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THE MATERIALS TESTING REACTOR

A Descriptive Discussion Prepared By

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CLASSIFICATION CANCELLED
DATE—9-24-53
For The Atomic Energy Commission

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ORO 34856
ACKNOWLEDGMENTS

The author wishes to thank those in the Technical and Operating Branches of Phillips Petroleum Company, Atomic Energy Division, who supplied helpful information, the Engineering Division for preparation of charts, and Drs., J. R. Huffman and R. L. Doan for their review and comments on the text.
The Materials Testing Reactor, one of a series of atomic installations located in the National Reactor Testing Station near Arco, Idaho, has recently been placed in operation. As the name implies, this reactor was designed to provide a research facility for testing various materials in a high-intensity radiation field. The U.S. Government, through the Atomic Energy Commission and its many design and operating contractors, is pushing ahead as rapidly as possible with the development of atomic research with emphasis on both military and industrial applications. In both of these fields, it is extremely important to determine what happens to various kinds of materials when subjected to high-intensity radiation. For example, if we are to design and operate atomic power plants, ships, submarines, and aircraft, the properties of the structural materials used in these engines must be known, and their performance in many thousand hours of operation must be accurately predictable. It is of paramount importance that a facility exists which is capable of furnishing quickly a great number of physical, chemical, biological, and engineering data at high thermal and fast fluxes and high gamma ray intensity on the basis of which future reactors can be designed within controllable and permissible limits of uncertainty in operating characteristics. Studies already made on the effects of irradiation on different materials have shown that significant changes occur even at fairly low flux intensity. The Materials Testing Reactor is the result of an evolutionary process in the design of a unit conceived for the express purpose of obtaining much needed information in the overall atomic energy program. The flux levels, i.e., neutrons per square centimeter per second, for which it is designed are those at which it is expected the next generation of power reactor will operate.

Various laboratories, universities, industrial concerns, and atomic energy contractors throughout the country are now conferring with the operator of the Materials Testing Reactor to work out plans for performing desired experiments. More specifically, these projects include the testing of fuel elements sections for proposed reactors, determining irradiation damage to structural materials, such as the creep of metal, efficiency of cladding, capture cross section studies, etc. Certain experiments require the circulation and irradiation of water, helium, and other fluids through the reactor at high temperature and pressure. Many fundamental nuclear studies will be conducted to add to the fund of basic research knowledge. These experiments will make use of special equipment such as neutron velocity selectors and crystal spectrometers. The reactor also is capable of the production of sizeable amounts of the medium weight and transuranic isotopes. High specific activity radioactive isotopes which are not recoverable directly from fission products can also be produced.

The history of the Materials Testing Reactor begins with the year 1944 when it was proposed that a reactor be constructed to perform the functions outlined above. Various designs were prepared and scrutinized in their conceptual stages before the reactor began to even remotely resemble the one actually constructed; however, by the summer of 1946 the design for the experimental high-flux reactor had become essentially stabilized. The initial work was carried on at the Oak Ridge National
Laboratory, at that time called the Clinton Laboratories. In December, 1947, the Atomic Energy Commission centralized reactor development work at the Argonne National Laboratory; however, since the basic reactor work had been performed at Oak Ridge a division of responsibility was outlined which, in essence, permitted Oak Ridge to complete the reactor design and gave Argonne the responsibility for specifying all of the reactor supporting facilities. A mockup, or pilot model, was constructed at Oak Ridge for use in testing the final design and as a place to train operators. At this time the site of the reactor was in doubt although the Oak Ridge and Chicago areas both had been considered. In November, 1948, a directive was issued to Argonne to proceed with the project, whereupon a steering committee was organized to coordinate and expedite the work. After further research and engineering work by both Argonne and Oak Ridge, the Chemical Plants Division of the Blaw-Knox Construction Company was selected as architect-engineer for the Materials Testing Reactor in July, 1949. In February, 1950, the Fluor Corporation was appointed as construction contractor and ground was broken at the National Reactor Testing Station in May, 1950. Phillips Petroleum Company entered into a contract with the Atomic Energy Commission to operate the Materials Testing Reactor in November, 1950, and early in 1951 selected the technical staff for training at Oak Ridge and in various other laboratories. Construction of the plant was essentially complete by March, 1952, and the reactor was brought to criticality on March 31, 1952.

The Materials Testing Reactor is a high flux heterogeneous enriched uranium reactor. The active part of the reactor consists of fuel elements spaced to allow water to flow between them, the water thus serving as both coolant and moderator. The purpose of the moderator is to slow the fission neutrons sufficiently to permit the capture of a portion of them by other fuel nuclei. For a reactor to operate or become critical, it must produce by fission as many neutrons as are lost by capture, leakage and fission. In other words the extra neutrons produced when a fission occurs must be available to cause additional disintegration and thus sustain a chain reaction. The use of enriched fuel (enriched, that is, in uranium 235) permits the construction of a very high flux high power output reactor in a small space, as compared to reactors which employ natural uranium consisting primarily of the uranium isotope of mass 238. Immediately surrounding the small enriched fuel lattice is a primary reflector of beryllium metal which is also water cooled. This assembly of active lattice and beryllium reflector is mounted in a tank system through which the water flows and which also contains the shim rods and regulating rods which control the reactor. Outside the tank system are a secondary reflector of graphite and a steel thermal shield, both air cooled, the whole being anchored in a concrete biological shield which provides protection for personnel. The reflectors increase reactor efficiency by returning to the active lattice neutrons which otherwise would escape into the biological shield. They also provide high flux regions for irradiation. Primary reactor control is obtained by the cadmium-shim rods and this control is supplemented by vernier control on the regulating rods. The mechanism by which movement is imparted to the regulating rods and shim rods is located external to and on top of the reactor structure. The entire reactor and its shield occupy a space approximating a cube having sides of about 34 feet each.

The biological shield is designed to reduce by absorption the high neutron and gamma fluxes escaping through the reflector and thermal shield. This shield is designed to reduce these radiations to a safe working level for personnel and to a level which will not disturb sensitive instruments operating outside the shield. Shielding efficiency is, in general, dependent upon the density of the material employed in construction and for this reason, the MTR biological shield is made out of a mixture of concrete.
Fuel for the reactor is loaded through the top, which can be opened, and discharged through a chute in the bottom which communicates with a water filled canal. The canal, which is located beneath the reactor, is a tile lined concrete basin about 160 feet long and 18 feet deep. Its purpose is to provide a place where spent fuel elements, shim rods, and experimental equipment can be stored under water while the radioactivity decays. It is necessary to cool the fuel elements before they can be processed or moved to other locations safely and the depth of the canal water is sufficient to provide adequate shielding while these intensely radioactive materials are being handled. Directly beneath the reactor in the canal is located the fuel unloading mechanism. This device consists essentially of a large tube which can be placed in an upright position to accept a fuel element, then tilted to a horizontal position to discharge the element into the canal water. The canal also contains a submerged sawing mechanism and storage racks for the fuel elements and shim rods. The canal extends outside the reactor building and is equipped with a hatch through which submerged equipment can be taken out of the canal for transportation to the other locations.

To fulfill the purpose of the Materials Testing Reactor the experimental facilities provided have been designed to be as varied as possible. The shield is penetrated by about one hundred holes of various sizes. Embedded in the concrete are all the permanent liners for the experimental holes. There are seventeen large experimental holes that lead from the four reactor structure faces either to the reactor tank wall or to the active lattice. They are characterized by the presence in each of a special radiation door, the sole purpose of which is to minimize danger to personnel in the reactor building during plug handling operations. These holes provide the largest volume of high flux in the reactor. In addition, where the highest fast flux is required spare control rod holes and unused spaces in the fuel section can be utilized if desired. The east wall of the reactor has access to a thermal column which is provided with seven horizontal and two vertical holes. Depending upon future demands space is available through the west wall for a shielding facility or another thermal column. In addition to the above mentioned facilities, there are two horizontal graphite holes, two pneumatic rabbit holes and one through hole, all of which extend into high flux region. Vertical hydraulic rabbit holes are placed in the reactor bottom plug and extend up close to the fuel section.

Other experimental holes are located in various positions on the sides and top of the reactor so that by suitable placement experiments can be carried out in a wide variety of flux fields. Each of these experimental test holes is initially filled with a dummy plug which can be removed and stored when it is desired to conduct an experiment in that hole. In formulating the design considerable thought was given to the future needs of the experimenters who will use these facilities. Each individual experiment, whether it be to test metal, to circulate a liquid or a gas or to test small sections of other reactor fuel elements must be designed to be inserted in some particular experimental hole in such a manner that it can replace the dummy plug which would ordinarily occupy such facility. Dummy plugs, which conform closely to the inside dimensions of the experimental hole, are constructed of materials which conform generally to the materials used in the adjacent section of the reactor, i.e. concrete, graphite or beryllium. The plugs located in high flux regions become heated at normal power levels and must be cooled by air or by circulation of water. Most experimental beam holes are provided with service facilities such as air, exhaust gas, fresh cooling water and process water. (The water which circulates through the reactor for cooling purposes is referred to as process water).
To remove the dummy plug or experimental plugs which have been irradiated presents the problem of adequately shielding the equipment as it is withdrawn. For this purpose a large handling cask filled with lead and mounted on a wheeled carriage is provided. Although this cask weighs about thirty tons it can be very accurately aligned with the beam hole so that the experiment or dummy plug can be easily pulled out of the reactor and into the cask. After the cask has been loaded it can be wheeled outside the reactor building and the radioactive equipment can be stored in a shielded steel tube. Removal or insertion of the radioactive plug is performed manually by means of a long rod. After the plug has been placed in the cask radiation doors in both the beam hole and cask are closed before the cask is pulled away from the face of the reactor.

All control and safety signals pertinent to the operation of the reactor, regardless of where initiated, result finally in a movement of the control or shim rods. In general, safety signals can request four things to happen: 1) slow setback, 2) fast setback, 3) reverse, and 4) scram. These are merely various methods of affecting a control of the power level, differing principally in the speed of response. To start the reactor, first the process water circulation and air exhaust systems are placed in operation, then the control rods and shim rods are gradually withdrawn from the lattice. Various interlocking time delay devices prevent the too rapid withdrawal of control rods, so that the flux buildup at any time can be kept under close watch by the operator and the instruments. If the controls were withdrawn too rapidly it is possible that the reactor could become prompt critical but all parts of the control system are designed so that this will not happen. For example, the shim safety rods are attached to the control drive mechanism by electromagnets. If the rate of neutron multiplication becomes too great the electromagnets are automatically deenergized, allowing the shim rods to fall into the lattice and scram the pile. Additional safety in operation is also provided by an arrangement for monitoring the water which flows past each fuel element. The monitor tubes measure the temperature and flow rate of the water and collect a small sample of the water from each element, which is then checked by an ionization chamber. If a fuel should warp and cut off the water flow or if it should rupture and release fissionable materials into the water, automatic devices will immediately warn the operator and shut down the reactor. Safety devices are also incorporated in the reactor cooling and air exhaust systems. The water and air streams are automatically checked for flow rate and for radioactivity and if the established quantities are not maintained the instruments assume control of the reactor to prevent damage.

Operation of the reactor involves the problem of disposing of the large amount of heat which is generated. Most of the heat is removed in the primary process water cooling system and a smaller portion is removed by air cooling. Process water which circulates through the reactor in the primary system is never allowed to mix with the secondary cooling water since contamination would otherwise result. Water warmed in the reactor is circulated through flash evaporators and the heat is removed by the secondary water stream which circulates through tubes in the evaporators. A positive head of water is maintained on the inlet side of the reactor by an elevated storage tank, with flow to the reactor controlled by a manually operated valve located upstream. After passing through the reactor tank system the heated water enters a seal loop, which is high enough to prevent draining of the reactor in the event of water failure, and then into a seal tank in the process water building. A radiation recorder is provided on this line near the entrance to the seal tank to check
for fission product activity. Normal flow from the seal tank is to the flash evaporators, which operate at a pressure of 0.949 psig. Since the seal tank is essentially at atmospheric pressure, this pressure difference serves to transfer the water into the evaporators. A portion of the process water flashes in the evaporators, thereby cooling the main body of water and deaerating it to remove the hydrogen and oxygen formed in the reactor. The evacuating system for the evaporators consists of a single stage hogging jet and a multi-stage steam ejector. The hogging jet is a high capacity unit provided to evacuate the ejectors in approximately fifteen minutes during startup. The vapor produced by flashing is condensed in a tube section in the upper part of the evaporators and the cooled water and condensate then flows through barometric legs to a sump tank. The seal and sump tanks are provided with floating heads to minimize contact of the water with air. Cold water from a conventional induced draft cooling tower is circulated through the condenser section of the flash evaporators. The volume of this secondary cooling water to the condenser sections is regulated by recording temperature controllers actuated by the water temperature in the downcomer lines from the evaporators. Cooled water entering the sump tank from the evaporators is picked up by the main circulating pumps and discharged to the elevated working reservoir, which completes the process water cooling cycle.

The entire process water circulating system is constructed of stainless steel while cast iron and carbon steel are satisfactory construction materials for the secondary water cooling system. Cooling tower or secondary water does not become radioactive and does not require any treatment except chlorination and acidifying for algae and pH control. The cooling tower is of the multi-cell type and because of the severe dusting problem encountered, is provided with one spare cell. Cooling water is moved from the cold water basin of the tower by pumps to the points of use (principally the flash evaporators) and back to the top of the cooling tower. For cleaning purposes the tower basin is so devised that there is a separate section for each cooling cell.

Air for reactor cooling and reactor building and laboratory ventilation is drawn in through an underground duct over coarse glass filters, preheated and then passed through electrostatic filters which remove all dust. Centrifugal blowers then raise the pressure of this air and direct it to the laboratory and reactor buildings, maintaining a positive pressure inside the reactor building to minimize infiltration of outside air. Cooling of the reactor graphite and thermal shield is accomplished by pulling air through the reactor with three positive displacement rotary blowers discharging into a 250 foot high concrete stack. This procedure disposes of the slightly radioactive air which has passed through the reactor and ensures personnel safety in the surrounding area. A constant check is made on the radioactivity of all reactor exhaust air to see that the activity is within established tolerances and to warn of any mechanical failure which might release fissionable material. Two smaller exhausters are included in the system to provide air circulation at times when the reactor is shut down; one of these units is operated electrically and the second is powered by an automatic starting gasoline engine. Radioactive or acid vapors which are released in the experimental laboratories are collected in gathering hoods, scrubbed with a caustic and subsequently discharged to the plant exhaust stack. Air which is free from acid vapors and which is of relatively low activity is exhausted from the laboratory hoods to the atmosphere by exhaust fans.
Water for the plant is provided by two deep wells fitted with submerged pumps delivering to ground storage tanks from which it is pumped to an elevated raw water storage tank or to the water treating area. Materials of construction are stainless steel, rubber lined cast iron and carbon steel, and wood. Water for general plant use is zeolite softened and subsequently chlorinated, while water for cooling tower makeup requires only chlorination and acidising.

In the operation of the reactor, the laboratories and the various experiments, large quantities of radioactive water or other liquids are collected by the drain system and those materials must be disposed of without danger of contamination of plant equipment or personnel. The degree of radioactivity in the various drain streams varies widely. Water from the warm drains in the reactor building basement and first floor flows by gravity to a reactor drain tank located in a shielded concrete pit below the basement floor provided with a sump which drains to the building process sump. The contents of this tank can be transferred by pumps to four underground warm catch tanks located in a remote area of the plant. The contents of any of these tanks can be mixed, transferred from one tank to the other or pumped to a large underground retention basin consisting of two concrete vessels provided with internal baffles. The size of each underground compartment is sufficient to contain the entire contents of the reactor process water system and one compartment is normally kept empty so that it can receive the reactor water in the event of a fission break. The rate of discharge of radioactive waste is such that it will normally be retained for about three days in the retention basin, after which it flows from the outlet end into a leaching bed located outside the plant fence. Radioactivity of the discharged waste is maintained at not greater than 18.5 disintegrations per milliliter per second of sodium activity. The leaching bed is merely an excavation in the lava overlay. It has been estimated that water which seeps into the ground from the leaching bed will reach the Snake River in about 150 years.

Steam is required in the plant principally for building heating, since the only other need is in the operation of the flash evaporator ejector system. The steam generating facility consists of three automatic oil fired package type units and their associated equipment, each having a maximum capacity of 16,500 pounds per hour at 150 pounds per square inch. Two of the units are adequate to supply normal process and heating steam requirements while the third unit serves as a standby. Fuel oil is brought into the plant by truck and stored in heated tanks having sufficient capacity for about sixty days of winter operation. For protection against fire the tanks are provided with piping where portable foamite generators can be connected. Demineralized water is used for boiler water makeup and all condensate except that from the steam ejectors is returned to the boilers from strategically located condensate gathering units.

The boiler house contains, in addition to the steam generating units, a 750 kva emergency diesel electric generator and the plant air compressors and air drying equipment. All mechanical equipment in the MIR with the exception of that required for emergency purposes is electrically powered, while standby pumps.
blowers and fans are powered by either gasoline or diesel engines. The electrical system required for the operation of the plant has been designed for high reliability in accordance with requirements peculiar to the operation of the project and local conditions, using dual feeder arrangements wherever practicable. The normal electrical power is routed to the MTR substation by a high line operating at 132 kv through the main substation serving the Reactor Testing Station, and dispatching control is maintained at that point. This overhead distribution system is brought into two air cooled 3750 kva transformers, the secondary of each transformer delivering power through breakers to a 2400 volt bus in the substation control house. Equipment requiring large amounts of electricity, such as the process water circulating pumps and the main air exhausters, receive power at 2200 volts directly from the MTR substation, while smaller power users and lighting needs are served by secondary transformers located in the various use areas. In the event of commercial power failure the diesel electric generator in the boiler house can supply power for operation of standby air and water circulating equipment and essential plant lighting. The diesel generator starts automatically upon loss of power to the plant substation or low voltage and is capable of picking up the emergency load in thirty seconds.

The power system for operation of the reactor controls and instrumentation must be absolutely interruption free. For this purpose a motor-generator and storage battery system is provided in the basement of the reactor wing, or laboratory building. This system receives its power from 440 volt stepdown transformers and keeps the batteries in a constantly charged state ready to take over in the event of power failure.

Health Physics work is an important part of the operation of an atomic energy installation. Personnel may be exposed to gamma ray radiation or to electrically charged alpha, beta and proton particles. Even though all of the plant equipment is designed with the utmost safety in mind, the conduct of experiments and laboratory work requires opening and closing of the reactor beam holes, and maintenance must often be performed on radioactive equipment. Tolerance standards have been prescribed for all types of radiation exposure and all employees are required to attend Health Physics indoctrination courses soon after they are employed on the project. The plant is divided into limited and exclusion areas and all personnel working in the exclusion area where the radioactivity is confined are required at all times to wear film badges and electrostatic pencils, which are monitored at frequent intervals to insure that an employee does not receive more than the specified safe dosage of any type of radiation. In an area where workmen or technicians could be exposed they are required to wear special clothing, and to monitor themselves at the completion of a job to see that they have not become contaminated. During the installation of an experiment and when maintenance work is in progress Health Physics representatives, using specially designed portable radiation detectors, maintain constant guard to insure safe working conditions.
The operation of a research tool such as the Materials Testing Reactor requires a highly trained group of specialized engineers, physicists, chemists and theoreticians, along with many non-technical operators and maintenance personnel having more than average ability. The experimental shops are equipped and staffed to perform chemical analyses, build developmental electronic equipment and mechanical devices, calibrate and measure radioactive sources, make metallurgical examinations, conduct experimental physics studies, and perform a multitude of functions related to a large research program. Phillips Petroleum Company, in addition to operating the reactor, has a competent technical staff to assist outside experimenters in the conduct of their work. There are sixty such physicists, chemists and engineers on the staff at the present time and these are assisted by approximately twenty-five technicians. Actual operation of the reactor and its supporting facilities requires the full time of forty non-technical people plus about thirty-five engineers of varied training. The bulk of the maintenance work in the plant is performed by another subcontracting organization, consequently Phillips keeps only a skeleton maintenance crew.

The cost of primary design and development work on the Materials Testing Reactor, estimated at $13,000,000, was borne by the Oak Ridge and Argonne National Laboratories. Actual construction cost including the fee to the Fluor Corporation and various subcontractors amounted to approximately $18,000,000, which was within the engineering estimate. The fee to the Blaw-Knox Chemical Plants Division for architect-engineering and inspection services amounted to roughly $2,000,000. Major expenditures were as follows: reactor and reactor building - $6,094,000; reactor wing or laboratory building - $1,365,000; process water building and process water tank - $1,356,000; raw water pump house and storage tank - $237,000; cooling tower and pump house - $290,000; demineralizer and water treating building - $402,000; fan house and stacks - $308,000.
ILLUSTRATIONS

1. Reactor Process Water – Cooling Air
2. Raw Water and Treatment System
3. Effluent Control System

BIBLIOGRAPHY
