CONCEPTUAL SYSTEM DESIGN DESCRIPTION OF THE
EBR-II IN-CORE INSTRUMENT TEST FACILITY

by

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ABSTRACT

More data are required pertaining to the performance of instruments and their cabling under actual operating conditions in a liquid-metal-cooled fast-breeder reactor. To provide such data, a facility for testing of instrumentation in the core of EBR-II has been proposed. This report discusses the results of a study of the feasibilities of various design alternatives for the facility and describes the design that appears to be the most feasible. The facility also is expected to be useful for irradiating various materials under temperature-controlled conditions.

The recommended facility would be in one of the existing control-rod locations in EBR-II. It would consist of a thimble assembly containing the test instrument sensors, and would be heated by natural gamma radiation. Sensor temperatures would be controlled within the range from 900 to 1400°F by circulating sodium from the primary tank of the reactor through the thimble assembly. The thimble assembly would be raised by its own elevating mechanism for fuel handling, and a special container would be provided for handling the irradiated sensors.

I. INTRODUCTION

The purpose of this study is to determine the feasibility and the best design concept of a test facility that would provide means for inserting and irradiating sensors in the EBR-II core. The need exists for performance data on

instruments in a high fast-flux environment. The effect of fast flux on sensors and cables is relatively unknown. This type of data is essential for the development of reliable instrumentation to monitor reactor parameters for future sodium-cooled fast-breeder power reactors.

The LMFBR Program Office, which also defined the need for these data, recommended that a test facility be designed which could be installed in EBR-II. EBR-II, a fast reactor that is now being used as an experimental facility, has the required in-core environment for performing reliable tests on fast-reactor sensors; a fast neutron flux of approximately 2×10^{15} nv exists in the control-rod locations of EBR-II.

As conceived, the facility will include a thimble assembly that can be installed and safely operated in one of the control-rod positions in EBR-II. The thimble will be closed at the bottom and will thus provide a "dry well" extending into the reactor core. It will serve as a container for the instrument sensors or cables to be irradiated. Cooling of the thimble assembly is a major aspect of the design, and various solutions were investigated. Three design concepts appear most favorable and are described in detail in this study: gas-cooled concept; reactor-primary-sodium-cooled concept; and NaK-convection-cooled concept. Each of these three concepts utilizes the naturally available gamma heating in the reactor to raise the temperature of the sensors under test to the desired values. Other concepts have been considered; these are discussed briefly in Section V (Methods of Heating and Cooling the Thimble Assembly). The design concept believed to be the most favorable was selected on the basis of the reasons given in Section VIII (Evaluation: Determination of the Most-favorable System).

The conceived test facility includes an elevating system to accommodate reactor fuel handling, a coffin for handling the irradiated components, a calibration facility, and general supporting facilities.

Interest in using the facility for irradiation of small material specimens in a controlled environment has been growing recently. In-reactor creep tests could be accommodated. Subsequent design efforts will provide detail for such applications.

II. EXPERIMENTERS' PRELIMINARY CRITERIA

Several experimenters tentatively agreed that the following test conditions would be acceptable for most instrument tests:

A. Sensor and Sensor-environment Temperatures

Minimum Sensor Temperature	-	750°F
Maximum Sensor Temperature	-	1400°F
Maximum Environment Temperature	-	1200°F

B. Sensor Leads

The portion of the sensor lead that is in the zone of high neutron flux should be at approximately the same temperature as the sensor.

C. Fluid Environment

The environment should be either helium or argon gas. A sodium environment would make postexamination of the instruments difficult. The experimenters agreed that even though most instruments are normally used in sodium, they may be effectively tested in gas. They agreed that the instruments could be individually encapsulated in sodium if an experimenter desired a liquid-metal environment.

D. Sensor Calibration

It would be desirable to provide the capability of using a thermocouple-calibration instrument with the test facility. After calibration checks are made, it may be necessary to move the calibration sensor vertically upward until it is out of the region of high neutron flux. If this is not practical, a calibration sensor may have to be inserted whenever a check on the environment is made.

E. Sensor Thermal Shock

It is desirable, if practical, to shock some sensors thermally at a rate of 80 to 100°F per sec.

F. Sensor-temperature Control

Means should be provided, if practical, to vary the test temperature during a test.

G. Sensor Position During Test

It may be desirable to move a sensor or group of sensors from 1/4 inch to 4 or 5 feet either during reactor operation or during reactor shutdown.

H. Sensors to be Tested

The capability for testing the following types of sensors or instrument components is desired: thermocouples; resistance thermometers; fission-powered and self-powered flux sensors measuring 1/4 in. in diameter and approximately 2 in. long; ultrasonic temperature sensors; acoustic sensors (boiling, etc.); flow-sensor components; cables and cable materials; pressure transducers; level-transducer components; strain gauges; gas-bulb thermometers; and fluidic thermometers.

Fabrication and actual test of these instruments are not included in the activity reported here.

III. DESCRIPTION OF EBR-II

The In-Core Instrument Test Facility (INCOT) is to be an integral part of the EBR-II facility. The EBR-II reactor and the entire primary system are contained in the primary tank, as shown in Fig. 1, and operate completely submerged in the sodium coolant. The primary-sodium coolant is pumped directly from the primary tank into the reactor vessel and up through the reactor core. The effluent coolant flows from the reactor vessel, through the shell side of a heat exchanger, and back to the primary tank. Sodium in the secondary system flows through the tube side of the heat exchanger. It transfers the heat it picks up to a steam generator, which supplies the steam for a turbine-generator.

The basic components of the reactor assembly (Fig. 2) are the reactor vessel, the grid-plenum assembly, and the reactor-vessel cover. The assembly is surrounded by the neutron shield and is submerged beneath approximately 10 ft of sodium.

The grid-plenum assembly supports and locates the subassemblies and incorporates the coolant inlet plena. The assembly accommodates 637 hexagonal subassemblies spaced on a triangular pitch of 2.320 in. The present nominal core loading consists of 77 (total) enriched-uranium driver and experimental-

Fig. 1. EBR-II Reactor Plant

Fig. 2. Reactor Assembly

irradiation subassemblies, 2 safety subassemblies (or safety rods), and 12 control-rod subassemblies (or control rods). The inner blanket contains 36 (total) natural-uranium and experimental-irradiation subassemblies, and the outer blanket contains 510 natural-uranium subassemblies.

All fuel subassemblies are the same size, resulting in a closely packed reactor geometry. Each fuel-subassembly tube is hexagonal, measures 2.290 in. across external flats, and has a 0.040-in -thick wall. A nominal clearance of 0.030 in. between fuel subassemblies facilitates their removal from the reactor. The same upper adapter is used on every type of fuel subassembly so that all fuel subassemblies are accommodated by the same handling and transfer mechanisms. The lower adapters are of different sizes to distinguish between the three regions of subassemblies, and are of different configurations to accommodate the two coolant inlet plena.

The reactor-vessel cover, which serves as a neutron shield as well as a closure, is clamped to the vessel flange by three holddown clamps. When the cover is lowered, it forms the reactor upper plenum from which the coolant flows to the heat exchanger.

The control-rod drive shafts operate through seals and guide bearings in the reactor-vessel cover. Each control rod is operated independently by an electromechanical drive mounted on top of the rotating shield plug (Fig. 3). In the event of a reactor scram, the 12 control rods operate simultaneously.

The two safety rods, which are a separate part of the system, do not provide operational control. Their main purpose is to provide available negative reactivity during reactor shutdown.

The primary tank contains the reactor vessel; two primary-sodium pumps; the heat exchanger; a storage basket for subassemblies; various instruments, mechanisms, and auxiliary systems; and 80,000 gal of sodium. The tank is of double-wall construction to provide maximum reliability of sodium containment. The inner tank is 26 ft in diameter; its side walls are constructed of 0.5-in.-thick plates, and its bottom is constructed of 1-in -thick plates. The bottom-plate structure of the inner tank supports the reactor-vessel assembly, the neutron shield, some of the primary-sodium piping, and the entire sodium load. This load is transferred by the tank wall to the top cover, which supports the tank. The structure of the outer tank is designed to carry the sodium load in case a leak develops in the inner tank. The cover of the primary tank is 39 in. deep and contains shielding material and thermal insulation. The region above the bulk sodium is filled with inert argon cover gas.

Fig. 3. Control-rod Drive

The primary tank has no side or bottom openings but allows access to its interior through 67 nozzles in the cover and one large circular opening in the center of the cover. Each nozzle accommodates one primary-system component, which is removable in most cases, and the central opening accommodates the rotating shield plugs.

The primary tank, its contents, and the components that are connected to the primary-tank cover are supported by six hangers, which in turn transfer these loads to the top-structure beams. Each hanger is supported by a roller so that differential radial expansion between the top structure and the primary-tank cover will not produce additional stresses in the system. The design of the primary tank and its method of support are arranged to provide radial expansion about the vertical centerline of the system. The reactor, the rotating plugs (which index the control-rod drives), and part of the fuel-unloading mechanisms are centered on the physical centerline of the system. Differential vertical expansion is reduced by using the same material for all equipment in the system and by maintaining isothermal conditions wherever possible.

An EBR-II modification is being planned to replace the existing control rods with the minimum number of higher-worth control rods that proves to be adequate. This arrangement will make available a maximum number of control-rod locations for components such as an oscillator rod, an instrumented subassembly, and the In-core Instrument Test Facility (INCOT) described in this report. A study of space requirements for the supporting facilities of the proposed INCOT led to a tentative choice of control-rod position No. 2 as the location for the facility. Figure 4 shows this position in relation to other existing control-rod positions.

IV. BASIC CONSIDERATIONS

The purpose of this study is to determine a design concept for the INCOT that will accommodate many types of instrument experiments with minimal effects on normal EBR-II operation. Certain considerations seem rather basic in the selection of the components or systems. These are briefly discussed in this section; some are discussed more thoroughly in subsequent sections.

The INCOT thimble assembly must fit into an EBR-II control-rod position. Each control-rod position contains a 2-3/4-in.-ID control-rod guide-bearing tube, which penetrates the rotating plug and the inert-gas space above

Fig. 4. Plan View of Small Rotating Plug, Showing INCOT Location

the sodium level in the primary tank. A guide bushing with a 2.577-in. ID is located at the lower end of the control-rod guide-bearing tube. The lower end of the INCOT thimble assembly must fit into a guide-tube assembly, supported by the reactor grid plates. The guide-tube assembly is fabricated from a hexagonal tube having an internal dimension at 2.210 in. across the flats. The dimensions of the INCOT thimble assembly must be within these existing dimensional limitations of the control-rod positions.

The EBR-II fuel-handling procedure requires that the reactor cover and the control drives be lifted during the transfer of fuel into or out of the reactor vessel. The INCOT thimble assembly also must have an elevating mechanism to lift it during fuel handling. The elevating mechanism for the instrumented subassembly resembles the elevating mechanism required for the INCOT thimble assembly. The existing design should be utilized to the maximum extent to minimize cost and time.

Testing sensors in liquid metal poses difficulties. The liquid metal or its chemical compounds may attack the sensors and alter the experimental results. In addition, adherence of radioactive liquid metals on sensors might make interim recalibrations or postirradiation examination more difficult. Thus, the design basis for INCOT is that of a "dry thimble", i.e., the environment for the sensors is a gas. Should an experimenter be interested in testing a sensor in liquid metal, however, the sensor can be encapsulated in liquid metal. This approach has the advantage that the chemistry of the liquid metal can be controlled.

Because of gamma heating in the core, the sensors may reach temperatures that are significantly higher than those reached by the coolant (see Fig. 5). The magnitude of the temperature increase of the sensor is related to the mass of the sensor and the thermal resistance of its surroundings.

The small cross section of the entire thimble assembly makes it desirable for the lead from the sensor to the sensor-lead terminal box (approx 34 ft) to be no larger in diameter than the sensor. This will maximize the number of sensors that can be placed into the thimble assembly at one time. Sensor-lead splices equal to or smaller in diameter than the sensor may be made if a smooth transition between the sensor and the lead sheath is provided. Larger-diameter splices would obstruct the space for other sensors. Under some adverse conditions, it may be desirable to assemble a split sleeve or equivalent over any smaller-diameter lead as an aid in sensor handling.

Fig. 5. Temperature of Typical Sheathed Thermocouple vs Radial Clearance in Thimble

A handling container is necessary because of the radioactivity of the portions of the sensors and their leads which reside in the reactor core during the test period. The basic capability to remove individual sensors, the sensor thimble or the multiple-sensor thimble assembly, and the entire thimble assembly must be provided.

Several other factors influence the basic considerations for this design. The space limitations resulting from the location of adjacent control rod drives must not be compromised. Disturbance to other experiments must be minimized. The cost of and time for designing and fabricating the facility must be reasonable.

V. METHOD OF HEATING AND COOLING THE THIMBLE ASSEMBLY

A major consideration is adequate temperature control of the space within the thimble assembly. Provision must be made for an internal heat source or a cooling medium, or both, that will leave adequate space for test sensors. Numerous alternatives are conceivable and are discussed in this section. To be comprehensive in view, the discussion includes mention of alternatives that obviously have a low degree of practicality.

A. Heating

Gamma heating exists as an inherent characteristic of the reactor and will prevail as a source of the primary or supplementary heat. Heating of the thimble assembly can be achieved also by using a source of energy external to the reactor. This method requires the transfer of energy down through the limited space available in the thimble assembly.

1. Heating with Fluids

A single circulating loop can be utilized to transfer energy. One might consider sodium, sodium-potassium, argon, helium, air, water, or oil as potential heat-transfer fluids. The first three of these (sodium, sodium-potassium, and argon) would present a radiation problem. These fluids would circulate into the reactor core at frequent circuit-completion intervals and thus saturate at a radiation level high enough to require several inches of shielding between the fluid and personnel on the operating floor of the reactor

building. Besides, the first two fluids (sodium and sodium-potassium) present a handling problem when external to the primary tank because of the possibility of exothermic reaction with oxidizing agents. Double containment would be a necessary safety feature, and this would be difficult to achieve.

Helium appears to be a very acceptable heat-transfer fluid so long as the required pressures for the quantity of circulation do not become so excessive as to present a safety problem. The same can be said of air, but in addition, a double wall would have to be used between the air and the primary system sodium.

Water (steam) is unacceptable as a heat-transfer fluid because of the very high pressures required to achieve the desired temperatures. The two heavy walls that would be required between the water and primary sodium would leave very little space for experimental sensors in the thimble assembly. Additionally, the hazards of a sodium-water reaction would need consideration.

Oil is unacceptable because of its instability under high radiation loads.

2. Heating by Electricity

Electrical conductors could be used to transfer energy to a resistance heater or heaters located near the sensors. However, as is the case with the passages for all the heat-transfer fluids described in Section V.A.1, electrical-heating leads would occupy a major portion of the sensor test space in the thimble assembly. (Electrical leads, however, would require less cross-sectional space than the passages for the heat-transfer fluids.) Finding suitable electrical insulation for the desired heater lifetimes in the core region also would be a problem. Reasonable electrical resistance-heater voltages are necessary to avoid excessive electrical-lead diameters.

3. Gamma Heating

When double walls with an insulating gas space are necessary to achieve temperatures much different than those of the primary system sodium, as seems necessary in this application, gamma heating has favorable aspects. The heat transfer through the insulating gas space is so small that the addition of very little heat is required to achieve very high temperatures. A 1/8-in.-dia stainless steel-sheathed thermocouple in a gas environment was

used as typical in determining gamma-heat generation in the thimble assembly. Calculations indicate that the thermocouple can be raised to any desired temperature by gamma heating. The maximum temperature attainable by gamma heating is limited only by the amount of restriction of the selected coolant flow.

B. Cooling

Cooling of the thimble assembly is required for even the highest sensor test temperatures. Various calculations based on the use of double walls indicate that a dependable coolant is required to avoid overheating the sensors.

1. Single-loop Cooling with Fluids

Cooling can be achieved by a single circulating loop containing sodium, sodium-potassium, argon, helium, air, water, or oil. The coolant would be pumped from the top of the rotating plugs and past the test region within the thimble assembly. Heat gained by the coolant would be transferred to a heat exchanger located either on top of the rotating plugs or on the operating floor. The comments on heating of the thimble assembly with a single loop (Section V.A.1) apply. In addition, the coolant heat exchangers would occupy a considerable amount of valuable operating-floor area. Because of the relatively low heat-sink temperature, further analyses were made of a single circulating loop containing air or helium. The results of these analyses are discussed in Section VII.A. (Gas-cooled Concept).

2. Dual-loop Cooling with Fluids

Cooling by a dual loop was considered, using the same heat-transfer fluids. In this case, the primary loop would extend from a desirable position within the test thimble to an elevation where the neutron flux is low within the primary tank. Coolant circulation within the loops would be maintained by natural convection. The heat gained by the primary loop coolant would be transferred to the secondary loop, which extends above the rotating plug. A heat exchanger on the rotating plug or on the operating floor would remove the heat from the secondary loop. The advantage of this method is that the secondary loop is essentially nonradioactive. Because of the

relatively low heat-sink temperature available to the heat-transfer fluid, further analyses were made of a dual-circulating loop containing sodium-potassium, which requires no heating to avoid solidification during standby periods. The results of these analyses are given in Section VII.C (NaK-convection-cooled Concept).

3. Cooling with Reactor Primary Sodium

The thimble assembly also can be cooled with the primary sodium coolant circulated through the reactor. This is the most dependable method of cooling; it relies on no auxiliary equipment. In this case, the 700°F sodium from the primary tank would be circulated in an annulus outside the test thimble. Coolant flow would be provided by the existing reactor cooling system. Because of the simplicity of obtaining primary sodium as a coolant, further analyses of this method were conducted. The results of these analyses are given in Section VII.B (Primary-sodium-cooled Concept).

VI. GENERAL APPRAISAL OF HEATING AND COOLING METHODS

A. Heating

Evaluation of the methods for heating the thimble assembly indicates that utilizing the natural reactor gamma heat to raise the temperature of the sensors to desired values is not only the best method but is unavoidable when the sensors are in a gas environment. The maximum test temperature attainable by this method is limited only by the maximum temperature to which the chosen coolant is restricted.

Heating by external loop or by electric heaters appears unfavorable. Operating and control equipment would have to be located in areas where space is extremely limited. Valuable testing space within the thimble assembly also would be occupied, thus reducing the usefulness of the facility.

B. Cooling

Cooling with single or dual loops filled with either water or oil is rejected because general safety practices restrict the use of these fluids in or near a sodium-cooled reactor. In addition, the oil has a limited lifetime due to radiation.

Cooling with argon gas in a single loop is undesirable because the gas piping in the region of the operating floor would require about 4 in. of steel shielding.

Cooling with any gas in a dual loop is unacceptable because of the poor heat-transfer characteristic of a gas.

Cooling with either air or helium in a single loop is acceptable; however, the external equipment required is complex and bulky. Considerable space would be required on the rotating plugs or on the operating floor. Also, the testing space within the thimble assembly would be reduced because of the need for gas passages.

Cooling by a dual loop filled with sodium is unacceptable because sodium lines through the rotating shield plugs and above these plugs would have to be heated and insulated. This would take up excessive space on top or near the rotating plug. Also, heating within the rotating plug is inadvisable because of space limitations and the possibility of excessively heating the adjacent shielding concrete in the rotating plug.

Cooling by a single loop filled with sodium or sodium-potassium is unacceptable because sodium or sodium-potassium lines above the rotating plugs would require extensive shielding. Lines carrying sodium would have to be heated and insulated also.

Cooling by a dual loop filled with sodium-potassium is acceptable; however, space for a heat-rejection surface would be required on the top end of the thimble assembly on the rotating plug. Also, the testing space within the thimble assembly would be greatly reduced.

Cooling by circulating primary sodium coolant through the thimble assembly appears to be a very promising method. It requires no external equipment, and hence the space congestion in the region of the rotating plug is minimized. Likewise, very little testing space in the thimble assembly is taken up by the coolant. Calculations show that there is sufficient available sodium head within the control-rod thimble to provide ample coolant flow within the small annular space. The minimum wall temperature of the sensor thimble is expected to be reasonably close to the 700°F primary sodium temperature. The temperature gradient in the gas between the wall of the thimble and the sensor will vary depending on the ratio of the mass to surface area of the sensor and on the width of the stagnant-gas gap between the sensor and the thimble wall. Various experiments will have different configurations.

VII. MOST ADVANTAGEOUS METHODS OF HEATING AND COOLING

After reviewing the entire field of alternative arrangements for the thimble assembly, three basic concepts were selected for more-detailed study: a gas-cooled concept, a primary-sodium-cooled concept, and a NaK-convection-cooled concept. Other concepts involved undesirable aspects such as cooling with a fluid which is not compatible with the molten sodium or cooling by evaporation of liquefied gases, a method which is not compatible with certain safety considerations. The three basic concepts and minor variations of them are discussed in this section. One of these three (the primary-sodium-cooled concept) is discussed in greater detail than the other two because it was subsequently selected as the most favorable.

Calculations show that the total heat generated by the sensors being tested and their containing thimble or thimbles is relatively small. However, gamma-heat generation will produce temperatures equal to the highest desired test environment when coolant flow or coolant heat-transfer capability is reduced. Thus, gamma heating has been selected as the most desirable heat source. Electrical heating would reduce the available space for experiments inside the thimble assembly and would pose electrical-insulation problems. Since INCOT does have to cope with the gamma heating, control of the environmental temperature by adjusting the quantity of coolant flow or heat-transfer surface seems natural. (The heat generation for stainless steel at core centerline is 3.7 W/g at 62.5 MWt.)

A. Gas-cooled Concept

The gas-cooled concept requires gas to be circulated inside the thimble assembly. The pumping and cooling system is located on the operating floor, and is connected to the thimble assembly with flexible hose connections (Fig. 6). (Lack of available space makes it impossible to locate the pumping and cooling system on top of the small rotating plug.) Fuel handling requires movement of the rotating plugs, on which most of the INCOT components are mounted. Therefore, the coolant lines would have to be disconnected during fuel handling.

Helium could be used as coolant gas, but would be expensive because of losses by leakage at the disconnects and purging requirements to ensure purity after fuel handling. Argon is unsatisfactory because it would attain a high radiation level as a result of its repetitive trips through the reactor core,

Fig. 6. General Configuration of Gas-cooled Concept

resulting in an unacceptable shielding requirement of about 4 in. of steel in addition to the pipe-wall thickness. Air is an acceptable coolant, requiring only standard pipe-wall thicknesses for personnel shielding. Since the coolant gas envelopes the sensors being irradiated, the choice between helium or air depends on the experimenters' requirements.

Figure 7 shows the thimble assembly for the gas-cooled concept. The cooling gas passes down through the 1.312-in.-ID central tubing and up the outer annulus, which has a 1.437-in. ID and a 1.875-in. OD. The upper portion of the coolant-gas passages are filled in places with steel to align shielding in the thimble assembly with that in the rotating plugs. The region of highest coolant-gas pressure drop is in this shielding area.

Each experimental sensor is contained inside an individual sensor thimble to make its insertion and removal possible. The large amount of space used by the coolant-gas passages restricts the number of sensor thimbles to one of about 1/2 in. ID. This is perhaps a prohibitively unfavorable feature of this particular gas-cooled concept. One permanently installed sensor, without a guide tube, can be fitted into the assembly. This sensor may read temperature or some important parameter associated with the group of tests. Cooling requirements cover a variety of situations. A typical requirement shows the need for 40 scfm of air and a total pressure drop of about 45 psi, including the pressure drop through the heat exchangers on the operating floor of the reactor building. Most of the total pressure drop (about 34 psi) is in the thimble assembly and the immediate connections thereto. A theoretical horsepower of 4.2, or an actual compressor-motor size of about 7-1/2 hp, would be required. Because of the high pressure drop, the existing cooling system for the EBR-II nuclear-instrument thimble, which has available flow capacity, but at only 4-psi pressure differential, cannot be used.

Two tubing walls would be used between the cooling gas and the primary-system sodium. A gas space between the two tubing walls would serve as thermal insulation to avoid heating the coolant gas. (The primary-system sodium, at 700°F outside the reactor vessel, increases in temperature from 700°F to about 900°F in the vessel. To conserve space, only a single wall would provide the barrier between the up and down coolant-gas flow streams. The 140°F inlet gas is estimated to increase in temperature to about 540°F as it passes down the thimble assembly to the reactor-core level because of horizontal heat transfer and friction heating. The cool gas to the sensor receives significant heat from the hot gas leaving the sensor. Most of the temperature rise at the sensor in the reactor core results from gamma heating of the stainless steel

Fig. 7. INCOT Thimble Assembly for Gas-cooled Concept

hardware surrounding the sensor. The amount of stainless steel in the core region is held to the minimum required for structures to guide the coolant-gas flow and for the sensor itself. Greater values of air flow improve the heat transfer but cause an unacceptably high pressure drop. If helium is used as the coolant gas, the mass flow rate is estimated to decrease by a factor of 4, the coolant flow volume to increase by a factor of 1.8, and the pressure drop to decrease by a factor of about 1.45; the compressor horse power, however, is estimated to remain at approximately the same value. If two walls were used between the up and down coolant-gas flow streams, an excessive amount of necessary space for test sensors would be lost.

The gas-cooled concept has the inherent advantages of using the lowest existing temperature heat sink and providing a gas environmental temperature of about 600°F. However, it has three over-riding disadvantages: (1) Space would be provided for only one or two test sensors; (2) major equipment would have to be added to the operating floor of the reactor building; and (3) solution of the very difficult problem of designing flexible quick-disconnect connections for high-temperature, radioactively contaminated coolant gases would be required.

B. Primary-sodium-cooled Concept

1. General Description

The primary-sodium-cooled concept utilizes the coolant from the reactor plenum to regulate the temperature rise of the test sensors due to reactor gamma heating. This concept lends itself for use in two variations, called Model 1 and Model 2.

In Model 1, an open-ended sensor tube (1.402 in. ID) contains several small individual sensor thimbles, each of which is closed on the bottom and houses a sensor kept in a helium or argon environment. Primary sodium cools the individual sensor thimbles by entering the open-ended sensor tube, flowing upward, and exiting into the primary-tank sodium approximately 13 ft above the reactor-core centerline.

In Model 2, a large sensor thimble (1.402 in. ID), closed at the bottom, contains several test sensors, which are kept in a helium or argon environment. Primary-sodium coolant flows upward in an annulus on the outside of the large sensor thimble and leaves the assembly at the same elevation as in Model 1.

These options offer flexibility for handling a variety of sensor sizes and for meeting a range of temperature requirements. The choice of either model depends on the test-temperature range desired. It is anticipated that most temperature objectives can be reached by combining coolant-flow control with the necessary degree of built-in thermal coupling to the sodium coolant.

2. Detailed Description

Model 1 (Figs. 8 and 9) pertains to a thimble assembly that consists essentially of three concentric tubes. The two outer tubes (the insulating-gas-tube assembly) serve mainly for insulating purposes, and the innermost tube, called the sensor tube (1.402 in. ID and 1.500 in. OD), acts as a coolant-flow guide. The sensor tube extends approx 4.5 in. below the bottom of the reactor core where it is attached to a coolant-flow control valve and a labyrinth seal that fits into the INCOT guide-tube assembly. (This guide tube replaces the control-rod guide tube.) The sensor tube contains several sensor thimbles, which are held in place by sensor-thimble spacers. Each sensor thimble is filled with gas and contains one test sensor. Each test sensor in this assembly can be moved vertically within its sensor thimble without disturbing the other sensors or thimbles. The thimble assembly is approx 35 ft long and extends from the sensor-lead terminal box, which is located above the rotating shield plugs, into the reactor vessel and reactor core. Shielding slugs are incorporated at the level of the rotating-plug shielding. The coolant-flow control valve near the lower end of the assembly is regulated by rotating the sensor tube over a small angle. The degree of rotation (which determines how much of the flow area is exposed within the valve) is set by adjusting the flow-control-valve operator that is connected at the sensor-lead terminal box. This operator is a simple mechanical drive that is adjusted manually.

The coolant-flow control valve regulates and directs coolant from the reactor high-pressure plenum into the sensor tube and hence around each individual sensor thimble. The coolant flows from the sensor tube and thimble assembly into the primary-tank bulk sodium via coolant exit holes. These holes are located well above the reactor-vessel cover, thus providing the sensor thimbles with a nearly isothermal environment for about 7 ft above the reactor core.

Fig. 8. INCOT Thimble Assembly for Primary-sodium-cooled Concept with Individual Sensor Thimbles (Model 1)

Fig. 9. Cross Sections of INCOT Thimble Assembly for Primary-sodium-cooled Concept with Individual Sensor Thimbles (Model 1)

Model 2 (Fig. 10) is similar to Model 1 with one important exception. Instead of several individual sensor thimbles (one for each sensor), Model 2 employs one common thimble (1.402 in. ID and 1.500 in. OD), which is closed at the bottom. It contains several individual small sensor tubes, each of which contains one sensor and its leads. The small sensor tubes are open at the bottom so that the sensors may extend into the argon-filled bottom cavity of the common thimble, called sensor thimble. Cooling is accomplished by sodium that flows through an annulus between the outside of the sensor thimble and the inside of the insulating-gas-tube assembly.

Both designs permit vertical movement of the sensors to expose them to a wide range of neutron-flux levels. Vertical motion can be accomplished either by moving the whole assembly upward as much as 40 in. or by moving individual sensors to different elevations. Such motions would not significantly affect coolant-flow control. Both designs incorporate gas- and sodium-filled annuli to serve as insulators between the various temperature regions.

3. Sensor Test Temperatures: Model 1

The design of the individual sensor thimbles for Model 1 must be tailored to the sensors under test, considering desired temperature levels, heating rates, size, shape, and heat-transfer characteristics. Some calculations have been made to evaluate temperature ranges of a typical 1/8-in. metal-sheathed thermocouple at EBR-II coolant-temperature levels. The results, shown in Figs. 11 and 12, are based on: (1) use of argon gas inside the gap in the sensor thimble; (2) a thermal emissivity of 0.2 for emittance of thermal radiation by the sensor (such as associated with clean stainless steel or refractory-metal surfaces); and (3) a thermal emissivity of 0.6 for the thimble (such as may be obtained by oxidation at high temperatures). These results indicate that: (1) temperatures above 1300°F can be reached; (2) flow control can provide the means for varying thermocouple temperatures, perhaps by as much as 350-400°F; and (3) some difficulty may be experienced in reaching levels below about 900°F in the same thimble.

Fig. 10. INCOT Thimble Assembly for Primary-sodium-cooled Concept with Common Sensor Thimble (Model 2)

Fig. 11. Temperatures of Typical Sheathed Thermocouple in Individual Thimbles with 1/64-in. Argon-filled Radial Gap

Fig. 12. Temperatures of Typical Sheathed Thermocouple in Individual Thimbles with 1/32-in. Argon-filled Radial Gap

4. Sensor Test Temperatures: Model 2

The Model-2 configuration may be advantageous for sensors which are larger in diameter and/or have higher-temperature capabilities. If a test loading consists of several sensors, the temperature each sensor attains will be influenced by its "view" (for radiation heat transfer) of the sodium-cooled sensor thimble. Calculations of radiation heat transfer for such arrays are quite involved, and lacking details of possible tests, refined temperature predictions have not been attempted. However, for a loading of several typical 1/8-in.-dia sheathed thermocouples, some preliminary estimates indicate minimum temperatures in excess of 1600°F. If necessary, higher temperatures may be obtained by using thermal-radiation shields.

5. Coolant-flow Requirements

The gamma-heat load from the thimble assembly is estimated to be about 8 kW at 62.5 MWt reactor power, including heat produced above and below the core. A plot of the rise of primary-coolant temperature vs Flow (Fig. 13) indicates that coolant-flow requirements may vary from 0.4 to perhaps 10 gpm. This range allows the sodium-coolant temperature to vary from about 700-725°F to a maximum level of 1250°F, which is the limit imposed by thermal stress in the structure.

6. Sensor and Thimble Handling

The design permits the sensors to be moved, removed, or inserted individually. Either the sensor tube holding the multiple sensor thimbles in Model 1 or the central sensor thimble in Model 2 can be removed without disturbing the enclosing insulating-gas-tube assembly. The entire thimble assembly can be removed from the control-rod guide-bearing tube. Versatility of removal modes is intended.

C. NaK-convection-cooled Concept

1. General Description

This natural-convection concept provides a method to achieve sensor environment temperatures below the 700°F level of the primary sodium. The

Fig. 13. Sodium-temperature Rise vs Flowrate in Primary-sodium-cooled INCOT

relatively cool air in the reactor building serves as the heat sink for the system. A dual system (primary and secondary loops) is required to avoid a serious radiation problem on the reactor-building floor during operation. Sodium-potassium alloy is the coolant in both loops, and since free convection is relied upon for circulation, no electrical power is needed to operate the cooling system.

2. Detailed Description

A tentative layout of the system was assumed so that advantages and disadvantages could be revealed. The concept pertains to a thimble assembly which extends from above the top of the rotating plug and down into the primary tank and reactor core. The thimble assembly (see Fig. 14) consists of an outer thimble (for insulation), whose lower end fits into the INCOT guide-tube assembly, and a sensor thimble, which forms the inner member. Located inside the sensor thimble are the primary and secondary NaK coolant loops. Each loop has three concentric tubes. The inside of the innermost tube provides the central downcomer passage, and the annulus between the outer tube and the middle tube serves as a riser. A gas space between the inner and middle tubes separates and insulates the two regions. A bellows assembly near the bottom accommodates dimensional changes of the tubing that are caused by temperature differentials. The primary NaK coolant transfers heat to the secondary NaK coolant via a small and intricate intermediate heat exchanger that is located inside the sensor thimble at an elevation just below the level of the sodium in the primary tank. The secondary NaK coolant circulates through a finned NaK-to-air heat exchanger installed above the rotating plug.

3. Thermal-Hydraulic Analysis

The detailed design and analysis of the compact intermediate heat exchanger to fit the limited space available appears to be quite involved and has not been carried to a firm conclusion. A semiquantitative thermal-hydraulic analysis was made, however, using the very optimistic assumptions that the heat exchanger would offer no resistance to flow and only minor thermal resistance. The results of this analysis appear in Fig. 15. Because of the configuration chosen, the heat load from the structural components to the NaK could range between 3.4 and 6.9 kW, depending on several factors

Fig. 14. INCOT Thimble Assembly for NaK-convection-cooled Concept

Fig. 15. Heat-removal Capacity vs NaK-temperature Rise for the INCOT Natural-convection Concept

including the arrangement of test sensors. From Fig. 15, it is found that the coolant-temperature rise could range from 300 to 470°F for this variation in heat load. A further consideration must be the temperature changes due to heat transfer between the imperfectly insulated riser and downcomer flows in both loops. The required NaK temperatures are summarized in Table I, where it is assumed that the NaK temperature at the outlet of the test region must be no more than 700°F if this concept is to offer any practical advantage.

TABLE I. Required NaK Temperatures for Convection-cooled INCOT Concept

Heat Load, kW	3.4	6.9
NaK Temp at Outlet of Test Region, °F	700	700
ΔT in Test Region, °F	300	470
ΔT in Downcomers, °F	95	150
ΔT in IHX (assumed), °F	20	40
Total ΔT , °F	415	660
Required Outlet Temp from Air-cooled Exchanger, °F	285	40

Since the temperature of the heat sink (room air) exceeds 40°F, this design obviously cannot meet the temperature objective at the higher heat load. Furthermore, it should be noted that since the flow resistance of the IHX is neglected, all the temperature-difference values listed are quite optimistic and the above conclusion is likely to apply for the whole range of heat loads. In any event, the results indicate that the required size of the finned heat exchanger is large relative to the available space above the rotating plug, possibly to the extent that movement of sensor-handling containers in this area could be impeded.

To summarize, it appears that several difficult problem areas exist in the system studied. Although other variations of this concept can be devised, the limitation on space is a handicap common to all designs. To provide a sensor test zone somewhat comparable in size to that offered by the primary-sodium-cooled system, restrictions would have to be placed on coolant passages, insulation thickness, and heat-exchanger size which conflict with the goal of extending environment temperatures to below 700°F. Some other disadvantages of the convection-cooled concept are complicated design, expensive construction and pretest verification, and radiation problems resulting from coolant penetrations through the reactor shielding. Furthermore, the design examined

does not offer the flexibility for changes in sensor-thimble sizes that appears possible with the sodium-cooled concept. In conclusion, although the convection-cooled concept may be useful in some special application where the importance of low environment temperatures is sufficient to downgrade other considerations, it does not appear promising as a convenient, flexible facility for general use.

VIII. EVALUATION: DETERMINATION OF THE MOST-FAVORABLE SYSTEM

The most favorable system employs the primary-sodium-cooled concept. This concept excels the gas-cooled and the NaK-convection-cooled concepts in fulfilling the major criteria as covered in other sections of this report and summarized in the following subsections.

A. Space Limitations on Top of the Shield Plug or on the Operating Floor

The primary-sodium-cooled concept requires no external loops or heat-removal systems for cooling the thimble assembly. This greatly reduces the shielding requirements for the facility and hence leaves more available space for supporting facilities such as the handling container and elevating mechanism. The other two concepts require external loops and heat-removal systems.

B. Complexity of Thimble Assembly

Since space within the thimble assembly is not taken up by cooling passages in the primary-sodium-cooled concept, more space is available for test sensors. Handling of the thimble assembly is not complicated by the necessity of disconnecting cooling pipes. Another factor is that the design of disconnects that maintain coolant integrity is always difficult.

C. Sensor Test Temperatures

Although each of the three design concepts is capable of achieving the desired maximum sensor test temperature of 1400°F, higher test temperatures can be reached with the primary-sodium-cooled concept. The other two concepts are limited to 1400°F because of difficulties in routing the hot leg of the cooling system through the rotating shield plug. The lower limit of the

temperature range for the primary-sodium-cooled concept is about the same as that for the other two concepts (approx 900°F) in cases of greater heat load. In cases of lighter heat loads, the other concepts could achieve somewhat lower temperatures.

D. Facility Operation

Operation of the primary-sodium-cooled concept is less involved than operation of the other two systems because it requires no ancillary cooling system. The only significant external equipment required is a gearmotor operator to rotate the thimble assembly through a small angle. This rotation is required in the primary-sodium-cooled concept to operate the coolant-flow control valve.

E. Safety Considerations

In the primary-sodium-cooled concept, no cooling medium exits from the primary tank. This reduces possible personnel hazards due to radioactivity, and simplifies shielding. No external coolant medium enters the primary tank, thus reducing the possibility of contaminating the primary-tank sodium. Also, because no external cooling is required, there is no need for emergency-cooling provisions.

In all of the concepts, an inert-gas-filled cavity exists inside the sensor thimble at the core elevation. In case of a leak, this cavity could fill with sodium and thus cause an increase in reactivity. The reactivity increase that would result from flooding of the 1.402-in.-ID tube over the whole core height was determined. The presence of all volume-reducing items such as the sensors or special capsules was not considered, which is a conservative approach. In this case, the predicted reactivity increase would not cause a reactor scram.

F. Cost Considerations

Because no external cooling loops are required, the need for costly heat-removal equipment is eliminated. This also leaves more space for thimble-handling equipment, which greatly simplifies and thus reduces the cost of such equipment.

G. Degree of Achievement of Experimenters' Preliminary Criteria with the Primary-sodium-cooled Concept

The main goal in preparing and evaluating several INCOT design concepts was to select a concept that could accommodate the greatest number and the most types of experiments. The experimenters' preliminary criteria listed in Section II were used as one of the guidelines in this effort. Summarized below are these criteria and the degree to which the primary-sodium-cooled concept fulfills them.

1. Minimum Sensor Temperature

The minimum desired sensor temperature is 750°F. Using argon gas as an environment, a minimum temperature of approximately 900°F can be achieved. However, if helium gas is used as an environment, sensor temperatures approaching 800°F may be possible.

2. Maximum Sensor Temperature

The maximum desired sensor temperature is 1400°F. There is no problem in achieving 1400°F; in fact, higher temperatures are quite possible.

3. Maximum Environment Temperature

The maximum desired environment temperature is 1200°F. With sensor test temperatures approaching 1400°F, a 1200°F environment temperature should be possible.

4. Sensor Leads

The sensor and its leads should be at the same temperature, at least in the high-flux zone. The sensor and its leads can be maintained at approximately the same test temperature only if the sensor's position in the thimble is near the top of the reactor core.

5. Fluid Environment

Fluid environment should be either argon or helium gas, or the sensor can be encapsulated in sodium. These criteria can be achieved without difficulty.

6. Sensor Calibration

Sensor calibration within the sensor thimbles is desired. The capability of the experimenter to insert his own calibration sensor is provided. This sensor can be moved out of the high-flux region at appropriate times.

7. Thermal Shock of Sensors

Our experimenters have expressed the desire to thermally shock sensors at a rate of 100°F per sec. Preliminary evaluation indicates that it would be difficult to achieve this shock rate in EBR-II.

8. Sensor-temperature Control

Means should be provided, if practical, to vary the test temperature during a test. A reasonable temperature range can be obtained during a test by operating the sensor-coolant flow-control valve by a remotely controlled valve operator.

9. Sensor Position During Test

It is desired to move a sensor or group of sensors 5 ft during reactor operations. The maximum movement that can be attained in the EBR-II reactor is approximately 40 in. This should be enough movement to accommodate most types of experiments.

10. Sensors to be Tested

The sensors listed under the heading Sensors to be Tested (II.H) can be accommodated.

IX. LOCATION OF FACILITY

To install the INCOT in the reactor, it will be necessary to remove a control rod and its drive assembly from one of the 12 control-rod positions in the rotating shield plug of the reactor. Most of the operating equipment needed for use in the INCOT system will be positioned and operated in the space vacated by this control-rod drive. Equipment such as the vertically movable thimble assembly, which will extend downward from the elevation of the operating floor, through the small rotating plug and reactor-vessel cover, and into the control-rod location in the reactor core, must be designed to fit within the confines of the control-rod area selected from those positions available on the rotating plug. Other equipment such as the handling containers and coffin will also be located within this arc and extend radially outward from it.

Therefore, the physical location of a specific control-rod-and-drive assembly chosen for replacement by the INCOT system becomes an important adjunct to the criteria used in determining the basic design of the INCOT system. Space limitations determine the complexity and size of the equipment necessary for inserting and removing individual experiments from the reactor without removing the entire facility each time. This important objective requires a reasonably accessible control-rod location on top of the small rotating plug.

Some of the more-important functional requirements involved in the selection of a specific control-rod location are:

(1) maintenance of operating control rods on both sides of the INCOT installation;

(2) the space relationship between existing reactor fuel-handling equipment and structures on the rotating plugs, with specific reference to the positioning and locating of instrument-handling containers, coffins, and shielding devices for the INCOT system;

(3) accessibility to off-plug communication leads and service lines for INCOT equipment and instrument-readout equipment;

(4) maintenance of a reasonably uniform control-rod spacing within the reactor core; and

(5) the continued use of the No. 6 and No. 8 control-rod locations by the instrumented-subassembly system and the oscillator-rod assembly, respectively.

An evaluation of the available control-rod-drive positions indicate that the No. 2 control-rod location meets the above requirements best (after eliminating locations No. 6 and No. 8 for the reasons stated above).

The No. 2 control-rod location has been given the highest preference for the installation of the INCOT facility because, on this side of the small rotating plug, there is less congestion between the centerline of the control-rod opening and the outer edge of the small rotating plug. The available space for the INCOT in this position is shown in Fig. 16. The accessibility to the No. 2 location for the handling containers and instrument-sensor read-out equipment, as well as the need for operator and maintenance inspection, makes this location the most reasonable selection for installation of the INCOT facility.

X. SUPPORTING FACILITIES

Although the principal part of INCOT is the thimble assembly, which contains the instrument sensors, supporting facilities are required for compatibility with certain reactor operations and handling of the irradiated sensors. A necessary portion of reactor operation is fuel handling, the mode of which cannot be altered, and because of this an elevating system for INCOT is required. During an experiment or at its conclusion, the sensors must be removed for evaluation. Because of their residence in the core, their radiation level is such that they must be handled in a coffin. It is also desirable to be able to calibrate sensors, to have cabling to remove data readout, and to have read-out equipment for the sensors.

A. Elevating System

The INCOT utilizes a 35-ft-long thimble assembly containing test sensors and attached instrument leads. This thimble assembly extends downward from the operating floor above the primary tank, through the reactor-vessel cover, and into a vacated control-rod position in the core. The operating life of the installed thimble assembly continues over a series of reactor operating cycles during which reactor refueling is required. Hence, the thimble assembly must be raised out of its in-core position approximately 80 in. before moving the rotating shield plugs to begin normal refueling operations.

Fig. 16. Plan View of Small Rotating Plug, Showing Available Space for INCOT

The elevating system to raise the thimble assembly (see Fig. 17) must not interfere with the existing control-rod equipment and structural devices on the small rotating plug.

The important parts of the INCOT elevating system are: guidance-and-support assembly; elevator assembly; drive system; and blanket-gas sealing arrangement. The guidance-and-support assembly provides the precise alignment necessary to keep the elevator assembly, which supports the thimble assembly, located over the centerline of the control-rod opening in the rotating shield plug for the entire 80 in. of elevator travel (see Fig. 18). The elevator assembly is the commuting apparatus that provides the means of attachment and movable support for the thimble assembly during its vertical movement in and out of the core. Elevator guidance is supplied by a guide track that is a 108-in.-long V-shaped rail, vertically attached to the existing control-rod center support column. The guide track also transfers to the center support column those reaction forces developed in the elevator assembly during the raising and lowering of the thimble assembly.

The thimble assembly is connected to the elevator assembly through the sensor-lead terminal box attached to the top flange of the thimble. The elevator assembly, in turn, is attached for support to a linear-bearing housing, which travels over the guide track. The bearing housing contains a pair of ball-nut assemblies that travel along two lead screws. The lead screws, one on each side of the guide track, are located in the open space between the center column and the sensor-lead terminal box. The location of the lead screws in this space, behind the thimble centerline, eliminates the need for a special outside frame to support the lead screws and elevator assembly. By using this location, only the elevator assembly need be detached from the linear-bearing housing during preparation for the removal of the thimble assembly or for positioning the sensor-handling equipment over this location.

The elevator assembly is a detachable unit and contains the following subcomponents: elevator arm; spherical guide-bearing support and connecting-rod assembly; mechanical-load-sensing apparatus; and force transducer.

The elevator arm is the main structural member in the elevator assembly. It is attached through its back surface to the linear-bearing housing previously described. (The linear-bearing housing is itself supported by the guide track and the ball-nut and lead-screw assemblies.)

Fig. 17. Vertical View of Installed INCOT Elevating System

Fig. 18. INCOT Elevator and Guidance-support Assemblies

The spherical guide bearing, located in the center of the elevator arm, contributes the radial support and guidance for the connecting-rod assembly. The connecting-rod assembly, which passes vertically through the center of the spherical bearing and elevator arm, provides the mechanical linkage between the elevator arm and the thimble assembly.

The mechanical-load-sensing apparatus, which is part of the safety provision for thimble-assembly overloads, is attached to the upper end of the connecting rod and is supported on its lower end by the spherical bearing. Micro-limit switches are set to monitor the operating positions of elevating-system components as part of the required safety-interlock system.

A load transducer electrically monitors the lifting forces experienced during vertical movement of the thimble assembly. Load-limit settings can be set to give an alarm in the same range as the limits used for the mechanical spring settings on the connecting rod.

A drive system is used in the elevating system to operate the precision lead screws that provide the lift to the elevating system. This drive is an electromechanical system similar to that used on the instrumented subassembly. The drive components have been arranged to form a compact mechanism, which is attached to the top of the extension of the center support column. The main parts of the drive system are a drive motor, a torque-limiting clutch and gearbox for driving the lead screws, two helical precision lead screws for driving the two ball-nut assemblies, and related interlocking safety devices.

The drive motor is a reversing, gear type with an automatic built-in braking system. The output shaft of the motor drives a mechanical torque limiter and backstopping clutch that automatically locks the drive train when the drive motor is stopped. The output shaft of the clutch drives a right-angle gear unit, which, in turn, drives a gear set. A rate of travel of about 16 in./min will be employed for raising or lowering the elevator assembly. The drive motor and elevator assembly can be stopped and restarted at any intermediate elevation between the full-up and the full-down position. Positional interlocks are incorporated into the drive system for safety considerations. A sliding yoke assembly operates as part of the drive system to engage the connecting-rod linkage on the elevator assembly when it reaches the up limit of its travel. This arrangement locks the thimble assembly at its highest point of travel and prevents the inadvertent lowering of the thimble during fuel handling.

A gastight seal is required between the thimble assembly and the top of the rotating plug to prevent leakage of blanket cover gas. This seal must also be gastight while raising and lowering the thimble assembly. This sealing requirement is accomplished through a bellows assembly that is attached to the top of the existing guide-bearing tube in the rotating plug.

B. Handling Containers

The INCOT facility requires a set of handling containers to enable operating personnel to: (1) insert radioactive sensors into the thimble assembly (reinsertion of previously irradiated sensors); (2) reposition or move sensors that are already inside the thimble assembly; (3) remove sensors from the thimble assembly for recalibration, inspection, or disposal; and (4) remove the radioactive thimble assembly from the reactor for subsequent inspection or disposal.

The type of sensor handling involved in the insertion, repositioning, and/or removal operations outlined above will necessitate handling equipment of a special design. The lower 3 ft of the test-sensor leads as well as the sensors themselves operate in or close to the reactor core and hence are subject to the most deleterious effects of reactor operation. Consequently, it is advantageous, for instrument-integrity reasons, to prevent bending or flexing of the lower 3 ft of sensor leads during insertion and removal of the irradiated instrument sensors. Some limited flexing of the sensor leads above the 3-ft elevation is assumed to be tolerated in these handling operations without resulting in degradation or compromise of the signal-response quality of the sensors and leads.

The sensor leads become radioactive after operating a short time in the reactor core and have a radioactivity of the order of 170 R/hr on removal. This level of radioactivity requires biological shielding around the handling containers used to store and transfer sensors during and after removal from the thimble assembly. Additional separate shielding is required around the control-rod opening and the cover-gas bellows seal in the rotating plug. This shielding must be a semistationary type that can be removed for service work around the rotating plug and thimble assembly.

Special handling containers and related ancillary apparatus are needed also to change the position of the sensors within the sensor thimble and to provide temporary out-of-thimble storage for the sensors and leads during sensor recalibration. The capability for changing the sensor position provides the means for varying the level of in-core exposure to which the sensors are exposed.

A group of sensors can be moved to a new common position in or out of the active flux zone of the reactor core by raising or lowering the entire thimble assembly with the elevator assembly previously described.

A single sensor can be moved to a new position within the sensor thimble by moving the top end of the sensor lead to a new position above the sensor-lead terminal box. This type of sensor movement, of the order of 4 to 5 ft, does not require the complete removal of the sensors or leads from the thimble assembly. Flexible electrical connections as well as a sliding gas-sealing arrangement are provided as part of the ancillary equipment on top of the sensor-lead terminal box.

1. Container Requirements

The principal design considerations governing the development of the handling containers and supporting equipment for the INCOT facility are:

(a) The configuration and dimensions of the handling equipment are limited to that space occupied by the existing control-rod drive and its scram-cylinder assembly.

(b) The location for the installation and operation of the INCOT determines the type and size of the handling containers that will not interfere with existing reactor fuel-handling equipment located on the small rotating plug (e.g., the reactor-cover-lifting structure).

(c) Provision is to be made for handling a flexible, 36-ft-long sensor lead without flexing the lead to more than a 4-ft-dia curvature but keeping the bottom 3 ft of the lead straight.

(d) Provision is to be made for handling a rigid or semirigid 36-ft-long sensor lead as well as large-diameter tubes (up to 2.5 in. OD) that cannot be readily bent or flexed during removal from or insertion into the thimble assembly.

(e) Provision is to be made for a biologically shielded, 3-ft-long coffin section, as part of the handling container, to house the gamma-active instrument sensor and attached leads while they are out of the reactor.

2. Handling-container Design

Two design arrangements for sensor-handling containers have been considered: (1) a straight handling container and (2) a reel type of storage container. The straight handling container, shown positioned over the No. 2 control-rod location in Fig. 19, is a two-piece system. It consists of a 3-ft-long, biologically shielded lower coffin piece that is flanged at the top for attachment to an unshielded extension piece that is 33 ft long. Each piece contains a 2.65-in.-ID opening through its center. The cross section of the shielded lower piece has a configuration that will fit within the space vacated by the control-rod drive (see Fig. 16).

The straight handling container incorporates internal electrical connections and locating guides to permit continuous communication with the sensor while it is being withdrawn from the thimble assembly into the handling container. The removal of a sensor from the thimble assembly is performed by connecting the upper terminal end of the sensor lead to a lifting connector within the central part of the handling container. The sensor and attached lead are drawn up into the handling container, but the most radioactive part of the lead and the sensor itself are retained within the shielded lower section. The radioactive sensor and lead can then be transported in the handling container by means of the overhead crane to an off-plug inspection or calibration station or to a point of final disposition if no further testing is required.

The internal configuration can be adapted to handle larger diameters and less-flexible items such as the 2.5-in.-OD instrument thimble assembly itself. The shielded straight handling container must be used when removing the radioactive thimble assembly from the reactor because the part of the thimble which was in the reactor is as radioactive as the sensors.

The alternative design concept, the reel type of storage container, is shown in Fig. 20. This container would be attached to the top of the shielded coffin section in the same manner as the straight handling container. The overall height of this container is much less than that of the straight handling container (8 ft vs 34 ft). This reduced height allows installation

Fig. 19. Straight Type of INCOT Handling Container

Fig. 20. Reel Type of INCOT Handling Container

and operation of the handling container on the rotating plug, and removal from the plug, without the necessity of disassembling and removing the reactor-cover-lifting drive motor from its supporting structure on the small rotating plug.

With the reel design concept, the instrument sensors and leads may be moved in and out of the core without structurally interfering with any of the fuel-handling and control-drive mechanisms on the rotating plug. This concept is based on the use of a 4-ft-dia takeup reel as the minimum bending curvature to which the sensor leads would be coiled. Based on the preliminary tests performed with straight, 1/8-in.-OD stainless steel-sheathed solid thermocouples wrapped around a 4-ft-dia drive, the thermocouples assume (in a free condition) a 10-ft-dia curvature. Flexure of the sensor leads over this diameter does not appear to compromise the electrical qualities of the standard type of sensor leads tested. No flexure or bending is imposed on the lower 3 ft of the sensor leads or sensors because the heavily shielded straight portion of the handling container is below the takeup reel.

Additional design variations of the reel design concept, such as a motorized drive and/or remotely operated apparatus, can be but are not included. This concept also requires the use of the overhead crane for transfer from the rotating plug to inspection or calibration stations.

C. Calibration of Instrument Sensors

Instrument sensors to be tested in the INCOT may require a calibration check at some stage in the testing program. The term "calibration" is used herein to describe a comparison of two items, one of which is a standard or system of known accuracy, to detect, identify, and reduce by adjustment any variation in the accuracy of the item being tested or calibrated.

An initial calibration of an instrument sensor may be performed before the sensor is inserted into the thimble assembly. Some sensor-testing programs, however, may require recalibration of individual instruments and sensors at varying intervals during the tests so as to determine sensor quality or variations in accuracy of the sensor. Therefore, the conceptual design of the INCOT includes consideration of the facilities necessary for out-of-core calibration of instrument sensors.

Other functions associated with the calibration of instruments and sensors are being considered as well. These include tests other than calibration that are intended to detect malfunctions and thus assure reliable operation between recalibrations or to prevent undue deterioration resulting from operational testing or recalibration. The tests would probably include visual checks for damage, wear, and surface quality as well as secondary functional checks for instrument characteristics such as distortion, ripple, regulation, and sensitivity.

Sensor recalibration and some secondary instrument checks must be performed at an out-of-core location in which the operating areas are biologically shielded to protect operating personnel from the sensor reactivity. The test sensor to be recalibrated will be withdrawn from the in-core thimble assembly into one of the appropriate handling containers described previously. The handling container and sensor then will be moved from the rotating plug to a calibrating location in the reactor building. There, the sensors will be inserted into an appropriate calibrating chamber or device.

Because a wide variety of instrument sensors as well as their attached communicating leads, cables, and related material components are potential candidates for testing in the INCOT, the calibration requirements are broad. The calibration equipment required includes electrical, thermal, and nuclear (gamma) source types. This equipment may be of a special nature, depending on the sizes and details of the sensors to be calibrated. Because of the wide variety of test instruments of a rather sophisticated nature, special calibration procedures and/or equipment undoubtedly will have to be developed and supplied by the individual experimenter or sensor designer. For this reason, it is not intended to supply an instrument-calibration service as part of the INCOT. However, it is intended to provide a space for the experimenters' calibrating equipment within the reactor building and to equip it with service connections.

The most logical location for a recalibration station is the existing 35-ft-deep x 8-ft-square storage pit within the reactor building (see Fig. 21). Visual inspection as well as remote manipulation of the sensor and/or communicating leads during calibration seems desirable. Provisions exist for locating a shielded viewing window in the lower part of the shielded walls of the pit to allow visual inspection of the sensor after it has been removed from the handling container. The existing overhead crane in the building would be used to transport the handling container and sensor from

Fig. 21. Plan View of Reactor Building, Showing Storage Pit Proposed as Location for Sensor-calibration Station

the rotating plug to a calibrating and viewing position in the storage pit. Refitting of this storage pit with the necessary viewing window, service connections, and shielding is included in the design concept. Electromechanical equipment required for sensor inspection and/or calibration, however, would require a development and fabrication effort which is very difficult to define at this time and is not considered part of this task.

D. Evaluation of Supporting Equipment Systems

1. Elevating System

In evaluating the merits of various equipment systems proposed for use in the INCOT supporting facilities, let us consider the INCOT elevating system first. This system, as described in Section X.A, uses the same basic approach as that used in the instrumented-subassembly system for EBR-II. The INCOT elevating system differs somewhat from the instrumented-subassembly system in the length of elevator travel as well as in the type and location of required ancillary apparatus.

A number of component parts of the two systems, however, will be of identical design, including the helical lead screws, guide track, torque clutches, and other drive-system components. This arrangement provides advantages such as a minimizing of spare-parts inventories as well as the use of similar maintenance and operating procedures for the two systems. A cost advantage derived by using similar systems is the reduction in the design and drafting effort required to develop the INCOT elevating-system components. Another advantage is that the similar components have already been tested for operation and fit into the limited control-rod space on the small rotating plug. Such cost and time advantages are considered in selecting the overall design.

2. Handling Containers

The detailed requirements for the INCOT handling container are not fully defined at this time. This is because the status of the sensor-test program is still preliminary, and thus the exact type, size, and numbers of sensors to be included in the tests have not been defined. There is, however, a known requirement for the straight handling container described

in Section X.B.2. This type of container will handle the removal of a radioactive thimble-assembly support tube for which the overall dimensions are known. It will also handle the removal of the semirigid multiple-sensor assembly from the thimble assembly. One disadvantage of the straight container is that the reactor cover-lifting support frame must be partially disassembled and removed before the container can be installed on the rotating plug. However, the straight container may lend itself to the adaption of an angular junction at its bottom connection to the shielded coffin section. This could provide clearance for the container to pass under the cover-lifting support frame, thus eliminating the need to disassemble and remove that structure when installing the container. An advantage of the straight container is that the design of the mechanism is simpler than that of the other types considered.

The reel type of handling container has certain inherent advantages, one of which is that the container can be installed on the rotating plug without removing the cover-lifting motor, as is required when using the straight container. The reel container, however, uses a more-sophisticated guidance arrangement for sensor leads. This arrangement wraps the lead around the storage reel and then unwinds and guides the sensor back into its guide tube in the thimble assembly.

Evaluation of all the factors stated above leads to the belief that the straight handling container should be designed and fabricated as the initial handling container and that the reel type should be designed and fabricated later as may be required by the experimental test program.

3. Calibration of Instrument Sensors

The requirements for test-sensor calibration are not known. With such a wide variety in type and size of instrument sensors that can be considered candidates for testing in the INCOT, it has not been possible, to date, to formulate comprehensive criteria for sensor-calibration requirements. Such criteria will be developed in cooperative efforts with the individual experimenters. Initially, only a calibration location will be supplied for the INCOT facility. A separate area in the reactor building will be prepared so that the experimenters' calibrating apparatus can be set up to calibrate the test instruments. The specialized sophisticated calibration devices and equipment will be the responsibility of, and furnished by, the experimenter.

The provisions which will be made within the reactor building to locate such sophisticated and specialized calibrating equipment as the experimenter may deem necessary will include the modification and refitting of the existing storage pit in the reactor building.

Additional modification and refitting of existing reactor-building facilities may be justified by future specific calibration requirements.

E. Readout Extension Cabling, Signal-conditioning Equipment, and Penetrations

Readout extension cabling is required to provide electrical-signal connections between the sensor-lead terminal box at the top of the INCOT thimble assembly and the signal-conditioning equipment located from 30 to 50 ft away on the reactor operating floor. This cabling will be supplied by the experimenter. It will consist of one or more cables, each made up of extension leads of appropriate conductor materials such as thermocouple wire or stainless steel wire if necessary. The cable ends at the INCOT must be supplied with multi-pin connectors so that the cables can be disconnected easily to permit plug rotation during fuel handling.

The signal-conditioning equipment makes the INCOT signals suitable for further transmission through copper wires to data-collecting points outside the reactor containment shell. The equipment consists of items such as millivoltage-to-current transmitters, thermocouple reference junctions, signal amplifiers, etc. Because of limitations of space and monitoring accessibility during reactor operation, very little data-collection equipment is permitted inside the reactor building.

The need for penetrations of the reactor containment shell will depend on the type of sensors and the requirements of the future experimenters.

F. Data Logging

A new data-acquisition system is being obtained for EBR-II use. It is a Sigma 5 computer and data-acquisition system made by Scientific Data System and is capable of handling 600 input signals in digital or analog form. The output information can be recorded by a printer, a card punch, or on magnetic tape. Sufficient channels in this system probably will be available for INCOT use.

The existing data-acquisition system is a 100-channel MIDAS system. The current demand on this system far exceeds the number of channels available; therefore, the system is unlikely to be available for much use with the INCOT.

Any direct analog recording equipment such as strip-chart recorders probably must be supplied by the experimenter because the amount of such equipment now available at ANL is limited.

XI. SAFETY CONSIDERATIONS

The basic objective of the INCOT is to provide an integrated in-core instrument-testing facility that can be operated in EBR-II in a compatible manner without compromising the safety and/or the operating characteristics of the present reactor system. The safety comments herein apply to the conceptual designs developed to date and do not represent an attempt to present an in-depth safety analysis of the INCOT system.

The INCOT can be divided into two basic areas of safety interest:

- (1) portions of the facility that are outside the reactor primary tank and
- (2) the in-core thimble assembly. The safety aspects of these two areas differ with respect to operating risks to the reactor.

A. Portions Outside the Reactor Primary Tank

The portions of the facility that are outside the primary tank consist of the elevating system, handling containers, and other ancillary equipment.

The elevating system involves a number of important safety considerations relating to safe operation of the reactor because it controls the in-core position of the thimble assembly. The elevator drive is an electrically operated mechanical arrangement of gears, clutches, torque limiters, helical drive screws, and ball-nut travelers that provides the controlled vertical movement for lifting the thimble assembly during reactor fuel handling. The structural support provided by the elevating system to the thimble assembly is a most-important safety consideration from a fuel-handling standpoint. Hence, a proof test of the elevating system will be performed to prove the structural and operational integrity of the system prior to its installation and operation in the reactor.

Appropriate mechanical and electrical interlocks are incorporated in the design of the elevating system for controlling the position of the thimble assembly in the reactor. The drive system cannot be operated to raise the thimble assembly unless the thimble operating-position interlock, which mechanically holds the thimble assembly, has been retracted. The elevator drive motor cannot operate unless the operating-position interlock is retracted.

The fuel-handling operation, including the rotation of the plugs, cannot begin unless the elevator assembly is in its fully up position and locked at this elevation by the sliding yoke assembly on the top of the center support column.

The drive system cannot be operated to lower the elevator and thimble assembly unless the rotating shield plugs are in their "reactor operating" position, at which point the proper electrical interlock circuits are made. These interlock circuits control the power supply to the drive motor.

During normal fuel-handling operations, appropriate mechanical and electrical interlocks will be incorporated into the reactor operating controls to prevent overload on the components of the thimble assembly and the reactor vessel, and to assure that all interferences have been eliminated before continuing the operating sequence.

Whenever excessive forces are experienced by the in-core thimble assembly, these will be reflected by the vertical motion of the spring package in the mechanical-load-sensing apparatus and sensed by an electrical force transducer. Electrical limits on these two systems then will be actuated. This actuation will either prevent operation of or stop the reactor-vessel-cover drive and the control-rod lifting platform used in reactor fuel-handling operations, or will stop the elevator drive motor, depending on the mode of operation in effect at that time.

In general, most of the safety devices required and discussed above are controls and interlocking circuits of an electromechanical or electrical nature. Such controls and interlocking circuits will be designed to be consistent with existing safety criteria of other EBR-II mechanisms being used in the reactor system.

The safety considerations for other out-of-core INCOT equipment such as handling containers and instrument-calibrating apparatus are concerned primarily with the biological-shielding aspects. Adequate biological shielding will be provided around all equipment and access openings used when

handling sensors and other items. Partial or "shadow" shielding will be required around the front of the INCOT opening in the small rotating plug as well as around the blanket-gas bellows-seal assembly. Circumferential shielding is provided on those handling containers used to remove and handle the radioactive thimble assembly and/or the irradiated test instruments.

B. The In-core Thimble Assembly

The INCOT thimble assembly is the interchangeable part of the INCOT and contains the test sensors and leads. An important safety consideration involved in the operation of the thimble assembly in the reactor vessel is the proper dimensional design and structural integrity of the thimble support tube. This tube is the main structural member in the thimble assembly. It passes through the opening in the reactor-vessel cover and into the test-facility guide thimble located in the reactor core. The outside dimensions of the thimble support tube must permit an unrestricted passage through these openings with proper clearances to prevent interference in the core, reactor-vessel cover, or primary-tank nozzle. The materials and assembly techniques for the tube and the thimble assembly will conform with proved design criteria for nuclear, thermal, and chemical environments of the EBR-II reactor.

In the proposed INCOT, there will be no nuclear fuel materials inside the thimble assembly. This eliminates a number of potential operating risks involved in handling nuclear materials in the system (e.g., fission-product release, fuel melting).

Since none of the reactor coolant used by INCOT will leave the primary tank, no additional external shielding for the radioactive coolant will be required. Since no INCOT coolant will be supplied from outside the primary tank, the probability of introducing problems related to chemical compatibility and to pressure and volume in the primary tank will be avoided. Other safety-related features are: (1) No additional auxiliary or emergency power sources are required as secondary backup to the reactor system. (2) A failure of a test sensor within the in-core thimble assembly would not be cause for shutdown of the reactor for safety reasons. (3) The thimble assembly utilizes only a small portion of reactor primary sodium, which is a reliable, existing source of supply.

The containment requirements will be included in the design and fabrication of the thimble assembly as well as the test sensors and leads. The test sensors will be contained within the lower end of the sensor thimbles, thereby providing a stainless steel barrier between the reactor coolant and sensor (as described in Section VII.B). The communicating sensor leads will pass upward through the central part of the thimble assembly and will be sealed at the top of the support tube, thereby creating a secondary barrier for the thimble assembly. The end terminations of the sensor leads will be sealed in the sensor-lead terminal box. Appropriate safety devices such as sodium-leak detectors will be included in the thimble assembly to detect the presence of a leak in the assembly. Provisions for sealing the thimble assembly, the sensor-lead terminal box, and the sensor-lead terminations against the primary-tank cover gas are included in the design of these items. Sealing of the terminal box will permit pressurizing it with an inert gas to a pressure level slightly above the pressure of the primary-tank blanket gas. This will provide containment and aid in the detection of any primary sodium coolant which might travel up the thimble assembly in the highly unlikely occurrence of a leak in the thimble assembly.

Other safety aspects that concern the nuclear operation of the reactor and the INCOT as an integrated system are being considered. One of these is the operation of the reactor system with fewer control rods. Although the reactor core has 12 control-rod positions, it has operated with only 10 control rods when two of these positions were being used for other operating-test systems. By the time that the INCOT is installed in one of the remaining control-rod positions, higher-worth control rods are expected to be available for use in operating the reactor with a lower number of control rods. These higher-worth control rods are being designed under a different task.

The fabrication and assembly of the components of the assembly and supporting facilities will be performed according to the total quality-assurance program developed for the entire INCOT.

XII. CONCLUSION

This study concludes that it is feasible and desirable to design and fabricate an in-core instrument test facility (INCOT) for use in the EBR-II reactor to test various sensors. The most favorable of several schemes evaluated seems to be the primary-sodium-cooled concept, which uses the

available gamma heating and controlled sodium cooling. This facility will provide the capability to obtain instrument-test data for the Liquid Metal Fast Breeder Reactor Program. Capabilities for irradiating materials at controlled elevated temperature levels will be included.

Barring unforeseen delays, the facility should be available for use in the third quarter of calendar year 1971.