ANL-5552
Physics

-1-

ARGONNE NATIONAL LABORATORY
P. O. Box 299
Lemont, Illinois

INTERIM REPORT ON "ARGONAUT"

A GENERALIZED REACTOR FACILITY FOR NUCLEAR TECHNOLOGY TRAINING AND RESEARCH

by

D. H. Lennox and B. I. Spinrad

March, 1956

Operated by The University of Chicago
under
Contract W-31-109-eng-38

TABLE OF CONTENTS

3

"ARGONAUT" - A GENERALIZED REACTOR FACILITY FOR NUCLEAR TECHNOLOGY TRAINING AND RESEARCH

by

D. H. Lennox and B. I. Spinrad

PREFACE

The material presented here is preliminary and is intended solely for information as to the present status of the Argonaut Reactor concept.

I. Introduction

The great expansion of nuclear technology which is expected within the next decade requires new tools, both for education and for the performance of tests on the physics design of the systems to be studied. Presently existing research reactors were not designed to meet these needs. Their high power levels do not permit flexibility of installation and limit the usefulness of the reactors as measuring tools (for example, for danger coefficient and pile oscillation studies). Therefore, such reactors as CP-5, MTR, LITR, and the Brookhaven Reactor have become basically high-level neutron sources for experiments in pure science and radioactive engineering.

In designing new reactors and measuring reactor parameters, zero power systems have been widely used.[1] The ZEEP at Chalk River is perhaps the most famous of these systems and has been the most prolific of general criticality studies; but there are many more. The Argonne ZPR-I and II were systems which tested specific lattices; the North American Water Boiler, the ANL Fast Exponential Experiment, and the Savannah River TTR were used as low-level sources of neutrons for measurements on reactor properties; and the KAPL TTR, the Phillips RMF, and the Westinghouse DCTF were designed primarily as analytical tools for measuring physics properties of materials in reactors.

All of these low power or zero power experiments have been excellent facilities for the training of personnel in reactor physics operations and reactivity behavior. Since all such facilities have been flexible systems associated with experiments which vary their reactivity strongly, their operation has taught the experimenters a great deal about reactor physics.

With the advent of the School of Nuclear Science and Engineering (SNSE) at Argonne, demands for use of CP-5 as a pedagogical tool have competed with its use as a high-flux research tool. Moreover, shutdown of CP-2 has forced the Laboratory to discontinue danger coefficient and pile oscillation work. Consequently, there is need for a reactor which

4

would fill the pedagogic requirements of the School and also be available for reactivity test work and as a low-level neutron source for exponential experiments and instrument calibration. Although the TTR type was initially favored, having been used both as a neutron source and a test facility, other reactor systems were examined. Factors considered were convenience, safety, cost, and flexibility. Of the various types (water boilers, swimming pools, heavy water lattices, graphite lattices) only the swimming pool concept seemed competitive to the TTR in its general flexibility. The swimming pool system is superior to the TTR as a tank with control rods and instruments for generalized critical studies; but it is inferior in sensitivity and convenience, both of these defects arising from the presence of water, which requires either stainless steel or canned experiments and which is not a very good neutron reflector.

A further advantage of the TTR concept is its adaptability as the source core of an internal exponential experiment. This type of experiment appears so promising for reactor design work that this advantage cannot be overlooked.

Consequently, the TTR has been made the basis of a design study for a reactor system to be used for the purposes mentioned. Since these purposes are compatible with university nuclear engineering training and research requirements, it was decided to attempt a minimum cost design even at the expense of conventional design practices. As the concept proceeded, the design changes from the original TTR became so drastic that it was decided to rename the system. "Argonaut" was chosen as an easily remembered title combining the Laboratory's name and letters which stand for "nuclear assembly for university training"; or as an even simpler mnemonic, "Argonne Naught Power Reactor."

II. General Description

"Argonaut" is a thermal reactor consisting of an annular cylindrical core with an internal and external graphite reflector (see Figs. 1 and 2). The core is heterogeneous, the fuel elements consisting of Borax-type fuel plates in assemblies ca. 3" x 6" x 24". The moderator in the fuel element is water. Graphite separators are placed between the elements. The critical loading of the system is expected to be less than 4 kg of U^{235} at 20% enrichment. The reactor is capable of operation at a maximum of 10 kw of thermal power, at which level, only brief tests are recommended. Thermal neutron fluxes of 10^{11} neutrons per centimeter per second are available at this power.

The internal graphite reflector (also called "internal thermal column") may be used as a locus for danger coefficient work or replaced by a portion of a lattice assembly for internal exponential experiments. The diameter of this internal reflector is dictated by the minimum size of a lattice portion which might still give an equilibrium spectrum at its center; for graphite lattices, which have ordinarily the largest lattice spacings, it appears that a two-foot diameter will be barely sufficient and this diameter has, therefore, been accepted.

The annular core is contained between two aluminum tanks, 2' and 3' in diameter, both 4' in height, and the fuel elements are mounted at mid-height. The inner tank surrounds the internal thermal column and the outer tank is surrounded by a 1' thick graphite layer. On one side the graphite is extended horizontally to form an external thermal column. On the face opposite the external thermal column is a movable tank for shielding studies.

The two sides of the oblong thus formed are backed up with a shield consisting of ca. 5' of solid ordinary concrete block stacked in brick fashion with lead instead of mortar. The overall dimensions of the systems within the shield are 17' long by 15' wide by 8' high.

The top of the lattice is to be accessible for loading experiments or for the placement of an exponential assembly; therefore, it is necessary to keep this surface free of control mechanisms. That has been done by considering several comparatively novel control systems.

For the primary safety system, two events are to be initiated simultaneously to give fast and absolute shutdown. A rapid decrease in moderator bulk density is effected by nitrogen injection while the moderator (H_2O) is dumped through a quickly opening valve. The injection system is made "fail-safe" by using the nitrogen pressure to close a normally open moderator drain valve.

Secondary control is to be obtained from conventional absorbing materials placed next to the core in the outer reflector. Under consideration are several insertion methods as follows:

1. Gravity-actuated rods with a 1' travel, replacing graphite reflector with a cadmium-plastic absorber.
2. Mercury sheets, hydraulically operated.
3. Window-shade type blades.

For any of the above methods a multiplicity of rods or blades is needed so that only a cascading of mechanical failures can impair control.

With the design just described, it is possible to consider a comparatively low cost for the system as a whole. Excluding fuel rental charges, it is believed that the pile could be brought into operation for an outlay of less than $100,000. Each component has been scrutinized for cost and, where possible, a cheap way of doing things has been selected. Thus, the frame of the reactor, within which the graphite sits, is specified as of bolted construction (Fig. 3), allowing standard components and a minimum of field labor. Both the thermal column and shield are manufactured by stacking standard components. Special pieces have been reduced to those required for sample holes and to specially machined graphite pieces immediately adjacent to the cylindrical core. Stainless steel has been avoided, and, since the pile does not operate at a high power, the heat removal system is rudimentary.

A 50' x 50' floor space with 20' headroom is recommended, since a useful assembly attracts to it considerable equipment. However, in case floor space of this sort is not available and the user is in a position to insist on good housekeeping, a 20' x 30' space with 18' headroom immediately above the 5' square core and nearby reflector is a minimum. For the area on which the pile rests, a floor loading of 1500 to 2000 pounds per square foot is required. The utility requirements are water, at 10 gallons per minute at a maximum temperature of 75°F, and 35 kw of 110 volt AC, single-phase electricity.

III. Component Details

A. Internal Thermal Column

A standard configuration of the reactor uses an internal thermal column which is 2' in diameter and 3' long, constructed of pile grade graphite. The cylinder is penetrated by a sample hole along the axis and four other sample holes at 90° to each other and at varying radii.

B. The Active Region

The active region is contained between two tanks 4' high, made out of type 6061-T4 Al. The tanks are 2' and 3' in diameter, the outer being 1/4" wall and the inner, 3/16".

C. Fuel Elements (Fig. 4)

The fuel plates will consist of 20% enriched material, ca. 35 weight per cent of uranium oxide in Al as the meat. The plates are 2.8" wide by 24" long by 0.09" thick. They are to be loaded into a box 3" x 6" x 24", slotted for plate removal and permitting a maximum of 22 plates per box. The boxes are loaded into the annulus with the 6" dimension along a pile radius, and will probably be supported on the graphite wedges described below.

D. Dummy Fuel

Critical calculations predict that a smaller critical mass is achieved by interspersing graphite blocks in the annular core. These will be coated, if necessary, to resist swelling and crumbling in the water environment. They are of the same shape as, and interchangeable with, the fuel boxes. In addition, graphite wedges are used to space the fuel elements so that rectangular boxes will fit in the circular annulus.

While the final geometry has not been fixed, it appears that if 24 fuel box locations are provided, minimum critical mass is achieved when only eight of the boxes contain fuel and the others contain graphite dummies. This critical mass is estimated as between 3 and 4 kg.

E. Reflector

The active region is surrounded by AGOT graphite in blocks of 4" x 4" cross section (where filling of interstices is not required), stacked so that the core is imbedded in a graphite block 4' high and 5' square in cross section. Above and below the core is one foot of water.

F. External Thermal Column

This external thermal column immediately adjacent to the core consists of AGOT graphite 4' high and 5' wide. The length of this thermal column, presently specified as 5', is subject to change pending results of calculations and measurements on the cadmium ratio as a function of graphite thickness.

Removable stringers for sample placement are provided in the vertical direction and along the axis of the column.

G. Irradiation Facilities

Against the unshielded reflector face opposite the thermal column is a tank supported on a movable cart. Initially, the tank will be filled with H_2O for shielding studies; however, other materials can be substituted in the tank or stacked directly onto the cart.

H. Shielding

Experience with the zero power reactors in operation at Argonne has shown that extreme shielding difficulties exist when a bare reactor is placed inside a shielded cell. Consequently, "Argonaut" is constructed with an integral shield which eliminates many of the interlocking systems and shutdown radiation hazards of cell construction, besides permitting installation at a lower cost. On the sides of the reactor (i.e., those two faces of the square core which do not have the thermal column and radiation facility) walls are constructed of ordinary concrete blocks, 150 pounds per cubic foot, 18" x 18" x 30". These blocks are stacked with 1/16" lead gaskets used instead of mortar. This construction has provided adequate shielding in critical assemblies at Argonne at a lower cost than monolithic concrete. The maximum thickness directly adjoining the core sides is 5'; the ends are tapered. Immediately above the core and surrounding reflector is a high-density (250 pounds per cubic foot) concrete plug, 5' square and 3' high. The use of high-density material at this point is justified by doubled savings in head room. The remainder of the top shield is ordinary concrete block of maximum 3' depth.

I. Water Circulation System

In order to achieve the delicacy of control required for sensitive reactivity measurements, thermostating of the water in the core is necessary. Consequently, a circulating pump, with a maximum capacity of 10 gallons per minute, is included in the water line. The water is then passed through a heat exchanger of ca. 25 square feet of surface. The heat exchanger could conceivably be an old automobile radiator placed in a laboratory thermostat. Cooling water and heating elements may be included in the line to allow low power experiments on temperature effects. Water lines are standard plumbing materials, or plastic tubing where convenient.

Provision is also made for a three-liter mixed-bed ion exchange column to keep the water clean.

J. Control

The shutdown and safety system of simultaneous nitrogen injection into the water and water dump has already been described. Components of this system are being subjected to experimental test. Of particular significance are the steady-state bubble volume and the rise time of the bubble density in the system as a function of nitrogen pressure and valve and nozzle design. The secondary safety system and the regulating rods have not been selected. Initially, the reactor will be brought into operation with gravity blades, but these will be removed when another system has been checked out.

K. Start Up Source

The reactor is to be provided with an antimony-beryllium source capable of providing 10^7 neutrons per second. The antimony is removable for reactivation in CP-5 or other high flux piles. A source of this type has been in use at the SNSE for exponential experiments and equipment for handling is in existence. Pile charges from CP-5 for activation of the antimony have run around $20 per shot and the source itself costs ca. $200.

L. Instrumentation

Included as an integral part of the reactor is all instrumentation necessary for startup and normal operation. It is expected that auxiliary instrumentation for experiments will vary with individual interests and will be obtained separately. However, with the equipment supplied, a variety of experiments can be performed to demonstrate or explore the basic characteristics of thermal reactors.

Four independent trip channels, effective throughout the operating range of the reactor, will be used. A signal from any one of these safety circuits will be sufficient to initiate shutdown if a potentially dangerous situation is reached. Three of the channels will trip at a preset power level, the other at a given rate of increase. For two of the level trips, DC amplifiers fed from parallel plate, boron-coated ionization chambers will be used. A count rate meter working from a $B^{10}F_3$ chamber provides an additional power level trip circuit. The remaining trip circuit will be a logarithmic amplifier and pile period meter. This instrument will indicate the neutron flux level over a wide range without any switching or scale changes.

A continuous record of power level will be made with two strip chart recorders. One recorder will be fed a standard bucking voltage to provide a differential effect useful for monitoring small changes in power level.

For startup or multiplication measurements, there will be two proportional counters. An audio "popper" working from one of the proportional counters will serve as an audible indication of the reactor power.

Gamma background in the general area around the reactor will be monitored by a separate circuit working from either a scintillation detector or argon chamber. A visual and audible warning system will operate from this instrument.

The meters, switches, and recorders, together with indicators for rod and source positions, water flow rate, temperature, and level, and condition of trip circuits, will be brought out to a console desk. Scram buttons are located on the console, as well as at convenient points on the surface of the reactor shield.

M. Auxiliary Equipment

The components of the pile as described are all portable in that the pile could be disassembled and re-erected at another location. In line with the philosophy of complete portability, a jib crane plus electric hoist is provided with the structure. It is mounted at the inner wall of one of the side shields. With this there is no need for an overhead crane in the building where the pile is located, although it is really up to the user to determine the proper crane equipment for his purpose.

N. Experimental Equipment

Experience in the performance of reactor experiments is that very little equipment is reusable, except as raw material for fabricating new equipment. Hence, in Argonaut, emphasis is on providing space for experiments, rather than furnishing equipment. Although many items could be supplied, their inclusion in the Argonaut package would increase its cost markedly, without significantly improving its utility. Only instruments which are useful for reactor operation are provided.

Moreover, in a university environment, the purpose of instruction and research are well served by generating a "do it yourself" attitude in the user. Hence, while we recommend installation of a pile oscillator for cross section tests and a pile "modulator" for kinetic experiments, we believe that each user should design his own, making allowance for the inclusion of spare items which tend to accumulate on laboratory shelves. Similarly, the performance of exponential experiments requires external tanks and lines, which must be individually designed; in some cases, internal exponential experiments will require the inclusion of extra safety rods, which must be considered as part of the experiment. Precision flux monitors provide an excellent research field; automatic reactor control ought to be considered in the same light.

Because potential users of Argonaut may be generally expected to have counting equipment available, this, too has been omitted; if this is not the case, general counting needs can be amply satisfied by purchase or construction of scintillation counting equipment valued at about $5,000.

IV. Safety

Argonaut belongs in the category of "inherently safe" reactors. The particular group of which it is a member consists of the MTR, LITR, BSTF, and BORAX reactors, and it shares with these systems the following core properties:

a. Water moderation
b. Plate-type fuel elements, with water channel cooling
c. Enriched fuel contained in an aluminum matrix
d. Large leakage of neutrons from the core
e. Large negative void coefficients

With these properties, tests on BORAX have demonstrated that it is a problem of considerable magnitude to achieve a nuclear runaway which will damage the reactor, even when safety circuits are left inoperative.

11

While the Argonaut system is thus designed to be as safe as any reactor can be, it is nevertheless no safer than the user makes it. The following points of safety must be examined. For reference, we have used comparable laboratory situations as examples.

1. The equipment must be designed so that unavoidable accidents make it harmless to a user who carries out operations in a prudent manner. This implies either that the experimenter is shielded from the consequences of possible accidental failures (compare with a chemical experiment in which a potentially explosive reaction is performed behind safety glass) or that the experiment has self-limiting features (a situation not commonly encountered in exothermic chemical reactions except by exhaustion of reagent).

2. While an experimenter ought not to be severely hurt by the consequences of his own folly, the only ultimate safeguard is to prohibit his access. Since this means not performing an experiment, the alternative is to make access difficult enough so that this difficulty serves to remind the experimenter of possible hazard (compare with the use of high voltage equipment, whose casing may be removed for servicing with some difficulty).

It is also appropriate to point out that the proper safety attitude must be an integral part of any training program and that this is the best preventive of unsafe procedure. That respect for dangerous conditions can be instilled is indicated by the small number of calamities occurring in performing hazardous chemical research operations.

3. The possibilities of a given experiment being hazardous must be observable to fellow workers in the area, so that they may protect themselves (compare to the use of "poison" signs in connection with performance of experiments involving generation of HCN or H_2S; or the illumination of a panel light when current is on).

In this connection, training is also important, since it is the responsibility of workers in the area to judge, from the "announced" condition of the system, what hazards to keep in mind.

4. The ultimate requirement is that innocent bystanders (defined as people who are not connected with the experiment or use of the equipment) shall not be harmed as a result of experimental folly (compare with dangers of releasing noxious gases from a chemical hood).

Based on these requirements, the properties of Argonaut and the limitations on its use may be briefly examined.

1. The reactor is inherently safe in the self-limitation of reactivity due to boiling. In addition, the monitoring mechanisms and safety devices will automatically correct potentially dangerous situations before the

inherent safety mechanism of boiling shuts the system down. An extreme case of accidental failure is still not disastrous.

If monitoring and sensing or safety mechanisms fail while the reactor is in its normal configuration, or if the safety interlocks have been by-passed to allow criticality while the safety mechanisms are acting at capacity, the reactor can be brought to critical and above by pumping up water. This occurs relatively slowly and adiabatically. A high power level is achieved, and if a scram does not occur, the water is boiled away, in probably a bumpy, but not explosive manner. The nuclear energy liberated would be of the order of that required to boil all the water in the system, and the time required for this would be several minutes.

2. The most dangerous situation would be the dropping of a large mass of material into the internal thermal column while fuel is in the annulus and the water is up. This accident involves folly, rather than equipment failure, since standard procedure is to unload the annulus completely when making a gross change in internal column characteristics. However, such a gross blunder (comparable to performing glass-blowing operations in a room in which ether solutions are being evaporated) is guarded against by interlocking the water dump with the internal column removal; and since removal of the annulus plug is required before the internal thermal column can be removed, fuel unloading is made convenient.

3. The warning devices indicating the condition of the assembly are automatic, and are both visual and aural. This, which is general in critical assembly work, is far more satisfactory than the posting of signs, which should, however, also be done. Also, the reactor may be shut down by anyone in the area who considers an operation unsafe.

4. Except under the conditions postulated in (2) above, the shutting down of a nuclear runaway by boiling is not accompanied by liberation of large quantities of fission gases to the atmosphere. In an accident at Argonne which was terminated by partial vaporization of a hydrogenous core, the activity was confined to the cell in which the accident occurred. Nevertheless, the level of activity, even in this confined space, soon dropped below tolerance.

To summarize, then, the nuclear system of Argonaut is safe so long as the user takes the minimum precautions against grossly unsafe practices. To insure this, it is necessary that a research establishment with an Argonaut acquire competent personnel to supervise the reactor operation. Initially, such people can only be trained in existing installations; thereafter, the training will be a phase of student activity.

The operator, supervisor, or professor must accept the following responsibilities:

1. He must see that monitors, trips, and safety devices are functioning properly by means of operational checks; and when they are not, he must have authority to shut down the reactor until necessary repairs are made.

2. He must review all experimental proposals with regard to their safety, and train all experimenters in safe operation.

3. He must check that experiments are being safely performed.

These responsibilities are routinely expected of a conscientious industrial or research supervisor.

One final comment on safety is that internal exponential experiments convert Argonaut into a much different reactor. Hence, such experiments must be subjected to a separate safeguard review unless they differ in only minor respects from previously tested systems.

V. Types of Experiments

The following types of experiments can be performed in the standard system as described:

1. Pile oscillator measurements and danger coefficient studies can be made in the central thermal column.

2. Exponential experiments can be performed on the top of the system; with the top shield column removed and partially replaced by a graphite pedestal, approximately 10^7 thermal neutrons per square centimeter per second can be furnished in the bottom of the exponential assembly.

3. For pedagogic purposes, critical mass determinations on the annular core with various geometries and uranium concentrations can be made.

4. Fuel standardizations and instrument calibration experiments can be performed in the various irradiation holes in the thermal column, and in the shielding facility.

5. Shielding studies of the type now being done at Argonne can be undertaken in the shielding tank.

6. The thermal columns can be used for irradiations of fuel elements to get internal flux distributions, etc.

In addition the following experiments can be performed by making changes which are allowed by the design:

1. By removing the inner tank, graphite-reflected critical experiments can be undertaken on fully or partially enriched heterogeneous lattices of 3' diameter.

2. By replacing the internal thermal column with a portion of a reactor lattice, microscopic flux in lattice cells can be mapped in considerable detail and reactivity changes due to lattice perturbation can be checked by the danger coefficient method.

3. The shield test facility can be loaded with a lattice to permit exponential measurements in that location. It also represents a place where thermal migration properties can be measured.

By way of illustration, a sequence of experiments which may be tied into a single program is presented below.

Let us suppose that it is desired to investigate lattices containing heavy water and depleted uranium. The first step would be to intercalibrate foils which will be used in making flux traverses. This is accomplished by removing a graphite stringer in the external thermal column and mounting foils on a rapidly spinning wheel in the hole provided. The foils are irradiated simultaneously and counted against each other.

The second step, which is also preparatory, would be to construct a pile oscillator according to a design which may be anticipated as useful in an internal lattice test. Since the oscillator must be tested, some oscillation experiments on neutron cross section ratios are performed in the standard Argonaut. Next, again looking toward performance of an internal lattice test, a pile modulator (the name is used to signify a device which can alter the reactivity of the system harmonically in a frequency range up to a few hundred cycles per second) is constructed, with the expectation of using it in an internal lattice to measure reactor lifetime. This equipment may then be tested by measuring the transfer function of the standard Argonaut and comparing with theory and with other experimental data.

We are now ready to perform external exponential experiments. The top shield is removed and replaced by a graphite pedestal. An exponential tank is installed and several exponential lattices run. The results of this exponential experiment may be useful for further investigations, but in particular are necessary to provide calibration points for relative reactivities of the lattices.

By this time the Argonaut core will have become moderately radioactive owing to its operation as a neutron source. The external exponential experiment is removed and an internal exponential experiment designed. This experiment requires a separate safeguard review. Since reactivity would be added to Argonaut by its performance, it may be decided to include with the experiment two extra control rods. These are designed and tested. Meanwhile, the Argonaut core has been returned to low power use for other experiments.

Preparatory to installing the internal experiment, the annular core is completely unloaded. This must be done using coffins. The internal experiment is installed and the compound system brought up to critical, as in a critical mass test, by building the annulus up in small increments. The lifetime of the combined system at critical is measured by the transfer function technique and compared with predictions. The internal exponential experiment is then run at low power to obtain lattice flux details. The central lattice cell is perturbed so as to resemble a typical cell of some of the exponential systems studied and a curve of ΔB^2 of the lattice vs. Δk of Argonaut prepared. Samples of proposed cladding materials are then oscillated in the experiment and their effect on Argonaut converted into estimates of their effect on buckling of the test lattice. Experimental samples of plutonium and U^{235} are compared by oscillation to determine some of the characteristics of reactivity change on irradiation. With this program the internal exponential experiments may be terminated and the Argonaut again brought back to standard configuration. Simultaneously with the external exponential experiments, shielding studies may have been performed on the various shield designs which may have been proposed for the reactor system under study.

The experiments just outlined might serve as an excellent basis for physics design of a lattice reactor. Moreover, in their performance, ample opportunities for theoretical analysis are present and experience is gained in virtually every experimental technique involved in reactor physics design. Such a series of experiments is, therefore, useful not only as a test, but also may be considered as providing material for several student investigations. Other problems with different emphasis could also lead to programmatic use of Argonaut.

We believe that, although the experiments indicated previously can all be performed on Argonaut, they do not, by any means, exhaust the list of possible experiments; nor have we yet touched upon its use as a teaching demonstration. We believe that, in the latter connection, such a reactor might eventually be used in connection with undergraduate work. Such work must certainly involve detailed expositions of laboratory experiments with special emphasis on safety. Since the prototype will be at Argonne National Laboratory, one of the first projects undertaken here will be the writing of such Laboratory manuals.

16

REFERENCE

1. Stewart, H. B., F. G. La Violette, C. L. McClelland, G. B. Gavin, T. M. Snyder, "A Low-Power Thermal Test Reactor Adaptable to Nuclear Physics Research." KAPL-832 (November 3, 1952).

Tonks, L., "The Thermal Test Reactor of the Knolls Atomic Power Laboratory." AECD-3530 (1953).

"Research Reactors" - Prepared by the United States Atomic Energy Commission. McGraw-Hill Book Company, Inc., New York, (1955).

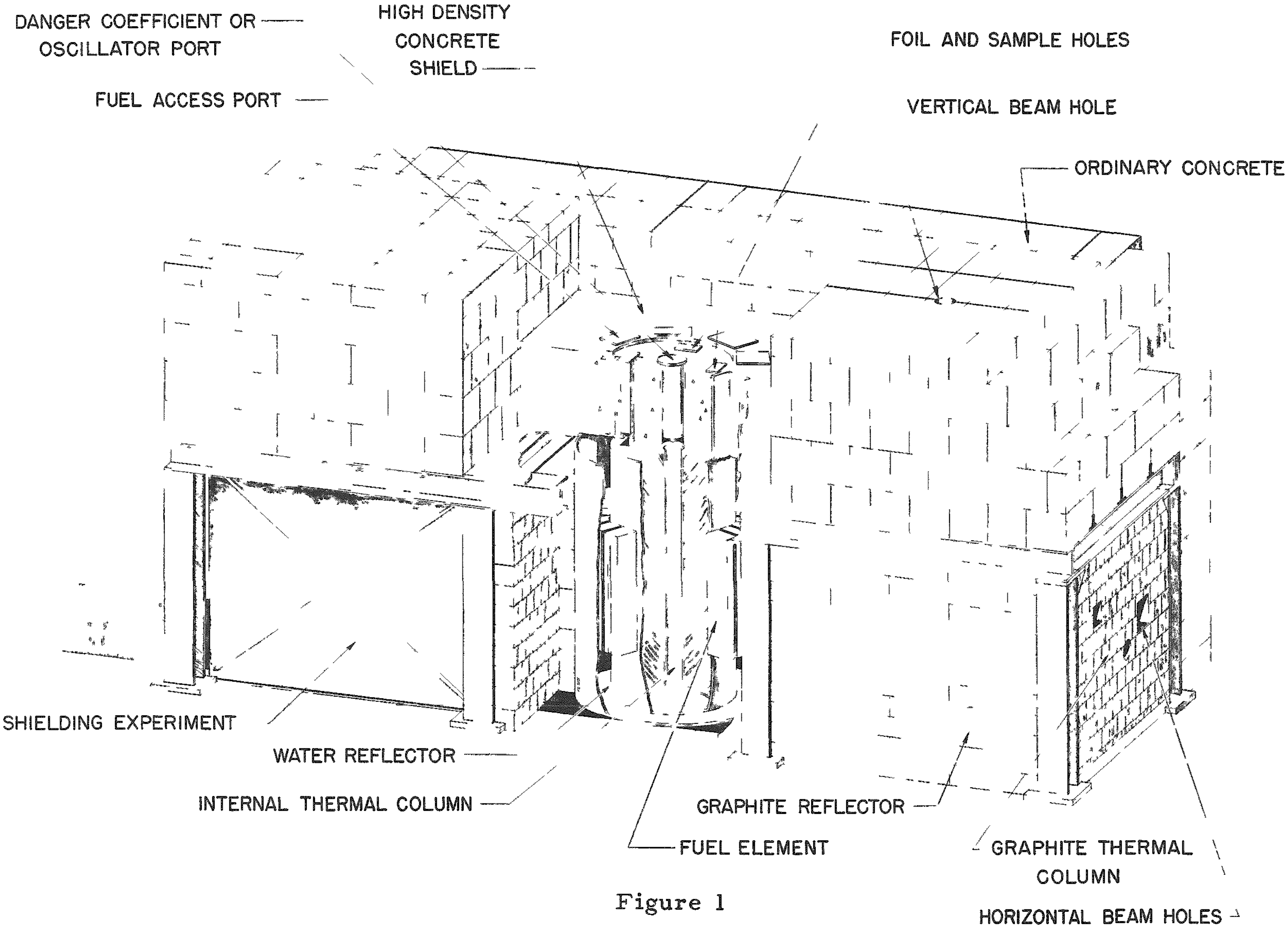

Figure 1

CUTAWAY VIEW

"ARGONAUT"

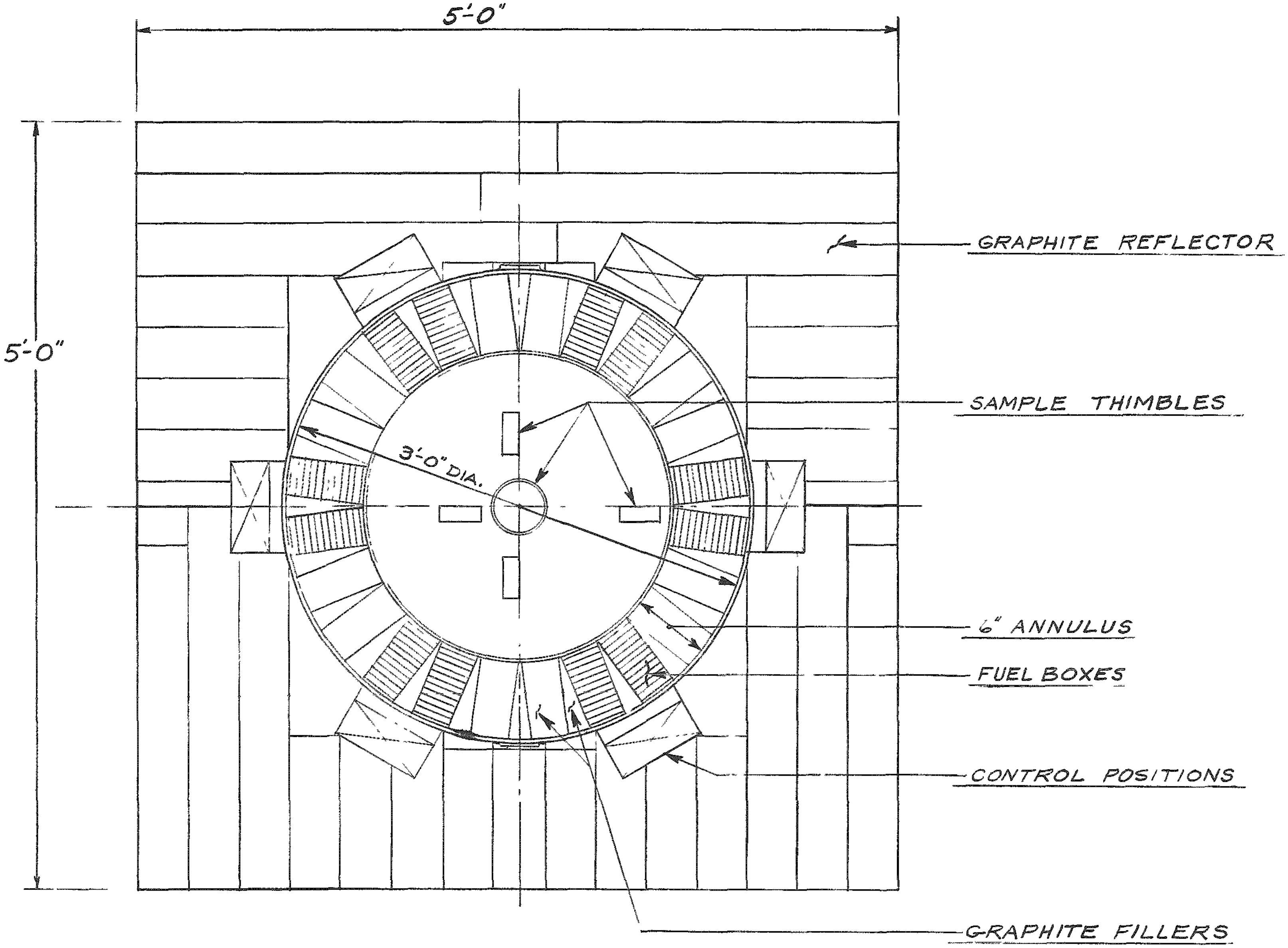

Figure 2. Top View of Core Region

RE-6-17560-C

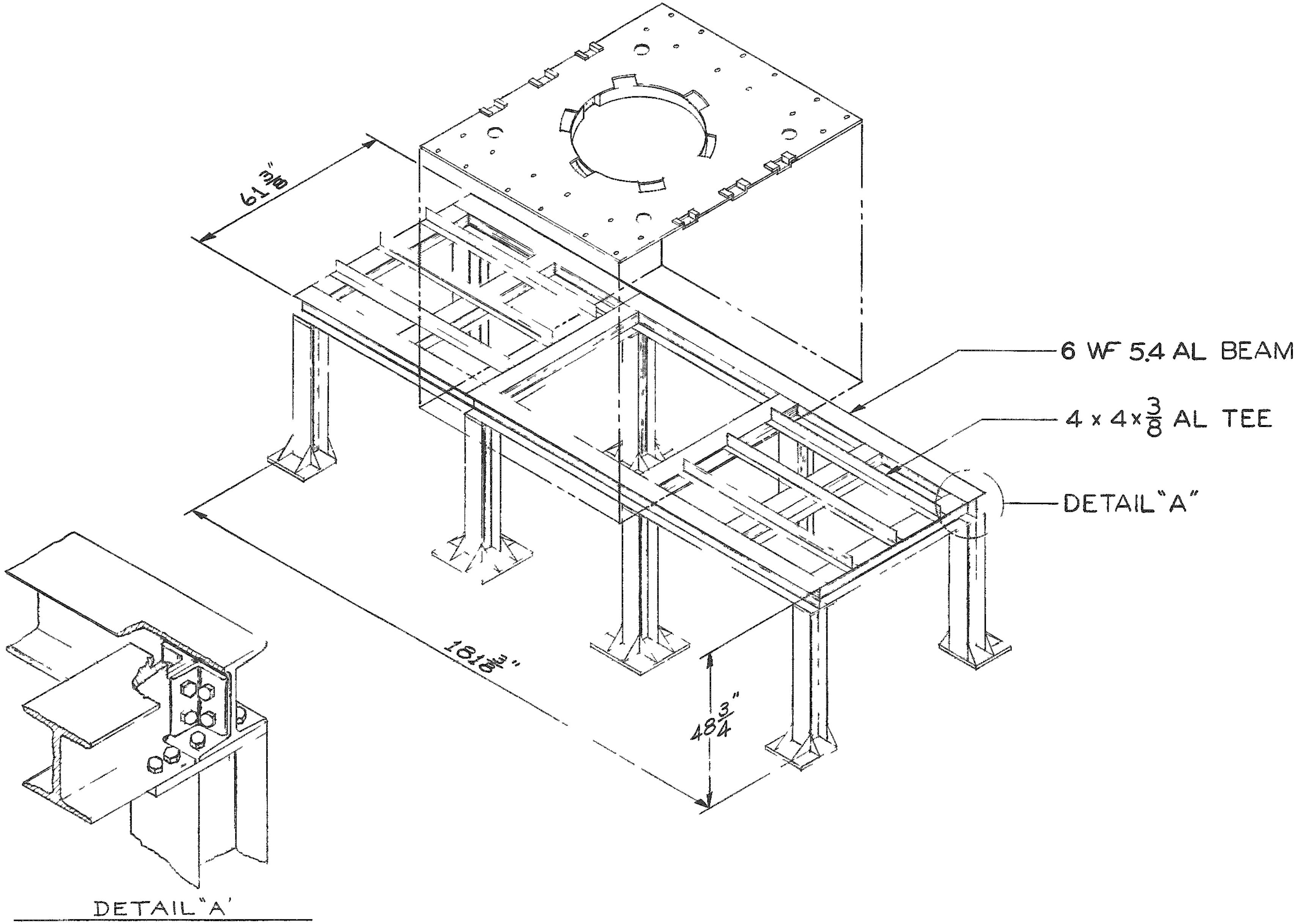

Figure 3. Structural Assembly

RE 6-17561-C

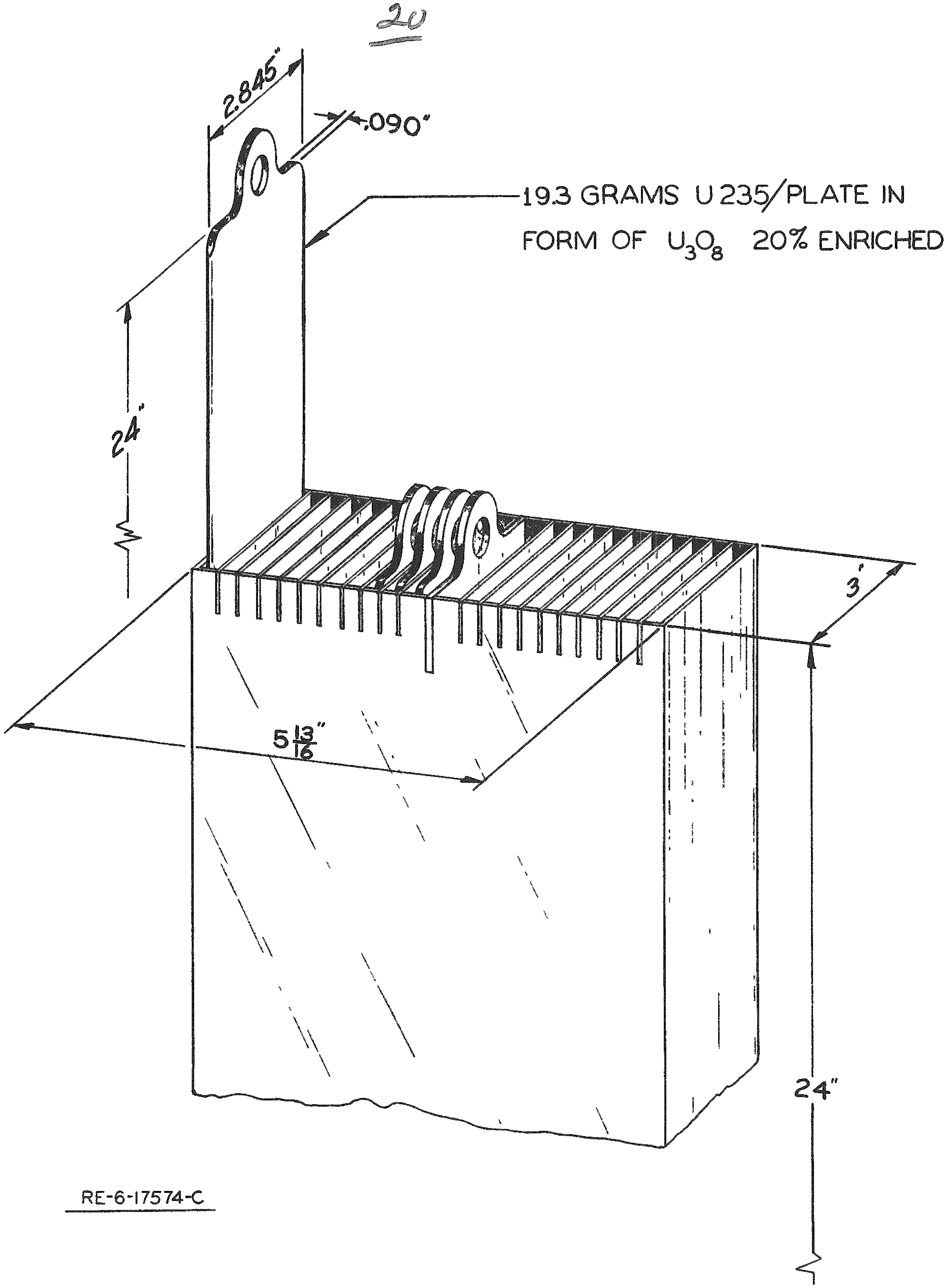

Figure 4. Suggested Fuel Elements