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AEC RESEARCH AND DEVELOPMENT REPORT

HW-77732

A DESCRIPTION OF THE HIGH TEMPERATURE LATTICE TEST REACTOR

W. W. BROWN and R. E. HEINEMAN

MAY 27, 1963

HANFORD LABORATORIES

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

GENERAL ELECTRIC

AEC-GE RICHLAND, WASH.

HW-77732

UC-80, Reactor Technology
(TID-4500, 20th Ed.)

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HANFORD ATOMIC PRODUCTS OPERATION
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Work performed under Contract No. AT(45-1)-1350 between the Atomic Energy Commission and General Electric Company

Printed by/for the U. S. Atomic Energy Commission

Printed in USA. Price 50 cents. Available from the

Office of Technical Services
Department of Commerce
Washington 25, D. C.

ABSTRACT

A High Temperature Lattice Test Reactor (HTLTR) now under design by Hanford Laboratories is described. A central experimental core region may be removed and any solid-moderated reactor lattice may be inserted for testing. Reactivity transients of the test lattices associated with changes in temperature of either moderator or fuel can be obtained in support of design and hazards analyses of proposed power reactors. The experimental equipment and facilities associated with the reactor are also described. A listing of the Scope Design data is included as well as diagrams showing examples of core loadings.

A DESCRIPTION OF THE HIGH TEMPERATURE LATTICE TEST REACTOR

INTRODUCTION

The High Temperature Lattice Test Reactor (HTLTR), now under design by the Hanford Laboratories, will add a new dimension to the routine measurement of the reactor physics properties of nuclear systems utilizing solid moderators. In this new facility, measurements of these properties may be made as a function of the temperature of the system to 1000 C. The experimental program will support the design and safety analyses of high temperature power reactors. Even though this temperature is well in excess of that attainable in an operating power reactor with the technology currently available, the maximum temperature may be pushed to 1200 C with some future modifications. Yet higher test temperatures will be routinely achieved in the central test region of this versatile critical facility.

The versatility of this test reactor is the result of many years of research [1, 2] at Hanford, using the Physical Constants Testing Reactor (PCTR), on the novel, but powerful, null reactivity method of measuring reactor multiplication constants. The versatility derives from the fact that the very minimum quantity of test material (reactor lattice being studied) is required for precise nuclear measurements.

The test lattice is positioned in the central core region of the test reactor and may be exchanged in a matter of hours, or days if complex piping is involved, for a completely different test lattice. The economy associated with minimizing the quantity of the test lattice is illustrated for natural uranium-graphite systems in the following table.

VOLUMES OF NATURAL-URANIUM GRAPHITE LATTICES
(Cubic Feet)

Typical Test Volume			Typical Volume of Critical System
PCTR	HTLTR	Exponential	
12 to 25	36 to 80	400 to 600	8000

The maximum replaceable volume of the HTLTR is 250 cubic feet.

This experimental technique is powerful because small variations in the multiplication constant caused by changes in the composition or temperature of the test lattice may be measured accurately and easily. In addition, those measurements of neutron flux distributions usually made in critical experiments are also available with this method.

The experimental test core can accommodate any solid moderator. It is possible to use any type of fuel and coolant of interest to a reactor project. Pressure tubes to contain a pressurized liquid or gas coolant should of course be used if this provides a closer mock-up of the proposed reactor system to be tested. The variety of data which have been obtained in room temperature experiments in the PCTR in support of a power reactor design has been described.[3]

The main features of the reactor are described here in sufficient detail that its potential usefulness in support of power reactor programs can be evaluated. It is anticipated that the reactor will also be used in a longer range research program for an integrated study of various temperature coefficients of neutron multiplying media. Studies of specific reactor designs can be accomplished in periods of time from 2 to 6 months, plus planning and procurement lead time, depending upon the type and quantities of experimental data required. It is expected that the reactor will be ready for operation in August of 1965.

GENERAL FEATURES OF THE REACTOR AND ASSOCIATED EQUIPMENT

The HTLTR consists of a 10-foot cube of graphite surrounded by a thick layer of thermal insulation. Traversing the entire graphite stack from front to rear is a square lattice of horizontal holes into which either fuel rods or heating elements can be placed in a variety of arrays. Graphite bridge bars support the top portion of the stack and permit the removal of all graphite in the central 5 by 5 foot experimental core section. The general layout of the reactor and associated experimental equipment is indicated in Figure 1.

The heating elements are graphite rods which are capable of raising the temperature of the reactor to 1000 C in 120 hours.

When operated at elevated temperatures the reactor is maintained in an atmosphere of nitrogen. A metal sheath surrounding the thermal insulation provides for containment of the gas. To accelerate the attainment of a uniform elevated temperature throughout the reactor, the gas can be continuously circulated at a slow rate. The reactor can be cooled from 1000 C to 260 C in 24 hours by circulating nitrogen gas through the reactor and a heat exchanger at the rate of 150 pounds per minute.

The metal sheath surrounding the reactor also provides containment of any hazardous materials which might inadvertently escape into the reactor, such as plutonium or other radioactivity from test fuel elements. Monitoring instrumentation is also provided in the gas streams and stack gas.

On one end, insulation may be removed over the entire face of the graphite stack for insertion or removal of fuel or heating elements anywhere in the reactor. The other end has an opening large enough for the insertion or removal of any materials in the experimental core. There are plugs in the large openings on each end for positioning any of several types of experimental equipment. The plugs will be routinely used for equipment to withdraw the central test cell in the experimental core and to oscillate small samples

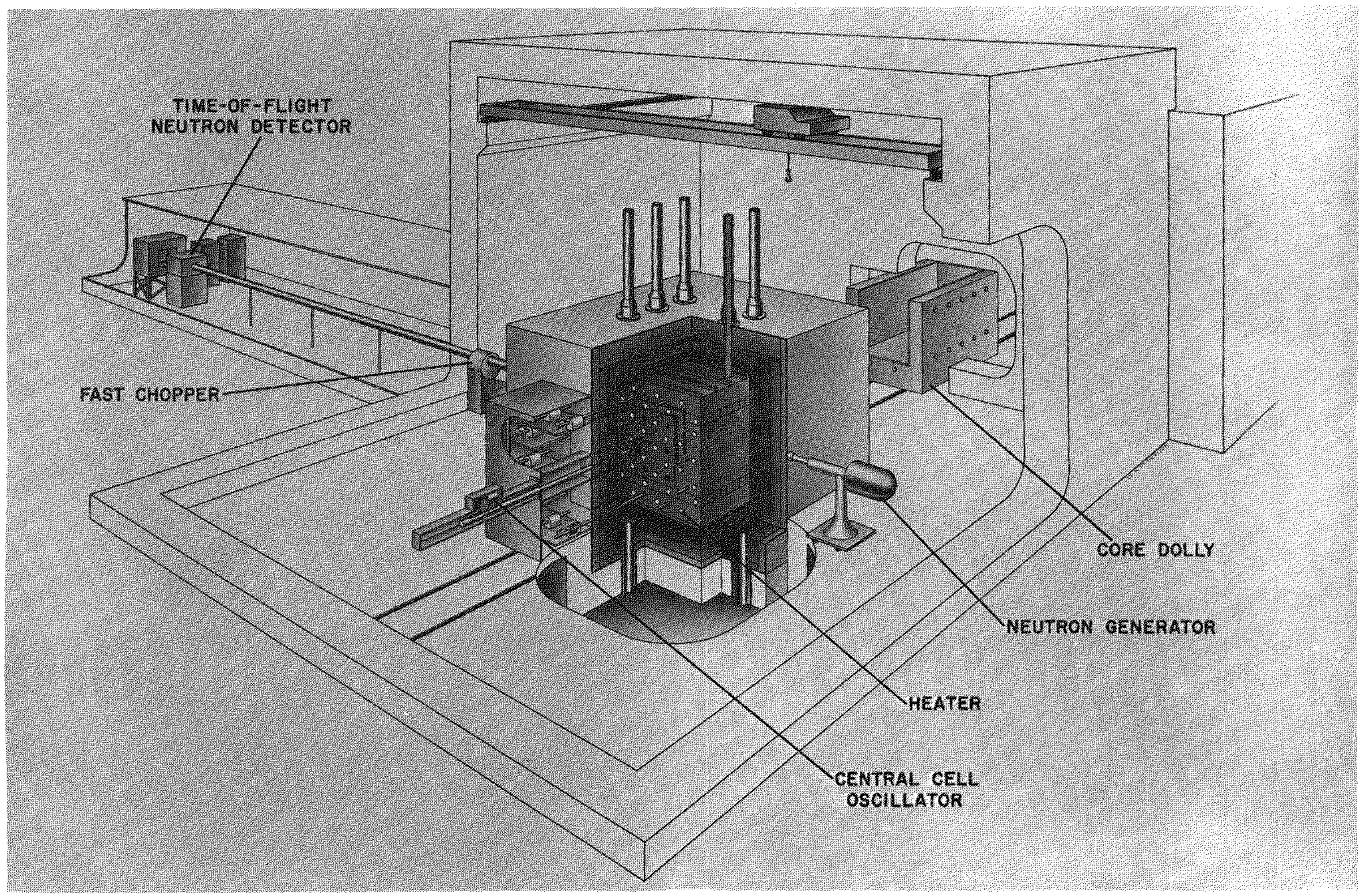


FIGURE 1

Cutaway View of the High Temperature Lattice Test Reactor and Associated Equipment of poison or other reactor materials while the reactor is held at the operating temperature. Ports in the sheath and insulation provide means of introducing lateral flux traverse equipment, of admitting neutrons from a pulsed source for startup of the reactor, for taking out beams of neutrons to the ion chambers which indicate the power level, for future piping of special coolants to the test fuel, and other experimental purposes. A neutron chopper and time-of-flight apparatus is located at the center beam port for the analysis of neutron velocity spectra in the test cores. The pulsed neutron source is capable of delivering up to 10^{11} neutrons per second of 14 Mev energy. It may be installed either at the side port, or in the basement directly beneath the center of the reactor.

The control rods have been designed in a way that maintains the axial symmetry of the neutron flux irrespective of the position of the rods. This is achieved by constructing the rod of a series of 6-inch long hollow cylinders which are alternately composed of fuel or graphite. A similar set of cylinders contained within these, and coaxial with them, consists alternately of boron carbide andfuel. A 6-inch motion of the inner set is thus all that is needed to go between the least reactive and most reactive positions.

Many aspects of the control and operation of the reactor and associated equipment are executed with the aid of a data logger--an electronic system for the acquisition and the treatment of data. It will generate various output signals upon a programmed demand. For example, it observes power level, control and safety rod positions, flow and radioactivity conditions of the gas and liquid coolant systems, and temperatures indicated by thermocouples in the reactor. It performs some of the nuclear safety functions. It also performs routine analyses, such as: the determination of periods, decay times, and reactivity; the correction and compensation of counter data; the control of heating currents to be used to achieve uniform temperature rapidly; and the initial treatment of data from the time-of-flight analyzer.

The reactor is located in a room 32 by 50 feet. The reactor room communicates through a shield door with an experimental assembly room which is 20 by 53 feet, into which the experimental section of the reactor can be rolled on a dolly. There is thus adequate space for experimental equipment during assembly or testing operations.

USE OF THE FACILITY

The construction of the graphite stack is an important factor contributing to the usefulness of the reactor. The HTLTR stack has an horizontal orientation because the insertion of samples and experimental cores from either end is made much simpler. A cross section of one-quarter of the graphite stack is shown in Figure 2. Three examples of possible loadings of the reactor and the removable, experimental core volume are shown in Figures 3 and 4. Since the whole experimental core region, 5 by 5 by 10 feet, is replaceable, this volume may be filled with any configuration which may be desired.

The loading in Figure 3 is typical of a loading for which the facility is primarily designed. In this example a heterogeneous test loading of 25 lattice cells, each of which is 4 feet long except for the central cell, is located in the experimental core section. This loading requires 106 linear feet of the test fuel assembly and a volume of 48 cubic feet of lattice material for an eight-inch lattice spacing. The flux matching region will contain either enriched driver fuel or natural uranium oxide fuel provided with the reactor facility.

The comparison of the reactivity of the central test cell to that of a void is accomplished with the aid of the central cell oscillator. Figure 3 shows the geometry of the central cell when the void replaces the cell. The oscillator will provide this configuration by pulling the cell out quickly. The cell will remain in this position for a predetermined and variable length of time, and the oscillator will then push the cell back in quickly, with a variable period for this oscillation. The length of the stroke is also variable and will usually be about 2 or 3 feet.

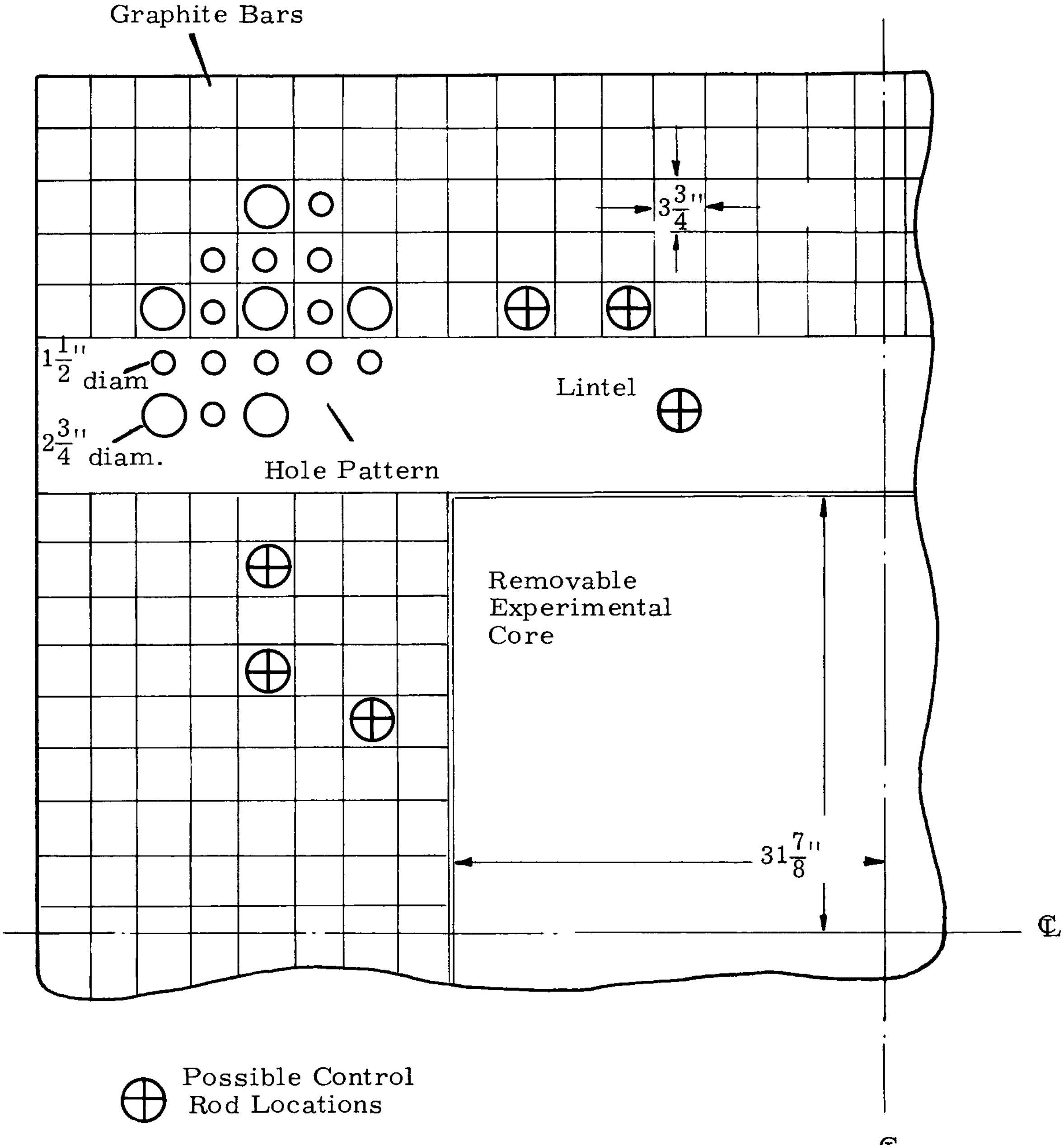
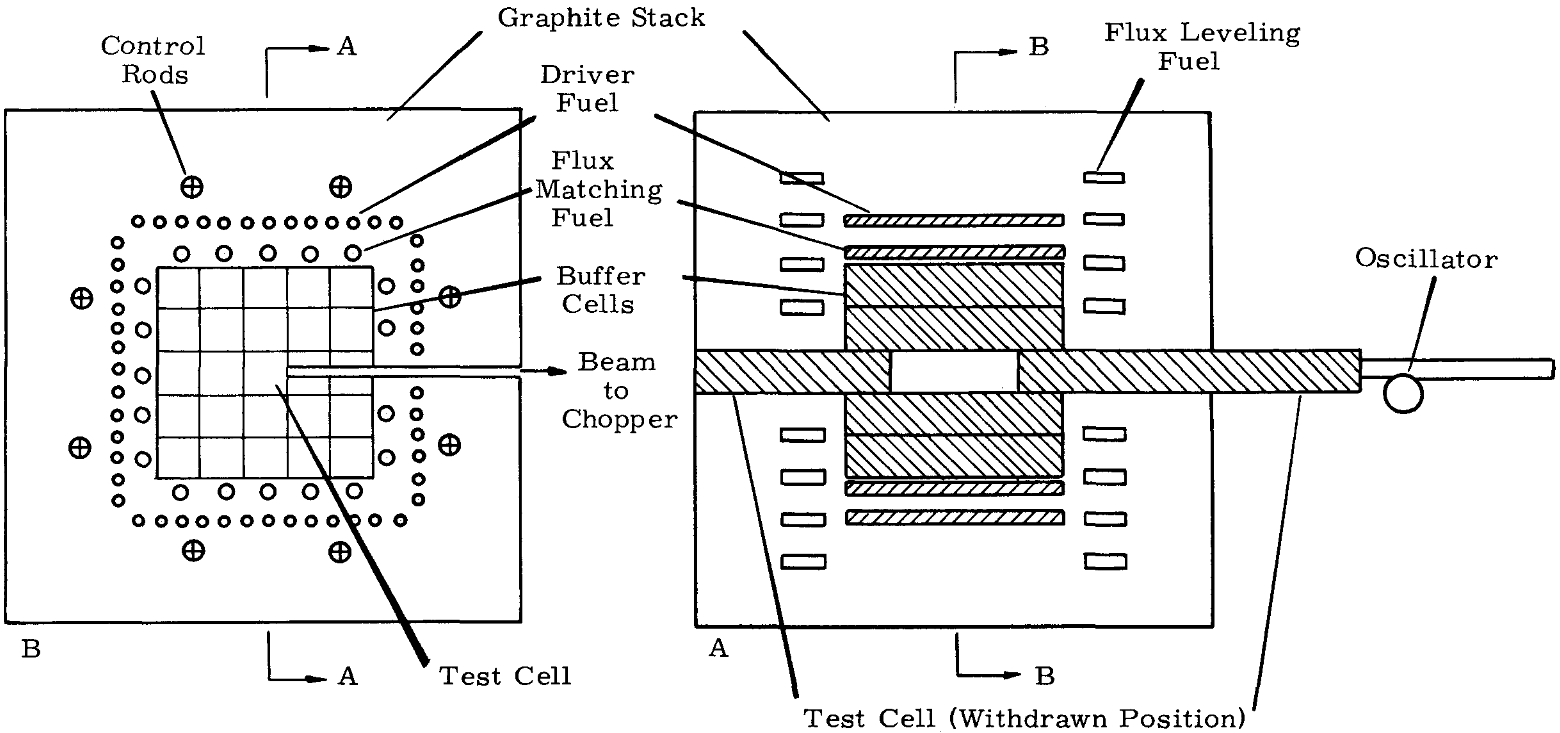


FIGURE 2

Cross Section of One Quadrant of the HTLTR Graphite Stack



<u>FIGURE 3</u>

Reactor Loading for Measurement of Transients in k_∞

After having compared the reactivity of the cell to a void to obtain k_∞ for the lattice, the reactivity effects of small changes in k_∞ caused by heating the fuel may be obtained by heating the fuel in the central 2 or 3 feet of the central test cell.

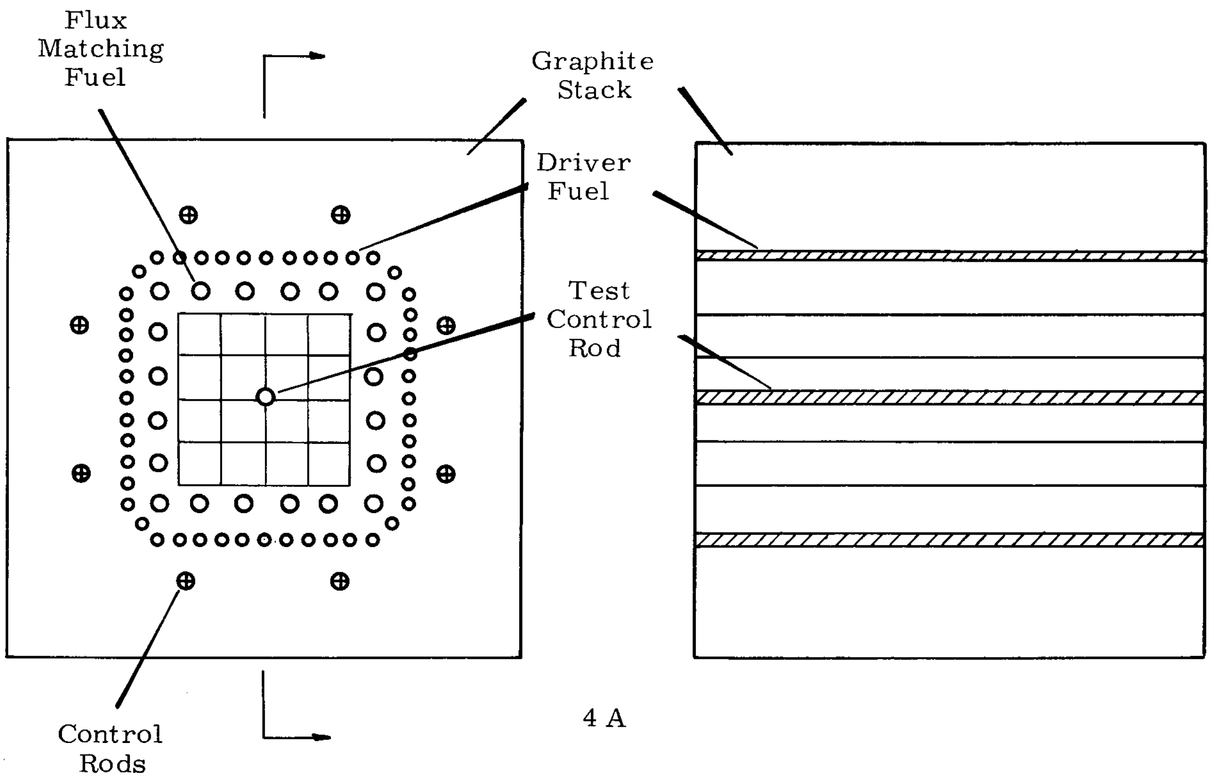
Although the sample oscillator on the opposite end of the reactor is used primarily to oscillate a thermal poison by which the worth of the central cell is calibrated, it can also be used to obtain reactivity coefficients for small samples of fuel or absorber samples with resonances.

To test the change in local strength of a test control rod with a change in temperature the lattice k_∞ and the local control strength at room temperature are first determined. Then, with the control rod positioned as shown in Figure 4A, the change in reactivity with temperature is noted with the control rod present or absent. Again, a normalization to the worth of a distributed thermal poison is made using the sample oscillator.

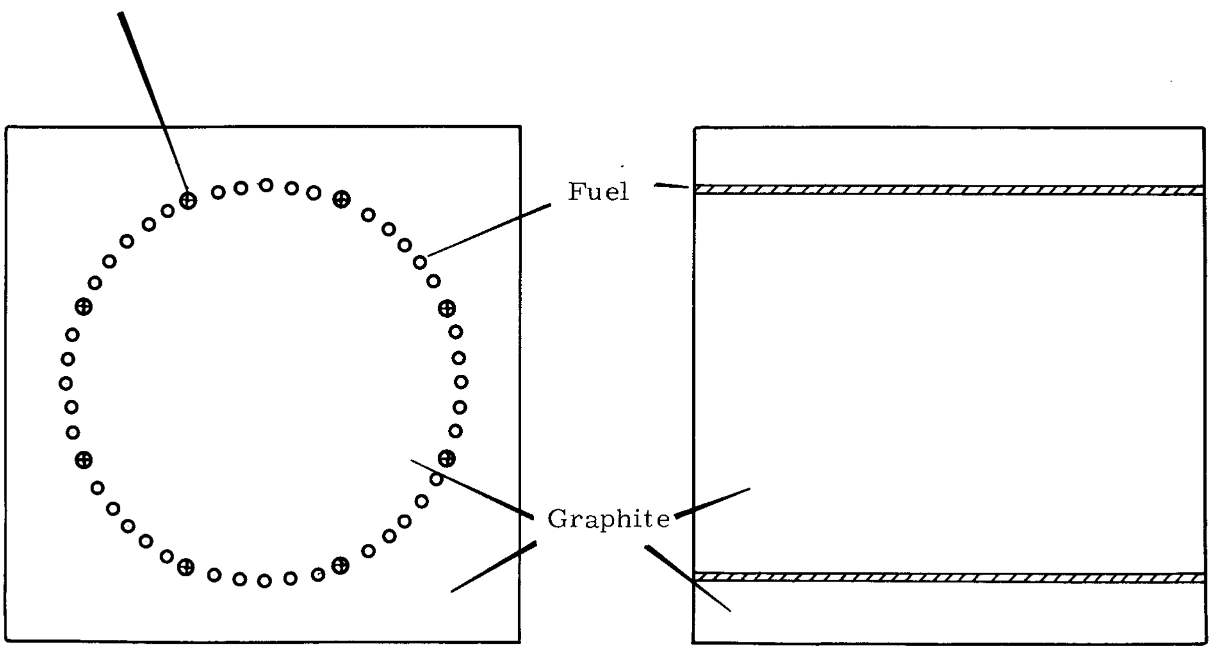
Measurements of the reactivity coefficients of samples in a very thermal flux is made possible by the loading shown in Figure 4B. Foil irradiations may also be made. Temperature gradients may be induced through any temperature interval up to temperatures as much higher than 1000 C as the heating elements and internal insulation used in an experiment will permit.

A completely uniform loading of fuel can be used, but no plans have yet been made for doing so. The uniform loading of fuel can be made at lattice spacings of 3.75 x n or 3.75 $\sqrt{2}$ x n inches, where n is a small integral number, 1, 2, 3, etc.

The configuration of the beam hole which feeds neutrons to the chopper may be arranged as shown in Figure 3. The configuration may be a heterogeneous medium having $k_\infty \cong 1$. Although there would be a very small



4 A



4 B

FIGURE 4

Fuel and Test Core Arrangements for Measurement of:

A. Temperature Induced Changes in Control Rod Worths,
B. Reactivity Coefficients of Samples in a Thermal Flux

overall buckling of the flux, the flux gradients in a lattice cell make transport corrections necessary. These are minimized if the source block is the edge of the cell as illustrated. The test medium shown in Figure 3 may be a homogeneous medium which is buffered by a closely matching lattice arrangement. Of course, a homogeneous buffer of the same composition as the central region under test can be used. There is an advantage of measuing spectra for some homogeneous media since these may be compared to the usual infinite medium calculations made with multigroup reactor codes.

HTLTR DESIGN DATA

Since the following data are derived from the scope design[4] of the HTLTR they constitute only a tentative and incomplete list of the characteristics of the reactor.

Reactor	
Nuclear power (maximum)	2 kw
Central neutron flux at 2 kw	10^{10} cm^{-2} sec^{-1}
Moderator and reflector (fixed portion)	Graphite
Moderator outside dimensions	10 x 10 x 10 ft
Initial maximum reactor temperature	1000 C
Removable experimental section	5 x 5 x 10 ft
Test cell maximum dimensions:	
Length	10 ft
Cross section	15 x 15 in.
Atmosphere	Nitrogen
Maximum pressure	1 psig
Graphite	
Type	SGBF
	TSGBF
Density (20 C)	1.65 g cm^{-3}
Bar cross sectional dimensions	3.75 x 3.75 in.

Diameter of lattice holes:	
Large	2.75 in.
Small	1.5 in.
Lattice pitch:	
Large holes	7.5 in.
Small holes	3.75 in.
Transverse hole through center	3.75 x 3.75 in.
Driver Fuel	
Composition	UO_2
Enrichment of U	10% by weight
Cladding	Hastelloy X
Thickness	0.010 to 0.020 in.
Control Rods	
Number	8
Number of rod locations	16
Length	6 to 8 ft
Orientation	Horizontal
Maximum withdrawal speed	2 in. min^{-1}
Motive power	Stepping motor
Minimum step	0.0010 in.
Position indicator	Linear Transducer
Reproducibility	0.001 in.
Insertion time on scram	1 sec
Maximum operating temperature	1000 C
Safety Rods	
Number	4
Thickness	0.25 in.
Width	4 in.
Length	9 ft
Orientation	Vertical
Composition	Boron Steel or B_4C in sheath
Maximum withdrawal rate	1 ft min^{-1}
Minimum insertion time	1.5 sec

Thermal Insulation	
Graphite wool (next to reactor)	7.5 in.
Nitrogen gas	3.75 in.
Aluminum oxide (G32)	9 in.
Aluminum oxide (G26)	9 in.
Calcined diatomeacious earth	6.75 in.
Sheath surface temperature (maximum)	78 C
Maximum inner surface temperature	1200 C
Thermometers	
Number of monitoring thermocouples	32
Operating range	20 C to 1200 C
Accuracy above 400 C	0.75% of reading
Sheathing	Inconel
Heater control thermocouples	
Maximum temperature to record	1600 C
Type	W-W, 26% Re
Sheath	
Where above 1200 C	Mo
Where below 1200 C	Inconel
Electrical insulation	Al_2O_3
Number of resistance thermometers	2
Accuracy (room temperature)	± 0.01 C
Operating range	20 C to 400 C
Heating and Cooling	
Heating element composition	Graphite rods
Rod diameter	0.5 in.
Heated length of element	8 ft
Number of heaters	32
Electrical power available to heaters	500 kw
Heater surface temperature (maximum)	1600 C

Moderator heating time	
20 C to 1000 C	120 hr
900 C to 1000 C	16 hr
Coolant	Nitrogen
Maximum pressure in reactor	1 psig
Recirculation flow (maximum)	4000 ft^3 min^{-1} (260 C)
Temperature, heat exchanger outlet	260 C
Maximum oxygen	0.003%
Storage capacity (liquid)	8000 gal
Maximum flow from storage	60 ft^3 min^{-1}
Continuous purge flow (maximum)	50 ft^3 min^{-1}
Cooling time, 1000 C to 260 C	24 hr
Nuclear Detectors	
For power level	BF_3 ion chambers
Range	7 decades
Location	Top, outside sheath
Number of groups of chambers	2
Current, all rods in, source normal (more sensitive group)	5 x 10^{-11} amps
Additional detector	BF_3 proportional counter
Flux monitor in reactor	Activation wire
Maximum wire diameter passable	0.15 in.
Mode insertion and retraction at temperature	Remote operation
Traverse directions	Axial and transverse
Mode of retrieval	Cooling chamber
Neutron Source	
Strength, continuous operation	
Maximum	10^{11} sec^{-1}
Normal	10^{10} sec^{-1}
Type	Accelerator

Reaction used	d - t
Target	Tritium, regenerated remotely
Pulse length	1 to 100 μ sec
Pulse repetition rate	10 to 200 sec^{-1}
Shielding	
Reactor room walls	Ordinary concrete
Thickness	3 ft
Reactor room ceiling	Ordinary concrete
Thickness	2 ft
External covering over reactor	Boral
Thickness	0.125 in.
Insulating Shell Penetrations and Plugs	
Front access door, size	10 x 10 ft
Rear access dooe, size	6 x 6 ft
Square openings in each door and plugs to fill them, centers on longitudinal axis of reactor	18 x 18 in.
Cylindrical opening in rear door plug for heavy duty oscillator drive	3 in. diameter
Diameter of side openings (2) centered on transverse reactor axis	18 in.
16 cylindrical openings to admit control rods (rear face)	2.5 in. diameter
Number of openings for experimental purposes	12
Diameter	6 in.
Data Logger	
Circuitry	Solid state
Memory	Ferrite core
Capacity	4096 words
Expandable to	16, 000 words
Word length	24 bits

Time to extract and replace a word from memory (maximum)	10 μ sec
Precision of converting analog signal to digital form	0.03%
Outputs:	Typewriter
	Numerical display
	Meters
	Chart recorder
	Signals to relays
Fraction of time spent on routine functions	0.3
Neutron Chopper and Analyzer	
Rotation speed	100 to 3600 rpm
Flight paths	20 and 50 ft
Range of neutron energy measurement	0.002 to 100 ev
Number of channels in analyzer	256
Channel widths	10, 20, 40, and 80 μ sec
Register time resolution	1 μ sec
Detectors	BF_3 proportional counters
Oscillators	
Heavy duty oscillator	
Location	Rear door
Maximum weight of sample	1200 lb
Minimum cycle time	2 min
Maximum horizontal stroke (when moving entire cell)	36 in.
Maximum horizontal stroke (when moving only fuel)	78 in.
Light duty oscillator	
Location	Front door
Maximum weight of sample	5 lb
Maximum stroke length	9 ft
Time to travel between extremities of stroke	2.5 sec
Minimum cycle time	2 min
Mode of retrieval of samples from oscillators	Cooling chambers

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