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THE WHITE SANDS MISSILE RANGE PULSED REACTOR FACILITY

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ELECTRO-MECHANICAL LABORATORIES

Robert L. Long

THE ARMY MISSILE TEST AND EVALUATION DIRECTORATE

WHITE SANDS MISSILE RANGE
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Prepared by: Robert L Long
LT. ROBERT L. LONG
Nuclear Effects Laboratory

and: Russell A Boor
RUSSELL A. BOOR
Nuclear Effects Laboratory

and: William M. Cole
WILLIAM M. COLE
Nuclear Effects Laboratory

and: Glenn E. Elder
GLENN E. ELDER, Chief
Nuclear Effects Laboratory

Approved by: Glenn E. Elder
GLENN E. ELDER, Chief
Nuclear Effects Laboratory

Released by: W. R. Jewell
W. R. JEWELL, Director
Electro-Mechanical Laboratories

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ELECTRO-MECHANICAL LABORATORIES
Army Missile Test and Evaluation Directorate
White Sands Missile Range, New Mexico

ABSTRACT

PART A

A brief statement of the mission of the White Sands Missile Range Nuclear Effects Laboratory is given. The new Nuclear Effects Laboratory Facility is described. This facility consists of two buildings - a laboratory and a reactor building.

PART B

The White Sands Missile Range bare critical assembly, designated as the MoLLY-G, is described. The MoLLY-G, an unreflected, unmoderated right circular cylinder of uranium-molybdenum alloy designed for pulsed operation, will have a maximum burst capability of approximately 2×10^{17} fissions with a burst width of 50 microseconds. The reactor construction and operating procedures are described. As designed, the MoLLY-G will provide an intense source of pulsed neutron and gamma radiation for a great variety of experimental and test arrangements.

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PART A

THE NUCLEAR EFFECTS LABORATORY FACILITY

I. Introduction

The mission of the Nuclear Effects Laboratory at White Sands Missile Range, New Mexico, may be briefly stated as follows:

1. To operate and maintain the required facilities and equipment for the conduct of and the analysis of nuclear effects laboratory and laboratory-related field tests of sub-systems, assemblies, and components of weapon systems.

2. To conduct, or observe, and analyze tests of sub-systems, assemblies, and components of weapon systems in a nuclear environment.

3. To provide scientific and engineering consultant services in the technical discipline of nuclear effects as directed.

4. To plan and conduct state-of-the-art investigations and developments in the nuclear effects field as directed.

In order to better accomplish this mission the Nuclear Effects Laboratory Facility is now in the final design phase and construction will be started in July 1963. The facility will be located 3 miles Southeast of the WSMR Technical Area.

II. The Nuclear Effects Laboratory Facility

The facility consists of two buildings - a laboratory and a reactor building. The laboratory building is 143 feet by 189 feet overall. Figure A.1 shows the plan view. The Gamma Linac and Pulsed Neutron Generator (PNG), presently in operation in an existing building, will be housed in shielded cells 18 feet by 20 feet and 20 feet by 20 feet respectively. The Gamma exposure room is 19 feet by 26 feet and is shielded from the Linac cell by 3 feet of concrete. The external walls of the cells are standard construction with a thick earth berm to provide the shielding. This will permit ready expansion of the cells when required. There are screen rooms adjacent to the Linac and PNG to contain the monitoring and recording instrumentation for tests utilizing these devices. The remainder of the building consists of shops, dosimetry labs, and offices.

Figure A.2 shows the site plan. The reactor building is 3100 feet from the laboratory. Figure A.3 is a plan view of the reactor building. The reactor cell is 50 feet by 50 feet by 20 feet. The reactor cell walls are constructed of 2 feet of concrete. The cell is lined with 8 inches of borated gypsum board. The control room, reactor operations office, and instrumentation room are adjacent to the cell with 20 feet of earth shielding between. The control room is 12 by 22 feet; the operations office is 10 by 31 feet; and the instrumentation room is 22 by 24 feet. Figure A.4 is an elevation view of the reactor building. As is shown, the top of the lower floor of the building is at ground level. The mechanical equipment room also contains a small preparation room and latrine facilities. When not in operation, the reactor is stored in the pit which is 38 feet deep for $1/r^2$ shielding in addition to protection provided by a one foot thick lead shielding door. Connections for reactor control and operations are located on the top of the reactor cell to provide an outdoor burst site. The reactor can be readily moved to this site with a shielded fork lift truck. The reactor cell shielding is adequate to permit manned instrumentation trailers on the top of the cell during indoor bursts. Conduits are provided from the cell top to the interior of the reactor cell for cables.

The design of the reactor building is the summation of all of the recommendations from the experts and veterans in the pulsed reactor field. We are particularly indebted to Dr. Easely and his group at Sandia Corporation, especially Paul O'Brien and his co-workers and to Dr. Wimett and Roger White of Los Alamos.

PART B

THE WSMR BARE CRITICAL ASSEMBLY

I. Introduction

The White Sands Missile Range bare critical assembly, designated as the MoLLY-G, is an unreflected and unmoderated right circular cylinder of uranium-molybdenum alloy. The MoLLY-G is a pulsed reactor designed to give a maximum burst of approximately 2×10^{17} fissions with a burst width of 50 microseconds. It is also designed for operation at a maximum steady state power level of 10,000 watts for short periods of time. As designed, the reactor will provide an intense source of pulsed neutron and gamma radiation for a great variety of experimental and test arrangements.

II. Characteristics of Uranium-Molybdenum Alloy

Several pulsed reactors have been built (for example, Godiva II[1] and SPRF[2]) which utilize unalloyed uranium (oralloy) for the fuel. In oralloy only the alpha uranium crystalline structure can exist at room temperatures. The alpha crystal is anisotropic, and when heated, it expands in two directions and contracts in the third direction. When oralloy is deformed by rolling, swaging, extrusion, and so forth, the crystals orient themselves in preferred directions. Because of the anisotropy of alpha uranium, this preferred orientation results in dimensional changes when the material is thermal cycled or exposed to radiation. The degree of preferred orientation is determined by the method of fabrication and treatment. Casting of parts and proper heat treatment tend to give a random orientation to the crystals and allow the fuels to be used. However, the effect of temperature cycling, such as that which occurs in the routine operation of a pulsed reactor, may still create high internal stresses which can result in permanent distortion, surface roughening, and possible fracture.[3,4]

As is well known, uranium metal exists in three different crystal structures. The third, high temperature phase, termed gamma, is a body centered cubic crystal and is isotropic. The retention of this isotropic crystal structure at room temperatures may be accomplished by the use of suitable alloying agents. The MoLLY-G utilizes an alloy of fully enriched uranium (93.2% U^{235}) and ten per cent by weight of molybdenum. This U-10 w/o Mo alloy imparts excellent stability to the gamma phase at room temperature. At higher temperatures, for example 550°C, it would require about eight hours to start transformation from the gamma phase. The improved characteristics of the U-10 w/o Mo alloy increases the maximum allowable operating temperature to a level which will permit outputs greater than those obtained from the oralloy reactors. The only U-10 w/o Mo reactor built and operated to date, the ORNL Health Physics Research Reactor [5], has obtained bursts of 1.7×10^{17} fissions and temperature increases of 400°C.

III. Description of Reactor Core

Figure B.1 shows an isometric section of the MoLLY-G core. The main section of the core consists of a stack of stepped annular uranium molybdenum alloy disks forming a right circular cylinder 8 inches in diameter and 7.5 inches long. These disks are joined together and to the core support plate by three uranium molybdenum bolts. A safety block cavity is concentric with the main core assembly axis. The three cavities for the two control rods and the burst rod are displaced at 120° on a 3.125 inch radius, as measured from the axis of the assembly. All exposed surfaces of the main section of the core are plated with .002 to .005 inches of nickel which prevents oxidation, provides protection from external wear, and facilitates handling.

The safety block is a right circular cylinder of uranium molybdenum alloy which fits into the center cavity of the core. It is 3.84 inches in diameter and 5.75 inches long. Through the center of the block is a 1.25 inch diameter stainless steel support shaft. When removed from the core the safety block has a shut down reactivity worth of approximately $35. The two control rods and the burst rod are also made from uranium molybdenum alloy. The control rods are 1 inch in diameter and 6.5 inches long and have a total reactivity control worth of approximately $1.50 each. The burst rod is 1 inch in diameter and 5.125 inches long. The length of stroke is adjusted to give a reactivity insertion of approximately $1.08. The center insert in the top fuel disk contains a mass adjustment ring which may be removed to compensate for large additions of reactivity caused by the location of moderating experimental set-ups external to the reactor core. Figure B.2 is a photograph of a lucite mock-up of the reactor core.

IV. Description of Reactor Control System

A physical description of the MoLLY-G control elements, a safety block, two control rods, and a burst rod, has been provided. As a means of describing the functions of these control elements, the operations during a burst sequence will be followed. After hazardous areas have been cleared of personnel, equipment and instrument check-out procedures have been completed, and a pre-operational sequence has been completed, the operation sequence may proceed. A plutonium-beryllium neutron source is moved to a position close to the core to insure reliable indication of the start-up multiplication changes. The safety block is pneumatically driven from its scrammed position to a position $\frac{1}{2}$ inch from full insertion. The operator may then complete insertion by energizing a slow mechanical drive. The control rods can then be mechanically driven into the core to a position where the reactor is supercritical. The power level is allowed to increase to about one watt, at which time the rods are carefully adjusted to establish a delayed critical configuration.

After delayed critical is established and no detectable upward or downward drift in power level is observed, the safety block is pneumatically driven out of the core and the neutron source is dropped into a shielded position. The reactor is now subcritical and the delayed neutron precursors within the fuel assembly are permitted to decay during a 20 minute waiting interval. During this waiting interval the control rods may be withdrawn slightly to compensate for possible increases in reactivity caused by cooling of the fuel assembly.

Following the waiting interval the safety block is returned to its fully inserted position. The reactor is again in a delayed critical configuration. The burst rod is rapidly inserted by means of a pneumatic drive. This action increases the reactivity to approximately $1.08 above delayed critical to produce a burst yield of 2×10^{17} fissions. The reactivity contribution of the burst rod is constant from burst to burst and is determined by the mechanical stops of the insertion mechanism. Once initiated, the burst is self limiting because of the thermal expansion and negative temperature coefficient of the U-10 w/o Mo fuel.

At the time of burst initiation the MoLLY-G will have two features which have not been routinely used in other pulsed reactor systems. (The SPRF is presently being modified to incorporate a system similar to the one planned for the MoLLY-G). The Godiva II and similar systems depend on the fission burst being initiated by neutrons from spontaneous fission, cosmic radiation, or delayed neutron precursors. After insertion of the burst rod there are often wait times of several seconds before the occurrence of a burst if no external neutron source is present. In the MoLLY-G system, activation of the burst key at the control console begins the following sequence of events: (1) the scramming devices are initiated, (2) the burst rod is inserted, and (3) an external pulsed neutron generator is triggered. The external pulsed neutron generator provides the initiation of the burst and establishes a time reference signal to the pre-set scram system. The pre-set scram system initiates the fast scram system in less than 10 milliseconds after the burst time signal is received. The use of this system accomplishes two important functions: (1) the uncertainty as to time of burst is eliminated and (2) by utilizing a pre-set scram, the length of tail following the burst is minimized.

The safe operation of the MoLLY-G system is guaranteed by a series of interlocks which control the operating sequence and by tight administrative control over the reactor cell and experimental set-ups. Figure B.3 shows the reactor on its stand and contained in its protective cover. The cover prevents the placing of experimental equipment directly in contact with the core. In addition, it contains a layer of cadmium which reduces the reactivity contribution due to reflector materials being located around the reactor. The cover also acts as a coolant manifold for a forced air cooling system which reduces the minimum time between bursts to less than one hour. Figure B.4 shows the reactor control console. The two television screens are part of a closed circuit TV system which permits observation of the reactor cell at all times.

V. Output and Applications

The MoLLY-G is expected to provide an excellent source of neutron and gamma radiation for the simulation of nuclear weapon environments. Table I shows a tabulation of the anticipated operating characteristics of the MoLLY-G. The neutron spectrum will be a slightly degraded fission spectrum. The ratio of neutron dose to gamma dose will be approximately 10 to 1.

When it becomes operational early in 1964, the MoLLY-G will provide a most desirable source of neutron and gamma radiation for the determination of transient effects of nuclear radiation on electronic components, materials, and complete systems. It will provide a source for nuclear shielding experiments, activation experiments, biological effects experiments, and evaluations of range and reliability of nuclear radiation detectors.

TABLE I

MoLLY-G OPERATIONAL CHARACTERISTICS

Burst Yield, Fissions	5×10^{15} to 2×10^{17}
Burst Repetition Rate	1 per hour
Integrated Neutron Flux 1 Inch Above Reactor Surface, Neutrons/cm^2	$> 1 \times 10^{14}$
Total Leakage Neutrons	2.5×10^{17} maximum
Initial Reactivity Insertion Above Prompt Critical, $	0.08
Initial Reactor Period, μsec	13
Burst Half Width, μsec	50
Maximum Temperature Rise, °C	500
Average Temperature Rise, °C	240
Total Temperature Coefficient, $/°C	-0.003
Maximum Steady State Power, Watts	10,000
Maximum Allowable Temperature, °C	600

REFERENCES

1. T. F. Wimett, *et al*, "Godiva II - An Unmoderated Pulse-Irradiation Reactor", *Nuclear Science and Engineering*, *8*, 691-708 (1960).

2. J. L. Colp and P. D. O'Brien, *The Sandia Pulsed Reactor Facility (SPRF)*, Sandia Corporation Monograph, SCR-229, August, 1960.

3. B. Kopelman, Editor, *Materials for Nuclear Reactors*, McGraw-Hill Book Company, Inc., New York, 1959.

4. Private communication, Combustion Engineering, Inc., December 4, 1961.

5. J. T. Mihalczo, *Super-Prompt-Critical Behavior of an Unmoderated, Unreflected Uranium-Molybdenum Alloy Assembly*, Oak Ridge National Laboratory Report, ORNL-TM-230, May, 1962.

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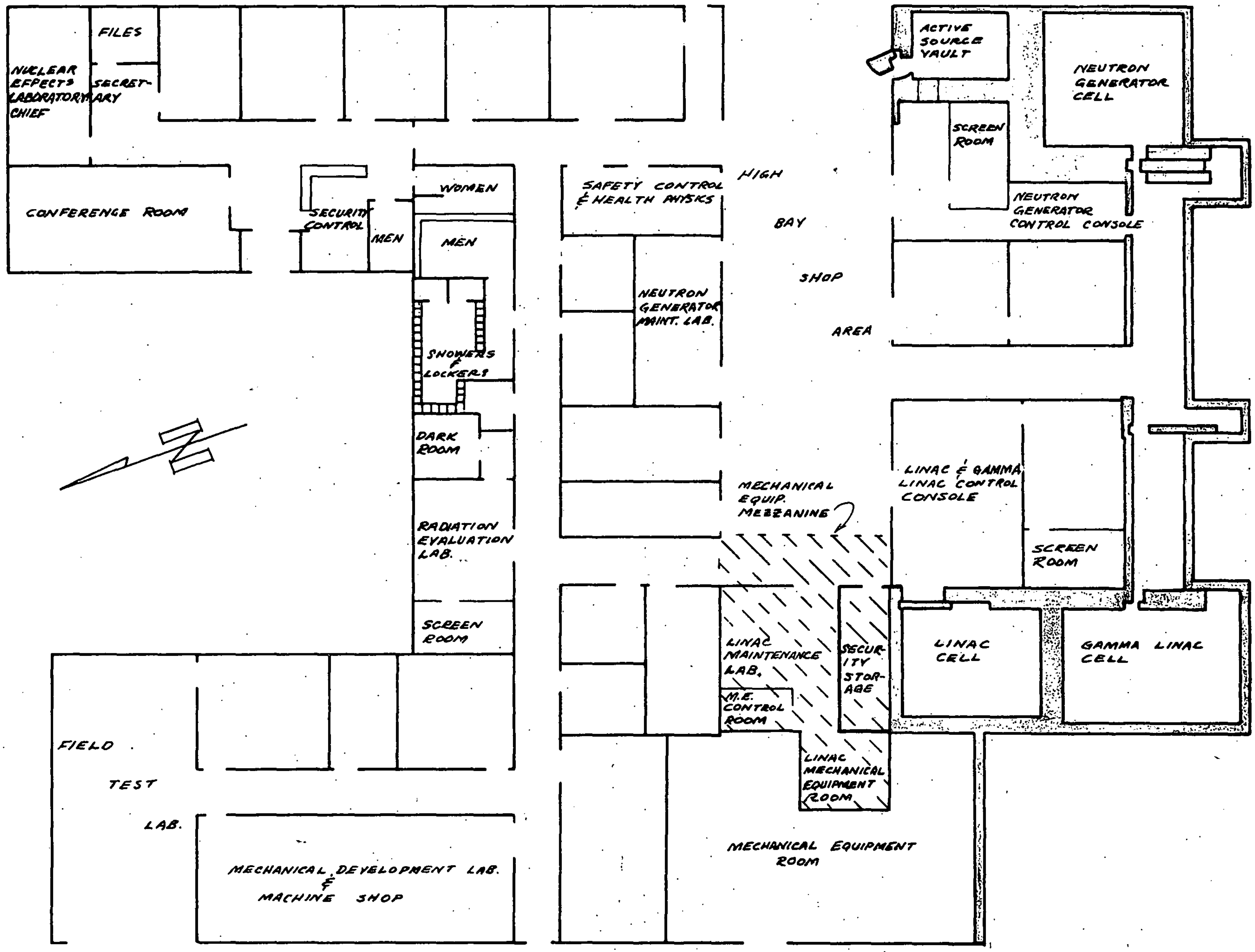
FIGURE A.1 LABORATORY BUILDING PLAN VIEW



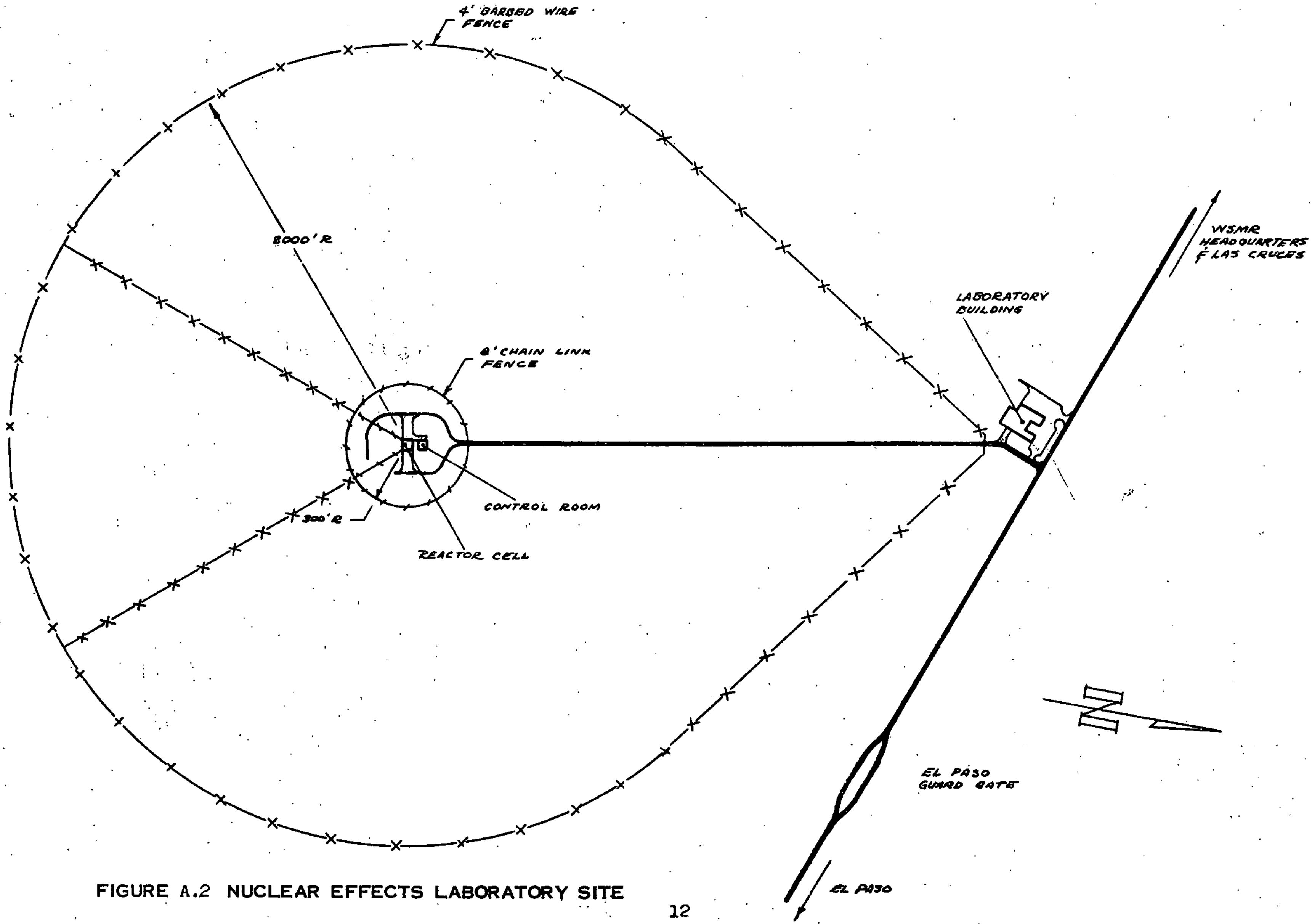


FIGURE A.2 NUCLEAR EFFECTS LABORATORY SITE

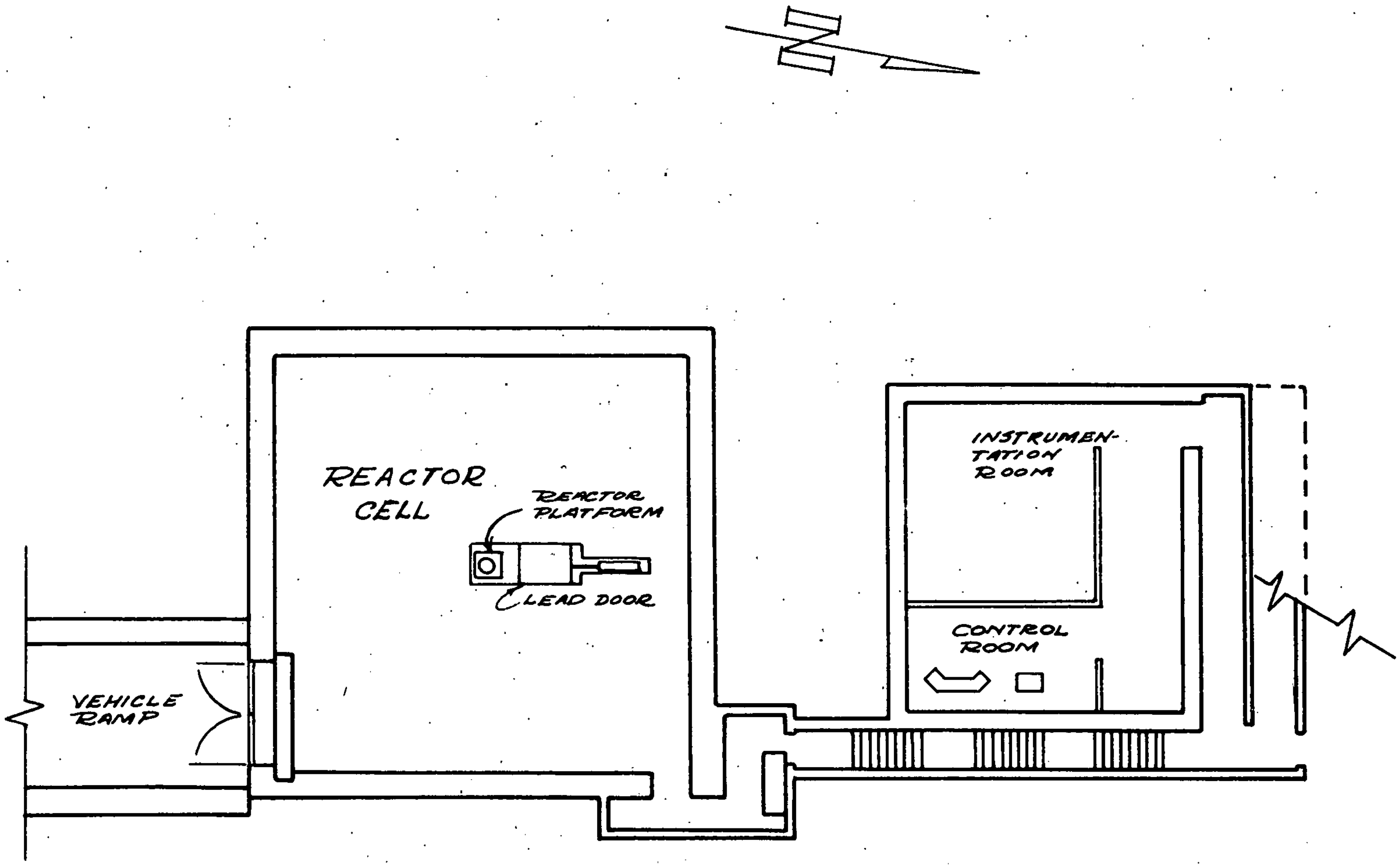


FIGURE A.3

PLAN SECTION OF MOLLY-G CONTROL BUILDING
AND REACTOR CELL

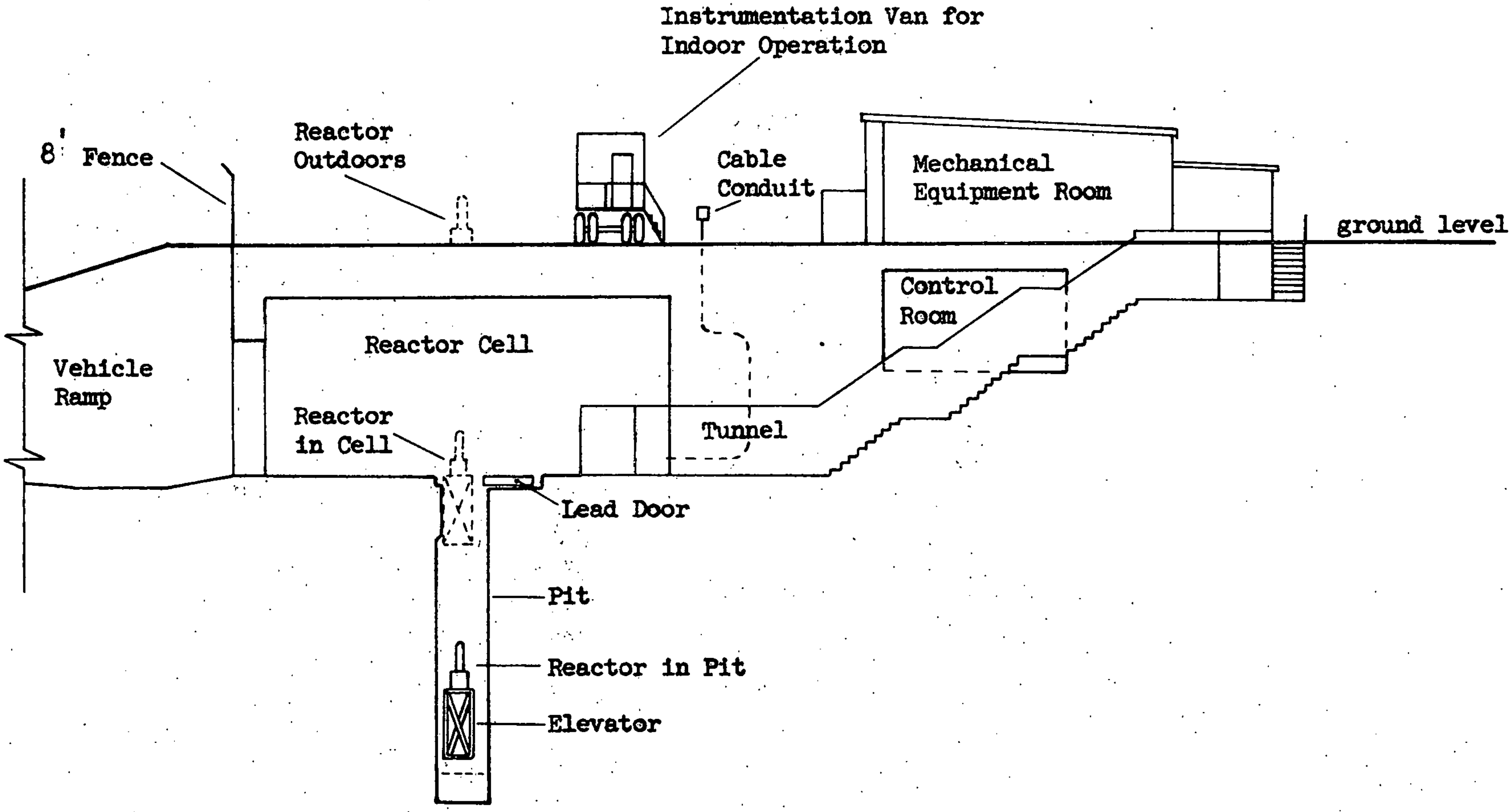
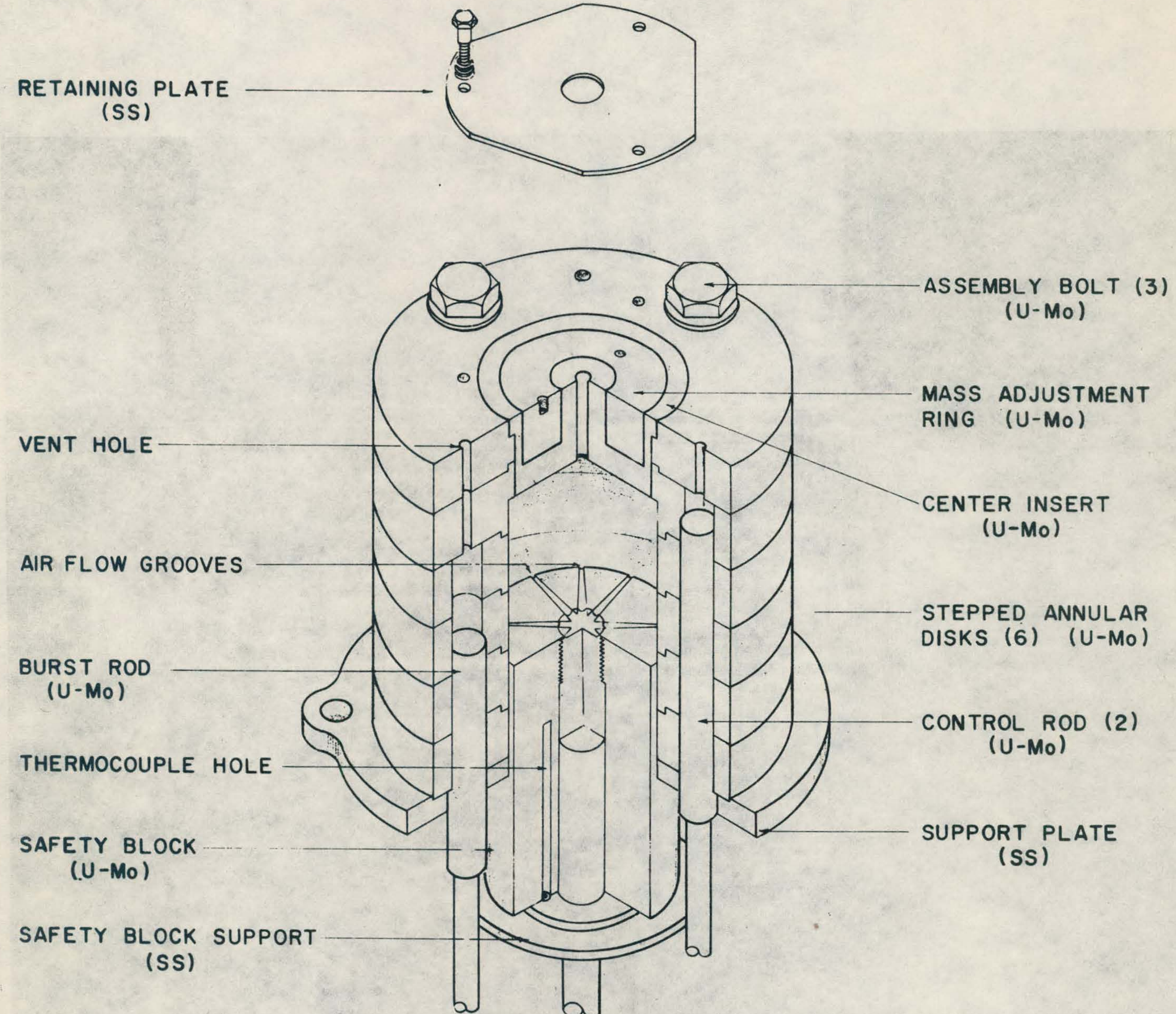


FIGURE A.4

ELEVATION SECTION OF MOLLY-G
CONTROL BUILDING AND REACTOR CELL



ISOMETRIC SECTION OF
MoLLY-G CORE

FIGURE B.1
ISOMETRIC SECTION OF MoLLY-G CORE

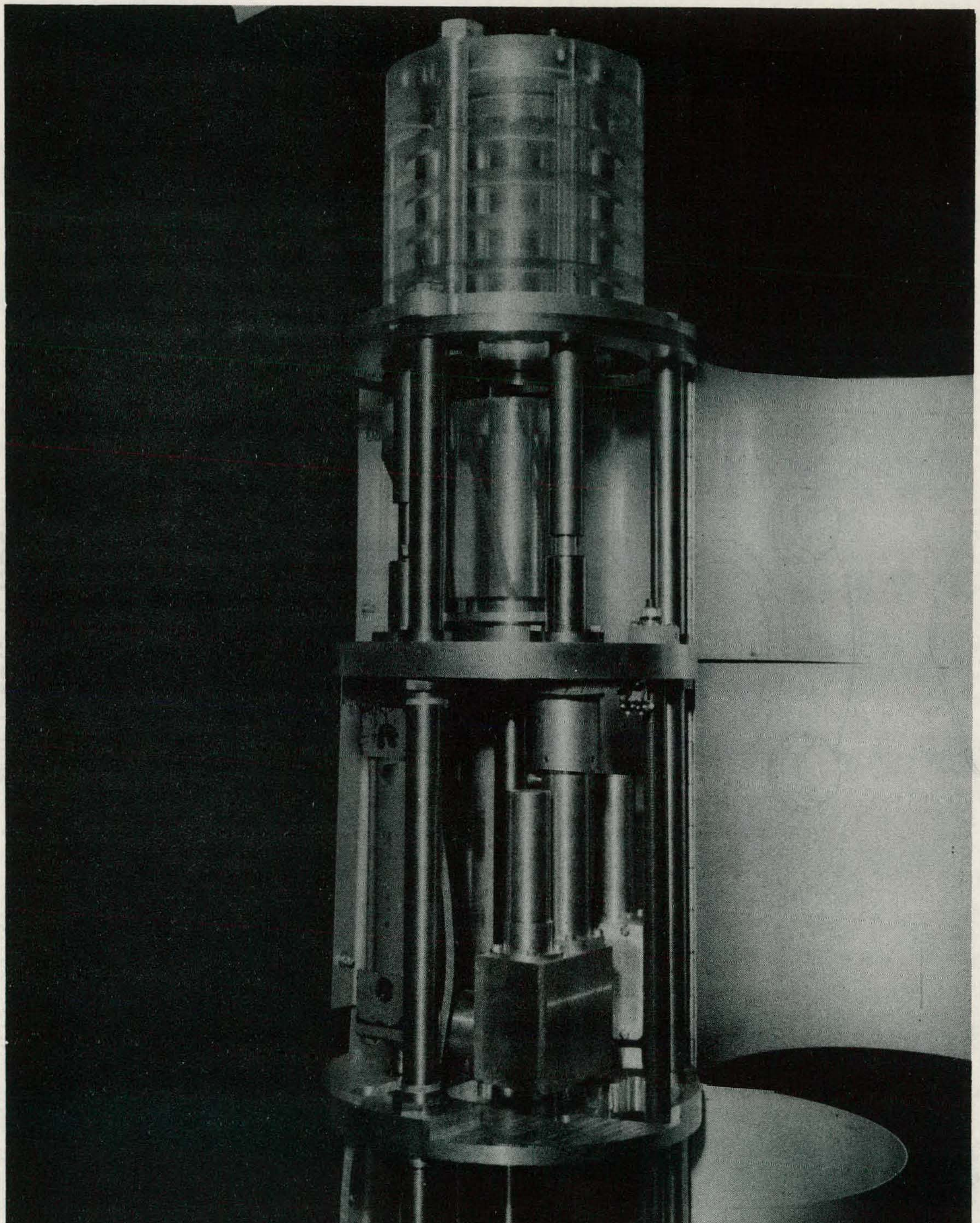


FIGURE B.2
LUCITE MOCK-UP OF MoLLY-G CORE