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Argonne National Laboratory

DESIGN, CONSTRUCTION DETAILS,
AND PREOPERATIONAL TESTING OF
AN ARGONNE FAST CRITICAL FACILITY

by

Leon R. Dates

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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Reactor Physics Division

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April 1966

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DESIGN, CONSTRUCTION DETAILS, AND PREOPERATIONAL TESTING OF AN ARGONNE FAST CRITICAL FACILITY

by

Leon R. Dates

ABSTRACT

This report describes the component details and methods and procedures of construction of an Argonne fast reactor facility. Certain tests, and data resulting from such tests, have been included to illustrate structural stability. Accuracies of fits and alignment of mating parts, table-surface flatness, precision leveling, etc., are given to indicate the reliability of the data taken during reactor experiments. The basic machine was designed and fabricated to tolerances that are consistent with large machine-tool fabrication. Further dimensional refinement would result in much higher cost with very little, if any, gain in reliability. The erection of the facility is discussed in a stepwise manner to provide a clear description of each part and how it fits the overall assembly. Safety and fail-safe features are explained in detail.

Much of the design criteria was dictated by experience gained from the operation of ZPR-3.¹ Matrix deflection behavior and magnitude were predictable through studies made on the ZPR-3 matrix loadings.

I. INTRODUCTION

Theoretical and experimental studies on fast reactor systems indicated the need for a large critical facility. ZPR-6, a zero-power critical assembly with a 2.4-m cube system, was designed and built to satisfy this need.

Site location, reactor building, reactor containment cell, management, and operation were discussed completely by Kato *et al.* in ANL-6271.² Criticality was achieved for the first time on July 23, 1963. Subsequent operation has proven the adequacy of design criteria with respect to mechanical function, operating characteristics, and diversified utility. The new critical facility has been used to investigate the nuclear characteristics

of unmoderated dilute reactors having neutron energy spectra whose maximum range is from a few tens of kilovolts to hundreds of kilovolts. In addition to the standard-type critical experiments, the areas of investigation have been (a) determination of the sodium-void coefficient as a function of composition, geometry, and sodium density; (b) measurements of the Doppler temperature coefficient for U^{238} , U^{235} , and other fissile and fertile materials; and (c) a study of the range of validity of measurements obtained from a multizone reactor system.

II. THE CRITICAL FACILITY

A. General Description

ZPR-6 is a split-table or two-half type of facility, which is a type used to mock up unmoderated or solid moderator reactors. This concept has been used successfully in the United States over the past 13 or 14 years at such laboratories as KAPL (PPA), LASL (Honeycomb), ORNL, ANL-Idaho (ZPR-3), Hanford (PCTR), and Pratt and Whitney.

The facility basically consists of two tables each 3.7 m wide by 2.4 m long, one stationary and the other movable, both mounted on a bed. On each table is stacked an array of square stainless-steel tubing with a 5.52-cm cross section. The tubes are stacked to form a square 2.4 m by 2.4 m honeycomb-like structure.

Figure 1 shows the arrangement of the stacked stainless-steel tubes and their supports. The tubes are constrained in position by Meehanite supports on both sides. An array of 45 horizontal rows and 45 vertical columns of the 1.2-m-long square tubing on each table forms half of a 2.4-m reactor. Drawers of 38- and 61-cm length, containing materials such as enriched uranium, depleted uranium, stainless steel, aluminum, and zirconium are available to simulate many reactor compositions.

The split-table machine was chosen for safety and convenience in the loading and unloading operations. Splitting the reactor in two sections provides a fairly large decrease in reactivity.

Each half of the reactor facility has five dual-purpose control/safety rods. These rods are of the reactor-core removal type consisting of stainless-steel drawers containing the core composition, fastened to a drive mechanism. Up to four rods per half may be used as control rods by changing the circuitry in the control console. The remaining dual-purpose rods will be used as safeties. In the event of a scram signal, all ten rods will be driven out of the reactor by compressed springs. In addition to the dual-purpose rods, up to six B^{10} loaded safety rods per half will be available for use when there is insufficient shutdown reactivity in the

dual-purpose rods while large dilute systems are being studied. Since these rods act as a poison, they will be normally in the withdrawn position and will be inserted into the reactor at a rapid speed on a scram signal. The number of these safety rods used will depend on the size of the reactor being studied.

Fig. 1. Pictorial Drawing of ZPR-6 Basic Components

Each half of the assembly contains an americium-beryllium start-up neutron source, which may be driven in or out of the assembly by means of a motor drive.

A control console and nuclear instrumentation are available in the control room to control movement of the table and rods and to monitor the neutron population.

To assist in the loading and unloading operations, a platform which is hinged at the wall is swung down between the separated halves. Desired working heights are then obtained by elevating or lowering the platform as desired. A conveying system is available to aid in the loading work by mechanically transporting core and blanket materials up to personnel on the working platform.

B. ZPR-6 Components

The components of the ZPR-6 being described here are as follows:

- (1) Bed assembly
- (2) Stationary-table assembly
- (3) Movable-table assembly
- (4) Bed and tables assembly
- (5) Matrix assembly
- (6) Rod-drive mounting plate and support structure
- (7) Matrix drawers
- (8) Dual-purpose drive mechanism and drawer assembly
- (9) Safety-rod, guide-sheath, and rod-drive assembly
- (10) Neutron-source drive assembly

Information concerning the above-listed components is presented in the following paragraphs.

1. Bed Assembly

The bed assembly includes the following items:

- (a) Bed casting
- (b) Runways
- (c) Guide principle
- (d) Ball-bearing nut and lead screw
- (e) Stop blocks
- (f) Movable-table drive system

The above-listed items are described in the following paragraphs.

a. Bed Casting. The bed casting material is close-grained, high-tensile (45,000-psi minimum) semisteel, the cupola charge being ~50% steel and 50% iron. The chemical analysis as follows:

Carbon	3.10-3.20%
Silicon	1.65-1.75%
Manganese	0.90-1.0%
Phosphorus	0.15%
Sulfur	0.09-0.12%

The bed is a one-piece casting of box-type construction, heavily ribbed for rigidity and stiffness. Formal stress relieving was not required because the casting was completely cooled, slowly and uniformly, while in the mold.

The bed is 650 cm (256 in.) in overall length by 262 cm (102 in.) in overall width.

A cross-section thickness of 43 cm (14 in.) was determined to be adequate to maintain all alignment specifications while giving sufficient support and rigidity to the combined load of the tables 19,958 kg (44,000 lb) plus the maximum weight of a fully loaded matrix, 163,293 kg (360,000 lb), equally divided on two tables. Typical load distribution per table is shown in Fig. 2.

b. Runways. Four runways, shown in Fig. 3, contain hardened and ground replaceable inserts on which the movable-table roller bearings ride. The inserts are fabricated from a graphitic alloy steel (TIMKEN GRAF-MO). Being flame-hardened and stress relieved to RH "C" 55-58, and ground as a set to a $63\text{-}\mu$ in. finish, the inserts present excellent wear surfaces for high unit loads. Their lengths assure a 152.4-cm (60-in.) table movement.

c. Guide Principle. One runway is used as a guide principle for the movable table (Fig. 3). It is also the reference surface to which the stationary table is clamped to keep it square and true when in closed contact with the face of the movable table. For these reasons, a high degree of dimensional accuracy is required. This is attained by close-tolerance machining and hand scraping the sides of the runway parallel and flat to 0.025 mm (0.001 in.). The guiding principle is positioned parallel with and as close to the lead screw as practical so as not to allow canting of the movable table during its traverse.

d. Ball-bearing Nut and Lead Screw. A ball-bearing nut and lead screw transmit the motive force to the movable table. The lead screw is an integral part of the bed assembly. One end is supported in a bearing housing, which is fastened to the bed. The other end is supported by and extends into the gearbox where it receives its driving power through a slip clutch (the gearbox and its components are described in paragraph f below). The lead screw is made from SAE 4140 steel, stress-relieved at 1150-1200°F for 4 hr before the thread grooves are flame-hardened (Rockwell "C" 50-55) to a depth of 0.19 cm (0.075 in.). The finish ground size produces an extremely accurate screw of great strength. The maximum lead error allowed is 0.0005 cm (0.0002 in.)/ft.

The nonrevolving, antifriction, ball-bearing nut assembly is premounted on the lead screw, later to be bolted to the under side of the movable table (see Fig. 4). This assembly consists of two halves accurately spaced and bolted together so as to preload the balls in their raceway. Backlash inaccuracies are thus eliminated. Both halves are made of SAE 4615 steel. The threads are carburized to a depth of 0.178-0.216 cm (0.080-0.085 in.) and are hardened and drawn to Rockwell "C" 60-63.

Fig. 2. Table-loading Grid

112-1198-A

Fig. 3. Bed and Tables Assembly

112-2149-C

Fig. 4. Location of Ball-bearing Nut and Lead Screw

e. **Stop Blocks.** Two metal-plate stop blocks, each 12.7 cm (5 in.) wide x 9.2 cm ($3\frac{5}{8}$ in.) long x 3.2 cm ($1\frac{1}{4}$ in.) thick, are pinned and bolted securely to the depressed surface between the guiding runway and the outboard runway (see Fig. 5). The position of the stop blocks is fixed in the travel path of the movable, table-mounted, solenoid-operated, tumbler assemblies. (The tumbler assemblies are discussed as part of the movable table assembly in paragraph 3 below.) The stop blocks act as barriers to limit the closing motion of the movable table unless the tumblers are lifted by action initiated by the operator. The stop blocks also serve as safety stops if a limit switch fails to halt the table motion at predetermined positions.

Fig. 5
Stop-block and Tumbler
Assembly

112-2150-A

f. Movable-table Drive System. Figures 6 and 7 display the power gear train, gear motor drives, and clutch couplings. The fast-, intermediate-, and slow-speed drive motors use a gear train common to all three. This system supplies power through a slip clutch to the drive screw that moves the table to closure. The slip clutch is a jaw-in-jaw type, adjustable from 500 to 800 in.-lb, a range that provides a variable force at the lead-screw ball nut from 4180 to 6700 lb.

The force is varied by positioning an adjusting nut, which preloads eight compression springs against one half of the slip clutch. Adjustment settings vary in accordance with the size of the core being studied. The design provides that when the clutch slips, the jaws separate to actuate a microswitch plunger. This action is indicated at the control panel by a blinking light. The motors are all reversible, 208-V, three-phase, gear-head type. Individual ratings as follows:

Fast drive:	3/4 hp, 56 rpm, 756 in.-lb output torque.
Intermediate drive:	1/2 hp, 56 rpm, 530 in.-lb output torque.
Slow drive:	1/4 hp, 13.5 rpm, 992 in.-lb output torque.

The system on the left-hand side of the drive screw includes retraction units, which effect the table separation. The gear train in this system does not transmit its power through the slip clutch, but is directly connected to the lead screw.

Normal scram power is provided by a 1-hp, 100-rpm, gear-head, 208-V, three-phase motor, which delivers 630 in.-lb of torque to an electromagnetic clutch. The torque rating for this clutch is 840 in.-lb start and 1500 in.-lb running. Drive power is transmitted to

Fig. 6. Transmission

112-2152-A

Fig. 7. Movable-table Drive System

a gear, which is splined to the lead screw that moves the table. The beam strength of the gear tooth at the yield point of the material is 7000 lb, so that with the electromagnetic clutch delivering 1500 in.-lb of running torque, which loads the gear teeth to 800 lb, there is an 8.85:1 safety factor.

An emergency, air-operated, scram device backs up the electric-motor scram system. It consists of a 0.9-hp, 270-rpm air motor and a double-acting air cylinder, which connects the air motor to the scram gear train by sliding a splined key into the driving head of the motor. Thus coupled, the air motor will drive a gear train to deliver its power to the same lead-screw-mounted gear that is used during normal retractions of the movable table, bringing it to a full separation. The gear-tooth loading at air-motor stall torque is 692 lb, which provides a safety factor of 10.2:1.

The air-scram system operates from 70 to 100 psi initial pressure. Minimum allowable initial pressure of 50 psi would produce

96 in.-lb of torque at the air motor and 6000 lb of force at the ball nut. Torque values for normal operation are as follows:

210 in.-lb, run;
360 in.-lb, start;
480 in.-lb, stall.

The force at the ball nut for the above running torque is 13,200 lb, and at stall torque is 27,150 lb.

Air-volume requirements are 40 cu ft/min to operate the air motor at 270 rpm, a speed necessary to retract the movable table at 76.2 cm/min (30 in./min). The 2-min operation time needed to traverse 1.52 m (60 in.) will require 80 cu ft of free air.

Events that will initiate the coupling of the air motor are as follows:

- (1) Total electric power failure occurs.
- (2) Electric-motor magnetic-clutch power failure occurs.
- (3) A timing switch senses that the centrifugal switch, which is normally satisfied by the revolving lead screw, is not actuated within a 0.5-sec period following a scram signal.

2. Stationary-table Assembly

The table casting structure and material are the same as those described for the bed casting. The table is 3.7 m (144 in.) wide and 2.4 m (96 in.) long. The table depth of 46 cm (18 in.), plus finite structural-rib placements, provides that face distortions do not exceed 0.07 mm (0.003 in.) over the entire loading surface. Figure 2 displays the magnitude and distribution of the load for which the table was designed.

Two tee slots machined in each side face and eight tee slots machined across the loading face offer convenient positions for securing matrix components and associated equipment.

The closure face (the face making contact with the movable table) is machined with extreme accuracy. It is parallel to the opposing face of the movable table over its entire 144-in. width and 90° to the mounting surface that makes contact with the bed runways. Deviations do not exceed 0.025 mm (0.001 in.).

Double gibbing provides a method for aligning the tables with each other and with respect to the guiding runway. Two sets of gibs mount to the understructure of each table so as to straddle the runway. One set

mounts near the front, and the other mounts near the rear end of the table. Each set consists of one fixed member, which bears against one side of the runway and is blocked and pinned in position. The adjustable member fits against the opposite side of the runway. The degree of pressure exerted against the runway depends on whether the table is movable or stationary. In the case of the stationary table, the adjustable half is clamped tightly and locked there to fix the table in position. The movable-table gibs are fitted to provide 0.05-mm (0.002-in.) clearance, which will allow a sliding fit against a film of oil that is dispensed through oil grooves machined into the face of the gib. This clearance is attained by a longitudinal adjustment actuated by an adjusting screw. The tapered gib face moves with respect to the matching tapered mounting face of the table, thereby increasing or decreasing clearance as desired. The final setting is secured with locking setscrews. These gibs are fabricated from a phosphor-bronze material (SAE No. 64). The high lead and tin content (~10% each) of this alloy gives it excellent wear resistance and good strength and antifriction qualities.

3. Movable-table Assembly

The design of the movable-table casting is basically the same as that for the stationary table. Descriptive information in paragraph 2 above applies to both units. Additional features are required on the movable-table assembly because of its functional requirements and are described in the following paragraphs.

a. Table Mobility. Table mobility is achieved through 18 antifriction roller-bearing assemblies, mounted to the undersurface of the movable table. The layout pattern is such that each assembly assumes its equal portion of the combined load of the core and matrix assembly plus the weight of the table. Five bearing assemblies ride on the hardened inserts of each of the two outboard runways; four assemblies ride in a like manner on each of the two inboard runways. The construction of the roller-bearing assemblies is shown in Fig. 8. An endless chain of rollers is recirculated around a roller block while being confined to a linear path by roller guides. The roller block is hardened and drawn to Rockwell "C" 58-63. The wear surface that makes contact with the rollers is finished to 8-10 μ in. A total of 34 rollers are assembled to form the chain loop, 13 of which are in contact with the hardened insert of the runway. Each roller is hardened, ground, and finished to an 8-10- μ in. finish. Individual bearing-assembly safe-load ratings are 32,660 kg (72,000 lb), so that the total load-carrying capacity for 18 assemblies is 587,800 kg (1,296,000 lb). Using the above figure, and assuming a maximum total bearing load, including the weight of the table, of 90,720 kg (200,000 lb), a safety factor >6 was used in the design to achieve reliable table mobility. The possibility of a bearing roller being fractured is so remote as to not be considered. Should breakage occur, it is more likely that it would be a pin or a link in the roller chain. In this event, it is anticipated that the roller would feed its way out of the race onto the track and then be pushed along ahead of the following roller assembly.

Fig. 8. Roller-bearing Assembly

112-2149-A

Fig. 9. Tumbler-mechanism Mounting

b. Retainer Clamp Bars. Retainer clamp bars, bolted to the movable table, are fitted around the outer runways of the bed at the time of assembly to provide a sliding clamp action. A clearance of 0.05 mm (0.002 in.) between the clamp bars and the runways interlocks the table to the bed, but permits the table to move in an unrestricted manner.

c. Tumbler Mechanisms. Two solenoid-operated tumbler mechanisms are attached to the underside of the movable table (see Fig. 9). Their mountings are such that when the table is assembled to the bed, each occupies its own individual position between the guiding and the outboard runways. Each tumbler mechanism is in longitudinal alignment with its own stop block (described in paragraph 1 above); thus, each one can be independently operated, however, coordinately interlocked for maximum reactor safety.

Each mechanism consists of a steel tumbler block 7.6 x 7.6 x 10.2 cm (3 x 3 x 4 in.), suspended on a swivel pin and aligned by two guide pins. The tumbler is raised by a pull-type 110 V a.c. solenoid and falls to its normal "down" position aided only by gravity.

This motion actuates a double-pole-double-throw microswitch, which relays a signal to the control panel to indicate the alternate positions of the tumbler.

d. Lubricating System. The movable-table assembly is equipped with a lubricating system (see Fig. 10), which provides oil to the gibs, roller-bearing assemblies, ball-bearing nut, and drive screw. A reservoir containing Vactra Oil No. 2 supplies a solenoid-operated lubricator pump. Oil is pumped to a header, where it is metered into tubes that deliver it to the various components in need of lubrication. Gross flooding is not required or desired; therefore, the flow of oil is metered through orifices so that the lubrication is restricted to film coverage only. The pump operating time is limited by an adjustable re-cycling timer.

112-2149-B

Fig. 10. Lubrication System

e. Position Readout System. The table position is monitored with a precision rack, which actuates a position readout system. This equipment is shown in Fig. 11. The gearbox is mounted to and moves with the movable table. Its location is such that as the table travels, a pinion gear is rotated as a consequence of the pinion and rack teeth being in mesh. A flexible steel band normally protects the rack teeth. One end of the band is secured to an end of the rack. The band then extends to the gearbox, which it enters, and is guided around rollers so as to clear the pinion for contact with the rack. Upon leaving the gearbox, the band continues its protective cover across the remaining section of the rack and is terminated with a tensioner fitting. Tension in the protective band eliminates any sag that would cause it to wrinkle while being traversed by the gearbox. Figure 12, a simplified diagram of the readout system, indicates that movements of the movable table are translated into synchrorotation by means of the precision rack and gearbox. A torque motor eliminates

112-2151-A

Fig. 11. Table-position Monitoring Components

Fig. 12

Movable-table Position Read-out System (Schematic Diagram)

backlash in the precision gears. The output from the synchrogenerator, which indicates the position of the table, is sent to the synchrocontrol transformer. The output of the synchrocontrol transformer, which indicates the error in angular correspondence between the two synchros, is sent to the servoamplifier. After amplification, the error signal is sent to the servomotor to cause a motorized correction of the error. Thus, a simple follow-up system is obtained in which the control transformer quickly and accurately follows the angular motion of the synchrogenerator. Tachometer feedback is used for stabilization. Two digital counters are geared mechanically to the control transformer; therefore, each movement of the table is accurately translated into a change in the counter reading. The specifications of the readout system are summarized in Table I.

TABLE I. Specifications of the Readout System

Range:	0-2500 cm (0-999 in.)
Maximum Rated Speed:	305 cm/sec (120 in./sec)
Power Input:	115 V $\pm$ 10%; 1.5 Amp; 60 cps
Accuracy:	$\pm$ 0.013 mm (0.0005 in.)
Maximum Acceleration:	Will follow any acceleration from zero speed to 305 cm/min (120 in./min) without pulling out of synchronism.
Torque Coefficient:	(a) 2.5 g-cm (0.225 oz-in.) per degree, measured at motor shaft. (b) 33.5 g-cm (3 oz-in.) per 0.025-mm (0.001-in.) reading division, measured at counter shaft.

112-2154-A

Fig. 13. Way Wiper

f. Way Wipers. Neoprene way wipers (Fig. 13) clear each runway of grit, dust, etc., ahead of the roller bearings. These wipers are replaceable if they become worn or damaged.

4. Bed and Tables Assembly

Dimensional stability of the facility depends to a great extent on the rigidity of the platform on which it sets. Figure 14 is a layout of the area that supports the facility. Foundation details and leveling and holddown devices are also shown. The figure shows that the weights of the reactor and its components are borne by 44 leveling jacks, which also true-up the bed and tables assembly with the horizontal. Figure 15 shows how the leveling jacks were installed. As each block was placed in its proper

Fig. 14. Foundation Plan and Leveling Method

112-759-A

Fig 15. Leveling-jack Installation

position, adjustment was made by first setting each adjusting screw approximately in the center of its adjustment. The preleveling screws were then manipulated to provide that the reference surface of each jack was parallel with the horizontal (as checked with precision levels), and that the vertical heights of each surface did not vary more than 0.25 mm (0.010 in.) (as measured with optical instruments). When all the jacks were positioned and preleveled, grout compound was floated under and around each block to fix it in position and assure a total load-bearing surface. After the grout was cured, the bed was lowered to its rest position on the preleveled reference surfaces of the leveling jacks. Further adjustments were made by manipulating the adjusting screws that raised or lowered the jacks. Hold-down studs secured the bed to a final adjusted position, which was not more than 0.076 mm (0.003 in.) out of true parallel with the horizontal (as measured with precision levels). Both tables were now assembled to the bed. The stationary table was first to be positioned and aligned with the guiding way. Tapered gibs (described earlier in Section II.B.2) were adjusted, clamped, and locked. After the alignment was accomplished, holddown screws ensured that the table did not move out of position. Next to be assembled was the movable half. It too was aligned by its tapered gibs; however, because the table must move, the gibs were not clamped. A minimum clearance was provided to allow a sliding fit along the guiding way, thereby allowing the movable half to close accurately to a reproducible position without the table canting during its traverse. The ball-bearing nut assembly was next bolted to the underside of the table. The

retainer clamp bars were then assembled and adjusted for clearance around the outer runways of the bed. After the table position readout device was properly installed and the stop-block assemblies checked for alignment, electrical connections were made through the coupling of a flexible cable. At this time, the table was moved to a closed position to facilitate final adjustments. Closure faces were made parallel to each other within 0.02 mm (0.001 in.) across the entire 3.7-m (144-in.) width. Repeated openings and closings revealed that the "table-closed" position reproduced each time to accuracies less than 0.007 mm (0.0003 in.).

Table-travel limiting double-pole-double-throw switches were now installed at the 46-cm (18-in.) and 7.6-cm (3-in.) positions, as shown in Fig. 16.

112-2153-A

Fig. 16. Limit-switch Placement

Further assembly work was discontinued at this stage of erection in favor of the following operational checkout: With the 3/4-hp motor operating, the table was driven from a fully separated position of 152.4 cm (60-in.) to the 45-cm (18-in.) position at which the limit switch stopped the motion by shutting off the power to the drive motor. The speed of traverse was checked and verified at 0.42-cm/sec (10 in./min). At this point a hold button at the control console was pressed to energize the solenoid that raises a tumbler, which clears a stop block to continue table-closure motion. The table was subsequently driven to the 7.6-cm (3-in.) separation by a 1/2-hp motor.

Functional inspection and verification of 0.25-cm/sec (6-in./min) closing speed completed this event. Finally, under continued scrutiny, the last stop block was cleared and the 1/4-hp motor drove the table to closure at a speed of 0.021 cm/sec (0.5 in./min).

Table-retraction tests were next performed. First, the drive speed of the 1-hp retraction motor was measured. Then the emergency-scram 0.9-hp air motor system was tested. Both systems operated efficiently and separated the halves at a speed of 76.2 cm/min (30 in./min).

The operational checkout of the bed and table assembly also included the following:

1. The bed and table assembly was inspected to ensure that adequate but not excessive lubrication was delivered to runway bearings, guiding gibs, and the ball-bearing drive screw.
2. Proper positioning and functioning of travel-limiting and closure-indicating switches was checked.
3. The slip-clutch adjusting devices were manipulated to assure varied torque settings in conformity with varied matrix loadings.
4. Reliable indication of slip-clutch ratcheting as displayed by a blinking light at the control console was ensured.
5. The accuracy of table-position information transmitted to, and displayed on, appropriate readout instruments at the control console was verified.
6. Clearances, fits, and adjustments of all working parts were checked and approved.

The next determination to be made was how well the machine would operate when subjected to the weight of a loaded matrix, what sort of deflections would be encountered, and how this might affect the accuracy in alignments and reproducibility.

To validate deflection readings, the flatness accuracy of the table on which the load was to be applied had to be known (see Fig. 17).

An Auto-Collimator (an alignment telescope) made a flatness survey of the table loading surfaces (see Fig. 18). An optically flat target-mirror is placed on the surface in question. An image of the internally illuminated cross wires in the alignment telescope is reflected from the target-mirror back toward the alignment telescope. Surface irregularities

112-1199-A

Fig. 17. Bed and Table Assembly before Loading

LINE	ACTUAL DEVIATION FROM FLAT													
A TO B	.000	.000	.000	.000	-.001	-.001	-.001	-.002	-.003	-.002	-.001	-.001	.000	.000
B TO C	+.001	+.002	+.002	+.003	+.003	+.002	+.001	+.001	.000	.000				
C TO D	.000	.000	.000	.000	-.001	-.003	-.003	-.003	-.002	-.002	-.001	-.001	.000	.000
D TO E	.000	.000	.000	.000	-.001	-.002	-.003	-.003	-.002	-.002	-.001	.000	.000	.000
F TO G	.0000	.0000	.0001	.0003	.0005	.0002	.0002	.000	.000					

Fig. 18. Survey of ZPR-6 Table Flatness

cause tilting of the mirror, which misdirects the reflected light beams. Perfect collimated register is achieved only when the reflected image and the actual cross wires are in exact alignment. Deviations from perfect collimation are measured by a micrometer, internally mounted in the eyepiece.

Measurements were made by moving the target mirror along the lines indicated on the plot plan (Fig. 18) in 30.5-cm (12-in.) increments. Readings were recorded for positions from A to B, B to C, etc. The completed survey showed that the loading surfaces of both tables, when closed, did not deviate more than 0.0076 cm (0.003 in.) from a true flat.

Following the flatness survey, both tables were loaded with 26 armor-steel plates, as shown in Fig. 19. Each plate was 15.8 cm ($6\frac{1}{4}$ in.) thick by 91 cm (36 in.) wide by 2.7 m (9 ft) long and weighed 3130 kg (3.45 tons). These plates imposed a load of 81,400 kg (~90 tons) per half and a total load on the bed of 162,800 kg (180 tons). Precision levels were placed, where possible, to detect any change in table flatness. No significant change was noted. Measurements were then made between the runway surfaces of the bed to the top surface of each table. The stationary table showed no measurable change with the load. The movable table settled as a unit to show a 0.005-cm (0.002-in.) change. This condition is explained by the fact that the stationary half rests directly on the

112-1217-A

Fig. 19. Test-loaded Bed and Table Assembly

bed, where it is bolted securely, whereas the movable half is mounted on roller-bearing assemblies to achieve mobility. It is reasonable to assume 0.005-cm "take-up" through these bearing assemblies and their mountings.

The movable table was moved through several closure, retraction, and/or scram cycles, demonstrating no operational change due to the heavy loading. It was concluded that since no matrix loading would exceed the load imposed by the armor plates, it would be safe to assume maximum mechanical operational reliability regardless of the core being tested.

All armor plates were removed, and preparations were made to begin the loading of the matrix components.

5. Matrix Assembly

The ZPR-6 matrix assembly was built using Type 304 stainless-steel tubes, which were first bundled in groups of 25 (5 x 5 square), then stacked in an array of bundles (9 x 9 square) to form a honeycomb-like cross section, 2.44 m (8 ft) square. Individual tube specifications are shown in Fig. 20.

DIMENSIONS IN INCHES

Dimension A: Convexity not to exceed 0.0127 cm (0.005 in.) from flat. No concavity allowed.

Dimension B: Allowable deviation from straight, 0.0406 cm (0.016 in.) in total length of tube, 121.9 cm (48 in.).

Dimension C: Twist not to exceed $1/2^\circ$ in total length.

Dimension D: Squareness, measured across corners, ± 0.0127 cm (0.005 in.).

Mechanical properties: Yield strength = 4900 kg/cm² (70,000 lb/in.²).
Ultimate strength = 7000 kg/cm² (100,000 lb/in.²).

Fig. 20. Typical Matrix Tube

The physical dimensions and tolerances specified in Fig. 20 reflect maximum reasonable working requirements consistent with production methods and cost economy. Certain inaccuracies in the assembly are not predictable but are measurable. To reduce these inaccuracies, and to be able to stack with greater ease, bundles were made by welding a group of tubes together in a 5 x 5 square assembly. The tubes were placed in a fixture where they were pressed and clamped to a nominal assembly size. The average measurement across the sides of individual bundles was 27.625 cm (10.876 in.), with variations up to ± 0.038 cm (0.015 in.) from bundle to bundle. Heliarc and spot-welding was completed while the tubes were held in the clamping fixture. Figure 21 shows a typical bundle.

Squareness: Measured diagonally corner to corner not to exceed ± 0.079 cm (1/32 in.).
Twist: Not to exceed $1/2^\circ$ in total length.

Fig. 21. Typical Matrix Bundle

Lateral constraint of each half of the matrix is provided by matrix-holding knees. Each knee is fabricated from type GA Meehanite, cast into the shape of an L. Meehanite metal was chosen because of its ability to sustain greater static loads. Its yield point approximates 80% of its ultimate strength, and its compressive strength is generally three or four times its tensile value. Meehanite castings also demonstrate a high resistance to stress cracking caused by notches, holes to accommodate experimental equipment, etc. A few pertinent physical properties of Meehanite are as follows:

Specific gravity (density)	7.31
Minimum tensile strength (psi)	5×10^4
Compressive strength (psi)	1.75×10^5
Modulus of elasticity (psi)	2×10^7
Coefficient of thermal expansion	
°F from 100 to 1000°F	6.87×10^{-6}

The knees were placed on their respective tables, separated by a dimension equal to nine bundle widths plus sufficient clearance to allow each bundle to be slid into position with light pressure. Figure 22 shows the knees, positioned and bolted to the table surfaces. Tee slots machined at suitable intervals across the face of the tables provided a convenient and adjustable method of securing the knees by using tee nuts and bolts.

112-1531-A

Fig. 22. Tables with Matrix Knees Mounted

Bundles were stacked row by row, alternating between the movable and stationary halves. The first row was placed on the movable half where it was flushed out with the table interface. A dial-indicator surface gauge measured the accuracy of the placement. Clamps, shown in Fig. 23, retain this row while the next row was being stacked. As each successive row was stacked, "C" clamps prevented axial movement of individual bundles until sufficient weights were amassed, making unwanted movement improbable. Bundles being stacked on the stationary half were

brought to contact with the face of the bundle opposing it on the opposite half in the following manner:

- a. Reactor halves were driven to closure.
- b. A dial indicator was fixed to detect movement of the bundle on the movable half that was in line with the bundle on the stationary half about to be brought into contact.
- c. Gentle tapping on the rear face of the bundle with a rawhide mallet resulted in axial movement. This motion was forced until the needle on the dial indicator displayed a slight waver, indicating that the bundle ends had impinged. Figure 24 shows the bundles being stacked.

Matrix building followed the mode described above until an assembly nine bundles high by nine bundles wide had been stacked on each of the two halves. Tie rods were installed across the top of the matrix, and the knee jacks were attached to the side of the table as shown in Fig. 25. The empty matrix was now squared by snugging up the holding knees. The tie bars and knee jacks were tightened, the knees being moved until the measurements across the top and bottom of the stack equalled the height. Each knee was secured in this position with holddown bolts. Precision levels were repositioned at locations outside the area covered by the matrix assembly components to again detect any deformation in the table surfaces during and after sample core loadings. A slight downward deflection toward the outer edges of the tables was noted after the matrix-holding knees and stainless-steel tube bundles that form the matrix were assembled as shown in Fig. 25.

112-1538-A

Fig. 23. Bundles Temporarily Clamped during Stacking

112-1541-A

Fig. 24. Matrix Stacking

112-1579-A

Fig. 25. Matrix Assembly

The combined overhung load of the knees and table, which is cantilevered ~61 cm (28 in.) out from its nearest support, plus the lateral force of closely packed tubes pressing against the upright surfaces of the knees, produces a bending moment to cause a 0.010-cm (0.004-in.) deflection at the outer edges of the movable table. The stationary table deflected in a similar manner. However, the amount of deflection was only 0.005 cm (0.002 in.), which may again be explained by the fact that the table is bolted directly to the bed.

Before a load was applied to simulate a core, zero-reference measurements were made between certain designated locations throughout the matrix to the bottom row of tubes, which rests on the table surface. Each of these locations is identified with an "x" in Figs. 26 and 27. The device used to make all matrix-deflection measurements is pictured on Fig. 28. A block, to which a dial indicator is fastened, moved across the bottom row from one tube column to the next as measurements progressed across the matrix. Vertical positioning of the upper block made it possible to measure distances between tubes from any vertical position to the bottom. After a position was chosen, the rod was fixed to the upper block by inserting a snug-fitting pin through both the rod and the block. Any movement or

Fig. 26. Movable Half, Homogeneous Loading No. 1

alternate position assumed by the tube position marked "x" actuated the dial indicator. The guide block served only to steady the rod over the nib of the dial indicator.

The first loading consisted of front and back drawers (to be described in paragraph 7 below) filled with U^{238} . The drawers were inserted into the matrix tubes at locations as indicated in Figs. 26 and 27. The combined weight of the uranium, 28,066 kg (61,875 lb), and the drawers, 620 kg (1367 lb), impressed a total load of 28,686 kg (63,242 lb) on each half. Such a loading was applied mainly to settle the tubes to an optimum condition and to test the rigidity of the complete assembly.

The movable half was loaded first. Measurements were taken at all "x" positions. The resulting data indicated what might happen to a matrix of the ZPR-6 type subjected to a load immediately after stacking. A divergent settling pattern from column to column and row to row demonstrated the effect of loose packing, dirt particles being crushed between tube bundles, and horizontal shifting as the load is applied. The condition was not considered truly representative of matrix deflection.

The table was next moved to a 35-cm ($13\frac{3}{4}$ -in.) separation where differential readings between the two table heights, as well as table-flatness readings, were taken. This information is shown in Fig. 29. Arrows

Fig. 29. Table Deflection with Movable Half Loaded

indicated where precision levels were placed. The arrow heads point toward the high side of the slope, and the numerals indicate the amount of slope measured per lineal foot. Figure 29 shows that the slope readings indicate that the rise is toward the center and back of the tables. None of the readings shows disturbing variances in flatness.

Differential table-height readings substantiate earlier findings, namely, that the movable table deflects as a unit because of bearing "take-up," and that there is an insignificant drop-off of the table surfaces toward the side edges. The table level of the actual matrix loading surface remained flat within 0.0013 cm (0.0005 in.).

Following these measurements, the tables were fully separated and all loaded drawers were removed from the matrix. Measurements were again taken at all "x" positions to compare the loaded to the unloaded condition. With the load removed from the matrix, an equilibrium condition was achieved. The motion of the matrix tubes to equilibrium is identified as "springback." Measurements showed this springback to be greatest through the central columns and to diminish as readings were made outwardly approaching the knees. Lateral rigidity offered by the knees increased frictional resistance between bundles, thus allowing less movement.

A procedure identical to that used to load and unload matrix drawers, and to measure and remeasure deflections associated with the movable half was applied on the stationary half. The resulting measurements verified the deductions made during the studies on the movable half. Figure 30 displays the load effect on the flatness and differential heights of the table loading surfaces.

The shape pattern and magnitude of the springback compared very closely to that found on the movable half.

It could now be reasoned that the unloaded or "sprungback" matrix was an optimum condition, which should be used as a zero reference for future measurements. It was also reasonable to assume that if a loading identical to No. 1 was reapplied, the deflections, if measured at the same "x" locations, would be of the same order of magnitude as the springback measured after loading No. 1 was removed. It would therefore follow that matrix deflections and springback may be considered as synonymous. For this reason, and in consideration of the tremendous labor effort involved in homogeneous reloading, it was decided to load a "typical" core.

The movable half was loaded in accordance with the pattern shown in Fig. 31, using front and back drawers filled with U^{238} as in loading No. 1. The radial blanket area was simulated by close packing. Drawers

Fig. 30. Table Deflection with Stationary Half Loaded

Fig. 31. Typical Core Loading of Movable Half

were inserted in alternate tubes to mock up a core area 50% as dense as the blanket. The combined weight of the uranium, 36,407 kg (80,264 lb), and the drawers, 792 kg (1746 lb), effected a concentrated load of 37,199 kg (82,010 lb).

Although this loading was labeled typical, it represents a severe condition. Most core volumes will be much smaller and more dilute. Measurements were made at all "x" positions, and, as expected, deflections were greatest through the central columns, mainly because with a typical cylindrical core and blanket configuration the highest loading occurs at the central columns. Although there were measured deflections up to 138 mils, this is an integral sum of deflections over a height from the table face (Row 45) to the top of the core (Row 09). Figure 32 shows the trend of deflections as measured over this height at center column No. 23.

Fig. 32. Deflection at Vertical Centerline of Core (Column No. 23)

Through the area occupied by the control rods (Rows 17 to 29), the differential reading, when the worst condition was considered, was only 40 mils, which averages 3 mils per tube. Even at the most heavily loaded area near the bottom of the matrix, the greatest deflection measured from the table surface to Row 43 was 13.5 mils. The average deflection per tube, across the width of the matrix, was 7 mils. This means that individual tube deflections could vary from 4 to 7 mils.

Using these data to extrapolate, if a sample matrix tube, having the minimum inside dimensions allowed by manufacturers' tolerances, was reduced 10 mils in the vertical direction by an assumed load, there would still be 20 mils clearance over the maximum control drawer and 9 mils clearance over the maximum matrix drawer. Nominal control- and matrix-drawer sizes would provide 7 to 10 mils additional clearance.

This condition is amenable to safe reactor operation since 10 mils deflection per tube is an extreme amount and probably will never occur. If we grant that it might occur, this would be less than 30% of the elastic limit of the tube material.

For the core loadings anticipated for ZPR-6, the magnitude of the deflections predicted by the measurements reported in this text should be of little concern. If adjustments and shimming are provided, rod positions can be repositioned to compensate for any misalignment due to matrix shift or sag.

It was postulated that continued measurements on the stationary half with a typical core loading would only confirm the readings observed on the movable half. The configuration would be identical; therefore the deflection would be comparable.

Measurements were consequently discontinued at this point. As a result of the investigation previously described, it was concluded that the more meaningful data were those taken subsequent to settling the matrix to an optimum condition. Initial loadings only tend to include anomalies not present after the matrix is properly settled and aligned. Table stability was substantially proven by comparing before and after matrix-loading effects. The diverse table-mounting conditions account for the variation in total table deflection between the two halves; however, the maximum difference in table surface heights in the area between the faces of the holding knees did not exceed 0.005 cm (0.002 in.).

6. Rod-drive Mounting Plate and Support Structure

The attitude of the matrix was now finalized, and with reasonably accurate predictions being possible regarding deflections, rod-drive mounting plates and their support members could be positioned. Shims were applied between the foot pads of the mounting-plate frames and the table surfaces. Shims were also applied between the pads of the spacer arms and the edges of the knees to position the frame horizontally (see Fig. 33). Final positioning of the rod-drive mounting plate was established by assuming an average core size that would cause the matrix to deflect a predetermined amount. The center-rod position on the plate was centered with the predicted deflected position of the central matrix tube. The plate, thus centered, was bolted securely to the mounting frame

making it ready to receive the attachment of up to nine dual-purpose rod drives (safety or control) and up to six blade-type safety-rod drives.

112-2756-D

Fig. 33. Reactor Assembly

7. Matrix Drawers

Two types of matrix drawers (see Fig. 34) are provided to hold core and blanket materials. One type, identified as a core or front drawer, is supplied in three lengths. The length selected for use in a particular core will depend on the size and shape of the core under consideration. This drawer features an accurately located lug, which is securely fastened to its side. When inserted into a matrix tube, the lug nests into a receiving slot like the ones shown in Fig. 20. By fully inserting and bottoming-out the lug, each drawer can always be repositioned accurately and the faces of all drawers will be aligned with the face ends of the matrix tubes. Each core drawer is assigned a particular insertion position in the matrix. A character stamped into the metal of the face or lug end of the drawer denotes that position. The letter M or S signifies

whether it is to be inserted into the movable or stationary half of the reactor. The numerals indicate its coordinate position in the half with respect to the horizontal and vertical axes. The blanket or back drawers are basically the same as the core drawers. Their cross-sectional measurements are identical; however, the blanket drawer is available in only one length. No positioning lugs are attached to this drawer, nor are letters and numerals stamped on its end for identification. A curved handle, formed as part of the rear end plate, provides a way to grasp the drawer when it is to be removed from the rear of the matrix.

Fig. 34. Matrix Drawers

Both styles of drawers are fabricated from Type 304 stainless steel. The drawers are dimensionally held to close tolerances to assure good accuracy of fit to the matrix tubes. Holes are perforated in the end plates of all drawers so that their contents can be inventoried after insertion into the matrix.

8. Dual-purpose (Safety or Control) Drive Mechanism and Drawer Assembly

a. Description

(1) Drive Mechanism. The drive mechanism (shown in Figs. 35 and 36) is 14 cm (5.5 in.) square and a little over 1.16 m (46 in.) long. The transmission, which consists of a gear train, drive motor, and selsyn transmitter, is designed to stay within the 14-cm-square limit and adds 12.4 cm (4.875 in.) to the overall length. The drive motor is a 27-V d.c., 1/30-hp, permanent-magnet type, which delivers power through the stepdown transmission to a pair of lead screws, each of which drives a ball-bearing nut. Both ball-bearing nuts are fixed to a saddle so that as the screws turn, the saddle travels in or out, depending on the direction of screw rotation. The saddle is guided by bushings, which ride on polished tie bars. The free travel must be not less than 61 cm (24 in.). Mounted to and traveling with the saddle are a tubular carriage, primary and secondary springs, a spring spacer, and the electromagnet assembly. When the lead screws drive the saddle in, the primary and secondary springs are compressed against the piston-armature assembly. This motion is continued until the springs are fully compressed and the electromagnet latches on to the armature. A shaft extends from the piston-armature assembly through a wiper and guide bushing and couples to the control drawer (the control drawer is described in paragraph 2 below). Therefore, any movement of the saddle toward the reactor will drive the drawer into the matrix. Reversing the drive motor will, of course, withdraw the drawer from the matrix. The springs being compressed, with their energy contained by the holding power of the electromagnet, provide a "cocked" condition. Release is effected when the electric power to the electromagnet is interrupted. In this event, the springs drive the piston away from the reactor, rapidly withdrawing the control drawer. Two springs in series provide this energy. One is a short, heavy spring, which effects the high initial acceleration. The other is a lighter spring of greater length, which continues the motion that completes the withdrawal of the drawer. As the scram or drawer withdrawal is completed, the piston enters a cylinder with proper clearance so that ambient air is trapped and compressed to serve as a dashpot and absorb the energy at the end of the stroke. The final shock, when the piston bottoms, is absorbed by a 1.27-cm (0.5-in.) neoprene pad. This absorber pad is also needed if the mechanism scrams near the "rod-out" position before it has traveled far enough to trap sufficient air to act as a cushion. The magnet and armature are fabricated from ARMCO (commercially pure) iron. Their function becomes more dependable through the use of this material because of its high magnetic flux, low ampere-turns, and low residual magnetism. Further dependability is realized by hard-chrome-plating the contact surface of the armature. This provides a 0.0076-cm (0.003-in.) gap, which allows the magnet to release faster and reduces the effect of dirt and misalignment between mating faces.

112-1735-A, -1739-A

Fig. 35. Dual-purpose Drive Mechanism

Fig. 36. Dual-purpose Drive Mechanism and Drawer Assembly
(Cutaway and Exploded Views)

Wear resistance and weight considerations were the prime factors in choosing materials from which the remaining components were fabricated, and machining tolerances were kept to a minimum. In or out limit switches give evidence of extreme rod positions. A continuous monitoring of rod position is followed by a digital counter, driven by a selsyn transmitter that couples to the drive gears of the rod-drive transmission. Latching of the magnet and armature is indicated by a switch (located behind the magnet), which is actuated by a push rod extended axially through the center of the magnet. All the above conditions are displayed at the control console.

(2) Control Drawer. The drawer that is used as a control element features the same cross-sectional dimensions as the regular matrix drawers. Its length is 103 cm ($40\frac{5}{8}$ in.). The drawer consists of two sections, separated by a "T" bar. This bar diverts a portion of the inertial loading away from the drawer walls when the assembly is scrambled. The front section is loaded with core and fissionable materials in a pattern identical to that of the fuel drawers. The rear section is provided for core-blanket materials, which will be loaded in an arrangement typical of the neighboring blanket drawers. A connecting bar extends from the rear face of the drawer to a flexible coupler, which in turn fastens to the drive mechanism as shown in Fig. 36.

b. Functional Requirements. The full stroke of the rod is 61 cm (24 in.). The rod speed is controlled by a variac that regulates the voltage to a d.c. power supply. The maximum insertion speed selected depends on the worth of a control drawer and is adjusted so that the rate of reactivity addition is no greater than $0.03\% (\Delta k/k)/\text{sec}$. This speed never exceeds 0.25 cm/sec (0.394 in./sec.).

Under scram conditions, the rod is "fired" to the out position by ~350 kg (775 lb) of force supplied by the two compression springs. The rod is designed to travel 90% of its full stroke in about 280 msec. The first 15 cm (6 in.) should be traversed in about 120 msec after the initiation of the scram signal. The rod drive must operate dependably with minimum grease and oil lubrication.

c. Testing. A test setup was made to mock up the actual operating conditions to which the mechanism would be subjected in the reactor. A control drawer loaded to ~30 kg (66 lb) was connected to the shaft of the drive by means of a flexible coupling. Its travel path was confined to the inside of a stainless-steel matrix tube where it rode on a minimum amount of graphite lubrication. (Light lubrication simulated actual conditions because the mating wear surfaces of both the matrix tube and control drawer, as used in the reactor, are coated with a baked-on film of lubricant, known commercially as ELECTROFILM.)

After ~100 scrams were observed, it was apparent that minor modifications would be required. The dashpot action was inefficient. New pistons were fabricated to provide a skirt several inches longer than the original lengths. The new pistons were installed and testing continued. Further observations indicated that the secondary spring was being overcompressed causing the spring windings to overlap. This resulted in entrapment between the electromagnet and the armature so as to prevent latching. As a corrective measure, the external spring-guide tube on the spring spacer was moved forward to contact the piston skirt, preventing the secondary spring from becoming fully compressed.

Upon completion of the previously mentioned modifications, the mechanism was reassembled and retested. The piston tended to bounce excessively. This indicated the need to change the size of the bleed orifice in the bottom of the cylinder. A series of pipe plugs, each with a different size orifice, was used to vary the openings until the proper size was found experimentally. High-speed motion pictures monitored the extent of bounce experienced with different orifice openings. The optimum size, which limited the bounce to an acceptable amount, was determined to be 4.76 cm (0.1875 in.). Bleed holes were sized, and the necessary modifications were completed on all remaining drive assemblies. Testing continued thereafter until all units operated in accordance with specifications. Figure 37 is typical of the scram times demonstrated by the ZPR-6 dual-purpose rod drives operated under previously described test conditions.

Fig. 37. Dual-purpose Rod-drive Scram Speed

9. Drive Mechanism, Safety Rod, and Guide Sheath

a. Description

(1) Drive Mechanism. The design of the safety-rod drive mechanism (see Figs. 38 and 39) is similar to that of the dual-purpose drive mechanism. One obvious difference is that the dashpot end is reversed. This is characterized by a cylinder extending 40 cm (16 in.) out from the mounting face toward the reactor matrix. A completely diverse type of element is used for shutdown, and its method of attachment is appropriately different. The drive arrangement is essentially the same as that described for the dual-purpose assembly. The drive motor is a 27-V d.c., 1/30-hp, permanent-magnet type, which delivers power through a speed stepdown transmission to the twin lead screws. The lead screws drive a pair of ball nuts, which are fixed to a saddle. A spring guide, the scram spring, and an electromagnet attached to and move simultaneously with the saddle. Moving as a unit, the assembly guides on the polished tie bars located diagonally opposite the lead screws. The sequence of events leading up to the latching of magnet and armature follows identically to that described for the dual-purpose drive. In the safety-rod drive mechanism, one spring (instead of two) is compressed by the action, and the direction of travel for latching is reversed. The armature is assembled to the piston with stripper-type bolts to permit self-alignment while being mated with the electromagnet. Two extension rods are fastened securely to the piston. They extend through bushings and wipers, which have been fitted into the end flange closure of the dashpot cylinder, and are connected to the boron-filled safety rod as shown on Fig. 39. By this connection, when a latch-up is effected, rod position is controlled by operating the ball-nut and lead-screw drives. The spring is fully compressed when the latch-up occurs; therefore the assembly is "cocked" and any interruption of power to the magnet, whether planned or accidental, releases its attraction to the armature. The spring takes over when this release occurs and drives the boron-filled rod into the reactor core to effect the shutdown. Under normal operating conditions, the rod is adjustable over a 76-cm (30-in.) range. Rod-position readout is given by ten roller-actuated switches, which are separated at intervals of 7.6 cm (3 in.) and mounted to a tie bar, which parallels the direction of the rod motion. A bracket is fastened to the lead-screw drive saddle. As the saddle traverses the 76-cm range, the bracket moves across the switches. Except at the fully inserted or withdrawn positions, two switches are always depressed at any given position in the traverse. As the bracket passes off one of the two depressed switches, the next switch is contacted and activated simultaneously. Each switch is represented by a light at the control panel; thus the operator may observe rod positions in increments of 7.6 cm. He will also know when the rod is fully in or out of the core.

(2) Safety Rod. Figure 39 displays the rod in a blade form ~1 cm (0.375 in.) thick, 5 cm (1.940 in.) high, and 78 cm ($30\frac{7}{8}$ in.) long. The

112-1733-A, -1738-A

Fig. 38. Safety-rod Drive Mechanism

Fig. 39. Drive Mechanism, Safety Rod, and Guide Sheath

skin thickness of the stainless-steel envelope is 0.08 cm (0.032 in.). About 230 g of enriched boron powder is contained within the envelope. This neutron-absorbing material extends from the forward end of the blade assembly over a 61-cm (24-in.) length. A flexible connection is made to the extension rods of the drive mechanism through a knuckle joint.

(3) Safety-rod Guide Sheath. Figure 39 shows a stainless-steel guide sheath fastened to the forward flange of the drive mechanism. The sheath extends into and through the matrix providing a path in which the safety rod travels as it is inserted into or withdrawn from the core. The inside dimensions are sized to fit loosely over the safety rod, yet serve as a true guide. The overall length of the guide sheath is 161.3 cm ($63\frac{1}{2}$ in.), which positions its end just short of the interface between reactor halves.

b. Functional Requirements

The safety-rod drive mechanism, being an insertion type, must "fire" dependably into the reactor core upon the initiation of a scram signal. The rod must move over a 61-cm (24-in.) distance in not more than 100 msec. The force that effects the insertion speed is supplied by a single compression spring. After the spring is compressed to a ready position, with the mechanism latched, a force of 181 kg (400 lb) is exerted against the piston. The position must be infinitely adjustable over the entire 76-cm range with a speed that is variable from 0 to 76 cm/min.

(1) Testing. The conditions used to test the safety-rod drives were the same as those used to test the dual-purpose drives. A set-up to simulate actual reactor operating conditions was mocked up. By the time the first mechanism was scrambled for ~100 times, it was evident that some modifying changes would be required. The mechanism was disassembled and the following changes were made:

(a) The drive-motor strength proved marginal; therefore a replacement motor was installed. This motor was directly interchangeable with the original motor. Although only slightly longer than the original motor, the replacement motor delivered 50% more torque.

(b) When the parts were removed and inspected during disassembly work, it was discovered that the scram spring had shaved chips from the aluminum spring guide. New stainless-steel guides were fabricated and installed.

(c) The blade extension rods had loosened at both end fastenings. The rods were retightened into the clamp at the knuckle end, holes were drilled through both the rod and the clamp, and V-groove type pins were applied. The end that attaches to the piston was secured with redesigned nuts of the type that could be safety-wired in position after being properly tightened.

(d) During the testing of the first mechanism, excessive bounce was observed when the piston stroke was damped out in the dashpot. This condition, like that displayed by the dual-purpose rods, was easily corrected by varying the size of the bleed orifice until the optimum size was obtained.

The remaining mechanisms were modified and tested until all operated satisfactorily. Figure 40 displays the typical scram times recorded for all safety-rod drive mechanisms.

Fig. 40. Safety-rod Scram Speed

10. Neutron-source Drive Assembly (Fig. 41)

a. General Description. Two neutron-source drive assemblies are required on ZPR-6, one drive for each half. The function of the drive assembly is to provide a means to guide and insert a neutron-emitting capsule into a predetermined location within the matrix of the reactor. The drive assembly must also withdraw the capsule from the matrix and guide it into a container that will shield personnel in close proximity from exposure to escaping neutrons.

b. Components. The neutron-source drive assembly includes a "TELEFLEX" cable assembly, conduit, and control-box network, which are designed to motivate the source capsule through the necessary phases of operation. The cable is made up of wire strands wound to provide maximum flexibility and maximum strength. A single larger strand is helically wound around the cable. The pitch of the windings matches that of the drive wheel and has accuracies of ± 0.005 cm (0.002 in.), which assures a good match with minimum backlash. On one end of the cable is mounted a nylon sleeve to actuate a switch, and on the other end a fitting to which the source capsule attaches. The cable is threaded through the control box, which contains the driving wheel. This wheel is specially hobbled with grooves to match the pitch of the helically wound wire around the cable (see Fig. 41). The control-box housing confines the cable in a way that causes it to wrap partially around the wheel. Thus the windings are forced to nest into the grooves. In this way, the cable can be positively driven in either tension or compression to produce a force in either direction. The drive wheel is coupled to a 1725-rpm, 1/6-hp, single-phase motor through an overload clutch and a 300:1 speed-reduction unit. The path of travel is through both flexible and rigid conduit. An adjustable guide tube is used to position the source capsule to various penetrations of the reactor matrix. When withdrawn from the reactor for storage, the capsule comes to rest in the center of a 61-cm (24-in.)-diam cask filled with borated paraffin. Travel limits are controlled by limit switches and adjustable stops to control cable travel in both directions. A push rod actuates a limit switch when the source capsule is in the inserted position, and the nylon sleeve on the end of the cable actuates a switch when the capsule is in the stored position.

Fig. 41. Neutron-source Drive Assembly

III. AUXILIARY EQUIPMENT

The principal auxiliary equipment for the ZPR-6 includes the following assemblies:

- a. Loading platform
- b. Matrix-drawer conveyor
- c. Reactivity-coefficient sample changer
- d. Ultraprecision (nonscramming), control-rod drive unit
- e. Autorod mechanism

The above-listed auxiliary equipment is described in the following paragraphs.

A. Loading Platform

A loading platform (see Fig. 42), designed to lower like a draw bridge into the separation between reactor halves and then to be elevated to a height most convenient to load or unload drawers, was installed for use with ZPR-6. The platform structural members were fabricated of aluminum and covered with magnesium tread plate to provide a working-area surface 4.9 m (16 ft) long by 1.4 m ($54\frac{3}{4}$ in.) wide. A 0.06-cm (0.25-in.)-diam cable is fastened to and unwinds from a grooved drum. The cable plays out over a pulley system and is anchored at its opposite end to a fixed bracket, which is attached to the carriage frame. A gear motor, with a 300:1 ratio, working through a positive, one-way, torque-control unit, rotates the grooved drum. As the cable unwinds from the drum, the platform swings down; rewinding causes the platform to return to its upright position. When the platform is lowered to the horizontal position, which takes approximately 3 min, a switch is depressed to indicate that the full down position has been reached. This switch also closes a circuit to allow the platform to be elevated to the desired working height at a speed of 58 cm/min (23 in./min). The elevating motion is accomplished by a carriage riding against vertical tracks, which have been fastened securely against the reactor cell wall. The carriage is driven over a 1.5-m (60-in.) distance by an acme-thread lead screw, which is directly connected to a 15:1 speed reducer. A 3/4-hp, 1725-rpm, three-phase motor supplies the driving torque to the speed reducer. A safety chain assures the stability of the lowered platform. The safe load limit on the outer end of the platform is not to exceed 363 kg (800 lb). The unit can be manipulated by control switches on the platform, or remotely from the control room. The local controls override those at the control-room station. Signal lights at the control panel are energized through limit switches to indicate when the platform is stored against the wall or swung out 90° to the horizontal position. These switches tie into an interlock system so that the platform cannot be lowered unless the reactor halves are fully separated. Conversely, the

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TYPICAL PLATFORM STORAGE
AGAINST THE WALL
(PICTURE TAKEN DURING ERECTION)

PLATFORM SHOWN
IN A LOWERED POSITION

PLATFORM SHOWN
IN AN ELEVATED POSITION

Fig. 42. Loading Platform

reactor cannot be started unless the platform is in the vertical storing position. Position readout gives evidence of the elevated height of the lowered platform when it is moved to desired working attitudes.

B. Matrix-drawer Conveyor

During reactor loading operations, the integrity of the cell is maintained by keeping personnel entrance doors closed. Loaded matrix drawers enter and leave the cell through interlocked doors, which are fitted to circular ports and located in the wall 6.7 m (22 ft) from the working area between halves. A matrix-drawer conveyor (Fig. 43) was installed to transport loaded drawers across that distance. It consists of two parallel tracks with a closed-loop roller chain operating in each track. Mounted on each chain are loading stations, which consist of "DELRIN" plastic plates linked so that a flat surface is provided to support the drawer being transported. The assembled length of each station is limited to a length that will allow only one drawer to be supported thereon. The stations are spaced around the chain loops so that only one drawer per track can be transported across the length of the conveyor at any one time. The chains operate in opposite directions; that is, one track delivers drawers to the reactors, the other transports them from the reactor back to the transfer ports. A switch is depressed as each drawer is delivered to its respective waiting station. The delivered drawer must be removed so that the switch is reset before the conveyor chain drive will operate again. In this way no more than two drawers can occupy the conveying system, thereby eliminating hazards of criticality caused by inadvertent bunching of fuel drawers. Each chain loop is driven by a 115-V, split-phase, 1/6-hp motor-reducer with a ratio of 48:1. A swivel joint connects the conveyor to a wall-mounted bracket. This flexible joint allows the conveyor to be swung to service the rear or blanket side of the matrix as well as the area between halves. When not in use, the conveyor can be folded and stored against the wall as shown in Fig. 43. A cable, pulley, and winch system provides the means to fold or unfold the conveyor assembly.

C. Reactivity-coefficient Sample Changer

The reactivity-coefficient sample changer (see Fig. 44) is designed and built for remotely exchanging $4.9 \times 4.9 \times 2.5$ -cm ($1\frac{15}{16} \times 1\frac{15}{16} \times 1$ -in.) samples of various materials in a container that can be remotely positioned at the center of the core assembly. In this way reactivity changes for each alternate material can be observed much more rapidly than if the reactor were shut down to allow the exchange to be made manually. The accuracies of the measurements are considerably improved by the remote operation. The main drive consists of a reducing gear set driven by a 1/30-hp, shunt-wound gearmotor through an adjustable slip coupling. A drive pinion meshes with a rack

112-5774-A, -5772-A, -5773-A

Fig. 43. Matrix-drawer Conveyor

112-1734-A, -5437-A

Fig. 44. Reactivity-coefficient Sample Changer

assembly, which in turn is coupled to the sample drawer by means of a flexible connection. The drawer is identical to the dual-purpose control drawer (described on p. 46), except that a compartment, measuring $5 \times 5 \times 2.7$ cm ($2 \times 2 \times 1\frac{15}{16}$ in.) inside, is welded to the front or interface end. This compartment is designed to accept any one of the various samples available for selection. Twelve samples are contained in a tray-magazine assembly (see Fig. 45), mounted on sliding ways. Positioning motion is provided by a pull-type, 60-cps, 110-V a.c. solenoid, which features pulling power of 11 kg (25 lb) with a 3.8-cm ($1\frac{1}{2}$ -in.) stroke. Stepwise selection may be made across 12 samples by pulsing current to the solenoid by means of a push-button switch at the remote-control console.

Positioning accuracy is achieved by a pawl, which engages a notched rail. The magazine carriage is held steady in each position, No. 1 through No. 12, by a constant-force "NEGATOR" spring. The carriage may be automatically returned to position No. 1 by releasing the pawl mechanism. All 12 sample positions are characterized by numerals and lamps on the control console panel board. As the carriage moves, a gear rack causes a pinion gear to rotate another gear. This gear is attached to a rotary multicontact switch so that as the gear turns, a wiper arm moves across a contact to light a bulb under the proper numeral identifying the sample at the delivery position. The sample may now be moved from the tray to the receiving compartment by a transfer arm (see Fig. 45). The transfer arm is guided by brass ways and is actuated by an air cylinder through a special linkage. Two double-pole-double-throw switches are mounted so that an indication is provided to inform the operator whether the sample is in or out of the receiving compartment. After the arm has transferred the sample to the compartment, the arm remains in that position until the sample has been transported to the desired insertion into the core and returned. The arm then returns the sample to the tray, the mechanism is indexed to bring the next sample into position, and the cycle is repeated as required to satisfy the experiment.

D. Ultraprecision (Nonscramming), Control-rod Drive Unit (Fig. 46)

An ultraprecision (nonscramming) control-rod drive unit is used to position a control element with a high degree of reproducibility. It includes a ball-bearing lead screw and preloaded nut assembly, which are driven by a variable-speed, d.c. stepping motor.

The lead screw is made from 17-4 PH stainless steel, hardened and ground to an accuracy of 0.0005 cm (0.0002 in.). Maximum lead error per 30.5 cm (12 in.) of thread may be cumulative but is not to exceed 0.001 cm (0.0004 in.) over the total 66 cm (26 in.) of thread length. The lead screw drives the ball-nut assembly, which is rigidly fixed to a grooved

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Fig. 45. Sample-changer Tray-magazine Assembly. a. With Samples Ready for Insertion. b. With Sample Inserted.

Fig. 46. Ultraprecision (Nonscramming), Control-rod Drive Unit

hollow shaft. This shaft extends through two ball-spline assemblies that mesh with these grooves to restrain the shaft from rotating as it is moved in a linear direction by the revolving lead screw. The spline assemblies are radially preloaded against the grooves to prevent backlash. The control element is connected to the shaft end through a flexible-joint coupling.

The length of stroke of the control element is adjustable over a 61-cm (24-in.) range. Proximity-type limit switches limit the travel at both ends of the stroke.

Rigidity is maintained through the use of rugged end-mounting plates spaced and bolted to four shouldered tie-bars, which have been machined as a set.

Position readout is accomplished by a rotary photo switch, connected directly to the motor shaft. A detailed description is presented by Main and Dates in ANL-7140.³

E. Autorod Mechanism

The autorod mechanism (Fig. 47) is designed so that the guide tube extends into the matrix of the ZPR-6. A capsule, in the shape of a thin-walled cylinder containing a little more than 4.5 g of enriched boron, is inserted into the core through the guide tube. Its position is automatically adjusted over a range of 15 cm (6 in.), dependent on the magnitude of the desired reactivity changes, in the following manner: The input signal to the auto-rod is obtained from the output of a picoammeter connected to one of the ion chambers in the reactor. This d.c. signal is compared with a d.c. reference level. The difference between these two d.c. levels determines the direction of motion of the rod, and the magnitude of the difference determines the speed at which the rod is driven.

The capsule is threaded to the end of a connecting rod. The opposite end of the connecting rod fastens to a rack, which is driven by a pinion rigidly pinned to the drive motor shaft. The 1/750-hp drive motor is a modified gearmotor with a reduction of 72:1. The direction and speed of rotation of the motor are a function of the criticality of the reactor. The range of movement of the rod is limited by positive stops. The "in" limit is adjustable; the "out" limit is fixed.

A potentiometer is driven by a pinion gear, which meshes with the drive rack. The potentiometer is used to indicate the position of the rod. When a d.c. reference voltage is applied to this potentiometer, a voltage is obtained, which is directly proportional to the position of the rod.

112-5771-A

Fig. 47. Autorod Mechanism

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John F. Pohlman**	Final design and construction
William J. Kann	Testing and design revisions
Martin C. Glass	Testing and reporting

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