel-enrichment-zone core. A detailed description of the FTR is given in Chapter 4 of the Final Safety Analysis Report for the FFTF.[1]

Reactor Access

To obtain the desired characterization data, active and passive devices must be placed at selected locations within the reactor. Access to the reactor environment will be gained by use of the following components:

- Characterizer assemblies.
- An In-Reactor Thimble (IRT).
- The Vibration Open Test Assembly (VOTA).
- Sensor pin holders in the In-Vessel Storage Module (IVSM).
- A conduit in the reactor cavity.
- Instrument trees and contact instrumented assemblies.
- Standard driver fuel assemblies.

The characterizer assemblies are similar to standard FFTF fuel, reflector and In-Core Shim (ICS) assemblies, but have modifications that allow insertion and removal of dummy fuel pins containing passive sensors. They do not provide access for active instrumentation. Current experiment plans require eleven characterizer assemblies:

- Three inner driver characterizers.
- Three outer driver characterizers.
- One nonfueled ICS characterizer.
- Four radial reflector characterizers.

These are the primary vehicles to be used for mapping reaction rates within the reactor. Each of the fueled and ICS assemblies has 21 removable pin positions as illustrated in Figure 3. The reflector characterizer intended for use in the first ring of subassemblies outside the core, Row 7, has nine removable pin locations. The other three reflector characterizers have provisions for five sensor pins (see Figure 4). With the exception of the central pin in each assembly, all removable pins will be approximately the same length as standard FFTF fuel pins (∿8 ft.). The characterizers have been designed so that the central pin is longer (∿11 ft.) to extend down to the vicinity of the core support structure. The RCP calls for the use of this set of characterizer assemblies in two irradiations. By proper selection of core positions in the two irradiations it is possible to obtain data in most of the different types of locations within the reactor.

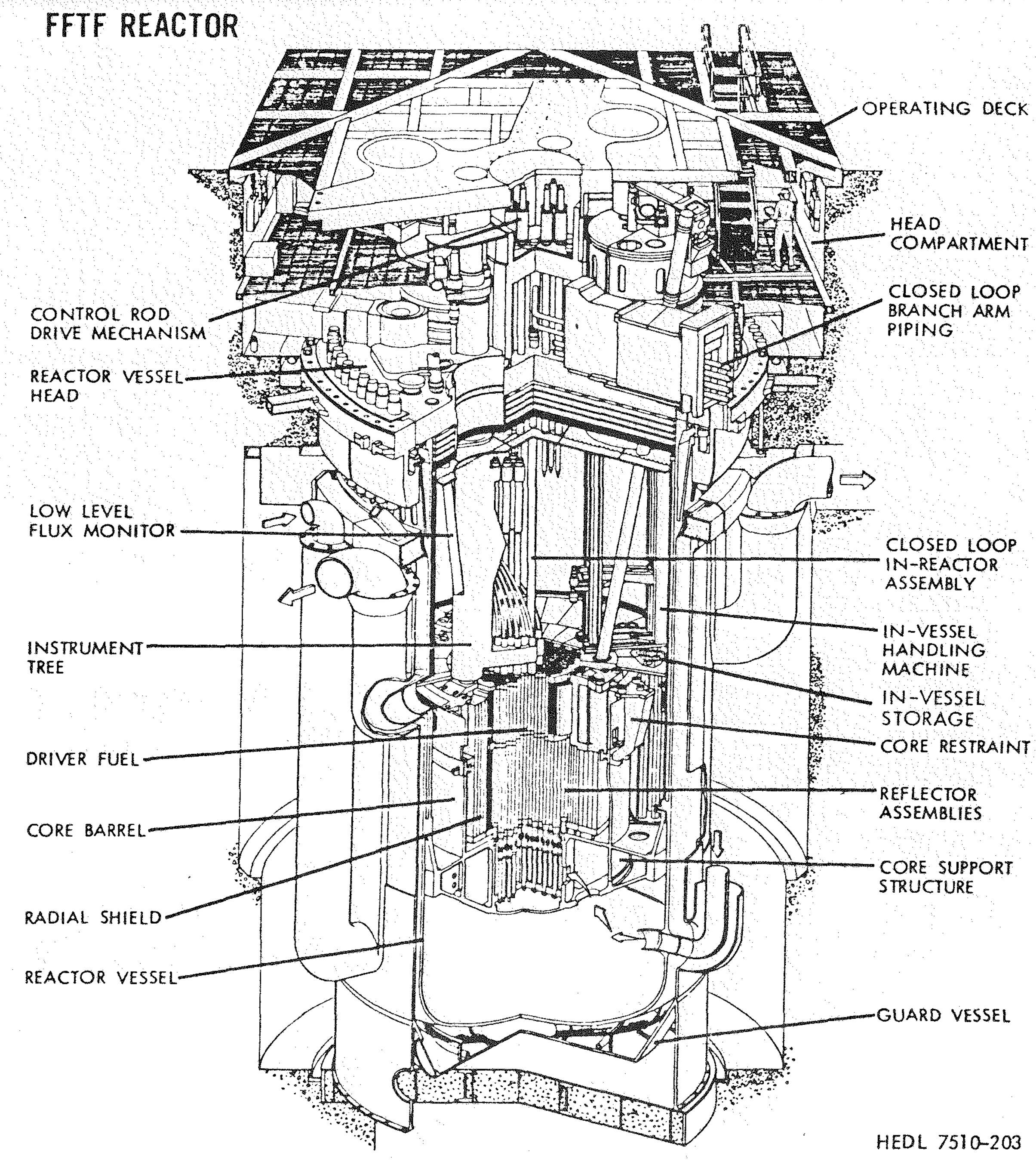

Figure 1. Cutaway of Reactor Elevation.

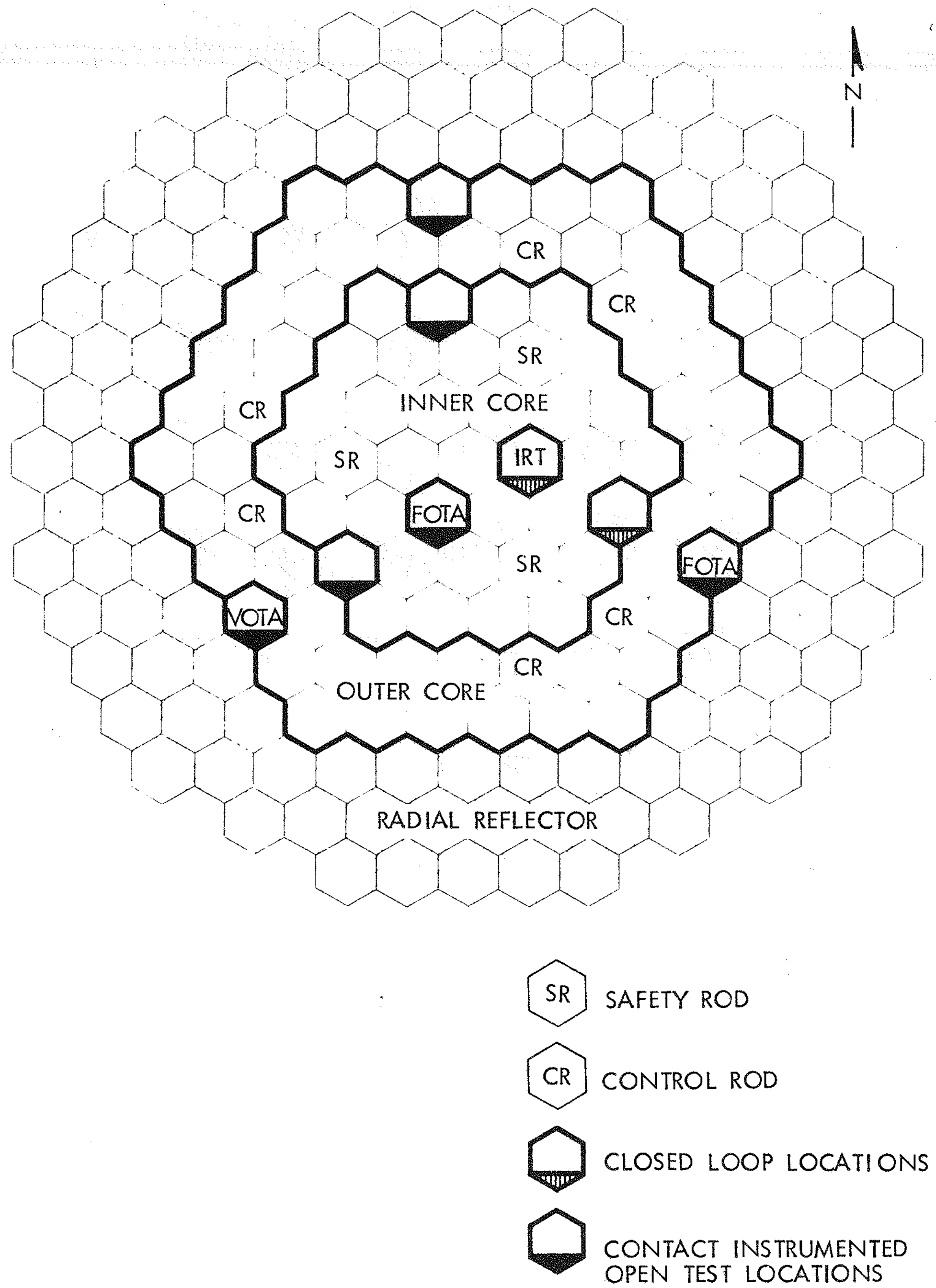

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Figure 2. Core Map.

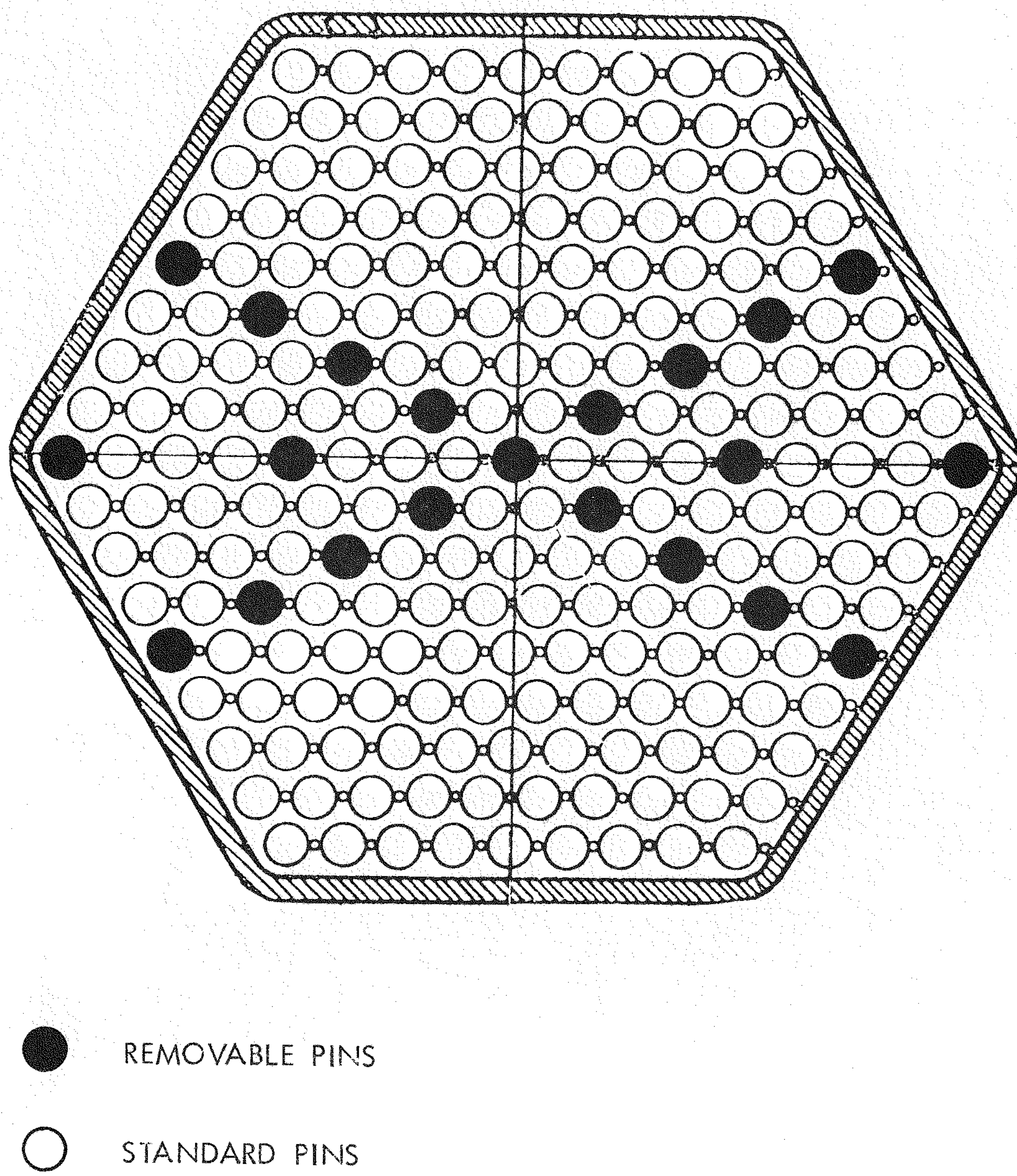

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Figure 3. Pin Arrangement for Fuel and ICS Characterizers.

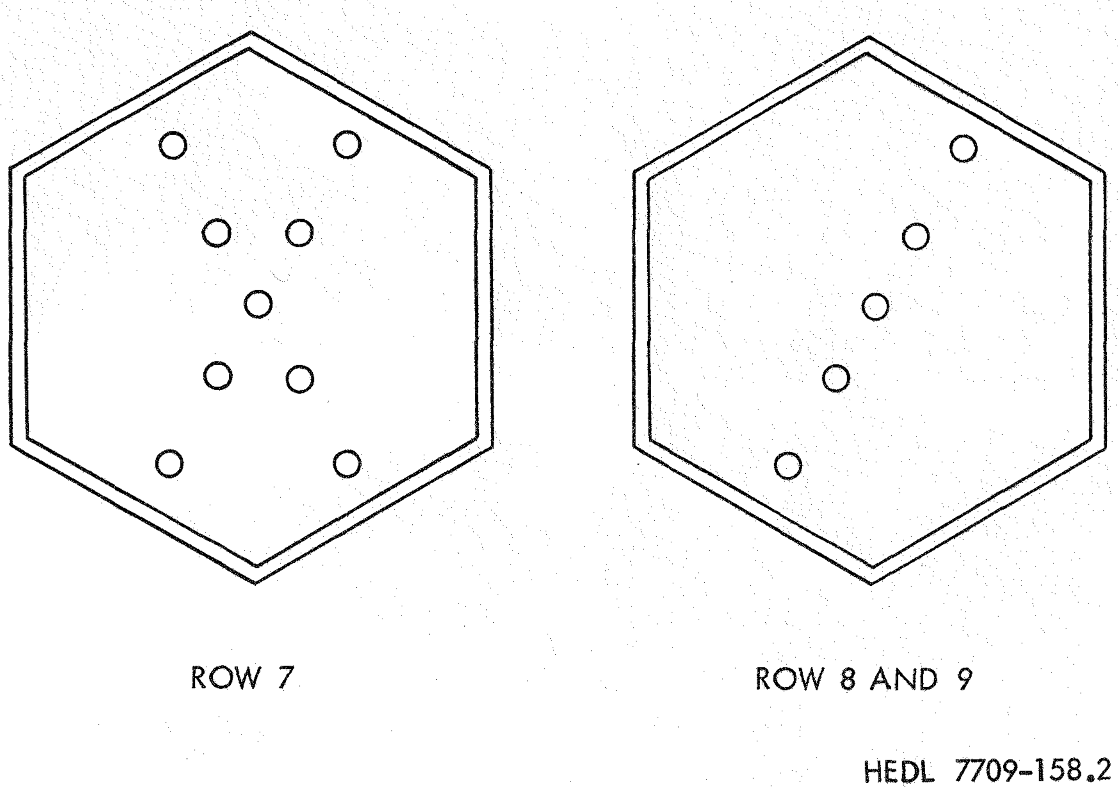

Figure 4. Sensor Pin Arrangement in Reflector Characterizers.

The IRT provides a cavity isolated from the sodium coolant extending from the reactor head down through the core to the core support structure about four feet below core midplane. Fission chambers will be installed in the IRT for the initial FTR fuel loading. After criticality is achieved the startup fission chambers will be removed and the IRT will be used to provide access to the core and vicinity for active and passive characterization measurements. Because of its accessibility the IRT provides a suitable location for the irradiation of samples having short half-life products. By adding insulation and a cooling system, measurements can be made with instruments that otherwise would not operate at the elevated temperatures within the reactor.

The VOTA is a nonfueled assembly originally proposed as a vehicle to allow active measurement of reactor vibrations. It is now considered a multipurpose test assembly and as such provides a location within the reactor core for active neutron and gamma sensors. The sensors will be immersed in sodium and must be capable of operating at temperatures as high as 950°F. The VOTA is to be located at the outer edge of the reactor core (see Figure 2).

A specially designed In-Vessel Storage Sample Holder (IVSSH) will be used to extend the characterization measurements out to the IVSM. Passive sensors can be irradiated in the IVSSH with the reactor operating at full power. The sample holder will be located directly below the fuel loading port which will allow rapid retrieval of samples since the sample holder can be withdrawn from the vessel without waiting for the In-Vessel Handling Machine to be put into operation.

To obtain environmental data outside the reactor vessel, a conduit was installed in the cavity between the reactor guard vessel and the concrete wall. Passive sensors can be inserted into and removed from the conduit whenever the reactor is not in operation without interfering with normal fuel handling operations. Passive sensors will be installed in the conduit for irradiation at the elevation of the reactor core.

Three instrument trees (Figure 1) support eddy current flowmeters and thermocouples above selected reflector assemblies and all core positions except safety rods, control rods, closed loops and contact instrumented open test locations (Figure 2). Closed loops and contact instrumented assemblies will have their own flowmeters and thermocouples.

In addition to the special test vehicles already described, standard driver fuel assemblies will be used to provide additional characterization data. Special capsules to investigate gas tag burnin and burnout effects have been loaded into the fission gas plenum of two inner driver fuel pins and two outer driver fuel pins. These pins have been loaded into assemblies that are scheduled for removal from the core during the first refueling period - after approximately 100 full power days of reactor operation.

Measurement Sequence

The initial reactor characterization measurements are part of the overall FFTF Acceptance Test Program. Other testing will be carried out before, during, and after the characterization measurements. The first characterization experiments will be done in the IRT shortly after initial criticality.

A set of startup fission chambers will be located in the IRT to provide neutron count rate data during the initial fuel loading. After initial criticality has been achieved, the startup chambers will be removed from the IRT and a series of reactor characterization experiments will be performed. These IRT experiments include gamma ray spectrometry, gamma dose and heating measurements, neutron spectrometry, and measurements of neutron reaction rates and fission product yields.

When this series of IRT experiments is completed, the IRT will be removed and the reactor will be taken to full power for the first time. Following first full power operation the characterizer assemblies will be loaded into the reactor and samples will be installed in the cavity conduit for an irradiation at about 4 MW (1% of full power) for one day. This low power irradiation will be followed a short time later, after the characterizers have been reconstituted, by a second irradiation at full power for eight days. In the full power irradiation, samples will be in the characterizers, the IVS sensor holders, and the cavity conduit. Detectors in the VOTA are designed for full power operation; however, data will be recorded whenever the signals are of sufficient strength to be of experimental value.

Data obtained from the IRT measurements and the two irradiations will be supplemented with information obtained from the examination of standard driver fuel assemblies removed at the first refueling shutdown.

Measurement Methods

Neutron Flux and Spectra

For most locations throughout the FTR, the best estimate of the neutron flux spectrum will be derived from the calculated spectrum adjusted to minimize discrepancies between measured and calculated reaction rates at that location. To obtain the desired reaction rate data for spectral adjustments, packages containing selected materials (spectral sets) will be irradiated at locations that scope the different spectra within the reactor. Reaction rate maps will be generated for sets of reactions that provide good spectral indices. A spectral unfolding code, such as SAND-II,[2] will be used to adjust the calculated spectrum to provide the best agreement with the reaction rates at any desired location.

The IRT provides an environment that allows other methods of spectral determination. The IRT will be insulated and cooled to approximately room temperature. The neutron spectrum in the IRT will be measured using proton recoil proportional counters, proton recoil emulsions, and possibly ^6Li sandwich spectrometers, the benefits of which are currently being evaluated. Spectral measurements will be made at core midplane and at two axial locations outside the core. Spectral packages will be irradiated at each location, the measured reaction rates will be used to adjust the calculated spectra and the results will be compared with spectra obtained by the high-resolution methods. This should provide an indication of the confidence level that should be assigned to the adjusted spectra throughout the FTR. The neutron flux spectrum in the IRT is expected to be similar to that in a closed loop.

The total neutron flux at any location can be obtained by summing the group fluxes of the multigroup flux spectrum at that location. The total neutron flux in the IRT will also be determined by "neutron flux transfer" between the National Bureau of Standards (NBS) ^{252}Cf fission neutron source and the FTR-IRT neutron field. This will be done by accurate absolute measurements of the ^{239}Pu fission rates in both neutron fields using an NBS double fission chamber with adjustments for spectral differences.

Fission Rates and Distributions

Data on fission rates in FTR will be obtained by the following methods:

- Active measurements with absolute fission chambers and traversable fission chambers.
- Irradiation of small encapsulated samples of fissionable isotopes and FTR fuel; and determination of the number of fissions by measuring the fission product gamma activity.
- A similar procedure using uranium wires.
- Irradiation of solid state track recorders (SSTRs), and determination of the number of fissions by counting the number of fission tracks.
- Gamma scans of irradiated fuel pins.
- Measurements of fission product gamma activity of irradiated fuel pellets.
- Destructive analysis of irradiated fuel pellets to determine the absolute concentrations of fission products.

Absolute fission rates for ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu and ^{241}Pu will be measured at three axial locations in the IRT using NBS double fission chambers. Fission track recorders and small encapsulated samples of the same five isotopes will be irradiated in the same three axial locations to provide an intercomparison of measurement methods. Axial fission rate distributions for the five isotopes listed above will be measured using small traversable fission chambers. Axial traverses will be made with two different control rod configurations to investigate the effect of control rod insertion on axial fission rate distributions.

The spatial distribution of isotopic fission rates in the FTR will be measured by irradiating small encapsulated samples of fissionable isotopes, track recorders and gradient wires at selected locations in the low power and high power irradiations using the characterizer assemblies and the IVSSH. These data will be compared with and supplemented by gamma scans of a few fuel pins from each of the fueled characterizer assemblies.

Additional gamma scan data will be obtained by scanning fuel pins from standard driver fuel assemblies removed from the core during the first refueling period - after approximately 100 full power days of reactor operation.

To develop a better understanding of the gamma scan results, fuel pellets will be removed from a few of the pins that were scanned. The pellets will be individually gamma counted. In addition, selected pellets will be destructively analyzed to determine absolute amounts of fission products produced.

Capture Rates and Capture-to-Fission Ratios

During the low power irradiation, high purity samples of ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu and ^{241}Pu will be irradiated along with solid state fission track recorders within selected fuel pins in the characterizer assemblies. Capture rates will be determined by radiometric analyses of the ^{238}U samples and mass spectrometry analyses of the other isotopic samples. Fission rates will be determined from the fission track recorders, yielding direct capture-to-fission ratios. Samples will be irradiated at locations chosen to yield capture rates and capture-to-fission ratios over the range of spectra available in the FTR.

Small encapsulated samples of the five isotopes listed above will be irradiated in nonfueled pins in the characterizer assemblies during the high power characterization irradiation (400 MW for eight days). This will provide sufficient fluence to produce measurable quantities of fission and capture products. Capture rates and capture-to-fission ratios will be inferred from measurements of the concentrations of capture and fission products produced. Concentrations of capture and fission products will be determined by mass spectrometry.

Other Neutron Reaction Rates

In addition to the uranium and plutonium fission* and capture rates and those reaction rates that are of interest as spectral indicators, a number of other reactions are of interest for a variety of reasons, and will be measured as part of the RCP for comparison with calculations. Preparations are being made to measure the following additional reaction rates:

$^{23}Na(n,\gamma)^{24}Na$
$^{23}Na(n,2n)^{22}Na$
$^{41}K(n,p)^{41}Ar$
$^{50}Cr(n,\gamma)^{51}Cr$
$^{78}Kr(n,\gamma)^{79}Kr$
$^{126}Xe(n,\gamma)^{127}Xe$
$^{241}Am(n,\gamma)^{242}Am$

Isotopic Depletion and Buildup in FTR Fuel

Stainless Steel Activation

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* The ^{237}Np fission rate is one of the reactions included in the spectral sets.

The ^{24}Na, ^{22}Na, ^{41}Ar, and ^{51}Cr production rates and the stainless steel activation rates are of interest primarily because they are significant sources of radioactivity during and after reactor operation. The production of ^{79}Kr and ^{127}Xe are being measured to provide additional data for the fuel pin tag gas system. Measurements of the depletion and build-up of actinides are being made primarily to improve predictions of the neutron source strength in the reactor.

In cases where the daughter products have short half-lives and rapid retrieval is important, samples will be irradiated in the IRT and in the IVSSH. Reaction rate mapping will be done primarily by irradiating samples in characterizer assemblies during the low power and high power irradiations. Where greater fluence is required, data will be obtained from standard driver fuel assemblies removed at the first refueling shutdown. Special gas tag capsules have already been added to two fuel assemblies for this purpose.

Fission Product Yields

Fission yield measurements require the determination of total number of fissions and the amounts of various fission products produced in irradiated samples of fissionable material. Data will be obtained in the IRT and in characterizer assemblies in the low power and high power irradiations.

In the IRT, fissionable isotopes will be irradiated at the same locations and in the same invironment as the absolute fission rate measurements made with NBS double fission chambers. A monitor chamber will be used to provide power normalization. The concentrations of radioactive fission products in the irradiated samples will be determined by standard radiometric and isotope dilution mass spectrometry techniques.

In the low power irradiation, small encapsulated samples of fissionable isotopes and solid state fission track recorders will be irradiated in characterizer assemblies at a variety of core locations selected to encompass a range of neutron spectral variation. Absolute yields of radioactive fission products will be obtained from radiometric determinations of fission product concentrations and track recorder measurements of absolute fission rates

The high power irradiation will produce sufficient quantities of stable fission products in the small encapsulated samples of fissionable isotopes to be measured by mass spectrographic techniques. These samples will first be gamma counted to determine the amounts of radioactive fission products before being dissolved to determine the stable fission product concentrations. Absolute yields of stable fission products can be obtained through reference to absolute yields of radioactive fission products in the same or similar core positions determined from the low power irradiation.

Gamma Ray Spectra, Dose and Heating

Gamma ray measurements in the FTR are conveniently divided into three groups: (1) measurements in the IRT, (2) measurementsin the VOTA, and (3) temperature mapping in the characterizer assemblies.

Because of its controlled environment, the IRT permits measurements that cannot be made elsewhere in the reactor. The gamma ray spectrum is to be measured within the IRT at core midplane and two other axial positions outside the core using a Compton recoil gamma ray spectrometer. The experiment will be performed with the reactor at essentially zero power in the clean core (prior to any operation of the reactor at full power).

The gamma ray dose in the IRT will be measured using thermoluminescent dosimeters (TLD). The TLD will be distributed axially from the bottom of the IRT (∿4 feet below core midplane) up to an elevation approximately eleven feet above the midplane elevation of the core. Two irradiations will be required to cover the gamma intensity range to be measured. Short irradiations (∿2 hours) at power levels of 1 kW and 100 kW are planned.

Gamma energy deposition data will be obtained in the IRT using calorimeters and ion chambers. Calorimetry measurements are to be made at the same three axial positions at which the gamma ray spectrum is to be measured. In addition, axial traverses are to be made from the bottom of the IRT to an elevation about four feet above core midplane using ion chambers to obtain gamma energy deposition curves for three types of materials (low-, medium-, and high-Z).

Measurements within the IRT will be made with the reactor operating below 1% of full power and with the sodium coolant at essentially refueling temperature; ∿400°F. The VOTA provides a location within the reactor core for active instrumentation with the reactor operating at full power. Gamma ion chambers and calorimeters will be installed in the VOTA to measure gamma energy deposition at full power. Although the VOTA ion chambers and calorimeters will be designed for full power operation, data will be recorded at as low a level as possible to provide overlap with the IRT measurements.

Thermal Expansion Difference Detectors (TED) will be installed in the characterizer assemblies during the high power irradiation to map the maximum temperatures attained during the irradiation. These temperatures are proportional to the local gamma ray heating.

Thermal Hydraulic Data

The reactor thermal power will be obtained from measurements of the coolant mass flow rate and bulk temperature rise across the reactor. Mass flow rate and inlet and outlet temperatures are directly-measured quantities using in-place reactor plant instrumentation.

Mass flow rate data will be obtained from permanent magnet flowmeters in each of the three primary heat transport loops and from both permanent magnet and Venturi flowmeters in the secondary heat transport system.

Temperatures will be measured using Resistance Temperature Devices (RTD) installed in primary and secondary loop hot and cold legs.

Because of the unique capability built into the FFTF to provide flow and temperature instrumentation for each core position, a greater degree of thermal hydraulic characterization is possible than in any other sodium-cooled fast reactor today.

Extensive flow mapping is planned prior to fuel loading and at zero power after fuel loading. During the first ascent to full power, flow, temperature and power distributions will be determined at the 10%, 35%, 75% and 100% power levels.

An independent assessment of subassembly powers and total reactor power will be obtained from the measurements of fission rate distributions, described earlier, and neutronics calculations. This method will be combined with the thermal hydraulic power measurements to provide a "best value" for the reactor power level.

Utilization of Experimental Results

The initial reactor characterization program will provide data for the FTR with fresh fuel and the initial test loading configuration. Much of the measured data will be directly applicable to many other core configurations; however, the primary method for utilizing the results of the experiments will be through comparisons with calculations. Such comparisons will provide a basis for making adjustments to calculations, for estimating uncertainties in the calculations and for identifying areas where improvements are needed in analytical methods or cross sections. Figure 5 illustrates how the characterization measurements and calculations are combined to achieve the objectives of the RCP.

Schedule

Current schedules for the FFTF call for completion of construction and sodium fill in 1978. Initial criticality is projected for summer 1979. The experiments outlined in this paper are scheduled to be completed before the end of 1979.

Acknowledgments

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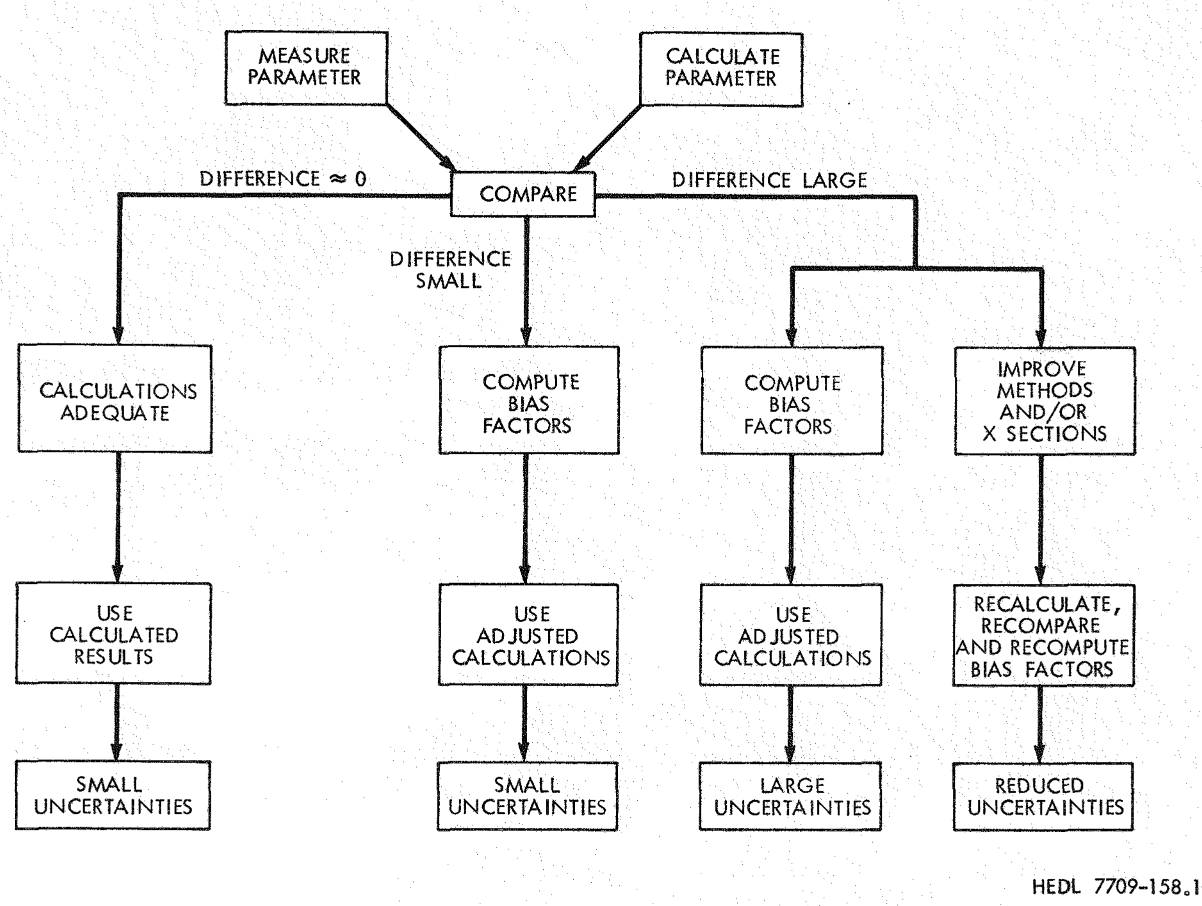

Figure 5. Utilization of Characterization Results.