BMI-ACRS-601(Rev.)

PHYSICS

UNITED STATES ATOMIC ENERGY COMMISSION

HAZARDS SUMMARY REPORT FOR THE BATTELLE RESEARCH REACTOR

By
J. W. Chastain
R. F. Redmond
A. Klickman
J. Anno
S. L. Fawcett

April 4, 1955

Battelle Memorial Institute
Columbus, Ohio

Technical Information Service Extension, Oak Ridge, Tenn.

This report has been reproduced directly from the best available copy.

Printed in USA. Price 40 cents. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

AEC, Oak Ridge, Tenn.

DISCLAIMER

HAZARDS SUMMARY REPORT
FOR THE
BATTELLE RESEARCH REACTOR

April 4, 1955

by

J. W. Chastain
R. F. Redmond
A. Klickman
J. Anno
S. L. Fawcett

BATTELLE MEMORIAL INSTITUTE
505 King Avenue
Columbus 1, Ohio

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

HAZARDS SUMMARY REPORT FOR THE BATTELLE RESEARCH REACTOR

by

J. W. Chastain, R. F. Redmond, A. Klickman, J. Anno, and S. L. Fawcett

STATEMENT OF REQUESTED ACTION

This report is submitted by Battelle Memorial Institute to the Advisory Committee on Reactor Safeguards for their consideration and action concerning the proposed Battelle Research Reactor.

Specifically, Battelle is requesting permission from the Atomic Energy Commission to do the following:

(a) To construct the swimming-pool-type reactor described at the location defined in this report.

(b) To receive from the AEC enriched uranium in the following form:

28 MTR-type fuel elements (10 plates with 162 grams each)	4536 grams
5 Special half elements (voids for control rods)	405 grams
2 Half elements	162 grams
Total	5103 grams

(c) To initiate testing operations after construction of the facility for periods not less than the following:

(1) Zero-power tests	1.5 months
(2) Operational tests up to 100 kw	1 month
(3) Operational tests up to 1000 kw	1 month

(d) To operate the reactor at 1000 kw for 24 hours per day, 6 days per week, after completion of the above testing schedule.

(e) To load the fuel elements in the core in various ways such that continuous operation at 1000 kw in the two operating positions is possible, and a reactivity not in excess of 0.015 is available for irradiation experiments.

SUMMARY

This report was prepared for the Advisory Committee on Reactor Safeguards for their review and consideration of the potential hazards concerning the Battelle Memorial Institute Research Reactor. As such, it is considered to be a part of the application to the Atomic Energy Commission for a license to construct, to have fissionable material for, and to operate this reactor.

The proposed reactor is a modified "swimming-pool" reactor and will operate at 1000 kw. At this power, it will provide fluxes of fast and slow neutrons and gamma rays sufficient for a variety of experimental applications. After much study, a reactor incorporating an experimental stall attached to a large pool was designed. The reactor can be operated in the stall into which the beam tubes and thermal column converge. The reactor can be operated also in the open pool for shielding studies and large-scale irradiations. The plans for this facility and for the instrumentation, shielding, and controls are described in the report.

The research reactor facility will be located 13 miles west of Columbus on a 400-acre tract owned by Battelle. The building will be constructed of masonry and Q-metal siding and will be devoted exclusively to the reactor. The minimum distance to the exclusion fence is about 1200 ft; an uninhabited swamp is on the other side of the fence at this point. The only buildings within 2000 feet are structures housing the Battelle critical-assembly facility and the hot-cell laboratories. The off-site area is farming country and is very sparsely settled. Only 60 permanent residents live within a one-mile radius.

Discussions on the make-up of the surrounding area, including climatology, geology, hydrology, seismology, and the distribution of population and industry, are included. In the appendixes the reports from the sources (i.e., U. S. Geological Survey, U. S. Weather Bureau, etc.) are given. The conclusions in all cases are favorable to the site.

The report further discusses the operating procedure, the fuel inventory required, which is 5103 grams, and the time schedule, which suggests February 15, 1956, as a target date for initial criticality.

The last two sections of the report are devoted to hazards during normal operation and hazards following an accident. During normal operation, cracking of the shield, inadequate shielding, and fissure of a fuel element could be hazardous. These and the ventilation and disposal systems are considered along with the methods for removing the associated dangers.

Two reactor accidents and their hazards are considered: (1) a "maximum credible accident" in which an instantaneous increase in reactivity causes a power pulse and a Borax-type excursion, and (2) a "maximum hypothetical accident" in which there is complete vaporization of the fuel elements into a cloud. In the latter, which is the most extreme, direct radiation, inhalation, and fall-out of the radioactive cloud are considered. The results of these considerations indicate that, even in this hypothetical accident, the exclusion area is large enough to reduce the hazards to the general public to manageable proportions.

It is concluded that the design is safe and that the location provides an adequate exclusion area.

INTRODUCTION

Since its founding in 1929, by Gordon Battelle, the Battelle Memorial Institute has been devoted to "the encouragement of research and the making of discoveries and inventions for industry". As established, Battelle provides, on a not-for-profit basis, the physical plant, equipment, and personnel for conducting research. Industrial concerns, groups of companies, individuals, and Governmental agencies contract with the Institute for research services in practically all fields of science and technology.

The Atomic Energy Act of 1954 and other developments that have made the atomic energy field attractive to industry have encouraged Battelle to expand its facilities for nuclear research. Three major installations are in the planning or construction stage:

(1) A hot-cell facility for handling irradiated materials

(2) A critical facility for conducting zero-power reactor mock-up experiments

(3) A research reactor to provide various radiations.

All three will be housed in separate buildings located on a 400-acre tract of land near West Jefferson, Ohio, about 13 miles west of Columbus. The first two facilities have been designed and construction is under way.

It is expected that the reactor will be broadly useful, providing neutrons and radiation for experimental work in all sciences and technologies. A plan has been worked out to make the reactor facilities available to Battelle's neighbor, The Ohio State University. It is expected that the needs of the University will be largely centered around the production of short-lived isotopes for medical, biological and other uses, solid-state studies, and activation analysis. Experimental work on the reactor-core configuration will not be permitted.

An examination of possible needs indicated that facilities should be provided for the following types of studies:

(1) Radiation damage
(2) Activation analysis
(3) Isotope production
(4) Beneficial effects of radiation
(5) Neutron diffraction
(6) Exponential experiments
(7) Shielding experiments.

A study was made to determine what reactor type would fulfill the greatest number of these requirements. Reactors such as the Omega West and the LITR have facilities such as fixed beam tubes and a thermal column which provide radiation for the first six of these studies. However, shielding experiments and radiation damage on large-scale engineering loops are more readily carried out in a pool-type reactor. The reactor which has been designed is a combination of these two types. It consists of a large pool with an 8-foot-wide slot at one end into which the experimental facilities converge.

To do useful research with this reactor, a neutron flux approaching 10^{13} neutrons/(cm^2)(sec) should be available. The critical loadings for this reactor necessitate operation at about 1000 kw to obtain this flux.

In order to conserve time and money, it has been decided to maintain the design as close to an existing proven design as is practicable and further to contract for the design and construction of the major components. The American Machine and Foundry Company has been retained to provide mechanical parts and engineering services. An architectural firm employed by Battelle will design the building, and Battelle's general contractor will construct both pool and building.

REACTOR

Brief Description

General

The proposed reactor is a water-cooled, water-moderated "swimming pool" reactor similar to the Bulk Shielding Reactor Facility except that the reactor core can be operated in an experimental stall into which the beam tubes and thermal column converge. The other reactor operating position will be in open water in the pool. See Figures 1 and 2. The reactor core will be suspended from a movable bridge in much the same fashion as the BSR.

It is proposed that the reactor operate at 1000-kw power output, which will produce an average thermal neutron flux in the core of approximately 7×10^{12} n/(cm^2)(sec) when water reflected. The reactor will be cooled by forced convection of the water in the pool downward through the reactor, through a shielded cooling loop, and back into the pool. Water in the pool will be purified by circulation through a demineralizer so as to minimize corrosion of the fuel elements. Figure 3 is a block diagram of the cooling and purification system.

The reactor core will be made of MTR-type elements in which the fuel is contained in 10 plates per assembly. The elements are supported by a bottom grid plate similar to the one used in the BSR. The lower end of each element will have a cylindrical sleeve which will fit into a hole in the grid plate. The grid plate will have 54 holes arranged in a 6 x 9 pattern. These holes will be used for supporting the active lattice, reflector elements, and experimental equipment.

The reactor-core grid plate will be fastened to the bottom of a support tower made of aluminum angle welded together. This tower will in turn be supported by a bridge spanning the pool. The bridge will run on rails mounted on the pool side walls so that the reactor core can be moved from Position A to Position B on Figure 1. The bridge will be clamped into the proper operating position, and electrical interlocks with the control system will be provided to prevent operation of the reactor unless it is clamped down. The hand-operated drive will be padlocked to prevent unsupervised movement. The control drive mechanisms will be mounted at the main-floor level of the center of the bridge, with a superstructure floor built over them.

The reactor is controlled by four cadmium shim-safety rods, using lead for ballast, and one stainless steel regulating rod. The regulating rod

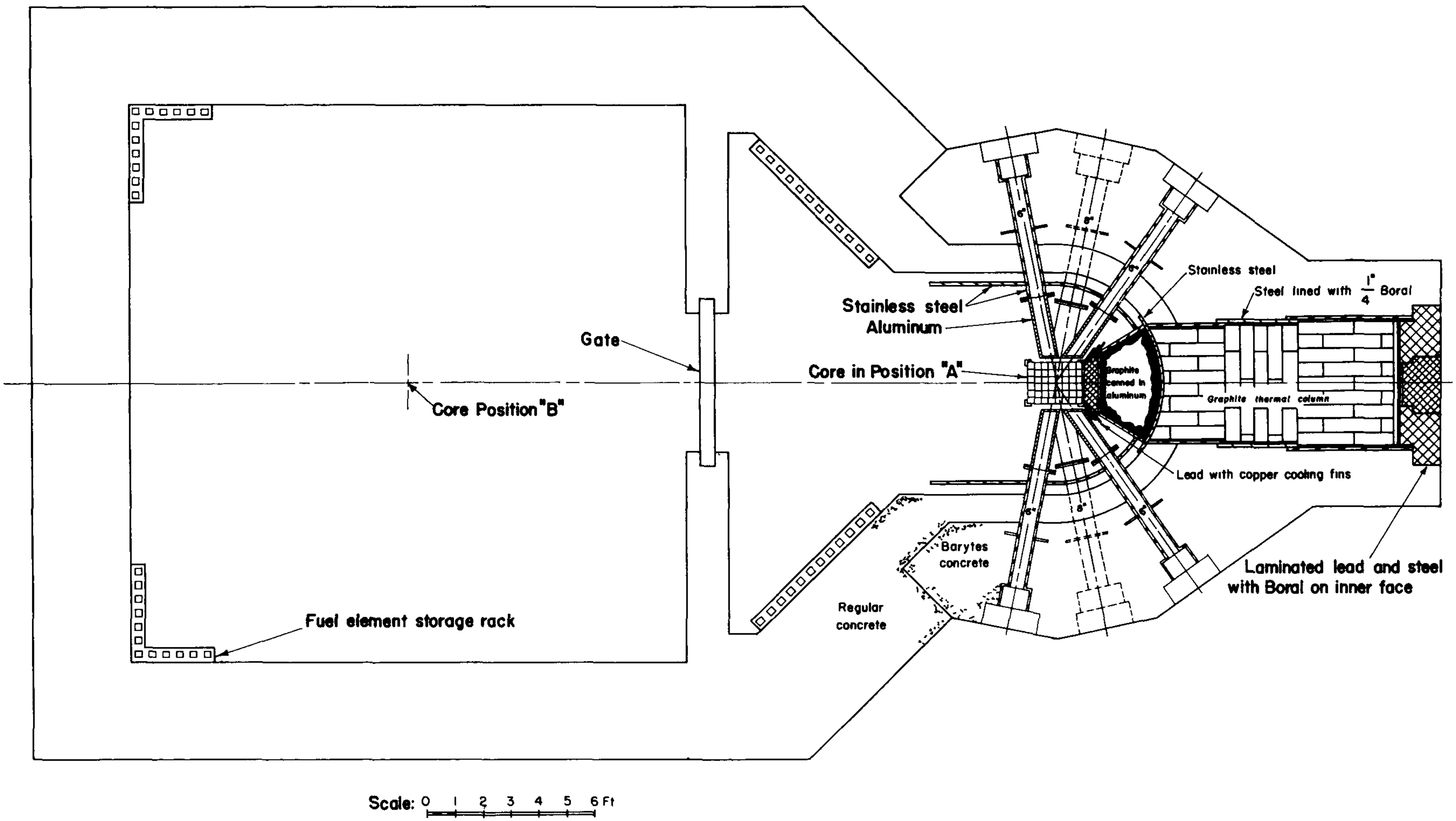


FIGURE 1. PLAN SECTION THROUGH CORE

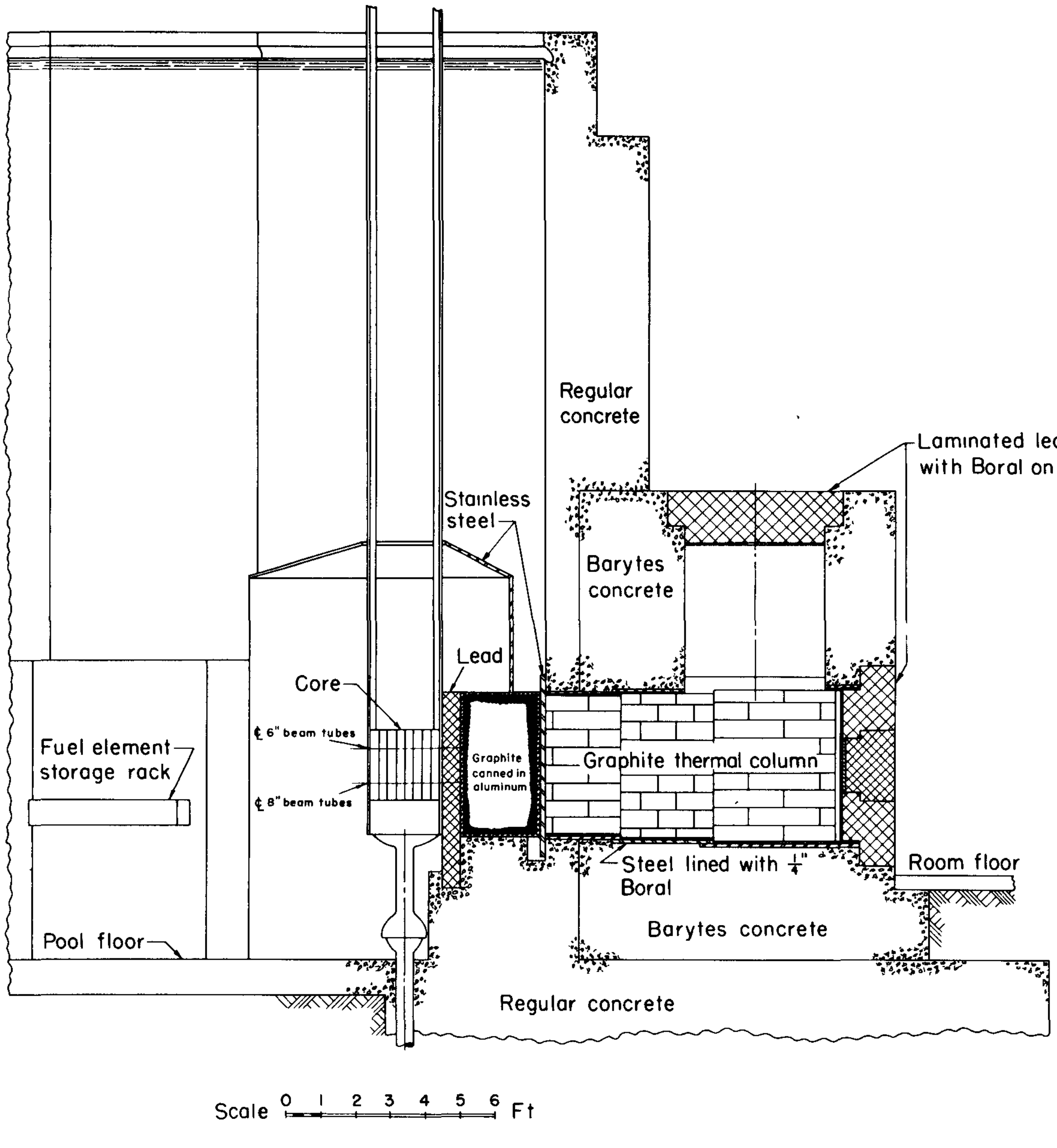


FIGURE 2. VERTICAL SECTION THROUGH CORE

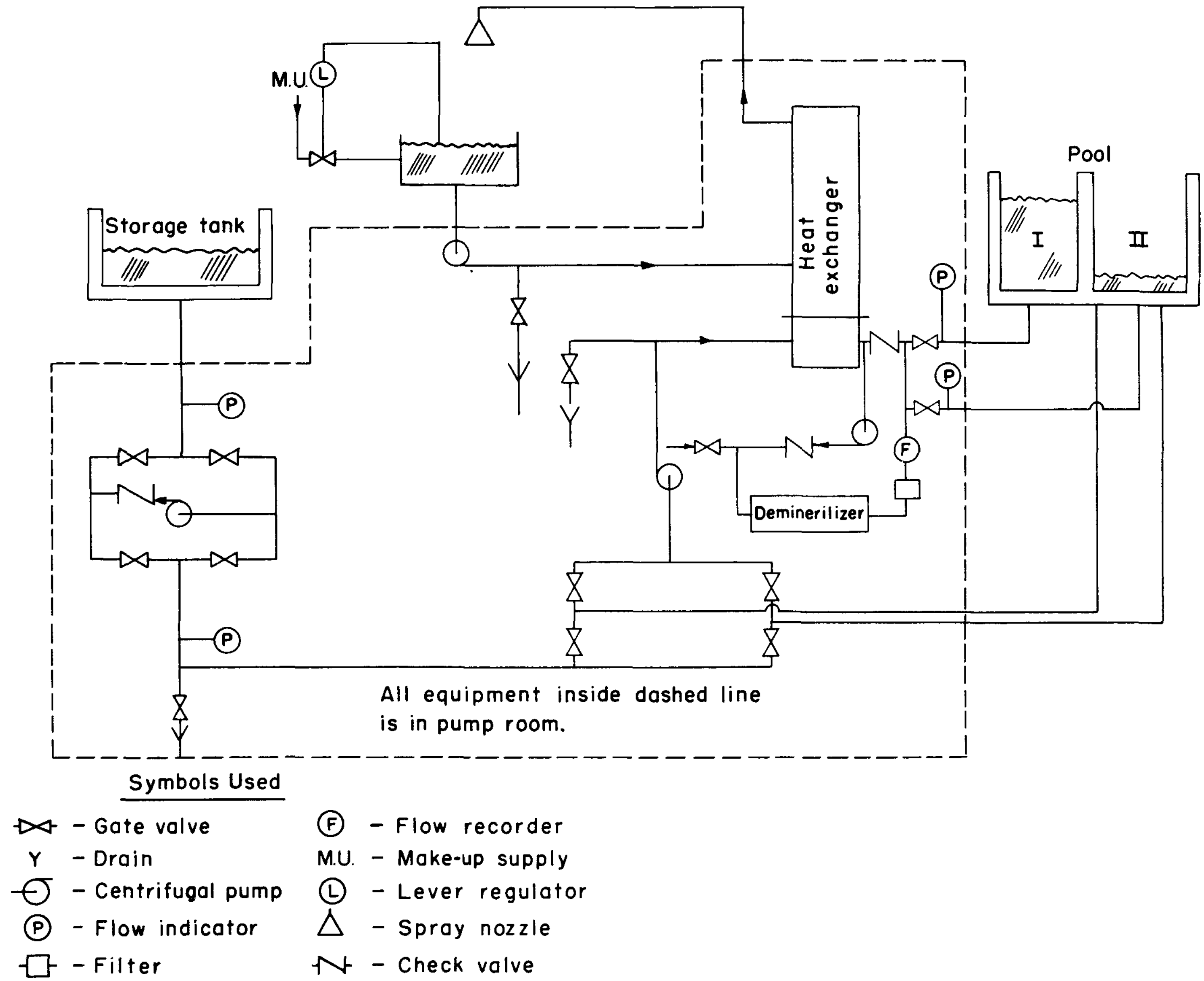


FIGURE 3. COOLING AND PURIFICATION SYSTEM DIAGRAM

will have a maximum effectiveness of 0.6 per cent k, which means that no misoperation of the regulating rod can result in prompt criticality. Each shim-safety rod has a value in excess of 3 per cent k.

The shim-safety rod drives are powered by induction motors and are coupled to the rods by lifting magnets. The excitation of the lifting magnets is controlled by the reactor safety system; when a potentially dangerous condition exists, the current to these magnets is interrupted and the four shim-safety rods fall by gravity, thus reducing the core to subcritical.

One of the four shim-safety rods is selected by the operator to be used as a pure safety rod. Power is not available to the magnets of the other three shim-safety rods until or unless the safety rod is on its upper limit.

The maximum rate (synchronous motor speed) of withdrawal of the shim rods is full travel in 5 min. Assuming the worth of each shim-safety rod to be 3 per cent k, the rate of insertion of reactivity, as determined by operation of the drives at synchronous motor speed (never quite obtainable) and the three rods in gang, is 3×10^{-4} k/sec.

The major components of the system are shown in the control-system block diagram, Figure 4. The design is essentially the same as for the BSR except that the Minneapolis-Honeywell safety amplifier has been substituted for the ORNL amplifier. To further insure safe operation of the reactor, the following conditions must be met before power is available to the lifting magnets.

(1) Bridge locked in place.

(2) The fission-chamber circuit must indicate the presence of the source. This instrument channel must be kept in range until the log-N channel is in range.

(3) The three radiation monitors in the building must indicate that the neutron plus gamma level is below AEC tolerance (7.5 mr/hr for 40-hr work week).

(4) Power level must be below 150 per cent rated (alarm sounds at 110 per cent).

(5) Period must be longer than 2 sec (alarm at 10 sec or shorter).

(6) Circulating flow must be maintained for power levels above 100 kw.

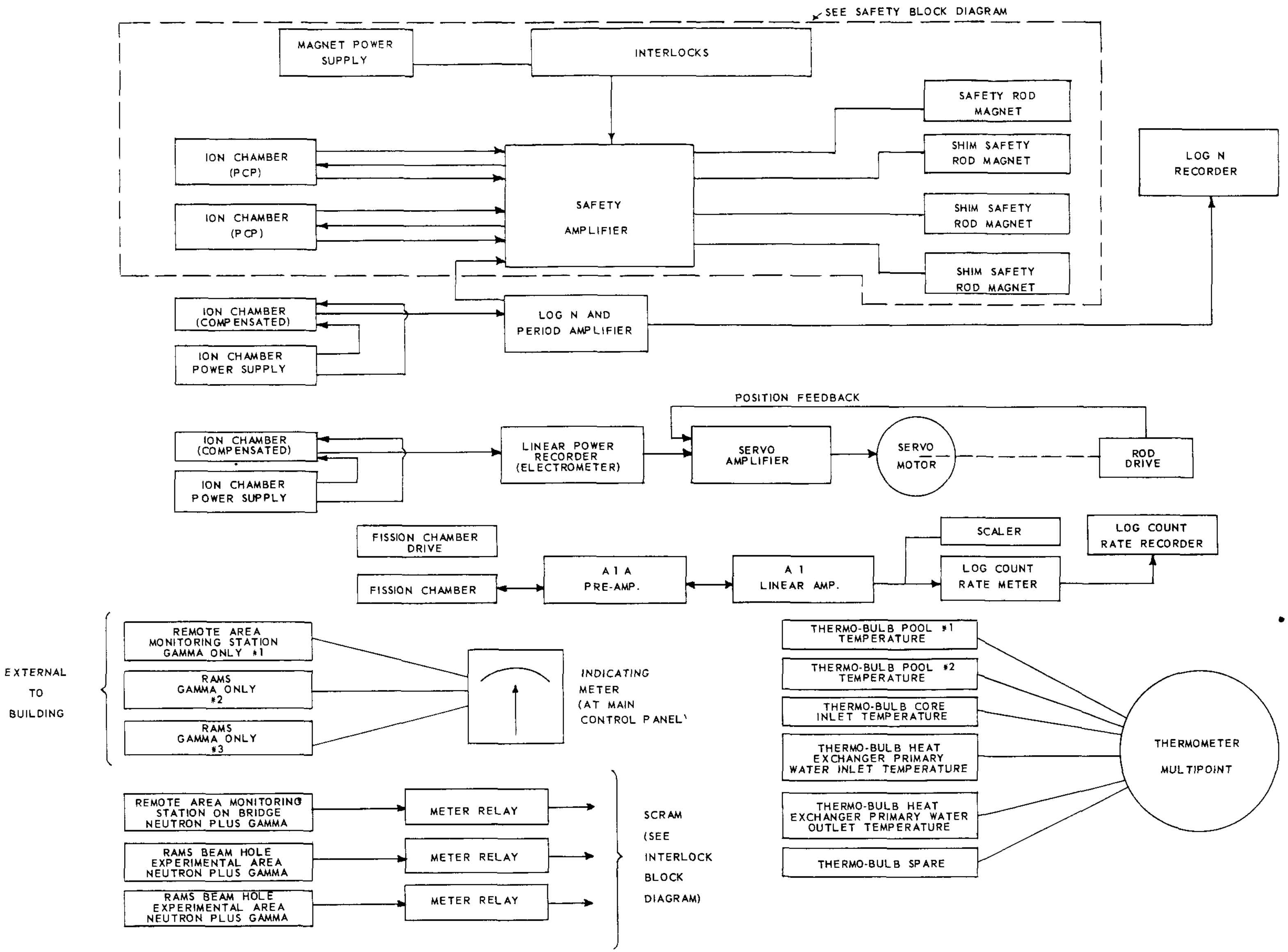


FIGURE 4. BLOCK DIAGRAM REACTOR CONTROL AND INSTRUMENTATION

(7) One shim-safety rod must be in full-out position before any other rods can be withdrawn, thus assuring that at least -3 per cent k is always available.

The block diagram of this system is shown in Figure 5.

Shielding

The shielding requirements of the reactor pool are dictated by the worst conditions due to the geometrical configuration. Shielding material will essentially consist of the following substances at various locations: lead, water, iron, structural cement, and barytes concrete. The barytes mixture has the following substances in the indicated proportions by weight.

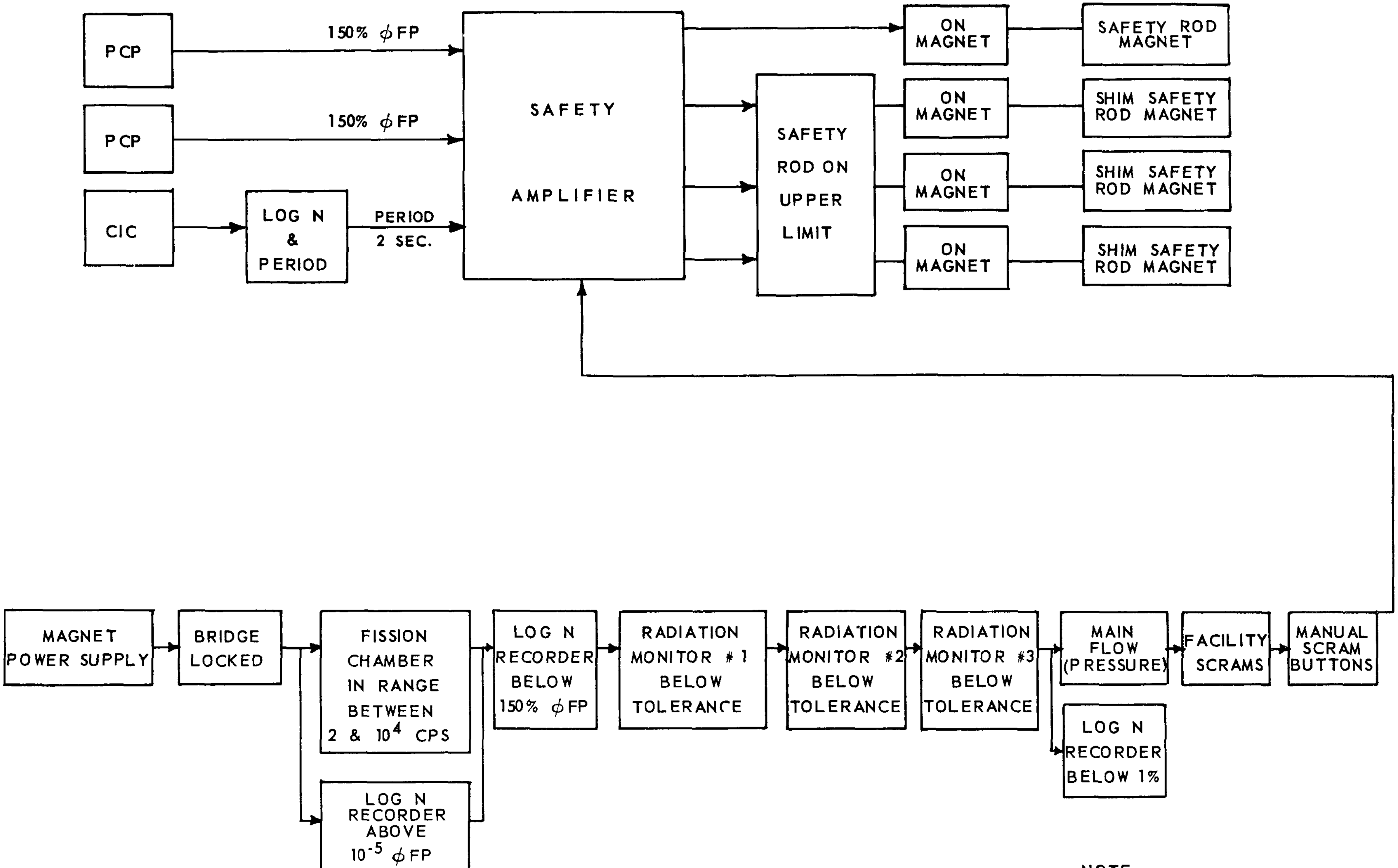
40.4 per cent barytes aggregate ($BaSO_4$), coarse
19.2 per cent barytes aggregate ($BaSO_4$), fine
22.2 per cent limonite, $2Fe_2O_3 \cdot 3H_2O$
11.2 per cent portland cement
7.0 per cent water

Shielding directly above the core will be provided by the water of the pool. Water to depth of 22 ft above the core will reduce the level to 3 mr/hr at 1-megawatt power level. With the core in the pool location (Position B), gamma radiation is most critical at the concrete wall at the corner formed by the junction of the second floor level and the pool wall. Calculation shows that about 3 ft of ordinary concrete, density 2.3 g/cm^3, is needed to reduce the intensity level to 3 mr/hr at 1-megawatt power level. Shielding around the beam holes and thermal column is accomplished by a composite shield of the following construction: a 3.5-ft thickness of water, a 1-ft thickness of regular concrete, and a 4-ft thickness of barytes concrete. The fast neutron flux is reduced by this shield to a level of less than 10^{-1} fast neutrons/ $(cm^2)(sec)$ at 1 megawatt; the gamma flux is reduced to 1 mr/hr at 1 megawatt.

The thermal-column door consists of 1/4 in. of boral and a 15-in.-thick shield laminated of steel and lead. The core gammas are suppressed by 6 inches of lead between the core and the thermal column.

Experimental Facilities

Since this reactor is intended to be a research tool, the design is intended to provide collimated beams of fast and thermal neutrons of highest possible intensity and also to provide a high thermal-neutron flux in the thermal column. In addition, adequate room must be provided for bulk



NOTE:
ϕFP = FULL POWER FLUX

FIGURE 5 SAFETY SYSTEM BLOCK DIAGRAM

A-14239

shielding and irradiation of large-scale engineering components. To accomplish this, the reactor pool is divided by a partition and movable gate into two areas. These two areas provide two positions for the core. As previously mentioned, Position A is a stall at one end of the pool and has provisions for six neutron beam holes, while Position B is a location in the center of the second pool area. Here, the reactor core is in an exposed position, thus affording greater versatility for experimentation, and may be operated as water or graphite reflected. There are no external beam holes provided in this location.

Division of the pool into these two areas eliminates the necessity of completely removing the core from the pool if it is desired to set up experimental facilities in one location or for maintenance-repair operations at either location. In addition to this, the unused half of the pool may serve the purpose of a storage space for "hot" samples or elements.

In the stall section of the pool, there will be four 6-in. and two 8-in. horizontal beam tubes leading from the core face through the water and the concrete shield. The holes in the shield will be formed by pouring the concrete around 1/4-inch-thick steel tubes. The steel tube will be bolted to an aluminum tube which will extend from the shield to the core face. The tube liners will be stepped to prevent radiation leakage when the plugs are in place. In the same position, the core is against the thermal column, which is 4 x 4 x 8 ft long. A vertical and horizontal access, both 4 x 4 ft, are provided.

In addition, a 2-in. rabbit tube for short-time irradiations will pass on the open-pool side of the core face. This assembly will have a guide pin which will fit a hole in the grid and will be moved as part of the bridge.

Fuel Requirements

Using a 10-plate MTR-type fuel element, the estimated critical mass for the cold, clean, completely water-reflected core is about 3.5 kg of U^{235}. If the core is reflected on four sides by 6 in. of graphite, the mass is reduced to about 2.5 kg. The various possible configurations which can be used in the experimental stall have masses which lie between these two loadings. However, in order to make this reactor a useful experimental tool, fuel in excess of 3.5 kg is necessary. In fact, Battelle hopes eventually to operate on a schedule calling for 6 days or so of continuous operation at full power. The reactivity allowances required for this type of operation are shown in Table 1. Values are included for operation in the experimental stall and the pool, the only difference being the allowance for the beam holes.

TABLE 1. REACTIVITY ALLOWANCES FOR 6 DAYS' CONTINUOUS OPERATION AT 1 MEGAWATT

Item	Experimental Stall	Pool
Control	0.003	0.003
Temperature	.003	.003
Fractional element	.002	.002
Xenon	.020	.020
Samarium	.005	.005
Beam holes	.022	--
Core experiments	.015	.015
Total	.070	.048

Using the maximum reactivity allowance of 5 per cent, for the pool position, the maximum required loading would be about 4.5 kilograms. To allow for the desired flexibility, Battelle is asking for 5103 grams of U^{235} made up as follows:

28 fuel elements (10 plates with 162 g each)	4536 g
5 special half elements (for control rods, 81 g each)	405 g
2 half elements (81 g each)	162 g
	5103

Various arrangements of the fuel elements in the core grid support are possible with this reactor design. This is necessary and desirable in order to insure that a minimum loading compatible with the experiments in progress and the length of the operating period can be used. In no event will a loading be used that has not been evaluated by a previous cold, clean, critical experiment to determine its reactivity characteristics.

Time Schedule

The following time schedule is based on obtaining initial criticality on February 15, 1956, and power operation shortly thereafter. The intermediate deadlines are somewhat flexible, but it is hoped that any changes will not be large enough to seriously affect the final completion date. Realizing, then, that the time requirements for certain phases of the work cannot be determined exactly, this schedule has been arrived at and is, of course, subject to obtaining the necessary approvals by the AEC.

Review by ACRS	May, 1955
Complete final detailed design	July 1, 1955
Begin building and pool construction	July 1, 1955
Complete building and pool construction	Jan. 1, 1956
Complete component testing and initiate zero power tests	Feb. 15, 1956
Begin tests at 100-kw operation	April 1, 1956
Begin tests at 1000-kw operation	May 1, 1956
Begin normal operation	June 1, 1956.

Operating Procedure

The detailed construction program and proposed operating procedure for the reactor will be presented to the AEC in the application for a construction permit and operating license. The tentative procedure is discussed briefly below.

Battelle is assuming the prime responsibility for the design, construction, and operation of the reactor. The American Machine and Foundry Company has contracted to supply the instrumentation, controls, the cooling and purification systems, and engineering services. The building will be designed by Dan A. Carmichael, Jr., architects, and constructed by E. Alfred & Sons, general contractors.

The ultimate responsibility for the safe operation of the reactor will lie with the Manager of the Physics Department. The Battelle Radiological Safety Committee, composed of specialists in reactor physics, radiochemistry, health physics, and safety will advise the Physics Department Manager in regard to safe operation of the facility.

Supervision of the reactor operation will be maintained through the Engineering Mechanics Division of the Physics Department. The actual operation of the reactor will be controlled by an Operating Supervisor who is an engineering graduate, trained on the BSR at Oak Ridge, and a licensed operator. The reactor will be operated only be personnel licensed as reactor operators by the AEC, whose sole job will be to stand watch at the controls while the reactor is operating.

All proposed experiments using the reactor facilities will be reviewed and evaluated from the standpoint of safe and efficient operation of the reactor and safety to personnel.

REACTOR BUILDING

The reactor is to be located in a building which is shockproof, fireproof, and relatively gas tight. The building is 90 ft long and 66 ft wide and is about 56 ft high above grade. The building will be constructed of cement block faced with brick up to 12 ft above grade, and aluminum Q-metal siding the rest of the way.

Partial floors at the second and third floor level are supported by the reactor shield and building walls. The first or experimental floor level is 12 ft below grade and is only partially excavated. The unexcavated portion around the reactor sides reduces the amount of concrete shielding needed. The entire first floor is serviced by an overhead crane and a drive-in truck port. The pumps and other cooling equipment are located at the first floor level along the pool sides.

Laboratory facilities and office space are located on the second floor. Only a low-level counting room is provided here, since high-level samples can be handled in the hot-cell laboratory nearby. The control room is located on level of the third floor and provides visual coverage of the bridge and the experimental beam room. On the third floor an area 20 ft wide around three sides of the pool is unassigned space and will be used for storage and other uses as the need arises. Figures 6, 7, 8, and 9 are floor plans and an elevation of the building.

The building will be ventilated by forced-air circulation, with exhaust air controlled by dampers. The air for the offices, laboratories, and control room will enter from outside and will be exhausted into the reactor room. This air will be discharged to the atmosphere after passing through suitable filters. All air intakes and exhausts will be closed automatically by monitors when dangerous amounts of radioactivity are present. In this event, an internal circulating system will recirculate the air continuously through filters.

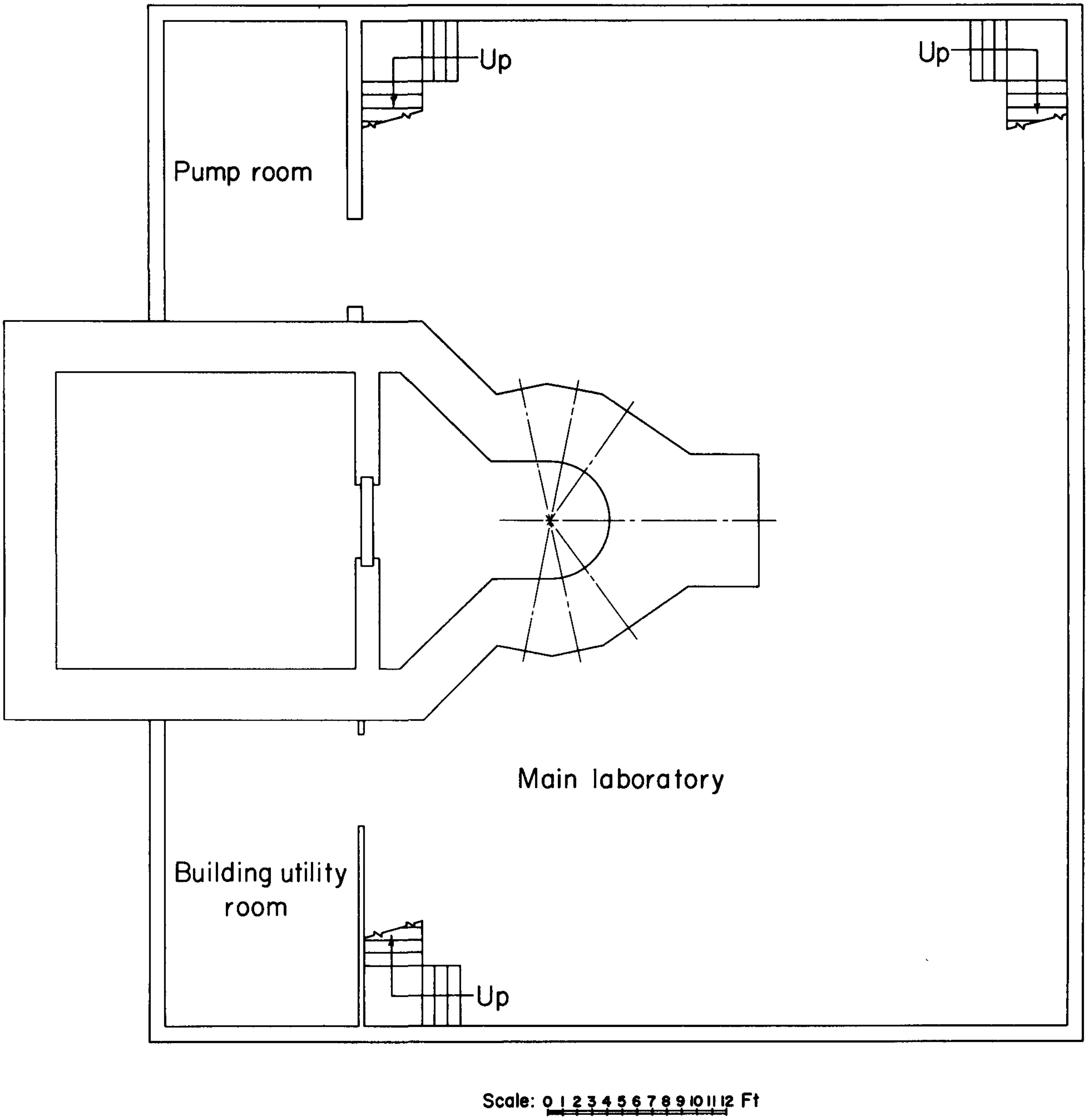


FIGURE 6. FIRST FLOOR PLAN OF BUILDING

B-14206

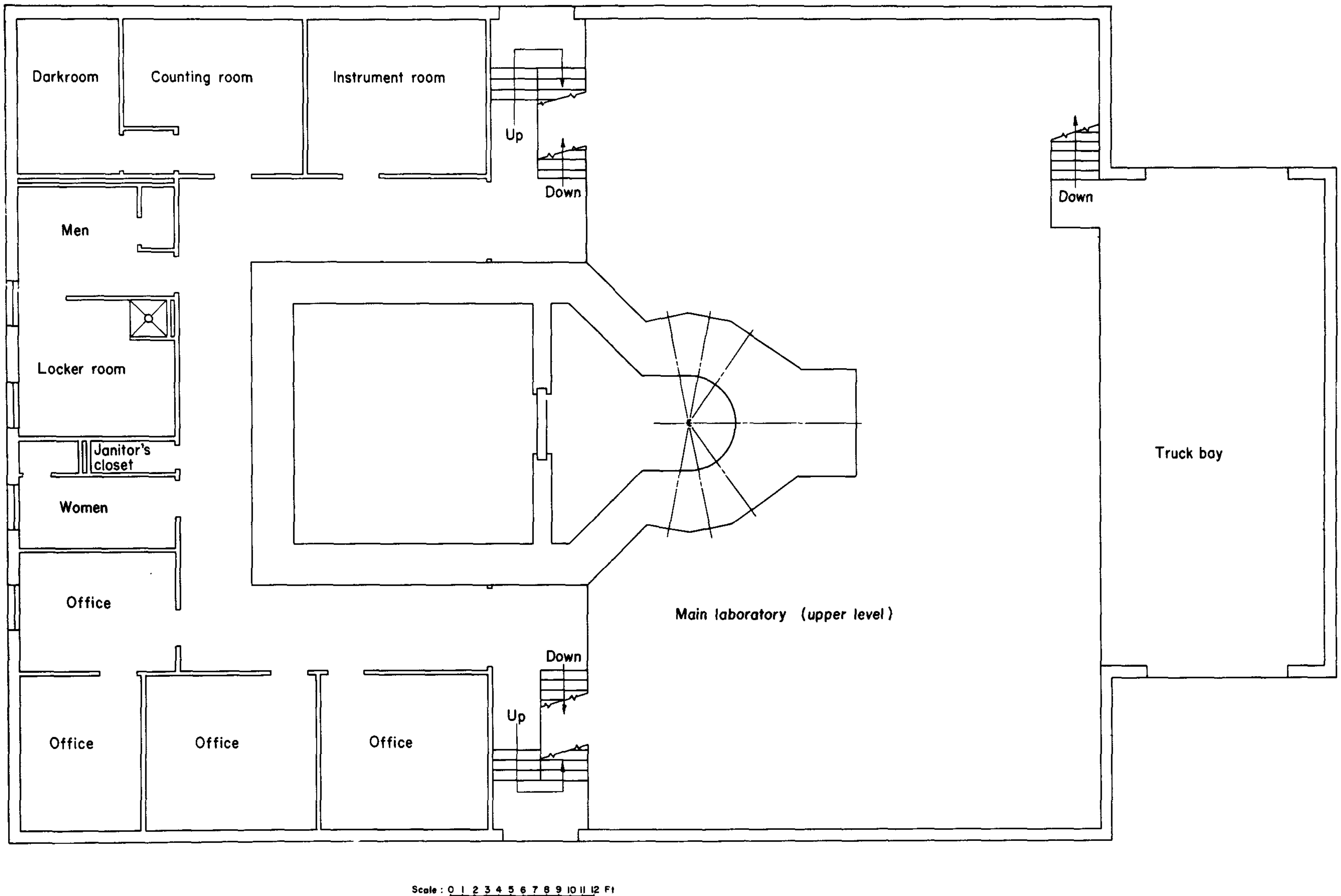


FIGURE 7. SECOND FLOOR PLAN OF BUILDING B-14207

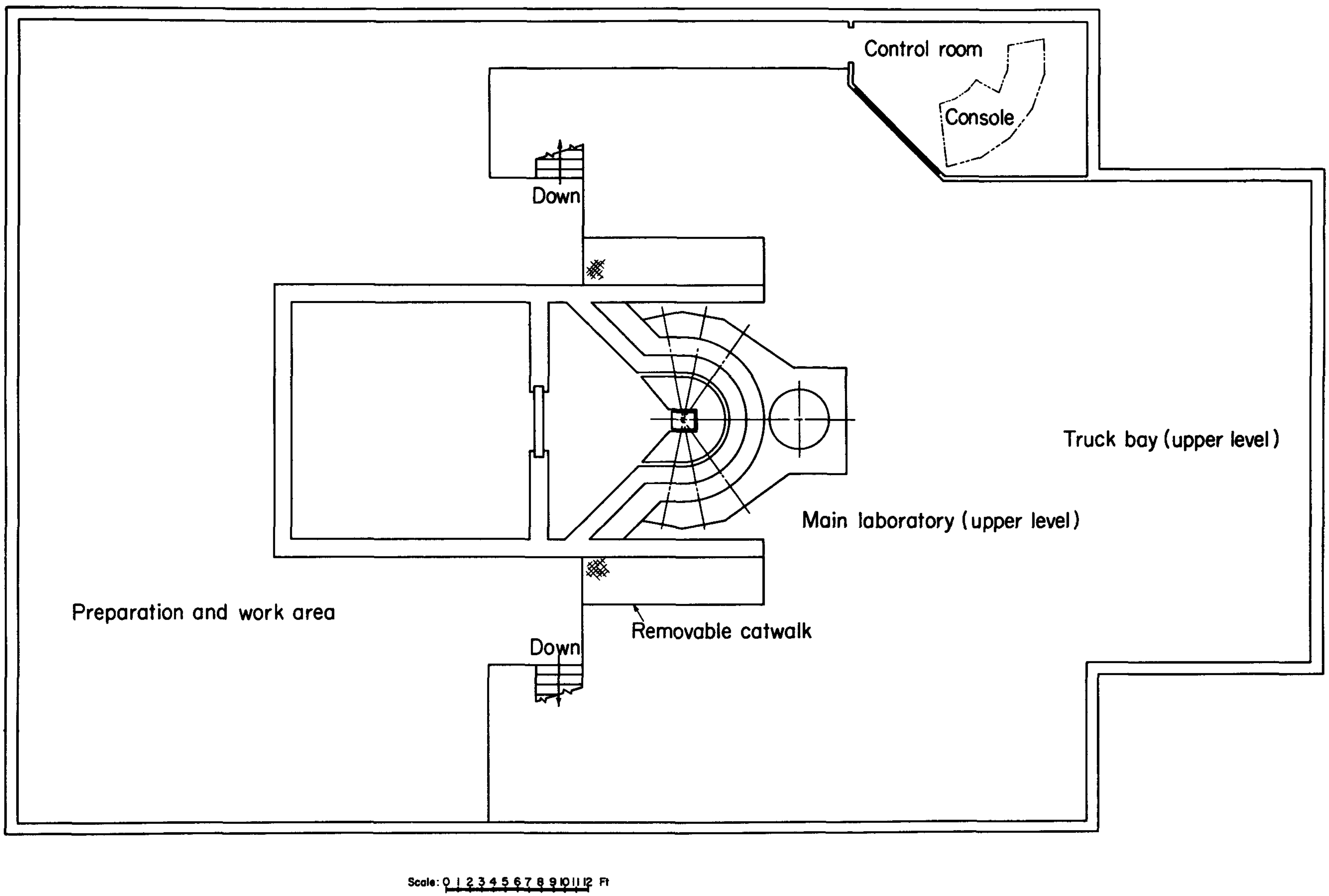


FIGURE 8. THIRD FLOOR PLAN OF BUILDING B-14208

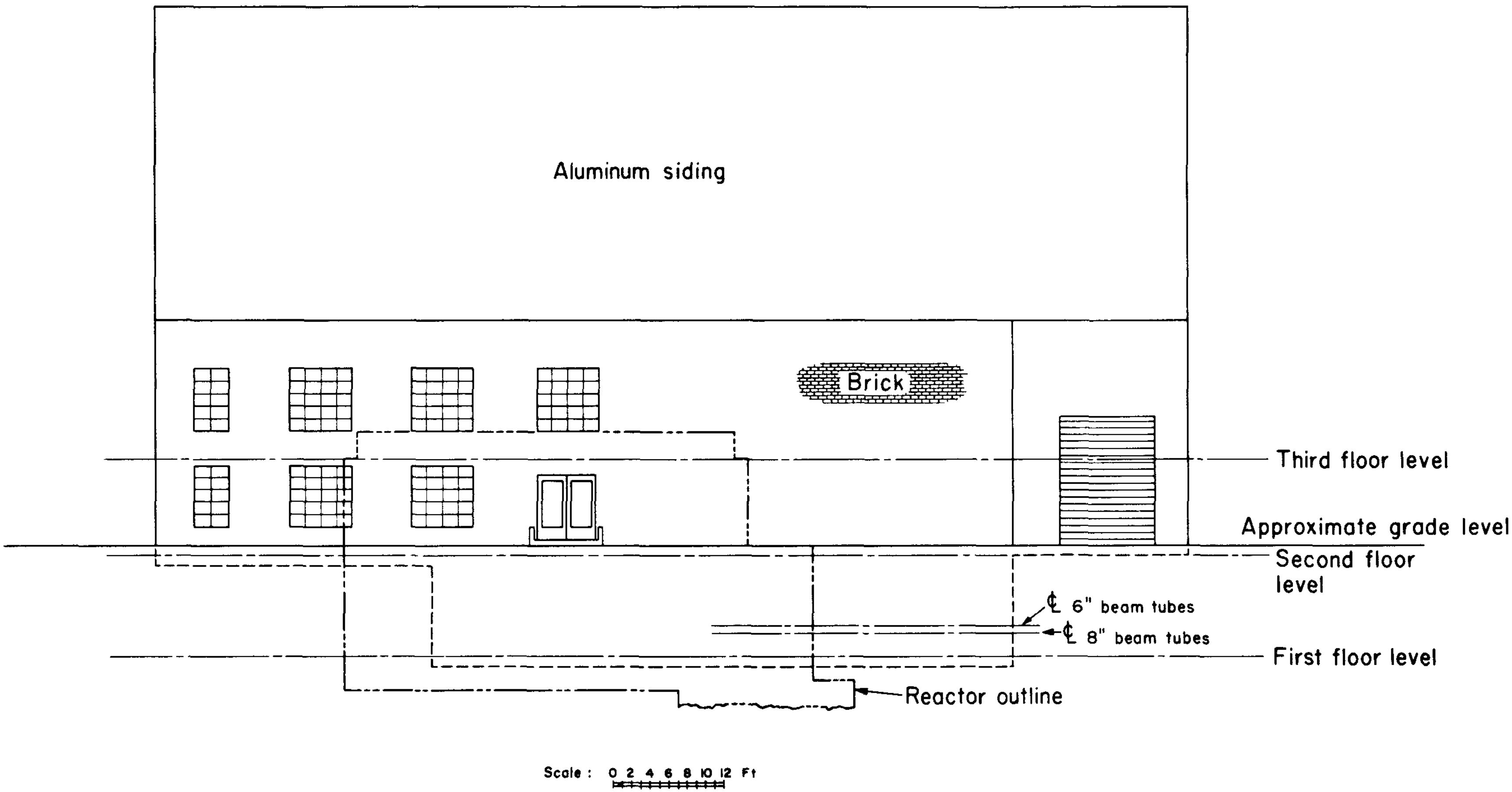


FIGURE 9. SAMPLE ELEVATION OF BUILDING B-14209

MAKE-UP OF SURROUNDING AREA

Regional Conditions

Location and Topography

The site proposed for the research reactor is located in Madison County, Ohio, 13 miles from downtown Columbus. The property faces on the Georgesville-Plain City Road, an improved county highway which is not heavily traveled. The Battelle-owned land is bounded on the south by the Pennsylvania Railroad and on the east by the Big Darby Creek which is the boundary between Franklin and Madison Counties. The tract contains a total of 400 acres and extends about 5000 ft north from the railroad tracks. Figure 10 is a topographic map and shows the site in relation to Columbus and the surrounding area.

The surrounding area is a farming community and is sparsely populated. The closest town is West Jefferson, population 1647, which is about 2 miles southwest of the reactor location. The closest major centers of population are Columbus to the east and Springfield, population 78, 508, located 30 miles to the west. The distribution of population is discussed in detail in a later section.

As concerns terrain, the site is located in the physiographic area of Ohio called the till plains, which are flat but are broken from north to south by several rather wide river valleys with gently sloping sides. The average elevation in the immediate vicinity of the site is about 900 feet above sea level, while the average elevation of downtown Columbus is more nearly 750 feet. This change in elevation takes place by a gradual rise over the 13-mile interval. The site is composed of a layer of glacial till or drift 50 to 100 feet thick on a bed of limestone. The terrain in the immediate site area is quite flat but drops off rather abruptly about 50 ft to the flood plains along the creek. A flat-bottomed ravine about 40 ft deep and several hundred feet wide runs across the plot from east to west. This ravine is the bed of a small intermittent stream.

Figure 11 is an aerial photograph and shows the location of the research reactor in respect to the neighboring buildings. The closest buildings are the critical-assembly and the hot-cell facilities, both presently under construction. The buildings are 150 ft and 300 ft, respectively, from the reactor. The closest off-site building is a barn 2000 ft northwest of the proposed site and the closest dwelling is 3100 ft to the southwest. For several weeks in the summer a Girl Scout camp located across the river is inhabited. The site is about 2000 ft from this camp. The estimated total number of residents within the mile-radius circle is 60.

Climatology

The climate in the Columbus area is definitely temperate and continental in character. As such, it is subject to a wide seasonal range in temperature, although precipitation is distributed fairly uniformly throughout the year. Summers are quite warm and sometimes humid; winters are moderately cold. Maximum summer temperatures generally run in the middle eighties, but 90 degrees or higher is expected about 20 times per year. The normal mean daily temperature for June, July, and August is 73.3 F. During the months of December, January, and February, the normal seasonal temperature is 31.2 F. Ordinarily, Columbus does not have many severely cold days; 3 subzero nights per winter being the average.

In the general Columbus area, the primary prevailing wind direction is from the southerly quadrant (41 per cent of the winds blow from the general direction SE to SW). The secondary prevailing direction is from the NW. The average wind speed is 8.4 mph with 58 per cent of the winds occurring in the 4 to 12-mph interval. No large seasonal or diurnal variation exists in either the direction or speed of the winds. During a 51-year period in Columbus, peak wind speeds have been observed to exceed 51 mph in every month of the year. The maximum recorded speed was 84 mph occurring in July.

Rainfall, averaging nearly 3-1/2 in. per month, is quite evenly distributed from April to August. The record single days' rain was 3.87 in. in July, 1947. The bulk of the summer rainfall comes in frequent thunderstorms, and tornadoes are not unknown. However, local storm records show that only 4 tornadoes occurred in the Columbus area since 1931.

Since Ohio is located in the path of many winter storms, Columbus receives a generous amount of cold-season precipitation. The bulk of it comes in the form of rain, but the average winter will yield a total of 22 in. of snow. This is quite variable and, in the largest snowfall of recent times, a 7-day period in 1950 produced 15.2 in., of which 7.5 in. fell in one day. The greatest depth on the ground at any time was 13 in., which halted traffic completely for a 24-hr period.

A report prepared by the Scientific Division of the U. S. Weather Bureau is given in Appendix B.

← Contour interval 20 feet | Contour interval 10 feet →

FIGURE 10. TOPOGRAPHICAL MAP

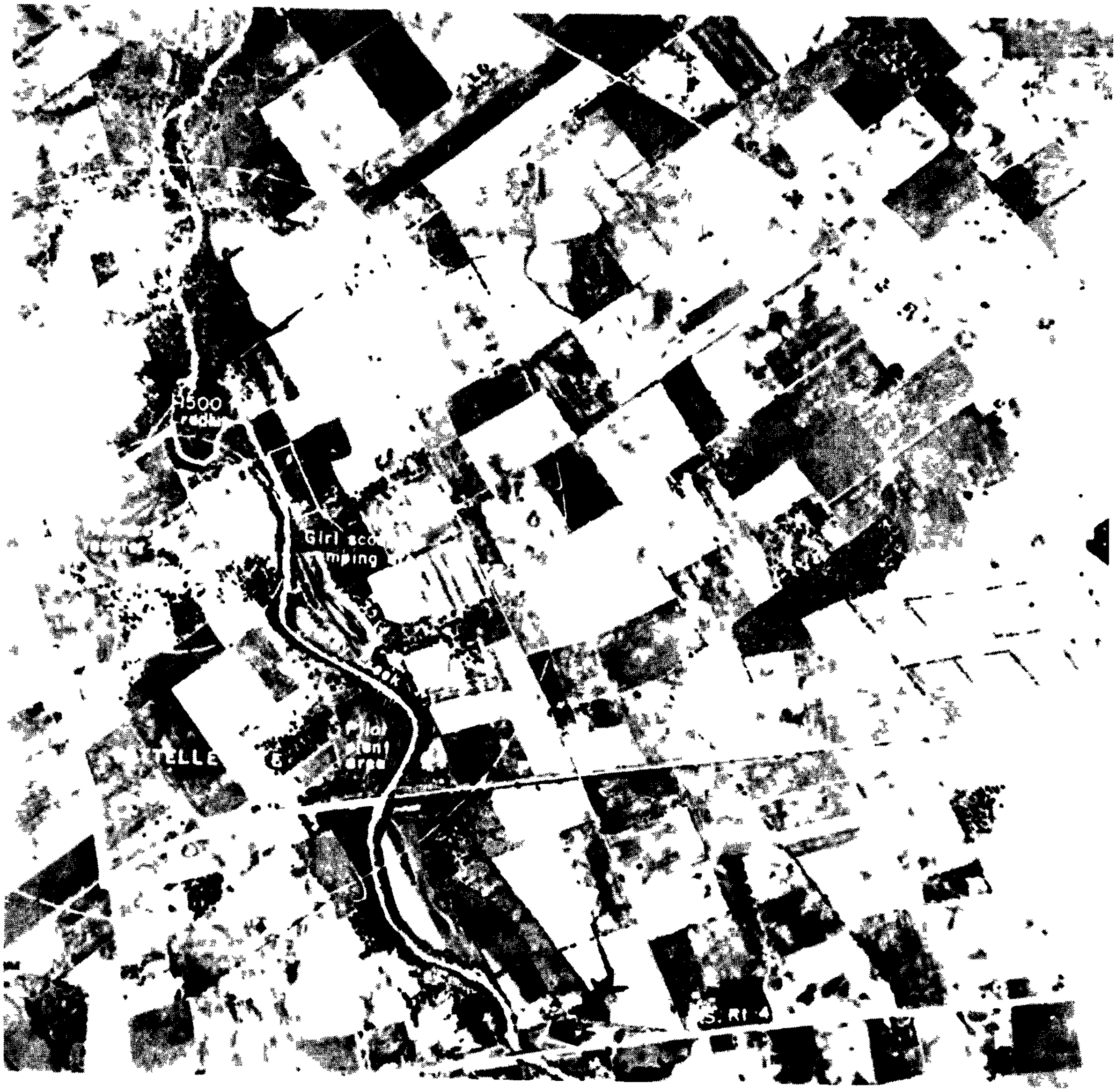


FIGURE 11. AERIAL PHOTOGRAPH OF THE SITE VICINITY

Seismology

In determining the earthquake probability of a given area, all that can be done is to examine the earthquake history of that vicinity and then conjecture that future earthquakes are more likely to occur in places where there have been previous ones.

Several areas in western Ohio have suffered minor earthquake damage. A map of the earthquake epicenters is shown in Figure 12. There is no record of earthquakes having occurred in West Jefferson, Ohio, and immediate vicinity. The nearest seismic activity in recent years was recorded in 1937 in the Anna, Ohio, proximity, which is over 50 miles from the proposed reactor site.

The information on western Ohio earthquakes was obtained from Reverend V. C. Stechschulte, Xavier University, Cincinnati, Ohio, and from the U. S. Coast and Geodetic Survey. Letters from these two sources are included in Appendix C.

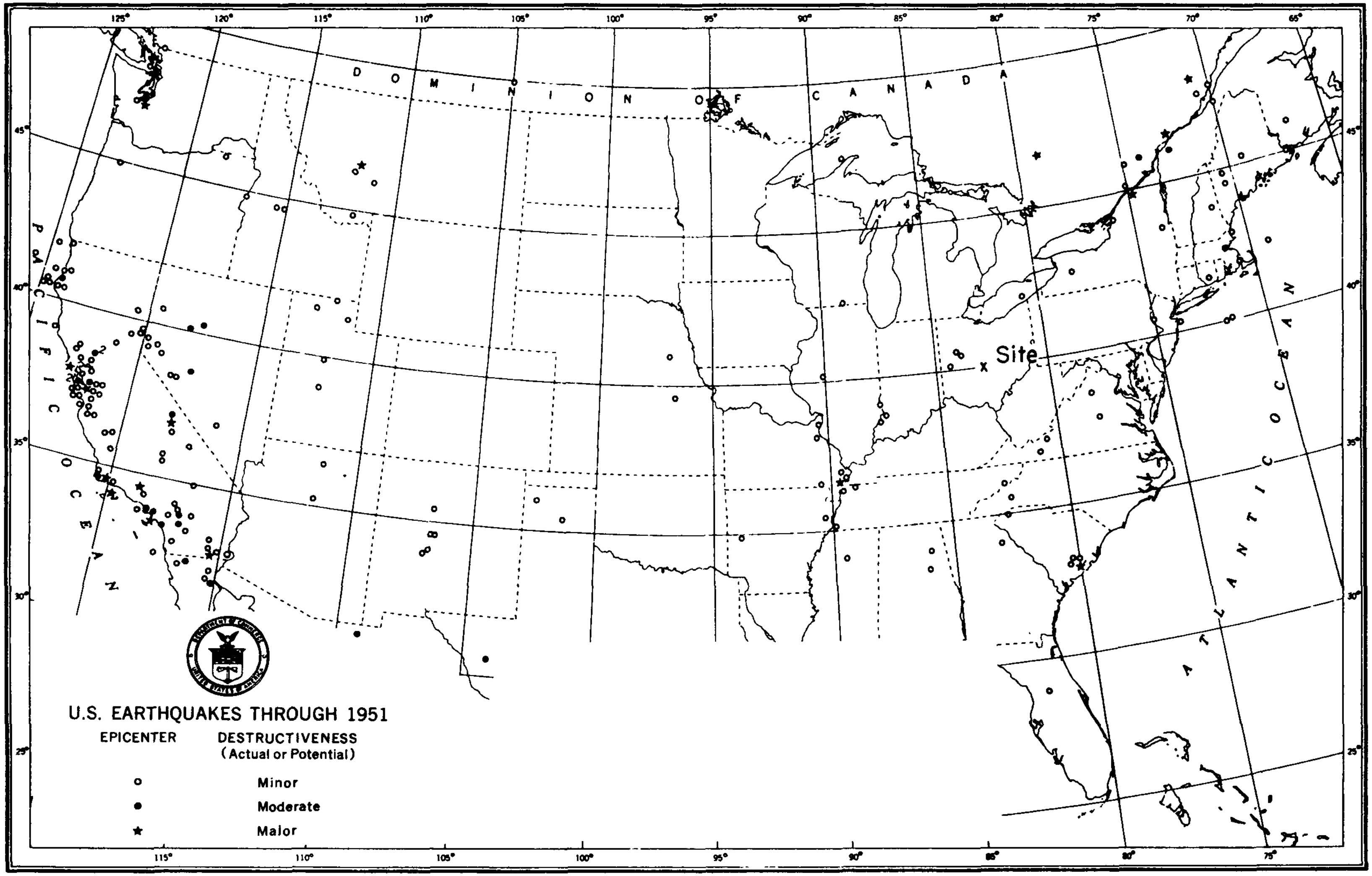
Geology and Hydrology

The principal glacial deposits at the surface in the Battelle site area consist of till and outwash which accumulated as the Wisconsin ice sheet of the Pleistocene Age receded. The till, an unstratified matrix of clay containing rock fragments, underlies the Battelle site to depths ranging from approximately 60 to 200 ft. The outwash, composed of stratified layers of sand and gravel, is thin and discontinuous in the site vicinity. Fringing the locality is a narrow strip of Columbus limestone, forming in places a 3-ft surface stratum.

Underlying the glacial deposits of the area are several hundred feet of nearly horizontal beds of limestone, dolomite, and shale through which preglacial streams carved a branched valley system. The distance from the soil surface to the bedrock on the Battelle property ranges from a few feet in areas along Big Darby Creek to over 200 ft in the northwest corner of the property.

There are two aquifers in the Battelle site area, one a shallow one of minor importance underlain by the major aquifer of sand, gravel, and limestone. Yields up to 300 gallons per minute have been obtained from wells drilled into the principal aquifer in the area.

Chemical analyses of the well water show that all the mineral constituents are within the range common to natural waters in a limestone region. All ground-water samples were high in iron and total hardness.



A-11943

FIGURE 12. EARTHQUAKE DATA FOR THE SITE

Surface-water samples show chemical characteristics similar to those of the ground water.

The ground water comes entirely from local precipitation and the shallow aquifer is recharged almost uniformly from the precipitation. The water table is everywhere less than 40 feet from the surface, and the contours are a subdued replica of the surface topography. Calculations indicate that water in the principal aquifer in the vicinity of the Battelle site is moving at a rate somewhat less than 1 ft per day. The water in the till overlying the principal aquifer is estimated to flow at a considerably lower rate, measurable in hundredths of a foot per day.

Ground-water movement downward through the thick till takes place very slowly. A long period of slow percolation occurs before water reaches a zone in which it may move laterally at appreciable rates. All the ground water is discharged into Darby Creek; hence, water entering the ground on the Battelle property is already near its place of discharge.

Darby Creek accounts for the principal surface-water flow. The mean flow is 420 cubic feet per second, based on a 24-year record. Ground-water seepage from the impermeable deposits in Madison County adds little to stream flow. The water of Darby Creek is of good quality and is not polluted.

The conclusions of a report prepared by the U. S. Geological Survey on the geology and hydrology of the Battelle site are given in Appendix D. It is concluded that in case of liquid spillage most of the liquid would flow overland to the Darby Creek and the remainder, once reaching the water table, would also discharge into the creek. The chances for radioactive contamination of well water in the surrounding area are considered nil.

Population Distribution

The proposed site is located in a sparsely populated area. As seen on the map (Figure 13) a 10-mile-radius circle enclosing the site includes a small portion of Columbus having a population of about 20,000 people. The only other significant population center near the site is West Jefferson, Ohio, located about 2 miles from the site, with a 1953 population of 1647.

The population distribution at various radii from the reactor facility site was obtained, for the most part, from the Chamber of Commerce 1954 statistics and the State-Wide Highway Planning Survey, 1953. The distribution of population at various distances from the site is shown in Table 2.

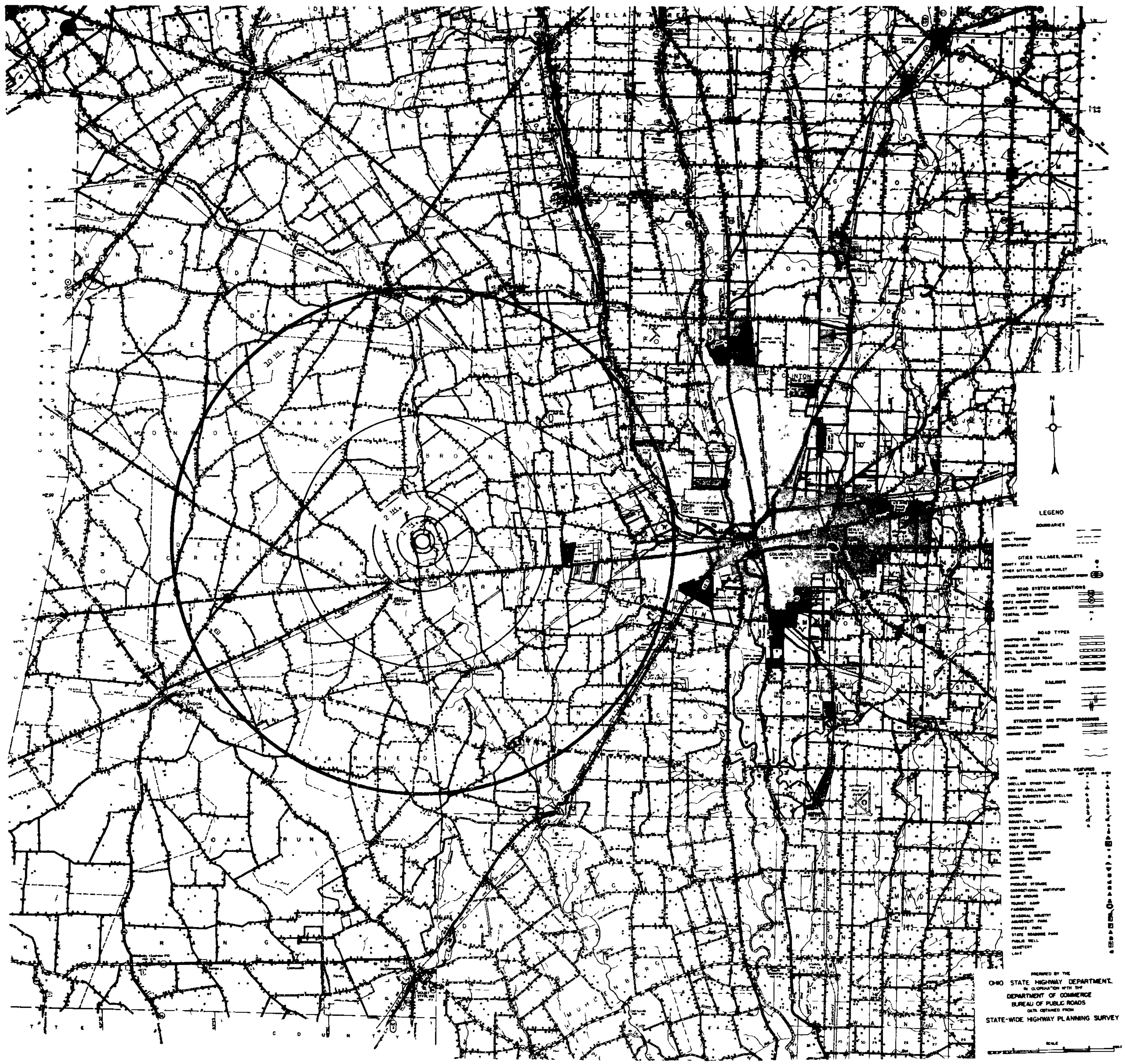


FIGURE 13. ROAD MAP OF SITE VICINITY

TABLE 2. POPULATION DISTRIBUTION WITHIN VARIOUS DISTANCES FROM SITE

Distance Radius	Population
1500 feet	0
2500 feet	0
1 mile	60
2 miles	1,150
5 miles	5,100
10 miles	43,000

Industry Adjacent to the Site

Within the 10-mile circle are located 12 industries. Ten of these employ less than 100 people while the Westinghouse Electric Corporation and the General Motors Corporation, both 8 miles from the site, employ 2068 and 3931, respectively. Closest to the site are two small industries in West Jefferson which employ less than 100. The industries and information pretinent thereto are tabulated in Table 3.

At a distance of 8 miles from the site is located a new housing project, Lincoln Village. Opened for settlement in July, 1954, the village has a present population of approximately 850. Future expansion is to include several industries; the information regarding these industries has not yet been released.

TABLE 3. INDUSTRIES WITHIN A 10-MILE RADIUS OF PROPOSED REACTOR FACILITY SITE

Industry	Products	Number of Employees[a]	Distance From Site
Ternstedt, Columbus Division, GMC	Auto parts	3931	8 miles
Westinghouse Electric Corporation	Refrigerators, appliances	2068	8 miles
Stokely's Canning Company[b]	Canned sweet corn	75-85	2 miles
Hartley Printing and Publishing Company	Printing and publishing	27	10 miles
Columbus General Machine, Inc.	Dies, tools, fixtures	12	10 miles
H. J. Upperman and Company	Lumber	12	9 miles
Columbus Stationery Company	Stationery	Less than 10	9 miles
Five Manufacturing Company	Farm wagon unloaders	Less than 10	9 miles
Georgiton Candy and Ice Cream Company	Ice cream, candy	Less than 10	10 miles
Merriman Cement Products, Inc.	Cement blocks	Less than 10	2 miles
Stiles Gauge Pin Company	Gauge pins	Less than 10	9 miles
West Jefferson Sand and Gravel Company	Sand and gravel	Less than 10	3 miles

(a) August, 1954.

(b) Seasonal. In full operation in August and September only. Closed in 1954.

HAZARDS DURING NORMAL OPERATION

Several possible hazards exist during normal operation against which precautions must be taken. These hazards cannot be guarded against by automatic devices and, consequently, proper design and administration must be used. A number of these are listed below, with the steps taken to minimize or remove the danger.

Cracking of the Shield

The energy of the core gammas and indirectly of the neutrons absorbed in the biological shield create a radial temperature gradient. An exact calculation of the temperature distribution in the concrete is quite difficult but preliminary estimates of the heating and subsequent stresses indicate that a 1-in. stainless steel thermal shield will reduce the stresses to a value below the strength of the concrete. However, the decision concerning the need for and thickness of a thermal shield will be deferred until experimental data from the Omega West reactor becomes available. These temperature data will permit an accurate evaluation at the 1-megawatt power level, and the thermal shield, if needed, will be chosen to insure completely safe operation.

Other possible causes of cracking the shield, such as earthquakes, tornadoes, lightning, etc., do exist. Cracking from such causes can, at best, be minimized by sturdy construction. However, the pool floor is approximately 12 feet below grade level. A rupture of the pool would result in flooding the building to a height of about 9 feet above the pool floor. Thus, the pool water would be contained within the building and below grade level. Also, the core would remain covered by water and melting would not occur.

Radiation Due to Inadequate Shielding

Calculations were made to determine the radiation intensities around the reactor. The results of the calculations are shown in Table 4.

TABLE 4. RADIATION INTENSITIES

Position	γ Dosage, mr/hr	Fast Neutrons, n/(sec)(cm^2)	Slow Neutrons, n/(sec)(cm^2)
Face of shield	0.3	< 1	< 1
Bottom of bridge	0.25	< 1	< 1
Over exit water line	0.25	< 1	< 1

The maximum permissible doses for external radiation were assumed to be(1)* 5.7×10^6 n/(cm^2)(sec) for fast neutrons, 2.16×10^8 n/(cm^2)(sec) for slow and epithermal neutrons, and 300 mr/week for gamma rays. Any possible combination of the calculated dosages is greatly below the tolerance levels.

Disposal of Spent Fuel Elements

Eventually, it is hoped to operate the reactor continuously with a 24-hr scheduled shutdown once a week. During the shutdown periods, experiments will be set up or modified and the fuel elements will be shifted as needed to maintain a uniform burnup. Elements with U^{235} burnup between 15 per cent and 20 per cent will be removed and placed on racks under water in the pool. Since the average life of a fuel loading, assuming 15 per cent burnup, will be approximately 2 years, the cooling-off period can be on the order of 1 year without maintaining a large fuel-element inventory.

After the cooling-off period, the spent fuel elements will be placed in a lead shipping container and sent to a reprocessing plant. Estimates indicate that after long-time operation and a cooling-off period of 1 year, a lead shipping container with a wall thickness of approximately 9 inches will lower the radiation level at the surface of the container to 7.5 mr/hr.

Ventilation, Sewage, and Waste Disposal

The principal concern associated with radioactive wastes is the possibility of active material ultimately penetrating food or drinking water or, because of its activity, being a hazard to those immediately exposed to the waste. Consequently, controls must be imposed upon the disposal of the radioactive wastes.

*See References.

Ventilation

A forced-air ventilation system will take fresh air from outside the building, circulate it through the offices and laboratories, then into the reactor room where the stale air will be discharged through filters at the top of the building. Although only minute quantities of radioactive gases will be given off during normal reactor operation, the ventilators will be fitted with automatic louvres for closure in the event of sudden excessive contamination of the air.

Sewage

The nonradioactive wastes including the normal sewage from the sinks and toilets will be discharged into a dilution tank and then into a filter bed which will remove the solids. The remaining liquids will be run into Big Darby Creek.

Radioactive Gases

After flowing through the reactor, the cooling water is drawn into the pump room, circulates through the cooling system, and then enters the pool 14 ft below surface level. The time required to traverse the cooling system and return to the pool is rather long (estimated greater than a minute).

The principal radioactive gas produced is N^{16}, of 7.3-sec half life. The long cycling period allows for the elapse of several half-lives before the gas is returned to the pool, and consequently the radioactivity will be greatly reduced. It does not appear that the disposal of radioactive gases during normal operation is a problem.

Radioactive Solids in Cooling Water

During the reactor operation, a small quantity of material from the fuel plates and from the cooling system will enter the coolant water. The coolant water will circulate at 20 gpm through a mixed-bed deionizer where the impurities will be removed from the water. The principal ions will be those of aluminum and copper from the fuel plates and cooling system, respectively. Many others will be present in minute quantities; iron, cobalt, zinc, sodium, and manganese being the most prominent radioactive-wise.

The $Al^{27}(n, \gamma) Al^{28}$ reaction will account for the radioactive aluminum in the system. Since Al^{28} has a half-life of 2.3 min, the radioactive accumulation in the deionizer from this source will be small. A more important source results from the Al^{27} (n, α) Na^{24} reaction, which is initiated by fast neutrons (threshold energies of 3.3 mev). However, the cross section for this reaction is only 0.001 barn. Iron, zinc, manganese, and cobalt ions, although present in minute quantities, will contribute appreciably to the radioactive accumulation because of their relatively long half-lives.

It is estimated that the saturation activity in the deionizer will be less than 1 curie. These moderate activities can be handled by draining the resin regenerants into shielded containers which will be removed by a disposal service.

Fissure of a Fuel Element

Various estimates(2) and experiments(3) have shown that a hole in the fuel-plate cladding has to be several square centimeters in size before the radioactivity can be detected in the pool. This indicates that no dangerous activities will occur in normal operation, since holes of this size are improbable. However, a monitor on the outlet water is designed to detect such contamination and will warn of a fissure long before dangerous activity levels are reached.

HAZARDS AFTER AN ACCIDENT

Since the reactor is set below grade about 12 ft, the off-site population is protected from direct irradiation. Furthermore, in most azimuthal directions (over 270°), the exclusion fence is more than 1500 ft from the reactor. The minimum distance to the fence is about 1200 ft and an uninhabited swamp is on the other side of the fence. Thus, an actual vaporization and release of the fuel elements would have to occur to endanger public persons.

If large amounts of fission products were released either in a cloud or into the cooling water, possible danger to the population might result from (a) inhalation of radioactive particles or gases, (b) ingestion of polluted food or water, (c) direct irradiation by a cloud, or (d) direct irradiation by contaminated ground surfaces after a fall-out. The nearest center of population is West Jefferson (population 1647), approximately 2 miles southwest of the reactor location. However, the prevailing winds are from the southerly quadrant, with the secondary direction being from the northwest. When precipitation is falling, there is no major shift in prevailing wind direction frequencies, although northwest becomes the primary maximum in this case.

The hazards associated with such spreading of radioactive materials are considered below as resulting from either of two extreme accidents: a Maximum Credible Accident and a Maximum Hypothetical Accident.

Maximum Credible Accident

In discussing the accident possibilities associated with the reactor operation, it is convenient to classify the reactivity effects into two categories: (1) reactivity effects which can be introduced instantaneously, and (2) reactivity effects which decay or occur over an extended period of time. A breakdown is given in the following tabulation for 1-megawatt operation.

	Per Cent k
Possible Instantaneous Effects	
Beam tubes (one 8 in. and two 6 in., flooding or removal)	1.1
Core experiments, to be limited to	1.5
	2.6
Other Reactivity Effects	
Poisons	2.5
Control	0.3
Temperature	0.3
	3.1

Since the thermal column and core separate the two sets of beam holes, an object could not smash all the beam tubes without disrupting the operation of the reactor. Hence, only three of the six beam tubes are considered under possible instantaneous effects.

Considering, then, the extreme case of flooding three beam tubes and removing the core experiments simultaneously, a 2.6 per cent k reactivity addition would result. In view of the Borax experiments, the instantaneous addition of 2.6 per cent k would probably lead to a small-scale steam explosion with some damage to the core structure. It is also likely that some melting of the fuel elements would occur during such an excursion. The building enclosure will retard the escape of fission products to the atmosphere, and the exclusion area will protect the public from danger as shown in the next section.

Maximum Hypothetical Accident

For the maximum hypothetical accident, an explosion which results in the complete vaporization of the fuel elements and the expulsion of all the reactor fission products in the form of a cloud above the site is assumed. The operation history of the reactor prior to the accident is assumed to be that of long-time 1-megawatt operation accompanied by a power pulse similar to that of the Borax excursion with an integrated energy of 135 megawatt-seconds. No mechanism for the vaporization is postulated.

As this cloud drifts downwind, the total accumulated radiation that would be received by a person at various distances from the reactor is calculated. The hazards resulting from a "wash-out" and from inhalation of radioactivity are also investigated.

Radiation From Radioactive Cloud

To evaluate the cloud problem, the nomographs constructed by J. Z. Holland of the U. S. Weather Bureau were employed, and the diffusion theory of O. G. Sutton[3,4] was assumed to be valid. The meteorological data were prepared by the Scientific Services Division of the U. S. Weather Bureau and are shown in Table 5.

TABLE 5. PARAMETERS FOR DOSAGE CALCULATIONS[a]

h, meters	n	c^2 u = 1 m/sec	c^2 u = 5 m/sec	c^2 u = 10 m/sec
25	1/5	.064	.046	.040
	1/4	.021	.014	.012
	1/3	.009	.005	.004
	1/2	.006	.002	.002
50	1/4	.015	.010	.008
100	1/4	.008	.005	.004

(a) h = height of cloud from ground, m
u = mean wind speed, m/sec
c = virtual diffusion coefficient, $m^{\frac{n}{2}}$
n = Sutton stability index, dimensionless.

The stability parameter, n, may vary from 0 to 1, such as

Large lapse	1/5
Zero or small lapse	1/4
Modified inversion	1/3
Large inversion	1/2.

Using these data and the nomographs, the total accumulated radiation was determined for various distances from the reactor as a function of the cloud radius, σ, the cloud height, h, the wind velocity, u, and the stability parameter, n. The results are shown graphically in Figure 14. The average wind velocity in the site vicinity is 4.5 m/sec and the Sutton parameter values usually range from 0.20 to 0.50.

These results indicate that for distances greater than 10 m, persons would not be subject to a lethal dosage from a radioactive cloud for any set of conditions. A 20-m cloud radius was assumed, since this is roughly the size of the longest dimension of the building. For initial cloud radii greater than this, the dosage received is less than that shown on the graph. Also, for initial cloud heights greater than 25 m the dosage values decrease.

It can be concluded that persons outside the 1200-ft-radius exclusion area, although exposed to the radioactive cloud, would receive only small amounts of radiation.

Radiation Due to Wash-Out From the Radioactive Cloud

As the cloud containing 100 per cent of the fission products drifts downwind, a continuous wash-out and fall-out of the radioactive material is assumed to occur.

The equations used to compute the dose rate received by an observer as a function of his distance from the cloud origin are reported in Appendix A. The radius of the cloud has been assumed to vary according to Sutton's diffusion equations, and the cloud radius for various distances was calculated from the nomographs.

The dose rate received by an observer at the first instant of exposure to the cloud, termed "instantaneous dose rate", is shown graphically in Figure 15 for various wind velocities, Sutton stability parameters, and distances from the cloud origin. The dose rate for any given set of conditions decreases with time according to the approximate expression $t^{-0.2}$. As seen from the graph, a person in the nearest village would receive, under the worst conditions (high wind velocity and large inversion), a maximum dose rate of 33 r/hr. Thus there would exist ample time to warn

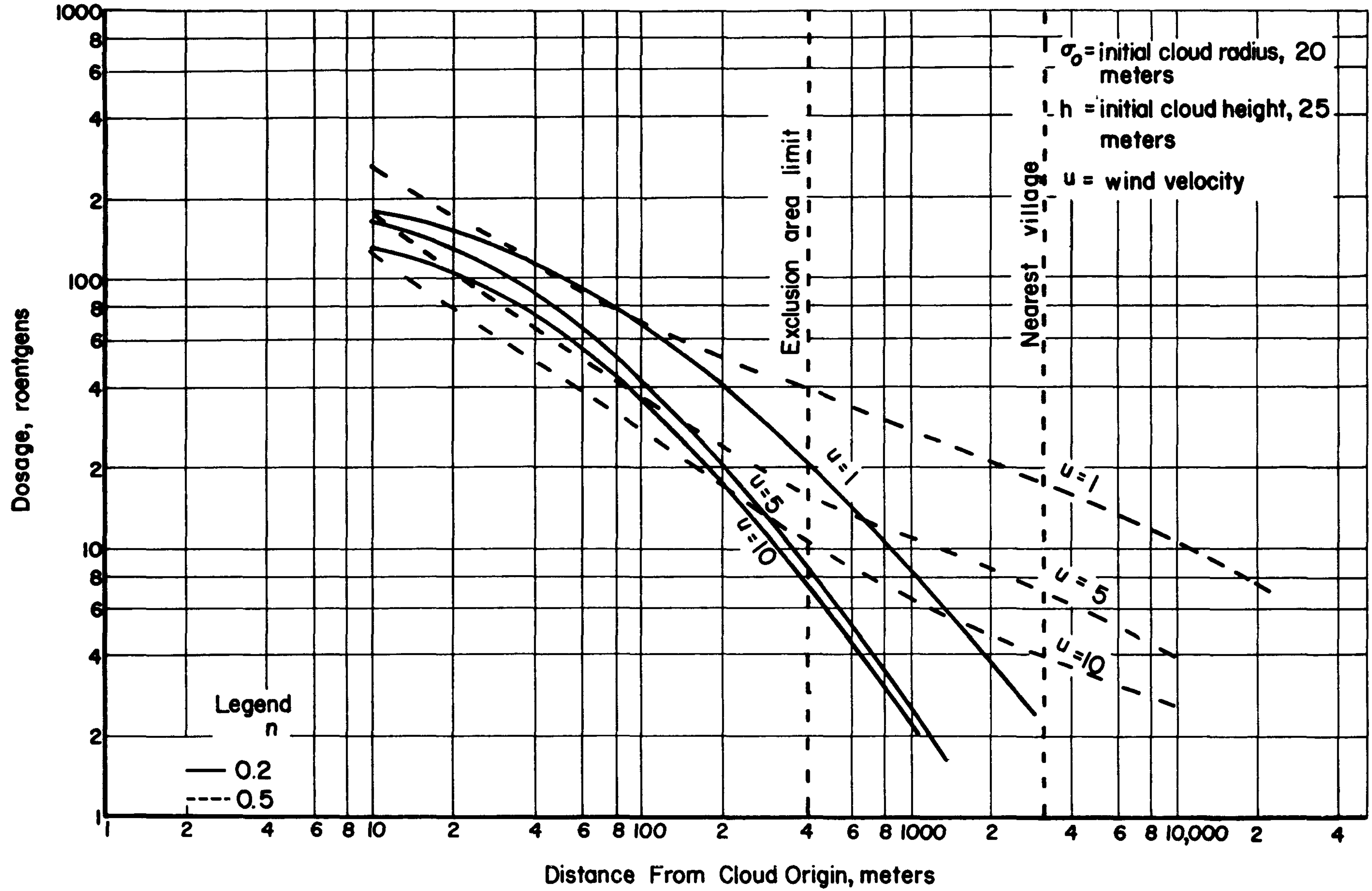


FIGURE 14. DIRECT IRRADIATION FROM A RADIOACTIVE CLOUD CONTAINING 100 PER CENT OF THE FISSION PRODUCTS

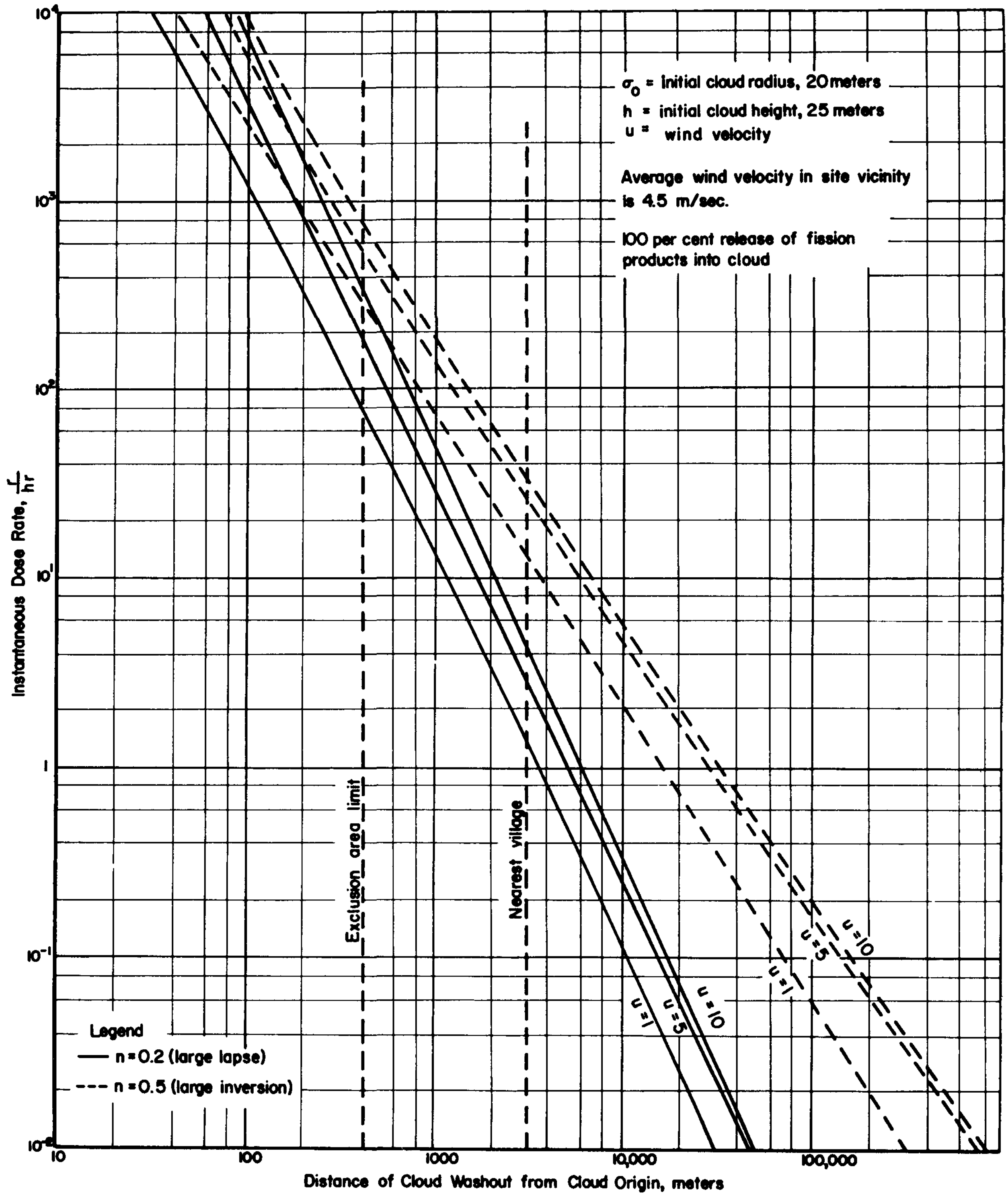


FIGURE 15. DOSE RATES DUE TO RADIOACTIVE CLOUD WASHOUT

persons in this area before a lethal dosage was received. At the exclusion fence, dosage rates on the order of 800 r/hr would be received in the worst case for this hypothetical accident. However, this still allows time to warn a person to evacuate the contaminated area.

Inhalation Activity Due to Radioactive Cloud

The equations used for calculating the inhalation activity for the various isotopes are given in Appendix A. The results are shown graphically in Figures 16 and 17. Under large lapse conditions (good diffusion conditions), the only isotope of concern is I^{131}. At the nearest village, the instantaneous activity is just above the tolerance value. However, no extreme damage to the lungs should be caused by this isotope. The dosage due to the short-lived fission products is almost negligible.

During the worst diffusion conditions, almost all the fission products will produce activities in West Jefferson above the tolerance values. Some of these activities might produce harmful biological effects. However, the curves show only the initial doses and these would be decaying with time. In addition, pessimistic assumptions, such as a large inversion, an improbable wind direction, and a 100 per cent fission fragment release, have been made.

Discussion

The results of the hazards calculations show that, even for the maximum hypothetical accident, the Battelle exclusion area is sufficient to reduce the dose from a cloud to well below the tolerance level. Also, the instantaneous dose rate from a fall-out at the exclusion fence is small enough to permit ample time for evacuation of the contaminated area. At the nearest center of population, this dose rate for the worst case is only 33 r/hr. Furthermore, for good diffusion conditions, the doses from inhaled fission products are quite small by the time the cloud reaches West Jefferson. For a large inversion, the doses from inhalation are above tolerance level based on 0.3 rep/week. However, because of decay, it is difficult to say how harmful these amounts might be.

In considering the results of such calculations, it is always possible to postulate a bigger accident. For instance, in the accident which destroys the reactor, a larger energy release might occur if a greater amount of reactivity could be added instantaneously to the reactor. Such an energy pulse could add perhaps a factor of 10 to the dose rate from the

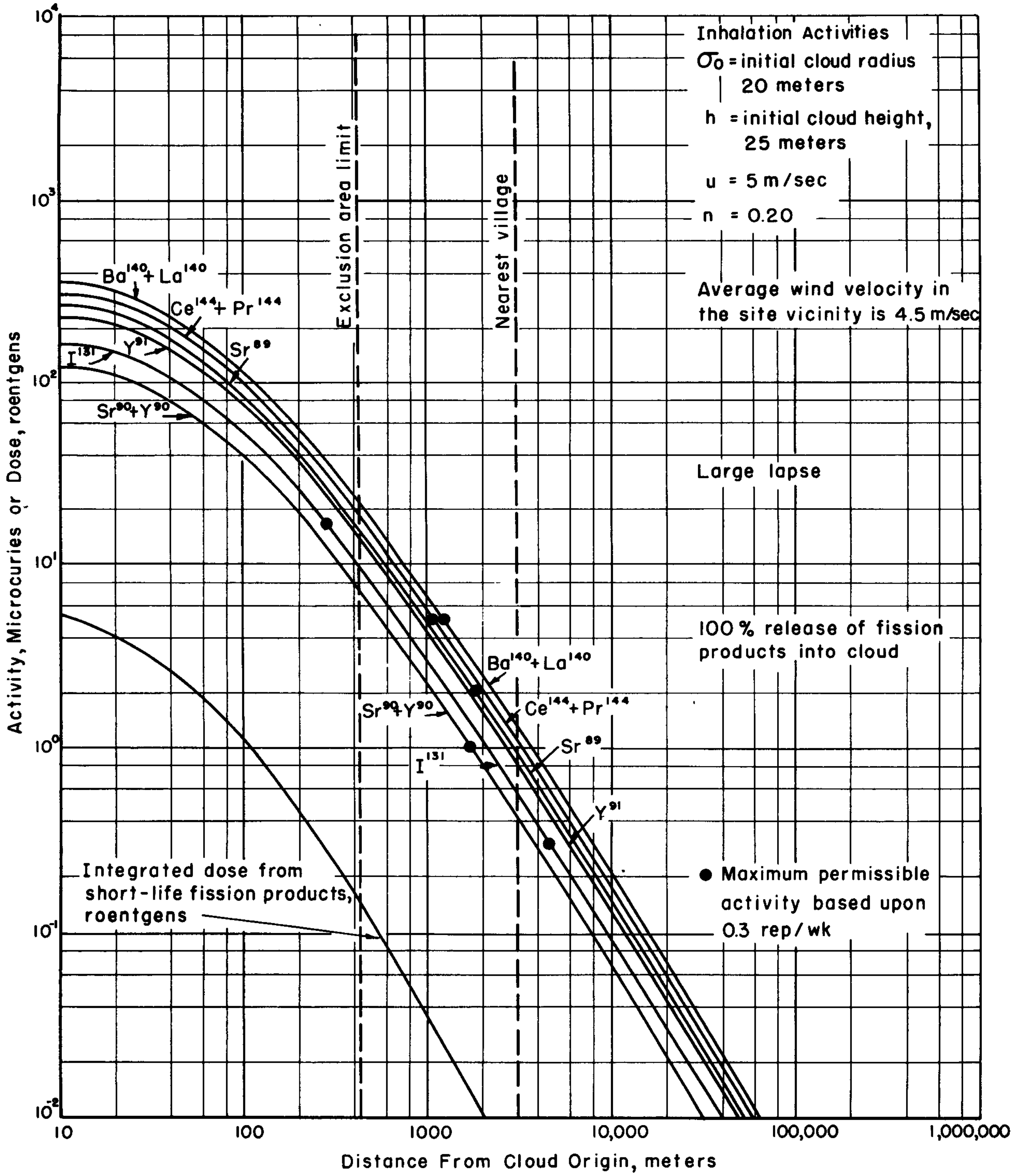


FIGURE 16. INHALATION ACTIVITIES FROM RADIOACTIVE CLOUD

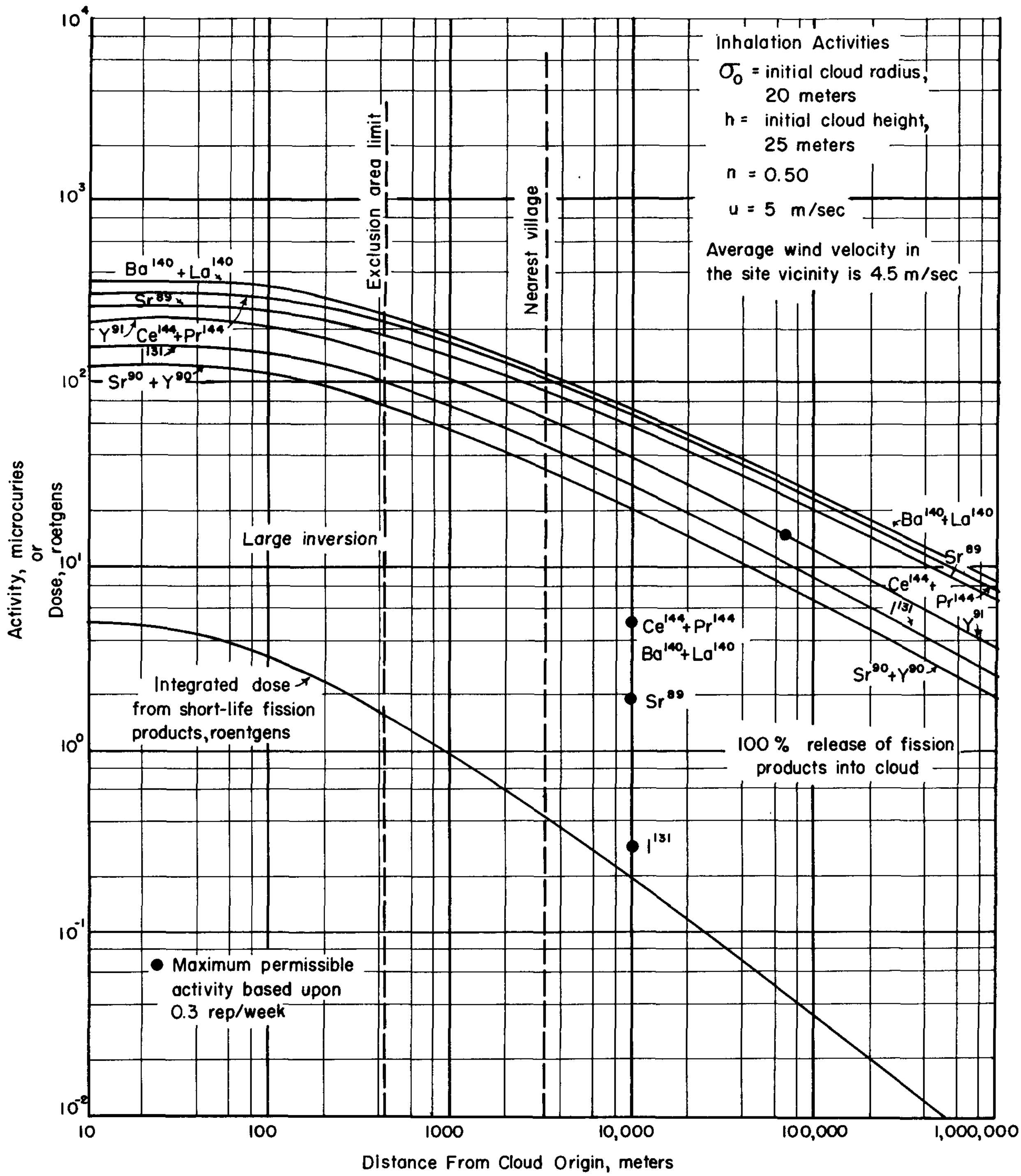


FIGURE 17. INHALATION ACTIVITIES FROM RADIOACTIVE CLOUD

short-lived fission fragments. This would be felt most in the immediate vicinity, where in some cases the radiation is already rather high.

On the other hand, in the Borax experiments substantially less than 100 per cent of the fission products escaped from the fuel plates. In the Argonne ZPR accident, only about 15 per cent of the fission products escaped from the building and these were released over a rather long period of time.

With the present Battelle building, the volume is large enough that a nuclear explosion can probably be contained without damage to the building. Hence, the escape of fission products will be reduced to leakage from the building and will occur over an extended period of time. The accumulated dosage outside the building will thereby be much less than the values shown in the graphs.

CATASTROPHE PLAN

A plan for coping with an accident involving catastrophic release of radioactivity will be established. The tentative plan of action covers four phases:

(1) Immediate warning.

The three monitors in the reactor building will detect excess radioactivity and sound alarms in the building, outside the building, and at a central guard post nearby.

(2) Evacuation and isolation of the area.

All personnel in the area not assigned to the catastrophe team will evacuate. The catastrophe team, composed of the reactor operator and two guards as a minimum, will secure the building, determine the extent of the initial radioactive burst from external area monitors, and alert the local police and civil-defense authorities. They will then monitor the area to determine the extent of the contamination and, if necessary, the direction of motion of the cloud. If it becomes necessary, the local authorities will be notified and the populace downwind warned to stay inside or possibly to evacuate.

(3) Decontamination and clean up.

(4) Reactor reconstruction.

These latter two phases will be conducted on a nonemergency basis at a later date.

REFERENCES

(1) General Monitoring Handbook, R. F. Barker, LASL, 1953.

(2) MTR Project Handbook, ORNL-963 (SECRET).

(3) Sutton, O. G., "The Theoretical Distribution of Airborne Pollution From Factory Chimneys", Quart. J. Roy. Meteorol. Soc., 73 (1947).

(4) Sutton, O. G., Micrometeorology, McGraw-Hill, New York (1953).

(5) Method of Evaluating Radiation Hazards From a Nuclear Incident, KAPL-1045, J. J. Fitzgerald, H. Hurwitz, Jr., and L. Tonks (1954).

APPENDIX A

HAZARD CALCULATIONS

Inhalation Dose From Radioactive Cloud

An observer receiving an internal dose from inhalation of a radioactive cloud from an explosion would be in danger of having the thyroid gland, bones, and lungs affected by the more hazardous fission products I^{131}, Sr^{89}, $Sr^{90} + Y^{90}$, $Ba^{140} + La^{140}$, $Ce^{144} + Pr^{144}$, and Y^{91}. The short-lived fission products will also damage the lungs.

The activity of a given isotope retained by the entire body by inhalation is assumed to be 25 per cent of the activity inhaled. The activity retained may be obtained from the equation

$$A(\text{millicuries}) = 4.2 \times 10^{-3} \frac{J}{v} \frac{Q}{V^{2/3}}, \qquad \text{(A-1)}$$

where

J = inhalation rate, 17 liters/min

v = cloud velocity, m/sec

Q = total curies of given isotope in the cloud at time of inhalation

$V = (\sqrt{\pi}\sigma)^3$

σ = radius of cloud at time of inhalation.

The total curies, Q, of a given isotope may be obtained from the easily derived equation

$$Q = fe^{-\lambda \frac{x}{v}} \left\{ F(1-e^{-\lambda T}) + G\lambda \right\}. \qquad \text{(A-2)}$$

where

f = fission yield fraction of isotope (atoms isotope/100 fissions)

x = distance from cloud origin, m

λ = decay constant of isotope, sec^{-1}

F = average fission rate of reactor over reactor lifetime, fissions/sec

T = reactor lifetime, sec

G = fissions which occur during power excursion causing accident.

The most hazardous accident occurs if the fuel elements have been subjected to maximum allowable burnup (15 per cent in this case). It is assumed that a maximum average power of the reactor is 0.5 megawatt. A power pulse of 135 megawatt-sec is assumed to cause the accident. Thus,

$$F = 1.86 \times 10^{16} \text{ fissions/sec}$$

$$T = 6.21 \times 10^{7} \text{ sec}$$

$$G = 4 \times 10^{18} \text{ fissions.}$$

This assumes that 2.55 kg U^{235} is contained in the cloud.

Table A-1 gives the important data for the hazardous isotopes of interest. The cloud radius at the time of inhalation is found from data* based upon Sutton's diffusion equation.

The short-lived fission products are assumed to decay according to the Way-Wigner formula and it is assumed that the power pulse yields all of the short-lived fission products. The amount of activity from this source which is retained by the body is given by Equation A-1, where

$$Q = 2.88 \times 10^{8} \left(\frac{v}{x}\right)^{1.2}, \qquad \text{(A-3)}$$

Q in curies

v in m/sec

x in m.

The integrated lung dosage from the short-lived fission products is given by

*Unpublished data furnished by J. Z. Holland.

TABLE A-1. DATA FOR IMPORTANT FISSION PRODUCTS[a]

Isotope	Critical Organ	Fission Yield Fraction[b]	Fraction of Inhaled Products Retained by Total Body	Decay Constant, sec^{-1}	Maximum Permissible Amounts in Total Body, microcuries
I^{131}	Thyroid	0.028	0.25	1.01×10^{-5}	0.3
Sr^{89}	Bones	0.046	0.25	1.52×10^{-6}	2.0
$Sr^{90} + Y^{90}$	Bones	0.050	0.25	8.81×10^{-9}	1.0
$Ba^{140} + La^{140}$	Bones	0.0617	0.25	6.28×10^{-6}	5.0
$Ce^{144} + Pr^{144}$	Bones	0.053	0.25	2.92×10^{-7}	5.0
Y^{91}	Bones	0.040	0.25	1.41×10^{-6}	15.0
Short-lived fission products	Lungs	--	0.25	--	--

(a) Data taken from Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water, Handbook 52, U. S. Department of Commerce, National Bureau of Standards, 1953, except where indicated.

(b) Data from Reactor Handbook, Vol 1, "Physics", Table 1.2.8; Fission Yields.

$$D(\text{roentgens}) = \frac{1.18 \times 10^4}{v\sigma^2} \left(\frac{v}{x}\right)^{0.2}$$

where it is assumed that each disintegration in the lung leads to the absorption of 0.5 mev of energy in the lung tissue.

Dose Rates From Wash-Out of an Explosion Cloud

The term wash-out is here used to describe that condition in which continuous rain-out and fall-out from a radioactive cloud occurs as it drifts downwind from the origin. The fundamental assumption is that a constant fraction of the radioactivity in the cloud falls out per unit distance as the cloud travels downwind and that for each distance this fall-out rate is that which renders the dose a maximum at that point. Assuming uniform concentration of activity and correcting for attenuation, the dose rate may be expressed as*

$$D_r = \frac{2\sqrt{\pi}\,\alpha\, C_x}{\sigma} \quad E_1\left(\frac{h}{\lambda}\right), \qquad \text{(A-4)}$$

where

D_r = dose rate, r/hr

α = unit dose rate per unit concentration on the ground, 0.57 E(mev), $\frac{\text{r meter}^2}{\text{curie-hr}}$

E = energy per disintegration, 0.5 mev

$C_x = \frac{C_o}{eX_o}$

X_o = distance from cloud origin to the point where the dose rate is being considered

C_o = activity of the cloud without fall-out but including decay at distance X_o, curies

*This equation is derived in: Method of Evaluating Radiation Hazards From a Nuclear Incident, KAPL-1045, Fitzgerald, J. J., Hurwitz, H., Jr., and Tonks, L. (1954).

σ = cloud radius at distance X_o, m

$$E_1\left(\frac{h}{\lambda}\right) = \int_{\left(\frac{h}{\lambda}\right)}^{\infty} \frac{e^{-t}}{t}\, dt$$

h = height above the ground that the dose is measured (1.525 meters).

λ = attenuation length, 200 m.

The above equation overestimates the dose rate at all distances.

The value of the activity of the cloud at any time, assuming no fall-out, may be derived as follows: According to the empirical relationship of Way and Wigner* the rate of release of both beta and gamma energy after fission is $\cong 2.66t^{-1.2}\ \frac{\text{mev}}{\text{sec-fission}}$ for time between 10 seconds and 100 days after shutdown. If the reactor has been operating for T seconds, the rate of energy release t seconds after shutdown from fissions occurring between τ and $\tau + d\tau$ seconds within the operation time is

$$\frac{\text{mev}}{\text{sec}} = F(\tau)\ 2.66 \left[T-\tau+t\right]^{-1.2} d\tau \qquad \text{(A-5)}$$

where $F(\tau)$ is the fission rate at time τ. Assuming this rate to be constant, integrating over the entire operating period gives

$$\frac{\text{mev}}{\text{sec}} = F(\tau)\ 2.66 \int_0^T \left[T-\tau+t\right]^{-1.2} d\tau$$

$$= F(\tau)\ 13.3 \left[t^{-0.2} - (t+T)^{-0.2}\right]. \qquad \text{(A-6)}$$

If the reactor has been operating at a power level of 1 megawatt (equivalent to $F(\tau) = 3 \times 10^{16}$ fissions/sec) then the rate of energy release becomes

$$\frac{\text{mev}}{\text{sec}} = (13.3)(3 \times 10^{16}) \left[t^{-0.2} - (t+T)^{-0.2}\right]. \qquad \text{(A-7)}$$

*Way, K., and Wigner, E. P., Phys. Rev., 70, 115 (1946).

If the reactor has been operating for a long period of time so that $T \gg t$, then $(t+T)^{-0.2} \cong 0$ and hence

$$\frac{\text{mev}}{\text{sec}} = 4 \times 10^{17} t^{-0.2}. \qquad \text{(A-8)}$$

As in the previous accident calculations a power pulse similar to that of the borax excursion leading to 4×10^{18} fissions (135 megawatt-seconds) will be assumed to occur. The fission products from the power pulse will decay at a much faster rate than those from the steady-power operation, according to the Way and Wigner relationship

$$\frac{\text{mev}}{\text{sec-fission}} = 2.66 t^{-1.2}. \qquad \text{(A-9)}$$

Thus, the total energy release rate from the fission products will be

$$\frac{\text{mev}}{\text{sec}} = 4 \times 10^{17} t^{-0.2} + 1.07 \times 10^{19} t^{-1.2}. \qquad \text{(A-10)}$$

By use of the fact that the energy per disintegration is approximately 0.5 mev, and 1 curie = 3.7×10^{10} disintegrations per sec, we have

$$C_o(\text{curies}) = 2.16 \times 10^7 t^{-0.2} + 5.76 \times 10^8 t^{-1.2}. \qquad \text{(A-11)}$$

The value of the cloud radius, σ , at various distances downwind is obtained from the nomographs constructed by J. Z. Holland of the U. S. Weather Bureau.

The results, giving the dose rates for various distances, stability parameters, and wind velocities, are shown in Figure 15.

APPENDIX B

METEOROLOGY REPORT

METEOROLOGY FOR THE PROPOSED RESEARCH REACTOR AREA BATTELLE MEMORIAL INSTITUTE COLUMBUS, OHIO

Prepared by

Scientific Services Division
U. S. Weather Bureau
Washington, D. C.
August, 1954

Introduction

The proposed research reactor area of the Battelle Memorial Institute is to be built on a 400-acre tract of ground approximately 16 miles west of Columbus, Ohio (2 miles NE of West Jefferson, Ohio). The eastern boundary of the site is formed by the Big Darby Creek, a shallow stream 15 to 25 yards wide with an adjacent flood plain 40-60 yards in width. The terrain in the vicinity of the proposed site is relatively flat, although there is a fairly abrupt decline to the east of 40-60 ft to the Big Darby Creek. A more shallow ravine runs east-west just to the south of the proposed site.

The purpose of this report is to review the meteorology of the Columbus, Ohio, area for use in the site evaluation and compilation of a hazards analysis.

Source of Data

Although no meteorological data exist for the proposed site itself, very complete meteorological records have been taken for many years at several locations in Columbus. There does not appear to be any significant difference in the general topography of the area between the site and Columbus, so, for most purposes, the meteorological data which have been previously collected should be adequate for this preliminary evaluation.

Climatological Review

In the present brief report, those meteorological parameters will be stressed which influence directly the spread of atmospheric wastes.

Surface wind direction - the hourly wind observations for a 6-year period, 1948-1953, for the Weather Bureau Airport Station (WBAS) at Columbus were studied in detail. Table I presents the percentage frequency of the wind direction. The prevailing wind direction is from the southerly quadrant (41% of winds blow from the general direction SE through SW). The secondary prevailing direction is from the NW. There does not appear to be any major change in wind direction frequency from season to season except that northwesterly winds predominate in the spring, while the south and southeast winds reach their maximum frequency in the fall. Table I also compares the wind frequencies for two periods of the day - 8 a.m. to 4 p.m. and 5 p.m. to 7 a.m. From a study of these data, it is clear that no large diurnal change in the wind direction should be expected on the average, although night-time conditions favor southeasterly directions and calms, whereas the prevailing daytime wind is south-southwest.

It is necessary to examine the wind structure during periods of precipitation in order to consider the effect of washout of possible waste contaminants. Table I also presents the percentage frequency of wind directions at Columbus during those hours when precipitation was falling. (This was approximately 15% of the time.) In this case, also, there does not appear to be any major shift in the prevailing wind direction frequencies, although NW is the primary maximum in this case.

Wind direction is also important when the lower atmosphere is very stable and atmospheric diffusion is at a minimum. From other meteorological studies of this correlation (Cincinnati, Dayton, and Detroit), it seems probable that the most stable weather in the Columbus area would accompany the southerly and southeasterly winds. The northwesterly winds would be associated with unstable or good diffusion atmospheric conditions. This tendency is borne out by the seasonal and diurnal variations, spring and daytime being the periods in which low-level instability is most common.

Surface wind speed - Table II presents the percentage frequency of wind speeds in various class intervals. There is a striking persistency to the distribution. Approximately 58% of the winds in the Columbus area will occur in the 4-12 mph speed interval. The average speed is 8.4 mph, although it is slightly weaker in the summer months and stronger in the winter. Winds less than 4 mph occur approximately 21% of the time on the average (10% during the day, 28% during the night, and 10% during those hours when precipitation is occurring). During a 51-year period in Columbus, peak wind speeds have been observed to exceed 51 mph during every month of the year. The highest recorded speed was 84 mph during July.

Two very localized types of storms which are accompanied with high wind speeds deserve special mention - thunderstorms and tornadoes. Thunderstorms occur on the average of 41 days per year primarily in the late spring and summer, although they have occurred during every month of the year. The peak activity is in June and July. These months average 8 thunderstorm days apiece. Thunderstorm activity is extremely variable, but a rare severe storm may cause winds in excess of 50 mph, 1 to 3 inches of rain in an hour, and hailstones 1/2 inch or larger in diameter. Situations favorable for the formation of severe thunderstorms are also conducive to tornado formation. However, this more violent storm is rare in the Columbus area. A 35-year study of United States tornadoes shows that 111 tornadoes occurred in Ohio during this period with the largest percentage of these storms in the northern and western portions of the state. Local storm records from 1931 through 1954 show only 4 tornadoes in the immediate Columbus area.

Precipitation - As is indicated in the attached Local Climatological Data, the Columbus area receives approximately 38 inches of precipitation annually which will be spread over approximately 140 days. Precipitation is distributed rather evenly throughout the year with the maximum occurring in the late spring and early summer. The maximum amount of precipitation ever observed in 24 hours was 3.91 inches. Columbus has an average snowfall of 22 inches which falls on approximately 6 days per year. The greatest amount ever recorded for a 24-hour period was 11.9 inches and for one month was 29.2 inches.

Atmospheric stability - Measurements of the vertical temperature distribution are not made in the Columbus area. However, measurements made at other locations have shown a high degree of correlation between low wind periods, restricted visibility and the occurrence of inversions. Conversely high wind speeds and good visibility are indicative of lapse conditions and good diffusion weather. The Columbus area experiences approximately 15 days on which heavy fog occurs for a few hours. Visibility is reduced to below 6 miles approximately 43% of the hours annually. For just fog, it is reduced to below 6 miles approximately 8% of the time.

Inversions form nearly every night, but there is nothing in the records which could be interpreted to signify that the Columbus area experiences an unusual amount of poor atmospheric stability conditions.

TABLE I

Percentage Frequency of Wind Direction, Weather Bureau Airport Station, Columbus, Ohio
(Based on hourly observations January 1943 through December 1953)

	Winter	Spring	Summer	Fall	Annual (All obs.)	Annual (8 a.m.-4 p.m.)	Annual (5 p.m.-7 a.m.)	Annual (only when precipitation was occurring)
N	3.9	5.7	6.9	4.5	5.3	4.5	5.8	4.3
NNE	2.4	3.8	4.0	3.0	3.3	3.0	3.5	2.7
NE	3.2	3.7	4.7	2.9	3.6	3.1	4.0	2.9
ENE	2.9	3.4	3.0	2.6	3.0	2.6	3.1	2.8
E	3.8	4.9	4.9	4.2	4.5	3.4	5.1	3.3
ESE	4.2	4.0	3.4	3.6	3.8	2.5	4.6	4.2
SE	9.0	8.3	9.9	11.0	9.5	7.0	11.1	8.9
SSE	8.4	5.2	7.5	8.7	7.4	6.5	8.0	6.9
S	10.8	7.6	9.2	10.5	9.5	10.8	8.7	8.4
SSW	9.6	7.4	7.0	8.2	8.0	11.4	6.0	9.6
SW	6.8	7.4	6.6	7.0	7.0	10.6	4.7	7.6
WSW	4.7	5.0	2.8	3.5	4.0	5.1	3.4	5.4
W	4.5	4.6	1.8	2.8	3.4	4.1	3.0	4.8
WNW	7.5	7.1	3.8	5.2	5.9	6.7	5.5	8.6
NW	9.8	10.9	8.3	9.1	9.6	9.8	9.4	11.2
NNW	6.1	7.6	8.0	7.4	7.3	7.4	7.3	6.8
Calm	2.4	3.4	8.1	5.7	4.9	1.6	6.9	1.3

TABLE II

Percentage Frequency of Wind Speed Groups (mph), Weather Bureau Airport Station, Columbus, Ohio
(Based on hourly observations January 1948 through December 1953)

	Winter	Spring	Summer	Fall	Annual (All obs.)	Annual (8 a.m.-4 p.m.)	Annual (5 p.m.-7.a.m.)	Annual (only when precipitation was occurring)
Calm	2.4	3.4	8.1	5.7	4.9	1.6	6.9	1.3
1-3	12.0	11.9	23.4	17.7	16.2	8.9	20.6	8.5
4-12	57.9	56.2	59.0	57.6	57.6	57.2	57.9	55.0
13-24	27.0	27.8	9.8	18.8	20.8	31.5	14.3	34.2
25-31	.7	1.0	*	*	0.5	0.7	0.4	0.9
32-46	*	*	*	*	*	*	*	*
46	-	-	-	*	*	-	*	*
Mean Wind Speed (mph)	9.7	9.7	6.4	7.9	8.4	10.5	7.1	10.8

* Only a few observations

APPENDIX C

LETTERS ON EARTHQUAKES

C-1

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
WASHINGTON 25

August 24, 1954

Mr. James N. Anno, Jr.
Battelle Memorial Institute
505 King Avenue
Columbus 1, Ohio

Dear Sir:

Replying to your request of August 19, 1954, we find no record of earthquakes having occurred in West Jefferson, Ohio and immediate vicinity. However, as Rev. V. C. Stechschulte stated, there have been several minor earthquakes in western Ohio. Among the most noteworthy are the following which are briefly described in SP 609, Part 1, Earthquake History of the United States.

1776	Muskingum River, Ohio
1875	Urbana & Sidney
1884	Columbus
1901	Wellston & Portsmouth
1909	Ohio Valley (38.7 N. & 86.5 W.)
1929	Bellefontaine
1931	Anna
1937	Anna & Sidney (Mar. 2 and 7.)

If we may be of further service please do not hesitate to write again.

Very truly yours,

/s/ Robert W. Knox

Acting Director

XAVIER UNIVERSITY
CINCINNATI 7, OHIO

August 18, 1954

Mr. Jim Anno
Battelle Memorial Institute
Columbus, Ohio

Dear Mr. Anno:

This is in reply to your telephoned request of yesterday afternoon.

The problem of determining seismic risk in a given area is largely a guessing game. All that can be done is to list the earthquakes, with the damage done, that have occurred there within the comparatively few years of our historical record, and then to say that where earthquakes have occurred in the past, they may more likely occur again in the future rather than in places where there has been no seismic record.

A few years ago the U. S. Coast and Geodetic Survey issued a "Seismic Probability Map", of which I enclose a copy on which zones are indicated. The original tentative map included as Zone 2 a much larger area through Ohio, Indiana, etc. I believe it was in response to my suggestion that this was cut down to the 50-mile circle shown on the map. This, of course, is largely guesswork, but it does include the area in which some damage has been done in the past. However, this map has been discontinued since it was found to be subject to misinterpretation. The map has been superseded by the Epicenter Map of 1952, of which I also enclose a copy. The legend on the map indicates the information it is intended to convey. In an instruction sheet which accompanies the map (but of which I do not have an extra copy) it is stated:

> The Coast and Geodetic Survey strongly recommends the use of its earthquake catalogs in making final risk evaluations for any locality...... The Bureau will assist in making such evaluations on request.

The catalogs that would be pertinent to your purpose would be:

Serial 609, Earthquake History of the U. S., Part I (pp 39-46).
Serial No. 511, United States Earthquakes, 1929 (p. 8)
Serial No. 553, " " " , 1931 (p. 7)
Serial No. 619, " " " , 1937 (p. 8, 9).

Mr. Jim Anno, p. 2

You may be able to get these at one of the depositories for U. S. documents in Columbus. Otherwise they are obtainable from the Superintendent of Documents, Washington, D. C., for 45, 15, 5, and 15 cents respectively. These will give you more detail than is indicated by the maps, listing places where the earthquakes were felt and where damage may have been reported. What it will all add up to is that there has been minor damage approximately within the 50-mile circle with more severe damage in a small area around Anna, Ohio. The small earthquake in the vicinity of Zanesville two or three years ago would make no significant change in the picture.

The above constitutes all the material on which one can base a guess--and it can be only that, not a prediction. There are two other papers to which I may make reference:

1. Recent Earthquakes in Western Ohio, by Rouse and Pritty (of Ohio State U.), Ohio Journal of Science, Jan. 1938.

2. A Macroseismic Study of the Ohio Earthquakes of March 1937, by Westland and Heinrich, Bulletin of the Seismological Society of America, Vol. 30, No. 3, July 1940.

You may retain the maps if they are useful to you.

Sincerely yours,

/s/ V. C. Stechsculte, S. J.

(Rev.) V. C. Stechschulte, S. J.
Director of the Seismological
Observatory

APPENDIX D

CONCLUSIONS OF GEOLOGY AND HYDROLOGY REPORT

The conclusions of a report* on the geology and hydrology of the Battelle site are reprinted here. This report appears in full in a previous Hazards Report on the critical assembly.

"The Battelle site seems to be almost entirely safe for the operation of a nuclear power reactor, with respect to the effects on the ground water resources resulting from accidental spillage of radioactive fluids in the site area. In the event of a spill, most of the liquid would flow overland to Darby Creek. Only a small portion would infiltrate the soil and seep downward to the water table or reach the principal artesian aquifer.

"Infiltration would be greatest when the soil is dry, especially during periods of large soil moisture deficiency, such as would occur during the growing season. Conditions least favorable for infiltration, and those which would promote most rapid runoff, would result from frozen or saturated ground, or would occur during a heavy rainstorm when a large volume of water is flowing overland towards Darby Creek.

"The course of a spilled liquid, once it reached the water table, also would be towards Darby Creek where it would discharge into the stream through springs and seeps. The shallow aquifer is unimportant as a source of water in the site area and the chances are almost nil under present conditions that a contaminant introduced into the shallow aquifer on the Battelle property would be diverted to wells or otherwise intercepted by man in the course of its slow underground journey to the discharge area.

"A greater chance for contamination of ground water supplies would result from radioactive fluid entering the principal aquifer in the site area. This danger is slight, however, for the principal aquifer receives most of its recharge in upland areas some distance west of the Battelle site. Only a relatively small amount of water percolates through the till to reach the principal aquifer in the immediate area of the site. Moreover, a contaminant reaching the principal aquifer in the immediate area of the Battelle property would already be down-gradient from almost all the wells in the area.

*Norris, Stanley, "Hydrology of a Proposed Reactor Site Near Columbus, Ohio", U.S. Geological Survey, Water Resources Division, Columbus, Ohio (August, 1954).

"Practically the only potential danger of contamination to a specific ground water supply is to the supply now being developed by the Battelle Memorial Institute near the southeast corner of their property. Pumping from the well now being drilled, and from possible future wells, would lower ground water levels in the principal aquifer in the immediate area of the wells. This would induce more recharge locally from the overlying till by creating a cone of influence which might encompass areas where the danger of contamination would be greatest. In view of this possibility a careful record should be maintained of the natural radioactivity of the water from the Battelle plant wells, to be used as a basis for comparison to detect any contamination should spillage occur.

"The greatest danger to human life and property resulting from spillage of radioactive fluid in the Battelle site area would be for the fluid to reach Darby Creek in volume and to move downstream in toxic concentration. Darby Creek is not now used either as a source of public or of large-scale industrial water supply, though it undoubtedly will be used eventually for both purposes. It is however, an important source of water for stock all along its course and it flows into the Scioto River above several important water supply developments, including the supply for the Atomic Energy Commission plant in Pike County.

"The velocity of flow in Darby Creek ranges from very low, when the stream is in pool stage and the only perceptible flow is over the riffles, to very high when the stream is in flood. The velocity of flow is important to any further evaluation of the fate of a spilled liquid once it reaches the stream and it should be studied under various conditions of discharge. Surface water samples should be collected and analyzed to determine the natural radioactivity of the stream, and the records maintained as a basis for future comparison."