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# NACA

# RESEARCH MEMORANDUM

for

The U. S. Atomic Energy Commission

NACA ZERO POWER REACTOR FACILITY HAZARDS SUMMARY

By Lewis Laboratory Staff

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

# NATIONAL ADVISORY COMMITTEE
# FOR AERONAUTICS
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Edited by B. Lubarsky and D. J. Connolley

SUMMARY

The Lewis Flight Propulsion Laboratory of the National Advisory Com-
mittee for Aeronautics proposes to build a zero power research reactor
facility which will be located in the laboratory grounds near Cleveland,
Ohio. The purpose of this report is to inform the Advisory Committee on
Reactor Safeguards of the U. S. Atomic Energy Commission in regard to the
design of the reactor facility, the characteristics of the site, and the
hazards of operation at this location.

The purpose of this reactor is to perform critical experiments, to
measure reactivity effects, to serve as a neutron source, and to serve as
a training tool.

The reactor facility is described. This is followed by a discussion
of the nuclear characteristics and the control system. Site characteris-
tics are then discussed followed by a discussion of the experiments which
may be conducted in the facility. The potential hazards of the facility
are then considered, particularly, the maximum credible accident. Finally,
the administrative procedure is discussed.

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# NACA ZERO POWER REACTOR FACILITY HAZARDS SUMMARY

## 1. INTRODUCTION

A zero power nuclear reactor is an essential part of the nuclear program of the National Advisory Committee for Aeronautics. The uses for such a reactor are many:

   1. To perform experiments for obtaining the critical dimensions, flux distributions, and various homogeneous coefficients of reactivity for both reflected and unreflected assemblies.

   2. To provide a research tool for measuring reactivity effects of voids, moderators, fuels, and absorbers, and for measuring flux distributions near these inhomogenieties.

   3. To serve as a neutron source for detection and activation experiments, and to provide neutron beams for nuclear interaction experiments and for measurements of diffusion and slowing down parameters in various media.

   4. To serve as a training tool both for personnel taking formal nuclear engineering courses in the NACA research divisions, and for personnel being trained for the NACA Reactor Facility at Plumbrook Ordnance Works in Ohio.

A homogeneous reactor using uranyl fluoride $(UO_2F_2)$-water solutions has been selected. This solution-type reactor is one of demonstrated reliability and sound technology (refs. 1.1 and 1.2). The safety characteristics of these reactors are excellent (ref. 1.3). They possess large negative temperature and radiolytic gas coefficients of reactivity, and so limit the severity of accidental power excursions. Furthermore, the relative simplicity of operation, and application of the reactor to the requirements mentioned above, make the solution-type reactor ideally suited.

The reactors will be cylindrical, reflected or unreflected assemblies, in which the fuel concentration may vary from assembly to assembly, and are essentially similar to the Oak Ridge assemblies (ref. 1.4). The facility is designed for steady-state reactor operation at a maximum total power of 10 watts, producing average thermal neutron fluxes up to $10^8$ neutrons/$(cm^2)(sec)$.

The description of the reactor facility and the discussion of the hazards associated with it are organized in the following manner. Section 2 contains a description of the facility including details of the fuel system, the control system, and the reactor physics associated with certain families of loadings. Section 3 discusses the site, section 4 the kinds of experiments being considered for the reactor, section 5 the hazards including those associated with the maximum credible accident, and section 6 the administrative procedures.

## 1.1 References

1.1 King, L. D. P.: Design and Description of Water Boiler Reactors. International Conference on the Peaceful Uses of Atomic Energy, vol. 2, paper P/488 (1955).

1.2 Research Reactors, chapter 1, TID 5275 (1955).

1.3 Hetrick, D. L., et al.: Preliminary Results on the Kinetic Behavior of Water Boiler Reactors. NAA-SR-1896 (1957).

1.4 Callihan, A. D., Morfitt, J. W., and Thomas, J. T.: Small Thermal Homogeneous Critical Assemblies. International Conference on the Peaceful Uses of Atomic Energy, vol. V, paper P/834 (1955).

## 2. THE REACTOR FACILITY

### 2.1 General Description of Facility

This section presents a general description of the proposed NACA Zero Power Reactor Facility.

2.1.1 Site. - The reactor facility will be located at the Lewis Flight Propulsion Laboratory of the NACA adjacent to the Cleveland Hopkins Airport, Cleveland, Ohio. A description of the site is contained in section 3.

2.1.2 Reactor. - The reactor will be of the homogeneous type. Different core configurations will be used at different times. The cores will consist of solutions of highly enriched uranyl fluoride $(UO_2F_2)$ in light water. The reactor may be bare or reflected. The reactor will be of cylindrical geometry with the top open to the atmosphere.

The reactor will ordinarily be run at a power level of approximately 1/10 watt with a maximum of ten watts.

Initial experiments will be performed with a reactor of hydrogen - uranium ratio of 500, and length - diameter ratio of 2. This particular reactor has a diameter of 29.5 cm and a height of approximately 59 cm.

2.1.3 Reactor control. - Reactor control during normal operation will be effected by control of the quantity of solution in the reactor vessel.

One control rod will be installed. This rod will be a safety rod only, and will not be used for regulation. There will be no provision for incremental positioning of this safety rod. In addition to the safety rod, provisions have been made to dump the reactor core solution into storage tanks with a "safe geometry" when an unsafe condition occurs.

A discussion of reactor control is contained in section 2.4.

2.1.4 Building. - The reactor building is an addition to the existing Materials and Stresses building at the Lewis laboratory. Figures 2.1 and 2.2 show a floor plan and section of the reactor building. The reactor building is a reinforced concrete underground structure consisting of a reactor room 20 feet by 32 feet by 20 feet in height, a solution room 15 by 21 feet by 10 feet in height, a personnel decontamination and locker

room, and a corridor. Adjoining space in the basement of the existing Materials and Stresses building will be utilized for a control room.

Access to the facility will be through the control room only; the corridor door will normally be locked. The control room door will have a lock and admittance will be limited to authorized personnel.

A platform 9 feet in height will support the reactor and associated equipment approximately midway between floor and ceiling of the reactor room. The floors of the reactor room and solution room will be covered with a stainless-steel sheet forming a pan approximately 6 inches in depth to contain any spillage. The floor levels of these two rooms is 6 inches below the general floor level. Walls and ceilings in these rooms will be protected with a strippable waterproof plastic coating to prevent contamination of the concrete in the event of an excursion.

2.1.5 Shielding. - The shielding is designed so that no person will receive a dose in excess of 1 millirem/hour when the reactor is operating at 10 watts power.

The reactor room will be isolated from the rest of the building during operation by a gas tight door at the end of the corridor (see fig. 2.1). This will prevent radioactive gases or vapors from contaminating other parts of the building. An interlock will prevent filling of the reactor if this door is not closed.

Operating personnel will be protected by a 54 inch thick concrete wall between the reactor room and the solution room. Shielding of the reactor room doorway will be accomplished by construction of a concrete block labyrinth (see fig. 2.1) portions of which will be removable to provide access for large pieces of equipment. Provisions are being made for installation of a 48 inch thick concrete shield door should the labyrinth type shield prove ineffective.

A six inch thick concrete floor, one foot thick reinforced concrete walls and roof, and a minimum of six feet of tamped earth cover will shield persons outside the building from radiation.

Local shielding will be placed around solution storage tanks to reduce the gamma radiation to an acceptable value.

2.1.6 Ventilation. - A schematic diagram of the ventilating system is shown in figure 2.3. Ventilation of the reactor room will occur only during shutdown periods. Air will enter the room through an opening in the gas tight door in the corridor. This opening will include a filter to remove dust and foreign matter; a gas tight cover is provided which will be secured during reactor operation. An interlock will insure that the cover is in place prior to reactor operation.

Air will be exhausted from the room to a short stack. This exhaust line will contain a remotely operated valve for sealing the line during operation. This valve will also be interlocked so that the reactor cannot be filled unless the valve is closed.

Ventilation of the reactor room will be accomplished by a 1000 cfm blower which will provide approximately 4 air changes per hour. Room air will be monitored prior to exhausting it to the atmosphere. If the activity of the room air exceeds the acceptable limit, exhausting the air will be delayed until the activity has decayed sufficiently.

Vents from all fuel and water tanks in the solution room will extend into the chemical hood which is exhausted to the atmosphere through a stack.

2.1.7 Fuel handling system. - All piping, tanks, and appurtenances coming in contact with the solution will, so far as is practical, be made from or coated with a material that is resistant to corrosion by the fuel solution. All pumps, valves, etc will be of the packless type to minimize leaks.

Fuel will normally be stored in shielded storage tanks in the solution room. The diameter of the storage tanks will be selected in accordance with the recommendations of reference 2.1, so that a safe geometry will be maintained, even for the case of infinite water reflector. In addition to these there are similar storage facilities under the reactor platform. The reactor fuel will be dumped into these tanks and held up there until the activity has subsided.

Fuel will be pumped into the reactor through a small line (no larger than 1/2 in.). A quick acting dump valve (not less than 1 in.) connecting the reactor and dump tanks will provide a rapid dump of the core solution in case of a scram.

Uranium concentration in the fuel solution will be controlled by the addition of deionized water for dilution and by vacuum evaporation for concentration. The evaporator will be sized for a safe geometry. A more complete description of the fuel handling system is given in section 2.2.

2.1.8 Water and waste handling systems. - Figure 2.4 is a schematic of the water and waste disposal systems. All water used for the reactor core and reflector will be deionized.

Two waste collection tanks are provided. The first, the radioactive waste tank is a sump for all liquids which may be contaminated. The other tank is primarily a holdup tank; however, drains from the uncontaminated sink and the reflector water storage tank will enter this tank.

Reflector water will be stored in a tank in the reactor room and pumped into and drained from the reflector as needed. The reflector water storage tank may be drained into either the radioactive waste tank or the holdup tank.

A bench in the solution room will be provided with 2 sinks, one for contaminated materials which will drain into the radioactive waste tank and another for uncontaminated materials which will drain into the hold-up tank.

In addition, a sink is being provided in a chemical hood. This sink will drain into the radioactive waste tank.

Contaminated water will be pumped from the radioactive waste storage tank through an ion exchanger into the holdup tank.

Water in the holdup tank will be monitored for activity. If the activity level is acceptable, it will be pumped into the laboratory sewer system. If the activity is too high, the water will be circulated through an ion exchanger until an acceptable level of activity is reached and the water will then be discharged into the sewer system.

It is expected that the amount of radioactive materials in the water will be quite small and therefore the resins in the ion exchanger will be usable for a long period of time. These resins will either be disposed of by an authorized disposal agency or cleaned up and reused. Economics and uranium accountability will determine which method is used.

## 2.2 Fuel System and Handling

2.2.1 General description of the fuel system. - The fuel for the reactor is a U-235 enriched aqueous uranyl fluoride solution. The fuel system (see fig. 2.5) is composed of two parts, one in the reactor room and the other in the solution room. The two are joined by a single line; a valve in this line isolates one system from the other. Each system has its own pump and storage facilities. The fuel system in the reactor room is used only for normal reactor operation, while that in the processing room is used for storage, concentration changes, mixing, and other processing that may be desired.

2.2.2 Reactor room fuel system and handling. - The fuel system in the reactor room consists of a storage bank, a pump, necessary valves including the dump valve, and the reactor itself.

The storage bank consists of five cylinders, with 19 liter capacity each, giving a total storage capacity of 95 liters.

The pump will be capable of pumping fuel solution both in and out of the reactor at a maximum rate of 4 liters/minute. The pump will be controlled manually by a spring-return, center-off switch on the control panel. The pumping rate is selected by the operator and is continuously variable up to the maximum pumping rate. The pump shall be designed to operate at flows as low as 60 ml/min so that the operator may easily control the fuel solution in the reactor vessel to within two milliliters. This pump will also be used to pump solution between the reactor and solution rooms. The valves will be so arranged that:

1. It is impossible to pump fuel from the solution room directly into the reactor.

2. It is impossible to pump fuel from the solution room into the reactor room while the reactor is in operation.*

The dump valve is interlocked with the scram circuit, as described in section 2.4. It is a normally open flush bottom valve held closed by an air cylinder. The valve will open if the normally open, air-cylinder vent valve opens. The dump valve will have a minimum diameter of 1 inch. Table 2.1 gives emptying rates for a 1 inch diameter valve as a function of height of the solution in the reactor tank.

Table 2.1. - Dumping Rates for a 1-Inch Diameter Valve

as a Function of Fuel Height in Reactor

| Height of solution, cm | Volumetric emptying rate, liters/min |
|---|---|
| 15 | 47 |
| 30 | 66 |
| 60 | 94 |
| 120 | 132 |

A float type check valve will prevent solution from entering the vent line from the top of the storage bank. A sampling tap will be provided to check the concentration of the solution in the storage bank.

A plastic cover for the top of the reactor tank will be provided to cover the tank when the reactor is not in operation.

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*It should be noted that since the line connecting the two parts of the system is on the suction side of the pump in the solution room, fuel cannot be pumped into the reactor room by this pump.

2.2.3 Processing room fuel system. - The fuel system in the processing room consists of two storage banks, evaporator, pump, filling funnel, and filter.

Each storage bank will be composed of five cylinders and will have a total capacity of 95 liters. Each bank will be provided with a sight gauge to determine the volume of solution contained.

The evaporator and condenser will operate under vacuum and will be capable of removing about five pounds of water per hour from the fuel. Air withdrawn from the system by the vacuum pump will be bubbled through the water storage to remove any entrained solids, and be blown out the hood exhaust system. Hot water will provide the heat in the evaporator and cold water will provide cooling in the condenser. The lower portion of the condenser will provide storage for the condensed water.

The filling funnel will have a capacity of 4 liters and be graduated every 5 cc.

The drain valve will be locked with a key to prevent unauthorized removal of fuel.

2.2.3.1 Fuel handling in processing room. - Concentration changes of the fuel solution will be accomplished by addition or withdrawal of water. Water is added by pouring it into the filling funnel to the desired level. Valves F and P, and valve A2 or B2, depending on which fuel solution is to be diluted, are then opened and the pump run to pump the water into the storage tanks.

Water is withdrawn by running the fuel solution through the evaporator. This is accomplished by opening valves E1, E2, A1, and A2 (or B1 and B2 if it is desired to concentrate the "B" solution) and running the pump. The amount of water removed will be determined by reading a sight gauge on the storage portion of the condenser.

The solution will be mixed by recirculating it through the storage tanks. This will be accomplished by opening valves P, A1 and A2 (or B1 and B2).

Fuel will be transferred to the reactor room by opening the proper valve A1 or B1, valve R and running the pump in the reactor room.

Sampling of the fuel solution will be accomplished by drawing solution out through the drain line.

2.2.3.2 Fuel inventory. - Storage facilities will be provided in which the fuel as received can be locked until it is loaded into the fuel system.

The fuel solution will be analyzed by standard chemical methods to determine the concentration of uranium

### 2.2.4 Chemical aspects of the fuel system.

- The concentration of the fuel solution may be varied to correspond to hydrogen - uranium ratios of from 1000 to 25. The solubility limit of uranyl fluoride in water at room temperature is about 65 weight percent which corresponds to a hydrogen - uranium ratio of about 18. The pH of the fuel solution will be maintained between 5 and 6. During operation of the evaporator, small quantities of hydrofluoric acid will be lost to the vent system from the fuel solution. Care will be taken to insure that the hydrofluoric acid is not released in a manner which will cause a health hazard. Acidity of the fuel will be maintained by the addition of hydrofluoric acid.

In order to maintain a high purity of the fuel solution, the entire fuel system, wherever feasible, will be of suitable plastic materials, or will be coated with a suitable plastic so that fuel solution will come in contact with plastic only.

### 2.2.5 Special physical aspects of the system.

- It is essential that the system design be such that it is impossible for the fuel solution to accidently become critical. All components and the integral arrangement of the fuel system have been designed within the tolerances given in Nuclear Safety Guide (ref. 2.1). The tolerances met are those for the most crucial H/U ratio and for an infinite water reflector. For example, all fuel storage tanks are of a diameter such that for an infinitely long cylinder containing an aqueous U-235 solution of any concentration and being surrounded by an infinite water reflector, the system will be subcritical. Likewise the evaporator, condenser, and all associated piping will be of safe geometry, even if they were to be filled with fuel solution and surrounded with an infinite water reflector.

Another important aspect of the system design is that it be such that loss of fuel will be kept to a minimum. A study of the fuel system schematic (fig. 2.5) will show that there are six places fuel can enter or leave the system:

(1) the drain at the low point in the system

(2) the graduated funnel provided for feeding the system

(3) the reactor itself, which is open

(4) the concentration system

(5) a leak in the system

(6) the sampling pipet on the reactor storage bank

The sampling tap and drain from which the fuel solution can be easily withdrawn will be under lock and key. The top of the filling funnel is higher than any point in the system, hence the fuel solution is not easily removable via this entry. Since the dump valve will be open when the reactor room door is not sealed, fuel solution cannot be contained in the reactor while people are working in the room. The concentration system, a vacuum evaporative system, will operate at low rates so that only water will be removed from the fuel system at this point. The actual amount of $UO_2^{++}$ carried over may be about 0.1 - 1.0 ppm (ref. 2.2). Should uranyl fluoride be carried over by improper operation of the evaporator, it will be collected in the water storage tank at the exit of the condenser.

Should a large leak develop in the system, the fuel solution would spread out on the floor (the floor drains are normally closed). It would be contained in the reactor room or solution room, since these floor areas are the lowest points in the structure and each is covered by a six inch deep stainless steel pan which extends over the entire floor area. In order to detect small leaks, the entire fuel system will be periodically checked. In order to prevent leaks, all components will be of the packless type.

2.2.6 Fuel activity and gas evolution. - Since the reactor may be run at power levels up to 10 watts, moderate fission product activity will be encountered. Table 2.2 gives activities of the fuel solution after operation of 10 and 100 minutes at 10 watts, and various shutdown times as computed by the Way-Wigner formula (ref. 2.3).

Table 2.2 - Total Activity After Operating at

10 Watts for Given Period

| Shutdown time, min | Activity, curies | |
|---|---|---|
| | 10 minute operating period | 100 minute operating period |
| 1 | 22 | 35 |
| 5 | 8 | 19 |
| 10 | 5 | 14 |
| 50 | 1 | 5 |

The radioactive fission gases released during reactor operation will be handled by the ventilation system as described in section 2.1.6.

The amount of $H_2$ and $O_2$ formed radiolytically will be about 150 cc per hour when the reactor is operating at 10 watts. Almost all of this gas will be released and will be handled by the ventilation system.

## 2.3 Reactor Physics

The specific reactor configuration which has been chosen for the initial criticality experiment is an unreflected cylinder with critical dimensions of 29.5 cm diameter and 59.0 cm height and with an approximate critical mass of 2100 grams of fully enriched uranium. Reactor analyses for the family of $UO_2F_2$-$H_2O$ solution reactors and some of the reasons for selecting the foregoing configurations as the first of a series to be studied are given herein. The method for calculating these homogeneous reactors is that of reference 2.4 which satisfactorily predicts the criticality of the Oak Ridge solution reactors presented in reference 2.5.

The method of reactor analysis is essentially a group diffusion analysis making use of the peculiarly rapid slowing down properties of hydrogen and including the effects of epithermal absorption and fission. The concept of reflector savings, evaluated by two-group procedures, is employed in calculating the criticality of reflected assemblies.

2.3.1 Uranium requirements. - The calculated fully enriched uranium requirements, for cylindrical cores of L/D (length-diameter ratio) of unity, are shown as a function of core diameter in figure 2.6. Critical requirements are shown for bare cores and for cores reflected by large thicknesses of water. Fuel concentration of the solutions are indicated by the hydrogen-uranium atom ratio, R.

The curves exhibit a minimum in both uranium requirement and core diameter. A minimum uranium requirement, occurring as a result of relative rates of neutron leakage, absorption, and production, is a usual criticality characteristic (see ref. 2.3). However, the characteristic of a minimum core diameter regardless of fuel concentration (within the limits of solubility) is peculiar to solution-type reactors and results from the rapid reduction in hydrogen-atom density due to displacement of water by uranyl-fluoride for solutions with values of R less than 200. The foregoing minima occur at respective values of R of about 500 and 80 and ensuing discussions will be restricted to these values of R.

Uranium requirements for critical cylindrical bare and water reflected cores of L/D other than unity are shown in figure 2.7. The specific reactor selected for the initial critical experiment is indicated in figure 2.7 at

$$W^U \qquad 2100 \text{ grams}$$
$$L/D \qquad 2$$
$$R \qquad 500$$

The anticipated critical heights, $H_c$, and critical diameters, $D_c$, for bare and water reflected cylindrical cores are shown in figures 2.8 and 2.9, respectively. Included in the figures are actual data points taken from reference 2.5 for values of R near 80 and 500. A comparison of calculations and experimental data for other values of R is presented in reference 2.4. Also shown on the figures are the calculated diameters for critical cylindrical cores of infinite height and heights for critical cylindrical cores of infinite diameter.

2.3.2 Sensitivity at criticality. - In order to gauge the sensitivity of the various cylindrical configurations at criticality, a series of reactivity calculations were made for particular configurations during the approach to critical. These results are presented in figures 2.10 and 2.11 in which the effective multiplication factor, $K_{eff}$, is shown as a function of core height for bare and water reflected cores, respectively. The slope of each curve is a measure of the sensitivity of the configuration to increments in core height. The "pancake" reactors of L/D of 1/4 are much more sensitive than the long reactors of L/D of 2.

Values of sensitivity may be expressed in units of reactivity per unit core height at criticality ($K_{eff} = 1$). The unit of reactivity used is the dollar which is equivalent to the reactivity associated with the delayed neutron fraction taken to be 0.00692 from the data of reference 2.6. The sensitivity in cents per millimeter is shown as a function of critical core diameter in figures 2.12 and 2.13 for bare and water reflected assemblies, respectively. Sensitivities are large for the "pancake" reactors, decreasing as L/D is increased. The sensitivity for the initial critical experiment is about 3 cents per millimeter of height as is indicated in figure 2.12.

These sensitivity results may be translated into volumes which will add prompt reactivity and so provide information which may be used to establish criteria for solution filling rates. These data are shown in figures 2.14 and 2.15 as a function of core L/D for bare and water reflected critical assemblies, respectively. The initial critical experiment is indicated in figure 2.14 for which a volume of 3200 cc is necessary to add prompt reactivity. It is interesting to note that the volume required to add prompt reactivity has a minimum which occurs in the region for "pancake" reactors.

2.3.3 Calibration of bare core height and reactivity. - In order to use a reactor to measure reactivity effects of fuel, moderator, absorber, or void, excess reactivity must be controlled in some manner. In thermal heterogeneous reactors, control rods are usually the most convenient way for measuring excess reactivity. The control rods may be experimentally calibrated by several methods. One commonly used method is to distribute thermal neutron poisons of known reactivity effect uniformly throughout

the reactor core; the decrease in reactivity due to these poisons is compensated by withdrawal of rod or rods to maintain criticality. In this manner a control rod calibration curve is generated. Another method is to withdraw a rod or rods suddenly so as to put the reactor on asymptotic stable periods, for which the corresponding reactivities are known from the inhour relation. This method is limited by the range in power that may be tolerated in permitting the reactor period to stabilize.

Both of these methods are applicable to homogeneous reactors; however, the unique situation of fuel solubility permits reactivity effects to be measured by changes in critical core height rather than by control rods. In this way the perturbing effects of the presence of rods in the core is eliminated. To establish experimentally the variation of core height with reactivity, the fuel itself may be used effectively as the distributed "poison" by varying its concentration and determining critical core height. Such calibrations would be valid for several percent reactivity about any given core configuration. An approximate calibration curve for the initial critical experiment under consideration is shown in figure 2.16 as calculated by present methods. The true calibration curve will be established by experiment. If one could satisfactorily represent the experimental data in an analytic manner (for example, with the group-diffusion criticality relations used herein), one could generate curves of $K_{eff}$ against core height as shown in figure 2.10 and 2.11. Such curves would then serve as working calibration curves for measuring reactivity effects of perturbations to critical assemblies.

In principle, it is also possible to use fuel concentration instead of core height as a measure of reactivity, although this is not a practical procedure in the present facility.

2.3.4 Neutron lifetime. - Mean prompt neutron lifetimes for the homogeneous assemblies are important parameters for estimating reactor periods following insertions of reactivity of the order of one dollar. These lifetimes or generation times have been estimated for a few bare critical assemblies as the sum of a neutron slowing down time and a thermal neutron diffusion time, and are given below in microseconds:

| Atom ratio, $R = N^H/N^U$ | Fraction total fissions in thermal region | Slowing down time, $\mu sec$ | Thermal diffusion time, $\mu sec$ | Mean prompt lifetime, $\mu sec$ |
|---|---|---|---|---|
| 500 | 0.95 | 6.2 | 43.5 | 49.7 |
| 80 | .60 | 5.3 | 8.8 | 14.1 |
| 25 | .20 | 5.3 | 3.3 | 8.6 |

The neutron slowing down time is that for water based on the value of 10 μs for an infinite water medium from reference 2.3 and corrected for leakage in the bare critical assemblies. The thermal neutron diffusion times for these bare assemblies are calculated by relations in reference 2.3. It is of interest that although a large fraction of fissions in the bare critical assemblies of R of 80 and 25 occur at energies other than thermal, these fissions occur in the epithermal region so that the slowing down times are not significantly affected. The thermal diffusion time, however, is reduced by the increased absorptivity of the solution.

The mean prompt lifetimes for reflected assemblies, of course, will be much longer because of the effective holdup in the water reflector. (The thermal diffusion time in water is about 200 μsec).

## 2.4 Reactor Control and Instrumentation

Inasmuch as the solution reactors considered herein are to be used in criticality experiments, in the measurement of reactivity effects, and as a neutron source at total powers up to 10 watts, minimal excess reactivities are required. The approach to criticality in every experiment is controlled by the filling rate of the fuel solution and core height is used as the measure of reactivity. Conventional control rods are absent in these reactors. Control of the reactor in approaching criticality is directly under the supervision of the reactor operator who controls solution filling or withdrawing rate.

The sole action overriding the control of the reactor operator is that of full scram. The scram mechanism will consist of a safety rod and a dump valve operated by the scram circuits. Annunciators will warn the operator of minor emergencies so that corrective action may be taken without scramming the reactor.

2.4.1 Instrumentation. - A block diagram of the instrumentation is shown in figure 2.17. The counter channels will be used mainly in start-up operation to obtain source multiplication curves. The ion chamber channels will be used as the control channels in the operating range.

Power failure will actuate all the scram circuits thereby making all the safety channels fail safe.

Fuel temperature in the reactor vessel and storage tank, reflector temperature, and room temperature will be monitored during operation. Dosimeters will be placed throughout the critical facility area to determine maximum level and doses in case of a power excursion.

To insure that safe procedure will be followed in start-up of the reactor, the following conditions will be established by the use of interlocks:

1. Gas tight door to the reactor room closed and locked

2. Filter cover in gas-tight door in position and locked

3. Safety rod fully withdrawn

4. Source fully inserted

5. All valves between solution storage room and assembly room locked in "operate reactor" position

6. Ventilation to reactor room off.

2.4.2 Control mechanisms. - Except in the case of emergency, control will be maintained by adjustment of the amount of fuel in the reactor. The parameter used in control will be the height of the fuel in the reactor tank. This height will be measured remotely by two independently operated micrometer screws. A pointer will be fastened to the end of the micrometer screw and contact with the surface of the fuel will complete an electrical circuit giving indication on an ohmmeter.

In case of an emergency, the first indication will be annunciators showing that a predetermined power level or minimum period has been exceeded. At this signal, the operator will stop adding fuel to the assembly, and, if necessary start withdrawing fuel. If this action fails to remedy the emergency, then the scram circuits will be actuated by a slightly higher power level or shorter period. The scram signal will cause both the safety rod to drop and the dump valve to open. The minimum periods and maximum power levels of the trip circuits will be determined by the scientist-in-charge before start-up of the reactor. Absolute limits will be determined by the local safeguards committee and will never be exceeded. A manual scram button will be located on the operating console for the use of the operator.

The safety rod will meet the following specifications:

1. Fail safe release mechanism

2. Shutdown reactivity worth of about 2 percent

3. Physical design such that the entry of the rod into the fuel will cause a minimum hydrodynamic disturbance

4. Actuating time compatible with the electronic circuitry governing the release of the rod.

The source drive mechanism will be a simple rack and pinion or cable and pulley assembly. A selsyn will indicate source position and, as previously mentioned, an interlock will insure that the source is fully inserted prior to start-up. Optimum source and detector locations for obtaining multiplication curves will be determined experimentally on a subcritical assembly before an attempt is made to bring the reactor critical.

2.4.3 Operations. - All operations will be preceeded by a detailed check-out procedure. This will consist of actuating all mechanisms and source calibration of all safety and control circuits. The person performing the check-out will enter all instrument readings obtained during the check-out and note the operation of all mechanisms in a logbook. This will be personally approved by the scientist-in-charge before any addition of reactivity to the assembly.

When fuel is transferred from the storage room to the assembly room, an analysis will be made before any operation to insure that the fuel is of the specified density.

A detailed approach to critical will be made following any change to the assembly or fuel concentration. This approach will consist of obtaining a reasonably linear plot of inverse count against fuel height so that the critical height can be extrapolated. Fuel will be added in increments decreasing in size as determined by the scientist-in-charge.

A detailed start-up and operating manual will be written prior to the operation of the reactor.

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# 3. SITE

## 3.1 General Site Location

The proposed NACA zero power reactor facility is to be located on the reservation of the NACA Lewis Flight Propulsion Laboratory. This laboratory is situated at the extreme southwest corner of Cleveland, Ohio, near the junction of Ohio routes 17 and 237. This location is indicated on figure 3.1, which is a map of Cleveland and some of the surrounding area.

Figure 3.2 is a composite aerial photograph of Lewis laboratory and the surrounding area for a radius of about three miles. Figure 3.3 is a closeup aerial photograph of the laboratory. These two figures present some idea as to the local terrain, and also the local population distribution. Adjacent to the laboratory on the east is Cleveland Hopkins Airport; to the north and west of the laboratory is a section of the Cleveland Metropolitan Park System; on the south is sparsely populated farm land.

The closest residence is about 900 feet to the southeast of the reactor and the second is about 2000 feet to the southwest. The nearest major airport buildings are about $1\frac{1}{2}$ miles to the southeast; there are some light plane hangars about 1000 feet from the proposed site. The closest point open to the public is on the airport grounds adjacent to the NACA fence (see fig. 3.3) at a distance of about 200 feet. The closest point not on airport grounds open to the public is about 700 feet from the reactor site. There is a fairly densely populated area to the north. This area is about $1\frac{1}{2}$ miles from the proposed facility.

In addition to the two aerial photographs, a plan of the laboratory is shown in figure 3.4. This figure shows the location of the proposed facility with respect to the adjacent buildings and facilities of the Lewis laboratory.

## 3.2 Meteorology

Meteorology data for the proposed site are presented in table 3.1 and in the insert (Local Climatological Data for the Cleveland area). Table 3.1 is a table of annual wind frequencies and velocities taken at Cleveland Hopkins Airport which is adjacent to the site. These data were obtained from the U. S. Weather Bureau at Cleveland, Ohio.

Inversion data have not been taken by the Cleveland Weather Bureau; it is the opinion of the meteorologist in charge of the Cleveland Weather Bureau that, if averaged over a long period of time, these data for the Cleveland area would not be too different from that of the Toledo area where radio soundings are taken (ref. 3.1). Table 3.2 is a table of the inversion data for the Toledo area.

Table 3.1. - Annual Prevailing Winds

Hopkins Airport, Cleveland, Ohio

| Direction | Percent winds 4-15 mph | Percent winds over 15 mph | Total percent |
|---|---|---|---|
| N | 0.6 | 5.4 | 6 |
| NNE | .6 | 3.4 | 4 |
| NE | .4 | 3.6 | 4 |
| ENE | .1 | 0.9 | 1 |
| E | .1 | 2.9 | 3 |
| ESE | .1 | 0.9 | 1 |
| SE | .6 | 6.4 | 7 |
| SSE | .9 | 5.1 | 6 |
| S | 1.0 | 8.0 | 9 |
| SSW | 1.9 | 7.1 | 9 |
| SW | 4.3 | 10.7 | 15 |
| WSW | 3.3 | 2.7 | 6 |
| W | 2.6 | 3.4 | 6 |
| WNW | 2.4 | 2.6 | 5 |
| NW | 1.7 | 4.3 | 6 |
| NNW | .6 | 2.4 | 3 |
| CALMS (0-3 mph) | | | 9 |

# LOCAL CLIMATOLOGICAL DATA

## WITH COMPARATIVE DATA

### 1956

### CLEVELAND, OHIO

## NARRATIVE CLIMATOLOGICAL SUMMARY

Cleveland is on the south shore of Lake Erie which has an average level of 572 feet above mean sea level. Metropolitan Cleveland has a lake frontage of 31 miles and it reaches inland about 16 miles with a total area of about 250 square miles or a little more than half of Cuyahoga County. The surrounding terrain is mostly level except for a ridge on the southeastern edge of the city rising some 500 feet above the shore terrain. A rather deep but narrow North-South valley, in which flows the Cuyahoga River, approximately bisects the City of Cleveland. The climate is mainly continental in character but with strong modifying influences by Lake Erie. Otherwise, local topography is of minor importance as a determining factor.

The Weather Bureau Office is located at Cleveland Hopkins Airport, 10 miles southwest of the downtown business area and about 5 miles south of the lake shoreline where the official weather records have been maintained since 1941. Records since 1871 were previously made in downtown Cleveland as designated on the last page of this publication. Comparative records show that daytime temperatures average from 2 to 4 degrees higher at the Airport except during the winter months and that nighttime temperatures average from 2 to 4 degrees lower at the Airport during all seasons. Differences as much as 12° have occurred on some individual days. Precipitation differences between the two locations are slight.

In the winter Cleveland lies in the path of many cold air masses advancing south and east from Canada but the accompanying low temperatures are usually mitigated by such air having to cross the relatively warm waters of the lake. Such a combination, however, despite the ameliorating temperature effects of the lake, results in an excessive amount of winter cloudiness and quite frequent snows. The persistence of snow cover is seldom great, though, since the temperature rarely remains freezing for any considerable length of time.

Spring is generally a brief and rather sporadic transition season, the noticeable change being rather from wintry to summerlike conditions in a relatively short period. The possibility of a temperature of 32° or below remains until the middle of May, although the average latest date is April 21.

In summer, Lake Erie plays its winter role in reverse; when sections further inland are experiencing heat waves, the "lake breeze" frequently sets in locally and sections near the shore enjoy its cooling effect which is noticeable for a considerable distance inland.

Autumn is usually the most pleasant season of the year with mild sunny weather often being prolonged into November and even December. The average date of the first temperature of 32° or below is November 2, and the average growing season is 195 days, considerably longer than for most locations in this latitude, or in Ohio.

Precipitation is moderate in amount and evenly distributed throughout the year, while humidity is moderately high. During excessively heavy rains in summer thunderstorms maximum falls have reached 1.20 inches in 10 minutes; 2.09 inches in one hour; 3.02 inches in two hours and 4.97 inches in 24 hours. Much heavier falls have occurred in the elevated sections of the eastern suburbs. Although tornadoes are fairly common in Ohio, only three have occurred in Cleveland during 84 years of record, the most severe of which occurred on June 8, 1953. Most damaging winds occur during summer thundersqualls.

LATITUDE        41° 24' N
LONGITUDE       81° 51' W
ELEVATION (ground) 787 feet

METEOROLOGICAL DATA FOR THE CURRENT YEAR

CLEVELAND, OHIO
CLEVELAND HOPKINS AIRPORT
1956

## Meteorological Data for the Current Year

| Month | Temperature Averages Daily maximum | Daily minimum | Monthly | Extremes Highest | Date | Lowest | Date | Degree days | Precipitation Total | Greatest in 24 hrs. | Date | Snow, Sleet Total | Greatest in 24 hrs. | Date | Relative humidity 1:30 a.m. EST | 7:30 a.m. EST | 1:30 p.m. EST | 7:30 p.m. EST | Wind Average hourly speed | Prevailing direction | Fastest mile Speed | Direction | Date | Percent of possible sunshine | Average sky cover sunrise to sunset | Number of days Sunrise to sunset Clear | Partly cloudy | Cloudy | Precipitation .01 inch or more | Snow, Sleet 1.0 inch or more | Thunderstorms | Heavy fog | Temperatures Maximum 90° and above | 32° and below | Minimum 32° and below | Zero and below |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan.  | 33.1 | 22.1 | 27.6 | 48 | 6   | 6  | 23   | 1151 | 2.75 | 0.92 | 30    | 14.1 | 7.6 | 30    | 83 | 83 | 75 | 82 | 12.4 | NNW | 30 | N   | 8  | 22 | 8.0 | 3  | 7  | 21 | 15 | 3 | 0 | 4 | 0 | 15 | 30 | 0 |
| Feb.  | 38.3 | 24.3 | 31.3 | 57 | 25  | 8  | 1    | 967  | 3.23 | 0.92 | 24-25 | 8.9  | 3.5 | 27-28 | 79 | 80 | 74 | 78 | 14.4 | WNW | 65 | W   | 25 | 31 | 7.7 | 2  | 7  | 20 | 21 | 3 | 1 | 6 | 0 | 6  | 28 | 0 |
| Mar.  | 44.3 | 27.6 | 36.0 | 66 | 7+  | 13 | 17   | 891  | 4.60 | 1.15 | 6     | 10.7 | 4.4 | 16    | 78 | 79 | 63 | 72 | 15.6 | S   | 61 | SW  | 1  | 44 | 6.9 | 7  | 7  | 17 | 15 | 2 | 2 | 2 | 0 | 4  | 26 | 0 |
| Apr.  | 55.1 | 36.7 | 45.9 | 76 | 27  | 28 | 9+   | 566  | 3.61 | 1.06 | 3- 4  | 2.0  | 1.7 | 7- 8  | 75 | 80 | 55 | 66 | 15.2 | S   | 47 | SW  | 4  | 48 | 7.7 | 4  | 7  | 19 | 21 | 1 | 7 | 1 | 0 | 0  | 11 | 0 |
| May   | 67.9 | 47.6 | 57.8 | 86 | 30  | 35 | 25   | 265  | 5.49 | 1.76 | 11-12 | T    | T   | 16    | 76 | 76 | 59 | 65 | 14.3 | S   | 57 | NW  | 12 | 54 | 7.1 | 3  | 10 | 18 | 14 | 0 | 9 | 0 | 0 | 0  | 0  | 0 |
| June  | 78.6 | 58.7 | 68.7 | 92 | 14+ | 45 | 2+   | 69   | 4.14 | 1.66 | 23-24 | 0.0  | 0.0 |       | 84 | 81 | 58 | 66 | 11.1 | S   | 43 | SW  | 13 | 53 | 5.9 | 8  | 11 | 11 | 14 | 0 | 9 | 2 | 5 | 0  | 0  | 0 |
| July  | 80.2 | 63.2 | 71.7 | 93 | 1   | 51 | 30   | 4    | 3.74 | 1.41 | 8- 9  | 0.0  | 0.0 |       | 83 | 82 | 60 | 63 | 11.8 | SSW | 65 | W   | 8  | 49 | 7.0 | 1  | 18 | 12 | 15 | 0 | 8 | 0 | 3 | 0  | 0  | 0 |
| Aug.  | 80.4 | 62.9 | 71.7 | 89 | 31+ | 51 | 25   | 13   | 5.14 | 1.17 | 5     | 0.0  | 0.0 |       | 82 | 84 | 60 | 70 | 11.4 | W   | 61 | W   | 18 | 53 | 6.4 | 7  | 10 | 14 | 13 | 0 | 8 | 0 | 0 | 0  | 0  | 0 |
| Sept. | 71.0 | 51.3 | 61.2 | 89 | 5   | 35 | 21   | 159  | 1.56 | 0.62 | 31- 1 | 0.0  | 0.0 |       | 80 | 80 | 53 | 68 | 11.1 | S   | 30 | NW  | 20 | 56 | 5.6 | 8  | 10 | 12 | 8  | 0 | 4 | 0 | 0 | 0  | 1  | 0 |
| Oct.  | 69.2 | 48.2 | 58.7 | 81 | 15+ | 31 | 11   | 198  | 0.85 | 0.59 | 6- 7  | 0.0  | 0.0 |       | 75 | 81 | 52 | 67 | 11.9 | SSE | 38 | SW  | 6  | 68 | 4.9 | 11 | 11 | 9  | 5  | 0 | 1 | 1 | 0 | 0  | 0  | 0 |
| Nov.  | 51.4 | 33.9 | 42.7 | 74 | 3   | 15 | 24   | 665  | 1.14 | 0.48 | 21    | 7.4  | 3.4 | 22-23 | 75 | 79 | 58 | 72 | 14.8 | S   | 50 | SW  | 21 | 39 | 7.0 | 5  | 8  | 17 | 15 | 3 | 2 | 5 | 0 | 4  | 15 | 0 |
| Dec.  | 44.5 | 31.5 | 38.0 | 68 | 6   | 15 | 30   | 828  | 2.70 | 0.89 | 6- 7  | 11.4 | 3.7 | 9     | 86 | 87 | 79 | 82 | 15.1 | SSW | 34 | NW  | 30 | 17 | 9.0 | 1  | 3  | 27 | 20 | 4 | 1 | 3 | 0 | 2  | 18 | 0 |
| Year  | 59.5 | 42.3 | 50.9 | 93 | July 1 | 6 | Jan. 23 | 57.6 | 38.95 | 1.76 | May 11-12 | 54.5 | 7.6 | Jan. 30 | 80 | 81 | 62 | 71 | 13.3 | S | 65 | W | July 8+ | 45 | 6.9 | 60 | 109 | 197 | 176 | 1t | 52 | 24 | 8 | 31 | 129 | 0 |

# NORMALS, MEANS, AND EXTREMES

| Month | Temperature Normal Daily maximum | Daily minimum | Monthly | Extremes Record highest | Year | Record lowest | Year | Normal degree days | Precipitation Normal total | Maximum monthly | Year | Minimum monthly | Year | Maximum in 24 hrs. | Year | Snow, Sleet Mean total | Maximum monthly | Year | Maximum in 24 hrs. | Year | Relative humidity 1:30 a.m. EST | 7:30 a.m. EST | 1:30 p.m. EST | 7:30 p.m. EST | Wind Mean hourly speed | Prevailing direction | Fastest mile Speed | Direction | Year | Pct. of possible sunshine | Mean sky cover sunrise to sunset | Mean number of days Sunrise to sunset Clear | Partly cloudy | Cloudy | Precipitation .01 inch or more | Snow, Sleet 1.0 inch or more | Thunderstorms | Heavy fog | Temperatures Max. 90° and above | 32° and below | Min. 32° and below | 0° and below |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (a) | (b) | (b) | (b) | 16 | | 16 | | (b) | (b) | 15 | | 15 | | 15 | | 15 | 15 | | 15 | | 15 | 15 | 15 | 15 | 15 | | 15 | 15 | 15 | 15 | 7 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| J | 36.0 | 20.9 | 28.5 | 73 | 1950 | - 9 | 1942 | 1132 | 2.38 | 7.01 | 1950 | 0.79 | 1946 | 1.74 | 1952 | 10.4 | 18.7 | 1945 | 9.3 | 1952 | 80 | 81 | 72 | 79 | 12.3 | S | 59 | SW | 1950 | 28 | 8.1 | 3 | 6 | 22 | 16 | 4 | * | 2 | 0 | 12 | 27 | 1 |
| F | 36.4 | 20.8 | 28.6 | 68 | 1944 | - 8 | 1951+ | 1053 | 2.28 | 4.64 | 1950 | 0.75 | 1947 | 1.77 | 1950 | 10.2 | 20.7 | 1942 | 7.5 | 1944 | 79 | 81 | 68 | 76 | 12.4 | S | 65 | W | 1956+ | 35 | 7.7 | 3 | 6 | 19 | 15 | 4 | * | 2 | 0 | 9 | 24 | 1 |
| M | 45.2 | 28.3 | 36.8 | 83 | 1945 | - 5 | 1948 | 874 | 2.89 | 6.07 | 1954 | 1.70 | 1946 | 2.76 | 1948 | 11.1 | 26.3 | 1954 | 14.9 | 1954 | 77 | 80 | 62 | 72 | 12.9 | WNW | 74 | W | 1948 | 45 | 7.2 | 5 | 7 | 19 | 16 | 4 | 2 | 1 | 0 | 6 | 21 | * |
| A | 57.1 | 37.5 | 47.3 | 88 | 1942 | 19 | 1954 | 531 | 2.73 | 5.90 | 1950 | 1.18 | 1946 | 1.92 | 1950 | 2.4 | 14.3 | 1943 | 7.4 | 1943 | 76 | 77 | 55 | 64 | 11.9 | SW | 65 | W | 1951 | 51 | 6.9 | 5 | 8 | 17 | 15 | 1 | 4 | 2 | 0 | * | 8 | 0 |
| M | 69.9 | 48.2 | 59.1 | 92 | 1944 | 29 | 1947 | 223 | 2.73 | 6.04 | 1947 | 1.04 | 1954 | 1.71 | 1949 | 0.0 | T | 1954+ | T | 1954+ | 79 | 76 | 54 | 66 | 10.3 | S | 57 | NW | 1956 | 57 | 6.6 | 5 | 11 | 15 | 14 | 0 | 6 | 1 | * | 0 | * | 0 |
| J | 80.4 | 58.3 | 69.4 | 101 | 1944 | 38 | 1945 | 46 | 3.05 | 6.07 | 1947 | 1.38 | 1954 | 2.79 | 1946 | 0.0 | 0.0 | | 0.0 | | 82 | 78 | 54 | 60 | 9.2 | S | 56 | S | 1953+ | 65 | 5.9 | 6 | 13 | 11 | 11 | 0 | 8 | 1 | 5 | 0 | 0 | 0 |
| J | 84.7 | 62.6 | 73.7 | 103 | 1944 | 46 | 1946+ | 19 | 3.04 | 5.37 | 1943 | 1.23 | 1952 | 2.73 | 1950 | 0.0 | 0.0 | | 0.0 | | 81 | 79 | 52 | 58 | 8.7 | S | 65 | W | 1956 | 70 | 5.3 | 10 | 12 | 9 | 10 | 0 | 7 | 1 | 8 | 0 | 0 | 0 |
| A | 82.7 | 61.1 | 71.9 | 102 | 1948 | 44 | 1952 | 10 | 2.64 | 5.19 | 1947 | 1.61 | 1945 | 3.07 | 1947 | 0.0 | 0.0 | | 0.0 | | 83 | 82 | 53 | 63 | 8.4 | S | 61 | W | 1956 | 67 | 5.2 | 10 | 13 | 8 | 9 | 0 | 6 | 1 | 6 | 0 | * | 0 |
| S | 75.8 | 55.1 | 65.5 | 101 | 1953 | 32 | 1942 | 75 | 3.13 | 6.37 | 1945 | 1.57 | 1953 | 1.85 | 1945 | 0.0 | 0.0 | | 0.0 | | 81 | 82 | 52 | 67 | 9.4 | S | 45 | S | 1953+ | 63 | 5.3 | 10 | 10 | 10 | 9 | 0 | 4 | * | 2 | 0 | * | 0 |
| O | 64.3 | 44.5 | 54.4 | 90 | 1946 | 25 | 1942 | 340 | 2.42 | 9.50 | 1954 | 0.61 | 1952 | 3.44 | 1954 | 0.5 | 6.4 | 1954 | 6.1 | 1954 | 78 | 82 | 55 | 70 | 10.1 | S | 43 | W | 1946 | 57 | 5.5 | 11 | 8 | 12 | 10 | * | 2 | 1 | * | 0 | 1 | 0 |
| N | 49.2 | 34.2 | 41.7 | 82 | 1950 | 7 | 1950 | 699 | 2.66 | 6.44 | 1950 | 1.14 | 1956 | 1.94 | 1950 | 6.7 | 22.3 | 1950 | 15.0 | 1950 | 77 | 80 | 64 | 73 | 12.6 | S | 59 | W | 1948 | 33 | 7.6 | 3 | 7 | 20 | 15 | 2 | 1 | 1 | 0 | 2 | 14 | 0 |
| D | 37.5 | 24.3 | 30.9 | 69 | 1941 | - 9 | 1951 | 1057 | 2.29 | 5.60 | 1951 | 0.96 | 1955 | 1.13 | 1953 | 11.3 | 28.9 | 1944 | 8.7 | 1944 | 79 | 80 | 70 | 77 | 12.6 | SW | 49 | W | 1949 | 28 | 8.0 | 3 | 6 | 22 | 16 | 5 | * | 1 | 0 | 10 | 25 | 1 |
| Year | 59.9 | 41.3 | 50.6 | 103 | July 1941 | - 9 | Dec. 1951+ | 6006 | 32.24 | 9.50 | Oct. 1954 | 0.61 | Oct. 1952 | 3.44 | Oct. 1954 | 52.6 | 28.9 | Dec. 1944 | 15.0 | Nov. 1950 | 79 | 80 | 59 | 69 | 10.9 | S | 74 | W | Mar. 1948 | 50 | 6.6 | 74 | 107 | 184 | 156 | 20 | 39 | 14 | 21 | 39 | 120 | 3 |

REFERENCE NOTES

(a) Length of record, years.
(b) Normal values are based on the period 1921-1950, and are means adjusted to represent observations taken at the present standard location.
* Less than one half.
- No record.
† Airport data.
‡ City Office data.
+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.

Means and extremes in the above table are from the last comparable locations. Extremes listed may have

Record mean values at the end of the Average Temperature and Total Precipitation tables are long-term means based on the period of record beginning in 1871. Values have not been corrected for changes in instrument location listed in the Station Location Table.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation and snowfall in inches; wind movement in miles per hour; and relative humidity in percent.

Sky cover is expressed in a range of 0 for no clouds or obstructions to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3 tenths; partly cloudy days on 4-7 tenths and cloudy days on 8-10 tenths. Degree days are based on a daily average of 65° F.

Data for earlier years may be obtained by contacting the Weather Bureau Office in city for which this summary was issued.

Heavy fog in the Means and Extremes Table includes data referred to at various times in the past as "Dense" or "Thick". The upper visibility limit for heavy fog is 1/4 mile.

Below zero temperatures are preceded by a minus sign.

## AVERAGE TEMPERATURE

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | An'l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1910 | 26.6 | 23.8 | 44.6 | 48.2 | 54.0 | 63.6 | 72.4 | 70.0 | 64.6 | 56.1 | 37.1 | 25.6 | 48.9 |
| 1911 | 30.6 | 31.8 | 34.3 | 45.6 | 64.4 | 69.3 | 72.8 | 70.7 | 65.0 | 51.8 | 37.4 | 36.6 | 50.9 |
| 1912 | 15.8 | 21.1 | 29.0 | 48.0 | 60.0 | 64.8 | 71.0 | 67.6 | 66.6 | 55.8 | 43.6 | 33.8 | 48.1 |
| 1913 | 35.3 | 24.4 | 38.0 | 47.4 | 57.8 | 68.2 | 71.8 | 71.2 | 62.6 | 53.9 | 44.6 | 35.4 | 50.9 |
| 1914 | 32.0 | 19.8 | 34.0 | 45.4 | 60.0 | 68.3 | 71.8 | 71.8 | 62.6 | 56.8 | 41.8 | 27.0 | 49.3 |
| 1915 | 26.0 | 32.8 | 30.4 | 51.8 | 54.2 | 63.9 | 69.8 | 67.1 | 67.0 | 55.4 | 43.9 | 30.8 | 49.4 |
| 1916 | 34.8 | 23.0 | 30.1 | 45.9 | 58.0 | 62.8 | 75.6 | 72.4 | 63.8 | 52.7 | 42.3 | 29.9 | 49.2 |
| 1917 | 27.3 | 21.3 | 37.3 | 45.4 | 51.2 | 64.8 | 71.4 | 69.8 | 60.5 | 46.5 | 38.2 | 22.4 | 46.3 |
| 1918 | 15.0 | 28.2 | 40.2 | 45.8 | 64.4 | 67.4 | 70.3 | 74.5 | 58.2 | 56.0 | 43.2 | 38.7 | 50.2 |
| 1919 | 32.6 | 31.3 | 37.1 | 47.0 | 56.4 | 73.4 | 73.2 | 69.8 | 66.4 | 58.8 | 41.1 | 25.7 | 51.1 |
| 1920 | 19.0 | 24.5 | 40.0 | 42.6 | 55.6 | 67.4 | 69.2 | 69.4 | 65.8 | 59.5 | 41.2 | 33.6 | 49.0 |
| 1921 | 32.0 | 32.1 | 45.6 | 53.9 | 59.8 | 69.8 | 76.8 | 69.3 | 69.0 | 53.6 | 42.0 | 32.6 | 53.0 |
| 1922 | 25.6 | 31.7 | 38.8 | 48.6 | 61.3 | 68.6 | 71.6 | 69.6 | 67.0 | 55.4 | 44.2 | 31.8 | 51.2 |
| 1923 | 30.2 | 23.8 | 34.8 | 45.8 | 54.5 | 70.8 | 71.2 | 69.0 | 64.7 | 52.2 | 42.0 | 40.4 | 50.0 |
| 1924 | 24.0 | 25.4 | 33.0 | 45.3 | 52.4 | 64.8 | 69.2 | 70.0 | 60.4 | 55.6 | 41.2 | 27.6 | 47.4 |
| 1925 | 25.6 | 33.8 | 39.0 | 50.6 | 53.6 | 71.6 | 70.8 | 70.9 | 67.2 | 45.2 | 39.6 | 28.9 | 49.7 |
| 1926 | 27.2 | 28.1 | 30.8 | 41.5 | 56.9 | 64.3 | 71.6 | 72.2 | 65.1 | 52.2 | 40.0 | 28.0 | 48.2 |
| 1927 | 26.6 | 33.7 | 40.3 | 47.2 | 57.2 | 63.2 | 71.6 | 65.4 | 67.6 | 57.6 | 46.6 | 32.2 | 50.8 |
| 1928 | 28.4 | 29.2 | 35.4 | 44.2 | 57.0 | 64.0 | 73.1 | 72.8 | 61.6 | 57.4 | 44.2 | 35.2 | 50.2 |
| 1929 | 25.0 | 25.2 | 43.6 | 50.6 | 56.4 | 65.8 | 72.5 | 68.0 | 65.6 | 52.2 | 39.4 | 32.0 | 49.7 |
| 1930 | 27.6 | 37.5 | 35.7 | 48.3 | 61.8 | 70.2 | 73.6 | 71.1 | 67.2 | 51.8 | 44.8 | 32.0 | 51.8 |
| 1931 | 31.6 | 33.0 | 33.9 | 47.4 | 57.5 | 68.6 | 76.3 | 72.3 | 69.8 | 58.5 | 51.2 | 40.2 | 53.4 |
| 1932 | 40.2 | 35.8 | 31.0 | 44.0 | 58.7 | 69.1 | 72.0 | 72.7 | 66.2 | 55.1 | 40.4 | 33.9 | 51.6 |
| 1933 | 38.0 | 31.2 | 35.8 | 49.8 | 60.8 | 73.0 | 74.5 | 71.4 | 68.2 | 53.4 | 39.0 | 33.6 | 52.4 |
| 1934 | 33.1 | 17.2 | 32.2 | 47.3 | 62.6 | 73.6 | 76.0 | 70.0 | 67.1 | 53.7 | 47.0 | 31.0 | 50.9 |
| 1935 | 28.9 | 28.6 | 43.2 | 44.6 | 53.4 | 66.0 | 76.2 | 72.0 | 63.7 | 54.0 | 43.6 | 26.9 | 50.1 |
| 1936 | 23.8 | 21.0 | 39.5 | 44.3 | 62.6 | 66.2 | 74.6 | 73.8 | 68.0 | 54.2 | 39.0 | 36.4 | 50.3 |
| 1937 | 35.8 | 30.9 | 31.7 | 47.1 | 59.4 | 67.5 | 73.2 | 74.4 | 63.3 | 50.8 | 40.6 | 30.1 | 50.4 |
| 1938 | 29.0 | 33.8 | 43.6 | 50.3 | 59.4 | 68.0 | 73.6 | 75.0 | 63.4 | 56.4 | 46.6 | 33.5 | 52.7 |
| 1939 | 32.5 | 32.0 | 37.5 | 45.5 | 61.6 | 71.2 | 73.2 | 73.2 | 67.4 | 56.2 | 41.8 | 35.9 | 52.3 |
| 1940 | 19.6 | 28.5 | 31.0 | 43.2 | 56.0 | 69.0 | 73.8 | 71.6 | 63.0 | 54.0 | 41.8 | 36.7 | 49.9 |
| 1941 | 29.6 | 26.6 | 30.5 | 52.0 | 62.2 | 70.6 | 75.2 | 70.7 | 67.8 | 56.4 | 43.2 | 36.9 | 51.8 |
| 1942 | 27.3 | 24.2 | 39.2 | 52.6 | 62.0 | 70.6 | 73.1 | 71.0 | 64.1 | 54.7 | 42.6 | 26.8 | 50.7 |
| 1943 | 26.8 | 29.0 | 36.1 | 43.2 | 58.1 | 73.7 | 74.0 | 71.8 | 62.6 | 51.8 | 39.3 | 28.4 | 49.6 |
| 1944 | 32.0 | 29.5 | 33.8 | 44.9 | 65.6 | 72.4 | 74.0 | 74.1 | 65.0 | 53.0 | 43.2 | 25.6 | 51.1 |
| 1945 | 18.8 | 29.4 | 48.6 | 52.0 | 54.1 | 66.6 | 71.7 | 72.0 | 66.9 | 51.8 | 43.2 | 25.2 | 50.0 |
| 1946 | 29.4 | 30.6 | 49.5 | 48.4 | 57.7 | 68.2 | 72.3 | 68.0 | 66.8 | 58.6 | 46.0 | 34.0 | 52.5 |
| 1947 | 32.7 | 22.6 | 31.8 | 46.8 | 56.2 | 67.0 | 70.0 | 77.8 | 66.6 | 61.4 | 38.2 | 31.5 | 50.2 |
| 1948 | 20.0 | 28.6 | 38.9 | 52.6 | 56.6 | 68.3 | 74.4 | 72.8 | 66.4 | 50.1 | 47.0 | 33.8 | 50.7 |
| 1949 | 34.8 | 34.2 | 37.1 | 47.4 | 61.8 | 73.9 | 77.6 | 73.4 | 60.0 | 59.2 | 41.3 | 34.2 | 52.9 |
| 1950 | 36.8 | 29.2 | 33.0 | 42.9 | 60.7 | 68.1 | 70.9 | 70.6 | 64.5 | 57.6 | 37.4 | 25.1 | 49.7 |
| 1951 | 29.9 | 29.9 | 38.1 | 46.8 | 60.9 | 69.1 | 73.6 | 70.3 | 62.9 | 57.8 | 35.7 | 30.4 | 50.5 |
| 1952 | 32.2 | 32.1 | 36.7 | 50.1 | 58.0 | 73.3 | 76.5 | 72.0 | 65.6 | 49.2 | 44.0 | 34.9 | 52.1 |
| 1953 | 33.6 | 33.7 | 40.0 | 45.5 | 61.9 | 71.5 | 74.4 | 73.5 | 65.6 | 57.4 | 45.2 | 34.1 | 53.0 |
| 1954 | 28.5 | 36.3 | 35.1 | 54.6 | 57.4 | 72.1 | 73.1 | 71.3 | 67.8 | 56.2 | 42.6 | 32.1 | 52.3 |
| 1955 | 26.9 | 30.8 | 38.6 | 55.9 | 62.7 | 67.9 | 79.1 | 76.1 | 67.2 | 54.8 | 38.7 | 28.4 | 52.3 |
| 1956 | 27.6 | 31.3 | 36.0 | 45.9 | 57.8 | 68.7 | 71.7 | 71.7 | 61.2 | 58.7 | 42.7 | 38.0 | 50.9 |
| RECORD MEAN TEMP | 27.8 | 27.9 | 35.9 | 46.7 | 58.2 | 68.0 | 72.4 | 70.9 | 64.7 | 53.8 | 41.4 | 31.4 | 49.9 |
| MAX | 34.6 | 35.0 | 43.4 | 55.2 | 66.6 | 76.2 | 80.4 | 78.5 | 72.8 | 61.8 | 48.0 | 37.5 | 57.5 |
| MIN | 20.9 | 20.7 | 28.3 | 38.6 | 49.8 | 59.7 | 64.4 | 63.3 | 56.5 | 45.9 | 34.8 | 25.3 | 42.4 |

## TOTAL PRECIPITATION

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1910 | 4.29 | 3.98 | 0.41 | 3.34 | 4.22 | 2.01 | 0.94 | 1.08 | 4.09 | 3.79 | 3.08 | 2.42 | 33.65 |
| 1911 | 2.80 | 1.81 | 1.54 | 3.42 | 1.97 | 2.88 | 1.71 | 5.18 | 4.67 | 5.16 | 3.56 | 2.67 | 37.37 |
| 1912 | 3.13 | 2.04 | 2.14 | 3.68 | 2.55 | 1.96 | 8.13 | 4.54 | 2.39 | 3.16 | 0.89 | 1.33 | 35.94 |
| 1913 | 5.66 | 1.66 | 2.10 | 2.47 | 2.84 | 1.33 | 4.85 | 2.26 | 2.10 | 3.96 | 3.98 | 1.57 | 40.80 |
| 1914 | 1.61 | 1.84 | 2.10 | 4.28 | 4.09 | 2.80 | 1.00 | 3.93 | 1.16 | 2.39 | 1.34 | 1.57 | 28.11 |
| 1915 | 2.52 | 2.02 | 0.92 | 0.65 | 3.13 | 2.03 | 4.73 | 1.47 | 4.23 | 1.77 | 1.84 | 1.75 | 27.06 |
| 1916 | 2.40 | 1.52 | 2.29 | 2.43 | 2.04 | 1.98 | 2.48 | 1.36 | 2.84 | 2.19 | 2.35 | 2.06 | 25.94 |
| 1917 | 2.55 | 1.22 | 2.14 | 3.24 | 2.89 | 3.59 | 3.60 | 4.65 | 2.74 | 5.09 | 1.37 | 1.41 | 34.49 |
| 1918 | 2.60 | 1.48 | 2.38 | 2.55 | 4.02 | 1.83 | 1.08 | 2.47 | 3.78 | 2.11 | 1.77 | 1.58 | 27.65 |
| 1919 | 0.63 | 1.11 | 2.67 | 2.96 | 4.15 | 1.24 | 2.46 | 7.19 | 1.79 | 3.17 | 1.31 | 1.32 | 30.00 |
| 1920 | 1.96 | 1.12 | 1.49 | 5.01 | 1.12 | 5.28 | 3.32 | 2.33 | 1.85 | 2.57 | 2.25 | 1.64 | 29.94 |
| 1921 | 1.53 | 2.19 | 4.39 | 2.58 | 1.51 | 2.38 | 3.52 | 3.32 | 2.77 | 2.91 | 3.93 | 1.75 | 32.78 |
| 1922 | 1.52 | 1.31 | 4.02 | 2.10 | 2.42 | 2.66 | 3.98 | 1.20 | 1.60 | 1.58 | 1.37 | 2.45 | 26.21 |
| 1923 | 2.61 | 1.39 | 1.89 | 2.21 | 2.91 | 1.49 | 2.09 | 3.97 | 3.32 | 1.73 | 2.64 | 4.50 | 30.75 |
| 1924 | 3.38 | 1.50 | 1.65 | 2.85 | 2.62 | 5.73 | 3.10 | 0.90 | 6.08 | 0.68 | 0.91 | 3.58 | 32.98 |
| 1925 | 1.49 | 2.42 | 2.95 | 1.37 | 2.24 | 1.81 | 4.52 | 1.42 | 5.62 | 3.38 | 3.60 | 1.45 | 32.27 |
| 1926 | 1.78 | 2.53 | 1.95 | 3.44 | 1.48 | 2.58 | 2.86 | 4.79 | 9.10 | 6.75 | 2.56 | 2.01 | 41.83 |
| 1927 | 1.51 | 2.83 | 3.62 | 1.75 | 3.44 | 1.63 | 3.11 | 0.70 | 2.74 | 1.85 | 7.19 | 3.91 | 34.28 |
| 1928 | 2.03 | 2.36 | 2.08 | 2.15 | 2.04 | 4.69 | 6.94 | 1.15 | 1.21 | 3.28 | 3.25 | 1.41 | 32.59 |
| 1929 | 5.23 | 1.98 | 3.54 | 5.26 | 3.41 | 4.17 | 6.30 | 1.98 | 1.62 | 2.68 | 2.92 | 2.68 | 41.77 |
| 1930 | 5.01 | 2.45 | 2.68 | 2.08 | 1.87 | 1.84 | 0.74 | 1.84 | 1.69 | 1.52 | 2.27 | 0.89 | 24.88 |
| 1931 | 1.47 | 1.29 | 1.51 | 3.46 | 2.36 | 3.51 | 2.17 | 2.75 | 3.93 | 1.76 | 2.48 | 2.65 | 29.34 |
| 1932 | 3.46 | 1.10 | 3.39 | 2.09 | 3.71 | 1.88 | 2.42 | 4.31 | 1.45 | 3.06 | 2.63 | 3.77 | 33.27 |
| 1933 | 1.40 | 1.99 | 3.51 | 2.42 | 2.86 | 0.39 | 1.26 | 1.98 | 2.73 | 0.97 | 3.06 | 1.60 | 24.17 |
| 1934 | 1.58 | 1.02 | 2.43 | 2.43 | 0.58 | 2.26 | 2.70 | 2.46 | 2.12 | 0.99 | 1.40 | 1.84 | 21.81 |
| 1935 | 2.15 | 3.26 | 2.06 | 1.34 | 1.87 | 1.45 | 2.61 | 5.70 | 2.78 | 1.69 | 1.71 | 2.83 | 29.45 |
| 1936 | 1.41 | 2.19 | 3.28 | 2.18 | 2.05 | 2.32 | 2.23 | 2.92 | 2.75 | 1.78 | 3.32 | 1.64 | 28.07 |
| 1937 | 6.58 | 1.74 | 2.00 | 3.33 | 2.27 | 6.64 | 4.87 | 2.10 | 0.99 | 3.36 | 1.47 | 2.52 | 37.87 |
| 1938 | 1.07 | 3.01 | 3.52 | 2.70 | 2.69 | 2.45 | 3.28 | 0.81 | 6.17 | 0.70 | 3.31 | 1.72 | 31.43 |
| 1939 | 2.43 | 2.99 | 2.77 | 2.80 | 1.48 | 3.25 | 1.53 | 0.72 | 2.93 | 1.84 | 1.24 | 1.17 | 25.15 |
| 1940 | 1.35 | 3.24 | 2.59 | 3.95 | 3.60 | 3.68 | 0.96 | 3.82 | 1.83 | 1.39 | 2.19 | 4.07 | 32.67 |
| 1941 | 1.85 | 1.35 | 1.28 | 1.13 | 2.41 | 2.79 | 3.34 | 3.23 | 1.49 | 3.22 | 1.11 | 1.76 | 24.96 |
| 1942 | 1.79 | 3.98 | 3.47 | 2.80 | 3.70 | 4.09 | 4.09 | 3.50 | 3.08 | 2.81 | 3.30 | 2.94 | 39.55 |
| 1943 | 1.88 | 2.50 | 2.95 | 3.43 | 4.64 | 4.02 | 5.37 | 2.50 | 3.53 | 3.40 | 1.21 | 1.02 | 36.45 |
| 1944 | 1.30 | 1.66 | 3.12 | 3.86 | 3.26 | 3.04 | 1.29 | 3.68 | 3.50 | 0.94 | 1.85 | 2.43 | 29.93 |
| 1945 | 1.21 | 1.67 | 4.13 | 3.66 | 3.61 | 4.41 | 3.11 | 1.61 | 6.37 | 4.20 | 1.86 | 1.36 | 37.22 |
| 1946 | 0.79 | 1.81 | 1.70 | 1.18 | 5.06 | 5.14 | 1.26 | 1.71 | 1.88 | 3.51 | 2.08 | 1.85 | 27.97 |
| 1947 | 4.44 | 0.75 | 4.15 | 4.38 | 6.04 | 6.07 | 4.69 | 5.19 | 2.51 | 1.92 | 2.01 | 1.84 | 43.99 |
| 1948 | 1.66 | 2.19 | 5.81 | 3.24 | 4.39 | 3.95 | 3.73 | 4.47 | 2.49 | 2.86 | 3.46 | 2.71 | 40.96 |
| 1949 | 3.61 | 2.39 | 2.66 | 2.78 | 4.18 | 1.63 | 4.21 | 3.59 | 2.87 | 1.04 | 2.73 | 3.30 | 34.99 |
| 1950 | 7.01 | 4.64 | 4.27 | 5.90 | 3.22 | 3.77 | 5.15 | 1.81 | 3.84 | 1.73 | 6.44 | 2.60 | 50.38 |
| 1951 | 3.72 | 3.79 | 4.80 | 2.69 | 2.60 | 3.25 | 3.47 | 2.43 | 4.49 | 1.53 | 5.85 | 5.60 | 44.22 |
| 1952 | 5.02 | 2.19 | 3.29 | 3.81 | 2.74 | 1.48 | 1.23 | 1.98 | 3.02 | 0.61 | 2.49 | 2.70 | 30.56 |
| 1953 | 4.04 | 1.21 | 2.05 | 2.82 | 4.00 | 3.30 | 3.87 | 1.57 | 1.28 | 2.32 | 2.62 | 2.62 | 32.16 |
| 1954 | 3.12 | 2.88 | 6.07 | 5.36 | 1.04 | 1.38 | 1.49 | 3.16 | 1.98 | 9.50 | 1.34 | 2.33 | 39.65 |
| 1955 | 2.22 | 2.69 | 5.59 | 3.72 | 5.00 | 2.68 | 2.50 | 3.82 | 1.61 | 5.88 | 2.87 | 0.96 | 39.54 |
| 1956 | 2.75 | 3.23 | 4.60 | 3.61 | 5.49 | 4.14 | 3.74 | 5.14 | 1.56 | 0.85 | 1.14 | 2.70 | 38.95 |
| RECORD MEAN | 2.61 | 2.40 | 2.94 | 2.67 | 3.12 | 3.24 | 3.36 | 2.92 | 3.13 | 2.67 | 2.57 | 2.39 | 34.02 |

DOWNTOWN CLEVELAND – 2605 EUCLID AVENUE PRIOR TO MARCH 1955, THEREAFTER FROM AIRPORT

## MONTHLY AND SEASONAL DEGREE DAYS

| Season | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1909–10 | 10 | 18 | 142 | 506 | 522 | 1252 | 1190 | 1154 | 644 | 504 | 348 | 124 | 6414 |
| 1910–11 | 2 | 18 | 71 | 297 | 837 | 1221 | 1066 | 930 | 952 | 582 | 150 | 16 | 6142 |
| 1911–12 | 8 | 21 | 69 | 406 | 826 | 880 | 1524 | 1274 | 1116 | 510 | 187 | 76 | 6987 |
| 1912–13 | 11 | 43 | 82 | 293 | 663 | 967 | 921 | 1137 | 837 | 517 | 255 | 86 | 5812 |
| 1913–14 | 8 | 9 | 145 | 373 | 632 | 910 | 1023 | 1266 | 961 | 594 | 218 | 58 | 6205 |
| 1914–15 | 5 | 4 | 131 | 268 | 719 | 1172 | 1209 | 902 | 1073 | 439 | 340 | 80 | 6342 |
| 1915–16 | 8 | 42 | 89 | 306 | 654 | 1061 | 936 | 667 | 1082 | 564 | 233 | 91 | 5733 |
| 1916–17 | 1 | 9 | 125 | 390 | 681 | 1113 | 1173 | 1223 | 861 | 595 | 438 | 65 | 6674 |
| 1917–18 | 18 | 18 | 152 | 572 | 802 | 1322 | 1550 | 1031 | 770 | 575 | 118 | 35 | 6963 |
| 1918–19 | 21 | 1 | 219 | 283 | 654 | 820 | 1005 | 945 | 864 | 538 | 280 | 11 | 5641 |
| 1919–20 | 0 | 12 | 55 | 237 | 717 | 1219 | 1428 | 1174 | 773 | 673 | 307 | 68 | 6663 |
| 1920–21 | 17 | 18 | 65 | 206 | 713 | 976 | 1020 | 920 | 606 | 356 | 206 | 41 | 5144 |
| 1921–22 | 0 | 13 | 20 | 371 | 690 | 1008 | 1221 | 936 | 813 | 498 | 141 | 26 | 5737 |
| 1922–23 | 10 | 19 | 73 | 333 | 621 | 1031 | 1077 | 1156 | 947 | 580 | 332 | 35 | 6214 |
| 1923–24 | 0 | 31 | 93 | 401 | 690 | 763 | 1276 | 1152 | 988 | 588 | 392 | 74 | 6448 |
| 1924–25 | 31 | 20 | 167 | 299 | 719 | 1158 | 1219 | 870 | 805 | 453 | 360 | 17 | 6118 |
| 1925–26 | 8 | 9 | 60 | 610 | 758 | 1129 | 1173 | 1034 | 1064 | 708 | 280 | 81 | 6914 |
| 1926–27 | 11 | 6 | 84 | 422 | 755 | 1147 | 1187 | 880 | 763 | 550 | 277 | 130 | 6212 |
| 1927–28 | 9 | 45 | 56 | 264 | 553 | 1019 | 1134 | 1038 | 920 | 635 | 272 | 94 | 6039 |
| 1928–29 | 3 | 6 | 176 | 276 | 620 | 926 | 1238 | 1117 | 665 | 455 | 319 | 0 | 5801 |
| 1929–30 | 0 | 0 | 97 | 398 | 768 | 1023 | 1159 | 772 | 908 | 508 | 192 | 0 | 5825 |
| 1930–31 | 0 | 0 | 54 | 413 | 608 | 1024 | 1031 | 897 | 964 | 539 | 265 | 0 | 5795 |
| 1931–32 | 0 | 0 | 47 | 235 | 418 | 770 | 771 | 847 | 1054 | 633 | 229 | 0 | 5004 |
| 1932–33 | 0 | 0 | 65 | 316 | 737 | 967 | 833 | 949 | 900 | 464 | 181 | 40 | 5452 |
| 1933–34 | 0 | 0 | 38 | 361 | 781 | 973 | 989 | 1340 | 1021 | 533 | 147 | 6 | 6189 |
| 1934–35 | 0 | 0 | 57 | 349 | 539 | 1053 | 1119 | 1019 | 679 | 612 | 372 | 62 | 5861 |
| 1935–36 | 0 | 24 | 94 | 341 | 644 | 1180 | 1279 | 1275 | 789 | 626 | 176 | 54 | 6482 |
| 1936–37 | 1 | 4 | 77 | 346 | 784 | 888 | 904 | 953 | 1034 | 535 | 208 | 24 | 5758 |
| 1937–38 | 14 | 0 | 134 | 453 | 729 | 1081 | 1118 | 873 | 675 | 459 | 221 | 20 | 5777 |
| 1938–39 | 0 | 0 | 91 | 289 | 560 | 974 | 1005 | 919 | 856 | 592 | 186 | 19 | 5491 |
| 1939–40 | 1 | 0 | 65 | 314 | 695 | 903 | 1410 | 1058 | 1056 | 657 | 303 | 42 | 6504 |
| 1940–41 | 16 | 29 | 119 | 348 | 695 | 877 | 1097 | 1076 | 1068 | 413 | 177 | 30 | 5945 |
| 1941–42 | 2 | 15 | 50 | 255 | 598 | 826 | 1135 | 1109 | 775 | 389 | 182 | 25 | 5361 |
| 1942–43 | 2 | 9 | 135 | 296 | 635 | 1134 | 1153 | 964 | 883 | 649 | 240 | 24 | 6124 |
| 1943–44 | 4 | 9 | 134 | 401 | 737 | 1081 | 987 | 983 | 959 | 596 | 108 | 24 | 6023 |
| 1944–45 | 0 | 10 | 90 | 374 | 818 | 1167 | 1398 | 989 | 533 | 400 | 360 | 106 | 6045 |
| 1945–46 | 7 | 7 | 75 | 389 | 626 | 1190 | 1064 | 956 | 503 | 508 | 247 | 76 | 5648 |
| 1946–47 | 11 | 33 | 54 | 204 | 542 | 906 | 982 | 1167 | 1010 | 547 | 283 | 76 | 5815 |
| 1947–48 | 9 | 3 | 123 | 128 | 735 | 996 | 1318 | 1026 | 806 | 389 | 264 | 48 | 5845 |
| 1948–49 | 4 | 1 | 56 | 413 | 484 | 917 | 905 | 824 | 823 | 525 | 183 | 24 | 5159 |
| 1949–50 | 0 | 4 | 126 | 199 | 663 | 883 | 846 | 963 | 976 | 656 | 203 | 37 | 5556 |
| 1950–51 | 4 | 7 | 90 | 222 | 780 | 1160 | 1061 | 949 | 832 | 536 | 187 | 28 | 5856 |
| 1951–52 | 1 | 12 | 90 | 250 | 805 | 996 | 976 | 925 | 857 | 464 | 234 | 19 | 5629 |
| 1952–53 | 1 | 7 | 64 | 450 | 554 | 875 | 919 | 823 | 739 | 567 | 179 | 19 | 5197 |
| 1953–54 | 1 | 2 | 76 | 218 | 529 | 863 | 1088 | 784 | 887 | 341 | 288 | 35 | 5112 |
| 1954–55 | 2 | 0 | 38 | 295 | 619 | 957 | 1126 | 940 | 812 | 268 | 126 | 35 | 5218 |
| 1955–56 | 0 | 1 | 52 | 320 | 785 | 1127 | 1151 | 967 | 891 | 566 | 265 | 69 | 6194 |
| 1956–57 | 4 | 13 | 159 | 198 | 665 | 828 | | | | | | | |

Special Data Tabulations have been printed in previous Summaries as follows:

1946 – Daily Extremes of Temperature and Year
1946 – Dates of Killing Frosts
1946 – Maximum Precipitation of Record
1944 – Times of Sunrise and Sunset

1944 – Lake Erie Average Water Temperature
1940 – Monthly and Annual Hours of Sunshine
1937 – Monthly and Annual Mean Maximum and Mean Minimum Temperatures.

# MONTHLY AND SEASONAL SNOWFALL

| Season | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1909-10 | 0 | 0 | 0 | 0.6 | 0.8 | 16.3 | 28.0 | 30.5 | 2.7 | 2.0 | 0 | 0 | 80.9 |
| 1910-11 | 0 | 0 | 0 | T | 10.6 | 17.1 | 8.9 | 10.0 | 6.1 | 1.8 | T | 0 | 54.5 |
| 1911-12 | 0 | 0 | 0 | 0 | 7.6 | 6.9 | 23.5 | 14.4 | 7.3 | 6.7 | 0 | 0 | 66.4 |
| 1912-13 | 0 | 0 | 0 | 0 | 1.3 | 3.3 | 6.2 | 14.0 | 9.2 | T | 0 | 0 | 34.0 |
| 1913-14 | 0 | 0 | 0 | T | 22.2 | 5.9 | 10.6 | 16.1 | 4.6 | 0.9 | 0 | 0 | 60.3 |
| 1914-15 | 0 | 0 | 0 | T | 0.7 | 6.9 | 17.1 | 4.8 | 3.3 | T | 0 | 0 | 32.8 |
| 1915-16 | 0 | 0 | 0 | 0 | 0.4 | 9.4 | 3.1 | 13.2 | 15.7 | 0.6 | 0 | 0 | 42.4 |
| 1916-17 | 0 | 0 | 0 | 0 | 10.1 | 12.3 | 11.6 | 9.9 | 6.1 | T | 0 | 0 | 50.0 |
| 1917-18 | 0 | 0 | 0 | T | 8.5 | 13.5 | 24.0 | 2.1 | 1.4 | 1.7 | T | 0 | 51.2 |
| 1918-19 | 0 | 0 | 0 | 0 | T | 2.0 | 1.3 | 4.3 | 1.2 | T | 0 | 0 | 8.8 |
| 1919-20 | 0 | 0 | 0 | 0 | 0.4 | 7.6 | 17.1 | 10.3 | 2.7 | 2.9 | 0 | 0 | 41.0 |
| 1920-21 | 0 | 0 | 0 | T | 3.5 | 5.3 | 4.2 | 10.8 | 0.6 | 1.7 | 0 | 0 | 26.1 |
| 1921-22 | 0 | 0 | 0 | T | 0.9 | 7.9 | 7.3 | 4.8 | 5.7 | 0.2 | 0 | 0 | 26.8 |
| 1922-23 | 0 | 0 | 0 | 0 | 2.6 | 13.1 | 6.9 | 8.9 | 6.1 | 0.1 | T | 0 | 37.7 |
| 1923-24 | 0 | 0 | 0 | T | T | T | 13.0 | 7.8 | 2.6 | 0.7 | 0 | 0 | 24.1 |
| 1924-25 | 0 | 0 | 0 | 0 | 2.4 | 5.6 | 12.6 | 2.1 | 2.4 | 0 | 0 | 0 | 25.1 |
| 1925-26 | 0 | 0 | 0 | 1.8 | 5.0 | 10.3 | 9.5 | 15.9 | 4.3 | 3.1 | 0 | 0 | 49.9 |
| 1926-27 | 0 | 0 | 0 | T | 3.9 | 14.2 | 5.6 | 11.0 | T | T | 0 | 0 | 34.7 |
| 1927-28 | 0 | 0 | 0 | 0 | 0.7 | 7.2 | 9.8 | 2.8 | 2.2 | 1.0 | 0 | 0 | 23.7 |
| 1928-29 | 0 | 0 | 0 | T | 1.2 | 1.9 | 16.6 | 6.8 | 1.2 | T | T | 0 | 27.7 |
| 1929-30 | 0 | 0 | 0 | T | 6.9 | 6.9 | 5.5 | 4.8 | 4.3 | T | 0 | 0 | 28.4 |
| 1930-31 | 0 | 0 | 0 | T | 10.5 | 5.1 | 3.7 | 0.5 | 4.1 | 1.5 | 0 | 0 | 25.4 |
| 1931-32 | 0 | 0 | 0 | 0 | 3.1 | T | 0.5 | 4.1 | 12.0 | 1.7 | 0 | 0 | 21.4 |
| 1932-33 | 0 | 0 | 0 | 0 | 2.0 | 8.7 | 3.2 | 8.4 | 5.0 | T | 0 | 0 | 27.3 |
| 1933-34 | 0 | 0 | 0 | T | 15.2 | 9.5 | 3.9 | 10.4 | 3.2 | 4.2 | 0 | 0 | 46.4 |
| 1934-35 | 0 | 0 | 0 | T | 1.5 | 20.4 | 4.2 | 20.9 | 1.4 | 3.6 | 0 | 0 | 52.0 |
| 1935-36 | 0 | 0 | 0 | 0.3 | 0.9 | 23.0 | 11.2 | 9.1 | 10.1 | 3.6 | 0 | 0 | 58.2 |
| 1936-37 | 0 | 0 | 0 | 0 | 14.3 | 4.3 | 5.3 | 6.5 | 9.7 | 0.1 | 0 | 0 | 40.2 |
| 1937-38 | 0 | 0 | 0 | 1.0 | 6.0 | 4.1 | 8.9 | 2.0 | 0.6 | 8.4 | 0 | 0 | 31.0 |
| 1938-39 | 0 | 0 | 0 | 0 | 6.7 | 7.8 | 12.7 | 10.2 | 3.0 | 2.2 | 0 | 0 | 42.6 |

| Season | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1939-40 | 0 | 0 | 0 | T | 0.4 | 3.9 | 17.1 | 14.9 | 13.4 | 5.3 | 0 | 0 | 55.0 |
| 1940-41 | 0 | 0 | 0 | T | 3.9 | 6.0 | 15.2 | 14.2 | 7.0 | 0 | 0 | 0 | 46.3 |
| 1941-42 | 0 | 0 | 0 | 0 | 0.5 | 3.1 | 5.6 | 20.7 | 8.8 | 0.4 | 0 | 0 | 39.1 |
| 1942-43 | 0 | 0 | 0 | W | T | 3.5 | 9.4 | 11.8 | 11.7 | 10.1 | 14.5 | T | 61.0 |
| 1943-44 | 0 | 0 | 0 | T | 5.8 | 6.9 | 4.8 | 14.2 | 11.2 | 2.3 | 0 | 0 | 45.2 |
| 1944-45 | 0 | 0 | 0 | 0 | 3.9 | 28.9 | 18.7 | 8.6 | 3.9 | T | 0 | 0 | 64.0 |
| 1945-46 | 0 | 0 | 0 | T | 1.3 | 18.2 | 6.1 | 9.1 | 1.8 | T | 0 | 0 | 36.5 |
| 1946-47 | 0 | 0 | 0 | 0 | T | 8.8 | 10.7 | 11.4 | 20.9 | T | 0 | 0 | 51.8 |
| 1947-48 | 0 | 0 | 0 | 0 | 4.2 | 3.4 | 12.0 | 4.0 | 7.1 | 0.3 | 0 | 0 | 31.0 |
| 1948-49 | 0 | 0 | 0 | T | T | 5.7 | 7.1 | 3.6 | 13.2 | 0.9 | 0 | 0 | 30.5 |
| 1949-50 | 0 | 0 | 0 | 0 | 16.0 | 7.6 | 3.7 | 13.8 | 10.1 | 3.0 | 0 | 0 | 54.2 |
| 1950-51 | 0 | 0 | 0 | 0 | 22.3 | 11.7 | 17.5 | 10.6 | 14.5 | 0.6 | 0 | 0 | 77.2 |
| 1951-52 | 0 | 0 | 0 | T | 18.8 | 22.1 | 9.3 | 8.6 | 9.0 | 7.8 | 0 | 0 | 75.6 |
| 1952-53 | 0 | 0 | 0 | 0.3 | 0.5 | 8.4 | 12.5 | 4.2 | 5.0 | 4.3 | 0 | 0 | 35.7 |
| 1953-54 | 0 | 0 | 0 | T | 8.4 | 6.0 | 13.2 | 14.7 | 26.3 | T | T | 0 | 68.6 |
| 1954-55 | 0 | 0 | 0 | 6.4 | 0.2 | 11.6 | 9.4 | 7.8 | 13.9 | T | 0 | 0 | 49.3 |
| 1955-56 | 0 | 0 | 0 | T | 8.7 | 9.8 | 14.1 | 8.9 | 10.7 | 2.0 | T | 0 | 54.2 |
| 1956-57 | 0 | 0 | 0 | 0 | 7.4 | 11.4 | | | | | | | |

The horizontal lines drawn on the Average Temperature, Total Precipitation, Monthly and Seasonal Degree Days, and Monthly and Seasonal Snowfall tables separate the data according to station location (see Station Location table).

# STATION LOCATION

| Location | Occupied from | Occupied to | Airline distance and direction from previous location | Latitude | Longitude | Sea level Ground | Actual barometer elevation (H₂) | Wind instruments | Extreme thermometers | Psychrometer | Telepsychrometer | Tipping bucket rain gage | Weighing rain gage | 8" rain gage | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **CITY OFFICE** | | | | | | | | | |
| Exact location unknown | 1-  40 | 10-  70 | | 41°30' N | 81°42' W | 678 | | | | | | | | | Present location of record unknown. Information on Coop station obtained from Index of Meteorological Records compiled by Records Division of Signal Office in 1893. At that time records were a part of Smithsonion collection. |
| Atwater Bldg. Superior and S. Water Streets | 10-17-70 | 4-29-73 | -- | 41°29.8'N | 81°41.9'W | 648 | 680 | 103 | 30 | -- | | | | -- | |
| National Bank Bldg. Superior & N. Water Sts. | 4-30-73 | 6-30-88 | 200 ft. N | 41°29.8'N | 81°41.9'W | 648 | 690 | 130 | 86 | 85 | | | | 73 | |
| Atwater Bldg. Superior and South Water Sts. | 7- 1-88 | 10-13-89 | 200 ft. S | 41°29.8'N | 81°41.9'W | 648 | 678 | 103 | 71 | 70 | | | | 61 | |
| Wilshire Bldg. Superior between W. 3rd & W. 6th | 10-14-89 | 4-30-92 | 800 ft. NE | 41°29.9'N | 81°41.8'W | 657 | 751 | 125 | 98 | 97 | | | | 89 | |
| Western Res. Bldg. Superior & N. Water Sts. | 5- 1-92 | 9-30-96 | 900 ft. SW | 41°29.8'N | 81°42.0'W | 648 | 740 | 130 | 123 | 122 | | | | 109 | |
| Society for Savings Bldg. Public Square | 10- 1-96 | 6-27-29 | 1850 ft. NE | 41°30.0'N | 81°41.6'W | 653 | 762 | 201 | 191 | 190 | | 165 | | 165 | Move from location (6) to improve wind instrument exposure. Interference, in wind exposure this location (7) with wind record partially interpolated after 1-12-25. |
| Engineers Natl. Bank Bldg. Ontario & St. Clair Streets. | 6-28-29 | 5-31-41 | 400 ft. WNW | 41°30.0'N | 81°41.7'W | 651 | 877 | 337 | 268 | 267 | | 264 | | 264 | Move from location(7)to improve wind instrument exposure. |
| | | | | | | **AIRPORT STATION** | | | | | | | | | |
| Airport Manager's Office Cleveland Municipal AP | 8-27-26 | 8-11-29 | | 41°24.2'N | 81°50.6'W | 787 | | # 25 | | | | | | | # Estimated. |
| Administration Bldg. Cleveland Municipal AP | 8-11-29 | 5-31-41 | 800 ft. SW | 41°24.2'N | 81°50.6'W | 787 | 805 | 56 | * 27 | * 27 | | | | ¢ 3 | * Temperature records began 1-1-30.  ¢ Precipitation records began 1-1-38. |
| Administration Bldg., Cleveland Hopkins Airport. | 6- 1-41 | 1-30-56 | No change | 41°24.2'N | 81°50.6'W | 787 | 805 | 56 | 27 | 27 | | | 4 | 3 | Consolidation of Cleveland offices. |
| New Terminal Bldg., Cleveland Hopkins AP | 1-30-56 | to date | 200 ft. NE | 41°24.2'N | 81°50.6'W | 787 | 812 | 88 | 28 | 28 | | | 24 | 24 | |

Exclusively Airways Reporting Station from establishment 8-27-26 until change to consolidated station and official reporting station CLE on 6-1-41.

Table 3.2. - Inversion Data (Toledo, Ohio 1946-1950)

(a) Percentage frequency of base of inversion.

| Inversion base | Winter | | Spring | | Summer | | Fall | | Annual | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | D | N | D | N | D | N | D | N | D |
| Surface | 39 | 14 | 49 | 4 | 73 | 1 | 67 | 5 | 57 | 6 |
| >Surface,<1000 ft | 3 | 19 | 9 | 11 | 2 | 6 | 2 | 19 | 4 | 14 |
| 1500 ft | 47 | 41 | 61 | 22 | 75 | 9 | 70 | 31 | 63 | 26 |

(b) Percentage of inversions with specified wind direction.

| Wind direction | Winter | | Spring | | Summer | | Fall | | Annual | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | D | N | D | N | D | N | D | N | D |
| N | 15 | 5 | 22 | 0 | 41 | 0 | 53 | 6 | 32 | 2 |
| NE | 20 | 0 | 38 | 2 | 54 | 0 | 50 | 5 | 42 | 2 |
| E | 38 | 14 | 62 | 1 | 65 | 0 | 74 | 2 | 61 | 3 |
| SE | 73 | 31 | 80 | 8 | 86 | 2 | 92 | 11 | 86 | 11 |
| S | 72 | 47 | 79 | 17 | 86 | 1 | 86 | 13 | 81 | 20 |
| SW | 48 | 23 | 60 | 2 | 83 | 1 | 71 | 4 | 65 | 8 |
| W | 24 | 8 | 41 | 1 | 70 | 1 | 38 | 4 | 39 | 4 |
| NW | 13 | 0 | 25 | 1 | 61 | 0 | 47 | 3 | 33 | 1 |
| Calm | 83 | 0 | 83 | 0 | 93 | 0 | 86 | 29 | 88 | 14 |

(c) Percentage of inversions base at the surface with specified wind speeds.

| Wind speed | Winter | | Spring | | Summer | | Fall | | Annual | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | D | N | D | N | D | N | D | N | D |
| <4 mph | 59 | 28 | 74 | 5 | 83 | 0 | 82 | 13 | 79 | 9 |
| All speeds | 39 | 14 | 49 | 4 | 73 | (a) | 67 | 5 | 57 | 6 |

[a]Less than 1 percent.
N   2200 EST
D   1000 EST

## 3.3 Geology

The site area is situated approximately five miles south of Lake Erie. The elevation at this point is about 760 feet, 188 feet above Lake Erie.

Test soil borings were taken at the Laboratory near the reactor site by the H. C. Nutting Company, Cincinnati, Ohio, in June, 1952. The maximum depth of the test holes was 50 feet. These borings indicate that, starting at the surface, there is between 8.5 and 10 feet of brown sandy clay with some gravel. This is followed by 14 to 24 feet of blue sandy clay and gravel, and this is followed by grey hard shale which appears at depths of from 24 to 34 feet.

Figure 3.5 is a geology map of a section of the Cleveland, Euclid, Berea quadrangle showing the location of the Lewis Flight Propulsion Laboratory and the location of the reactor facility.

## 3.4 Reference

3.1 Personal Communications, H. W. Burke (MIC), P. F. Jacobay, United States Weather Bureau, Cleveland Hopkins Airport, Cleveland, Ohio.

## 4. EXPERIMENTS WITH REACTOR

Experiments to be performed with the proposed solution-type reactor fall into three categories which will be separately discussed:

(1) Experiments concerned with criticality of various homogeneous reactor configurations.

(2) Experiments in which given reactor configurations are used to measure reactivity effects of inhomogeneities of various kinds and sizes in the core.

(3) Experiments in which the reactor serves as a neutron source to apparatus external to the core.

### 4.1 Critical Assembly Experiments

Criticality experiments will be performed for cylindrical homogeneous assemblies of $UO_2F_2$-$H_2O$ solutions for a range of core diameter, core length-diameter ratio, and fuel concentration. The cores will be bare, partially reflected, or fully reflected by water or other suitable reflector material. The approach-to-critical procedures are outlined in section 2.4.

The purpose of such a series of experiments is to establish sufficient information for calibrating particular reactor configurations for safely measuring reactivity effects of inhomogeneities in the core. The use of core height as a means of measuring reactivity has been discussed in section 2.3.3. Of course, the basic criticality data for these clean configurations also serves to provide data additional to that of reference 4.1 upon which to formulate general analytical models.

Techniques of flux distribution measurement and absolute power determinations may be perfected with these experiments. Radiation surveys of the reactor room and surroundings will be made. Fuel mass and temperature coefficients of reactivity will be ascertained.

### 4.2 Reactivity Effects Experiments

From the results of the critical experiments, it will be possible to select a safe and satisfactory reactor configuration with which to

measure various reactivity effects. The method of using adjoint fluxes in perturbation theory satisfactorily predicts homogeneous and local reactivity effects of changes in composition which are sufficiently small so as not to alter the neutron fluxes significantly. Most of the changes in reactor composition of practical interest, however, are sufficiently large to alter the fluxes in and around the disturbance.

For example, of greater interest to boiling reactors and to an understanding of shut-down mechanism in liquid reactors, is the spatial worth of bubbles or voids of various size. In the present reactor, reactivity effects of voids may be measured by a series of experiments in which plastic bubbles filled successively with fuel solutions, water, and air are traversed through the core. In each case, the core height at criticality serves as a measure of reactivity.

An extension of the foregoing experiment would be to superpose small voids along the axis of the core in order to estimate reactivity effects of neutrons streaming through axial air passages. Usual diffusion theory procedures for calculating reactors with gas flow passages involve homogenizing these effective voids. These reactivity experiments would supply a measure for the validity of such calculation procedures.

Another device usually employed in diffusion theory calculations is to ignore finiteness of clad fuel-element subassemblies and to assume that these are homogenized with other constituents of the core. Again, it may be possible to employ the present clean homogeneous cores as a three-dimensional integrating device to experimentally determine self-shielding factors for reactor repetitive "cells". This could be done by inserting these "cells" in the reactor container, filling with $UO_2F_2-H_2O$ solution until just critical and noting relative reactivities of various "cell" configurations.

A final example of the use of the reactor is the measurement of detailed flux distributions near concentrated absorbers like control rods or near core-reflector interfaces of greatly different diffusion properties. Such distributions would serve as checks on calculated fluxes obtained from diffusion theory approximations.

## 4.3 Reactor as a Neutron Source

Although the maximum power for these reactors is a total of 10 watts, average thermal neutron fluxes of about $10^8$ neutron/cm$^2$sec are available in bare cores and in reflectors of reflected assemblies. Hence, exposure of samples in these moderate fluxes permits various activation experiments to be performed.

Furthermore, the possibility of taking neutron beams out of the reflector provides means for measuring diffusion and slowing down parameters in various media through use of a fission plate. These beams may also be used for low level activations. A rather extensive set of reactor physics experiments which may be performed with low level neutron intensities are given in reference 4.2 and 4.3.

A very important use of the radiation fields outside of the reactor is for nuclear instrument development. The presence of leakage gamma and neutron radiations resulting from fission provide the exact spectra to be analyzed by spectrometers under development.

## 4.4 References

4.1 Beck, C. K. et al: Critical Mass Studies, Part III, Report K-343 April 19, 1949.

4.2 Reactor Physics Laboratory Manual, Oak Ridge School of Reactor Technology TID-5262, July, 1955.

4.3 Flora, J. W.: Educational Uses of the Small 5-Watt Laboratory Reactor, 2nd Nuclear Engineering and Science Conference. March 11-14, 1957. Paper 57-NESC-73.

# 5. HAZARDS

## 5.1 Hazards Due to Acts of God, Negligence, and Sabotage

5.1.1 Severe storms. - The two most severe types of storms common to the Cleveland area are thunderstorms and tornadoes. Thunderstorms average about 39 days a year in the area, and have been known to deposit 1.2 inches of rain in 10 minutes, with winds in excess of 50 miles per hour.

Tornadoes are fairly common in Ohio, but only three have occurred in the Cleveland area during 84 years of record, the most severe. of which occurred on June 8, 1953.

Because the facility structure is to be made of reinforced concrete and partly underground with a mound of earth over the top, neither thunderstorms nor tornadoes are expected to be damaging. At most, such storms could disrupt electrical power to the facility, but this would cause no harm to the reactor since the reactor would scram.

5.1.2 Floods. - Flooding of the area is highly unlikely because of the general sloping terrain. Immediately west of the laboratory is a deep river valley, and all of the surface drainage is into this valley. Flooding of the facility is also unlikely, but if it did occur, no serious hazard would result since all of the fuel not in use is stored in leak tight cans, and are so situated and sized that, even though fully surrounded by water, a critical assembly would not result. It is assumed that if flooding should start to occur during operation, sufficient time would be available for the operator to drain the reactor vessel fuel into the appropriate storage vessels.

5.1.3 Earthquakes. - Table 5.1 is a chart of earthquakes in Ohio. The Cleveland area has no reported earthquake history.

Table 5.1. - Major Earthquakes Having Epicenters in Ohio

| Date | Hour | Locality | | Area felt, sq mi | Intensity, Rossi-Forel |
|---|---|---|---|---|---|
| | | North latitude | West longitude | | |
| June 18, 1875 | 0743 | 40.2 | 84.0 | 40,000 | 6-7 |
| Sept. 19, 1884 | 1414 | 40.7 | 84.1 | 125,000 | 6 |
| Sept. 20, 1931 | 1705 | 40.2 | 84.3 | 40,000 | 8 |
| March 2, 1937 | 0948 | 40.7 | 84.0 | 90,000 | 8 |
| March 9, 1937 | 0045 | 40.6 | 84.0 | 150,000 | 8 |

The general area of these earthquakes is about 125 miles from Cleveland. It is felt that earthquakes present no great hazard to the facility.

5.1.4 Sabotage. - Sabotage is probably one of the most difficult hazards to provide for in a design. It would be very difficult for a nonemployee to gain access to the facility, because the reservation can be entered only through two well guarded gates. Furthermore, the proposed facility is to be built as an addition to one wing of an existing building. Access to the facility will be through this building which is under guard at all times.

Sabotage by an employee or a demented person is more likely to occur. It is foolhardy to say that sabotage by these types of persons could not be attempted, but an effort will be made, by a system of interlocks, to make it much more difficult to accomplish. Even if a saboteur did gain access to the facility, it would be difficult to sabotage the facility in such a way that the hazard to the surrounding population would be greater than that of the maximum credible accident which is discussed in section 5.2.

5.1.5 Negligence. - The history of accidents in atomic energy activities has shown that negligence is one of the largest contributing factors to accidents. Probably the most difficult task in preventing negligence is that of promoting continued safety consciousness even though no accidents have occurred.

In an effort to prevent negligence, rigid rules pertaining to the welfare and safety of persons in or around the reactor area will be established. The handling of the reactor and associated equipment will at all times be under the strict control of a licensed operator. A logbook and check lists will be maintained by the operator in charge of the facility. Also, any other precautions which are deemed necessary to prevent negligence, will be instituted.

## 5.2 Maximum Credible Accident

Two accidents will be considered here. First, the excursion resulting from the inability of the control system to compensate for a very rapid increase in reactivity. Second, a modified start-up accident in which it is assumed that the reactor vessel is being filled at the maximum possible rate (4 liters/min), that this filling rate is accidentally maintained beyond reactor criticality, and that control system fails to operate.

The order of discussion will be as follows:

(1) The magnitude of the nuclear excursion including esti-
mates of the total energy release and the maximum pres-
sure rise.

(2) The ability of the reactor room to contain the excursion.

(3) The radiological hazards from the release of the fission
products.

5.2.1 The nuclear excursion. -

5.2.1.1 The step-increase accident. - There are several different
types of accidental events which might result in very rapid increases in
reactivity; for example, the shift of a poison to a region of less sta-
tistical importance, the flooding of a void space in the core, surface
waves in a pancake type reactor, etc. In all cases, the increase in re-
activity would be in the form of a rapid ramp increase. The rate of this
ramp increase is difficult to predict because of the many different situ-
ations which might be encountered. Therefore, the conservative assump-
tion will be made that the reactivity addition is in the form of a step.
The further assumption will be made that the control system is ineffec-
tive because of the rapidity of the nuclear events in the reactor.

The effect on a solution type reactor of a step-increase in reactiv-
ity is being investigated in great detail, both analytically and experi-
mentally, as part of the KEWB program (refs. 5.1, 5.2, and 5.3). Fig-
ures 5.1 and 5.2 are theoretical estimates of the energy release and the
maximum pressure rise in the reactor as a function of reactor period
taken from reference 5.1. The excursions represent the result of step-
increases in reactivity (the size of the steps being such as to produce
the range of periods covered in the abscissa) with the reactor initially
operating at essentially zero power. The effects of inertial pressure
rise have been considered.

Inasmuch as a very wide range of reactor shapes, solution concentra-
tions, etc. would be run in the proposed NACA solution type reactor,
these results represent as reasonable a first approximation of what might
occur as are readily available. Most of the parameters of the above
analyses such as radiolytic gas production rate, gas bubble residence
time, core heat capacity, etc. would not vary too widely over a range of
solution type reactors. An important parameter which can vary over a wide
range is the prompt neutron mean lifetime (the thickness of the reflector
affects the excursion primarily through the mean lifetime). The prompt
lifetime will affect the reactor period produced by a given step-change
in reactivity, however, for a given reactor period (the abscissa in figs.
5.1 and 5.2), the excursion will be essentially independent of the prompt
mean lifetime.

The prompt neutron mean lifetime for several typical bare reactors are discussed in section 2.3.4. The lifetimes of these reactors (10 to 50 μsec) are typical of the shortest mean lifetimes likely to be encountered in the operation of the facility.

In order to keep the maximum credible accident within reasonable bounds the following criterion will govern all loadings. No experiment will be run where the loading, assuming all poisons, voids, etc. were accidently removed, would, produce a reactor period faster than 5 milliseconds. In applying the above criterion, conservative estimates of the prompt neutron mean lifetime will be used for any particular loading unless experimental determinations of the lifetime are available.

In view of the aforesaid limit, the maximum credible step-increase accident would be one that put the reactor on a 5 millisecond period. From figures 5.1 and 5.2 this period would result in an energy release of about 15 megawatt seconds (about $5 \times 10^{17}$ fissions) and a peak pressure rise of about 50 psi.

The value of 15 megawatt seconds energy release seems reasonable inasmuch as the observed energy release in excursions which have occurred with solution type zero power reactors is about 3 to 5 megawatt-seconds (refs. 5.4 and 5.5).

5.2.1.2 The modified start-up accident. - The maximum pumping rate of the filling pump is 4 liters per minute (see section 2.2.2). From figure 2.14 it can be seen that, for the most unfavorable length-diameter ratio and for a highly enriched solution $\left(\dfrac{N_H}{N_U} = 80\right)$, the time required to add sufficient excess reactivity to go from critical to prompt critical is of the order of 6 seconds (neglecting the compensating effect of radiolytic gas formation). This is equivalent to an average reactivity insertion rate of about $0.0012 \ \Delta K/sec$. This relatively slow rate of reactivity insertion should give the operator (who must keep a button pressed in order for the filling pump to keep operating) time to take remedial action. There are at least five individual control channels (two period and three level) which would activate annunciators and warning lights to alert the operator. The modified start-up accident should, therefore, never be anything more serious than a slow ramp inseration of reactivity in which the reactor is very unlikely to reach even prompt critical. The modified start-up accident is, therefore, considerably less serious than the step-increase accident and will not be considered further.

5.2.1.3 The equilibrium pressure after the step-increase accident. - The equilibrium pressure in the reactor room after the maximum credible step-increase accident was esimated by assuming that the energy generated in the excursion heats the water in the reactor and the air in the

reactor romm to the same temperature. The maximum energy release is about 15 megawatt seconds (section 5.2.1.); the reactor room air volume is about 14,000 cubic feet; the smallest reactor volume is about 17 liters. The temperature rise of the air would be about 50° F and the associated pressure rise about 1.4 psi. This is taken to be the equilibrium pressure after the maximum credible accident.

5.2.2 Containment of the maximum credible accident. - The discussion of the ability of the reactor room to contain the 15 megawatt-second step-increase accident will be divided into two parts: first, the damage due to the excursion will be discussed and then the probable leakage from the room.

5.2.2.1 Damage from the excursion. - As discussed in reference 5.2, shock waves in the fluid will probably not be encountered and as discussed in section 5.2.1.1, the peak pressure of the excursion will be about 50 psi. Therefore, it is extremely unlikely that any damage will occur except to fragile equipment very near the reactor. The reactor vessel should be entirely unharmed and the chief mechanical effect of the excursion would probably by the expulsion of some fuel solution from the reactor tank.

5.2.2.2 Leakage from the reactor room. - Inasmuch as the excursion will produce no mechanical damage other than to equipment very near the reactor, it can be expected that the leakage rate from the room for a given overpressure will not be affected by the excursion. The thickness of the reinforced-concrete walls and ceiling of the reactor room is 12 inches; the floor is 6 inches thick. The exterior walls and roof are all buried in an earth mound whose minimum thickness is 6 feet. All penetrations of the walls of the reactor room are into the adjacent building except one, the ventilation system stack. All penetrations will be carefully designed to be leak tight. The ventilation system is always shut off and the ventilating system stack valve closed during reactor operation.

A maximum allowable leakage rate from the room of 1/2 percent per day for an overpressure of 1.4 psi will be maintained at all times. A leakage rate of this magnitude can be measured by pressurizing the reactor room and measuring the reduction in overpressure over a period of one or two days; the average air temperature in the reactor room must be known to about 1° F. This type of test will be carried out periodically. If the allowable leakage rate were exceeded, the reactor would not be permitted to operate until the major leaks had been detected and eliminated. The leaks could be found rather readily with standard helium or halide leak detectors.

The floor of the reactor room is covered by a metal pan and, therefore, there should be no leakage to the ground of fuel solution which may have been expelled from the reactor.

5.2.3 Radiological hazards. - The chief radiological hazard is from the fission products generated by the 15 megawatt-second excursion inasmuch as the saturated activity due to continuous operation of the reactor will not exceed 100 curies while the activity generated by the excursion will be of the order of 10,000 curies 20 minutes after the excursion. Since the activity is primarily due to newly generated fission products, the rate of decay of activity will be much greater than if the activity were due to saturated fission products.

For the sake of conservatism, it will be assumed that 50 percent of the total activity is airborne and that it is uniformly mixed in the 14,000 cubic feet of air in the reactor room. The activity is assumed to decay as time to the 1.2 power. The overpressure in the reactor room is assumed to be 1.4 psi and the leakage rate at this pressure is assumed to be 1/2 percent per day. A good part of this leakage would be into the adjacent solution room since most of the penetrations of the reactor room are into the solution room. It will be assumed that 1/2 of the leakage is to the atmosphere; this should be a conservative estimate. For further conservatism, it will be assumed that this leakage is in the form of a point source at ground level.

Inasmuch as the control room is separated from the reactor room by the solution room, and there would be no appreciable overpressure in the solution room, it is expected that the personnel in the control room would not receive any appreciable dose.

As discussed in section 3.1, the distance from the reactor to the nearest residence is about 900 feet. Assuming a source of activity as described above, the atmospheric diffusion of the fission products was computed using the methods of "Meteorology and Atomic Energy" (ref. 5.6) for the unfavorable weather conditions of severe inversion (n = 0.5) and 1 meter per second wind velocity in the direction of the nearest point open to the public.

The deposition dosages were computed assuming a heavy rainfall which produces the maximum possible rainout deposition rate (ref. 5.6, eq. (7.21)) and lasts for 8 hours. The resulting surface source was conservatively approximated by an infinite plane source with a uniform radioactivity concentration equal to that of the location of interest. The dosage rate from this source was assumed to be 10 r/hr per 1 curie/sq meter of gamma activity and 25 mr/hr per 1 curie/sq meter of beta activity.

The inhalation dose was computed by assuming that an inhalation dosage of 10 curie sec/cubic meter would result in an internal radiation dosage the equivalent of 25 r.

The resulting integrated doses are tabulated below.

Table 5.2. - Dosages at Nearest Residence (Milliroentgen)

|  |  | Deposition | Inhalation |
|---|---|---|---|
| Integrated over the first hour | Negligible | Negligible | 34 |
| Integrated over the first 24 hours | Negligible | 1 | 57 |

It can be seen from table 5.2 that the dose to the public is of the order of 60 milliroentgens.

Transients on airport property near the reactor facility (see section 3.1) will be warned by means of a loudspeaker in the event of a hazardous fission product release and the maximum dose should not exceed 60 milliroentgens.

## 5.3 References

5.1 Remley, M. E., Flora, J. W., Hetrich, D. L., and Inglis, L. P.:
Program Review of the Water Boiler Reactor Kinetic Experiments.
NAA-SR-1525, March, 1956.

5.2 Remley, M. E., Flora, J. W., Hetrick, D. L., and Inglis, L. P.:
The Kinetic Behaviour of Water Boiler Type Reactors. NAA-SR-1618,
April, 1956.

5.3 Quarterly Progress Report, The KEWB Program, July-Sept. 1956. NAA-SR-1811, March, 1957.

5.4 Callihan, D., and Building 9213 Staff: The Radiation Excursion of
May 26, 1954. A Preliminary Report. ORNL CF 54-6-40, June, 1954.

5.5 Callihan, D.: Radiation Incident of February 1, 1956. ORNL CF-56-2-105, February, 1956.

5.6 U. S. Department of Commerce, Weather Bureau: Meteorology and Atomic
Energy. July, 1955.

## 6. ADMINISTRATIVE PROCEDURE

Administrative procedure divides into five phases as follows:

1. Operations

2. Safeguards

3. Programming

4. Health Physics

5. Security

6. Uranium Accountability

### 6.1 Operations

The organizational structure of the operating section will be:

1. Scientist-in-charge

2. Experimentalists

The function of the operating section will be to operate the critical facility and all associated equipment, as well as to supervise trainees who are participating in the operation of the facility as part of the NACA training program.

The scientist-in-charge will be a licensed reactor operator and all increases in reactivity will be made only under his personal supervision.

Experimentalists will be scientists and technicians assigned to assist the scientist-in-charge. Experimentalists will be the only personnel authorized to operate the reactor. There will be a minimum of two people in an operating crew.

A nuclear safety and operating manual will be written for the completed facility.

## 6.2 Safeguards

Safeguards will be under control of a local Safeguards Committee. Membership of this committee will be made up of at least three qualified persons. The function of this committee will be to determine that safe standards have been followed in the design of any proposed experiment, or of any proposed change in the facility.

## 6.3 Programming

This phase will be under the control of the Program Committee. The membership of this committee will be made up from delegated members of the branches and divisions that will design experiments to be run in the facility. The function of the committee will be to judge the feasibility of proposed experiments and to schedule acceptable experiments.

## 6.4 Health Physics

Health physics activities will be tied in with the existing health physics activities in the adjacent Materials and Stresses building. These existing health physics activities are related to the work with sources, which has been going on for the last seven years. Various different types of sources ranging in size from a few millicuries to 100 curies have been in use.

Health physics will be responsible for personnel dosimeters, protective clothing, air monitoring, and decontamination of all areas.

## 6.5 Security

The facility will be wholly within an existing "Q" cleared area. Therefore, the present guard facility will be adequate. Provision will be made for locking the critical facility area during nonworking hours.

## 6.6 Uranium Accountability

Uranium accountability procedures will be established to meet all the requirements of the Atomic Energy Commission.

WORK PLATFORM

₵ REACTOR

4 DUMP AND
STORAGE TANKS

RADIOACTIVE WASTE
₵ HOLD-UP TANKS

EXISTING BUILDING

8 SOLUTION STORAGE
TANKS

REACTOR ROOM
32'- 8" x 20'- 0"

CONTROL ROOM
21'- 6" x 15'- 6"

SOLUTION
STORAGE ROOM
21'- 6" x 15'- 6"

MOVEABLE BLOCK
SHIELDING

LADDER

CORRIDOR

STEEL DOOR - (GAS TIGHT)

LABYRINTH

STEEL DOOR,
NORMALLY LOCKED

MONITOR

WASTE CANS

LAVATORY

SHOWER

CD-5696
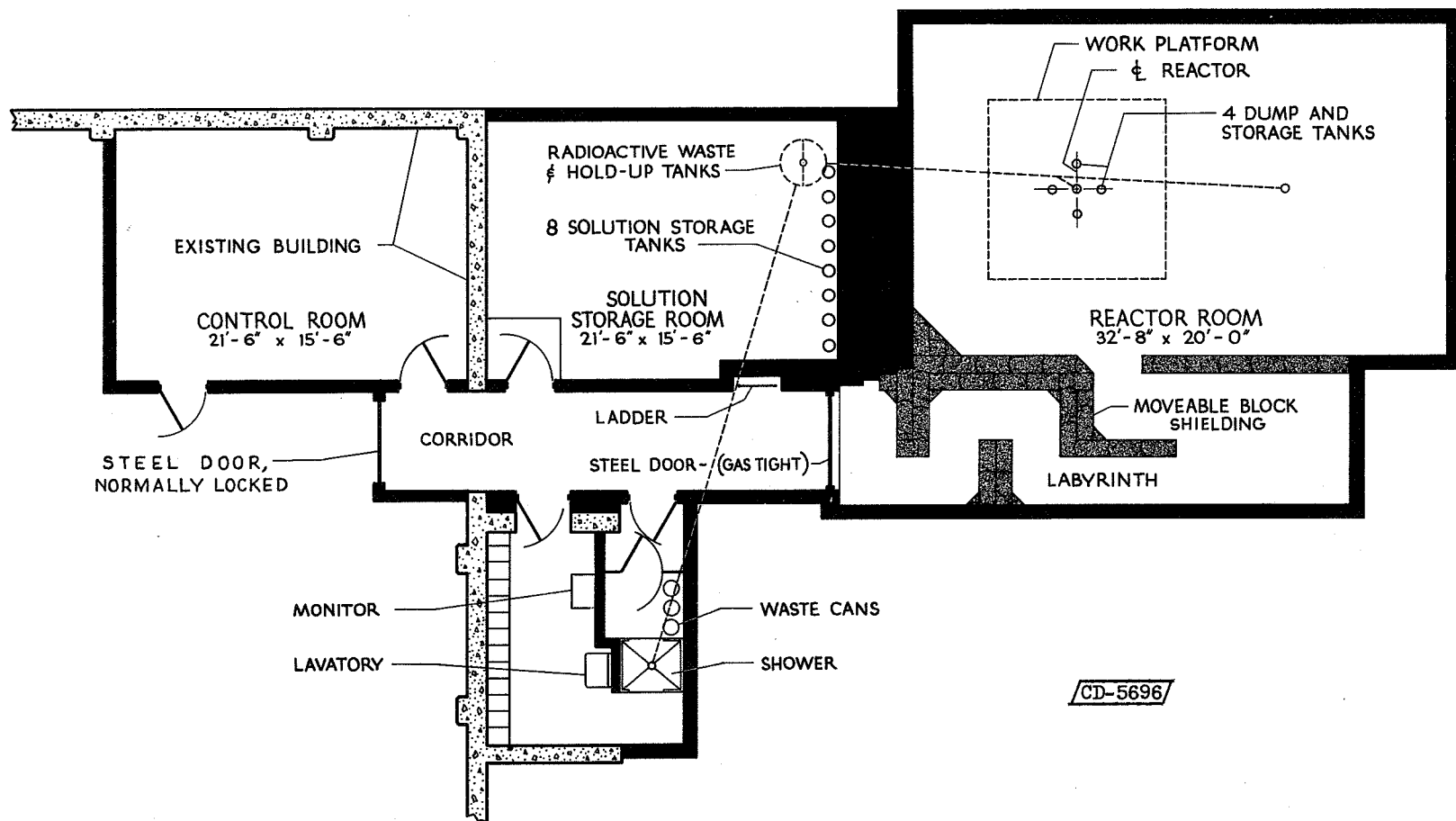
Figure 2.1. - Zero power reactor facility plan view.

EMERGENCY ESCAPE HATCH

CONTROL ROOM

SOLUTION ROOM

REACTOR ROOM

14' - 5"

10' - 6"

20' - 0"

81' - 5"

CD-5698
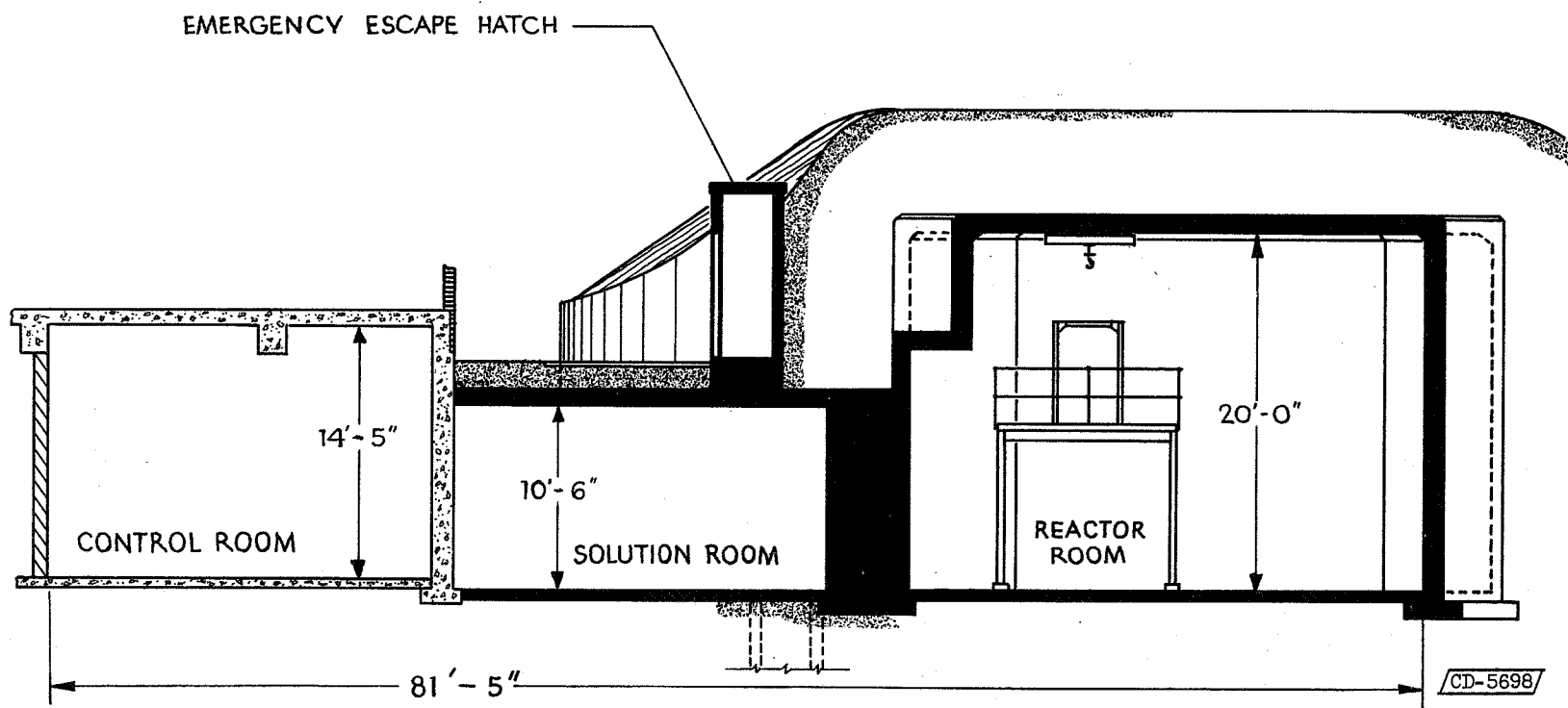
Figure 2.2. - Elevation of control, solution and reactor rooms.

TO ATMOSPHERE

TO ATMOSPHERE

HOOD    BLOWER

CONTROL  ROOM        SOLUTION  ROOM        REACTOR  ROOM

FILTER $ COVER PLATE

GAS TIGHT  DOOR

TO ATMOSPHERE

VENT FAN

PLAN

MONITOR

AIR OPERATED VALVE, N.C.

BLOWER

HOOD    BLOWER

MONITOR

ELEVATION
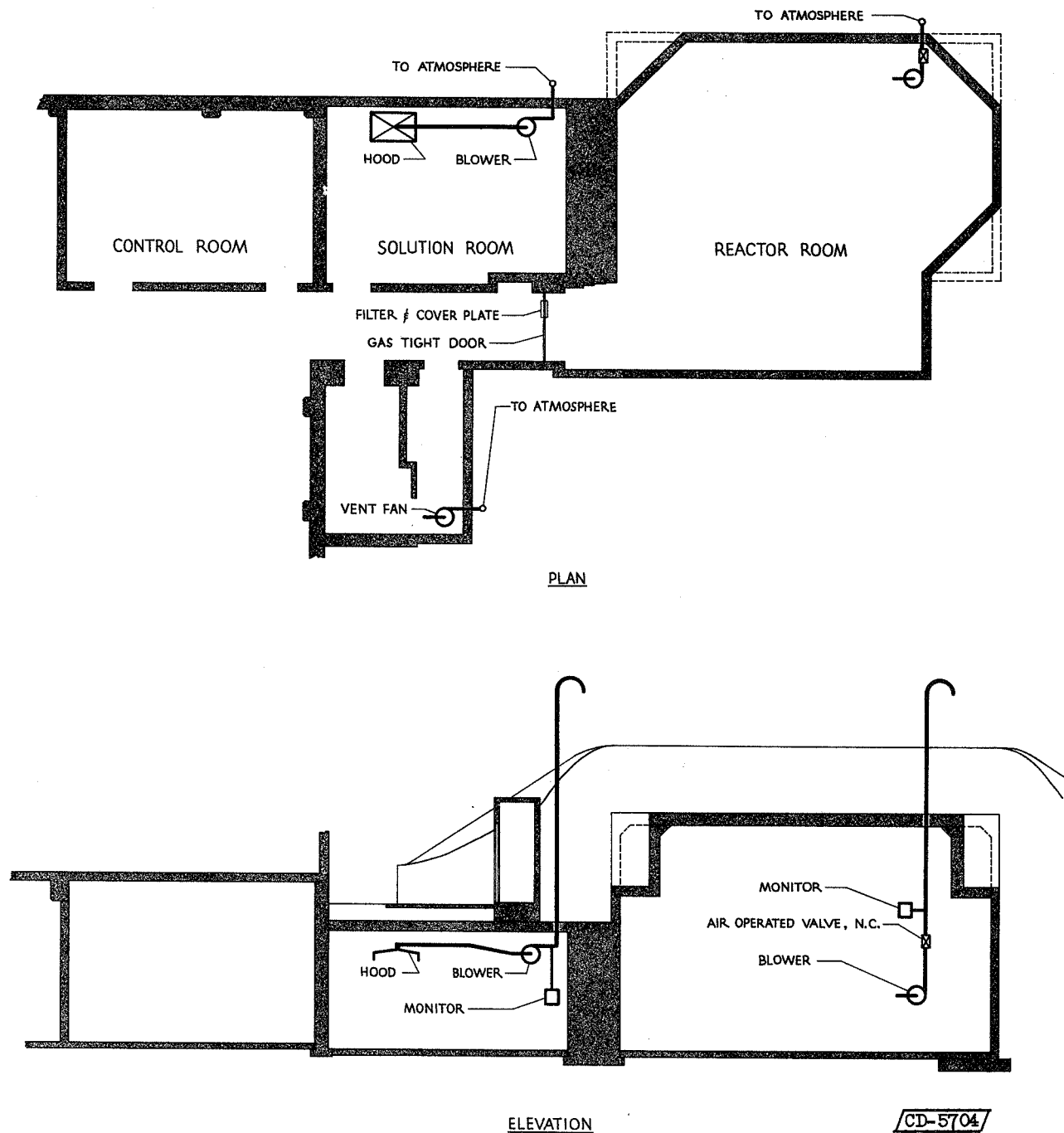
/CD-5704/

Figure 2.3. - Zero power reactor facility ventilation system.
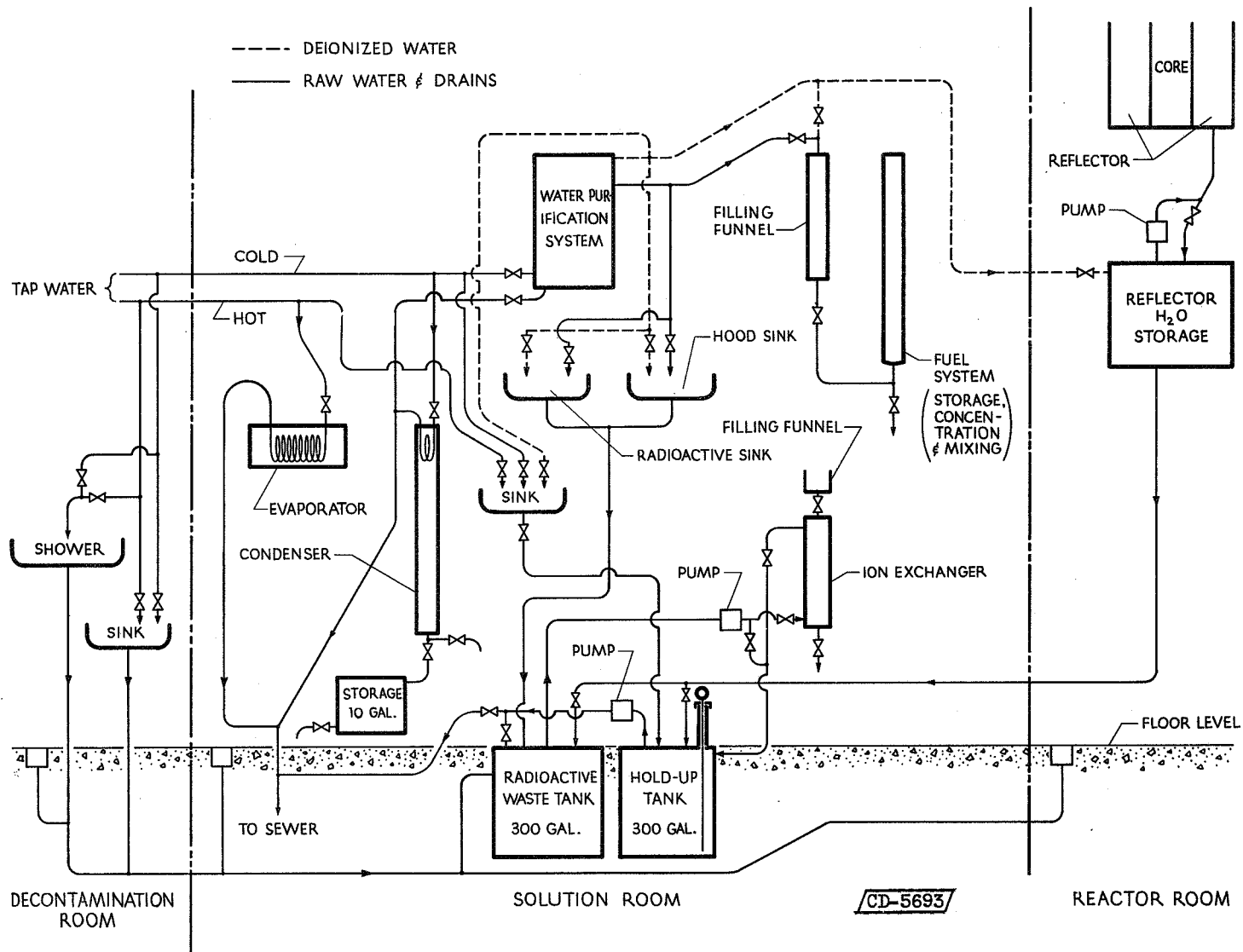
Figure 2.4. - Water systems and drains.

HOOD

A2

SIGHT GLASS

B2

FILTER
PUMP

FILLING

CONDENSER

STORAGE BANK A

A1

F

B1

STORAGE BANK B

E2

EVAPORATOR

P

E1

R

D

DRAIN

H₂O
TANK

VACUUM PUMP

SOLUTION ROOM

REACTOR
VESSEL

DUMP VALVE

FILTER

EXHAUST
TO ROOM

CHECK

AIR CYL. VENT VALVE

AIR CYL. PRESSURE VALVE

AIR CYLINDER

WEIGHT

SAMPLING PIPETTE

PUMP & VALVES
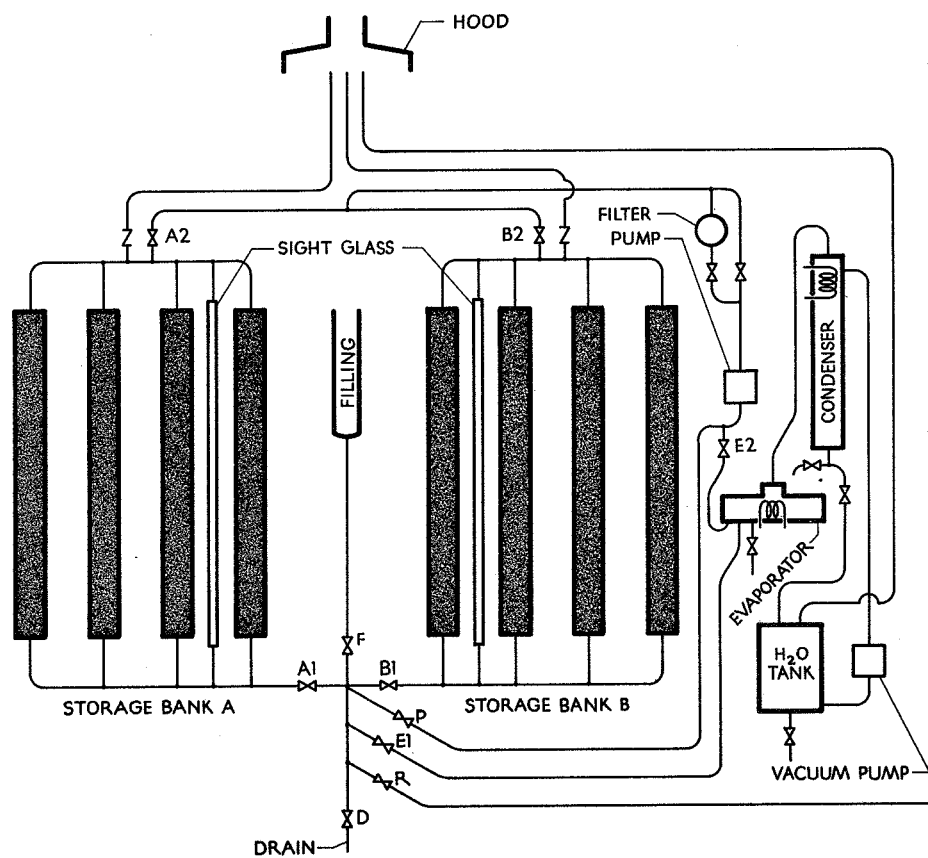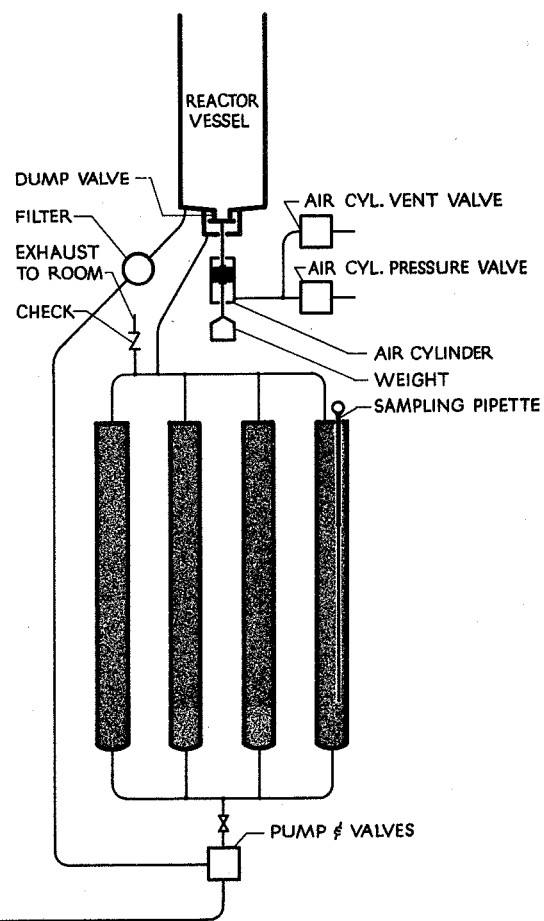
CD-5700

REACTOR ROOM

Figure 2.5. - Fuel system.
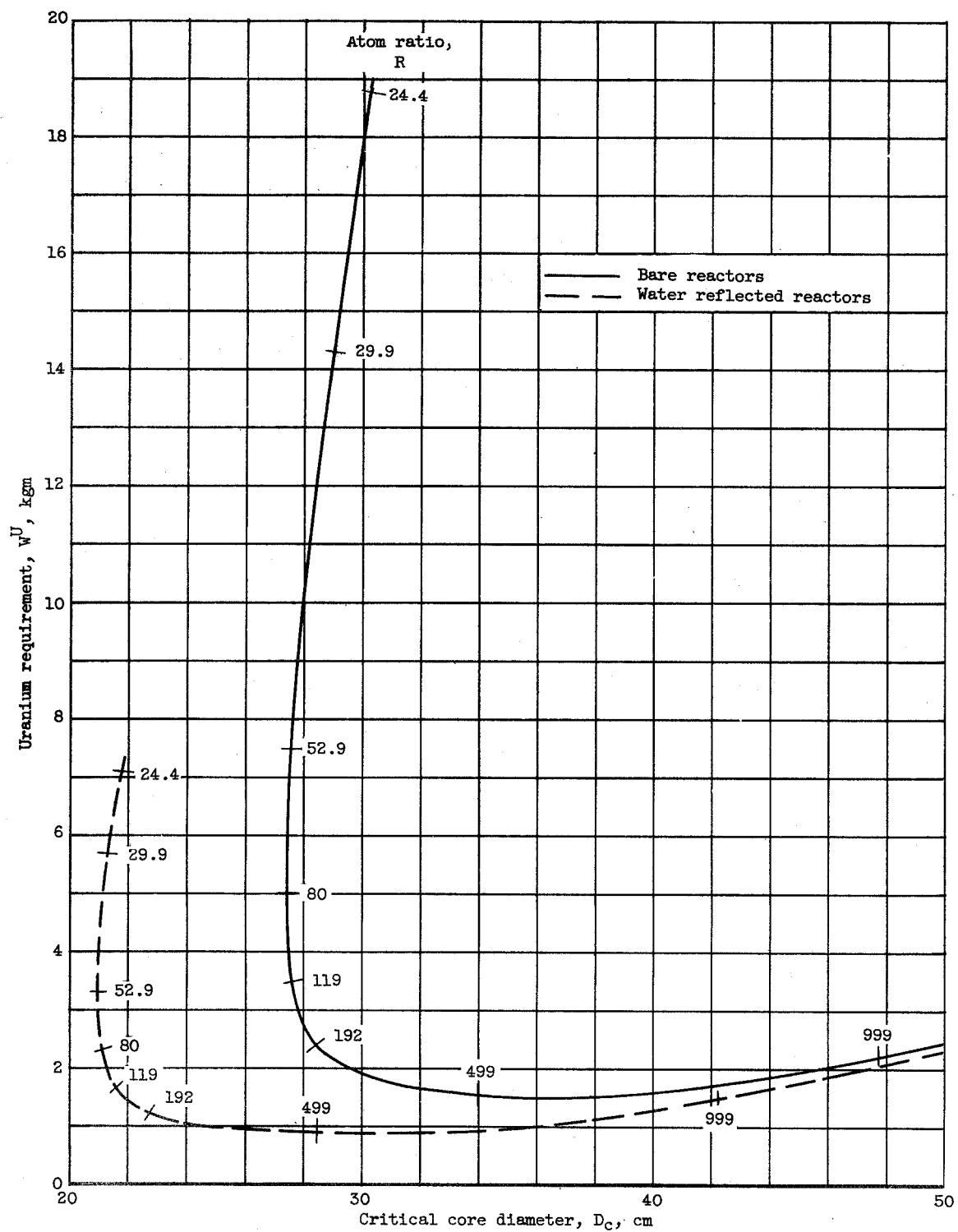
Figure 2.6 - Fully enriched uranium requirements for $UO_2F_2$-$H_2O$ critical cylindrical assemblies of $L/D = 1$.
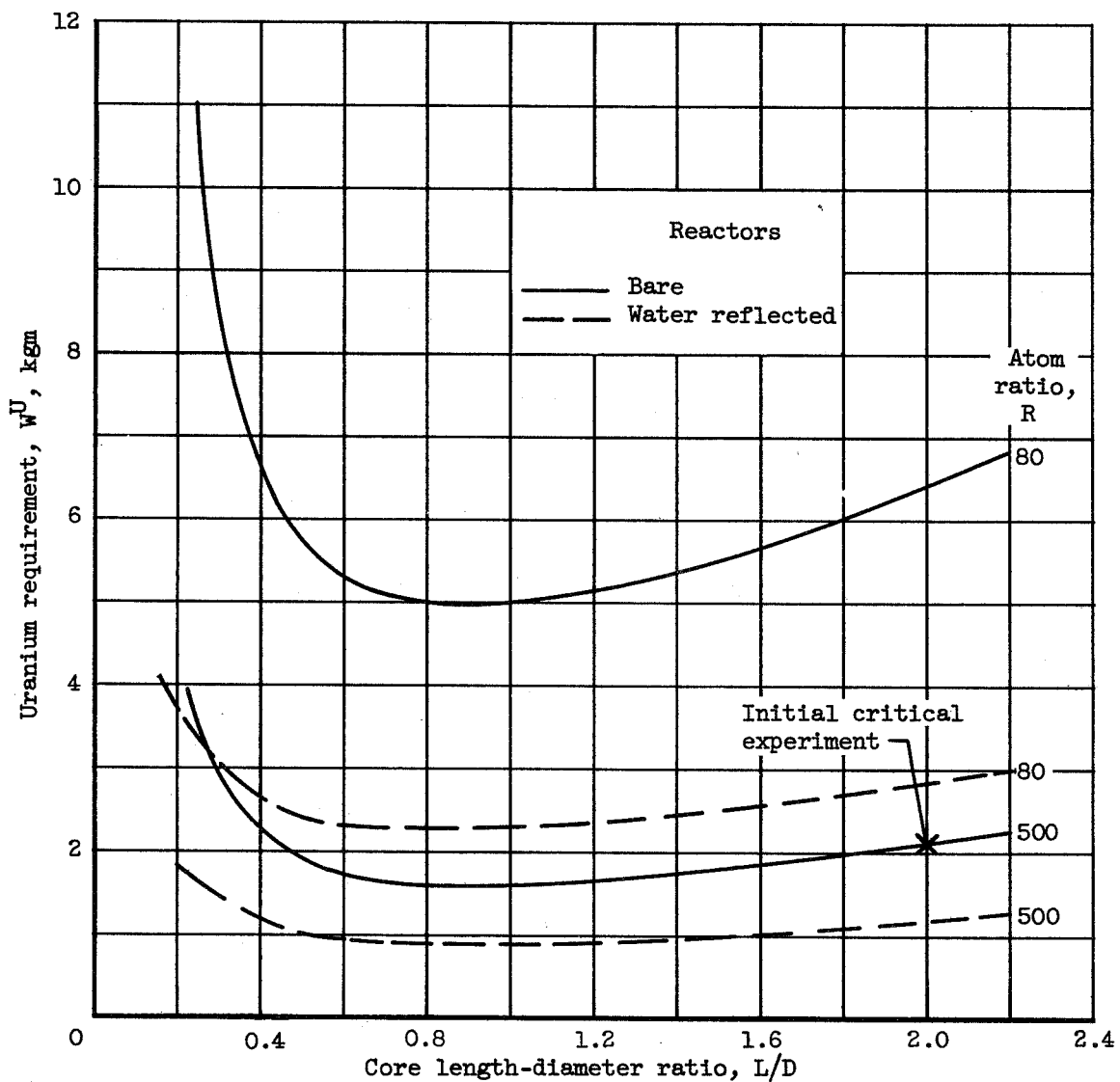
Figure 2.7 - Fully enriched uranium requirements for $UO_2F_2$-$H_2O$ critical cylindrical assemblies.
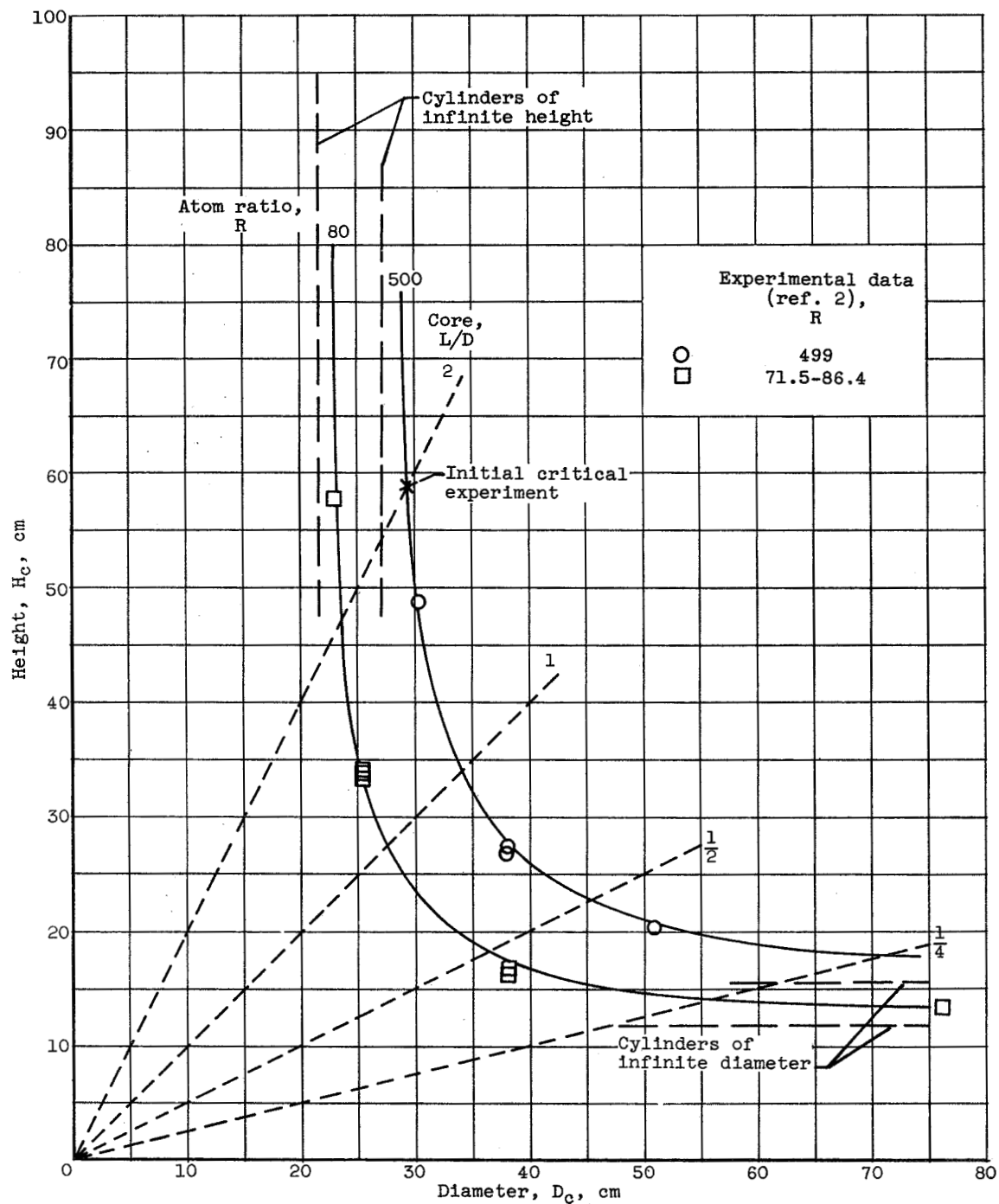
Figure 2.8 - Critical dimensions of bare $UO_2F_2-H_2O$ cylindrical assemblies.
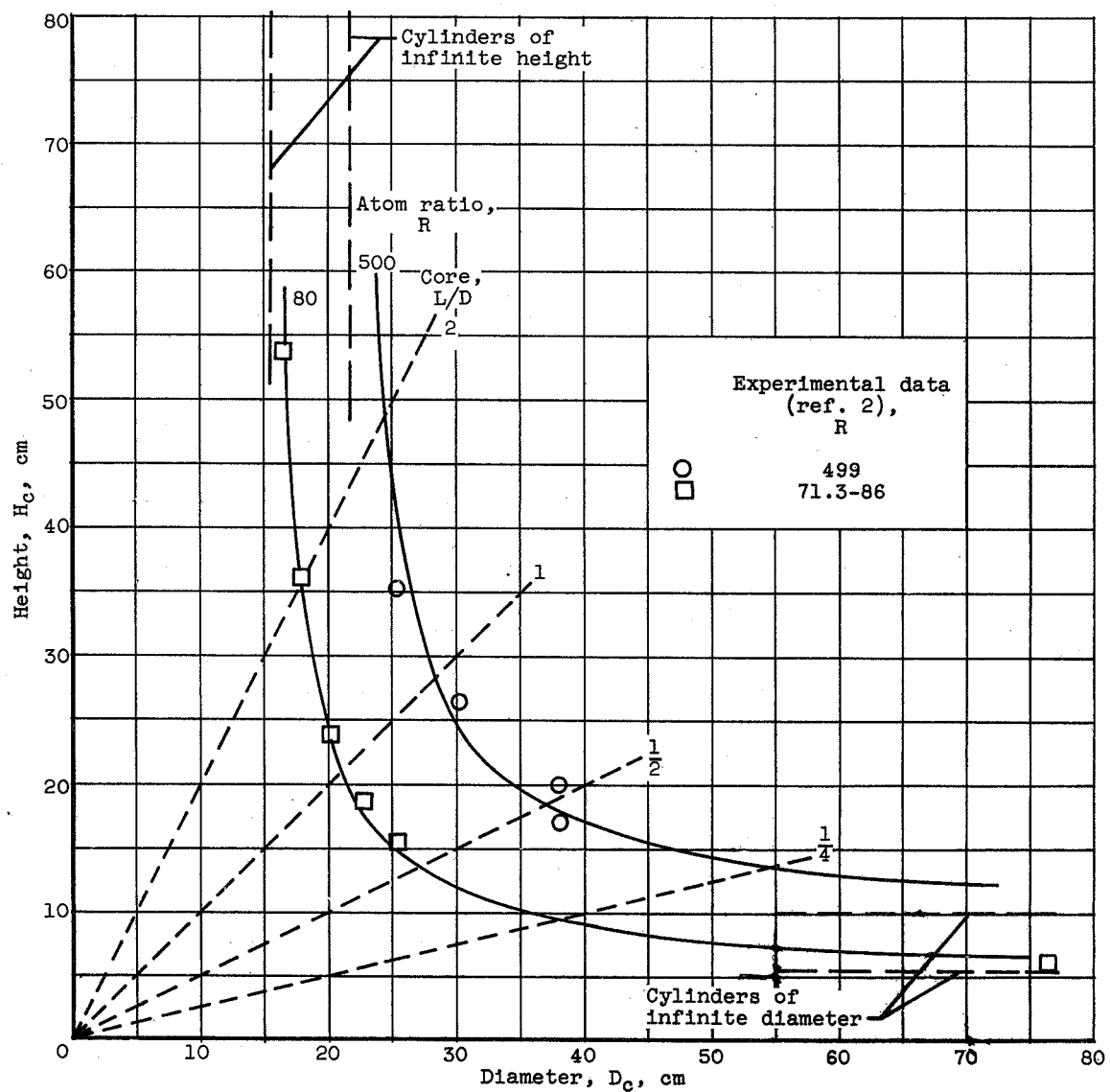
Figure 2.9 - Critical dimensions of water-reflected $UO_2F_2$-$H_2O$ cylindrical assemblies.
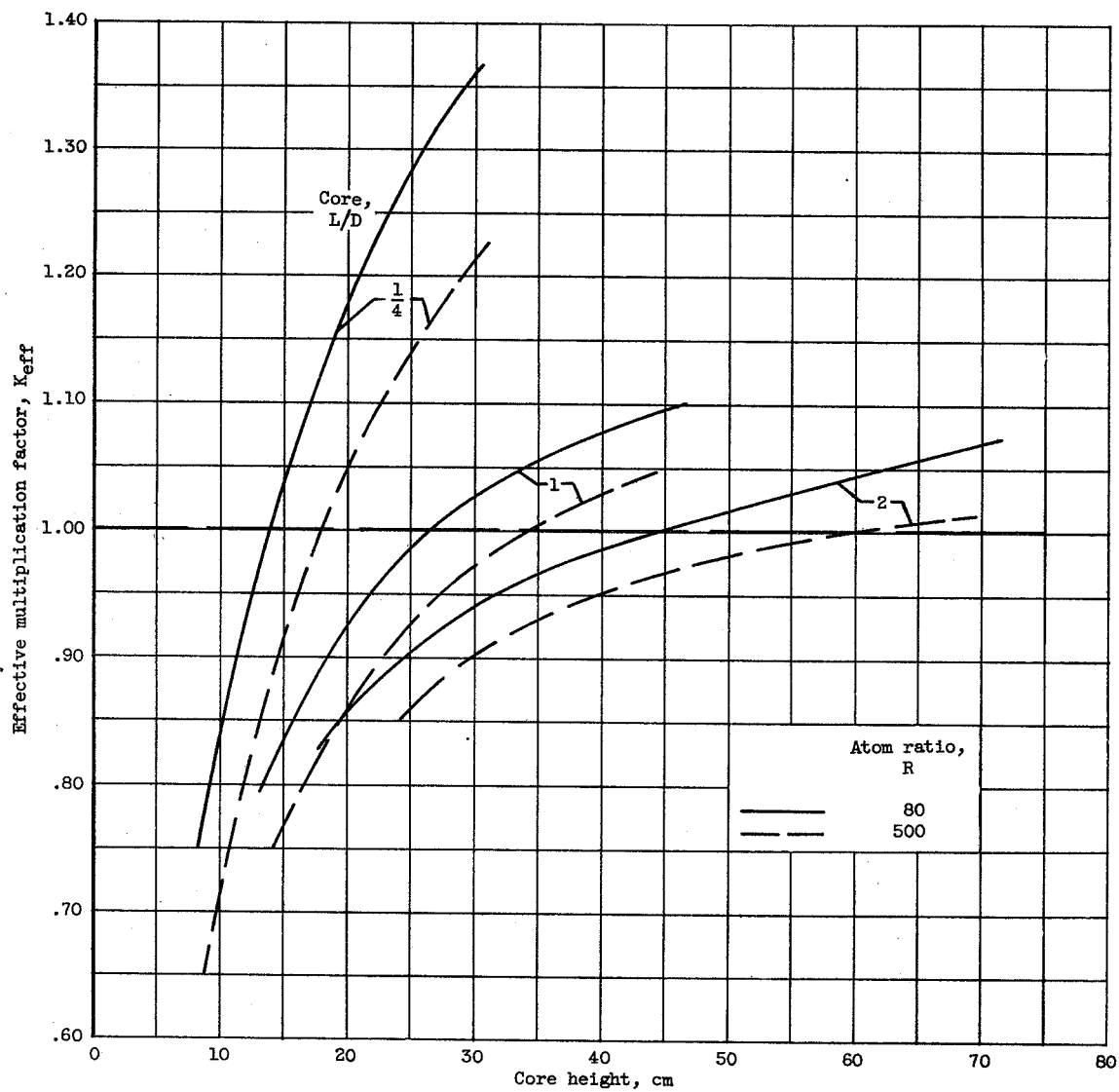
Figure 2.10 - Reactivity of bare $UO_2F_2$-$H_2O$ cylindrical assemblies.
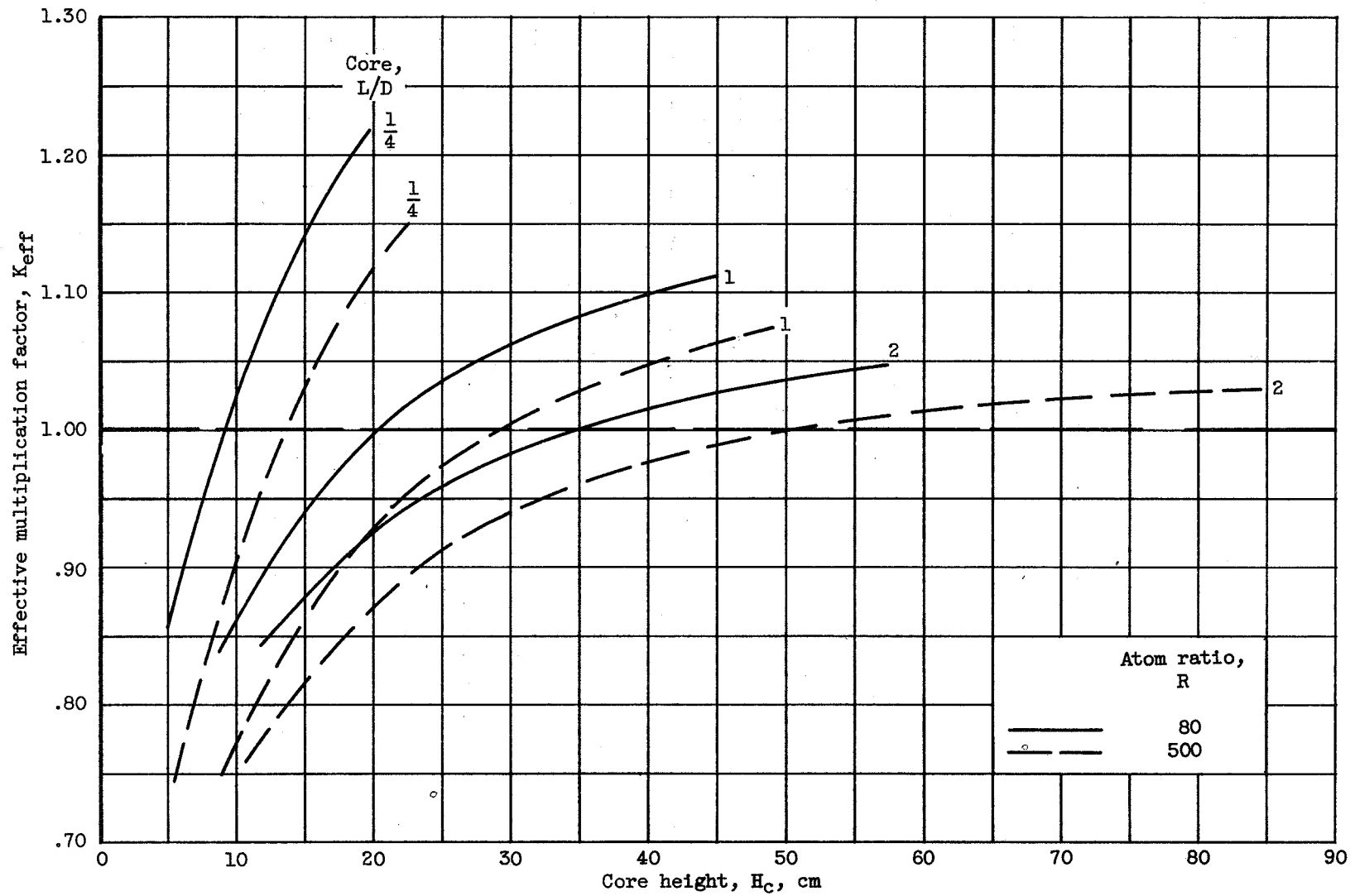
Figure 2.11 - Reactivity of water-reflected $UO_2F_2$-$H_2O$ cylindrical assemblies.
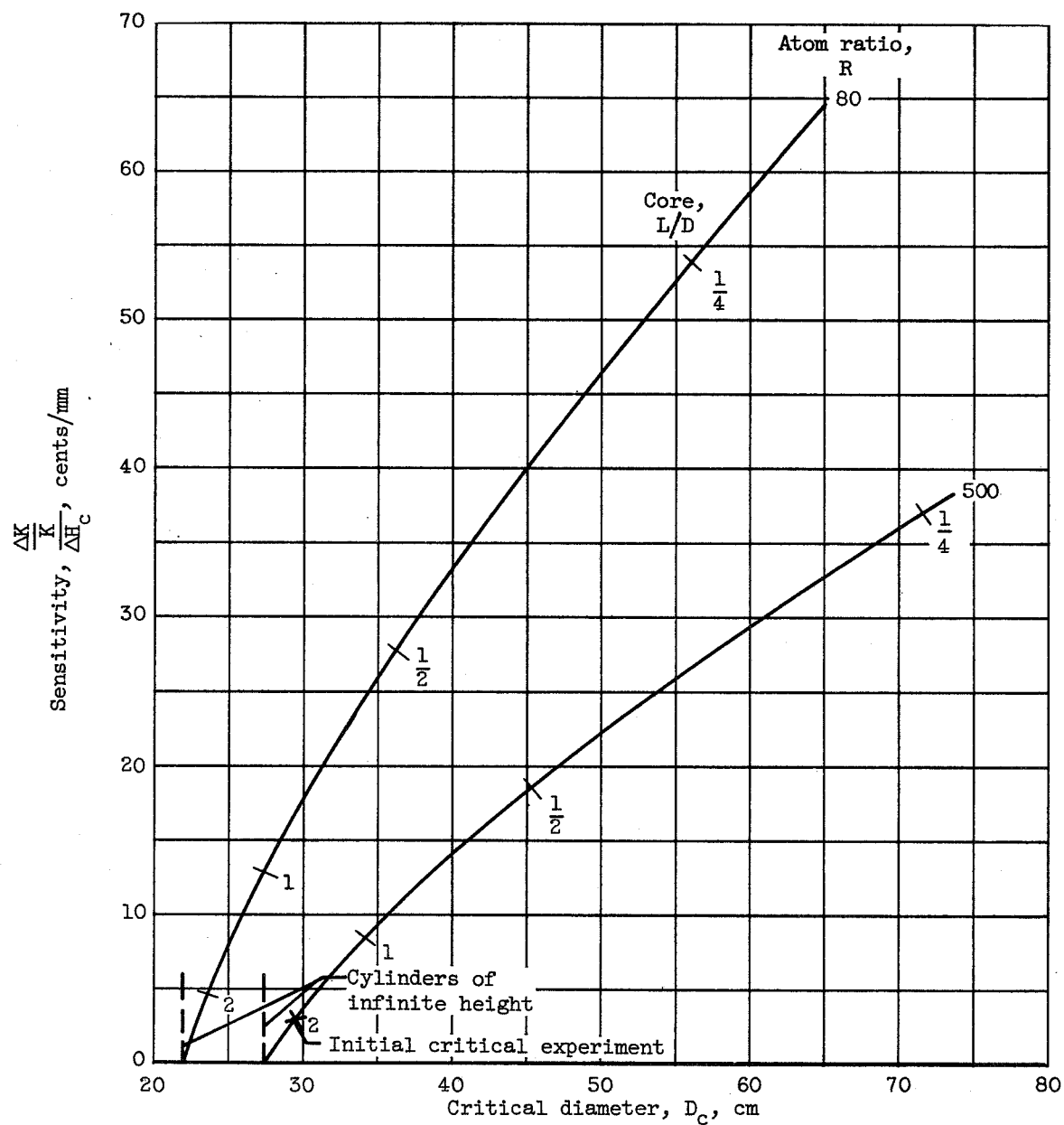
Figure 2.12 - Sensitivity of bare critical $UO_2F_2$-$H_2O$ cylindrical
assemblies to increment in core height.
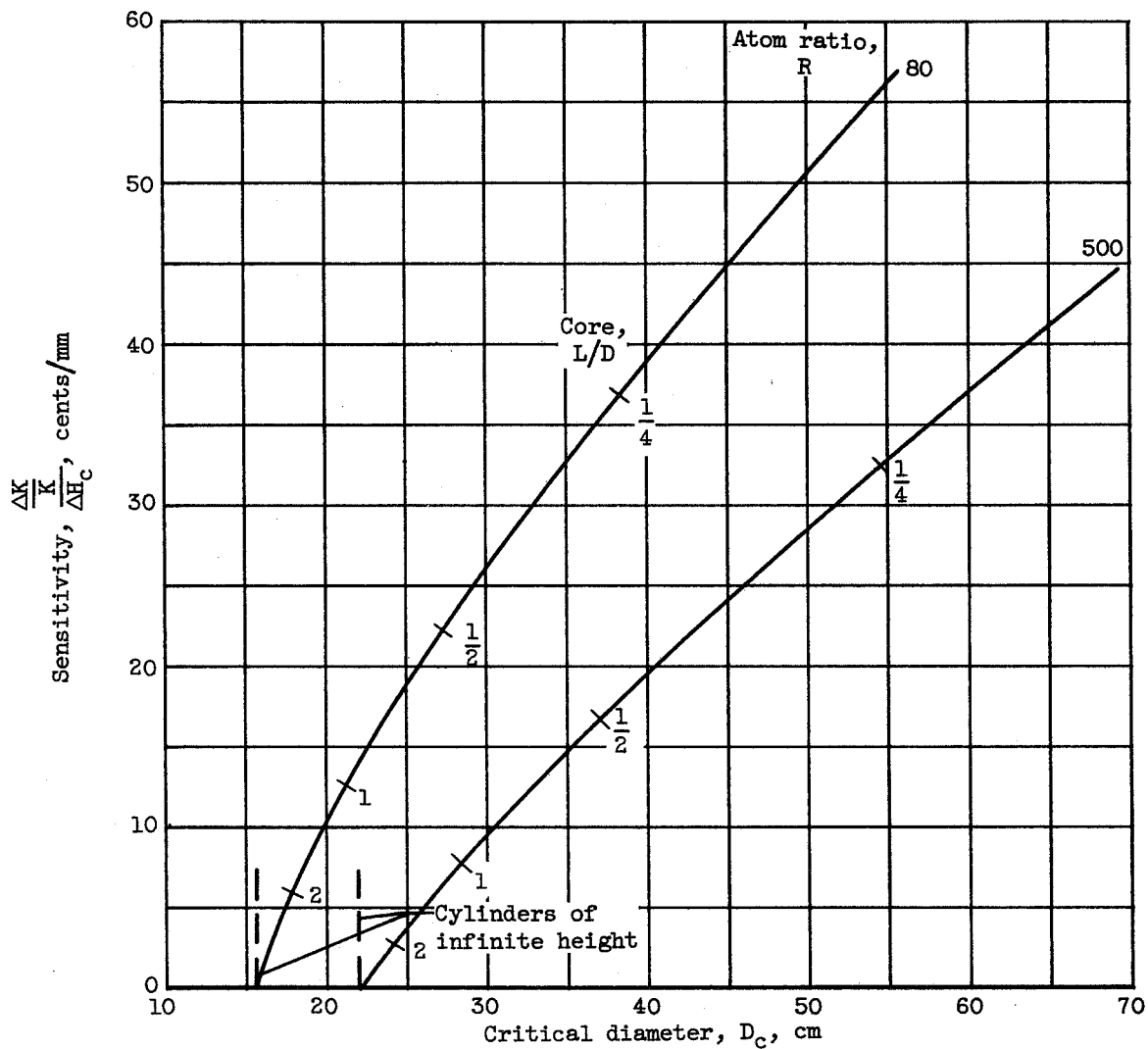
Figure 2.13 - Sensitivity of water reflected critical $UO_2F_2$-$H_2O$ cylindrical assemblies to increment in core height.
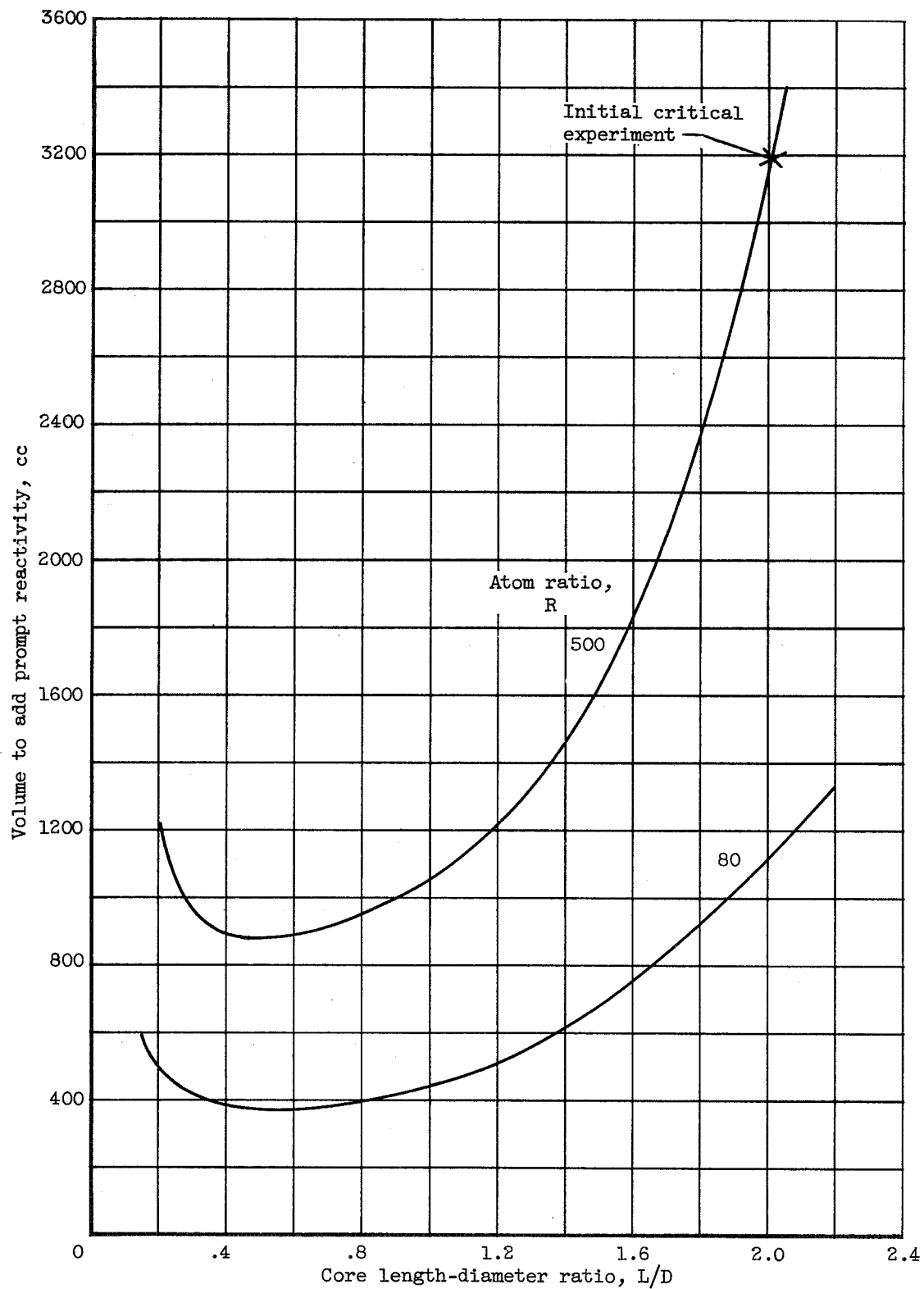
Figure 2.14 - Volume required to add prompt reactivity to bare $UO_2F_2$-$H_2O$ cylindrical critical assemblies.
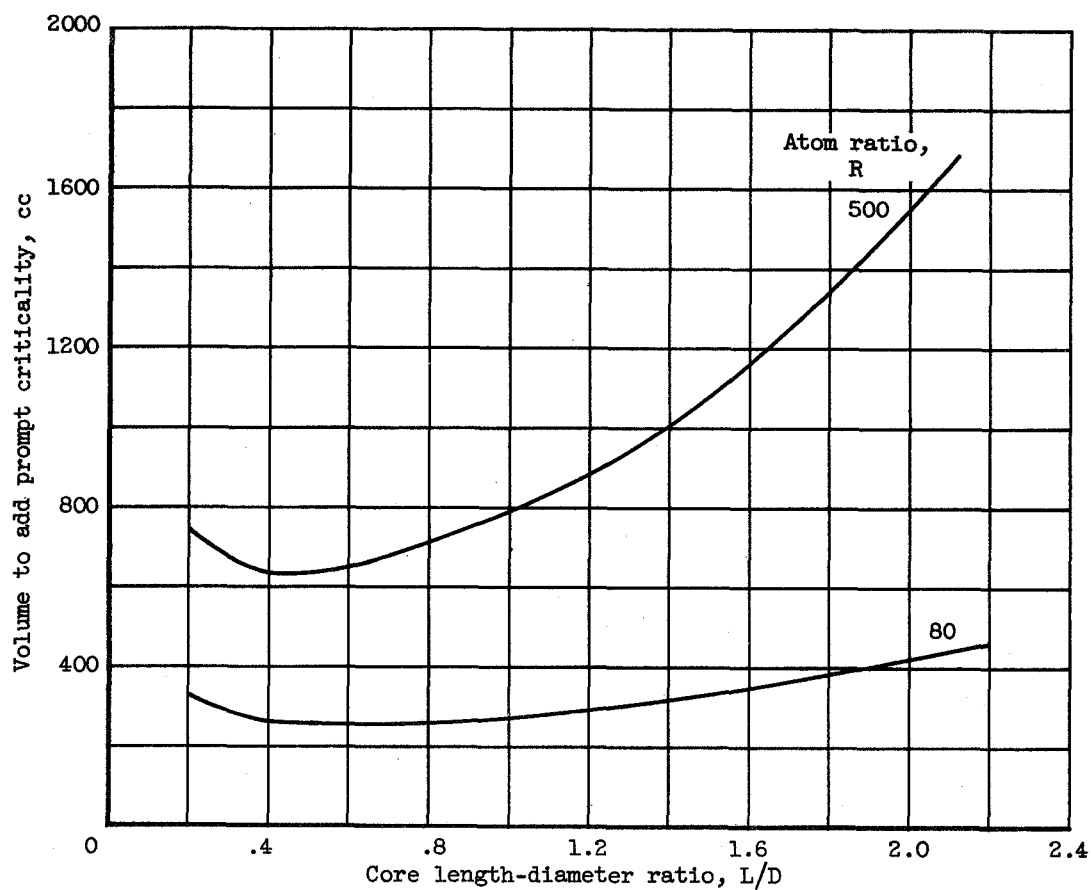
Figure 2.15 - Volume required to add prompt reactivity to water reflected
$UO_2F_2$-$H_2O$ cylindrical critical assemblies.
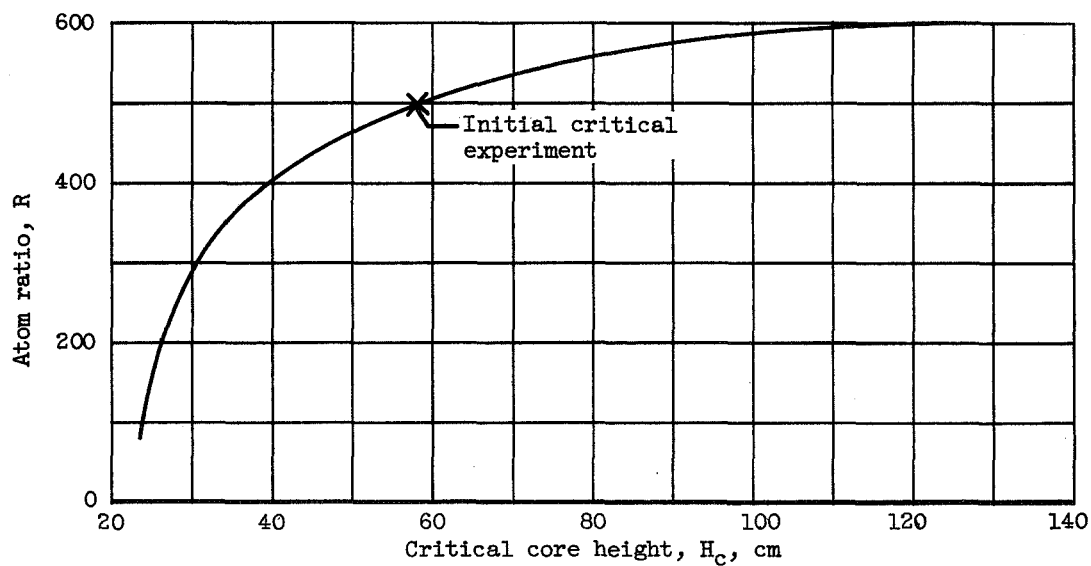


Figure 2.16 - Criticality data for a bare cylindrical core of diameter
29.5 centimeters with various $UO_2F_2$-$H_2O$ solution concentrations.
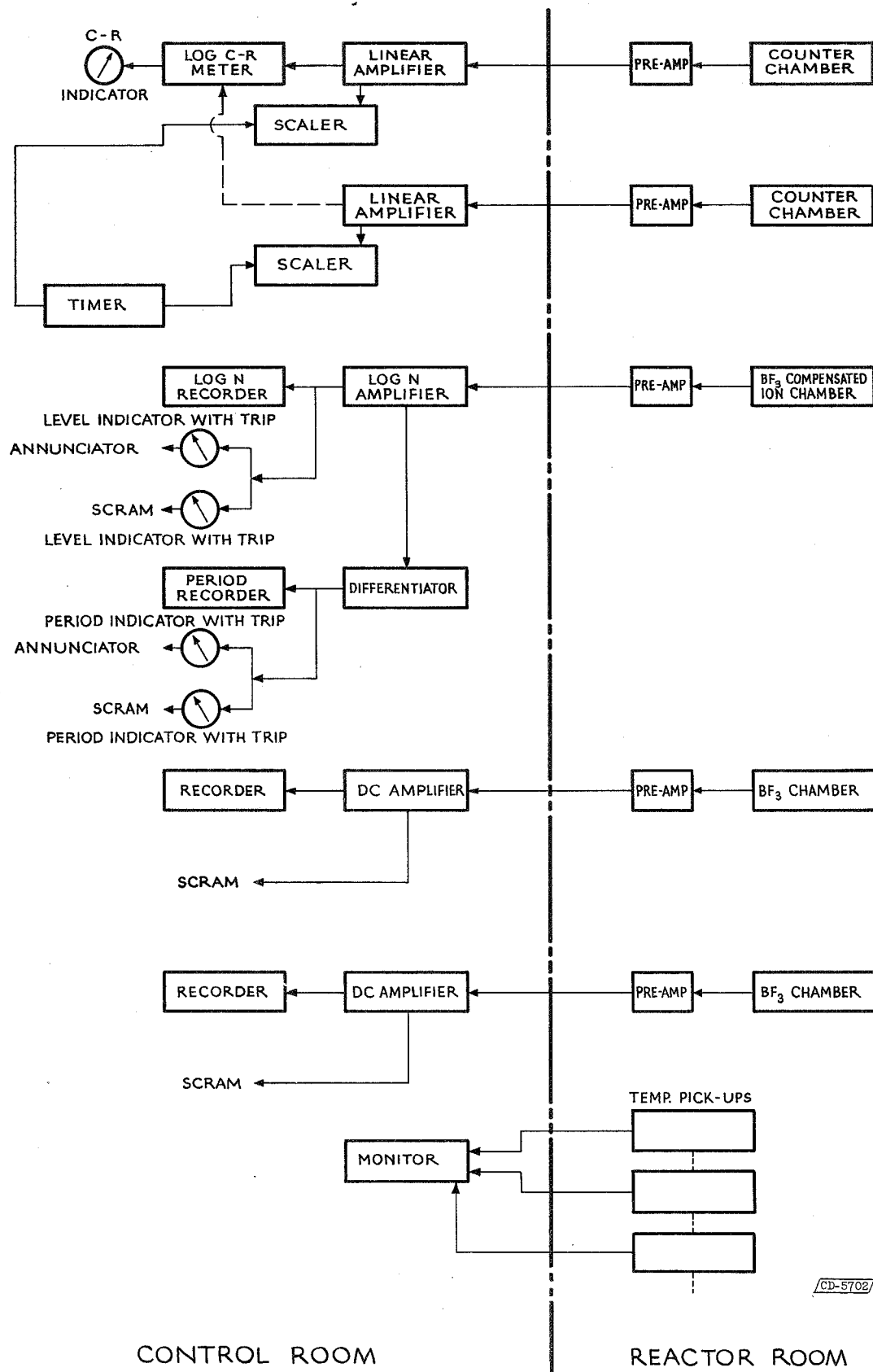
Figure 2.17. - Reactor instrumentation.
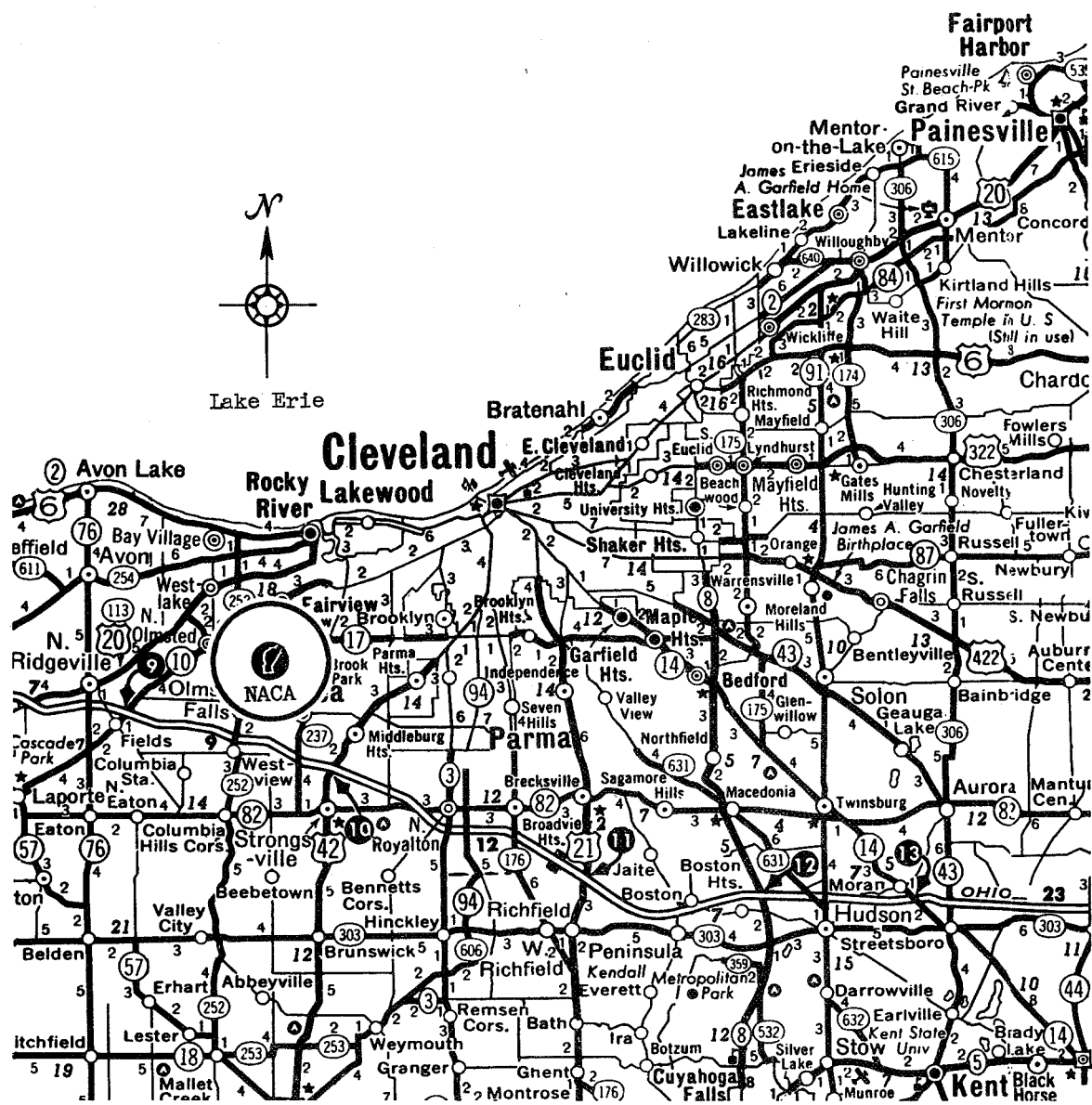
Figure 3.1. - Map showing reactor site in relation to Cleveland.
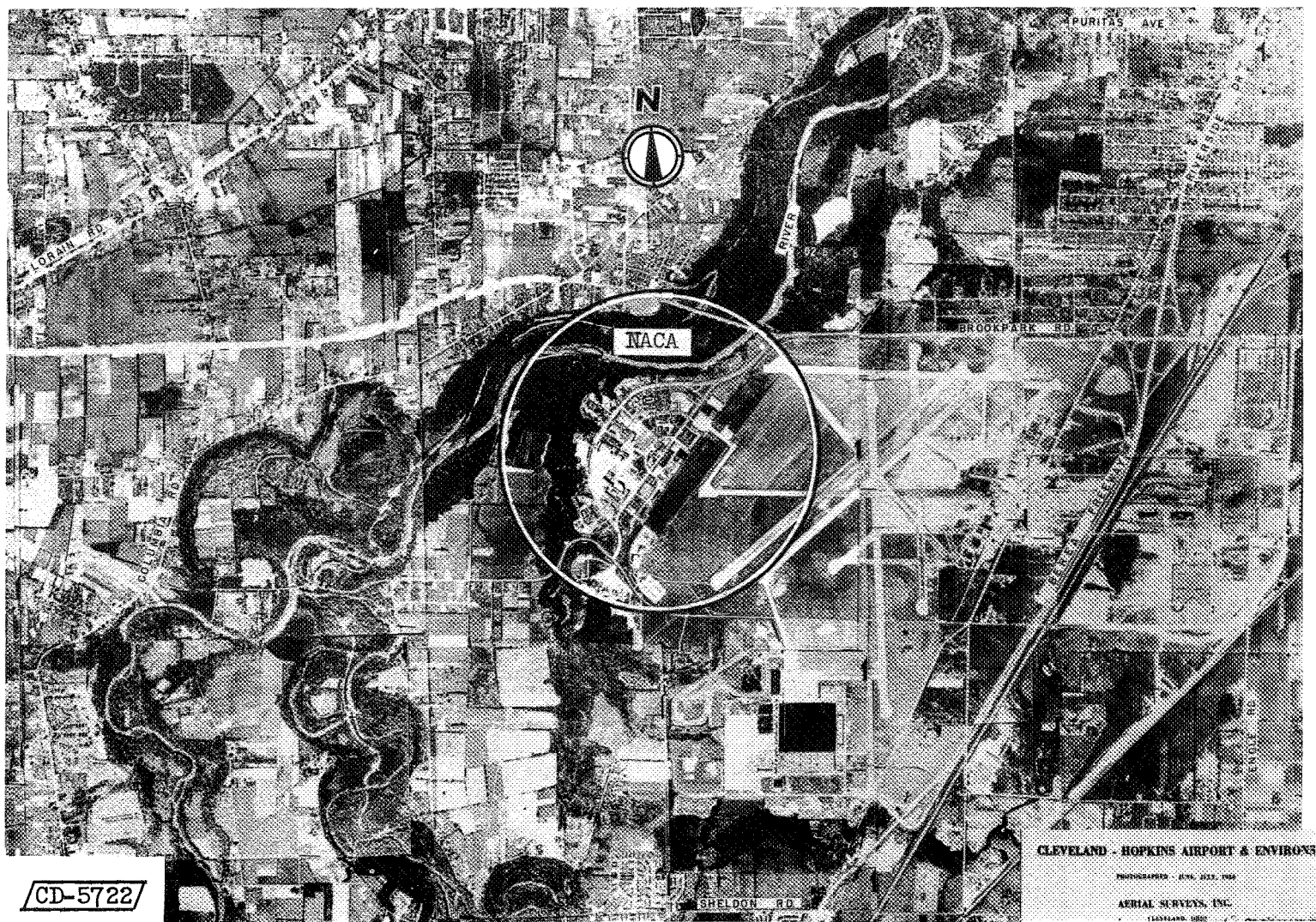
Figure 3.2. - Aerial mosaic of site area.
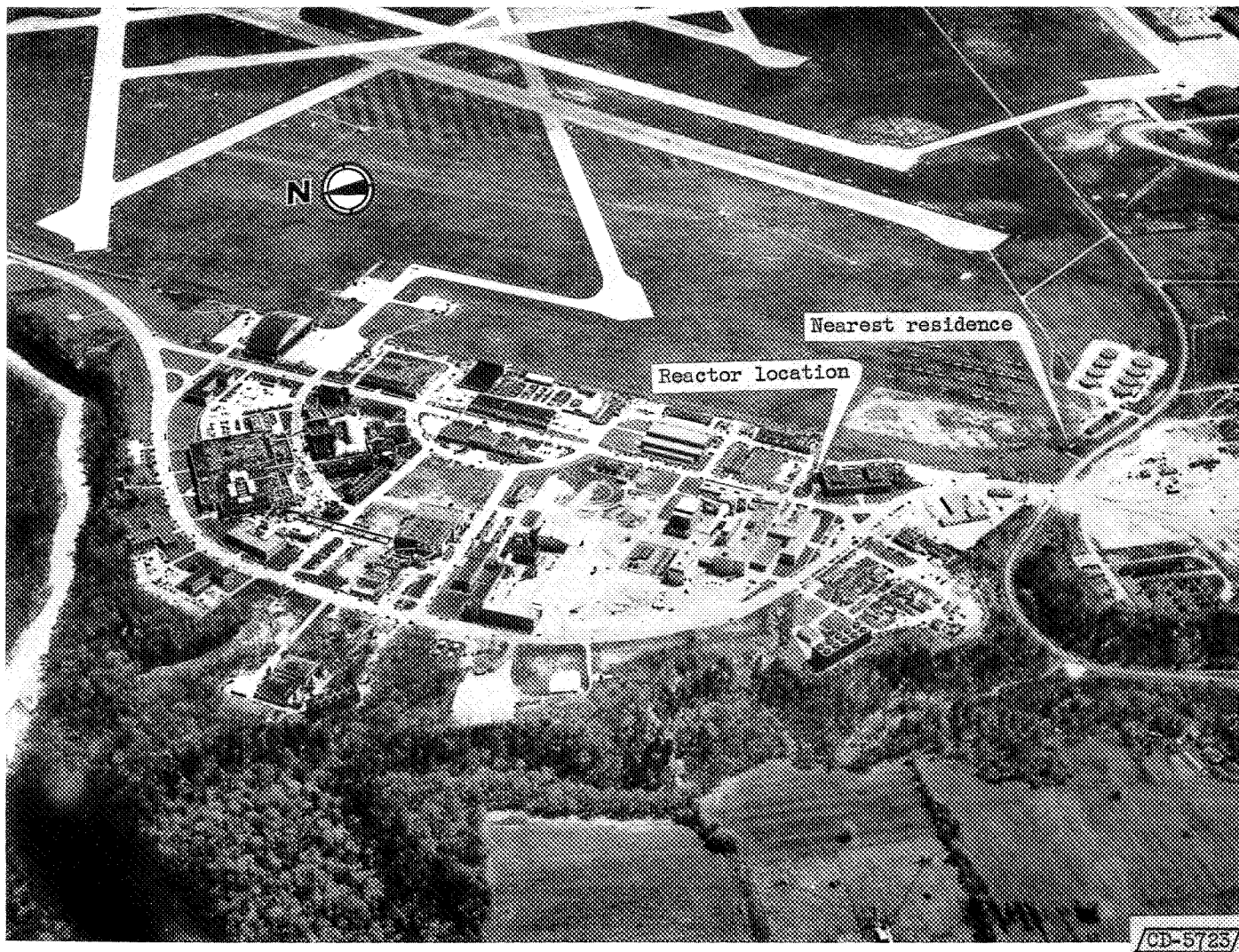
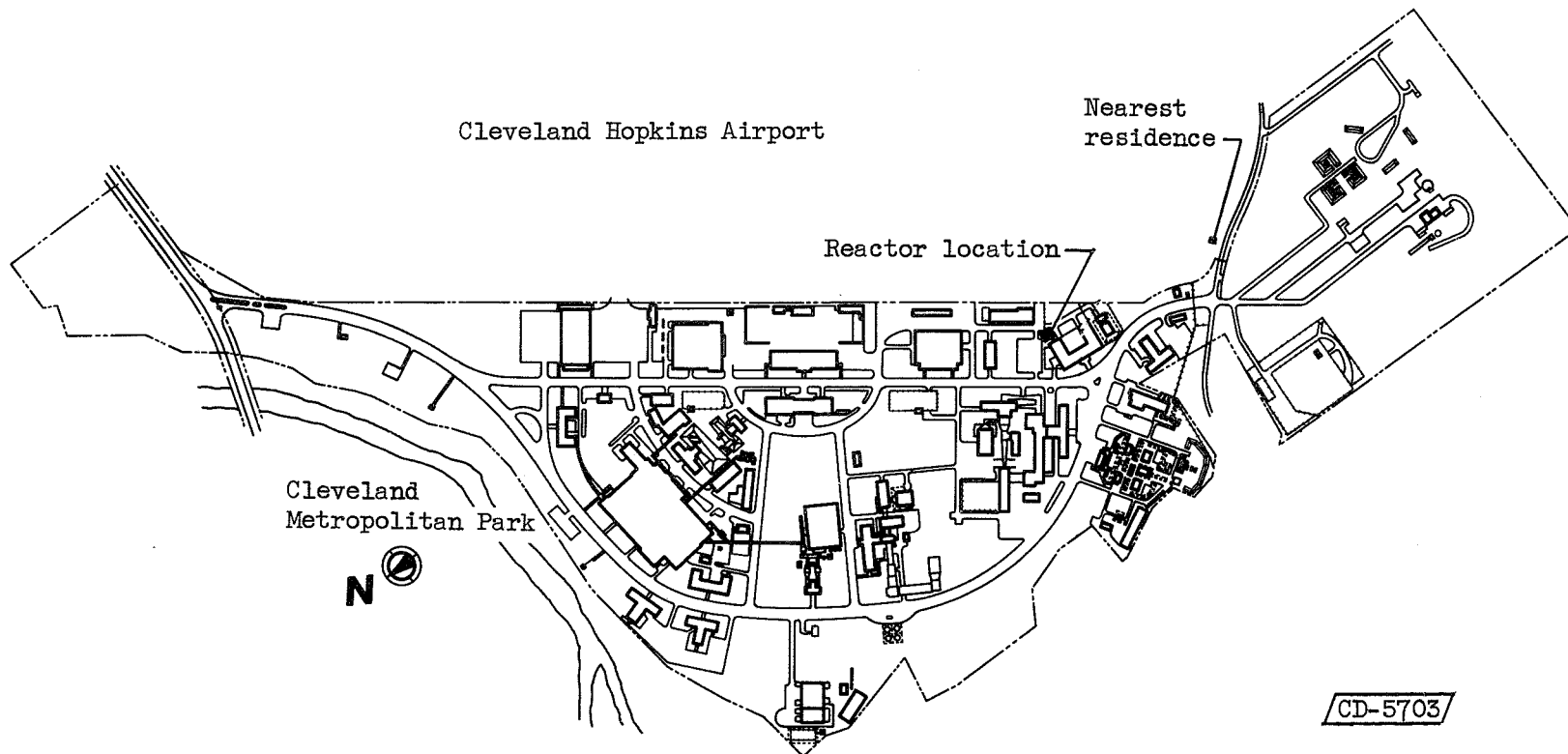Figure 3.3. - Aerial photograph of Lewis Flight Propulsion Laboratory, NACA.

Cleveland Hopkins Airport

Nearest
residence

Reactor location

Cleveland
Metropolitan Park

N

CD-5703

Figure 3.4. - Plot plan Lewis Flight Propulsion Laboratory, NACA.

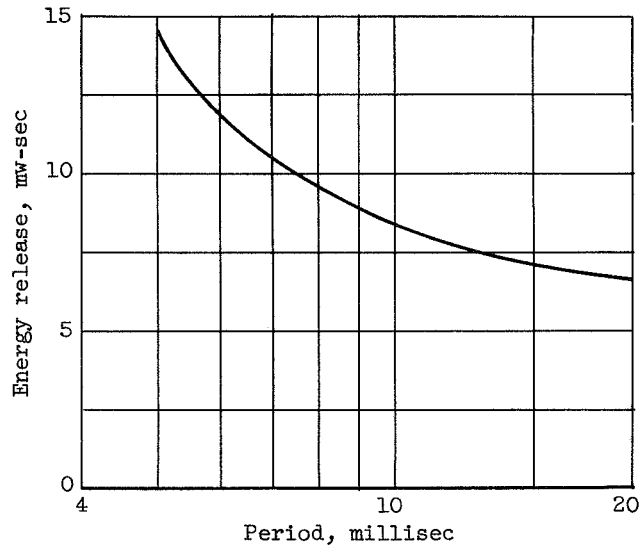Figure 3.5. - Segment of Euclid, Cleveland, and Berea quadrangles.

Figure 5.1 - Variation of total energy re-
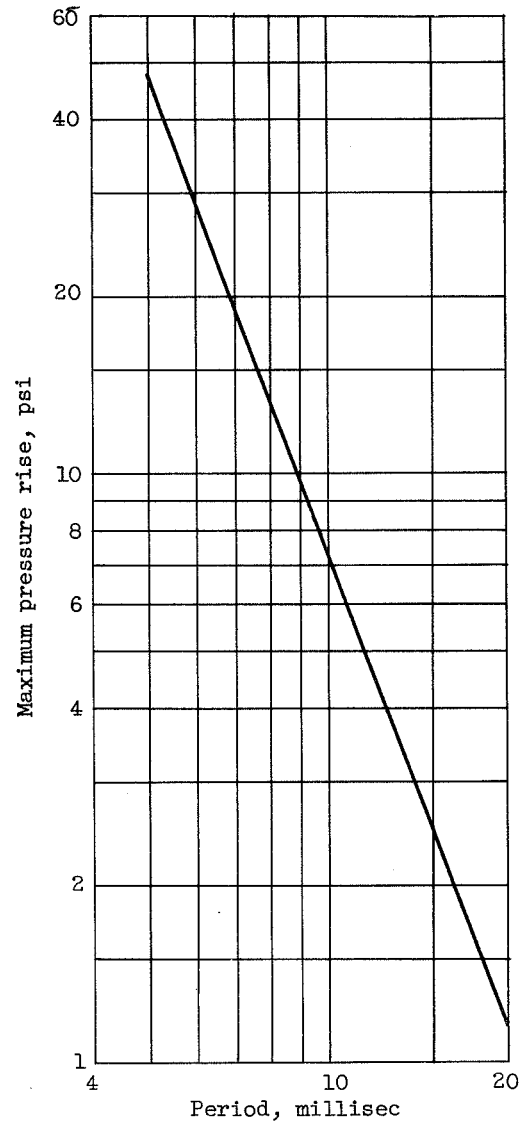lease with period (taken from NAA-SR-
1525).



Figure 5.2 - Variation of maxi-
mum pressure rise with period
(taken from NAA-SR-1525).