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THE MATERIALS TESTING REACTOR DESIGN

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By

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ABSTRACT

The Materials Testing Reactor, which has been under design and construction since 1945, is now in operation at the National Reactor Testing Station near Idaho Falls, Idaho. It is an enriched reactor, reflected with beryllium. It operates at the highest thermal flux of any known reactor. Experiments which will use many of the approximately one hundred available locations are already being inserted or are in the final stages of design.

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THE MATERIALS TESTING REACTOR DESIGNINTRODUCTION

The Materials Testing Reactor (MTR), now in operation at the National Reactor Testing Station (NRTS) in Idaho, is a high-flux heterogeneous enriched-fuel reactor. The active part of the reactor consists of enriched U²³⁵ fuel elements arranged to allow water to flow between them, the water thus serving as both coolant and moderator.

Immediately surrounding the small enriched lattice is a primary reflector of beryllium metal which is also water cooled. This whole assembly of active lattice and beryllium reflector is mounted in a tank system through which the water flows and which contains the control rods and their bearings. Outside the tank system are a secondary reflector of graphite, a thermal shield, and a biological shield, the whole forming an approximate cube of about 34 ft. to a side.

As the name implies, the reactor has been designed primarily to allow the testing of various materials in high-intensity radiation. To accomplish this purpose, about one hundred experimental holes have been provided, some going through each of the four walls, the top, and the bottom of the reactor. This article is a compilation of information on the design of the MTR taken from letters, reports, and other sources which have accumulated in considerable quantities during the course of development, design, and construction.

USES AND IMPORTANCE OF THE MTR

The principal large-scale uses of nuclear energy, aside from military use in a bomb, will probably be those in which the energy released is converted to electrical energy and mechanical work. However, the supply of fissionable material and of material that can be converted to fissionable material is small in comparison with the amount that may be tied up in power plants if nuclear power is used on a very large scale. Therefore all nuclear-power plants will tend to be operated at the highest specific power (watts per gram of fissionable material) possible. Furthermore, because of this limited supply, the conversion of nonfissionable to fissionable material (breeding) will be necessary before large-scale, widespread use of nuclear power becomes practical. In this case also a high specific power is necessarily to be desired since the breeding gain (the excess of new fissionable atoms produced per fissionable atom destroyed) is quite small, and, unless the specific power is large, the rate at which the supply of fissionable material is increased is small, or, in other terms, the doubling time of the fissionable material in the reactor is large. It is thus apparent that, both for power and for breeding, high specific power is likely to be a requirement of any useful reactor. Since the neutron flux in a reactor is proportional to the specific power, it is also evident that important reactors of the future will operate at high neutron fluxes.

As reactor technology enters these fields of higher fluxes, many problems arise which require experimental answers. For example, the effect of high fluxes, particularly of fast neutrons, on the properties of structural materials is still not well known. Some structural materials, such as graphite, are known to suffer ill effects in a relatively short time. However, the fluxes that will be used in future

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reactors are higher by a factor of 30 or more than any flux previously available. Metals which have desirable structural properties as a result of cold working or of heat treatment may conceivably undergo adverse effects under fast-neutron bombardment. Also, the cross section of the fission products may determine to a large extent the breeding gain or the operating time of a power reactor. It is possible that second-order reactions may be important and that nuclei of short-life and, at present, unknown properties may thus be disproportionately important in a high-flux reactor as compared with their importance at lower fluxes.

Aside from these highly urgent and immediately practical problems, there are the many fundamental experimental studies in high-flux regions which can be carried out in the MTR. The high density of epithermal neutrons in the MTR permits the extension of the practical range of the crystal spectrometer to higher neutron energies. The properties of fissionable isotopes in the lower resonance energy regions may thus be investigated and their nuclear constants more accurately determined. Again, reactions of higher order (the capture of two or more neutrons in succession by the same nucleus) can be made to produce significant quantities of rare isotopes, thereby permitting the study of their nuclear constants--heretofore impossible in many cases.

Another use of the MTR is in the production of radioisotopes in amounts and of specific activities heretofore not readily available. For example, the MTR can produce phosphorus compounds of higher specific activity which are usable directly, without purification or chemical separation, by clinical institutions. Strong Co^{60} sources are also easily produced.

The extent to which the criterion of higher flux is satisfied is best shown by comparison of the MTR with other reactors now in operation (Table I).

The MTR provides thermal-and fast-neutron flux levels for component testing and materials irradiation which are high enough to extrapolate to future reactors under consideration. It also provides several experimental holes designed to permit the irradiation of reactor components, such as fuel assemblies, under simulated operating conditions of temperature, pressure, and particular coolant. To produce these high neutron and heat fluxes, however, means a sacrifice in volume for experimental facilities and causes high fuel burnup and operational difficulties.

TABLE I
Comparison of Neutron Fluxes

<u>Reactor</u>	<u>Average Flux</u> <u>Neutrons/cm²/sec</u>
	<u>Thermal</u>
X-10 graphite (3800 kw)	5.0×10^{11}
CP-3' (275 kw)	1.7×10^{12}
NRX (10,000 kw)	2.0×10^{13}
MTR (30,000 kw)	2.0×10^{14}
BNL-1 (28,000 kw)	2.5×10^{12}

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DESIGN AND ADMINISTRATIVE HISTORY

Late in 1944 the Chemistry Division at Clinton Laboratories (now Oak Ridge National Laboratory) proposed the construction of a 50-kw homogeneous uranium heavy-water reactor whose main purpose would be to produce easily extractable fission products. Work on a 50-kw homogeneous reactor continued until 1945, when it was decided that the power of the reactor should be raised sufficiently to demonstrate the feasibility of a thermal-energy breeder.

Additional problems arose which led to difficulties in the conception of the control and technology of a homogeneous reactor. Principally, there was the instability of a homogeneous reactor that contains bubbles of gas arising from the disintegration of solvent molecules and the generation of fission products. Although the reduction of power to a 50-kw level would have eliminated the problem of bubbling instability, this would have defeated the purposes of such an enriched reactor, i.e., high thermal- and fast-neutron fluxes and all the advantages that follow from them. Accordingly, the alternative was to go ahead with another type of reactor which would produce similar flux conditions and to use it to study the problems of the homogeneous reactor by small-scale experiments at high flux.

A heavy-water-moderated and heavy-water-cooled enriched heterogeneous reactor was first designed. Later, on the basis of theoretical calculations by the Physics Division, the Technical Division of Clinton Laboratories submitted a design proposal in May 1946 for a high-flux thermal reactor of heterogeneous core which was to be light-water-cooled and heavy-water-moderated and -reflected. The use of light water as a coolant was believed preferable to the use of heavy water because light water increased the operational flexibility of the machine.

On critical examination of the above design, it was pointed out by Dr. Eugene Wigner that an important gain in fast flux could be obtained by using light water for both coolant and moderator. This change would result in a smaller reactor, and, because fast (virgin) flux is proportional to power per unit volume, a 30,000 kw reactor of the proposed type could produce a fast flux of approximately 1×10^{14} neutrons/cm²/sec and a thermal flux about equal (2×10^{14} neutrons/cm²/sec) to that of the previous design. In addition, a further volume decrease is gained with light-water moderation.

Actually, in the previous design with heavy-water moderation and reflection, the reflector merely provided space for experiments that could be accomplished otherwise. In August 1946 it was therefore decided to eliminate heavy water altogether and to make the reflector of beryllium. The decision with respect to beryllium was made possible by the rapidly improving situation in 1946 in the metallurgical techniques of handling and fabricating this metal on a production basis of tons rather than pounds.

Thus, by the summer of 1946, the design for the experimental high-flux reactor had evolved from an initially homogeneous fluid reactor to an all-metallic rigid machine, aside from the cooling fluid (ordinary water).

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While critical experiments were going on, the AEC assigned The Kellex Corporation to work on the high-flux reactor early in 1947 as the design contractor. Monsanto Chemical Co., the contractor for the operation of Clinton Laboratories, was to be the construction manager. Design work continued throughout 1947 under this contractual arrangement, so that by the fall of 1947 the design was very well advanced.

Between November 1947 and January 1948 certain administrative decisions were made which changed plans for the construction of the High Flux Reactor at Clinton Laboratories. The Kellex Corporation was withdrawn as design contractor in November 1947. On December 27, 1947, the AEC announced a decision to centralize reactor development at Argonne National Laboratory (ANL).

Work on the High Flux Reactor continued at ORNL during early 1948 and also at ANL toward the latter part of 1948. Further critical experiments for the verification of design choices and the design and construction of the High Flux Reactor mock-up were carried on at ORNL.

Then in November 1948 a directive was issued to ANL to proceed with the project. It was further directed that ANL and ORNL form a working partnership for this project in order that advantage might be taken of the facilities and experience at ORNL peculiar to this reactor. The name of the reactor was changed from the High Flux Reactor to the Materials Testing Reactor.

In accordance with the directive, the managements of the two laboratories organized a Steering Committee for the project. The committee consisted of the following people: Stuart McLain, Chairman; J. R. Huffman, ANL, to supervise project work at ANL; and M. M. Mann, ORNL, to supervise project work at ORNL. W. H. Zinn and A. M. Weinberg acted as ex-officio members and guided the committee to solutions of many difficult problems.

The Chemical Plants Division of the Blaw-Knox Co. was selected as architect-engineer for the MTR in July 1949, and early in August 1949 the Steering Committee initiated formal contact and transmitted information to Blaw-Knox so that engineering design could begin.

During this period the hydraulic and mechanical experiments on the full-scale model (mock-up) of the reactor at Oak Ridge were drawing to a close, and preparations were under way for a series of critical experiments in this facility. Preparations for these experiments were made in the fall of 1949, and in January 1950 this full-scale model of the MTR was brought to criticality. During the spring, summer, and early fall of 1950 this reactor was operated hundreds of times at power levels of a few hundred watts, and many measurements of vital importance to the MTR were made. As an example, it was on the basis of these measurements that the final design details of the graphite reflector and the thermal shield were evolved and the over-all design of these items was finally approved.

In February 1950 the Fluor Corp., Ltd., Los Angeles, was engaged by the Idaho Operations Office (IDO) of the Atomic Energy Commission as construction contractor for the MTR, and the first formal contact between IDO, Fluor, Blaw-Knox, and the Steering Committee was made in March 1950. Up to July 20, 1950, the Steering

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Committee approved all design and construction. At that time a major portion of this control authority was relinquished, and the Steering Committee acted as consultants to IDO, Blaw-Knox, and Fluor. However, the responsibility for the conceptual design process and functional layouts remained with the Committee.

Ground was broken for the MTR in May 1950, and construction was completed in February 1952.

In July 1951 the Phillips Petroleum Company was appointed the operating contractor. As the staff of this company was assembled, it was assigned to an intensive instructional program at ORNL in the spring of 1951. Headquarters was established in Idaho Falls during the summer of 1951. As various facilities were completed, Phillips personnel assisted in the acceptance tests. The MTR became critical on March 31, 1952, and underwent further tests preparatory to final acceptance by the operating contractor. On August 2, 1952, the first experimental tests were inserted in the reactor.

THE REACTOR

The reactor consists of U235 as the fissionable material, ordinary water as the moderator and coolant, and beryllium as the reflector. The active core in which the uranium is situated can be located as desired within a "lattice" which is 40 x 70 cm in cross section.

Each fuel element fits into a socket underneath the reactor, and a grid fits over the tops of the elements in order to preserve their spacing at the top.

Beryllium is located immediately around the elements. The beryllium continues to the inner wall of a 1-in.-thick 54-1/2-in.-I.D. cylindrical aluminum tank in which the active portion of the reactor and beryllium is situated. This tank extends both above and below the active portion of the reactor, forming a well which is, and must be, kept full of water at all times. Water enters near the top of the well at a distance of about 15 ft. above the reactor and leaves at the sides of the well about 5 ft. below the reactor.

The beryllium around the active portion of the reactor is perforated vertically with 3/16-in.-diameter holes through which water passes to remove the heat generated in the beryllium. In these beryllium assemblies other materials can be inserted to make use of the leakage neutrons.

Part of the purpose of the MTR is to provide as large a neutron flux as possible over as great a volume as possible. To accomplish this, a secondary reflector of graphite is placed outside the reactor tank. The main problem in the design of the graphite reflector was the possibility of graphite dimensional changes due to radiation, oxidation and temperature. To overcome this difficulty, the graphite reflector was divided into two zones: a pebble zone that is adjacent to the reactor tank and extends for a minimum of 40 cm. from the tank wall to form a square, and a permanent graphite zone that is 12 ft. over-all north to south, 14 ft. over-all east to west, and 9 ft. 4 in. high.

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The pebble zone is a volume 7 ft. 4 in. square by 9 ft. high. It surrounds the reactor tank and is filled by some 700,000 graphite pebbles (AGOT) 1 in. in diameter. The pebbles rest on a base plate mounted on the lower thermal shield plate and are free to expand upward. In this way any expansion will merely raise the level of the balls without exerting undue stress on the tank wall or the permanent graphite.

Two discharge chutes in the pebble-support plate can be opened into a discharge bin, thus allowing the removal of the pebbles at any time. This easy removal of the pebbles carries out the MTR feature that provides for removable tank sections. Furthermore, since the pebbles are in the highest flux region of the graphite reflector, any radiation damage will affect them first. When necessary, they can be replaced.

The permanent graphite is composed largely of 4- by 4-in. graphite bars stacked to a height of 9 ft. 4 in., with the bottom located 4 ft. below the center line of the active section. Figures 1, 2, and 3 show sections through the reactor structure.

This graphite structure is penetrated vertically by numerous holes which serve both to permit the passage of air for cooling the graphite and to permit the insertion of materials to be bombarded. In addition, the sides are penetrated by a number of holes designed especially for experimental uses. These are described more fully later.

Outside the graphite are two 4-in.-thick layers of steel, also air-cooled, which absorb most of the neutrons leaking out of the graphite and in which most of the residual energy of the radiation from the reactor is given up. The approximate size is 16 ft. in the north-south direction, 14 ft. in the east-west direction, and 12 ft. 6 in. high. This, the thermal shield, protects the concrete shield just outside it from overheating. Finally, a concrete shield is necessary for reducing the level of radiation to a value small enough so that sensitive instruments can be used in the vicinity of the reactor and so that personnel protection is provided. It is about 9 ft. thick and is made of barytes concrete, in which the gravel part of the mix is approximately 93 per cent BaSO_4 .

One of the important features of the reactor is the fact that its design makes it possible to replace the tank and the active portion of the reactor without dismantling the major portion of the graphite or of the shielding. This will, of course, be a major undertaking and will probably consume several weeks, even with careful planning. To this end the materials within the highly active zone in the reactor have been chosen in part for their lack of long-lived induced radioactivities. For example, aluminum is used in place of stainless steel in this zone. An attempt has also been made to design the reactor so that it can be dismantled under water piece by piece. For this reason the beryllium pieces are kept small, and for this reason also the proposal that the tank with all its contained beryllium be removed as a unit was turned down. This high degree of flexibility makes it possible to insert another type of reactor (of identical external dimensions) in the hole left by the removal of the present reactor tank. It also makes it possible to replace the reactor in the event of damage or failure in operation.

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Each fuel element will be left in the reactor until a certain per cent of the U^{235} contained has been consumed. When this point is reached, it will be desirable to withdraw the elements to remove the fission products from the uranium and then to return the uranium in the form of new elements to the reactor.

The physical removal and recharging of the reactor are accomplished using grappling devices by means of which an element can be lifted out of its socket and moved across the top of the lattice to a position directly over a hole through the beryllium, beneath which is a water-filled discharge tube leading to an unloading machine in a deep canal immediately under the reactor. The hole through the beryllium is plugged with a beryllium plug during operation. At the time of unloading, this plug is removed. The discharge tube that leads to the canal connects with a receiving tube through a valve and seal which act as locks to prevent excessive loss of water from the reactor. This receiver can be rotated hydraulically to a horizontal position to discharge the fuel element in a horizontal position under 10 to 15 ft. of water in the canal. New elements are loaded into the spaces left by the old ones by lowering them through the water from the top of the well.

PHYSICS AND DESIGN DATA

The power at which the reactor is designed to operate is 30,000 kw of heat. This is fixed primarily by the heat-transfer coefficients attainable in the active portion of the reactor and by the permissible surface temperature. In order to make it possible to operate at higher power if the above conditions turn out to have been too conservative, the cooling of the graphite, the shields, and the thickness of the shields are designed for 60,000 kw with some safety margin. The external water system is designed for only 30,000 kw, but additional cooling capacity can be added later.

Two points concerning the physics of the reactor deserve special mention. The first of these is the fact that the maximum slow-neutron flux exists not in the active portion of the reactor itself but in the adjacent reflector. The reason for this is that the cross section of the reflector per unit volume for absorption of slow neutrons is less than that of the reactor; therefore, neutrons which become slow in the reflector live longer than those which become slow in the reactor itself. This leads to a building up of neutron density in the reactor adjacent to the reflector. The extent of the rise of the slow-neutron flux outside the active section of the reactor depends on the shape of the reactor. It is greatest for a slab-type of loading and least for a cylindrical loading. Under the most favorable conditions the extent of the rise of the slow-neutron density is about a factor of 2 above that prevailing generally within the reactor. The amount of the rise depends not only on the shape of the reactor, as indicated above, but also on the percentage of water in the beryllium. This varies, being greatest at the surface nearest the active part of the reactor and decreasing as the extremities of the beryllium reflector are approached. The fact that the flux is highest outside the active portion of the reactor is an experimental convenience since this makes possible the insertion of materials to be bombarded into the region of highest thermal flux without interfering with the cooling of the reactor proper. Moreover, such objects will not have a large effect on the reactivity of the reactor, since, although they are in the region of highest slow-neutron density, in the present case this region is not the region of highest statistical weight.

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The other point of considerable interest from the nuclear-physics point of view is the fact that, owing to the high neutron flux, the reactivity of the reactor is strongly dependent on the growth and decay of the Xe^{135} which results from the decay of I^{135} formed in fission. Under steady operating conditions at 30,000 kw, the loss of reactivity due to Xe^{135} will be about 4 per cent $\delta k/k$. However, when the reactor is shut down after a relatively long period of steady operation at full power, the I^{135} already present as the result of fission (and having a half life of 6.6 hr.) continues to decay, giving rise to Xe^{135} , which has a half life of 9.4 hr. and a very high cross section. The result of this is that within the first hour after shutdown the reactor will lose 9 per cent of its reactivity and within 2 hr. after shutdown it will have lost 16 per cent excess reactivity.

The maximum loss of reactivity due to xenon occurs at about 10 hr. after shutdown. After 10 hr. the xenon content of the reactor decreases, with the result that after 48 hr. the reactivity is only a few per cent less than during steady operation at 30,000 kw prior to shutdown. After 63 hr. the reactivity is again equal to that prevailing at shutdown.

The significance of this state of affairs is that, if the reactor is accidentally shut down during steady operation at high power and not restarted promptly, it requires a large amount of excess reactivity to get it going again. Once started, the accumulated Xe^{135} will be rapidly consumed by the operation of the reactor itself, and the reactivity of the reactor then increases, approaching its normal steady running value. It is not considered safe to build into the reactor enough excess reactivity to take care of the maximum amount of xenon poisoning that might occur. This imposes on the operator the necessity of getting the reactor going quickly after an accidental shutdown. If he does not get it going quickly enough, he will not be able to start it for about two days. In consequence, the control system has been designed to permit starting the reactor rather rapidly. (This will be discussed further later.) Another and obvious consequence is that it will not be permissible to shut down the reactor at frequent intervals in order to accommodate experimental workers, unless the experiments in question are of considerable importance, since to do so is likely to put the reactor out of operation for two days. Accidental scrams of the reactor are also to be avoided unless there is some bona fide reason for them; for this reason the control system of the reactor provides automatic setback to a relatively low power level from which it is easy to come quickly to full power again if the reason for the alarm turns out to have been false or unimportant.

The general arrangement of the shielding of the reactor has been described above. The concrete shield is 9 ft. thick, which is conservatively ample to reduce the intensity of radiations of all kinds at the surface of the shield to one-tenth of 8-hr. tolerance or less. This is desirable in order to provide a low instrument background in the region around the reactor.

The shielding above the reactor during loading or unloading is just the column of cooling water. Its height (20 ft. above the center line) is such that the radiation level at its surface when the reactor is shut down is below 0.1 r/8 hr. When the reactor is in operation, however, additional shielding is necessary and is supplied by the top plug which is made of steel and is filled with an 11-in. layer of lead shot.

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CONTROL SYSTEM

The general scheme for controlling the reactor may be described as a combination of manual control by the operator and automatic control from the instrument signals, so that, particularly during startup, the operator and the instruments serve as mutual checks on each other. Motion of the shim safety rods to cause increased reactivity of the reactor requires the permission both of the operator and of various automatic devices and interlocks. However, an action tending to decrease the reactivity can be initiated by either the operator or several automatic devices independently. The action of the various scram circuits, i.e., those that shut the reactor down irreversibly in the event of an emergency, is entirely independent of the normal control and interlock circuits.

Stated in other words, the reactor is subject to effects of the control rods, auxiliary facilities, and certain disturbances. The reactor in turn affects certain instruments that produce information to be transmitted to the operator and to the control system. The operator and the control system also receive information from selsyns and other indicators of rod position or rod motion. On the basis of the information received, taken together with the operator's actions or instructions, the control system transmits to the motors or magnets (also called "clutches") appropriate control signals. The motors or magnets then cause corresponding rod motions, which in turn affect the reactor. Thus the main control loop is a closed path.

The two functions of the control elements are the safety function and the regulator function, the former being to guard against danger to the reactor and personnel and the latter to provide for start-up and shutdown as well as for maintenance of a satisfactorily close regulation of the neutron flux over the required range of operating levels.

The safety and protective elements consist of those which warn the operator that action is necessary and those which automatically limit the speed of the control rod, reduce the power level, and shut the reactor down. The latter three functions are accomplished, respectively, by "period" control, a motorized rheostat, and release of magnetic clutches on the shim safety rods. Period control is based on an electronic device that measures the time derivative of the logarithm of the neutron flux. It is used to prevent short reactor periods. Reduction of the power level to about 1 per cent of the normal operating level is valuable in emergencies in which the more drastic scram might not be justified and is brought about by signals not only from the instruments indicating neutron flux but also from the monitors on cooling-water activity, cooling-air activity, experimental facilities, instrument elements, etc. Scram signals come from instruments indicating the neutron-flux level and from a few critical monitors such as those for cooling-water flow. In addition to these devices a group of interlocks is used to serve as a step-by-step check on the operator to prevent serious consequences from mistakes or inadvertences.

The regulating requirements are met by a servomechanism which controls the motion of the regulating rod whose position in turn calls for the withdrawal or insertion of the shim rods. The regulating rod itself controls about 0.5 per cent of the reactivity (less than the effect of delayed neutrons) for purposes of fine regulation. The figure 0.5 per cent is chosen so that in the event of misoperation the servomechanism cannot change the reactor condition from critical to prompt critical.

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Regulating Rods

Although one regulating rod is sufficient for control of the reactor, a stand-by is provided, and four possible locations for these rods in the reactor are available. These locations are situated in the beryllium reflector adjacent to the active lattice. Each rod is 1.5 in. in diameter and contains a 23-in.-long center section which has cadmium sandwiched in stainless steel tubing. Guides are provided in the upper and lower grid supports. The total weight of the rod and connecting shaft is approximately 55 lb. The rod is driven by a low-inertia high-starting-torque d-c electric motor of special design through a pinion and rack that are integrated with the rod. The motor is driven by an amplidyne.

Shim Rods

There are eight spaces provided in the reactor lattice for shim safety rods, although all need not necessarily be used. These shim rods are driven mechanically by a worm drive and reversible 3-phase induction motors which are remotely controlled by reversing contractors, electrically and mechanically interlocked. The drives are furnished with the usual complement of upper and lower limit switches. The advantage of the induction motor is that no accident can make it run in excess of synchronous speed; therefore, the danger of overspeed withdrawal of shim safety rods is eliminated. No brakes are required during reversal since the drive mechanism utilizes the self-locking features of a worm-and-acme screw.

To provide the scram or safety feature to the shim safety rods, a magnetic coupling between the vertical lifting shaft and the rods is used. This is a bipolar or horseshoe electromagnet. Its lifting capacity is adequate to support the rod against the static and dynamic forces imposed by the high-speed cooling water surrounding and passing through the shim safety rod. The magnet is wound with 3500 turns of fine wire so that a current of 100 ma will hold a load of 500 lb. It should release a 600-lb. load held at 140 ma in 15 msec or less. The current is supplied by a vacuum tube which releases the magnet when the grid becomes less positive. The time lag (less than 0.02 sec.) in the release of the shim rod by the magnetic coupling is short enough so that if the operator should inadvertently withdraw the shim rods at their maximum rate, with the reactor superprompt critical, the chain reaction still would be safely stopped by the dropping of the shim rods themselves.

A period meter has been developed which gives a scram signal if the period is less than 1 sec., and it causes the insertion of the shim rods by means of their motors when the period is less than 5 sec. This instrument is most useful below one-tenth of the full reactor power.

The design of the safety scram circuits is such that they give an alarm in the event that they are not in perfect operating condition. These alarms indicate not only failure, but also incipient failure and where it occurs or is likely to occur (e.g., a short circuit in the cable, a weak tube, a lack of power).

The shim safety rods are constructed to bring fuel sections into the lattice as they are raised. They have a cadmium sheet in the upper section, and this section will reside in the reactor when the rods rest in their lower shock absorbers. Each rod is extended at the top and the bottom by square hollow stainless steel sections. The top of the rod forms the armature for the magnetic clutch, and the bottom is formed into a tapered plunger. On an emergency release of the rod the energy resulting from the fall is transferred to water forced out of a dashpot by the tapered plunger. Graphite-faced guides with roller bearings are mounted about 3 ft. above and below the active lattice in guide support grids and are lubricated by the cooling water.

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The motors, drive mechanisms, position indicators, limit switches, etc., associated with both the regulating and the shim safety rods are located on top of the reactor tank plug. The dashpots are located in the bottom of the reactor tank. The magnetic clutches work under water inside the reactor tank.

Figure 4 shows the assembly of the reactor tank system, including the top and bottom plugs, and the layout of the important reactor components.

CONTROL INSTRUMENTATION

The neutron-flux signals for operating the control circuits come from 10 to 14 instruments located in the 10 instrument holes provided in the reactor structure. Three ionization chambers are reserved solely for the safety function to furnish scram signals at 1.5 to 3 times the operating level and to furnish a slower signal to initiate reversible reduction of the operating level. Other signals provide either visual indication to the operator or signals to the servomechanism and other automatic devices. For visual indication from the operating level to 10^{-5} of the operating level, a direct-reading galvanometer is available. Another galvanometer shows the logarithm of the intensity factor from the operating level down to 10^{-11} of the operating level. In the lower part of the range the signal arises from a fission chamber and counting-rate meter.

There are three groups of instruments furnishing information to the operator and to the control system: (1) the reactor instruments measuring neutron flux or power level, (2) the rod-position and -motion indicators, and (3) the instruments for the auxiliary facilities.

Reactor Instruments

It is necessary to make a rather arbitrary distinction between reactor instruments and instruments on the auxiliary facilities, particularly on the cooling water. Reactor instruments include radiation instruments measuring the neutron level in the reactor and radioactivity in the water, temperature instruments measuring the distribution of exit-water temperature across the active lattice and temperatures in the thermal and biological shields, and Pitot tubes measuring the distribution of water flow across the bottom (exit) of the fuel assemblies. The reactor radiation instruments are listed in the following table:

Reactor Radiation Instruments

Instrument	Use
Parallel-circular-plate ionization chamber	Safety and servo signals
Compensated ionization chamber	Log N^* and period signal; galvanometer signal
Fission chamber, 12-ft. travel	Counting-rate signal
Air-wall ionization chamber (G.E. No. 97373341G1)	Water-flow N^{16} monitoring
Water-monitor ionization chamber (G.E. No. 9737814)	Water-sample monitoring
Boron thermopiles	Neutron flux in graphite

*N here means essentially neutron flux (nv)

The importance of having proper instruments for control purposes is made evident by consideration of Fig. 5, which shows the relation of the power (or neutron) level considered in four definite ranges to the choice of instrument and control action. These ranges serve as convenient divisions of the entire range of reactor operation. At the lowest level is the source range, which lies below the range of the counting-rate meter and in which control-rod withdrawal should be prohibited. Until the level is raised above 10^{-11} of full power by a suitable source, the effective k of the reactor should be kept less than 1.0, i.e., rods should not be

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withdrawn. Next comes the counter range, in which the combination of fission chamber and counting-rate meter is the source of a reliable signal. For the MTR, only intermittent rod withdrawal is permitted in this range. The lower limit of the period meter makes the transition to the period range. By the time this range is reached, the cold, clean reactor will have become critical and the level will be rising on a stable period. Finally comes the power range, over which an appreciable fraction of full power may be measured.

Fig. 5 - Relation of power level to instruments

Parallel-circular-plate Chambers

The parallel-circular-plate (PCP) ionization chambers are designed, constructed, and located in the reactor so as to give high-speed response to changes in neutron flux coming from the core of the reactor. The active section consists of a set of graphite disks, each of which is coated on both sides with B¹⁰. Alpha particles are emitted by the B¹⁰ (n, α) Li⁷ reaction when neutrons bombard these disks. These alpha particles cause the ionization which the chamber measures. The thickness of the boron coating (0.3 mg/cm²) on the graphite disks is chosen so as to give the maximum ionization current (about 50 μ a at their operating flux of 10¹⁰ neutrons/cm²/sec).

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The chambers cannot be located as near the reactor tank as would be desirable because of the high neutron flux. They are located in holes, looking directly toward the tank, with collimating boral sleeves ahead of the chambers to enhance their inherent directional sensitivity to flux directly from the tank. With this arrangement the major delay is the time, estimated at 5 to 10 msec, for neutrons to get from the core through the tank and into the graphite.

Compensated Ionization Chamber

The compensated ionization chamber is designed to give reliable measurement of neutron flux over a large range, particularly in the presence of relatively intense gamma radiation. The construction features two separate chamber volumes. The inner volume is contained between a movable cup electrode and a fixed inner electrode shell; the outer volume is between this inner shell and an outer electrode shell. The two volumes being approximately equal, the effects of gamma radiation on the two should also be equal. In addition, the outer volume is made sensitive to neutrons by B^{10} coatings applied to the electrode surfaces. Then, if the cup electrode is at negative potential and the outer-shell electrode is at positive potential with respect to the inner shell, the net current carried by the inner shell will be a measure of neutrons alone. Close balancing of the two volumes for zero gamma signal is carried out by moving the cup electrode, thus varying the inner volume.

Fission Chamber

The fission chamber is designed to give neutron measurements at low flux levels. The construction is quite simple. A brass shell carries a nickel liner with a coating of U^{235} on its inside surface. A central anode rod of 2S aluminum, 0.25 in. in diameter, is supported on a coaxial connector. Neutrons absorbed in the U^{235} produce fission fragments which ionize the gas in the chamber. The voltage pulse thus created by each fission is amplified and counted. These fission pulses are large and, by proper biasing of the amplifier, can be counted separately from the lesser currents due to alpha or gamma radiation; i.e., neutron flux can be accurately measured even in the presence of intense gamma radiation. By using argon gas, a short, sharp pulse may be obtained. However, the chamber performance is then very sensitive to gas impurities and to supply voltage; to minimize these difficulties, the argon is deliberately mixed with about 5 per cent carbon dioxide. Under these conditions pulses are distinguishable up to a limiting rate of nearly a million per second. The counting-rate meter used with the fission chamber, however, has a useful range from 1 to 10^4 counts/sec, and this is therefore the working counting range of the complete instrument.

To increase the neutron-flux range of the instrument, provision is made for moving the chamber over a maximum distance of 12 ft., from outside the top thermal shield to a point well inside it. This travel corresponds to an estimated change in sensitivity of 10^7 . At the innermost position the minimum flux to be expected (say from a source at the startup of a clean reactor) would be about 10^3 neutrons/cm²/sec, corresponding to 10 counts/sec. The maximum flux (reactor at full power) at the inner position would be 10^{13} neutrons/cm²/sec, and at the outer position, about 10^6 neutrons/cm²/sec, corresponding to 10^4 counts/sec, the upper limit of the counting-rate meter. In view of this range the fission chamber is used at three established positions in its instrument hole, motion from one to the other giving a neutron-flux range multiplication of about 3×10^3 , which is comfortably within the counting-rate range of 10^4 counts/sec. The means of moving the chamber is semiautomatic and is tied in with the control circuitry.

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Air-wall Ionization Chamber

The air-wall ionization chamber (G.E. No. 97373341G1) is used to measure the energetic 7-sec. gamma activity of N^{16} formed in the O^{16} (n,p) N^{16} process by neutron bombardment of the cooling water. The chambers are located in thimbles in the outlet flow. This signal should constitute a good over-all measure of the average reactor core flux. The chamber is 5 in. in diameter by 19 in. long, with cylindrical electrodes. The name "air-wall" signifies that it is made of materials having nearly the same atomic number as air and hence giving similar scattering.

Water-monitor Chambers

The water-monitor chambers (G.E. No. 9737814) are used in the monitoring room to measure beta and gamma activity in the water drawn through the sampling tubes from the exit face of the active lattice, one tube under each possible element position. Thus the distribution of radioactivity in the water flowing through the lattice can be observed. Water from each of the tubes is examined every 2 minutes by an automatic cycling device. The water is held up long enough for the N^{16} activity to become small; therefore the observed activity is either that induced by the flux in the demineralized cooling water or it is evidence of a fission break (rupture of a fuel element) in the core.

Boron Thermopiles

The boron thermopiles are used for an additional check on the neutron-flux level. They are all located in the graphite at the same horizontal level. These instruments consist of a large number of thermocouple junctions in series, alternate junctions being coated with boron. The coated junctions become warm owing to absorption of neutrons, thus yielding a net voltage which is a measure of neutron flux. The instrument case is about 0.5 in. in diameter by 6 in. long.

Other Instruments

In addition to the foregoing reactor instruments, all of which measure radiation, there are various temperature and water-flow measurements to be mentioned. Each of the sampling tubes under the fuel element positions is actually part of a triple-function assembly: sampling tube, Pitot tube for flow measurement, and thermocouple for water-temperature measurement. Knowledge of the distribution of water flow, velocity, and temperature is of obvious value. There are also numerous thermometric devices used for observing temperatures in other parts of the reactor. Most important of these, from the control standpoint, is the pair of thermocouples in the inlet and outlet water lines, measuring the temperature rise which is then multiplied by total water flow to give power absorbed from the reactor. A Venturi flowmeter feeds the signal to a flow recorder, and the thermocouples feed a differential temperature recorder. Impedances in these recorders are connected in a bridge circuit in such a way that the bridge output is proportional to the product of the two signals. The detector for this bridge is thus the power-level recorder.

In the thermal and biological shields there are about fifty positions for thermocouples. The signals from these instruments, however, tie into the control of the reactor only through the one annunciator channel reserved for them.

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Auxiliary-facilities Instruments

In the general scope of the control problem certain auxiliary facilities are of some concern to the operator and should, therefore, be mentioned here. It is, of course, possible that any conceivable detail of associated equipment, however remote, might under some circumstance be of concern to the operator. It seems reasonable to confine attention here to three vital facilities: process water, cooling air, and control power.

The process water which cools the reactor is perhaps the most important auxiliary facility. Undue changes in temperature or flow of this water can result in just as serious damage to the reactor as undue changes in neutron level. The water level in the main tank, or "working reservoir," is guarded with automatic safety actions. Scrams or setbacks are automatically caused by any dangerous changes in flow, temperature, or quantity of cooling water. In addition, the water system is provided with sundry alarms and recorders, which need not be detailed here. Most of these will engage the attention of personnel stationed in the process-water control and instrument center and will receive only marginal attention in the reactor control room.

In so far as cooling air is concerned, the operator is warned by alarms on pressure and flow of air and also on radioactivity in the air stack. Air-flow failure causes a mild automatic safety action (slow setback).

In order that reactor operation may be as free as possible from the effects of transient disturbances or outages on the purchased-power lines, electrical power for the control system is obtained from a special supply. This supply consists of two alternators operated from storage batteries that are kept charged by two converters on the power supply. In normal operation one alternator would supply instrument-bus voltage, and the other alternator would supply relay-bus voltage.

EXPERIMENTAL FACILITIES

Inasmuch as the reactor is primarily an experimental tool, a large and varied assortment of experimental facilities is provided. The substitution of an experimental device for one of the fuel elements or for a large number of the beryllium reflector assemblies is possible. There are at least two holes out of which a beam of neutrons can be taken and projected for a distance of 1/4 mile horizontally. These various experimental facilities are described very briefly, although considerable effort has gone into their detailed design.

Horizontal and Downbeam Experimental Holes

There are 17 large experimental holes that lead from the reactor faces either to the reactor tank wall or to the active lattice. These holes are treated separately from the vertical graphite holes because their sizes and locations require special design, shielding, and handling techniques. 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. Figure 6 shows a typical layout of a horizontal beam hole. Since these holes provide the largest volumes of high flux in the reactor, they are the most dangerous, and their use will probably be correspondingly difficult and complicated. They are as follows:

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1. Six horizontal beam holes, HB-1 to HB-6. These holes extend horizontally from the reactor face to the active lattice. Holes HB-2 and HB-5 are 8 in. in diameter to the reactor tank wall and 6 in. in diameter from the reactor tank wall to the active lattice. Holes HB-1, HB-3, HB-4, and HB-6 are 6 in. in diameter throughout.
2. Six downbeam holes, DB-1 to DB-6. These are 6-in.-diameter inclined holes which extend from the upper north and south faces to the reactor tank. They are located directly above the horizontal beam holes. Inside the tank wall they are essentially extended to the lattice by 2-in.-I.D. sealed empty aluminum cans in the beryllium reflector.
3. Two horizontal graphite holes, HG-5 and HG-6. These are 6-in.-diameter horizontal holes which extend to the reactor tank.
4. Two horizontal rabbit holes, HR-3 and HR-4. These are 4-in.-diameter horizontal holes which extend to the reactor tank.
5. One horizontal through hole, HT-1. This is a hole 4-11/16 in. square which extends from one reactor face to the opposite face. It goes through the reactor tank and lies adjacent to one side of the active lattice.

In formulating the design of these holes, considerable thought was given to the future needs of the experimenters who will use these facilities. Other factors that had a strong influence on the experimental-hole design are radiation hazards, material selection, cooling requirements, and the configuration of the reactor itself.

In addition to these main experimental holes there are six more horizontal through holes. Four of these, HG-1 to HG-4, are for experimental use; the other two, HI-2 and HI-3, are for reactor control instruments. HG-1 and HG-2 go through the full length of the east graphite wall, and HG-3 and HG-4 penetrate the west wall. The first two holes are 8 in. in diameter; the latter two are 4 in. in diameter through the graphite.

Access to HI-2 and HI-3 is obtained through the east and west faces of the reactor structure. These holes are used for the compensated ionization chambers for the log N and galvanometer circuits of the reactor control system. Both holes have a minimum diameter of 10-3/4 in. and are plugged only through the biological and thermal shields. The plugs used are barytes concrete tipped with a 30-in.-long aluminum casting. A 4-in.-diameter hole runs through the center of the plug to within 4 in. of the inner end. This allows the tip of the ionization chamber to be inserted to the inner side of the thermal shield. An adjustment of the ionization-chamber insertion rod enables the chamber to be moved back as much as 18 in. from the inner position.

Vertical Experimental and Instrument Holes

The MTR has 71 experimental and instrument holes accessible from the top of the reactor. Some of these penetrate into the pebble zone and some into the permanent graphite; two are also accessible from the sub-reactor room. The dimensions range

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generally from 2 to 4 in. in diameter. Four of these holes are 6-in. thimbles extending into the exit-water lines, two for measuring exit-water activity and two to provide high-gamma-flux experimental facilities. One hole is a 12-in. square penetrating to the inside tip of the HG-9 hole coming through the thermal column. Two other 12- by 12-in. holes also penetrate vertically downward into the thermal column.

Thermal Column

The thermal column is 6 ft. square and 8 ft. long outside a 4-in.-thick lead window. The outer face is protected by a 10-in.-thick lead shielding door. Six 4- by 4-in. graphite stringers penetrate the thermal column to the inner lead window. A 9- by 15-in. hole, HG-9, penetrates the column to the reactor tank wall. Two 4- by 4-in. holes at 90 deg to the column penetrate from reactor face to reactor face. In addition, the two 12- by 12-in. vertical holes mentioned previously are available.

At one time there was a second thermal column in the design. Later it was converted to a facility for testing shielding materials. Subsequently most of the features of this facility were canceled. At present the 6-ft.-square hole is filled with barytes concrete blocks. It can readily be converted to another thermal column.

Shuttle Tubes

Two pneumatic shuttle tubes are provided, HR-1 and HR-2. These are 1-in.-I.D. horizontal tubes which extend completely through the structure and pass within 1 in. of the active lattice. These are in addition to HR-3 and HR-4, which approach the tank wall radially and have been mentioned earlier. Actually, any beam hole can be adapted to provide shuttle facilities. These pneumatic shuttle tubes are generally thought to be useful for very short-time irradiations.

Hydraulically operated shuttles are also provided. These are for irradiations of small samples which require times up to the order of two weeks and require removal between normal reactor shutdowns. They consist of two 1-in.-I.D. vertical tubes running through the bottom plug into the beryllium reflector adjacent to the active lattice. In addition, tubes 1.31 in. in diameter can be used in any of the four regulating-rod positions which are not in use. These hydraulic shuttles are accessible through a short extension of the main canal in the reactor-building basement.

HEAT PRODUCTION AND REMOVAL

When the reactor is producing 30,000 kw of heat energy, the heat actually produced in the various parts is as follows:

<u>Part</u>	<u>Heat, kw</u>
Fuel Elements	28,800
Beryllium	1,200
Graphite	500
Thermal Shield	48
Concrete	~2

At the instant of reactor shutdown, the total heat liberated due to the absorption of gamma and beta radiation from fission products amounts to 2000 kw in the lattice and 400 kw in the beryllium. At any reasonable time, t sec., after shutdown these heats fall off proportionally with $t^{-0.2}$. Hence, although the water flow through the lattice at shutdown can be reduced to about one-fifteenth, the flow through the beryllium reflector can only be reduced by two-thirds, so that the latter is determinative in the parallel flow system of the MTR.

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EXTERNAL-WATER SYSTEM

The reactor is cooled by a recirculating stream of demineralized water flowing at about 20,000 gal/min. The water flows by gravity in 30-in. pipes from a 150,000-gallon constant-heat working-reservoir tank supported on a tower about 170 ft. above the reactor through a flow-control and -metering station and then through strainers and into the reactor. Flow from the reactor enters a 17,000-gallon seal tank which is arranged to prevent possible drainage of the reactor tank. Three streams of water (~7000 gal/min each) are drawn by vacuum from the seal tank to the flash tanks of steam-jet refrigeration units which remove from the water the heat generated in the reactor and the gases formed by decomposition of the water in passing through the active section of the reactor. The three equal-sized refrigeration units have a design cooling capacity of 33,000 kw, which is 10 per cent in excess of the rated level of the reactor. The normal operating temperature of the water entering the reactor is 100°F; leaving, 111°F. The chilled water and the condensate flow by gravity from the refrigeration units to a 100,000-gallon sump tank, 60,000 gallon for normal satisfactory operation of the pumps, and 40,000 gallon for accumulation of water in case the pumps fail. Three 100,000 gal/min high-head pumps (two operating and one stand-by) force the water from the sump tank up to the working-reservoir head tank to complete the circuit. The pumps are driven by electric motors.

Heat is removed from the three surface condenser type steam-jet refrigeration units by circulating 8910 gallons of water per minute from clear wells underneath open cooling towers through the main condensers. Under summer conditions (65°F wet bulb) the induced-draft tower cools this water from 95°F to 72°F. Continuous cooling-water make-up is supplied for entrainment and evaporation losses and to give sufficient purge to control the accumulation of total solids.

There is sufficient capacity in the working reservoir to supply process cooling water at the full rate for approximately 7.5 minutes, assuming that all pumps are stopped. For cooling during shutdown, either accidental or operational, one 8-in. line which bypasses the valves and flowmeter in the main 30-in. line is provided. This line will flow up to 1000 gal/min at all times. It can be fed by water from the working reservoir or by fresh demineralized water from the demineralized-water storage tank. In addition, it is provided with two 1000 gal/min pumps, one electrically driven and one gasoline-motor driven. These pumps will circulate water between the reactor and the seal tank. Finally, raw water can reach the reactor through another 8-in. line, permitting as a last resort the use of raw water either from the overhead raw-water head tank of 150,000 gallon capacity or from the two 500,000-gallon ground-level reservoirs through the raw-water pumps.

Purge water leaves the circulating system by overflow from the sump tank through a retention basin which will provide 90 hr. for the decay of induced activity to below tolerance level for release. The 720,000-gallon retention basin is made up of two 360,000-gallon sections, one is active and one is kept empty for emergency use. The empty section in the retention basin will hold approximately the volume of the entire process-recycle cooling system. These retention basins also receive active water from other sources. After passing through the retention basins the water goes to the desert through a leaching pond.

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The process-water stream becomes highly radioactive from neutron bombardment in passing through the reactor. Shielding of the recycle system is designed for one-tenth human tolerance at the surface in all working areas. This ensures a satisfactorily low activity level for instrument background and provides safe working conditions. The activation of the oxygen in the water produces N^{16} and O^{19} , resulting in very intense radiation of short duration (4×10^5 to 5×10^5 disintegrations/cm³/sec), which requires a 5-ft.-thick concrete shield around the pipes in the reactor building. In the external system these activities, having decayed, are inconsequential, but long-lived activities due to Mg^{27} , Cr^{51} , and Na^{24} will become controlling (10^4 disintegrations/cm³/sec). Between 12 and 24 in. of concrete provides sufficient protection here.

Before the purge water is discharged to the desert, it is held up four days in the retention basin. This delay is sufficient to reduce the water activity to 0.5 microcurie/liter or less (18 to 20 disintegrations/cm³/sec). The main source of radioactivity in this water is Na^{24} .

COOLING-AIR SYSTEM

All parts of the reactor structure outside the reactor tank are cooled by air. The design air flow of 2000 lb/min and pressure drop of 55 in. H_2O through the reactor cooling-air system are based on maximum temperatures of 570°F in the graphite pebble zone and 500°F in the permanent graphite at 45,000-kw operation of the reactor. This 2000 lb/min design flow consists of (1) the air flow through the graphite, 1610 lb/min; (2) the air to cool the top thermal shield, 250 lb/min; and (3) that allowed for leakage through and around experimental holes, 140 lb/min. During passage through the reactor the air will rise in temperature about 110°F.

Normal atmospheric air enters the reactor-building ventilation system through coarse filters and electrostatic precipitators. Air entering the reactor is taken from the building through glass-wool filters mounted in 2- by 12-ft. louvers high on each reactor face. Each louver feeds five or six 8-in.-square ducts (a total of 22) to a manifold which is continuous around the edge of the top thermal shield. A small amount of the air is bypassed through the top thermal shield. The main stream flows down between the walls of the side thermal shield, up through the permanent graphite and the graphite pebble zone, and out through two 30-in.-square ducts. These are connected to the top thermal shield at diagonally opposite corners and pass downward through the reactor structure to carry the air out in ducts below the basement floor. A 48-in.-diameter precast concrete pipe, 2 ft. underground, carries the air to the fan house.

Three half-capacity blowers of the positive-displacement type with damper systems are provided (two operating and one stand-by) for pumping the air during operation. In addition, there are two auxiliary 400 lb/min fans provided for air cooling during reactor shutdown periods. One of these is driven by an electric motor and one by a gasoline engine. These blowers and fans exhaust to the atmosphere through a 250-ft.-high stack.

A total activity of about 1500 curies/day of A^{41} will be exhausted to the atmosphere when the reactor is operating at 30,000 kw. Proper radiation-monitoring instruments, as well as standard control instruments, are installed in the air system. Shielding of up to 12 in. of concrete is provided.

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SITE PLAN AND BUILDINGS

The site plan is divided into two general areas. A "limited" or "clean" area, containing most of the nonradioactive operations and service functions, is separated by a fence from an "exclusion" or "hot" area, containing the reactor and its closely related radioactive and vitally necessary auxiliaries. In the exclusion area are located the reactor building and laboratory wing, the process-water building, the blower and fan house, the stack, the effluent-control system, the experimental plug storage, and the retention basin. In the limited area are the boiler house, the raw-water system, the demineralizer building, the cooling towers, the electrical substation, and other minor service buildings. All buildings in both areas are located so as to take advantage of surface-water drainage, underground water flow, and prevailing wind directions. Ample space is provided for the expansion of existing facilities and the addition of new facilities. Since the majority of the service functions, architectural features, and specifications are standard practice, only the reactor building and the laboratory wing will be mentioned here.

The reactor building is 130 ft. square and 80 ft. high. The lateral dimensions are determined by the provision of 40 ft. of clear space around the reactor structure. The height is required to give a 30-ft. clearance of the crane hook above the reactor structure. In order to provide for a basement, foundations, sumps, and underground ducts, the building extends 47 ft. underground. A canal extends 88 ft. outside the building on the east side of the basement.

The first-floor area (Fig. 7) is kept free of columns and permanent equipment so that the maximum possible space is available for experimental setups with sufficient space remaining for transporting heavy shielded containers. The floor is 3 ft. thick for a zone approximately 25 ft. out from the reactor to provide shielding to the basement. It is designed in this area for 900 lb. per square foot of uniform load to permit shielding walls of lead to be erected. Removable floor slabs allowing access to the basement and the canal, as well as several smaller "facility holes", are available. The entire 130-ft.-square area is serviced by a 30-ton crane.

Along one side of the building are two balconies (Fig. 8). The lower of these contains the instrument room, and the upper contains the reactor control room. These two rooms operate as a unit, with the instrument room having the amplifiers and relays and the control room having the indicating and recording instruments for reactor operation. Space is available on these balconies for other offices as desired, standard metal partitioning being used.

The basement (Fig. 9) has the same dimensions as the first floor and provides space for the erection of auxiliary shielded rooms to house circulating and cooling equipment for large experimental setups. Directly below the reactor is the heavily shielded sub-reactor room, allowing access to several experimental facilities, to the canal, and to several reactor components for maintenance. A monitoring room adjacent to the sub-reactor room contains instruments used in the continual monitoring of the reactor process-water temperature, flow, and radioactivity. Beneath the basement, and accessible by removable slabs, are various sumps and trenches to handle the cooling water, waste water, and cooling air.

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The canal contains equipment for the handling of elements discharged from the reactor and provides space for the storage of spent fuel elements, irradiated materials, and internal parts of the reactor. The main section is 8 ft. wide and 125 ft. long. A 3-ft. parapet permits the water level to be 2 ft. above floor level. The total depth of water is 18 ft. Directly under the reactor in the canal is the unloading machine, which receives the fuel elements as they are discharged from the reactor and places them on an underwater table from which they can be picked up and handled in the canal. In the canal also is an underwater saw for removing portions of the elements that do not contain fuel. Access to the canal for removing shielding containers containing fuel-element sections is possible through a roof hatch on the portion of the canal that extends outside the reactor building.

Although the reactor-building wing appears to be part of the reactor building, it is actually a separate building, having no structural dependence on the reactor building. In this way the transmission of vibrations is avoided. The wing is a single-story structure, 128 by 141 ft., whose internal layout is determined primarily by the laboratories and their auxiliary facilities. A modular wall plan is adopted to permit complete flexibility in laboratory size and interconversion of space to various uses. The building also contains a machine shop, staff shop, counting room, and other standard laboratory services. Design has been such that 70-ft.-wide wings can be added later.

The full basement provides adequate space for ventilating equipment, electrical-switching equipment, and battery and generator equipment associated with the reactor building and the laboratory wing. For example, all the air to both buildings passes through electrostatic precipitators and fans installed in this basement. A fair amount of additional space for storage and future use is available.

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FIG. 1
M.T.R.
NORTH-SOUTH VERTICAL SECTION

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FIG. 2
M.T.R.
EAST-WEST VERTICAL SECTION

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FIG. 3
M.T.R.
HORIZONTAL SECTION

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FIG. 4

FIG. 6

TYPICAL HB HOLE & PLUG

FIG. 7

REACTOR BLDG. FIRST FLOOR PLAN

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FIG. 8
SECOND AND THIRD FLOOR PLANS OF REACTOR BUILDING

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FIG. 9

REACTOR BLDG. BASEMENT PLAN

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