ORGANIC MODERATED REACTOR EXPERIMENT
FIRST PROGRESS REPORT
OCTOBER, 1955 – JULY, 1956
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ORGANIC MODERATED REACTOR EXPERIMENT
FIRST PROGRESS REPORT
OCTOBER, 1955 – JULY, 1956

EDITED BY:
C. A. TRILLING

ATOMICS INTERNATIONAL
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PREFACE

This report comprises a comprehensive review of technical progress on the Organic Moderated Reactor Experiment (OMRE), which is to be constructed and operated at the National Reactor Testing Station at Arco, Idaho. This is the first report of the series, and covers the period from the initiation of the project to July 31, 1956. Also included as an appendix to the report is a detailed description of the OMRE facility.

This report is based upon studies conducted for the Atomic Energy Commission under Contract AT(04-3)-88.
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I. INTRODUCTION
OBJECTIVES AND SCOPE OF PROGRAM

A. REACTOR EXPERIMENT

1. Purpose of Program - The purpose of the Organic Moderated Reactor Experiment (OMRE) is to investigate the feasibility of using an organic medium as moderator, reflector, and coolant in a nuclear reactor. The fundamental objective of the OMRE program is to obtain the following experimental information:

a. Rate of radiation and thermal damage to the hydrocarbon in the reactor.

b. Effect of this damage upon the operation of the reactor.

c. Suitable methods for ensuring satisfactory reactor operation in the presence of damaged hydrocarbon.

It is emphasized that the OMRE facility is neither a pilot plant nor a prototype of an organic power reactor, but is merely a minimum cost experimental facility designed to investigate the feasibility of applying the organic concept to power reactors. Because it is an experimental facility, sufficient flexibility has been incorporated into the design to permit operation under a wide range of conditions in order to establish the most favorable operating parameters for organic-moderated and -cooled reactors. No attempt will be made to develop components for an organic heat-transfer system, and the cooling system will be merely a service system which will allow operation of the reactor under the desired conditions. Wherever possible, commercially available equipment will be used, even if this equipment is not perfectly suited for the application. Compromises will be made and some disadvantages will be tolerated, either to avoid excess development effort or else reduce it to a practical minimum.

The primary purpose of the facility is to provide operational information on the behavior of a hydrocarbon under conditions of exposure to high nuclear radiation and thermal flux. Although the design has been predicated on the investigation of the behavior of diphenyl, sufficient flexibility has been built into the system to permit testing of other polyphenyls or mixtures of polyphenyls. The final selection of the hydrocarbon to be actually used in the OMRE is to be made on the basis of the best information available shortly before completion of construction of the facility. It is anticipated that the objectives of the program can be achieved in one year's operation of the facility.
2. Scope of Program - As stated above, the OMRE facility will be operated primarily for the purpose of obtaining data on the thermal and chemical behavior of hydrocarbons in nuclear reactors. The measurements of nuclear characteristics will be limited to data which are required to operate and control the reactor, such as critical mass, mass coefficient of reactivity, temperature coefficient of reactivity, and control-rod calibrations. The calculated operating data for the core of the reactor, based on information presently available for diphenyl, are shown in Table I.

Operation of the reactor will be directed at varying the following parameters:
   a. Bulk temperature of the coolant
   b. Coolant flow rate
   c. Maximum temperature of the surface of the fuel elements
   d. Power level of the reactor
   e. Time of exposure to radiation and heat
to determine their effect on:
   a. The heat-transfer conditions in the reactor
   b. The physical and chemical properties of the damaged coolant
   c. The concentration of degradation products in the coolant
   d. The relative volatility of the degradation products in the coolant
   e. The maximum allowable steady-state concentration of the degradation products in the coolant
   f. The minimum volatility of the degradation products allowable in the coolant under steady state operation
   g. The required operating conditions of the purification system (temperature, pressure, degree of separation)

B. SUPPORTING RESEARCH PROGRAM

   All the data obtained directly from the operation of the reactor would be of but limited value without a reasonable supporting effort to provide the additional information required to analyze and interpret the results. The supporting engineering, research, and development program provides the means of realizing the full benefits of the information gathered from the operation of the reactor. It is an essential part of the OMRE program, complementing the results obtained from the operation of the reactor and allowing a better understanding of the phenomena of radiation damage and thermal damage to a hydrocarbon.
TABLE I
OMRE DATA

Basis:

Hydrocarbon ........ Diphenyl
Maximum coolant velocity .......... 15 ft/sec (7200 gpm)
Maximum fuel element surface temperature .......... 800° F
Heat transfer area .......... 500 ft$^2$
U-235 loading ........ 20.6 kg

Hot channel factors:

Applied to bulk coolant temperature rise .......... 1.38
Applied to film drop .......... 1.32
Applied to heat flux .......... 1.23

Fraction of total power generated in fuel plates .......... 0.909

Position of control rods .......... All out (for purposes of calculating flux distribution)

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<td>Peak/Average Flux Ratio</td>
<td>3.15</td>
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<td>Extent of Radiation Damage</td>
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<td></td>
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<tr>
<td>% Tar</td>
<td>0</td>
<td>30</td>
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<tr>
<td>$\mu/\mu_0$ (viscosity ratio)</td>
<td>1.00</td>
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<td>1.00</td>
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<td>Maximum Specific Power, kw/kg</td>
<td>3,040</td>
<td>2,485</td>
<td>948</td>
<td>887</td>
</tr>
<tr>
<td>Average Thermal Neutron Flux in Fuel, n/cm$^2$-sec</td>
<td>$2.61 \times 10^{13}$</td>
<td>$2.13 \times 10^{13}$</td>
<td>$9.57 \times 10^{12}$</td>
<td>$8.95 \times 10^{12}$</td>
</tr>
<tr>
<td>Maximum Thermal Neutron Flux in Fuel, n/cm$^2$-sec</td>
<td>$8.22 \times 10^{13}$</td>
<td>$6.71 \times 10^{13}$</td>
<td>$2.65 \times 10^{13}$</td>
<td>$2.50 \times 10^{13}$</td>
</tr>
</tbody>
</table>
1. Fouling of Heat Transfer Surfaces and Coolant System

a. Purpose - Knowledge of fouling conditions and rates is of fundamental importance for the satisfactory operation of an organic-moderated and -cooled reactor. It is the purpose of this study to determine the effect on fouling of bulk hydrocarbon temperature, heat-transfer surface temperature, fluid velocity, and extent of radiation and thermal damage. Information will be sought on the tendencies of various components of the coolant system to become fouled or plugged. Means of minimizing fouling will be studied. An investigation will be conducted to provide an understanding of the nature of the fouling mechanism.

b. Scope - The extent of fouling will be determined by (1) visual methods, (2) measurements of temperature changes, and (3) actual measurements of amounts of material deposited. The rate will be studied as a function of the extent of hydrocarbon damage, fluid temperature and velocity, surface temperature, heat flux, and radiation flux. This will permit the establishment of many of the operating conditions of the reactor such as (1) maximum allowable extent of coolant damage, (2) maximum allowable surface temperature of fuel elements, (3) minimum allowable temperature of cold surfaces, and (4) minimum fluid velocity.

Direct measurement of fouling on fuel element surfaces or plugging of fuel element channels is not practical. Measurements of the rise in surface temperature and rise in temperature of the coolant from any particular element will provide the means of estimating the degree of plugging or fouling.

Fouling in components external to the reactor core is much easier to study. Here visual inspection methods are possible and will be used. The desired data can be obtained by means of a side stream passing through an apparatus permitting measurement of heat-transfer rate and visual inspection of heating surfaces.

Fouling behavior will control the operation of the purification system. Purification requirements will be established by determining the highest permissible concentration of degradation products in the coolant and by determining which of these cause the most severe fouling. Naturally, this requires that the main fouling agents be identified chemically and their chemical and physical properties be understood sufficiently well to allow for their removal from the system.
2. Purification of Damaged Hydrocarbon

   a. Purpose - The purpose of this study is to develop means for purifying the damaged hydrocarbon by distillation and to provide design data for future purification systems employing the distillation principle.

   b. Scope - Initial laboratory work will be conducted to determine whether batch distillation is technically satisfactory. If this proves to be the case, purification in connection with reactor operation will be performed in a batch still, which is flexible enough to test purification techniques under various conditions and rates. The initial tests will provide sufficient data for the design of an adequate continuous distillation system which may require rectification and/or stripping. Specifically, data provided by the initial tests are as follows: (1) extent to which certain constituents must be removed to permit continued operation of the reactor at the desired power level, (2) establishment of process temperatures, pressures, and boil-up rates, and (3) advantages and disadvantages of various types of equipment such as reboilers, heaters, condensers, vacuum systems, and process control instruments.

   After damaged hydrocarbon becomes available, laboratory work will be conducted to provide: (1) chemical identification of materials being separated, and (2) vapor-liquid equilibrium data for the damaged mixture in the temperature and pressure range of interest for a reactor purification system.

3. Physical Properties of Hydrocarbon

   a. Purpose - The purpose of this study is to determine the physical properties of the hydrocarbon moderator-coolant over the range of OMRE operating conditions for purposes of (1) control of the operation of the heat removal system, (2) control of the operation of the purification system, and (3) evaluation of the extent of hydrocarbon damage. The properties of interest are to be determined as a function of temperature and hydrocarbon composition.

   b. Scope - This program allows the correlation of various physical properties with extent of damage or hydrocarbon composition. The hydrocarbon composition will be determined by fractional distillation. Synthetic mixtures of diphenyl with pyrolysis or radiolysis products will be used initially for this investigation. These results will determine which of the physical properties can best be measured and used for control of the OMRE heat-transfer and purification systems.
Physical properties such as hydrocarbon density, viscosity, vapor pressure, and melting point will also be measured. Properties other than the above will be measured only if needed for proper control and effective operation of the OMRE.

The physical properties of the hydrocarbon through all phases of operation of the OMRE reactor will be determined as a part of this program.

4. Second Organic In-Pile Loop Experiment

a. Purpose - In order to investigate the operating characteristics of diphenyl and uranium fuel elements under the radiation, temperature, and heat transfer conditions expected in the Organic-Moderated Reactor Experiment (OMRE), a second in-pile loop will be constructed for installation and operation at the Materials Testing Reactor (MTR).

The design objectives for this loop are as follows:

1. Bulk hydrocarbon temperatures: 500° to 700° F
2. Fuel surface temperatures: 700° to 800° F
3. Maximum heat flux: 150,000 to 200,000 Btu/hr/ft²
4. Hydrocarbon flow rate: 5 to 15 ft/sec

b. Scope - This loop is designed for use in a reflector position of the MTR (such as A-13). The pump, flowmeter, and heat exchangers are located external to the reactor core tank in a portable console. This is possible since the data obtained from a previous loop experiment indicate that the induced activity in the coolant is quite small. The pump is a canned-rotor type which requires no shaft seal. The heat exchangers either heat or cool the organic fluid to the desired temperature. A turbine-type flowmeter is used to measure the flow rate. Sampling and feed lines connect to the external loop. The associated instrumentation is mounted in the instrument racks on top of the MTR shield.

The in-pile section of the loop consists of a hairpin loop having a heater in the return leg. Slightly enriched uranium, bonded to the stainless-steel fuel jacket with NaK, is used as the heat source. Thermocouples are installed in the coolant stream and along the fuel element surface and axis to measure the heat-transfer coefficients. The loop is traced and insulated.

The loop initially is cleaned, flushed, and filled with pure diphenyl. The coolant flow rate is adjusted to the maximum velocity (~15 ft/sec), then the bulk
temperature is raised in approximately 50° F increments starting at 500° F until a maximum fuel surface temperature of 800° F is reached. Heat-transfer coefficients are obtained for each new test condition. Before starting each new series of runs, the bulk coolant temperature is lowered to 500° F in order to check the starting coefficient. After the high boiler concentration of the diphenyl reaches 10, 20, and 30 per cent, the procedures are repeated in order to check for any fouling of the heat-transfer surface. High boiler concentrations are kept constant by feeding fresh diphenyl and bleeding off irradiated organic coolant during the course of the experiment.

At the completion of the tests, the loop is removed, sectioned, and examined. It is the objective of this test to obtain the following information:

1. Effects of irradiation and temperature on the degradation of the diphenyl coolant
2. Effects of temperature, flow rate, composition of the coolant, and fouling of the fuel-element surface on the heat-transfer coefficient of the fuel element.
3. Effects of irradiation on the residual radioactivity of the coolant
4. Effects of the degradation products on various sections of the loop

In order to obtain the above information, it is necessary to make the following measurements:

1. Diphenyl and degradation-product concentration as a function of time, exposure, and temperature
2. Surface or core temperature of the fuel element
3. Flow rate of coolant
4. Temperature of the coolant applicable to the measurement of the heat-transfer coefficient
5. Qualitative examination of the fuel elements for fouling, corrosion, and erosion
6. Fouling of other sections of the loop, such as heat exchangers, flow meters, pumps, pipes, elbows, restrictions, etc.
7. Residual radioactivity of the organic coolant as a function of exposure, time, and composition of coolant
8. Neutron- and heat-flux levels

9. Changes in pressure drop across a test section as a function of temperature, coolant damage, etc.

5. Hydrocarbon Exponential Experiment - In calculations on hydrocarbon-moderated reactors, one of the largest theoretical uncertainties is in the neutron age. In order to avoid complete dependence on these calculations, a limited number of exponential experiments will be performed on uranium-rod, hydrocarbon-moderated lattices for the purpose of determining the neutron age by a boron poisoning method. In addition, the neutron age and thermal neutron diffusion length in pure diphenyl and diphenyl-steel mixtures will also be determined. For these experiments, low-enrichment uranium will be used.

II. SITE AND FACILITIES

A. SITE (M. H. Slater)

The OMRE will be located at the National Reactor Testing Station, Arco, Idaho. This site is relatively isolated, has ample power (Utah Power and Light), and good ground water sources. It is served by the Union Pacific Railroad and is accessible to U.S. Highway 20. The OMRE site is three miles east of the Central Facilities Area, one quarter of a mile off of Jefferson Road, the access road for the SPERT location (Fig. A1). The OMRE uses power from the high line to SPERT and takes advantage of the SPERT access road.

The ground at the site is underlain with basalt sheet, the depth to the top of which varies from surface outcroppings to approximately 20 feet. The exact location of the reactor was established by means of probe-hole information from a preliminary survey.

Using local cost information for various earthwork classifications, an equation for optimum depth was set up, from which the elevation of the liquid surface in the reactor vessel was established. This firmed the main pump elevation and thus the floor datum. A spot was located on the probe hole map where the floor elevation was at grade and the bottom of the reactor assembly was at rock.
A study of U.S. Weather Bureau wind information for NRTS indicated that the wind blows predominately to and from the southwest (Fig. 1). The orientation of the operations structure was thus established, with the proposed working areas southeast of the reactor and the short dimension of the structure parallel to the most probable wind direction.

With the proposed building orientation and reactor location established, the engineering field crews at NRTS ran a comprehensive topographic and probe hole survey (Fig. 2). A possible well location was established, and it is estimated that water will be reached at depth of 600 feet.

B. BUILDINGS (M. H. Slater)

The OMRE floor plan (Fig. A2 and A3) consists of three distinct areas: the exterior reactor and piping area, the interior piping and process area, and the operations area. As much of the system is outside as can be justified by operations and maintenance requirements. The exterior area consists of the reactor, the removable sheet-metal housing over the reactor for protection of the control-rod drives, the pipe "culverts" and gallery, the main piping loop, and the airblast heat exchanger. The arrangement of these various items was dictated by the piping layout, and, as described above, by an attempt to keep a cross wind direction over the potentially hazardous pieces of equipment. The coolant piping is 16 inches in diameter and carries 7200 gpm of coolant at temperatures up to 750° F. The stress-relieving expansion loops and bellows thus controlled the location of the building with respect to the reactor and heat exchanger.

The building selected for this project is a prefabricated, steel-sheeted structure. The factors considered in this selection were the short design life expectancy, the high field labor costs, and the extreme weather conditions expected during the winter (design temperature of -20° F). The structure is insulated with a 2-inch blanket of fiberglass and protected from condensation with a sealed building-paper vapor barrier.

The piping and process area is located inside of the building and contains the main coolant pumps and valves and a distillation system for purification of the coolant. The lower sections of the walls in this room are finished off with sheet steel for easy decontamination and wash-down.
Fig. 1. Annual Wind Rose at 20-Foot Level
Fig. 2. Probe Hole Survey
The operations area is also within the building, but it is physically separated from the piping and process area by a 2-foot-thick concrete wall. The control room contains the console, electric switch gear, and office space for personnel. Also contained in this room are remote-control valve handles for standard operation of the piping system in the process room.

The laboratory contains a special fume hood into which are piped direct sampling lines from various points in the process-piping section. The change room contains counting equipment, personnel clothing lockers, and laundry storage. It serves as the only normal passage way from the possibly contaminated process area to the operations area. Showers are provided in the lavatory. The door between the control room and the laboratory will normally be locked, thus forcing personnel going between these rooms to go through the change room and the lavatory. The mechanical room contains the forced-air heating furnace and a fuel oil pressurizing pump. The generator room contains the emergency gasoline-powered electric generator. The storage room contains the coolant melt station, the nitrogen bottle manifold, and space for storing make-up diphenyl. A work bench for repairs of electronic and small equipment is located here. Entrance to the building for equipment or material delivery and pick-up is through two large truck-size sliding doors, one at the east end of the storage room and one in the south wall of the process room.

C. UTILITIES

1. Electrical Power (R. B. Hall)

   a. Substation - The 13.8-kv substation comprises one single-phase 13.8-kv, 240/120-volt, 250-kva transformer for induction heating and one 500-kva bank consisting of three 13.8-kv, 480-volt, 167-kva single-phase transformers connected delta-delta for power and lighting. The transformers are located on a concrete pad to simplify design and construction. The 13.8-kv line is terminated overhead at an H-frame type dead-end structure and brought down to the transformers through fusible disconnect switches. Transformer secondary connections are taken underground in conduit to the reactor building switchgear.

   The substation is enclosed by a fence to keep unauthorized persons at a safe distance.
b. Station Grounding System - Station grounding consists of a combined buried grounding conductor and driven ground-rod system. A bare copper conductor, AWG size "O," is buried just outside the reactor control-building foundation. Cadwelded to this loop at several places are driven ground rods 10 feet long. Grounding is improved by a tap to the water-well piping and the reactor core-tank steel.

At convenient locations, individual ground wires are taken from the building ground wires to equipment and building-column steel.

A bare copper AWG size "O" tap ties the 13.8-kv substation and the guard house to the reactor building loop. The transformers and the substation fence are all grounded to the loop which is buried just outside the substation fence. Additional ground rods are driven at the corners of the substation fence.

c. Switching - Deadfront, free-standing switchgear in the control room distributes power for motors, heating, and lighting. Motors are protected by combination starters. Since radiation levels will not permit operators to approach pumps and motors during reactor operation, motors are controlled by pushbutton switches at the starters. Lighting circuits are protected by breakers.

Power to the heating circuits is supplied by fusible disconnect switches. Individual heating circuits are protected by low-cost lighting panel breakers.

Electrical construction in the Piping and Process Area is performed in accordance with the requirements for a hazardous explosion area.

Building illumination fixtures are single lamp incandescent.

d. Emergency Power - Critical instrumentation, lighting, and control requires emergency power in the event of failure of the normal 120-volt supply. The emergency supply is powered by a gasoline-driven engine which automatically starts and picks up load under emergency conditions.

e. Security Lighting - Security lighting is designed to provide 0.2-foot-candle of illumination along the fence line enclosing the OMRE test site. The luminaries, constant-current transformer, and protective relays are those typical for a series street-lighting circuit. The contactor which supplies 480 volts to the constant-current transformer is controlled from the guard house.
2. Ventilation and Heating (M. H. Slater) - Because of the inflammable nature of the hydrocarbon, the potential dust-explosion hazard, and the health physics aspects of reactor facilities design, a comprehensive ventilation system is used in the OMRE (Fig. 3). A header duct arrangement connected to the stack is provided with laterals and risers to each main pump; all sumps and drip collection drums draw off possible dust particles. The motor which drives the blower for this system is mounted outside the duct. A separate forced-air ventilation system is supplied for the melt station. This system is designed to remove all dust during the filling operation. (In effect, the melt station proper is placed in a hood with a small controlled opening through which the melt tank is filled.)

Health physics requirements of ten air changes per hour in the process area are provided by gravity roof vents and louvers in the walls. These louvers are raised off of the floor to keep them from plugging with snow. During reactor operations, the roof vents are closed and the entire ten air changes are all handled through the forced-air duct system. In addition, six air changes per hour are supplied to the operations area by gravity roof vents and gable louvers. The laboratory fume hood is separately ventilated to give 100 cubic feet of air per square foot of opening.

The control room, laboratory, change room, and lavatory are heated to 70°F with a forced-air oil fired unit furnace. The storage room and generator room are heated to 50°F with the same furnace. Air from the control room is the only air recirculated through the heater.

In addition to the ventilation dust removal system, a fire wall isolation system is employed. The 2-foot biological shield is an effective fire wall. The wall between the storage and control rooms is also a concrete fire wall with an automatic fire door. All other wall materials are incombustible (steel studs with gypsum wall-board collaterals). The wall separating the laboratory and the generator room from the control room has a one-hour fire rating with equivalent door ratings.

3. Waste Disposal (Fig. 4) - The process piping is ventilated to the stack. Impurities in the coolant and corrosion products in the system are all expected to contribute to the possible contamination of the stack effluent. A 0.1 maximum permissible concentration (MPC) at various points downwind from the stack was
Fig. 3. Ventilation Diagram
Fig. 4. Waste Disposal Diagram
the criterion employed to establish the required stack height (10 meters above air intakes).

The reactor cavity is vented to provide for gas expansion during start-up. To ensure a minimum air flow through the cavity, the openings through which the coolant pipes leave the pipe gallery are sealed with expansion bellows. Even though a high concentration of radioactive argon will build up in the cavity, it will not be expelled to the atmosphere. Main pump-bearing coolant leakage is collected in a 55 gallon drum for weekly removal. The pipe support structures are designed to carry a hand-operated monorail hoist to facilitate this operation.

Waste material from the distillation process is carried to a buried waste storage tank adjacent to the building. Piping connections are such that when this tank is filled, additional buried tanks can be coupled into the system. These tanks can be removed to the NRTS burial ground at the conclusion of the experiment.

A chemical analysis of a sample of water taken from the CFA well is given in Table II. An effective thermal neutron flux of $10^{10}$ nv at the instrument cooling tubes will produce activities in this water which are well below the maximum permissible concentration (MPC) in water recommended by the National Committee on Radiation Protection. This cooling process water (40 gpm) is therefore directed to the surface and allowed to evaporate, seep into the ground, or pond. Wash-down water is directed to the same ponding area.

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>CHEMICAL ANALYSIS OF WELL WATER</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.9</td>
</tr>
<tr>
<td>Total Solids</td>
<td>240 ppm</td>
</tr>
<tr>
<td>Calcium</td>
<td>39 ppm</td>
</tr>
<tr>
<td>Magnesium</td>
<td>14.4 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>0.05 ppm</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.02 ppm</td>
</tr>
<tr>
<td>Silicate</td>
<td>32 ppm</td>
</tr>
<tr>
<td>Nitrate</td>
<td>Trace</td>
</tr>
</tbody>
</table>
TABLE II (Continued)

<table>
<thead>
<tr>
<th>Table entries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity</td>
</tr>
<tr>
<td>Carbonate</td>
</tr>
<tr>
<td>Bicarbonate</td>
</tr>
<tr>
<td>Chloride</td>
</tr>
<tr>
<td>Sulphate</td>
</tr>
<tr>
<td>Fluoride</td>
</tr>
<tr>
<td>Hardness (as CaCO₃)</td>
</tr>
<tr>
<td>Sodium</td>
</tr>
<tr>
<td>Potassium</td>
</tr>
<tr>
<td>Dissolved Solids</td>
</tr>
</tbody>
</table>

A 20,000-gallon water tank receives water from the deep well pump. This water is fed to the process system and the domestic water system (not potable) through a booster pump which supplies water at the rate of 100 gpm at 50 psi. This is sufficient for all requirements, including cooling of instrument tubes in the reactor cavity area. This pump is on emergency power. A gasoline fire pump located at the well provides water at 275 gpm to a fire plug located east of the reactor operations building.

III. REACTOR

A. GENERAL

The reactor comprises the reactor vessel, fuel elements, source assembly, and the control rods and drives, as well as the grid plates and thermal shield and the fuel storage rack. (For a detailed description of the reactor, refer to Section C of the Appendix.)

B. REACTOR VESSEL (M. Mueller)

Fabrication of the core tank began in July, 1956, with completion expected in October. The original alloy requirements were changed from ASTM 301, Grade A to ASTM 301, Grade B because of availability.
C. FUEL ELEMENTS (M. H. Binstock)

1. Development Work on Plates and Assemblies - The OMRE fuel element (Fig. A4) is composed of thin, flat plates assembled into a rectangular box. The plate consists of a mixture of stainless steel and uranium oxide, which is clad in stainless steel. Sixteen active plates and two inactive end plates are fastened to side plates to form a box, and end plugs are welded to this box to form a complete fuel element.

A major portion of the present effort was expended on ordering and installing the equipment necessary for the manufacture of the OMRE fuel elements. This included a rolling mill, globar furnace and gas-handling equipment, shear, 500-ton hydraulic press and many smaller items such as glove boxes, scales, and cleaning tanks. All the equipment has been inspected, and a few preliminary samples have been made to "shake-down" the equipment and eliminate the usual "bugs" present in all new installations.

In the initial phase of plate development, stainless-steel powder was compacted, sintered, inserted into stainless-steel "picture frames" (Fig. 5) and hot- and cold-rolled (Fig. 6) to finish size. In addition, four compacts containing depleted uranium oxide were fabricated in a similar manner. The preliminary oxide samples demonstrated that the equipment, as installed, was capable of handling the development work necessary to establish the process for future manufacturing. The plates containing uranium oxide were radiographed. The uranium oxide was shown on the radiograph to be uniformly distributed with the edges essentially straight.

The major development items on the plates which will be investigated are: bonding, uranium-oxide distribution, dimensional tolerances of core and sheath, and non-destructive inspection procedures.

The experimental assembly of flat plates into a box element is at present being accomplished by welding (Fig. 7). The initial development for OMRE assembly was done by manual tungsten-arc welding while awaiting the automatic equipment. The jigs and tooling for holding each fuel plate in correct alignment during welding were designed. Several welding processes were
Fig. 5. Powder Metallurgy Core Preparation for OMRE Fuel
Fig. 6. Hot Rolling Flat Plates for Fuel Element Assembly
considered and investigated with product application details such as method of assembly, reproducibility, and simplicity of tooling always in mind. Resistance welding and automatic gas-shielded tungsten-arc welding with and without internal chilling were investigated. The automatic tungsten-arc method was pursued and the problem of distortion resulting from weld shrinkage was studied.

As shown in Fig. 8 through 12, many various approaches to the welded structure were tried. A continuous seam weld was tried with little success due to shrinkage of plates and distortion resulting from differential heat transfer across the plates. A combination of longitudinal and transverse seam welding and Heliarc spot welding was tried with some success. The nature of the process requires complex indexing fixtures due to the fuel element design; therefore, more study and design work is scheduled for future plans.

A better procedure for assembling the plates into a fuel element is required in order to minimize distortion. During the next quarter, further work with internal and external chilling will be done. In addition, brazing will be investigated and evaluated.


a. General - One of the fundamental objectives of the OMRE is to obtain data on the behavior of organic coolants in a reactor core. Thermal and radiolytic decomposition of the organic coolant may result in the formation of decomposition products which deposit on various surfaces in the flow path. As scale or deposits build up on a fuel plate surface, the increased resistance to heat flow will cause an increase in the surface temperature of the fuel plate. Temperature measurements at the surface of the fuel plates are considered to present the best method of obtaining continuous information from the core of the OMRE. These are to be obtained by means of thermocouples to be installed in such a way that the temperature pattern at the point of measurement be disturbed as little as possible.
Fig. 7. Heliarc Welding Operation on Fuel Element Assembly
Fig. 8. Combination of Heliarc Transverse and Longitudinal Seam Welds
Fig. 9. Heliarc Seam Weld (One Inch Longitudinal on Each End)
Fig. 10. Heliarc Seam Weld
Fig. 11. Heliarc Spot Weld With Heliarc Seam Weld on Each End
Fig. 12. Heliarc Spot Weld
b. Thermocouple Specifications - If a thermocouple installation on an OMRE fuel-plate surface is to alter the surface temperature as little as possible and if the junction is to be essentially at the same temperature as the surface, it is necessary that the following requirements be satisfied:

1. No fuel must be removed in the vicinity of the installation.
2. The thermocouple junction must be in good thermal contact (welded or brazed) with the fuel plate cladding.
3. The thermocouple leads must be as small as possible and located so that they are at the temperature of the fuel plate surface for some distance from the junction to minimize heat losses by conduction along the leads.
4. The thermocouple must cause as little interference as possible with the flow of coolant between fuel plates.
5. The thermocouple must be securely attached without damaging the 5-mil thick cladding. The thermocouple must not become detached by the turbulent flow stream.
6. The neutron cross-sections of the materials in the thermocouple installation must be such that the thermal neutron flux is not measurably changed in the vicinity of the installation.

c. Thermocouple (Preparation and Installation) - After consideration of all of the above points, the following method of attachment was decided upon. The thermocouple chosen was chromel-alumel with 5-mil-diameter wires, insulated with magnesia powder and encased in a 3/16-inch diameter stainless-steel sheath. The sheath is stripped and the wires are bared for a suitable length. A ceramic frit is applied to the wires and fired to a dense adherent coat. The ceramic coat is then removed at the end of the wires to expose the junction. Specially designed holding brackets are attached to the side of the fuel plate and the thermocouple is pushed through into position. The thermocouple is attached to the cladding with an arc-discharge welder. The junction is then covered with a deposit of electroless nickel which serves to hinder the coolant from sweeping under the wires and pulling them loose. The ceramic coating on the wires prevents the deposit of nickel from shorting the thermocouple wires away from the junction.
d. Ceramic Frit Development - From the standpoint of thermal stability and adherence, suitable ceramic frits were at hand, but subsequent analysis showed high boron contents in all cases. The possibility existed that this boron content would alter the thermal neutron flux in the vicinity of the thermocouple and cause less heat generation in the plate, and, at the same time, it would cause additional heat to be generated around the wires, causing the thermocouple to indicate a higher temperature than that existing on the plate surface. The net effect would be erroneously high readings on a relatively cool area where fouling would be least likely to occur. Therefore, an attempt was made to find a suitable ceramic frit with a lower boron content.

A study order was placed with a commercial firm to develop a suitable coating. The ceramic coating proposed by this firm consisted of a commercial frit containing approximately 2-1/2 per cent lithium oxide with lead oxide, sodium oxide, potassium oxide, and titanium oxide, plus suitable mill additions for flocculation of the water suspension. These mill additions contained approximately 2 per cent boric acid, giving a total boron oxide content of 0.04 per cent and 2.0 per cent lithium oxide.

The variables tested were pretreatment of the wires and mill additions to the frit. The pretreatment consisted of one of the following methods: anneal, chrome flash, or nickel flash (the latter two were preceded by a caustic etch). The mill additions consisted of one of the following: 5 per cent \( \text{Cr}_2\text{O}_3 \), 10 per cent \( \text{Cr}_2\text{O}_3 \), 20 per cent \( \text{Cr}_2\text{O}_3 \), 2 per cent CoO, or no addition. Flexing tests and thermal stability tests resulted in the selection of the 1100° F annealing treatment, followed by the application of the frit with a mill addition of 5 per cent \( \text{Cr}_2\text{O}_3 \). The frit used in compounding the coatings had a density of 3.73 grams per cubic centimeter.

e. Thermal Tests in Diphenyl - It was necessary to determine the stability of the various materials used in the thermocouple lead wires and connectors upon exposure to hot diphenyl. Accordingly, the materials listed below were sealed in individual capsules and heated in a diphenyl bath to 850° F at a pressure of 300 psia.
<table>
<thead>
<tr>
<th>Material Tested</th>
<th>Result of Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lavite &quot;A&quot; (unfired)</td>
<td>Slight darkening; 6 per cent weight increase</td>
</tr>
<tr>
<td>&quot;Supramica&quot;</td>
<td>Darkening; 0.003 per cent weight increase</td>
</tr>
<tr>
<td>&quot;Refrasil&quot;</td>
<td>Impregnated with diphenyl; lost flexibility; 70 per cent weight increase</td>
</tr>
<tr>
<td>Chromel-Alumel duplex wire with glass - asbestos insulation</td>
<td>Color coding bleached out; saturated with diphenyl; 15 per cent weight increase</td>
</tr>
<tr>
<td>Stainless-steel sheath (1/8 inch) over Chromel-Alumel</td>
<td>Diphenyl penetrated 1/4 inch into MgO insulation causing darkening from white to gray; 0.8 per cent weight increase</td>
</tr>
<tr>
<td>Stainless-steel sheath (1/16 inch) over Chromel-Alumel</td>
<td>Same as above; 10 per cent weight increase</td>
</tr>
</tbody>
</table>

These tests showed that the Chromel-Alumel duplex lead wire with glass-asbestos insulation should be satisfactory for the thermocouple leads in the region out of the reactor core. They also showed that the "Lavite" insulator plugs would be suitable for use in the Cannon connector plug which is exposed to the hot diphenyl vapor.

**f. Pressure Tests** - Consideration was also given to using the stainless-steel sheath-type thermocouple as a lead-through into the pressure vessel. To determine the effectiveness of the magnesia powder insulation as a pressure seal, a series of tests was performed after sealing the thermocouple into a pressure vessel. The vessel was pressurized with helium; any gas leakage through the insulation powder was detected with a helium mass-spectrometer leak detector. A six-inch length was leak-tight at 750°F up to 60 psi. At this same temperature, no leaks were detected through the twelve-inch length at pressures up to 500 psi.

**D. SOURCE ASSEMBLY (W. K. McCarty)**

1. **Description of Assembly** - The OMRE source assembly (Fig. 13) consists of a stainless-steel capsule which contains irradiated antimony tetroxide and which is enclosed in a beryllium cylinder.
Fig. 13. Beryllium Capsule and Antimony Source Assembly
The capsule is made of welded Grade 304 stainless steel, is 8-1/2 inches long and 7/8 inch in outside diameter, and weighs 200 gms. The capsule will be filled with 115 gms of Sb\textsubscript{2}O\textsubscript{4}, which has been prepared from commercial reagent-grade Sb\textsubscript{2}O\textsubscript{3}, and will be packed by means of an arbor press to a 3000-lb load.

2. Irradiation of Antimony Source - Arrangements have been completed for irradiation of the source element at the MTR. The approved AEC Form 320 was received just prior to the close of this report period. Arrangements have not yet been completed for shipment of the source from the MTR to the OMRE site. Drawings of the shipping cask have been sent to the MTR project engineering staff and to Dr. V. G. Beard at the Idaho Operations Office for their approval.

It is planned to irradiate the source in a flux of \(2 \times 10^{14}\) n/cm\(^2\)-sec for 76 hours and allow it to cool for 30 days. The activity level will then be measured to determine whether it is as required (20 curies of Sb\textsuperscript{124}). If the activity is below level, the source will be reinserted for a calculated time in the MTR.

E. CONTROL RODS AND DRIVES (D. W. Staub)

1. Preliminary Studies (R. O. Williams, Jr.) - Several types and geometrical arrangements of control rods were studied. The estimated reactivity worths of the four cases investigated are tabulated below:

<table>
<thead>
<tr>
<th>Case</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Two control plates, black, 1/4 inch thick</td>
<td>Diphenyl, 700\textdegree F, Poisoned</td>
</tr>
<tr>
<td>II. Control ring, black, 1/4 inch thick</td>
<td>Diphenyl, 700\textdegree F, Poisoned</td>
</tr>
<tr>
<td>III. Control rods 1, 2, 3, 4</td>
<td>Diphenyl, 700\textdegree F, Poisoned</td>
</tr>
<tr>
<td>a) 1 inch diameter</td>
<td>12. 9</td>
</tr>
<tr>
<td>b) 1-1/4 inch diameter</td>
<td>15. 3</td>
</tr>
<tr>
<td>c) 1-1/4 inch diameter</td>
<td>12. 7</td>
</tr>
<tr>
<td>IV. Control rods 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16</td>
<td>Diphenyl, 212\textdegree F, Unpoisoned</td>
</tr>
<tr>
<td>a) 1 inch diameter</td>
<td>8. 0</td>
</tr>
<tr>
<td>b) 1-1/4 inch diameter</td>
<td>9. 8</td>
</tr>
</tbody>
</table>
The three geometries considered are shown in Fig. 14.

In addition to these rod calculations, calculations were made to find the nuclear effects of thimbles and guide rods in the core. The use of stainless-steel thimbles and guide rods was considered to be impractical because of the increased fuel loading required to offset the poisoning effect of these materials.

Four control plates would probably be adequate from a nuclear standpoint; mechanically, however, they do not seem desirable. They have a large mass relative to round rods; they weaken the upper fuel-assembly support plate because of the long slots required; and the saving in drive mechanisms is questionable since it is necessary to drive a relatively large mass.

The cruciform type control rod and the fuel-poison type rod were also considered. The cruciform rod gives a large effective radius without occupying the volume of a cylindrical rod; however, estimates of the worth of this type of element were considered less reliable than for the cylindrical rod. From a mechanical standpoint, the cruciform rod suffers the same disadvantages as the control plate in that it requires the removal of a large mass of material from the upper support plate. The fuel-poison type rod, although providing a large reactivity change, was rejected because of the difficulties of equipping the fuel portion of the rod with thermocouples.

The control rod arrangement selected for use in the OMRE consists of 12 cylindrical rods 1-1/4 inch in diameter occupying positions 1, 2, 3, and 4 as an inner ring and positions 6, 7, 9, 10, 12, 13, 14, and 16 as an outer ring. Since it was desirable to hold the number of rod-drive mechanisms to a minimum, the twelve rods are driven in pairs, reducing the number of drive mechanisms to six. Each rod pair will be used as a combination shim, safety, and control rod with a total reactivity worth of 12.7 per cent at a bulk moderator temperature of 400 °F.

The following materials were considered for use in the control elements:

<table>
<thead>
<tr>
<th>Material</th>
<th>$\Sigma_a \text{ (cm}^{-1}\text{)}$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hafnium</td>
<td>4.6</td>
<td>Availability questionable, high cost probable</td>
</tr>
<tr>
<td>Silver</td>
<td>3.3</td>
<td>Available, high melting point</td>
</tr>
<tr>
<td>Mercury</td>
<td>18.1</td>
<td>Boiling point too low</td>
</tr>
</tbody>
</table>
CONTROL PLATES
(PLATES SPAN CORE AND ARE 1/4" THICK.)

CONTROL RING
(PLATES ARE 1/4" THICK.)

CONTROL RODS
(DIFFERING PATTERN AND RADII.)

Fig. 14. Experimental Control Element Arrangements
<table>
<thead>
<tr>
<th>Material</th>
<th>$\Sigma_a$ (cm(^{-1}))</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>115</td>
<td>Melting point too low</td>
</tr>
<tr>
<td>Iron Boron (2 per cent)</td>
<td>1.86</td>
<td>Very difficult to work</td>
</tr>
<tr>
<td>Boron carbide</td>
<td>62.1</td>
<td>Poor structural properties, readily available</td>
</tr>
<tr>
<td>Cadmium silver alloy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70-30</td>
<td>81.5</td>
<td>Suitable, but not readily available</td>
</tr>
<tr>
<td>30-70</td>
<td>36.8</td>
<td>Suitable, but not readily available</td>
</tr>
</tbody>
</table>

The use of powdered boron carbide sheathed in a stainless-steel cylinder was considered the most satisfactory.

2. Mechanical Design (J. L. Hedgecock) - The control rod consists of a forked control element at the bottom of a hanger rod with dashpot in the middle and a soft iron magnetic core at the top. The rods are magnetically coupled to a hydraulic drive cylinder. The stroke is 36 inches. There are six control elements.

The control element is made of two 1-1/4-inch outside diameter by 0.120-inch wall Type 304 stainless-steel tubes which are joined by a yoke at the top and filled with boron carbide (Norbide) powder. The two tubes of the element differ in overall length (but not in poison material length) by one inch to facilitate the remote replacement of an element, should this become necessary. The control element tubes slide through two hard guide bushings. One guide bushing is round and one is elongated slightly in the plane of the element to allow for some slight non-parallelism of the tubes.

Helium gas is generated in the control element; this is expected to create a pressure of as much as 1200 psi after about a year's operation. It is presently planned to confine this gas. The boron carbide section is 36 inches long, the same length as the core, and when all the way down the top of the boron carbide is at the level of the top of the core.

The hanger rod is attached to the control element by a 3/4-inch pipe thread. The male part is on the element and the female part is in the hanger rod. Two universal joints are in the hanger rod to allow for slight misalignment between the upper and lower ends of the rod. The dashpot slides on and travels with the
hanger rod. As the rod moves down, the dashpot cylinder hits the guide bridge above the reactor core and stops; then, a piston attached to the hanger rod moves down inside the dashpot cylinder. A set of Bellville springs is attached to the dashpot cylinder to reduce the impact on the guide bridge, and additional ones are located inside of the cylinder to reduce the final impact of the rod. The dashpot stroke is six inches.

The iron core at the top of the hanger rod is part of the magnetic coupling. At the top of the reactor vessel are six 2-inch outside diameter by 0.049-inch wall stainless-steel thimbles. The iron core runs on the inside of the thimble and a large (4-inch outside diameter by 24-inch long) magnet runs on the outside. The magnet (on the outside) is driven by a hydraulic cylinder and the control rod (on the inside) follows.

The position of the magnet is transmitted by a selsyn. An indicator to show relative position of the control rod with respect to the magnet is being developed. The magnet draws approximately 4 amperes at 115 volts dc.

At this time, all parts for testing the control rod mock-up are complete and testing has begun. Test results are discussed in Section 3, following.

3. Experimental Development (A. E. Miller, H. Strahl) - A program has been instigated to test the operation, the reliability, and the characteristics of the OMRE magnetic control rod under reactor operating conditions of temperature and atmosphere. It is aimed at determining if any components of the rod or drive are inadequate, and developing and improving such components if necessary. Low-frequency induction heating is being used to heat the section containing diphenyl, and data on operation and control of these heaters are to be obtained in addition to information on control-rod design.

During this period, a prototype of the magnetic control-rod system was fabricated. Three pressure vessels were mounted one above the other and flanged together to make up a suitable pressurized container to test the control-rod operation in a diphenyl pool at temperatures to 700° F. Since the vapor pressure of diphenyl at 700° F is approximately 110 psia, the vessel is pressurized with argon to 200 psia to prevent boiling. A dump tank was connected to the main vessel to store the diphenyl. Safety relief valves were installed on both the main vessel and the dump tank, and a liquid level gage was installed on the main vessel.
After checking to make certain that the system was leak tight, about 450 pounds of diphenyl were added to the system and melted by induction heating. Eight kilowatts were required to raise the vessel temperature to 490°F in two hours. The power factor varied from 0.85 to 0.88 during this time. No difficulty was encountered in heating the vessel, and the low-frequency current did not affect the thermocouple readings.

After numerous unsuccessful attempts and one successful attempt to raise the rod were made, the thimble and core were disassembled and found to be galled. Subsequent to repair and re-assembly of these components, only the first attempt to cycle the rod through its full stroke was successful. A second disassembly revealed that the same parts were damaged.

Galling between the magnet and outside of the thimble was also noted. Preliminary measurement of the magnet velocity indicated that the magnet did not move at design speed and that the speed was affected by the weight of the rod. It was observed that rod regulating speeds varied from time to time. It is suspected that both pressure valves contributed a major share to the erratic behavior of the hydraulic system. At least once during these tests, the main relief valve (which has since been replaced) jammed in such a manner as to by-pass the pump output. At times this valve chattered, causing fluctuations in line pressure. As much as 75 psi was required to drive the magnet up when it was moving the rod. This indicated that the present relief valve, which has a maximum setting of 75 psi, would have to be replaced by one of a higher rating. Such a valve has been ordered.

The thimble and magnet core were azorized and the control rod reassembled. This thin, hard chrome plating allowed the rod to be cycled four times before failure occurred. Damaged surfaces were repaired and an aluminum bushing added to center the magnet core in the thimble. Six cycles were completed before galling between the bushing and thimble caused termination of the tests. The thimble has been replaced with a new tube and two additional thimbles are being fabricated, one of which will be chrome plated. Bushings of various hard and soft non-magnetic materials are being fabricated.

During measurement of the lifting characteristics of the magnet as a function of temperature the magnet winding shorted out. The limited data obtained before failure indicated that the curve is flat between 80°F and 325°F. The magnet is now being rewound.
IV. HEAT TRANSFER SYSTEM

A. GENERAL

The heat-transfer system includes the reactor, the main piping and valves, the main coolant pumps, and the airblast heat exchanger. (For a detailed description of this system, refer to Section D of the Appendix.)

B. MAIN COOLANT PUMPS (F. W. Herrmann)

Two identical horizontal pumps and drivers are installed in parallel for a total capacity of 7200 gpm at a 154-foot differential head. The fluid to be pumped is diphenyl at a design temperature of 750° F and a pressure of 400 psia. The equipment is to be installed above ground level in a closed, ventilated building. The pumps are of the single-stage, overhung, hot-oil type, with a spacer-type coupling to permit dismantling of the pump without disturbing motors or piping. Mechanical shaft seals are provided to ensure that the leakage rate does not exceed 3 gallons/day per pump. The pumps are hydrostatically and helium leak tested.

The electric motors are ball-bearing, explosion proof, NEMA Class 1, Group D chemical type, squirrel-cage induction motors which operate from a 440 volt, 3-phase, 60-cps power supply to deliver 150 hp at 1760 rpm.

C. AIRBLAST HEAT EXCHANGER (F. W. Herrmann)

The heat produced in the reactor core is transferred by the diphenyl coolant to the heat exchanger, where it is dissipated to the atmosphere. The exchanger will operate over a wide range of heat load, from 16 megawatts to 1 megawatt. The heat exchanger is of the forced-draft type, with finned-tube construction and all-welded construction for leak tightness. The design temperature and pressure required of the equipment is 750° F and 400 psia, respectively. The unit includes Hartzell variable-pitch fans, motors, gear reducers, air-flow control instrumentation, a preheating system, and insulation. Preheating of tubes and headers is to 200° F, and is accomplished by an oil-fired forced draft. Aluminum fins are provided for maximum heat-transfer efficiency. A very sensitive air-flow controller system to regulate the pitch of the fans blades (and hence the air flow) is provided. This sensitivity is very important at low loads. Motor-operated
horizontal shutters are also provided above the tubes for preheating and air flow control purposes. Two 25-hp motors are used to drive the two four-bladed, 10-foot diameter fans.

V. INSTRUMENTATION

A. PROCESS INSTRUMENTATION (R. B. Hall)

1. Temperature Instrumentation - The bulk of the process temperature indication is provided by board-mounted millivoltmeters (calibrated in degrees Fahrenheit) each with a four- to ten-point selector switch connected to iron-constantan thermocouples at the various desired points in the process system. This type of temperature measurement is used for the following points in the process: all tanks used in diphenyl service (except for the waste storage tank); the still vapor trap; all cooling water outlet points; coolant at bottom, center, and top of the reactor vessel; at the top, center, and bottom of the reactor vessel wall; the reactor cavity; and the nitrogen purge outlet.

Board-mounted temperature-indicating controllers are used at the following points: (1) reactor vapor trap to control power to heater; (2) evaporative cooler outlet (for controlling power to solenoid valve on water line to the cooler); and (3) airblast heat exchanger. The sensing elements for the above indicating controllers are iron-constantan thermocouples.

A temperature indicator with a high-temperature heater cutoff limit switch is used on the vacuum still. The sensing element is an iron-constantan thermocouple. A temperature switch-point recorder with a high-temperature heater cut-off limit switch is used on the by-pass heater. The sensing elements for this heater are iron-constantan thermocouples.

Null-balance potentiometer recorders are used for the following purposes: (1) coolant temperature difference in and out of the reactor (with resistance bulb sensing elements); (2) coolant temperature reactor outlet (resistance bulb sensing element); and (3) fuel-element temperatures (chromel-alumel thermocouple sensing elements).
Six null-balance potentiometer indicators are used for measuring the fuel-element temperatures. These indicators are provided with switches for pre-scram alarms and for scrams and scram alarms.

A two-pen recorder actuated by mercury bulb elements is used to record the temperature upstream and downstream of the still.

Millivolt indicators with high-temperature alarm switches are used to measure the bearing temperatures on the primary coolant pumps and the auxiliary coolant pumps.

The only local temperature measurements used are from thermometers on the melt tank and the domestic water line.

Preheating temperatures are measured by means of two null-balance potentiometer-type indicators. The sensing elements are iron-constantan thermocouples which are welded to the piping, vessels, and equipment at the desired points and connected to four seventy-point selector switches located at the board; these are in turn connected to the above mentioned indicators.

2. Pressure Instrumentation - Board-mounted pressure indicators are provided for all points of concern on the process piping, vessels, and equipment. All pressure gages are 4-1/2-inch size. Direct connection is used between pressure tap locations and gages for all service except diphenyl. For diphenyl service, chemical diaphragm protectors are used at the pressure tap locations, and fluid-filled capillary tubing is used for transmitting these pressures to the board-mounted gages.

A locally-read pressure indication is used on the domestic water line with a board-mounted low-pressure alarm. Local pressure indication is also used for the nitrogen purge line and the main cooling-water heater.

Pressure-reducing control valves are used for the nitrogen purge inlet and nitrogen supply outlet. Back-pressure regulating valves are used in the nitrogen purge outlet lines and a relief valve is located downstream from the rupture disk on the purge outlet relief line.

A vacuum control valve is used between the vacuum pump and the distillate hold tank in the purification system.
A vacuum recorder-controller is used to measure the absolute pressure in the vacuum still and to control the power input to the still heaters.

3. Liquid Level Instrumentation - Board level indication is provided on the drain, feed, waste-hold, still-supply, vacuum-still, and distillate-hold tanks. The level sensing method used is the displacer type with pneumatic transmission to board-mounted 6-inch receiver gages.

Reacto-level indication is provided by a nitrogen purge-type sensing device with pneumatic transmission to the 6-inch board-mounted receiver gage. A high-level and a low-level pre-scram alarm and a low-level scram are provided for the reactor coolant level.

A level control on the still cooler is provided by means of a float valve.

4. Flow Instrumentation - A board-mounted flow recorder is used to measure the primary coolant flow. The sensing element is an orifice plate with straightening vanes upstream of the plate. Pneumatic transmission is used to relay the signal to the board-mounted recorder.

A rotameter-type flow instrument with pneumatic transmission to a board-mounted indicating receiver is used for the auxiliary loop of the diphenyl line.

A turbine flowmeter with electrical transmission to a board-mounted indicating receiver is used on the by-pass diphenyl line.

Rotameter-type sensing elements with electrical transmission to board-mounted indicators are used on the nitrogen purge outlet flow (both normal and emergency lines).

All other flow instruments are locally-read rotameter-type instruments. These are used on all cooling-water lines and the nitrogen purge inlet lines.

5. Airblast Heat Exchanger Instrumentation - For the airblast heat exchanger, board-mounted instruments are provided for fan-pitch and louver position indication.

B. NUCLEAR INSTRUMENTATION (R. B. Hall)

The OMRE nuclear instrumentation (see Fig. 15) comprises six channels consisting of detectors, power supplies, and associated amplifiers and indicating
The detectors are thermal neutron-sensitive instruments with output signals proportional to the power produced by the reactor.

The pulse channels contain two boron trifluoride counters which have a range of approximately 5 decades. These counters supply signals to linear and log count rate meters. A recorder receives signals from the log count rate meter. In the intermediate range, two compensated ionization chambers monitoring the flux level over a range of six decades supply signals to the log N and period amplifier chassis, and thence to the log N recorder and to the emergency shutdown system. The power range contains two compensated ionization chambers which provide signals to the safety amplifiers for power level indication, high level scram protection, and reactor control via power level recorder and flux controller.

The instrument channels are in duplicate to provide maximum reliability of service and scram protection. The successive sets of channels have overlapping ranges which provide uninterrupted level information from shutdown to full power.

VI. AUXILIARY SYSTEMS AND EQUIPMENT

A. AUXILIARY COOLING SYSTEM (F. W. Herrmann)

1. General - The auxiliary cooling loop is designed to remove decay heat following reactor shutdown. (For a detailed description of this system, refer to Section D of the Appendix.)

2. Auxiliary Cooler - This unit is a single steel coil, spray-type, evaporative cooler which will be used to remove heat after reactor shutdown or during power failure. Diphenyl will be circulated through the cooler at a rate of 14 gpm by a pump to complete the coolant loop through the reactor core. The cooling-water spray is regulated by a valve controlled by a temperature-sensing element in the downstream side of the diphenyl.

3. Auxiliary Coolant Pump - This is a horizontal, centrifugal, overhung-type pump with base and motor. A coupling is provided for ease of detachment, and a mechanical seal is installed. This pump is designed to deliver 14 gpm at 15 psi differential head.
B. BY-PASS HEATER LOOP (F. W. Herrmann)

1. General - The by-pass heater loop provides continuous information on the change in heat-transfer characteristics of the coolant during reactor operation. (For a detailed description of this loop, refer to Section D of the Appendix.)

2. By-Pass Filter - This filter is a conventional disc-type filter with an electric motor for cleaning the filter element. A 4-inch extension was added to keep the motor away from the heat source.

3. By-Pass Heater - This is a device for monitoring any change in the heat-transfer coefficient of diphenyl. It consists of a 1/2-inch copper-rod heating element inserted in a copper tube which abuts a stainless steel tube, silver soldered together. This heater element is then inserted in a seamless steel pipe jacket through which approximately 10 gpm of diphenyl flow. Thermocouples are provided in the fluid stream and at various points on the heater surface. Power supply is 11 volts, 600 amperes, 2-phase, 60 cps.

C. PURIFICATION SYSTEM (F. W. Herrmann)

1. General - The purification system employs a batch vacuum-distillation process to remove the radiation-damaged portion of the organic coolant. (For a detailed description of this system, refer to Section F of the Appendix.)

2. Still Pump - This equipment, which consists of a horizontal pump and driver, delivers 10 gpm of diphenyl at 122 feet differential pump head and at an operating temperature of 250° F. The equipment is to be installed in the still loop in a closed, ventilated building. The pump is a centrifugal, seal-less, canned-rotor type, of 316 stainless-steel construction. The electric motor drive is a 220/440-volt, 3-phase, 60-cps, Class H motor, designed for Group D explosion-proof operation.

3. Vacuum Pump - The vacuum pump is a rotary piston type, single-stage, oil-sealed pump, mounted on a base with a motor, designed to handle condensable vapor. The gas pumped is a mixture of nitrogen and diphenyl vapor. The 1-1/2-hp motor is totally enclosed, non-ventilated, and explosion proof. A discharge filter was considered unnecessary.

4. Still Cooler - The still cooler consists of coiled steel tubing inside of a steel shell. Diphenyl circulates through this tubing at a rate of 10 gpm and is
cooled by a boiling-water jacket vented to atmosphere. A float valve maintains a constant water level in the jacket.

5. **Distillate Condenser** - This equipment is an injection-type condenser with a spray nozzle. The unit consists of a 4-inch cast iron fume scrubber with various sizes of interchangeable spray nozzles. The condenser will handle liquid diphenyl at 10 gpm and 250°F at a pressure of 50 psig at the nozzles. The condenser will handle diphenyl vapor at 2 to 4 cfm at 500°F to 600°F. The vacuum pump maintains the vapor system at a pressure of from 500 mm to 30 mm Hg absolute.

6. **Still Vapor Trap** - This unit, which is installed on the vacuum-pump suction, is an air-cooled trap that is used to freeze out the diphenyl vapor in the line. The vapor is defrosted at the end of each run by an electric heating element wrapped around the 2-inch finned pipe element. The diphenyl is then allowed to drain back to the distillate hold tank. An additional baffled separator is provided at the outlet of the trap. A mesh, or packing, will be provided later.

D. **NITROGEN SYSTEM**

Nitrogen is used to pressurize the reactor system, to provide an inert atmosphere at all free surfaces, and to purge the gases generated during the thermal and radiolytic breakdown of the organic moderator-coolant. (For a detailed description of the nitrogen system, refer to Section F of the Appendix.)

E. **WATER COOLING SYSTEM**

Water from the main water supply is used to cool various components. (For a detailed discussion of this system, refer to Section F of the Appendix.)

F. **INDUCTION HEATING (A. M. Elmore)**

Diphenyl at normal ambient temperatures is a solid with a melting point of 157°F. During startup and during some operating conditions, piping and equipment must be heated to melt the diphenyl. Except for a few resistance-heating applications, induction-heating windings are used exclusively.

Induction-heating calculations are much too lengthy and involved to be completely described here. Briefly, they depend upon the determination of the ampere-turns and the circuit impedance for a unit length of pipe or vessel.
All windings are wrapped uniformly with two turns per inch after lagging is installed on piping and vessels. The circuit impedance which varies for different size pipes and vessels and for desired heating temperatures determines the length of piping or vessel wrapped per circuit. Windings are Type RH or RH-RW copper conductor except on the reactor core tank and in some high-temperature and high-radiation areas where Type RSS-74 conductor is necessary. Type RSS-74 is designed for use at moderately high temperatures and is not expected to be adversely affected by high radiation. With a few exceptions, the circuit rating is 120 volts at 60 cycles. Table III lists the wire sizes and design current ratings for the various components in the system.

**TABLE III**

**INDUCTION HEATING DATA**

<table>
<thead>
<tr>
<th>Component</th>
<th>Wire Size (AWG)</th>
<th>Design Current (Amperes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-inch pipe</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>10-inch pipe</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>2-inch pipe</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>1-inch pipe</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>1/2-inch pipe</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>Tanks</td>
<td>8</td>
<td>Determined by tank size and shape</td>
</tr>
</tbody>
</table>

Thermocouples are welded on pipe and vessel surfaces to provide the temperature information required to control the preheating. Circuits may be manually energized or de-energized as required.

**G. RESISTANCE HEATING (A. M. Elmore)**

Pumps cannot be easily heated by induction heating, since their shape and configuration make calculations doubtful and the application of turns difficult. Pumps are therefore heated by resistance-heating cable which is wrapped on the pump casing before applying the lagging. Since the mass discontinuities require
slow heating to avoid warping and damaging stresses in the pump casing, heater wattages per unit length are conservative. Reactor operation will raise some pump temperatures higher than obtainable with the heaters; therefore, the higher ambient temperature was considered in selecting the heaters.

H. MISCELLANEOUS EQUIPMENT (F. W. Herrmann)

1. Valves - Valves range in size from 1/4-inch to 10-inch and include globe, gate, and check valves. Valve bodies and bonnets in the 600-lb series are cast carbon-molybdenum steel. The 400-lb series are cast or forged carbon steel. The 250-lb series are high-grade cast iron. All valve trim is stainless steel. The stem packing consists of die-formed metallic foil rings made of Durametalllic D-100 aluminum foil. All valve stems are hardened and have hard chrome plating in the area subject to wear in the stuffing box. Remotely-operated valves have extension shafts and wheels furnished by AI.

2. Melt Station - This equipment consists of an insulated steel tank of 150 gallons capacity with cover and gear-motor-driven agitator. Resistance-type strip heaters are strapped to the tank, and the wall temperature is controlled by an externally-calibrated adjustment. The heaters are rated at 22 kw, 440 volts, 3-phase, 60 cps. The agitator-motor drive is a 1-hp, 440-volt, 3-phase, 60-cycle gear motor which includes magnetic contactor and thermostat.

3. Air Compressor - The air compressor is a two-stage, non-lubricated, water-cooled compressor with a water-cooled aftercooler, automatic condensate trap, and water valve. This unit will deliver oil-free air for instrumentation purposes.

4. Feed Pump - This pump is a positive displacement, diaphragm-type pump, with motor and base. The diphenyl flow rate is approximately 83.5 gallons per hour at 300 psi differential pump pressure. The pump case is carbon steel with a stainless-steel diaphragm.

5. Expansion Header - This equipment consists of 16-inch steel pipe (Schedule 40) spooled between two 16-inch tees which form the inlet and outlet ends of the header. Expansion is provided for in both horizontal right-angle directions by slotted holes in bases and by two bellows expansion joints. Tie rods are provided across opposite bases to stabilize any movement. This header is designed for 400 psi, 750° F service.
I. HANDLING TOOLS (P. M. Mallon)

1. Reactor Vessel Working Platform Assembly - The working platform assembly (Fig. 16) consists of the ring assembly, the work platform, and the tool guide.

   a. Reactor Vessel Work Platform Ring Assembly - The ring, or track assembly, which is indexed to the top flange of the reactor, provides a track for the platform and acts as a protector for the sealing surface on the reactor flange. The assembly includes a pointer with lock pin which is screwed to the side of the track.

   b. Work Platform - The work platform, circular in shape, rides on the ring assembly and supports the fuel element handling tools. The platform is constructed of aluminum and weighs approximately 225 lbs; this material was chosen so that it could be lifted manually into place. A covered access hole is located in the platform to provide access to the fuel element thermocouples. The platform is calibrated along the periphery (Fig. 17) to give one index point for locating the various fuel elements and control rods in the core and in storage locations. A slot, 4 inches wide and approximately 26 inches long, extends from the center of the platform to within 6 inches of the edge. This slot is calibrated along its edge to give the second index point for fuel element and control rod locations. These calibrations will be inscribed onto the surface of the platform after its installation at the site. To locate a fuel element or control rod, the platform will be rotated until the peripheral index number of the chosen element is opposite the pointer (top, Fig. 17). The lock pin on the track pointer will then be inserted to hold the platform at this index point while the tool and tool guide are located opposite the appropriate slot index number. At this position, the tool will be directly over the correct location of the fuel element or control rod in the reactor (Fig. 18). The element may then be located and removed, as required.

   c. Tool Guide - The tool guide consists of a tube about 3 feet in length which is welded to a guide plate about one foot from the upper end. The assembly is split lengthwise on the centerline of the tube. Two clamps on the guide plate hold the two halves together during use. With the tool guide halves separated, the fuel-handling tool with an element attached may be lowered into the reactor, the halves clamped together, and the element guided into the core.
Fig. 16. OMRE Reactor Vessel Working Platform Assembly
Fig. 17. Fuel Element and Control Rod Loading Pattern
Fig. 18. Fuel Element and Control Rod Locations in Reactor
The tool guide acts as a safety against the dropping of the fuel element during handling operations and also carries the weight of the element and fuel-handling tool during removal of the element from the core to the storage rack.

2. Fuel Element Handling Tool Assembly - The function of this tool is to load fuel into the core, remove fuel from the core to the fuel storage rack in the reactor, and place expended fuel in position for removal into the fuel handling cask.

The tool consists of two coaxial aluminum tubes; the inner tube is about 21 feet long and the outer one is about 20 feet long. One end of the inner tube is equipped with a tee handle and the other with a quick-disconnect coupling. The outer tube is attached by a screw fitting to the locking ring of the coupling and by a machined part to the other end; this allows rotation but prevents longitudinal movement in relation with the inner tube. Turning the outer tube moves the locking ring from open to closed or closed to open position.

A fitting which mates with the coupling is provided on each fuel element. This fitting is attached to the actuating shaft on the mechanism used to lock the element in the core. The torque required for this operation is delivered from the tee handle through the inner tube and a pin in the coupling to the fitting and locking shaft.

A series of holes, approximately 30 inches apart, are drilled through the two tubes with the tool in locked position. The auxiliary handles are attached to the handling tool by these holes. One set of holes is located in such a position that the fuel element is held at the correct height to enter the storage rack with the auxiliary handle resting on top of the tool guide. These holes, plus the two auxiliary handles, allow the element to be lowered into the core by stages and restrict the free fall to a maximum of 30 inches in case the tool and element are accidentally dropped.

3. Auxiliary Handle - The auxiliary handle consists of two pipe handles welded to a C-shaped machined block and a spring-loaded pin. The block is machined to fit the outside tube of the fuel handling tool, and the spring-loaded pin fits the drilled holes in the tool. The pin, which runs lengthwise through one handle, through one side of the block, and then indexes into a blind hole in the opposite side of the block, has a ring on the end for withdrawal from the handling tool.
4. General Purpose Hook - This hook consists of a tube, which is 20 feet long and has an "S" hook at the end. The hook is used for manipulating radioactive materials or for any other use where a radiation hazard exists.

5. Fuel Element Lifting Tool - This tool is used for carrying the fuel element (by hand) before placement in the reactor. The tool holds the element in the work platform slot while the fuel handling tool is being attached for lowering the element into the reactor.

6. Control and Safety Stop Bridge Handling Tool - This tool is to be permanently attached to the lock eye-bolt on the bridge. With it, the eye bolt can be unscrewed and the bridge raised and locked in open position.

VII. REACTOR PHYSICS

(R. O. Williams, Jr.)

A. BASIS OF CORE DESIGN

At the outset, the design of the OMRE core was based on two requirements: the use of a proved fuel element capable of operating at the desired temperatures, and a minimum fuel inventory. A fuel element consisting of a UO$_2$-stainless steel sintered sandwich and stainless-steel cladding was chosen since it embodies the requirements of known compatibility with polyphenyls, is capable of operation at high temperatures, and has already had substantial development work completed on it. Preliminary calculations indicated that a minimum inventory could be obtained by using an open array of such fuel elements, polyphenyl-moderated and graphite-reflected. This first core was rated at 4 Mw.

Subsequent calculations indicated that the savings in inventory provided by using a graphite reflector rather than a polyphenyl reflector were not as great as had been indicated in earlier calculations. Further, simplicity of design pointed toward the desirability of using a polyphenyl reflector.

B. LATTICE STUDIES

Studies were made of the effect of lattice size on the critical mass to determine the optimum configuration. The lattice studies were carried out in equivalent cylindrical geometry, with the fuel material and moderator homogenized in a
central cylindrical region and diphenyl in an annular reflector about it. Two models were used in this study: a one-group model which assumed a uniform slowing down density in the moderator; and a two-group model which accounted for the decrease in fast flux outside the fuel box, thereby giving a greater slowing-down density in the moderator within the fuel box than in that exterior to the fuel box.

Because the two-group model does account for the variation in slowing-down density (see Fig. 19), it was chosen as the better of the two models. The core constants were obtained from the flux-weighted cell constants and two-group - two-region core calculations were performed for the several lattice sizes. Figure 20 is a plot of critical mass vs cell size for a diphenyl-moderated and -reflected reactor operating at 700° F, with uranium oxide-stainless-steel fuel elements containing 25 per cent highly enriched UO₂ in the active layer. As is seen in Fig. 20, a minimum critical mass occurs at a lattice spacing of about 4.5 inches. This lattice size has been selected for the OMRE.

Specifying the lattice spacing is, in essence, specifying the fuel-to-moderator ratio. With this in mind, a series of calculations was made for a core consisting of alternately-spaced fuel plates and moderator, similar to pressurized water reactor designs. The reference spacing between plates was taken as 0.134 inches. Table IV shows the effect on critical mass for various gap thicknesses.

<table>
<thead>
<tr>
<th>Gap (in.)</th>
<th>K∞</th>
<th>Critical Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.200</td>
<td>1.6618</td>
<td>16.4</td>
</tr>
<tr>
<td>0.268</td>
<td>1.6258</td>
<td>13.6</td>
</tr>
<tr>
<td>0.402</td>
<td>1.5579</td>
<td>11.7</td>
</tr>
</tbody>
</table>

The critical masses are for a core 24 inches high. The 0.402-inch gap case is comparable to the 4.5-inch lattice case and gives substantially the same
Fig. 19. Unit Cell Flux Distribution (212°F, Unpoisoned)
Fig. 20. Effect of Fuel Element Spacing on Critical Mass (700 °F Diphenyl, Xe and Sm Poisoned)
unpoisoned critical mass. Heat-transfer considerations precluded the use of the 0.268-inch and 0.402-inch gaps, while the uranium loading of the 0.200-inch gap design was excessive; hence, this alternate core plan was not pursued beyond this point. It might be mentioned that a closed lattice design with decreased fuel inventory per plate would yield appropriate critical masses and plate spacings; however, the increase in core power due to the increase in total plate surface and the desire for high heat fluxes excluded this arrangement from consideration.

Three control element arrangements have been considered for the OMRE. These are shown in Section III, E, Fig. 14. Of the three cases shown, only the two control plates and the control rods were estimated to have adequate worth, the control ring being worth only about 10 per cent. The plates, although satisfactory from a nuclear point of view, were not satisfactory from a physical point of view, since they were found to channelize the flow excessively.

The final reference core design is shown in Fig. 21, and the fuel element is shown in Fig. 22. Table V summarizes the pertinent data relating to the core.

**TABLE V**

<table>
<thead>
<tr>
<th>PERTINENT CORE DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fuel elements</td>
</tr>
<tr>
<td>Number of active plates per element</td>
</tr>
<tr>
<td>Mass of U$^{235}$ per plate</td>
</tr>
<tr>
<td>Dimensions of core</td>
</tr>
<tr>
<td>Number of control rods</td>
</tr>
<tr>
<td>Control rod materials</td>
</tr>
<tr>
<td>Diameter of control rods</td>
</tr>
<tr>
<td>Reflector</td>
</tr>
</tbody>
</table>

C. CORE CALCULATIONS

1. Method of Calculation - Detailed cell and core calculations have been performed on the system just described. The principal area of uncertainty in
Fig. 21. OMRE Core Plan
Fig. 22. OMRE Fuel Element Cross Section

16 ACTIVE PLATES

MEAT: 0.020"
CLADDING: 0.005"
nuclear constants involved the thermal and fast properties of diphenyl. Specifically, the transport mean-free-path for thermal neutrons in diphenyl ($\lambda_{tr}$) and the mean squared slowing-down length* ($6r$) had to be determined. The scattering cross section of hydrogen in a hydrocarbon is shown in Fig. 23. Assuming the cross section to be related to the bound atom cross section by the relationship

$$\sigma_s(E) = \sigma_{sb} \frac{A^2}{(1 + A)^2},$$

the transport cross section is given by

$$\sigma_{tr}(E) = \frac{\sigma_s(E)}{3} \left[ 5 - 2 \sqrt[3]{\frac{\sigma_{sb}}{\sigma_s(E)}} \right],$$

which is illustrated in Fig. 24.

Combining this relationship with the carbon transport cross section gave the dependence of $\lambda_{tr}$ on energy. The expression for $\lambda_{tr}$ was then integrated over a Maxwellian spectrum to obtain the average thermal transport mean free path. The thermal diffusion coefficient is shown in Fig. 25. The age calculations followed (in part) the method of Marshak for pure diphenyl, while the formula

$$\tau(t) = \tau_0 \left[ \frac{1 + V}{\rho(t) + \beta V} \right]^2$$

was used for diphenyl-steel mixtures. Although this empirical formula was first developed for water-metal mixtures at KAPL, its use in diphenyl-steel mixtures seems justified on the basis of limited calculations, using the Marshak equation. The result of age calculations is shown in Fig. 26.

2. Disadvantage Factors - In developing the lattice constants, two disadvantage factors resulted: the first is the disadvantage factor of a single fuel plate, while the second is the disadvantage factor of the entire fuel element. These are shown as a function of temperature in Figs. 27 and 28. Figure 29 shows the variation in cell fluxes for extremes in temperatures of 200° F and 700° F. The core

*Physical Review 76, 1257 (1949).
Fig. 23. Hydrogen Scattering Cross Section for Hydrocarbons
Fig. 24. Hydrogen Transport Cross Section for Hydrocarbons
Fig. 25. Thermal Diffusion Coefficient in Diphenyl
Fig. 26. Fast Diffusion Coefficient in Diphenyl
Fig. 27. Fuel Plate Disadvantage Factor
Fig. 28. Fuel Element Disadvantage Factor
Fig. 29. Clean Fuel Element Flux Distribution
constants were obtained by flux-averaging the lattice constants. The variation of the infinite multiplication factor is shown in Fig. 30.

3. Results - Two-group - two-region calculations were performed on the reactor core without control rods, the reactor core with a single ring of control rods, and the reactor core with a double ring of control rods. The effective multiplication factor for the reactor core without control rods is shown in Fig. 31. The flux in the horizontal plane is shown in Fig. 32 for temperatures of 200° F and 700° F. The peak-to-average flux ratio in the horizontal plane was evaluated and is shown as a function of coolant temperature in Fig. 33. The evaluation of control-rod worths and the flux in a plane containing the control rods was solved by replacing the square core by a cylindrical core having the same cross-sectional area. The problem was solved for a radially-reflected core, using an extension of the Nordheim-Scalator control-rod theory. The worths of the banks of rods are tabulated below:

   Inner bank alone                      5.7 per cent
   Inner and outer bank                  12.7 per cent

Figures 34 and 35 show the thermal flux through a plane containing the control rods.

The axial power distribution for control rods partially inserted was obtained, using the "window-shade" technique. A typical axial distribution is shown in Fig. 36. (The shaded area indicates the distance of control rod insertion.)

The OMRE has an antimony-beryllium source with an initial strength of $6.4 \times 10^7$ n/sec. The source is offset as shown in Fig. 21. The multiplication and harmonic excitation due to this source location was compared with a centrally-located source. The flux developed in the equivalent bare core is shown in Fig. 37. This information, together with the attenuation curves for fast and thermal neutrons shown in Fig. 38, was used to evaluate instrument fluxes at shutdown and full power. Also associated with the instrument problem is the photo-neutron source developed due to the deuterium present in the core. This additional source has been evaluated for times after shutdown vs various operating times prior to shutdown; the results are presented in Fig. 39.

The neutron lifetime was evaluated, using two-group perturbation theory. The values of lifetime are summarized in Table VI.
Fig. 30. Infinite Multiplication Factor
Fig. 31. Effective Multiplication Factor
Fig. 32. Clean Reactor Flux Distribution in the Horizontal Plane
Fig. 33. Peak-to-Average Flux Ratio in the Horizontal Plane
Fig. 34. Radial Flux in Plane Containing Two Rings of Control Rods
Fig. 35. Radial Flux in Plane Containing Single Ring of Control Rods
Fig. 36. Axial Flux Plot for Core with Gauged Control Rods
(500°F, Clean Core, Xe and Sm Poisoned)
Fig. 37. Comparison of Central and Offset Source
Fig. 38. Flux Attenuation in OMRE
Fig. 39. Shutdown Photoneutron Production


<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>Lifetime (μsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clean Core</td>
</tr>
<tr>
<td>200</td>
<td>113</td>
</tr>
<tr>
<td>500</td>
<td>123</td>
</tr>
<tr>
<td>700</td>
<td>144</td>
</tr>
</tbody>
</table>

TABLE VI
NEUTRON LIFETIMES

VIII. REACTOR HEAT TRANSFER

A. NEUTRON FLUX DISTRIBUTIONS

The heat-generation distribution in the OMRE reactor was taken to be the same as the thermal-neutron flux distribution. The following thermal neutron flux distributions and peak-to-average flux ratios for the core at 500 °F and poisoned were used in the calculations of the thermal power of the OMRE reactor:

1. Thermal-neutron flux distributions in the axial direction for control rods out of the core and for control rods 53 cm into the core (maximum expected insertion during operation), as shown in Figs. 40 and 41, respectively (the respective peak to average ratio values are 1.31 and 1.52)

2. A peak-to-average flux ratio in the horizontal plane of the core of 1.485

3. A peak-to-average flux ratio in the horizontal plane of a fuel element of 1.62

B. HOT CHANNEL FACTORS

1. Hot Channel Factor Values - The hot-channel factor applied to the bulk coolant temperature rise, $F_{\Delta T}$, the hot-channel factor applied to the film drop, $F_\theta$, and the hot-channel factor applied to the heat flux, $F_\phi$, have been evaluated for the OMRE as shown in Table VII.
Fig. 40. Axial Thermal Flux Distribution at 500° F, Poisoned (Control Rods Out)
Fig. 41. Axial Thermal Flux Distribution at 500°F, Poisoned (Inner Bank of Control Rods Inserted 53 cm)
TABLE VII

HOT CHANNEL FACTORS

<table>
<thead>
<tr>
<th></th>
<th>$F_{\Delta T}$</th>
<th>$F_\theta$</th>
<th>$F_\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation in fuel meat thickness</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>Variation in $U^{235}$ dispersion</td>
<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
</tr>
<tr>
<td>Variation in channel thickness</td>
<td>1.06</td>
<td>1.03</td>
<td>--</td>
</tr>
<tr>
<td>Effect of possible warping of fuel plates</td>
<td>1.07</td>
<td>1.04</td>
<td>--</td>
</tr>
<tr>
<td>Effect of flow distribution due to non-uniformity of pressure distribution in core</td>
<td>1.01</td>
<td>1.01</td>
<td>--</td>
</tr>
<tr>
<td>Inability to predict flux</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>Total Product</td>
<td>1.50</td>
<td>1.43</td>
<td>1.33</td>
</tr>
</tbody>
</table>

2. Basis for Hot Channel Factor Values

a. Variation in Fuel Meat Thickness - The values of the hot-channel factors due to this variation are based on the proposed specification for the tolerance in fuel meat thickness, namely, 0.020 inch ± 0.003 inch.

b. Variation in $U^{235}$ Dispersion - The values of the hot-channel factors due to this variation are based on the proposed specification for the tolerance in non-uniform dispersion of $U^{235}$ in the fuel meat, namely, ± 2 per cent.

c. Variation in Channel Thickness - The values of the hot-channel factors due to this variation are based on the proposed specification for the tolerance in channel thickness, namely, 0.134 inch ± 0.010 inch.

d. Effect of Possible Warping of Fuel Plates - The values of the hot-channel factors due to this effect are based on the bending that might be incurred by the end fuel plates due to the bending and compressive forces to which they are subjected during reactor operation by virtue of the non-expansion of the cold end plates.

e. Effect of Flow Distribution Due to Non-Uniformity of Pressure Distribution in Core - The values of the hot-channel factors due to this effect are based on the non-uniform flow rate among the fuel elements resulting from the
greater pressure drop incurred by the coolant flowing from the exit of the central fuel element to the core outlet than by the coolant flowing from the exit of an edge fuel element to the core outlet.

f. Inability to Predict Neutron Fluxes - The inability to predict neutron fluxes results from errors in material properties and in the mathematical description of the reactor geometry. As can be seen from inspection of the curves of NAA-SR-1608, the errors in flux distribution due to the material constants are not great in the overall picture. It is therefore the uncertainty in the geometrical model used which is considered to have the greatest influence. Calculations which bracket the actual flux distribution, and which are considered to represent the extreme variations due to geometry, are within 10 per cent of the figures utilized. The adjustment of this number with material uncertainties and the overall flux distribution resulted in the hot-channel factor of 1.15

C. CALCULATION OF THERMAL POWER

1. Physical Properties of Coolant - Table VIII lists the physical properties of irradiated diphenyl (assumed to be 70 per cent diphenyl and 30 per cent tar) on the basis of data given in Monthly Progress Letter No. 14, October 31, 1955, and Monthly Progress Letter No. 16, January 15, 1956, Monsanto Chemical Company, St. Louis, Missouri.

<table>
<thead>
<tr>
<th>Temperature °F</th>
<th>Thermal Conductivity Btu/hr ft °F</th>
<th>Specific Heat Btu/lb °F</th>
<th>Density lb/ft³</th>
<th>Kinematic Viscosity ft²/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0.070</td>
<td>0.550</td>
<td>53.7</td>
<td>0.01665</td>
</tr>
<tr>
<td>600</td>
<td>0.068</td>
<td>0.595</td>
<td>50.8</td>
<td>0.01280</td>
</tr>
<tr>
<td>700</td>
<td>0.066</td>
<td>0.640</td>
<td>47.7</td>
<td>0.01045</td>
</tr>
<tr>
<td>800</td>
<td>0.064</td>
<td>0.685</td>
<td>45.6</td>
<td>0.00968</td>
</tr>
</tbody>
</table>
2. Equations - The power $q'$ from the hottest fuel plate is given by:

$$q' = \frac{w c}{F \Delta T} (t_s - t_1) \left(\frac{w c F \phi}{\phi + q} \right)_{\text{max}}$$

where

- $w$ = weight rate of flow of coolant associated with the fuel plate
- $c$ = specific heat of coolant
- $t_s$ = maximum coolant-fuel plate interface temperature
- $t_1$ = inlet temperature of coolant
- $h$ = coolant film heat-transfer coefficient
- $A$ = heat-transfer surface area of fuel plate
- $\phi_z$ = heat flux through fuel plate surface
- $\bar{\phi}$ = average heat flux for fuel plate
- $q_z$ = heat transferred to coolant from fuel plate in distance $z$
- $q$ = thermal power of fuel plate

The combined thermal power, $Q_f$, of all the fuel plates is given by

$$Q_f = q'n \left[\left(\frac{\bar{\phi}}{\phi_{\text{max}}}\right)_{\text{radial, fuel element}} \left(\frac{\bar{\phi}}{\phi_{\text{max}}}\right)_{\text{radial, core}}\right]$$

where

- $n$ = number of fuel plates
- $\left(\frac{\bar{\phi}}{\phi_{\text{max}}}\right)_{\text{radial, fuel element}}$ = ratio of average-to-peak heat flux in the radial, fuel element direction in the highest-power fuel element.
- $\left(\frac{\bar{\phi}}{\phi_{\text{max}}}\right)_{\text{radial, core}}$ = ratio of average-to-peak heat flux in the radial, core direction in the core.

The thermal power $Q$ of the reactor is

$$Q = Q_f + Q_m = Q_f \left(1 + \frac{Q_m}{Q_f}\right)$$

*This equation was derived by T. T. Shimazaki, R. O. Williams, Jr., and R. F. Wilson.*
where \( Q_m \) = heat liberated in the reactor, other than that generated in the fuel plates, and picked up by the coolant.

The maximum heat flux is

\[
\phi_{\text{max}} = \frac{q' F \phi}{A} \left( \frac{\phi_{\text{max}}}{\bar{\phi}} \right)_{\text{axial}}
\]

3. Values of Variables - In calculating the thermal power, the following values were used:

- a. Maximum coolant-fuel plate interface temperature, \( t_s = 800^\circ \text{F} \)
- b. Coolant inlet temperature, \( t_1 = 500^\circ \text{F} \)
- c. Nominal coolant velocity = 15 ft/sec
- d. Physical properties of irradiated diphenyl as shown in Section 3a
- e. The heat transfer coefficient for the coolant as given by the Sieder-Tate equation*
- f. The number of fuel plates, \( n = 400 \)
- g. The heat generation distributions and peak-to-average power density ratios as given by the thermal-neutron flux distributions and peak-to-average flux ratios described in Section 1.
- h. \( \frac{Q_m}{Q_f} = 0.10 \).

4. Results - The application of the hot-channel factors given in the heat-transfer calculations in Section B gives the following results:

<table>
<thead>
<tr>
<th>Control Rods</th>
<th>Control Rods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out</td>
<td>53 cm In</td>
</tr>
<tr>
<td>Reactor Power, Mw</td>
<td>12.2</td>
</tr>
<tr>
<td>Maximum Heat Flux, ( \frac{\text{Btu}}{\text{hr-ft}^2} )</td>
<td>317,000</td>
</tr>
</tbody>
</table>

The coolant and fuel-plate surface temperature distributions for the highest power fuel plate are shown in Figs. 42 and 43 for control rods out and control rods 53 cm in, respectively.

---

Fig. 42. Temperature Distribution for Fuel Plate Surface and Coolant (Control Rods Out)
Fig. 43. Temperature Distribution for Fuel Plate Surface and Coolant
(Inner Bank of Control Rods Inserted 53 cm)
D. DISCUSSION

The thermal power calculated by using the hot-channel factors evaluated in Section B is conservative inasmuch as the values for these hot-channel factors are based on the assumption that the various factors contributing to a hot spot would all occur and at the same point.

The capacity of the cooling system for the OMRE reactor must be based on at least the probable maximum power, if not the maximum possible power at which the reactor might have to operate in order to obtain desired temperatures in the core. If hot-channel factors are used in the determination of the required cooling capacity, the values for these hot-channel factors should be evaluated on a probability basis. If this is done, the thermal power of the reactor with control rods out is 15.1 Mw.

To summarize:

1. The OMRE reactor is capable of operating at a thermal power of at least 10.8 Mw without exceeding a coolant-fuel plate interface temperature of 800° F when the coolant inlet temperature is 500° F and the coolant velocity between fuel plates is 15 ft/sec.

2. Operation of the OMRE reactor at a thermal power of up to 15.1 Mw may be necessary in order to obtain the desired temperatures in the core.

IX. REACTOR CONTROL AND SAFETY

A. CONTROL ROD PROGRAMMING SYSTEM (R. O. Williams, Jr.)

Rod programming on the OMRE has several distinct advantages over a completely manual rod-shimming system:

1. Rods are withdrawn from the core in a predetermined manner, thereby assuring the best power distribution for a particular set of operating conditions.

2. Programming ensures that the rods may not be withdrawn to a region of poor differential worth and thereby impose excessively long delay times on the safety system.
3. Programming relieves the operator of the burden of observing the positions of individual rods and constantly making adjustments on individual positions.

A total of twelve control rods are used, of which four are located in an inner circle 3.2 inches in radius and eight are located in an outer circle 7.1 inches in radius. The rods are operated in pairs by individual hydraulic drives so that there are two hydraulic drives for the inner group of four rods and four hydraulic drives serving the outer group of eight rods.

A block diagram of the rod-programming and automatic-power-level-and-temperature-control system is shown in Fig. A8 in the Appendix.

Three independent modes of operation are available with this system:

1. **Programmed-Automatic** - In programmed-automatic operation, the rods go through programmed withdrawals and insertions, and the signals which actuate the rods are derived from an automatic-power-level-control system.

2. **Programmed-Manual** - In programmed-manual operation, the rods go through programmed withdrawals and insertions, and the signals which actuate the rods are derived from a switch manipulated by the reactor operator.

3. **Individual-Manual** - In individual-manual operation, the motion of each rod pair is provided for by a manually-operated switch associated with the rod pair.

During programmed operation, the signals for rod motion originate in the power-level control channel. Assuming that the rods are fully inserted into the reactor core, the following sequence should occur on a "rods out" signal:

1. The outer rod group is withdrawn to an intermediate position.
2. The inner rod group is then withdrawn to this same intermediate position.
3. Both the inner and outer rod groups are withdrawn simultaneously after the inner group reaches the intermediate position.

A "rods in" signal simply reverses this sequence.

The maximum rate of reactivity change with this control system is 0.0001 Δk/k per second. The principal consideration in establishing this rate is...
the danger of an accident due to an uncontrolled withdrawal of all rods simultaneously.

B. AUTOMATIC FLUX AND TEMPERATURE CONTROL SYSTEM (D. J. Cockeram, E. B. Ash)

The automatic control system for the OMRE is primarily a constant flux system; however, provision is made for a slow override of the flux-control point by a fuel-element surface-temperature control signal. The rod-programming and automatic-power-level-and-temperature-control system is shown in Fig. A8 in the Appendix. Completely automatic control is obtained. Manual control of the fuel-element surface-temperature set point, neutron-flux set point, or rod motion is available when needed.

Fuel element surface-temperature control can be obtained from any one of thirty-five thermocouples located on the surface of the fuel plates of seven of the fuel elements. These thermocouples are so designed as to have a minimum effect on the fuel-plate surface temperature at the point of attachment and to maintain the temperature of the thermocouple junction at essentially the same temperature as the fuel-plate surface.

The reactor neutron flux is regulated by a controller with proportional rate-and-reset action. The controller receives a neutron flux signal from a compensated ionization chamber which also serves as one of the two safety chambers. Temperature reset action is obtained from a temperature indicator and controller which supplies a temperature OVERRIDE signal to the flux controller. A rod-position signal is required for proper function of the neutron flux controller. This rod position signal is a voltage proportional to the position of the rod and is obtained from a special potentiometer driven by a low-inertia servo motor.

C. STARTUP ACCIDENT STUDIES* (L. R. Blue, D. J. Cockeram, R. P. Varnes)

A startup accident assumes that with the reactor shutdown all rods are simultaneously and continuously withdrawn, the reactor goes critical, and the power level continues to increase until the overflux level scram shuts down the reactor. Hand-calculated and analog-computed studies were made of the startup

*A detailed discussion of possible accidents and hazards associated with operation of the OMRE is contained in a memorandum which was presented to the Committee on Reactor Safeguards in July, 1956. A separate report discussing the stability analysis of the OMRE is in preparation.
accident for various initial conditions of temperature, rod worth, and shutdown reactivity.

The startup accident power excursions and fuel plate metal temperature transients for inlet coolant temperatures of 250° F, 500° F, and 700° F are shown in Figs. 44 through 47. The results of these studies were used to establish the maximum rod-withdrawal rate and the time-response characteristics of the reactor safety system. The maximum rate of increase of reactivity due to simultaneous withdrawal of all rods was set at 0.0001 Δk/k per second. If the overflux scram points are set at 16 megawatts for 250° F and 500° F inlet coolant temperatures startup, and at 6.2 megawatts for 700° F inlet coolant temperature startup, no damage to the reactor will result if the rods fall at an acceleration of one "g" and the total response time of the safety system does not exceed 250 milliseconds.

D. CONTROL-STUDIES OF THE AIRBLAST HEAT EXCHANGER (D. J. Cockeram)

The heat produced in the OMRE is dissipated to the atmosphere by means of an air-cooled heat exchanger. The diphenyl temperature leaving this exchanger must be well controlled if the purposes of the experiment are to be realized. A study was made of the effects of temperature variations at the reactor inlet on the control and stability of the reactor. It was concluded that if this temperature variation did not exceed ± 3° F over the proposed operating range of the reactor, the interaction with flux control would be slight. Based on these studies, requirements for an automatic outlet-temperature control system for the heat exchanger were established.

Further studies were made of reactor inlet temperature transients that could result from failure of the heat-exchanger temperature control system.

1. Loss of Fans - The heat rejection rate of the heat exchanger is controlled by varying the pitch of the fan blades which force air up through the tube bundles. If these fans suddenly go to zero pitch or if the fan motors are lost while the reactor is operating at high power, a sudden increase in reactor inlet temperature will result. Analogue computer studies indicate that under the worst conditions the reactor inlet temperature will rise about 30° F at an initial rate of about 5.6° F per second. Curves of the reactor power and fuel plate metal temperatures
Fig. 44. 250° F Startup Accident Power Excursion
Fig. 45. 250°F Startup Accident Fuel Temperature Transient
Fig. 46. 500°F and 700°F Startup Accident Power Excursion
Fig. 47. 500°F and 700°F Startup Accident Fuel Temperature Transient
as a function of time after loss of fans are given in Fig. 48. The safety system is considered adequate to handle such a transient without damage to the reactor.

2. Sudden Increase in Fan Pitch - If the fans suddenly go to full pitch when the reactor is operating at low power and high temperature, a rather severe reactor inlet-temperature transient is obtained. In the worst case, if the fans suddenly go to full pitch, the reactor inlet temperature will decrease. However, because of the large negative temperature coefficient, the power level will increase rapidly. The net result is that the fuel-plate temperature goes up. As a result of this study, it was recommended that the overflux scram level be reduced during high-temperature - low-power runs.

E. LOSS OF COOLANT FLOW STUDIES (L. R. Blue, D. J. Cockeram, T. T. Shimazaki)

Loss of coolant flow assumes simultaneous failure of both primary coolant pumps. Such a failure could result, for example, by loss of electrical power to the pump motors. A study was made with an analog computer representation which included a mockup of the thermal characteristics of the core, a five delayed-neutron group representation of the neutron kinetics, a flow-decay generator, a time-delay unit, and a rod-insertion generator. All cases analyzed were at a reactor power level giving a maximum fuel-plate surface temperature of 800° F (unless more than the maximum power level of 16 megawatts would have been necessary to obtain this temperature).

The per cent of rated flow as a function of time after failure of main pumps is given in Fig. 49. Figure 50 gives plots of flow rate, fuel plate metal temperature, reactor power, and negative reactivity insertion after scram as a function of time following failure of main pumps.

These studies indicate that danger to the reactor would not result from complete loss of coolant flow due to pump failure with the response time of the safety system and the rod drop time as determined by the startup accident studies.

F. STABILITY ANALYSIS OF THE REACTOR (E. B. Ash)

As part of the analysis of the overall control problem on the OMRE, it was considered necessary to study the transient response of the reactor with no external control system. At first glance, it would seem reasonable to assume that
INITIAL CONDITIONS:
POWER = 124 Mw  INLET TEMPERATURE = 250°F
FULL FLOW = 7200 gpm

TRANSIENT:
INLET TEMPERATURE INCREASES AT 5.6°F/sec
SCRAMMED AT 20 Mw

Fig. 48. Reactor Excursion After Loss of Airblast Heat Exchanger Fans
Fig. 49. Coolant Flow Decay Upon Failure of Main Pumps

**CURVE NO.1** — EXPECTED FLOW DECAY. SHADEN AREA — PROBABLE RANGE OF FLOW DECAY.

**CURVE NO.2** — ANALOG REPRESENTATION OF NO.1

$$V = 0.150 + 0.85 e^{-0.335t}$$

**CURVE NO.3** — DECAY CONSTANT

≈ 1 SECOND
FAILURE OF MAIN PUMPS

Fig. 50. Reactor Analog Transients After Failure of Main Pumps
a reactor with a negative coefficient is inherently stable, i.e., any disturbance to the system would result in an increase or decrease in reactor power in such a manner as to hold the average coolant temperature close to a constant value. However, because of the coolant flow pattern in the OMRE, it is possible that a disturbance could start an oscillation in the reactor power and temperature. These oscillations could be either damped, self-sustaining, or divergent.

An analysis was performed in an attempt to determine whether or not these oscillations are damped and, if so, how close the reactor system is to a point of instability. Within the errors of the assumptions made and the constants used in the analysis, it was concluded that the OMRE would be stable with respect to this type of oscillation with no external control system. That is, any reactivity disturbance may cause oscillations in power level, but such oscillations will decay with time at an adequate rate. The margin of stability for each of the operating conditions was determined. The polar frequency response plot for the worst operating condition is shown in Fig. 51.

G. COOLANT LOOP STABILITY STUDIES (E. B. Ash, D. Balcomb)

The possibility of instability exists in any closed reactor coolant loop, because a change in reactor outlet temperature, after flowing around the loop, can reaffect the outlet temperature in such a way as to produce system instability. This instability can be of several types:

1. **Non-Oscillating Instability** - In which the temperatures in the loop will continue to rise or fall.
2. **Oscillating Instability** - In which temperature oscillations exist and continue to grow in amplitude with time. This effect is due to reinforcement of oscillations when the period of oscillation is some multiple of the loop transport time.

As a result of these studies, it was concluded:

1. That the OMRE coolant loop is stable with respect to either types of the above mentioned instabilities with full negative reactivity coefficient and no external control. The open-loop frequency response plot of the system is shown in Fig. 52.
2. That the OMRE coolant loop is a highly self-regulating system which will tend to hold the reactor outlet temperature constant for a given
Fig. 51. Nyquist Plot of Gain and Phase Margin
Fig. 52. Open Loop Frequency Response
control rod position. Operation of the OMRE as a self-regulating plant with no external control system is possible with the following limitations:

a. Fluctuations in the outlet temperature of the airblast heat exchanger, due to such disturbances as wind gusts, must not represent a problem.

b. The coolant temperature must be in the proper range so as to produce a strong negative temperature coefficient.

X. SHIELDING

A. RADIATION LEVELS FROM THE OPERATING REACTOR (R. L. Ashley, A. R. Vernon)

Calculations have been made of the radiation levels at various locations near the reactor. The results are summarized in Table IX for a reactor power of 16 Mw. The sources considered in the analysis were neutrons and gamma rays from the reactor core, and capture gamma rays in the material surrounding the core. Radiation levels from the activated coolant were considered separately (see below). The active coolant above the core should add approximately one r/hr to the level quoted for the location above the reactor tank, and smaller amounts at the other locations.

**TABLE IX**

RADIATION LEVELS DURING OPERATION AT 16 Mw

<table>
<thead>
<tr>
<th>Location</th>
<th>Dose Rate</th>
<th>Gammas r/hr</th>
<th>Neutrons rem/hr</th>
<th>Total rem/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above reactor tank</td>
<td></td>
<td>5</td>
<td>Negligible</td>
<td>5</td>
</tr>
<tr>
<td>Maximum intensity at ground level in area around reactor</td>
<td></td>
<td>0.6</td>
<td>0.05</td>
<td>0.6</td>
</tr>
<tr>
<td>Streaming through coolant pipe outlets</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. At pipe outlets</td>
<td></td>
<td>12.5</td>
<td>7.5</td>
<td>20</td>
</tr>
<tr>
<td>b. At distance of 550 ft</td>
<td></td>
<td>0.0075</td>
<td>Negligible</td>
<td>0.0075</td>
</tr>
<tr>
<td>&quot;Sky shine&quot; from reactor at 20 ft</td>
<td></td>
<td>0.0001</td>
<td>Negligible</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
The area around the reactor is to be designated an exclusion area during operation, and will be appropriately fenced and posted. Under these conditions, the only value listed in Table IX which is still considered to be excessive is the radiation escaping through the coolant pipe outlets. This radiation escapes in a horizontal direction through the openings where the coolant pipes emerge from the earth-fill mound around the reactor. To reduce the effect of this radiation, a 12-inch concrete wall is to be erected projecting from the south wall of the process room to interrupt the beam. This wall will reduce the radiation level to less than 7.5 mr/hr within the exclusion fence, and reduce the level at the south wall from about one r/hr to less than 100 mr/hr.

B. RADIATION LEVELS FROM THE REACTOR AFTER SHUTDOWN
(R. L. Ashley, A. R. Vernon)

Radiation levels from the reactor core 24 hours after shutdown following one year of continuous operation at 16 Mw were calculated. The results are shown in Table X. The contribution from coolant activation was neglected in this analysis. Actually, however, a larger contribution to post-shutdown levels is expected to be received from spent fuel stored in the fuel storage rack, the top of which is located 5 feet above the core. Very crude estimates indicate that the radiation level above the reactor due to a single one-day-old element in this position could be as high as 220 mr/hr. A program of calculations is in progress which will yield more accurate values for the post-shutdown radiation levels from all sources.

C. RADIATION LEVELS FROM DIPHENYL ACTIVATION (D. S. Duncan, R. J. Beeley)

Analysis of induced activation experiments performed at the Materials Testing Reactor has shown the presence of small amounts of Na, Mn, Hg, and Cl in several coolant samples. The presence of long-lived activities, such as Co$^{60}$, was uncertain due to the relatively short irradiation times.

Calculations were made to determine the extent of activation of the OMRE coolant due to each of these elements, including Co. The radiation levels at the surface and 1.5 feet from the surface of a 16-inch steel coolant pipe were calculated for a one-ppm concentration of each of the above elements. The results are shown in Table XI.
TABLE X
POST SHUTDOWN RADIATION LEVELS FROM THE REACTOR

<table>
<thead>
<tr>
<th>Location</th>
<th>Dose Rate</th>
<th>mr/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above reactor (lid removed)</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Streaming through pipe hanger recesses: (See Fig. 53)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. No shield</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>b. 6 inch ordinary concrete</td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>c. 9 inch ordinary concrete</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>d. 12 inch ordinary concrete</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>At coolant outlets</td>
<td></td>
<td>21</td>
</tr>
</tbody>
</table>

TABLE XI
RADIATION LEVELS FROM 1 PPM CONCENTRATIONS OF VARIOUS IMPURITIES IN OMRE COOLANT

<table>
<thead>
<tr>
<th>Element (1 ppm)</th>
<th>Activity (dps/cm³)</th>
<th>Radiation Level at Surface of 16 in. Pipe (mr/hr)</th>
<th>Radiation Level 1.5 ft from Surface of Pipe (mr/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>$1.86 \times 10^4$</td>
<td>890</td>
<td>240</td>
</tr>
<tr>
<td>Mn</td>
<td>$2.01 \times 10^5$</td>
<td>3900</td>
<td>1200</td>
</tr>
<tr>
<td>Cl</td>
<td>$3.48 \times 10^3$</td>
<td>56</td>
<td>18</td>
</tr>
<tr>
<td>Hg</td>
<td>$2.13 \times 10^4$</td>
<td>27</td>
<td>9.1</td>
</tr>
<tr>
<td>Co</td>
<td>$3.52 \times 10^4$</td>
<td>990</td>
<td>340</td>
</tr>
</tbody>
</table>

Table XII lists the anticipated radiation levels based on the impurity content of four different samples of coolant material. The total dose rates were obtained by adding to the results of the impurity calculation the results of a calculation of the radiation levels to be expected from Mn⁵⁶ and Fe⁵⁹ activities which may enter the coolant from the reactor during operation.
Fig. 53. Location of Pipe Hanger Recesses
TABLE XII

RADIATION LEVELS AT SURFACE OF A 16-INCH PIPE
AS PREDICTED FROM ANALYSIS OF SEVERAL SAMPLES

<table>
<thead>
<tr>
<th>Sample</th>
<th>Radiation Level at Pipe Surface from Impurities (mr/hr)</th>
<th>Total (mr/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diphenyl (Vendor A)</td>
<td>239</td>
<td>502</td>
</tr>
<tr>
<td>Diphenyl (Vendor A)</td>
<td>295</td>
<td>558</td>
</tr>
<tr>
<td>Diphenyl (Vendor B)</td>
<td>50</td>
<td>313</td>
</tr>
<tr>
<td>Santowax-R</td>
<td>496</td>
<td>759</td>
</tr>
</tbody>
</table>

Mn$^{56}$ can enter the coolant stream from three sources:
1. Fe$^{56}$ (n, p) Mn$^{56}$ products which recoil directly from the steel into the coolant.
2. Fe$^{56}$ (n, p) Mn$^{56}$ products which do not leave the steel in the recoil, but enter the coolant through corrosion of the steel.
3. Mn$^{55}$ (n, y) Mn$^{56}$ reactions producing activity in the coolant through corrosion.

The source of Fe$^{59}$ activity is the Fe$^{58}$ (n, y) Fe$^{59}$ reaction, which produces activity in the coolant through corrosion. Both corrosion of activated isotopes and activation of corroded material contribute to the total activity.

The Mn$^{56}$ activity due to recoils was calculated by assuming a recoil range of $10^{-5}$ cm and estimating that 1/4 of the Mn$^{56}$ recoil paths are oriented properly to reach the coolant. The (n, p) cross section was taken to be 12.5 barns, averaged over the fission neutron spectrum. The contribution from this source to the dose rate at the surface of a 16-inch pipe was computed and found to be approximately 181 mr/hr.

For the remaining sources of activity, which depend on corrosion processes, the corrosion rate was assumed to be 0.003 mil/month. The sum of the contributions to the dose rate from these sources was found to be approximately 82 mr/hr. Thus, a total of 263 mr/hr was added to the dose rates calculated at the pipe surface due to coolant impurities alone.
In all the above calculations it was assumed that the reactor was operated at 16 Mw for 500 days. The removal half life of the coolant was taken to be 140 days.

D. FUEL REMOVAL COFFIN (R. L. Ashley, D. S. Duncan, W. K. McCarty)

Shielding requirements for the removal of irradiated fuel elements were calculated for both lead and iron shields. It was assumed that the reactor was operated continuously for 300 days at a power of 16 Mw and that it was desired to remove a fuel element within two days after shutdown. The results of the calculations are presented in Fig. 54.

Additional calculations were made to determine the dimensions of an extension of the fuel coffin, which is to be used during the removal operation to shield the element while it is being drawn up through the space between the coffin and the diphenyl pool. The dimensions determined were those necessary to prevent radiation levels from exceeding 1 r/hr at any time in areas adjacent to the base of the coffin. These calculations were based on removal after 1000 hours of continuous operation and 10 hours cooling. It was also assumed that the diphenyl level was five feet below the upper flange of the core tank and that the diphenyl temperature was 300° F.

The shield thicknesses required for the coffin extension were determined to be 8.2 inches of lead for the upper 40 inches and 15 inches of lead for the remaining 8 inches of length.

When a fuel element is in a raised position such that a portion of the element lies between the surface of the diphenyl and the lower face of the coffin extension, gamma rays reflected from the inside of the core tank will contribute significantly to the dose near the base of the coffin. It was found that a 4.0-inch thickness of steel or a 1.2-inch thickness of lead placed over the opening would be necessary to prevent the radiation level from exceeding 1 r/hr at this point.

E. NEUTRON SOURCE GAMMA ACTIVITIES (R. L. Tomlinson, D. S. Duncan)

The startup neutron source will be obtained by irradiation of beryllium by an antimony gamma-ray source which is to be activated in the Materials Testing Reactor. Calculations have been performed to determine the gamma activity and dose rate from the antimony source, which will consist of 115 grams of Sb₂O₄.
NOTE: DOSE RATES FOR LEAD ARE
AT 15 FEET FROM FUEL ROD
DOSE RATES FOR IRON ARE
AT 20 FEET FROM FUEL ROD

Fig. 54. Shield Requirements for OMRE Fuel Coffin
contained in 200 grams of Type 304 stainless steel. The irradiation times considered were 44 and 76 hours, in a thermal neutron flux of $2 \times 10^{14}$ nvt.

The total beta activity of the source is plotted in Fig. 55 as a function of decay time. In addition to the Sb$^{124}$, which is shown separately in Fig. 55, the major contribution to the activity after 30 days is from 27-day Cr$^{51}$.

Data in the literature* relating to the decay schemes of Sb$^{122}$ and Sb$^{124}$ is not complete. In order to determine the gamma-ray dose rates in water** from the neutron source, the following assumptions were made. Sb$^{122}$ was assumed to decay by emission of a beta particle followed by a 0.56-Mev gamma-ray. The following decay scheme was assumed for Sb$^{124}$:

<table>
<thead>
<tr>
<th>E (Mev)</th>
<th>Gamma-Rays Per Disintegration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.60</td>
<td>0.95</td>
</tr>
<tr>
<td>0.65</td>
<td>0.08</td>
</tr>
<tr>
<td>0.714</td>
<td>0.24</td>
</tr>
<tr>
<td>1.708</td>
<td>0.70</td>
</tr>
<tr>
<td>2.056</td>
<td>0.06</td>
</tr>
<tr>
<td>2.3</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

In determining the gamma-ray dose rate as a function of water thickness, point-source geometry was used and self absorption was neglected. Dose rates as a function of the water thickness are plotted in Fig. 56 for decay times of 30 and 60 days.

Calculations to determine the required shielding for transportation of the antimony source were based upon ICC shipping regulations, which require that the dose rate at the surface of the shield not exceed 200 mr/hr, and that the dose rate one meter from the source not exceed 10 mr/hr.††

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*NBS Circular 499 and Supplements 1950-1952.
**Measurements of Sb$^{124}$ activity in a freshly-irradiated source cannot be accurately made in air, since it will be masked by the much stronger Sb$^{122}$ activity. However, by utilizing a suitable water shield, the low-energy Sb$^{122}$ activity may be attenuated sufficiently to permit accurate determination of the higher-energy Sb$^{124}$ activity.
††Note that ICC regulations also specify that the maximum strength of any source to be transported by public carrier may not exceed: 2.0 curies of radium, polonium and other members of the radium family; or 2.7 curies for all other elements. Since a 20-curie Sb$^{124}$ source exceeds these limits, it cannot be shipped by public carrier unless special permission is obtained from the Bureau of Explosives.
Fig. 55. Beta Activity in OMRE Neutron Source
Fig. 56. Gamma Dose Rate in Water from OMRE Startup Source After Irradiation in MTR
For a 20-curie source, which is the strength required, a shield thickness of 17.2 cm of lead or 28.4 cm of steel will satisfy both of the above requirements.

XI. HEALTH PHYSICS

(L. R. Adams)

Health Physics participation in the OMRE design and planning has consisted of two phases: a hazards analysis has been prepared, and the required radiological safeguards, equipment, and instrumentation have been specified.

A. HAZARDS ANALYSIS

In the hazards analysis, attention has been focused on the following possible hazards: (1) the routine release of radioactive materials to the environment; (2) radioargon production; (3) incidents leading to the release of fission products; and (4) radiation intensity at various points at the OMRE site.

1. Routine Release of Radioactive Materials

a. Main Sources of Radioactivity - An analysis indicated that the main sources of radioactive materials would be as follows:

1. Activation of carbon atoms in diphenyl; C$^{13}$ (n, $\gamma$) C$^{14}$.
2. Activation of impurities in diphenyl; Na$^{23}$ (n, $\gamma$) Na$^{24}$, Mn$^{55}$ (n, $\gamma$) Mn$^{56}$, Co$^{59}$ (n, $\gamma$) Co$^{60}$.
3. Activation of contaminants arising from corrosion; Fe$^{54}$ (n, $\gamma$) Fe$^{55}$, Fe$^{58}$ (n, $\gamma$) Fe$^{59}$, Mn$^{54}$ (n, $\gamma$) Mn$^{55}$.
4. Corrosion of activated structural material, plus Fe$^{56}$ (n, p) Mn$^{56}$.
5. Activation of nitrogen blanket gas dissolved in coolant; N$^{14}$ (n, p) C$^{14}$.
6. Radiolytic gases, H$_2$, CH$_4$, and C$_2$H$_6$, produced from decomposition of coolant.
7. Activation of impurities in water used to cool nuclear instruments.
b. **Release Mechanisms** - The mechanisms by which radioactive materials would be routinely released to the environment appeared to be as follows:

1. Coolant leakage around seals of main coolant circulating pumps.
2. Purge of pressurizing gas blanket through vapor trap to main stack. Many of the contaminants listed above are likely to be suspended in this gas.
3. Venting of purification system vessels to main stack.
4. Discharge of instrument cooling water to ground.

c. **Calculations of Specific Activity and Rate of Release** - Calculations were made to determine the specific activity of the various isotopes and the rate of release through the various processes. The results of these calculations indicated the following:

1. The combined contribution of the various isotopes released during routine reactor operation will result in a maximum average ground level airborne concentration of about 0.1 per cent of the Maximum Permissible Concentration (or 0.001 MPC) established by the National Committee on Radiation Protection.
2. Infrequent non-routine operations such as elevation of coolant temperature and vessel depressurization will not result in an average ground level airborne concentration in excess of 0.1 MPC.
3. The activity induced in instrument cooling water will not exceed the permissible limits established by the Health and Safety Division, Idaho Operations Office.
4. Ground water contamination has been found to be negligible. The analysis included consideration of the behavior of fission-product-contaminated coolant upon being released from the coolant system.

2. **Radioargon Production by the OMRE** - Argon-41 is produced in the airspace surrounding the lower portion of the reactor vessel. It has been recommended by Health Physics that the radioargon be vented to the atmosphere through the main stack of the OMRE. Stack height calculations have shown that the height of the OMRE stack is sufficient to reduce ground level concentrations to less than 0.1 MPC.
3. Radiation Intensities at Airblast Heat Exchanger - An estimate was made of the probable radiation levels in the OMRE airblast heat exchanger. The results of the calculations indicated that radiation levels at the inlet end of the heat exchanger may vary from 100 to 400 mr/hr, depending upon the concentration of chlorine impurity in the coolant.

B. DESIGN PHASE HAZARD CONTROL RECOMMENDATIONS

Health Physics specifications and recommendations have been utilized in the design of the following items:

1. Fixed Instrumentation - Instruments for remote indication of radiation intensity levels are to be located as indicated in Table XIII.

2. Stack Monitor - A monitor will be provided to determine the activity of gases in the stack. Gas samples will be collected from the stack by a flask-sampling technique.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>Range</th>
<th>Accessories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main coolant pumps</td>
<td>0.01 - 10 r/hr</td>
<td>Beta discriminator</td>
</tr>
<tr>
<td>2</td>
<td>Coolant by-pass line filter</td>
<td>0.01 - 10 r/hr</td>
<td>Beta discriminator</td>
</tr>
<tr>
<td>3</td>
<td>Top of reactor vessel</td>
<td>0.01 - 10 r/hr</td>
<td>Beta discriminator</td>
</tr>
<tr>
<td>4</td>
<td>Control console</td>
<td>0.1 - 100 r/hr</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Entrance to exclusion area</td>
<td>0.1 - 100 mr/hr</td>
<td></td>
</tr>
</tbody>
</table>

XII. REACTOR OPERATIONS

A. GENERAL

The efforts of the Organic Reactor Development Group's operations personnel during the period covered by this report have been:

1. Review of the OMRE design.
2. Generation and accumulation of operational variables, system parameters, and other data required to establish adequate operational procedures for the facility.

3. The planning and preparation of pre-operational tests to ensure safe and adequate operability of the OMRE systems and components.

4. The training of personnel who will be responsible for the operation of the OMRE.

B. DESIGN REVIEW

The design of the OMRE system and the selection of components for the system has been reviewed in detail as design has progressed. This review and the resulting recommendations were based on a criteria of component adaptability to the overall operational scheme, adequacy of the systems to perform as required by the design criteria, accessibility of all components requiring maintenance, and overall general safety of the facility. This effort will continue until such time as the facility design has been completed.

C. PRE-OPERATIONAL TESTS

An outline is in preparation which covers the pre-operational testing program that will be conducted on the reactor components, cooling circuits, organic purification system, and service systems to verify adequate operability and to establish some of the operational parameters. The special test instrumentation that will be required during this phase of operation has been ordered. The tasks of the pre-operational testing of the facility fall into the construction and checkout phases described below:

1. Construction Phase

   a. Inspection and Operability of Inaccessible Components - System components such as buried or encased piping and associated thermocouples and heater circuits will be checked for operability and conformity to design specifications. Any malfunction of these components or deviations from design specifications shall be rectified before construction proceeds to the point where the components become inaccessible.

   b. Coolant Loop Pressure Test - The coolant loops, including the reactor vessel, the heat exchangers, and associated piping, will be pressure-tested
to 700 psig, using kerosene as the test fluid. This test will be conducted prior
to lagging and installation of heating circuits to determine the reliability of the
field assembly of the various components. Kerosene is used to deter the forma-
tion of rust and scale which would result if the conventional hydrostatic test were
used. To minimize the fire hazard associated with kerosene handling, all free
liquid surfaces in the system will be blanketed with nitrogen gas at all times.

c. Induction Heating Circuits - Each circuit, after it is installed, will
be tested for proper temperature control and heat distribution as required by the
general operational scheme.

2. Checkout Phase - Upon completion of reactor construction and instal-
lation of all associated equipment, except fuel elements, a detailed inspection
and test program will be conducted on the reactor, the controls, the safety circuits
and interlocks, the monitoring systems, the pumps, the purification system, the
fuel-handling system, and other components. The test program will be carried
out on the various reactor components, as follows:

a. Coolant System - The coolant system will be cleaned initially by
the use of in-line screens and filters to remove particulate contaminants from the
initial kerosene charge. The kerosene will be circulated by the coolant system
pumps during this period. Tests on the reactor cooling system will be made with
circulation up to and including full design flow. Special attention will be given to
possible leaks in piping or heat exchangers and to reliable pump operation.
General information will be obtained on the operability of the system pumps, heat
exchangers, valves, heater circuits, and instrumentation. The kerosene flush
will be removed from the system via the reactor drain line. Any residual kerosene
will be removed by heating the system to approximately 300° F and purging with
nitrogen gas. The purge gas will be vented at the coolant loop vents located at
the inlet to the airblast heat exchanger.

Upon completion of flushing and purging, a diphenyl charge will be melted
and introduced into the system. Operational parameters of various equipment
and servicing systems will be established at this time.

b. Reactor System - The control-and safety-rod system and associated
instrumentation will be completely checked to ensure proper operability. The
drive system will be disassembled and all linkages extending to the reactor core

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will be removed and reinstalled through the diphenyl pool as normally required by the fuel-handling procedures. Artificial shutdown alarm and interlock signals will be fed into the system and the response will be noted. Measurement of such important parameters as rod release rate and time of fall will be carefully made.

Dummy fuel elements will be charged and removed according to normal fuel-handling procedures. Handling will initially be performed on the dry core, then through the diphenyl pool at approximately 300° F. Any difficulties with the various tools, alignment, or differential expansion due to temperature will be rectified at this time.

The nitrogen supply, pressure reduction stations, and the control and relief valves will be tested for operability and adequacy.

c. **Purification System** - Operability of the purification system equipment will be established during this period. Synthetic mixtures of damaged organic will be introduced through the still supply tank and the various operation parameters of the system will be noted.

d. **Site Utilities** - Utility systems will be given nominal tests to establish adequacy of operation. These systems include the water distribution system, the electric power distribution system, and the sanitary sewage system. Slightly more rigorous testing procedures will be applied to the building-heating and-ventilating and the fire-alarm and control systems.

**D. PERSONNEL TRAINING**

The personnel who will be classified as Chief Reactor Operators and who will have the shift operational responsibility for the OMRE facility have been temporarily assigned to the Moderator Development Unit of the Organic Reactors Group. These personnel have been given the responsibility of operating Organic In-Pile Experiment NAA-20, which is located at the Materials Testing Reactor. It is felt that this work assignment will greatly aid these personnel in acquainting themselves with the problems encountered in the handling and pumping of activated organics under conditions very similar to those which will exist at the OMRE.
A. FIRST ORGANIC IN-PILE LOOP EXPERIMENT (NAA-18)* (S. Nakazato, R. H. J. Gercke)

This experiment was conducted to test the behavior of a diphenyl-ortho-terphenyl eutectic mixture being circulated and absorbing energy within a nuclear reactor. Although built and tested before desired operating conditions for the OMRE were delineated, the results obtained from this loop served as a guide for the OMRE design and the NAA-20 in-pile loop design. Specifically, the following conclusions were reached from the NAA-18 experiment:

1. The decomposition rate of the liquid is low and predictable, and such as to produce 35.8 weight per cent polymer in 2400 grams of the eutectic after an integrated exposure of $8 \times 10^{18}$ nvt by thermal neutrons, $1.9 \times 10^{17}$ nvt by fast neutrons, and gamma radiation absorption of 77 kwh.

2. The viscosity increase due to decomposition is of a low enough magnitude that it is not expected to be a problem in the operation of the OMRE. The viscosity of the original eutectic was 1.8 centipoises at 212° F, while that of the 35.8 per cent decomposed mixture was 20 centipoises. Since the temperature coefficient of viscosity changes with residue content, the viscosity ratio at a higher temperature (~700° F) will be considerably lower.

3. The melting point of circulating coolant can be expected to decrease significantly as decomposition progresses. The eutectic melting point decreased from 73° F for the original mixture to 23° F for 35.8 weight per cent decomposition.

4. OMRE process pumps and piping will be accessible for maintenance: i.e., the radioactivity of the circulating organic liquid is expected to be relatively low. The gamma activity was approximately 0.4 microcurie per milliliter after experiment.

5. The low activity also indicated that corrosion of steel by the hydrocarbon would be negligible.


1. Objectives - The NAA-20 in-pile loop was fabricated for the purpose of providing information on the behavior of circulating organic coolants under conditions of intense radiation, high heat flux, and high temperatures, such that projected operating conditions of the OMRE would be simulated. By this means, information will be obtained which will be useful for the design, the operation, and the evaluation of the OMRE.

Specifically, the following information is desired on various coolants:

a. Coolant decomposition rates
b. Fouling of heat transfer surfaces
c. Changes in physical properties
d. Corrosion rates
e. Coolant radioactivity levels
f. Effectiveness of materials, joints, thermocouple bonds, etc.
g. Heat-transfer coefficients

The following parameters will be controllable during the in-pile experiment:

a. Initial coolant composition (diphenyl, terphenyls, alkyl diphenyls, and mixtures thereof will be tested).
b. Coolant temperatures (500° to 700° F)
c. Coolant velocity (5 to 15 ft/sec)
d. Heat-transfer surface temperatures (600° to 800° F)

Since the heat flux is determined by the original heater design and the neutron flux level in the MTR, it will not be controllable during operation of the loop. It is expected that the thermal-neutron flux will be $2 \times 10^{13}$ neutrons/cm²/sec, and that the heat flux will be 200,000 Btu/hr/ft².

2. Description of Apparatus (Figs. 57 and 58) - The loop utilizes a pump, an in-pile heater, an external heater, a cooler, a flowmeter, a filter, and appropriate temperature-measuring instrumentation. Means are provided for periodic sampling. Corrosion and thermocouple specimens are included within the in-pile coolant section. Thermal- and fast-neutron flux and gamma flux will be monitored.
Fig. 57. Second Organic In-Pile Loop (NAA-20)
Fig. 58. In-Pile Heater
a. In-Pile Heater (Fig. 58) - The uranium heater was designed to produce a heat flux of 200,000 Btu/hr/ft² in the A-13 position of the MTR, where the thermal-neutron flux is estimated to be approximately $2 \times 10^{13}$ neutrons/cm²/sec. The heater consists of an enriched (2.78 per cent U$^{235}$) uranium slug assembly. This assembly is 5 inches in length, 0.398 inches in outer diameter, 0.218 inches in inner diameter, and weighs 135.09 grams. The uranium is thermally bonded by NaK to a stainless-steel tube having a 0.625-inch outside diameter. Heat generated within the uranium heater is removed by the organic at this surface. Thermocouples are appropriately located near the inner surface of the uranium cylinder and the outer surface of the stainless-tube in order to obtain the desired heat-transfer data.

One of the most difficult details in fabrication was the location of the thermocouples at the outer surfaces of the stainless-steel sheath. Thermocouple wells 0.040 inches in diameter were drilled longitudinally through the 0.065-inch wall of the stainless steel to depths of as great as 2-3/4 inches. The thermocouples, consisting of 0.005-inch chromel-alumel wires, insulated by magnesium oxide and sheathed in a stainless-steel tube, were inserted through these holes. The junction ends of each thermocouple were inserted into the 0.040-inch longitudinal holes which met holes at an angle to the axis leading to the outer surface at the required axial position. The junction ends of the thermocouple were then passed through two small holes in a 0.010-inch thick copper disc which was silver-soldered to the outer surface of the 5/8-inch tube, so that the thermocouple junction was estimated to be within 0.014 inch of the outer surface.

As shown in Fig. 58, the organic flows within an annular space formed by this outer surface and the inner surface of an enclosing mild-steel tube 0.709 inch in inside diameter and 0.875 inch in outside diameter. Velocities in this region are of the same order of magnitude as expected in the OMRE, namely 5 to 15 ft/sec. After passing through this annular space the liquid then reverses flow, passing between the outer surface of the 7/8-inch tube and the inner surface of an enclosing 2-inch pipe. The inclusion within the radiation zone of this large volume is primarily for the purpose of providing an adequate amount of decomposed liquid for physical-property and purification tests, and secondarily for the location of corrosion and thermocouple specimens, and calorimetric gamma monitors.
The entire in-pile section is located within a square, close-fitting aluminum shell, having the same external dimensions as the MTR "A-piece." Nickel and cobalt alloy wires are located longitudinally outside the corners of this shell, for the purpose of monitoring the fast- and thermal-neutron flux, respectively.

b. External Electrical Resistance Heater - The heater consists of a 3/8-inch outer-diameter stainless-steel tube with an active length of 10 inches and a wall thickness of 0.016 inch. The current enters the center terminal, where it is divided, with half of the current flowing to each outside (grounded) terminal. This heater is designed to provide the same linear velocity and heat-transfer rates as the in-pile heater.

c. Circulation System (Fig. 57)

(1) Pump - A canned-rotor pump is used for the circulation of the organic coolant. As is typical with this type of pump, the motor housing is contiguous with the pump housing, thus eliminating the stuffing box. A by-pass stream of the main circulating fluid is pumped by an auxiliary impeller through the motor housing as a lubricant for the graphite bearings and as a motor cooler. The by-pass stream then gives up its heat while passing through a heat exchanger wrapped around the motor housing, and finally flows back to the suction side of the auxiliary impeller.

(2) Fittings, Valves, and Piping - Ring-joint flanges, with oval O-rings and flat-bottomed grooves, are used at all joints between valves and piping. Other joints are welded.

Packed valves were found to be unsuitable and replaced with bellows-sealed valves.

Piping, valves, and fittings are generally of mild steel or stainless steel. Virtually all piping is electrically heated by tracing wire and insulated for pre-heating to a temperature above the melting point of the coolant used. Those tubes which must be immersed in the reactor water are placed inside larger tubes, creating an annulus within which the electrical tracing is located.

Side-stream valves and connections are provided for connecting to evacuated steel sample bombs.
d. Tanks - A surge tank communicates with but is not in the main line on the suction side of the pump. This tank serves to allow for thermal expansion and contraction of the organic coolant, and to minimize the possibility of pump suction starvation.

The feed tank, communicating with the discharge side of the line, is for the purpose of providing a ready source of melted organic, as needed.

Each of these tanks is surmounted by a vapor trap. This is merely a section of the pressurizing line which has a relatively high cross-sectional area so that diffusing organic vapors in vented gases will be slowed down and frozen in the trap rather than in the small pressurizing lines. The diphenyl in the trap would ultimately be remelted.

The "ballast" tank is for the purpose of receiving vent gases, which might contain diphenyl and/or radioactive material.

e. Filter - A filter is installed in the valve console for the purpose of protecting the pump from abrasive particles and for removing particulate radioactive materials from the flow stream. The filter element is of sintered bronze, capable of retaining all particles larger than 130 microns.

f. Diphenyl Cooling System - It is expected that during in-pile operation it will be necessary to remove heat in the order of 5000 watts (17,000 Btu/hr) from the system. This removal is accomplished by a double-pipe cooler, on the cold side of which flows a mixture of Dowtherm A and xylene having a bubble point of about 310°F at atmospheric pressure. This mixture passes from the diphenyl cooler to a reflux condenser where the vapor is condensed at atmospheric pressure by water and recirculated along with unvaporized liquid.

g. Instrumentation

(1) Temperature - Thermocouples are appropriately placed at all piping points where freezing of the coolant could conceivably occur. In addition, both the resistance heater and the uranium heater have sufficient thermocouples so that heat-transfer and heat-balance information can be obtained. These thermocouples are appropriately located on the surfaces of the heaters and in the body of the circulating coolant. The output of these thermocouples can be indicated on either a recording potentiometer or a precision potentiometer.
The output of one thermocouple near the inside surface of the uranium heater assembly and one thermocouple at the outside surface of the stainless-steel sheath will be used to actuate the MTR warning-and scram-system.

(2) Pressure - Loop pressure is measured at the surge tank and on the feed tank by means of diaphragm-type chemical pressure gauges.

(3) Flow - The flow rate of the coolant is measured by a flowrator.

(4) Electrical Parameters - Voltage and current to the external resistance heater are accurately measured in order to calculate the power input to the heater.

3. Testing of the NAA-20 Loop at Atomics International - The loop was intermittently operated at Atomics International from April 19 to June 10, 1956. Total operating time was about 430 hours.

This operation was for the purpose of determining the adequacy of various components in the loop prior to in-pile operation. Results of these tests and modifications made are discussed below:

a. Pump

(1) Bearing Wear - During the first 80 hours of operation the diphenyl became discolored. This was subsequently found to be due to abrasion of the graphite thrust face on the front bearing of the pump. The manufacturer stated that the excessive forward thrust was due to the inadvertent omission of pressure-equalizing holes which should have been drilled longitudinally through the impeller at the hub.

The loop was then operated for 180 hours with the "equalized" impeller. Again the diphenyl became discolored. After this period, it was found that the thrust face of the back bearing was appreciably worn.

The excessive wear on the thrust face of the back bearing was attributed to the fact that the second impeller had been balanced for a higher-density liquid than was used during loop operation. The back-thrust balancing at the factory had been obtained by partially drilling holes in the back shroud of the impeller near the periphery. The loop was subsequently operated with an impeller which did not have the partially drilled shroud holes (but which did have the hub holes). Furthermore, the steel thrust washers were chrome-plated to minimize scoring.
Under these conditions, operation proceeded for 170 hours at 550° F to 600° F bulk temperature without further bearing wear or discoloration of the diphenyl.

(2) Gassing - There was some evidence of undesirable heating in the motor-housing part of the pump due to evolution of dissolved nitrogen. This gassing occurred during a 100-hour run after modifications made subsequent to the first 160 hours of operation. These changes included a line for partial circulation of surge tank diphenyl into the main stream. This circulation raised the temperature of the diphenyl in the surge tank (which is pressurized with nitrogen at 300 psig) to the circulation temperature of approximately 600° F as compared with 300° F in the circulating lubrication stream within the motor-housing. Thus, an inverse gas-solubility effect, such as is known to occur in water, could cause the gassing by absorption of nitrogen at 600° F in the surge tank and liberation at 300° F in the motor-housing.

Another change which also was made after the first 160 hours was the installation of welded 1/4-inch copper tubing for external return to the auxiliary impeller of the auxiliary coolant stream. This tubing had only a 1/8-inch diameter, and hence could have caused overheating by restricting circulation.

Gassing and overheating were eliminated by installing a bleed line from the motor-housing to the surge tank, and by using a copper return-line having a larger internal diameter.

(3) Motor Secondary Coolant - The by-pass stream of main circulating fluid which is circulating through the motor-housing is itself cooled by another coolant. During the first 260 hours of loop operation, the secondary coolant was a Dowtherm A-xylene mixture, the composition of which was adjusted for a bubble point of about 310° F. This mixture was selected to prevent freezing in the motor-housing during operation with Santowax R, which melts at 293° F. This secondary pump coolant system functioned satisfactorily. However, since it was decided that diphenyl (melting point: 157° F) would be the first material to be irradiated in the MTR, and since it is desired to keep the motor-housing as cool as possible to minimize bearing wear, water at about 160° to 180° F was used as the secondary coolant for the motor in the last 170 hours of tests. (The Dowtherm A-xylene mixture was still the coolant used in the main system for cooling the diphenyl as it passed through the main cooler.)
b. Resistance Heater - The annular electrical resistance heater originally used had a 0.042-inch annulus. The heat transfer was at the surface of a stainless-steel tube 5 inches in length and 0.625 inch in outside diameter, which was enclosed by a steel tube with an inner diameter of 0.709 inches. Two models of this heater failed during loop operation due to an electrical short circuit across the annular space. The short circuit occurred at about 600 amperes and 2.75 volts across the annulus between the high voltage end of the heater section and the outside (grounded) pipe.

After the two failures a tubular heater was installed. Heaters of this type were operated successively in the loop for approximately 300 hours without incident. For over half this time, the heaters were operated at a heat flux of over 200,000 Btu/hr/ft$^2$ and a bulk diphenyl temperature of 600° F.

Preliminary data indicate that this type of heater gave satisfactory heat-transfer data, although there was some heat loss from the terminals by conduction.

c. Fittings and Valves - During the first 160 hours of loop operation, leakage occurred from fittings used in the valve console. Because of the many possible factors which could be involved in the leakage at these fittings, no conclusions could be drawn concerning the adaptability of the fitting for the service. To remedy the situation, the joints were welded wherever possible. This reduced the leakage to about 480 grams/day during the last 100 hours of operation. Although this change decreased the leakage by a factor of six, this leakage was still considered to be excessive. At this rate of leakage (and, hence, makeup of fresh diphenyl), the concentration of decomposed material in the circulating diphenyl would not approach the desired concentration of 35 per cent by weight in the limited time allotted for in-pile irradiation. Furthermore, this rate of vapor leakage might constitute somewhat of a radioactive health hazard for operators required to be in the vicinity of the console during in-pile operation.

The remaining leakage occurred primarily through the packing of the valves (Durametallic D aluminum-graphite packing). At temperatures varying from 350° to 600° F and pressures up to 300 psig, it was found necessary to tighten the eleven valves of the console intermittently. One factor contributing to the leakage was system temperature cycling, which caused alternate tightening and loosening of valve packing, probably because of yielding of the packing. Therefore,
it was decided to use bellows-sealed valves with steel O-ring seals, since these seals could be expected to remain within the elastic range under a wide range of temperatures and pressures.

The valve console was rebuilt with bellows-sealed valves, and operated at a bulk temperature of 550° to 600° F for 170 hours. During the initial 90 hours, two small leaks were detected at the valve bonnet flanges. These leaks were eliminated by replacement of the steel O-rings. No further leakage occurred.

4. Testing of the Loop at the MTR - The loop was shipped to the MTR in June after completing tests satisfactorily at AI. The loop was then reassembled and operated for 120 hours to the satisfaction of the MTR personnel. At the request of the MTR staff, a rupture disk was installed above the coolant surge tank and a pressure relief valve in the secondary coolant surge tank.

The loop was inserted into the MTR for Cycle No. 73, which began July 23, 1956. Shortly after the reactor startup, the instrument conduit developed a water leak which made it necessary to remove the experiment from the MTR. The next scheduled insertion date is August 13 for MTR Cycle No. 74.

C. HEAT TRANSFER AND FOULING STUDIES (R. H. Chesworth, S. Nakazato)

Prior to, and also concurrent with, the testing of the second organic in-pile loop (NAA-20), heat-transfer work is being done with the laboratory heat-transfer loop. Information obtained from this loop will extend much of the data obtained from the loop. Furthermore, heat-transfer conditions in the heat-transfer loop will be completely amenable to variation as desired for providing information useful to the design, the operation, and the evaluation of the OMRE.

The laboratory heat-transfer loop (Fig. 59) consists of a pump, a turbine-type flowmeter, a preheater, a heat-transfer test section, a surge tank, a melt-drain tank, and a throttling valve.

Heat transfer runs have been made thus far on diphenyl, ortho-terphenyl, and the eutectic mixture of these two fluids consisting of 30 weight per cent diphenyl. The range of operating conditions was as follows:

- Linear velocity: 7.0 to 22.0 ft/sec
- Organic bulk temperature: 500° to 700° F
- Thermal flux: 86,000 to 180,000 Btu/hr/ft²
- Heater surface temperature: 550° to 837° F
Fig. 59. Laboratory Thermal Loop
The data for diphenyl gave heat-transfer values which were approximately 12 per cent higher than those predicted from the Sieder-Tate correlation:

\[ N_{Nu} = 0.027 \left( N_{Re} \right)^{0.8} \left( N_{Pr} \right)^{0.33} \left( \frac{\mu}{\mu_s} \right)^{0.14} \]

where

- \( N_{Nu} \) = Nusselt number \( \frac{hD}{k} \)
- \( N_{Re} \) = Reynolds number \( \frac{Dv\mu}{\mu} \)
- \( N_{Pr} \) = Prandtl number \( \frac{C_p\mu}{k} \)
- \( \mu \) = Fluid viscosity at bulk temperature
- \( \mu_s \) = Fluid viscosity at wall temperature

Within the limits of experimental error, the heat-transfer coefficients for the other two liquids were approximately the same as those for diphenyl.

D. PHYSICAL PROPERTIES OF ORGANIC COOLANTS (R. H. J. Gercke)

Parallel with the loop programs, it is necessary to measure salient physical properties of organic coolants, both fresh and irradiated. These data are required for design and operation of the OMRE and its purification system. In addition, the physical properties are essential for evaluating heat-transfer characteristics.

1. Diphenyl - Ortho-Terphenyl Eutectic Mixture - Since the physical properties of this mixture, both fresh and irradiated, are discussed in NAA-SR-1592,* they will not be presented here.

2. Diphenyl - An induced activation analysis of the impurities present in diphenyl was conducted at the MTR. The irradiation was carried out on two samples of diphenyl from one chemical company (representing two separate batches), and one sample of diphenyl from another chemical company.

Each of the above samples was irradiated for a period of 16 to 20 hours in a thermal flux of \(10^{12}\) neutrons/cm\(^2\)/sec. The quantitative results as computed from the gamma-ray spectrometer curves are outlined in Table XIV.

It is interesting to note from the table that the diphenyl from Vendor II has lower inorganic impurities than the diphenyl from Vendor I by a factor of 10 to 20. This is rather surprising, since its physical appearance is brownish, compared

to the pure white crystals of the latter. A re-run of this sample was conducted and the results verified these findings. However, it should be emphasized that the diphenyl from both sources was quite acceptably pure.

TABLE XIV

**PROPERTIES OF IRRADIATED DIPHENYL**

<table>
<thead>
<tr>
<th></th>
<th>Na (ppm)</th>
<th>Mn (ppm)</th>
<th>Hg (ppm)</th>
<th>Cl (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample A (Vendor I)</td>
<td>0.19</td>
<td>0.02</td>
<td>0.01</td>
<td>--</td>
</tr>
<tr>
<td>Sample B (Vendor I)</td>
<td>0.27</td>
<td>0.01</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Sample A (Vendor II)</td>
<td>0.03</td>
<td>0.006</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

A calculation was made of the activity to be expected from contaminants in the concentrations tabulated. This calculation indicated an activity of the order of only one microcurie/cc for the above materials.

It should be kept in mind that any long-lived impurities (such as Co$^{60}$) which may also be present could not be detected on the gamma spectrometer due to the short irradiation period. However, calculations based on instrument sensitivity indicate the cobalt concentration to be less than 0.1 ppm.

3. Santowax R and Diphenyl-Santowax R Mixtures - Santowax R is a mixture of terphenyls with the following typical composition:

- Diphenyl 1.00 w/o
- Ortho-terphenyl 12.70
- Meta-terphenyl 58.30
- Para-terphenyl 26.60
- High boilers 1.40

Santowax R is a readily available material which has a vapor pressure appreciably lower than that of diphenyl. Thus, at 700° F, where diphenyl has a vapor pressure of 7.5 atmospheres, Santowax R has an estimated vapor pressure of only one atmosphere.

The chief disadvantage of Santowax R is that it is completely liquid only at temperatures above 293° F (its melting point range is 140° F to 293° F).
melting point-composition curve of diphenyl-Santowax R mixtures was determined in the hope that small additions of diphenyl would result in a significant lowering of the melting point. The data are presented in Fig. 60. It can be seen that no useful lowering of the melting point occurs upon the addition of small quantities of diphenyl.

4. Density of Santowax R - The density of Santowax R was determined in the liquid phase in the temperature range of 300° to 625° F. The density was measured by means of a Hubbard pycnometer (25 ml nominal volume). Volume corrections due to glass expansion with temperature were calculated. All weighings were carried out to the nearest ± 0.2 milligram. Temperatures were measured with a thermocouple and Rubicon potentiometer. The thermocouple was calibrated to an accuracy of 0.1° C. The maximum uncertainty of the data is 0.02 per cent.

The results are shown in Fig. 61. Data for diphenyl are shown for comparison. It can be seen that the density of Santowax R is 8 to 12 per cent higher than that of diphenyl.

5. Viscosity of Santowax R - The viscosity of Santowax R was determined in the range of 300° F to 625° F. The determinations were made with an Ostwald-Cannon type viscosity pipette which had previously been calibrated with diphenyl. The data for Santowax R are shown in Fig. 62, together with equivalent data for diphenyl for comparison. Data for Fig. 61 and 62 are from ANL-5121.*

6. Activity of Irradiated Santowax R - A sample of Santowax R was irradiated at the MTR simultaneously with the diphenyl samples previously discussed. Analytical results were as follows:

<table>
<thead>
<tr>
<th>Na (ppm)</th>
<th>Mn (ppm)</th>
<th>Cl (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.43</td>
<td>0.009</td>
<td>1.39</td>
</tr>
</tbody>
</table>

E. PURIFICATION STUDIES (G. O. Haroldsen)

Since the organic moderator-coolant decomposes under irradiation, the OMRE must include facilities for continuous or periodic purification of damaged coolant.

A batch vacuum distillation was carried out on the irradiated coolant mixture from the in-pile loop experiment. Results of this distillation are shown in

Fig. 60. Variation of Melting Point with Composition for Mixture of Diphenyl and Santowax R
Fig. 61. Density of Diphenyl and Santowax R
Fig. 62. Viscosity of Diphenyl and Santowax R
Fig. 63. As can be seen from this figure, when about 60 weight per cent is distilled, the vapor temperature begins to increase rapidly, indicating a sudden large change in composition. Since this percentage agrees approximately with the percentage of undecomposed material known to be in the original feed, a fairly sharp separation was apparently obtained.

F. HYDROCARBON EXPONENTIAL EXPERIMENT

1. Introduction - As a part of the organic moderated reactor program, a series of measurements of neutron distributions in non-multiplying and multiplying exponential systems were planned. Pure diphenyl was used as the moderator in these measurements because its atomic composition is accurately known and is similar to that of moderators to be used in proposed reactors. This report describes the measurements of neutron age and diffusion length for the non-multiplying systems.

2. Experimental System - The diphenyl was contained in a cylindrical aluminum tank 27 inches in diameter and 6 feet high (see Fig. 64). The tank was placed on a 27-inch-diameter thermal column above the water boiler reactor. Cadmium cladding over its surface prevented thermal neutrons from entering the tank except through the bottom face. Eight 1250-watt strip heaters, three of which were located on a temperature control device, were fastened to the outside surface to maintain the diphenyl temperature at $185^\circ \pm 10^\circ$ F throughout the experiment.

For measurements in the pure diphenyl, the tank was filled to a depth of 33 inches. Some measurements were made in a mixture of stainless steel and diphenyl. The steel consisted of a series of 0.064-inch-thick plates parallel to one another and held on a supporting bar with their planes vertical and spaced at 0.320 inches. The plates were cut to fill the volume of the tank to a depth of 30 inches. When they were inserted the diphenyl depth was 39 inches. Thus, the volume ratio of diphenyl to stainless steel in the mixture was 5.0.

3. Method of Measurement - Thermal and epithermal flux distributions along the vertical axis of the tank were measured by activation of bare (aluminum-covered) and cadmium-covered indium foils. These foils were fastened to the shelves of an aluminum holder with their planes horizontal and spaced no closer than 2 inches apart. Foils of 0.005-inch thickness and with areas of 1, 4, and
Fig. 63. Distillation Temperature Curve for Irradiated Coolant

FEED IS 162 GRAMS OF 35.8 PER CENT DAMAGED EUTECTIC OF DIPHENYL AND ORTHO-TERPHENYL AT 30 MM PRESSURE
Fig. 64. Location of Diphenyl Tank Above Reactor
10 cm\(^2\) were used. Provision was also made for fastening flat disk-shaped fission sources with diameters of 2 and 3-1/2 inches to the bottom of the holder. The sources were of sufficient thickness of U\(^{235}\) to absorb about 80 per cent of the thermal neutrons falling on them.

A series of vertical traverses were made with bare and cadmium-covered foils of various sizes and with and without a fission source in the holder. Regions in which different-sized foils or sources were used were overlapped sufficiently so that the ratios of the activities could be determined. Eventually, by means of these ratios, all runs relating to a given type of measurement were reduced to a common set of source and foil sizes. In addition, during each run four foils were exposed in the positions indicated in Fig. 64 for the purpose of normalizing all runs to a common integrated exposure above the reactor.

4. The Diffusion Length of Thermal Neutrons in Diphenyl - From the vertical traverses made without a fission source, the distribution in diphenyl of the thermal neutrons entering the tank bottom was obtained. Along the vertical axis, this distribution can be represented by the function \(\sinh nH\), where \(H\) is the depth below the liquid surface. The average value of \(n\) obtained from the analysis of the runs is \(0.2155 \pm 0.0024\) cm\(^{-1}\). The radial distribution in a horizontal direction can be represented by the function \(J_0(MR)\), where \(R = 34.8\) cm is the extrapolated radius of the diphenyl cylinder. This gives \(M = 2.405/R = 0.0663\) cm\(^{-1}\). The diffusion length, \(L\), obtained from the relation \(L^{-2} = n^2 - M^2\), is \(4.88 \pm 0.05\) cm.

5. The Age from Fission to Indium Resonance Energies - The difference between the cadmium-covered vertical traverses made with and without a fission source gives the indium resonance neutron distribution about the source. The distributions in the pure diphenyl and in the diphenyl-stainless-steel mixture are given in Fig. 65. Because the intensity was fairly low, all runs were made at full reactor power with the source on the tank bottom. These are the conditions under which the data of Curve \(a\) for the pure diphenyl and the curve for the mixture were obtained. The depression at zero distance may be a result of partial masking of the source by the close foil, leakage of neutrons from the system through the space between the tank and the thermal column, or the change of moderator at the interface.

For the pure diphenyl the data of Curve \(a\), at distances less than 10 cm, were obtained using the smaller fission source. Curve \(b\) is for the larger source.
Fig. 65. Distributions of Indium Resonance Neutrons About a Fission Source
Curve c is also for the large source, but with the source raised 8.0 cm above the tank bottom so that, at this close range, the neutron distribution about it would be more nearly that in an infinite medium. Curve d is the result of multiplying c by the ratio of a to b. This corrects the data to those which would have been observed for the smaller source in the elevated position. Though the data for d still indicated a depression at the origin, it has been drawn horizontal to the origin to comply with the distribution that would be expected for a non-absorbing point source.

All of the data for the mixture were taken with the large source. These can be corrected by multiplying by the product of the ratios of a to b and c to b. This assumes that the distributions are similar enough to permit the measured corrections for the pure diphenyl to be applied to the mixture.

For the finally-corrected distributions, the integrals of the second and fourth moments were determined. At distances beyond those for which data were taken, the distribution was obtained by linear extrapolation of a semilogarithmic plot of its second moment. The mean-square crow-flight distance a neutron travels from fission to indium resonance energies is given by the ratio of the integrals of the fourth and second moments of the indium resonance distribution. One-sixth of this, which may be called the age, is $50.2 \pm 1.5 \text{ cm}^2$ for the pure diphenyl at $185^\circ \text{ F}$ and $51.3 \pm 2.5 \text{ cm}^2$ for the mixture. The errors quoted are not standard deviations but estimates based on the limits of accuracy in curve plotting and extrapolation.

The corrections to the distributions near the source account for about a 3 per cent correction to the age. Though the present data did not permit the correction to be carried to zero source and detector size, this is not expected to introduce much additional systematic error.

Another source of systematic error that has not been corrected for in the present work results from the fact that the activated indium foils were counted only on the side facing the source. The remote side, if counted, would in general show a smaller saturated activity by an amount dependent on the distance from the source. Measurements of indium resonance activity made with a mock fission source in light water indicate that (1) beyond 10 cm from the source, the ratio of the activity counted on the near side to that counted on the remote side of the foils
is constant, and therefore whether one counts one side or the other does not affect the shape of the resultant distribution; and (2) the ratio is relatively higher by about 5 per cent in the region 0 to 5 cm. If the situation in diphenyl is assumed to be similar to that in water, the resultant systematic error in the measured age would be small compared to the 1.5 to 2.5 cm$^2$ quoted above.

The leakage of neutrons from the system will tend to make the observed flux far from the source low compared to that in an infinite medium and hence will make the observed age low. Rough calculations indicate that the flux may be a few per cent low at 45 cm from the source. This is the maximum distance to which measurements were carried. The statistical errors in this region are already about 30 per cent; hence, the statistical error in the extrapolation from this point on may be expected to dominate over the errors arising from leakage.
APPENDIX

DESCRIPTION OF REACTOR AND FACILITIES
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A. GENERAL DESCRIPTION

The OMRE will be constructed and operated at the National Reactor Testing Station (NRTS) near Arco, Idaho. The site is in the south-central area of the NRTS (Fig. A1) approximately three miles east of the Central Facilities Area (CFA) and two miles south and west of the Special Power Excursion Reactor Test (SPERT) Site. The existing facilities and the nature of the location will permit the most economical approach to such problems as shielding, venting of exhaust gases, waste disposal, and reactor containment.

The principal components of the OMRE facility consist of the following:

1. A pressurized diphenyl-moderated and -cooled thermal reactor to simulate the conditions of neutron and gamma fluxes which will be encountered in organic power reactors.

2. A heat-transfer system which utilizes the organic moderator as a coolant to remove the heat generated in the reactor; this is accomplished through suitable pumps and piping, which transfer the heat to an airblast heat exchanger where it is rejected to the atmosphere.

3. Instrumentation and control equipment required for operation of the reactor and purification systems and instrumentation for measurement of experimental parameters.

4. A purification system for removing the thermal- and radiation-damaged constituents from the organic coolant.

5. Auxiliary equipment which provides for emergency afterglow cooling, inert-gas venting, organic melting and filling, draining, and preheating the vessels and piping.

6. A prefabricated, insulated "Butler" type building for housing the pumps, control valves, and purification system on one side of a shielding wall, and the reactor control console and electrical facilities, the mechanical room, the chemical laboratory, and the sanitary facilities on the other side of this wall.

7. The OMRE area, a 400- by 330-foot rectangular plot enclosed by an 8-foot high woven wire fence.
Fig. A1. NRTS Map
Essential site facilities will be provided which will include an electric power supply with a 900-kva combined transformer capacity, a gasoline-engine driven 18-kva emergency generator, telephone communication lines, fire and security alarm systems, a well water supply with a 20,000-gallon storage tank, fire protection equipment, sewage and waste-water disposal facilities, building heating and ventilating equipment, an access road from the southeast, a security guard house, and a parking area.

B. PLANT LAYOUT

The over-all arrangement of the OMRE facility is shown in an artist’s perspective, Fig. A2, and the general layout is shown in Fig. A3. The reactor will be located outside of the operations building under a corrugated sheet-steel shed to protect the control element drives from the weather and to provide shelter for maintenance personnel. The reactor vessel, a low-alloy steel pressure tank 28 feet tall and 4-1/2 feet in inside diameter, will be for the most part buried underground. The core will be located in the lower part of the reactor tank and will lie well below ground level. Inlet and outlet coolant pipes are attached to the tank just below and above the reactor core. From the tank they pass horizontally through separate tunnels to a pipe well where they make a vertical traverse to ground level. The hot outlet pipe then goes to the operations building, which houses the pumps, and from the pumps it goes out-of-doors to the airblast heat exchanger. The inlet pipe goes to the cold end of the airblast heat exchanger and completes the coolant loop.

The operations building (Fig. A3) will be a one-story, steel-frame structure having 32 by 84 feet of floor space. It will be divided into two areas which are separated by a two-foot-thick concrete slab wall. The area adjacent to the reactor and airblast heat exchanger is "open bay" and is referred to as the process area. It will contain the coolant pumps and valves, the purification system, the air compressor for pneumatically-operated valves and instruments, and various related equipment. Because of its proximity to the reactor and because it will contain the coolant pumps, piping, and purification system, the process area will be radioactive. The area away from the reactor and heat exchanger is subdivided into the control room, the chemical laboratory, the mechanical room, and the lavatory. In the control room will be the instrumentation and control console for
Fig. A2. OMRE Facility Perspective
Fig. A3. General Layout
the reactor, the instrumentation for the heat-transfer and purification systems, and the valve-stem gear-drive handles which pass through the concrete wall to permit remote mechanical manipulation of valves in the radioactive process area. The control room will also house all of the electrical switch-gear. The laboratory will be provided with a fume hood and sampling and testing equipment to be used in chemical analysis of the organic coolant and its decomposition products. A 20- by 40-foot lean-to will be attached to the operations building and shielded from the reactor and the process area by an extension of the concrete slab wall. It will also be of steel frame construction and will be referred to as the storage area. This area will house the non-radioactive part of the process equipment that requires shelter, such as the nitrogen supply and manifolds, the hydrocarbon supply, and the melt station. It also will be used for general storage of such items as maintenance equipment and spare parts.

Separate ventilation systems will be provided for the three principal areas described above. An exhaust stack with an induced draft fan will be provided on the roof of the operations building for venting gases and vapors from the reactor and process area. This stack will be 16 inches in diameter and will exhaust 37 feet above floor level. The melt tank in the storage area will have a hood with a separate induced draft fan and vent pipe. Likewise, the ventilation system for the operations area will be independent of the other systems. Use of separate vent systems minimizes the hazards of spreading radioactivity or fire from one area to another.

C. REACTOR

1. Reactor Core - A plate-type stainless steel-UO$_2$ fuel element has been selected for the OMRE because of its large surface-to-volume ratio and the advanced state of development of its manufacturing technology. Each fuel plate will consist of a 20-mil thick central matrix of approximately 25 weight per cent fully enriched UO$_2$ and 75 weight per cent stainless steel, clad on each side with 5 mils of stainless steel. The plates will be separated by a 134-mil coolant gap. Each element is to be assembled from 16 fuel plates placed between inactive end and side closure plates so as to form a rectangular box 2.8 by 2.9 inches in cross section. The active dimensions of the fuel plates are 36 by 2.5 inches. The plates will be supported by end boxes which are positioned and held in a 4-1/2-inch square
lattice by an upper and a lower grid plate. An artist's conception of the fuel element together with the end fittings is shown in Fig. A4.

Twenty-five fuel elements with a total $^{235}U$ content of 20.6 kg are estimated to be required to provide sufficient excess reactivity to compensate for temperature effects, xenon poisoning, and fuel burnup. One space in the lattice is reserved for the neutron source, and eleven additional spaces will be provided to allow for additional fuel elements, if required.

Coolant from the bottom plenum enters the lower end boxes, flows upward between the fuel plates into the upper end boxes, and discharges into the interstitial space between the fuel elements. It then flows downward around the outside of the fuel elements to cool the control rods and thermal shield. A final pass in the annular space between the thermal shield and the reactor tank discharges the coolant to the pool above the reactor core.

2. Control Elements and Drives - The reactor is controlled* by 12 hydraulically-driven control rods symmetrically located between the fuel elements (Section A-A, Fig. A5). Four of these rods are located on a 3.2-inch radius circle with respect to the centerline of the core, and eight are located on a 7.1-inch radius circle. The poison material is contained in a 1-1/4-inch OD stainless-steel tube with a wall thickness of 1/8-inch. The tube has an active length of 36 inches of compacted boron carbide powder with a boron density of from 1.75 to 1.9 gm/cc. The 12 rods are hung in pairs on 6 hanger rods, as shown in Fig. A5. Vertical alignment of the assembly is maintained by guide holes in the control rod bridge and the upper grid plate.

It is presently planned to electromagnetically couple the hanger rods to the hydraulic drives. The magnetic coupling is shown in Detail C of Fig. A5. The iron core of the magnet (23.75 inches long) is fastened to the hanger rod. The core is located in a steel thimble which seals the pressure vessel from the surrounding atmosphere. Solenoid coils placed outside the thimble are attached to and driven by the hydraulic piston. The clearance between the iron core and the thimble is rather small, and binding because of possible misalignment between the thimble and the control rod guide holes is prevented by two universal joints.

*The control rods also function as safety rods. No separate safety rods are used in the OMRE.
Fig. A4. OMRE Fuel Element
Fig. A5. Reactor and Control Rods
in the hanger rod, one just above the shock absorber mechanism and the other just below the iron core.

Motion of each pair of control rods can be controlled independently by a 3-position air-operated valve which admits hydraulic fluid under 150 psi pressure to either the top or bottom side of the hydraulic piston. Displaced fluid is returned to a reservoir. Hydraulic pressure is maintained by a positive displacement pump and a relief valve in a by-pass line. The maximum speed of control-rod withdrawal, which is 1.7 inches per minute, is fixed by the capacity of the pump.

"Up" and "down" limit switches and a Selsyn-type position indicator system are provided on each of the 6 sets of solenoids. The position of the rods is known only when a definite coupling is established between the solenoid coils and the iron core inside the thimble. It is planned to rely on inductance measurements for indication of whether or not a definite coupling exists between the iron core and the solenoid coils.

A reactor scram de-energizes the coils and allows the rods to fall freely except for the small viscous drag and buoyant force of the diphenyl. A dashpot and spring snubber engages the control-rod bridge and decelerates the rods in the last 6 inches of travel. The control-rod drive mechanisms may be removed as a unit.

A prototype of the hydraulic drive mechanism and electromagnetic coupling will be thoroughly tested by Atomics International prior to use on the OMRE. A mechanical system of the rack-and-pinion type with mechanical shaft seals will be used if the proposed electromagnetic system should prove to be unsatisfactory.

3. Reactor Vessel and Thermal Shield - The reactor vessel is a mild alloy steel (1/2 per cent molybdenum - 1 per cent chromium) pressure tank, 4-1/2 feet in internal diameter, 28 feet high, and with a wall thickness of 1 inch. The vessel is designed according to the ASME Unfired Pressure Vessel Code and will be so stamped. It will be fully stress-relieved and all welds will be 100 per cent X-rayed. The design conditions are: pressure - 400 psig; temperature - 850° F; stress - 14,200 psi. There are two flange-type closures above the diphenyl level of the tank: the tank head flange and the control-rod drive assembly flange. Both are sealed with "Flexitallic" gaskets made of a composite material of stainless-steel strip and asbestos filler.

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A 2-inch-thick thermal shield is located inside the vessel and separated from its walls by a 2-inch annular passage. It rests on the lower grid-plate support which is welded to the inner wall of the vessel. The upper grid plate and control-rod bridge are in turn supported by the thermal shield.

A spent-fuel storage rack is provided along the wall of the tank above the upper grid plate level. It is supported by brackets welded to the wall of the tank. A thermocouple is placed near the tank wall to measure the coolant temperature in the stored fuel region.

The reactor vessel is supported on a circular concrete slab 2 feet thick and 11-1/2 feet in diameter which rests on bed rock. A corrugated galvanized-steel liner 10 feet in diameter and extending from the foundation to the surface of the earthfill lines the cavity around the reactor vessel. The fill slopes away from the reactor cavity area for a distance of about 16 feet at a 30 degree angle to grade level. A 6-inch-thick concrete shelf is built into the annular space between the cavity liner and the reactor vessel at a level just above the outlet coolant pipe. The space above the shelf is filled with sand and serves as an inexpensive biological shield. An upper slab of concrete 6 inches thick is placed around the top of the reactor tank just below the head flange and gas vent lines to provide a floor and support for the reactor shed.

D. HEAT TRANSFER SYSTEM

1. Main Heat Transfer Loop - Most of the heat generated in the OMRE is transferred to the airblast heat exchanger by the main heat-transfer loop. A small auxiliary cooling loop having a capacity of 100 kw is provided to remove the afterglow heat during normal pump shutdown and in the event of a failure in the main loop. A single 16-inch pipe line carries the coolant from the reactor to the operations building. Before entering the building, the flow is divided between two 10-inch lines. Each of the 10-inch pipes go to a separate pump in the operations building and from there to one of the two sections of the airblast heat exchanger. On the discharge side of the heat exchanger the flow combines into a 16-inch line and is returned to the reactor. A schematic flow diagram is shown in Fig. A6.

2. Main Pumps - The two pumps of the main heat transfer loop are operated in parallel. These pumps are commercial refinery-type high-temperature
Fig. A6. Schematic Flow Diagram
centrifugal pumps with conventional mechanical shaft face-seals. The seal housing, pump supports, and bearing housing are directly cooled with water; the mechanical face seal has a separate water-cooled hydrocarbon loop (from the discharge to the suction side of the pump). Leakage is estimated to be about 16 fluid ounces per hour per seal. Each pump is powered by a 150-horsepower constant-speed motor and has a capacity of 3600 gpm at a 55-psi differential head across the pump. Flow control is achieved by means of globe throttle valves located downstream from the pumps. A gate valve is placed at the suction side of each pump and on the discharge side of each section of the heat exchanger to permit the removal of either pump and its corresponding heat-exchanger section from the system.

3. Airblast Heat Exchanger - The airblast heat exchanger contains two sections of air-cooled aluminum-finned steel pipes; the cooling air is delivered by two variable-pitch fans driven by constant-speed motors. Additional cooling control is obtained by manually-operated louvers installed over the tube bundles and headers. Doors are provided between the fans and the tube bundles to close the unit for preheating. These doors can also be used for additional cooling control. Preheating is accomplished by means of an oil-fired preheater, which supplies hot combustion gases diluted with air directly below the finned tubes. The heat exchanger will be fabricated according to the ASME Unfired Pressure Vessel Code. It will be halogen-leak tested and all welds will be dye-penetrant checked.

4. Expansion Tank - From its melting temperature to 700°F, the volume of the hydrocarbon increases by about 34 per cent. It is impracticable to provide space in the reactor vessel for this expansion. An expansion tank has therefore been provided. This is a horizontal tank, 3-1/2 feet in diameter and 20 feet long, directly connected with the reactor through both the liquid and gas spaces. The tank is located above ground (but below the level of the cover flange of the reactor vessel) in the area between the reactor and the operations building (Section A-A, Fig. A3). The gas spaces in the reactor vessel and the expansion tank are connected to the stack by a vent line equipped with a vapor trap. With this arrangement, the hydrocarbon level will increase from 14 feet above the core at 300°F to 17 feet above the core at 700°F.
5. Drain Tank - A drain tank which can hold the contents of the entire heat-transfer system is located in a 14- by 24- by 12-foot underground concrete vault adjacent to the lean-to. An 2-inch drain line connects the bottom of the reactor vessel to the top of the drain tank. The highest point of the line is well above the level of the reactor core, and in order to drain those parts of the system which lie below this point, it will be necessary to pressurize the system with respect the drain tank. To reduce the probability of dumping the coolant from the system because of a valve failure, two valves in series are provided in the drain line. These are normally locked closed.

Although the drain tank is vented to the exhaust stack, a 50-psig rupture disk is included on the tank to exhaust to the drain-tank vault in the event the vent-line valve is inadvertently closed.

6. By-Pass Heater Loop - The function of the by-pass heater loop is to provide continuous information on the change of heat-transfer characteristics of the coolant during operation of the reactor.

This loop is connected across the main heat-transfer loop in parallel with the reactor. It includes a micrometallic filter, an electric resistance heater, and a turbine-type flowmeter. The power input to the heater is such that the heat flux at its surface is of the same order of magnitude as the heat flux prevalent at the surface of the fuel elements. The flow through the by-pass heater loop is normally 20 gpm, but will be throttled down to 3 to 10 gpm during heat-transfer-coefficient measurements.

7. Auxiliary Cooling Loop - A small auxiliary cooling loop is installed across the inlet and outlet lines of the reactor vessel in parallel with the main heat-transfer loop. Its cooling capacity of 100 kw of heat is adequate for removing sufficient decay heat following reactor shutdown to ensure against boiling of the coolant in the core. The pump for this loop is connected to the emergency power supply. The loop will normally operate at a flow rate of approximately 14 gpm and will be ready to dissipate the decay heat load in the event of failure of the main heat-transfer loop.

8. Pressurization - The heat-transfer system is designed for an operating pressure of 400 psia. It will normally be pressurized to 300 psia with nitrogen to prevent boiling of the hydrocarbon. For diphenyl, this pressure corresponds
to a saturation temperature of 850° F. The estimated maximum fuel-plate surface temperature in the OMRE is 800° F. The vapor pressure of diphenyl at this temperature is 220 psia.

E. INSTRUMENTATION AND CONTROL

1. Nuclear Instrumentation - Three types of neutron detectors will be used to monitor the reactor flux in the range between source level and full power. Near source level, two BF$_3$ channels with a sensitivity of 4 cps/nv and a range of up to $10^4$ nv will supply signals to a linear count-rate meter and a log count-rate meter (Fig. 55, Section VI, B). In the intermediate range, two compensated ion chambers with a sensitivity of $10^{-14}$ amperes/nv will feed to the log N amplifiers. These amplifiers will provide a signal for the log N recorder, period indicator, and safety circuits. The log N amplifiers have a range of six decades. In the power range, two compensated ion chambers with a sensitivity of $10^{-14}$ amperes/nv will be used over two decades of power. These chambers will supply a signal to the power-level safety chassis and the power-level recorder. The power-level recorder will supply operating signals to the flux controller. The ranges of these detectors have been selected so that they will overlap and eliminate "blind spots" in neutron detection.

2. Experimental Instrumentation - Additional instrumentation will be used in the critical assembly and for the study of the variation in the heat-transfer characteristics of the coolant. The critical assembly will require the use of three boron-10 counters which will be placed in thimbles inserted in the core. Two of the counters will be connected to the circuits used by the BF$_3$ chambers, and the other counter will be connected to a scaler. The heat-transfer characteristics of the coolant will be studied by means of the by-pass heat-transfer loop. A turbine type flowmeter, sixteen thermocouples, and a heater power meter will be provided to make the required measurements.

3. Process Instrumentation - The operational instruments consist largely of pressure gages, flowmeters, temperature indicators and recorders, liquid level indicators, radiation detectors, ammeters, and electric power meters.
a. **Pressure Gages** - Seventeen pressure gages, which may be either indicating or recording gages, will be installed. The number to be installed and location of each instrument are given below.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Outlet line of reactor vessel</td>
</tr>
<tr>
<td>2</td>
<td>Outlet of primary coolant pumps</td>
</tr>
<tr>
<td>1</td>
<td>Outlet of main airblast heat exchanger</td>
</tr>
<tr>
<td>1</td>
<td>Still supply tank</td>
</tr>
<tr>
<td>1</td>
<td>Drain tank</td>
</tr>
<tr>
<td>1</td>
<td>Waste hold tank</td>
</tr>
<tr>
<td>1</td>
<td>Distillate hold tank</td>
</tr>
<tr>
<td>1</td>
<td>Feed tank</td>
</tr>
<tr>
<td>1</td>
<td>Inlet to still pump</td>
</tr>
<tr>
<td>1</td>
<td>Line from inert gas manifold to still supply tank</td>
</tr>
<tr>
<td>1</td>
<td>Reactor gas pressure</td>
</tr>
<tr>
<td>2</td>
<td>Nitrogen pressure before inlet reducing valves</td>
</tr>
<tr>
<td>1</td>
<td>Vacuum still</td>
</tr>
<tr>
<td>1</td>
<td>Nitrogen inlet to reactor vessel</td>
</tr>
<tr>
<td>1</td>
<td>Nitrogen pressure before outlet reducing valves</td>
</tr>
<tr>
<td>1</td>
<td>Instrument air compressor</td>
</tr>
<tr>
<td>1</td>
<td>Water booster pump discharge</td>
</tr>
<tr>
<td>1</td>
<td>Process water header</td>
</tr>
</tbody>
</table>

b. **Flowmeters** - Twelve flowmeters will be incorporated into the heat-transfer and purification system. The number to be installed and location of each instrument are listed below.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reactor nitrogen outlet to the stack</td>
</tr>
<tr>
<td>1</td>
<td>Reactor nitrogen outlet to the stack</td>
</tr>
<tr>
<td>1</td>
<td>By-pass heater loop</td>
</tr>
</tbody>
</table>
c. Temperature Indicators and Recorders - Approximately eighty temperatures throughout the system will be monitored. The more important of these temperatures will be continuously monitored; the others will be noted at intervals. Instrumentation provided for this purpose will consist of three multiple-point recorders, eight multiple-point indicators, four single-point recorders, and eight single-point indicators. The location of temperature measurements may be seen in the Piping and Instrumentation Diagram, Fig. A7. All of the tanks and vessels of the heat-transfer and purification system will be equipped with temperature-indicating devices. In addition, seven fuel elements within the core will be continuously monitored to protect against possible excessive fuel temperatures. These fuel elements will be equipped with five thermocouples, three on the hottest plate, and two at the outlet from the hottest channel; any one of these may be selected for the temperature indication on the main control panel.

d. Liquid Level Indicators - Instrumentation will include a continuous indication of liquid level in the following vessels:

1. Reactor vessel
2. Drain tank
3. Feed tank
4. Distillate hold tank
5. Vacuum still
6. Still supply tank

e. Radiation Detectors - In addition to having the stack gases continuously monitored, the areas listed below will be equipped with radiation detecting instruments.

1. Main coolant pumps
2. By-pass heater line filter
3. Top of reactor vessel
4. Control console
5. Entrance to exclusion area

4. Reactor Control - The purpose of the reactor controller is to hold the neutron flux at a level that will maintain the surface temperature of a selected fuel plate at some predetermined value. A block diagram of the reactor controller system is shown in Fig. A8. Its operation may be described as follows: The reactor flux is controlled by a commercial controller with proportional rate and reset action. The controller receives its flux signal from the power level recorder. The set point for the flux controller is also built into the recorder. Thus, the controller derives a flux error signal and moves the rods in such a direction as to reduce this error to zero. The reset action ensures that the flux error will always be reduced to zero, regardless of drift, load disturbances, etc. The rate action improves the dynamic performance by reducing overshoots. Proportional action ensures prompt rod motion for any change in either set point or load disturbances.

In order to obtain this three-mode control, a rod-position signal is required for proper controller functioning. A true rod-position signal is difficult to obtain, since there are several combinations of rod motion which can be used with the flux controller. Therefore, a rod-position signal will be obtained from a potentiometer which is driven by a low-inertia motor. This motor will be energized each time the rods are moved up or down. Thus, the position of the potentiometer will correspond approximately to the rod position. It is not necessary to have exact correspondence, since any difference between the rod speed and motor speed will only slightly affect the gain of the controller, and will not affect its ability to hold the flux at the desired value.

The set point for the flux controller will be changed by varying the potentiometer in the flux recorder. This is done automatically by a set-point drive motor. This motor will be energized by a temperature error signal derived from contact with one of the fuel-element temperature indicators. Thus, the flux-controller set-point drive motor is driven in the proper direction when the fuel element surface temperature deviates from its set point. The rate at which this set point changes can be adjusted so as to give the optimum speed of correction. This
Fig. A8. Reactor Controller Block Diagram
motor can also be operated manually so that the flux or temperature can be manually adjusted to a desired level. Interlocks are provided to prevent the automatic flux controller from being energized when the flux differs appreciably from its set point.

F. AUXILIARY SYSTEMS AND EQUIPMENT

1. Purification System

a. Method Purification - The purification system uses a vacuum distillation process for removal of the radiation-damaged portion of the hydrocarbon. The system is a batch system consisting of a still operating without reflux. The batch system was selected for several reasons: (1) It lends itself very well to frequent startup and shutdown operations. Unlike a continuous system, there is no concern about getting it "on stream." (2) The reclaimed hydrocarbon need not be a narrow cut or a specific cut. Rather, the requirement is that the hydrocarbon contain less than a certain maximum permissible concentration of heavier components, which a batch system can do as well as a continuous rectifying column. (3) The batch system lends itself to better handling of material over a wide range of processing rates. (4) Because experimental data indicate that a batch system without reflux adequately separates the higher boiling components from the coolant, such a system appears most suited to provide the versatility required for an experimental program such as the OMRE.

A schematic flow diagram of the purification system is shown in Fig. A9.

b. Description of Equipment - The system includes the following equipment:

1. Still supply tank
2. Vacuum still
3. Distillate hold tank
4. Still pump
5. Distillate cooler
6. Still vapor trap
7. Vacuum pump
8. Waste hold tank
9. Waste storage tank
Fig. A9. Schematic Flow Diagram of Purification System
All this equipment, with the exception of the waste storage tank, is located in the process area. The waste storage tank is buried below ground level next to the operations building.

The still supply tank receives damaged hydrocarbon in the desired quantity and rate through a feed line from the by-pass heater loop. From the supply tank, the material is transferred in 580-pound batches to the vacuum still.

The vacuum still is a 200-gallon vessel with four 1-1/2-inch pipes and one 3-inch pipe extending down from the bottom of the tank. The 3-inch pipe is located in the center and the 1-1/2-inch pipes are spaced 90° apart on a radius of fifteen inches. The four 1-1/2-inch pipes are formed to join the central 3-inch pipe at a point four feet below the tank. This provides four natural convection loops with a common cold leg – the central 3-inch pipe. The four 1-1/2-inch pipes will be heated by an electrical induction-heating system. The choice of this heating arrangement was selected to reduce the effects of unsteady boiling characteristics usually encountered in boiling at low pressures in pot-type vessels. A pump to circulate the material through a tubular heater would have presented another approach, but it was desired to avoid the problems associated with operation of a pump under a vacuum at high temperature.

The electrical induction-heating system for the still will be controlled by the still pressure-recorder controller. Heat cannot be applied to the system unless the pressure is less than 30 mm Hg. On the other hand, heat is automatically turned off if the pressure rises above 30 mm Hg.

The condensing system employs a direct-type condenser, actuated by a stream of cold distillate, to quench the vapors from the still. This is similar to the barometric condenser common in chemical processing except that it discharges into the distillate hold tank, which is maintained at low pressure, thus eliminating the need for a hydraulic leg. The direct-type condenser was selected over a conventional surface condenser to circumvent the problem of the distillate freezing during the latter stages of a distillation run when higher-freezing-point material is being collected.

The distillate from the condenser is collected in the distillate hold tank. From there it is recirculated by a canned-rotor pump to the still cooler and back to the condenser. Since this is a relatively low-temperature operation, pump
problems are not expected to arise. The still cooler consists of a coil immersed in a bath of boiling water. Boiling water at atmospheric pressure is a suitable medium for extracting the heat, since its temperature is sufficiently high to prevent freezing of the diphenyl. A boiling-water cooling system is simple, and easily lends itself to steady temperature control.

The still vapor trap, which condenses the vapors in the gas stream drawn from the distillate hold tank by the vacuum pump, consists of an inclined helical finned pipe. The temperature is controlled so as to promote as much refluxing of the liquid hydrocarbon as possible in the entrance portion of the trap and to freeze out the remaining material in the exit portion. Periodically, the line from the trap to the vacuum pump will be closed and the trap heated, permitting the frozen deposit to melt and flow back into the distillate hold tank.

After processing a batch of hydrocarbon, the system is let down to atmospheric pressure in preparation for discharging the reclaimed material and the waste. The reclaimed hydrocarbon is transferred by gravity from the distillate hold tank to the feed tank. The waste from the still is discharged by gravity to the waste hold tank and then to the 5000-gallon underground waste storage tank.

Associated with the purification system is a sampling system which permits sampling of the still bottoms, recirculating distillate, still overhead, and the hydrocarbon passing through the by-pass heater loop. All of these samples are conducted by 1/2-inch lines from their point of origin to the sampling hood located in the laboratory area. Here, the samples are collected in U-tubes located in the hood. The still-overhead sample, which is a vapor sample, is withdrawn through a heated line (600° F) by a small vacuum pump and condensed in a cold U-tube. The excess material from these samplers drained by gravity into the waste storage tank.

2. Organic Melt and Fill System - Diphenyl is received at the site in powder form. It is melted at 157° F in a 22-kw heated melt tank which is designed to bring a 150-gallon batch of diphenyl to a temperature of about 300° F in 6 hours. At this temperature the diphenyl will be drained by gravity into either the drain tank or the feed tank. A strainer in the outlet of the melt tank prevents particles of foreign matter from entering the system.
The heat-transfer system is filled at the expansion tank from the drain or feed tank by means of a 1-1/2 gpm feed pump which is capable of delivering a 300-psi head. This pump is a diaphragm-type pump which is located in the process area.

As the heat-transfer loop is filled, gas is vented at the two high points of the system which are at the nozzles of the heat exchanger. A float in each vent line automatically closes the vents when the loop is full. During normal operation the vents are not in use and will be closed with gate valves.

3. Nitrogen System - Nitrogen is used as the inert gas for the OMRE. It serves three functions: (1) to pressurize the reactor system to 300 psia, (2) to provide an inert atmosphere at all free surfaces, and (3) to dilute and purge the hydrogen and light hydrocarbon gases generated in the thermal and radiolytic breakdown of the organic moderator-coolant.

The nitrogen is supplied from standard cylinders through a system of reducing- and control-valves and manifolds. A duplex system with ten cylinders in each of two banks is arranged for automatic switchover when one bank has been depleted.

The nitrogen system is designed to supply a continuous purge flow of 30 scfh and at the same time maintain a pressure of 300 psia in the reactor vessel. For this purpose, the purge-gas control valve is set at 310 psia and a back-pressure control valve in the reactor vent line is set at 300 psia. The value of flow resistance that gives the required flow rate at a 10-psi pressure differential is then obtained by adjustment of a needle valve.

An emergency gas-supply control valve is provided in parallel with the purge-gas control valve. Its function is to open when the purge-gas control valve cannot supply sufficient gas to maintain the reactor pressure. It is set to open when this pressure reaches 290 psia. Similarly, an emergency relief valve is placed in parallel with the back-pressure control valve. A by-pass globe valve in parallel with each set of regulating valves allows for manual adjustment of the reactor pressure. A rupture disk is located in the 2-inch line which is connected to the vent line of the reactor tank. This will break at 600 psia in the event the relief valves fail and the pressure builds up so rapidly that the operator does not have time to relieve it manually. The 2-inch rupture disk line is connected to a
vertical 4-inch stack just outside of the reactor shelter. An emergency valve is incorporated in the rupture disk line to prevent excessive pressure drops after failure of the rupture disk.

4. Venting Facilities - All parts of the OMRE process requiring venting are connected by a network of piping and ducts to the exhaust stack. The reactor and drain tank vent lines join and run directly to the stack. All other vent lines from the process area first enter a vent header. The stack is 16 inches in diameter and discharges 37 feet above floor level. The stack and the induced draft fan are supported on a platform on top of the concrete shield wall which divides the operating building. Four guy wires fastened to the roof of the building give lateral support to the stack. The fan draws air from the various hoods in the process area and discharges it to the base of the stack.

There are two vapor traps in the process vent system. One of these vapor traps, which consists of a small tank filled with subcooled diphenyl, is used to trap the hydrocarbon vapor-gas mixture leaving the reactor tank. The second, an air-cooled unit, is installed in the vent line from the distillate hold tank to reduce the hydrocarbon content of the gases withdrawn from the purification system by the vacuum pump.

5. Preheating Equipment - Since diphenyl freezes at 157°F, some means of preheating is necessary before it can be introduced in the system. Once the system is filled, heat must be supplied to prevent subsequent freezing or to make up for the heat losses occurring at specified temperature levels. Temperatures in the heat-transfer loop can be maintained during operation by the thermal power of the reactor. With the exception of the waste storage tank, all other portions of the system which contain the hydrocarbon require a continuous external heat source.

Induction heating with 60-cycle current satisfies the greater part of the electrical heating requirements. Resistance heating is used for the melt tank and equipment such as pumps and valves which are difficult to heat by induction because of their geometry. Induction-heating coils are wrapped on the outside of the insulation of the pipes and vessels. Small equipment is heated by 120-volt circuits, while large equipment such as tanks and 16-inch pipe use 240-volt circuits. Manual control of heating is provided everywhere except on the purification
system, which is equipped with semi-automatic control. The total electrical heating load is supplied by a 250-kva, single-phase transformer.

The finned-tube airblast heat exchanger is heated by fuel-oil combustion gases diluted with air. The combustion unit is located under the heat exchanger between the fan pedestals, and the hot gases are ducted to each side around the fans. One blower supplies combustion air to the burner, and another blower supplies the excess air. Fuel oil is pumped from the main fuel-oil storage tank.

5. Water Cooling System - Cooling water for various components is supplied from the main water system. The supply header is located in the control room, and the various valved branch lines pass through the 2-foot-thick concrete wall into the process area. A total of about 50 gpm is supplied to the following: six nuclear instruments adjacent to the reactor vessel; main pump seal-coolers, seal-housings, bearing-housings, and supports; still cooler; air compressor; and by-pass-heater-loop flow meter.

A 20,000-gallon water storage tank is provided. It will supply the required emergency cooling flow for about 7 hours. For this purpose, the booster pump is connected to the emergency power supply.

G. SHIELDING

1. Reactor - Shielding against direct core radiations (including secondary capture gamma rays) is obtained by placing the reactor core well below ground level. The location of the reactor with respect to the operations building, lean-to, and adjacent areas is shown in the cross-sectional views of Fig. A3. The mid-plane of the reactor core is about 11 feet below the floor level of the operations building (see Section B-B) and a minimum of 22 feet of earth separates the reactor from the operations building. The nearest point in the control room is 40 feet from the top of the reactor vessel. A third of the reactor vessel is above natural grade level. Earth fill will cover the vessel to a level 2 feet below the cover flange.

The upper 12-1/2 feet of the annular space between the reactor vessel and the cavity liner is filled with graded river-bottom sand. The sand rests on a 6-inch concrete shelf and is covered by a 6-inch concrete slab which also serves as a floor of the reactor shelter. Radiation shielding above the reactor is also
provided by a deep pool of hydrocarbon above the reactor core. When the hydrocarbon is at the maximum operating temperature of 700° F, its level is 17 feet above the core. The cold level during shutdown and fuel handling is 14 feet above the core. A minimum of 9 feet of hydrocarbon separates the operator from a fuel element as it is lifted from the core and placed in the storage rack.

The large pipe tunnels and pipe gallery required for the 16-inch main coolant lines are a principal avenue for radiation to escape from the reactor to the surrounding area. Some shielding from radiation streaming is accomplished by two right-angle bends in the 16-inch pipes. Additional shielding is provided by a 1-foot thick concrete wall, perpendicular to the pipe tunnels, which reduces the radiation streaming from the tunnels to tolerance levels at the OMRE boundary fence. A 2-foot concrete wall in the operations building protects the personnel from the reactor radiations. The amount of core gamma energy impinging on the 1-inch thick reactor vessel and the resultant thermal stresses induced therein is reduced by the 2-inch cylindrical steel thermal shield which surrounds the core.

2. Heat Transfer System - The hydrocarbon coolant and associated impurities become activated as they pass through the reactor core region. Shielding requirements for this activity in the heat-transfer loops are held to a minimum by restricting personnel from the operating area during reactor operation. An induced-activation analysis of the impurities present in diphenyl and Santowax-R (a commercially available mixture of terphenyl) was conducted at the MTR. On the basis of this analysis, the radiation level at the surface of a 16-inch steel pipe is estimated to be less than 1 r/hr including transport activity from the reactor, if it is assumed that the OMRE is operated at a power of 16 Mw for a period of 500 days. Since the induced activity in the hydrocarbon cannot be predicted very accurately, the radiation levels surrounding the system must be measured after initial start-up, and the necessary fences will be built to exclude personnel from areas of excessive radiation. Direct gamma radiations from the process area are reduced in the control and laboratory areas by the 2-foot-thick concrete wall which separates the process area from the control and laboratory areas.

3. Purification System - The purification system which processes activated hydrocarbon must be controlled remotely, since the level of radiation is expected to be too high for direct operation. Shielding during operation of the system is
accomplished by locating the components of the purification system adjacent to the 2-foot-thick concrete wall and extending valve-stem gear drives through the wall to handles in the control room. Limited access to the process area during reactor shutdown permits maintenance of the purification system.

The waste storage tank is the only radioactive component of the system which is located outside of the process area. It is placed just outside the building on the far side from the reactor and is buried underground for gravity drain and shielding.

H. SERVICE FACILITIES

1. Heating and Ventilation - A fuel-oil fired, forced-circulation, hot-air furnace is used for space heating. A portable fuel-oil furnace is used for heating the process area as required. The fuel oil supply is stored in a large underground tank across the road from the operations building.

A ventilation system is provided for the process, control, and storage areas to discharge hydrocarbon vapors and air-borne radioactive contaminants from the building. To reduce the number of air changes per hour, exhaust air is pulled into hoods above equipment that is likely to have leaks: e.g., the main coolant pumps, the pit near the purification equipment, the sample hood, and the melt tank. In this way the air will always be moving toward regions of greatest vapor concentration.

2. Water Supply and Disposal - All water, except drinking water, is supplied from a well which will be located on the site. A well pump with a capacity of 400 gpm maintains 20,000 gallons of water storage in a tank above ground. A 7.5-hp stand-by pump with a capacity of 125 gpm and 65 psi head is provided in a by-pass line of the main outlet line from the storage tank. Both pumps are located in a pump house and receive electrical power from a transformer mounted on a pole outside the pump house. The stand-by pump can be used to develop a pressure head in the water main should it be required for fire fighting.

A booster pump located in the storage area supplies the normal water requirements of the facility at about 75 psi head. The power for the pump is supplied from the electrical substation. In the event of substation power failure, this pump will be switched to the emergency power generator. If the booster pump must be
shut down for repair or maintenance, water pressure for the facility can be obtained from the stand-by pump by a manipulation of valves in the pump house.

Waste water is collected in a single line that carries it to a drainage ditch about 150 feet from the reactor. A septic tank is provided to handle sewage from the lavatory.

3. Electric Power - Electric power is brought to the site by a 13,800-volt 3-wire delta high line from the Central Facilities Area. A substation on the site consisting of three step-down transformers supplies the required power. A 500-kva, 480-volt, 3-phase transformer supplies all power for the building facilities. A 250-kva, 120-240-volt, single-phase transformer supplies the power for induction- and resistance-heating of hydrocarbon-containing equipment. A 150-kva, 480-volt, 3-phase transformer supplies the power for the well pump and pump house. In the event of power failure, "emergency demand" power will be supplied by a gasoline engine-alternator in the operation building. The alternator supplies 18 kva at 208 volts and 60 cycles to a 3-phase, 4-wire system.

4. Communications - The OMRE facility has an intercom system throughout, including the building, reactor area, security guard house, and pump house. Communication with the outside is provided by three telephone lines and two fire-alarm lines tied directly to the Central Facilities Area.