THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Nuclear Engineering

Progress Report
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NEUTRON OPTICS

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A. REVIEW OF OBJECTIVES, TIME SCHEDULES, PROGRESS, AND PERSONNEL

Work on this project began in early May, 1960. While the general field of neutron optics has been under discussion, the year's effort has been almost exclusively devoted to the design, construction, and assembly of a flexible, double-scattering, neutron crystal spectrometer. It is planned to attempt initial measurements of inelastic scattering of "thermal" neutrons in selected solids and liquids. The spectrometer design is, consequently, patterned after the "triple axis" scheme used by the Chalk River group under B. Brockhouse. This design permits the measurement, either manual or automatic, of differential cross sections in both energy and angle.

It has been clear from the outset that the major obstacles to this program are: (1) the limited thermal flux levels available from the 1 MW Ford Nuclear Reactor, and (2) high background counting due to leakage of fast (~8 mev) neutrons from the core. Estimates of scattered intensities have led us to anticipate counting statistics on the borderline of practicality; uncertainties in the choice of many parameters require a full-scale calibration run to determine these intensities. We assume a background of 2 counts per minute and a true scattered intensity of 10 counts per minute to be on the borderline of acceptability. Inelastic scattering would be eliminated from the program if these levels are not obtainable.

A time schedule for the construction and initial operation of the spectrometer has been planned as follows:

(1) May 1, 1960, to May 1, 1961: design and fabrication and/or purchase of major mechanical components. These include reactor beam port plug, first Bragg arm with rotating shield turret, first crystal monochromator table and two-to-one linkage with Bragg arm, target table, second Bragg arm, second crystal table, third arm and detector mount; electronic detection system and detectors; procurement of monochromating crystals.

(2) May 1, 1961, to October 1, 1961: installation, alignment, and calibration of all items in (1) above; initial double-scattering experiment, manually programmed, to determine intensities available.

(3) October 1, 1961, to June 1, 1962: initial scattering measurements depending on results of (2). These would begin as a manually programmed operation. Procurement and installation of an automatic drive system, conversion of manual to automatic data taking; design, fabrication, and installation of new reactor beam port plug; fabrication and installation of order contamination rotor.

(4) June 1, 1962, to May 1, 1963: extended experiments on inelastic scattering if results of (2) permit.

Concurrent with this program, considerable effort has been and continues to be devoted to the following three study programs:

(1) Flux optimization experiment in the FNR reactor: the improvements available by use of (a) thick graphite core reflector with small re-entrant holes, (b) elimination of all light water barriers between reflector and port face surfaces, (c) use of a heavy water pad between core and port face, and (d) reshaping of core dimensions.

(2) Development of crystal growing techniques, first, for the procurement of large (3 x 8 in.) monochromating crystals and second for the preparation of scattering targets.

(3) Study of mosaic structures of various crystals to find optimum intensity monochromators.

The personnel contributing to this effort include the following:

1. Over-all Direction (1/5 time) - P. F. Zweifel, Professor, Department of Nuclear Engineering.

2. Direct Supervision of Design, Construction, and Study Program (1/2 time) - J. S. King, Associate Professor, Department of Nuclear Engineering.

3. Detection System, Mosaic Structure Study (1/2 time) - William Myers, Graduate Student, Department of Nuclear Engineering.

4. Mechanical Design and Crystal Growing Technique (1/2 time) - George Wang, Graduate Student, Department of Nuclear Engineering.

5. Port Flux Optimization, Spectrometer Assembly and Calibration (1/8 time) - John Donovan, Graduate Student, Department of Nuclear Engineering.

Additional mechanical design effort has been procured through ORA Services (Murlin Gurney, design draftsman) on an hourly basis.

B. DESCRIPTION OF EXPERIMENTAL ARRANGEMENT

The spectrometer is modeled after the "triple axis spectrometer" used by Dr. Bert Brockhouse at Chalk River.[1] A schematic layout of our adaptation is shown in Fig. 1. Sufficient freedom of motion is provided to allow simultaneous rotation of both Bragg angles, target angle, and scattering angle. This allows use of the "constant Q" technique developed by Brockhouse,[2] a scheme for programming angular motions which greatly facilitates the acquisition of inelastic scattering data.

BEAM PORT PLUG

The collimator and beam port plug assembly are sketched in Fig. 2. Shielding materials consist of alternate layers of lead and borated paraffin. The shield material for the inner 5 feet is concrete. A Soller collimator is used to establish the divergence of the primary beam. It is a 1/8-in. steel shell providing an inside volume 48 in. long by 0.8 in. high by 1.2 in. wide. Flexibility in the divergence angle is provided by a series of milled slots which accommodate from 1 to 5 steel shims and this allows from 2 to 6 parallel slits. The angular divergence can thus be varied between .0115 and .0036 radians by inserting shims through a turret shielding port.

Table I gives the beam dimensions at the source (reactor edge) and at a typical target position, as well as the divergence of the beam versus the slit choice. The corresponding energy resolution at .05 ev is also given, when the crystal effects are ignored.

The collimator dimensions were a compromise between flexibility and optimized intensity. To optimize intensity, it would be desirable to utilize the longest practical length and fewest slits for a given beam size and divergence. The present port plug would accommodate double the present collimator length, but the removable shim arrangement limits the length. It is planned to construct a second collimator plug with a longer, fixed slit arrangement. This model would also contain a liquid nitrogen cooled single crystal fast neutron filter. (Unfortunately, neither plug was provided for in the original project budget.)

FIRST BRAGG ARM AND ROTATING TURRET SHIELD

The first Bragg arm and rotating shield are shown in Figs. 3 and 4. The primary shielding consists of a 36-in.-radius, high-density, masonite turret which rotates 30° about the first crystal axis and is supported by two free ball-bearing races in a fixed plate. This plate is supported by removable jacks, any one of which may be removed at a time. The turret has four 3-1/2-in.-diameter stepped ports 30° apart so that the Bragg arm and turret may be moved through about 100° (50 Bragg degrees) by use of successive port plugs. For single experiments, a Bragg motion of 15° can be made without change of plug or jack, and this is ordinarily more than adequate.

The turret shield is made continuous to the reactor wall by use of a large plastic water bag (60 gallons), filled with borated water, which is supported at sides and bottom and forms to any new turret position. This is a difficult feature of the design. The alternative, for the same direct-beam-shielding radius, would be a 6-ft-diameter, completely round turret; space limitation on the reactor port floor dictated against such a large mass. It may be necessary to add fixed shielding tanks, in either case, and the round turret would again require more floor space.

A 6-in.-thick by 6-in.-high, 60° lead sector inlays the masonite to intercept the direct gamma beam (the gamma beam is collimated approximately like the neutron beam and has been measured at about 300 R at the first crystal axis at 1 MW power level). All ports but the one in use are sealed with masonite and lead port plugs. The used port contains a cadmium lined shielding collimator.

The crystal table is shown in Fig. 5. Translation and ±30° rocking motion are available by removable screwdriver sockets to allow manual centering of the crystal from outside the turret.

The crystal table nests in a spindle mount which is bearing supported inside the main Bragg arm roller bearing. A new and relatively cheap method of obtaining the necessary 2-to-1 turn motion between crystal and Bragg arm, devised by Murlin Gurney, utilizes .020-in. by 3/8-in. steel bands coupling between crystal spindle, fixed support plate, and Bragg arm. These bands wind upon steel tension plates. Initial calibration measurements show that the accuracy of the present system is about 1.0 minutes in 90° of rotation. The spindle arrangement is partially visible in Fig. 4.

TARGET TABLE AND SECOND MONOCHROMATOR

Figure 1 indicates the layout of the target table, second collimator arm, second crystal table, and second Bragg arm. The target assembly mounts on a 15-in.-diameter rotating head. The head may be positioned with its axis from 48 to 75 in. from the first crystal axis. The second collimator arm is flanged to the rotating head and rotation about the target axis fixes the scattering angle. Flanged to the opposite end of this arm is the second crystal table and support carriage. The scattering collimator fills the space between these two axes; the distance between axes is adjustable from 30 to 48 in. Collimator design and scattered-beam divergence angles will closely resemble the primary collimator, but with a premium on weight reduction.

Concentric with the target assembly head, the target table is mounted on separately movable bearings. The table itself is indexed for target orientation and is heavy-duty, to support heavy furnaces or cryostat equipment enclosing the target.

The second crystal table assembly will mount on a welded support framework which includes the cantilevered detector arm. The vertical load for this assembly is borne by a 5-in.-diameter ball-bearing castor which rolls on leveled floor plates.

The detector arm carries the BF_3 detector inside a 12-in.-diameter by 30-in.-long borated paraffin shield. The detector aperture is 2 in. in diameter and may be positioned from 24 to 36 in. from the second crystal. This shield is visible in Fig. 3.

DATA TAKING AND CONTROL SYSTEM

The counting and control system consist of two separate counting channels and a motor drive unit. Figure 6 is a block diagram of this system. One channel, called the Monitor Channel, receives counting pulses from a thin, low-efficiency neutron detector placed directly across the first monochromated beam at the shield turret exist. The second channel, called the Scattering Channel, receives the scattered flux counting pulses from the high-efficiency 2-in.-diameter BF_3 detector at the end of the second Bragg arm. Both channels utilize standard fast, nonoverloading amplification and regulated H.V. power supplies. The Monitor Channel feeds into a 1 MC Beckman preset counter whereas the Scattering Channel feeds into a 1 MC Beckman gated counter and printer. The preset counter generates relay switching and output pulses when a preset count is reached; it has been modified, also, to generate an external pulse as it resets to zero. The gated counter is turned on and off by these output pulses. The stop pulse from the preset counter also initiates the mechanical motion sequence of the motor drive unit (up to 5 independent motor drives activated). A reset pulse from the drive unit resets the preset counter to zero. The operating sequence is as follows:

(1) both channels counting;
(2) preset counter reaches preset number, stops, and generates initiating pulses;

  (a) gated counter stops and prints out, then automatically resets to zero;
  (b) motor drive sequence begins;

(3) Motor drive sequence ends, generates stop pulse;

   (a) preset counter resets to zero, generates start pulse, and begins counting;
   (b) gated counter turned on and begins counting;
   (c) motor drive unit resets automatically.

The preset counter may be driven from an external pulse generator if time base counting is desired (for miscellaneous calibration, etc.).

It should be noted that this monitor system eliminates uncertainties in the primary Bragg beam intensity due to reactor power fluctuations, and to variation in first crystal reflection as a function of energy.*

The motor drive system currently installed is a simple sequential timer (Eagle HM7) and is a cheap, temporary device to start and stop several drive motors in simple, linear programming (as, for example, angular distribution measurements). The ultimate design will be a tape program reader, d-c impulse generator, and 3 d-c impulse motors. This will provide precision small motions and can be programmed for nonlinear programs. These motor drives will independently move the main Bragg arm, the scattering arm and crystal table, and the target orientation. (Independent drive of the second crystal rather than the first one is optional.)

The scattering detector is a Reuter-Stokes BF_3 end window tube 2-in. in diameter by 12 in. active length, filled to 70 cm Hg with 96% $B^{10}BF_3$. Its efficiency is about 75% for neutrons at .05-ev energy. The monitor detector ultimately desired is a pancake-shaped aluminum fission chamber with 3-1/2-in.-diameter by 3/4-in. deep active volume, efficiency about 0.1%, and transparency about 99.5% for .03-ev neutrons. (Such a detector is being constructed by a graduate student with funds from the Department of Nuclear Engineering.) Meanwhile, a 1/4-in.-diameter 20-mil Al-walled Nancy-Wood BF_3 pencil has been installed and works satisfactorily.

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*Furthermore, in the "constant Q" method, the second crystal energy may be kept fixed, thus eliminating all reflectivity uncertainty.

C. STATUS OF THE DESIGN

The program outlined in part A is in general on schedule. Under part (1), the first beam port collimator plug, first Bragg arm and turret assembly with its 2-1 turn drive are installed and working. The detection system with initial simple timer is assembled and in operation. Monochromating crystals have been specified and ordered from a commercial firm and should be available for the calibration run by September 1, 1961. Copper half-cylinders, 3 by 6 in., grown and cut for reflection from the 200 planes, were selected.

Designed and ordered, but not yet delivered, is the collapsible water bag for the primary turret. This continues to be a difficult fabrication item, but delivery by August 15, 1961, is expected.

The design drawings for the target table, scattering arm, and second Bragg crystal and detector structure are completed but fabrication has not yet begun. This item is about 3 months late and is now the limiting factor in the program.

A number of smaller items, such as vernier scales, turret-arm locks, etc., must be designed but are not limiting.

Under part (2), installation and calibration is in progress. The initial double scattering experiment, using temporary target table and second monochromator structures, and manually programmed, should begin in early September. If the count rates are attractive, an intensive effort to convert to automatic programming will begin immediately.

REFERENCES

1. B.N. Brockhouse, Methods for Neutron Spectrometry, CRNP-947, Chalk River, Ont., January, 1961.

2. B.N. Brockhouse, *et al.*, Crystal Dynamics of Lead, CRNP-946, Chalk River, Ont., August, 1960.

TABLE I

BEAM DIMENSIONS, RELATIVE INTENSITY, AND RESOLUTION FOR FLEXIBLE COLLIMATOR*

No. Slits n	Shim Size ϵ	Slit Width s	Horizontal Angular Lim. $\alpha = s/\ell$	Vertical Angular Lim. $\beta = h/\ell$	Beam Size At Target H x W	Beam Size At Source H x W	Relative Total Beam Flux $\phi \sim \alpha^2$	Resolution at .05 ev $\Delta E/E$ (FWHM)
1		1.20"	.025	.0167	3.34"x5.00"	2.74"x4.10"	1.00	13.1%
2	.0937"	0.553"	.0115	.0167	3.34"x2.95"	2.74"x2.54"	0.42	6.0%
3	.0625"	0.358"	.0075	.0167	3.34"x2.33"		0.27	3.9%
4	.0312"	0.277"	.0058	.0167	3.34"x2.07"	2.74"x1.88"	0.22	3.0%
6	.0312"	0.174"	.0036	.0167	3.34"x1.75"		0.13	1.9%

*Collimator length ℓ = 48"
Collimator width $ns+(n-1)\epsilon$ = 1.20"
Collimator height h = 0.8"

Distance
From collimator front to target = 76"
From collimator back to source = 60"

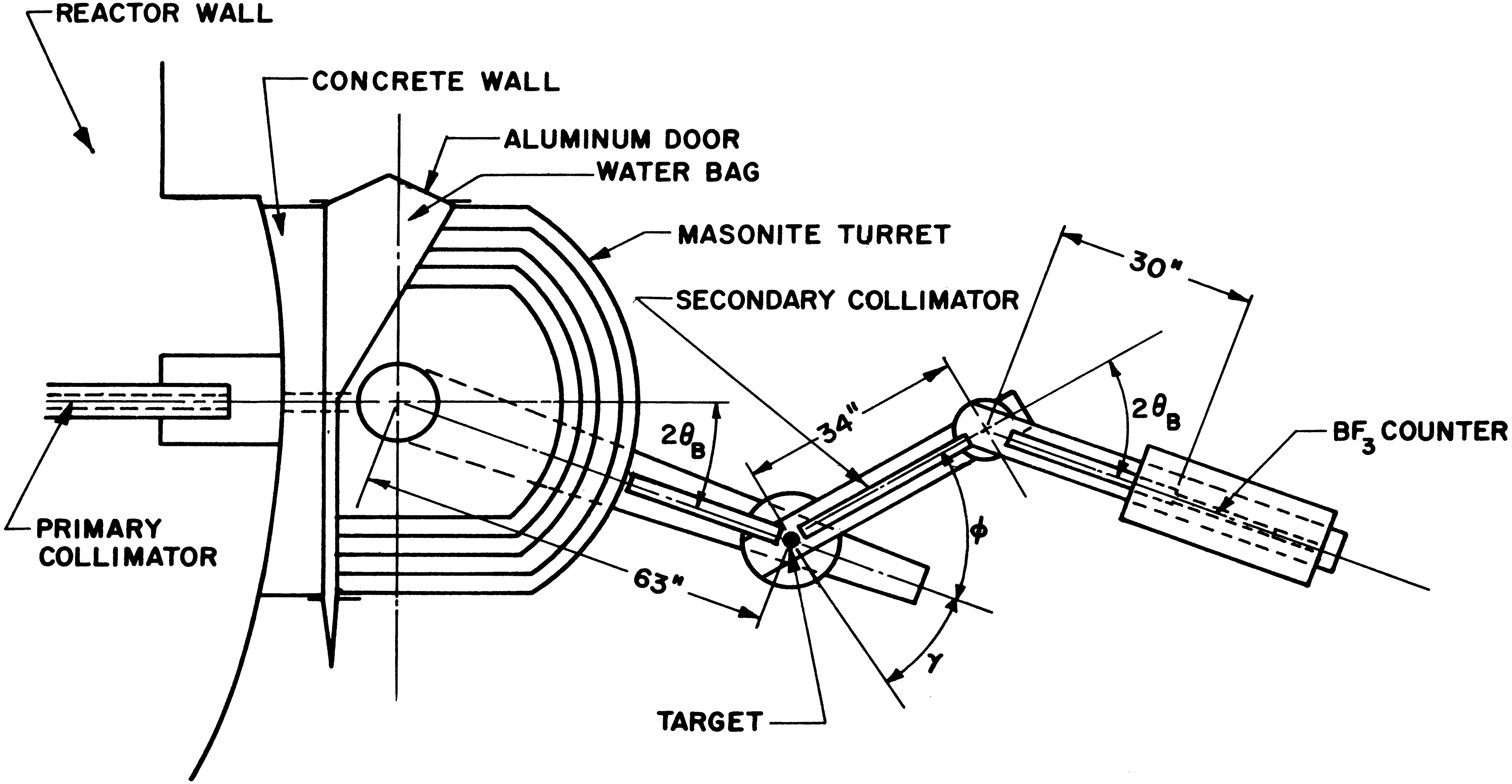

Fig. 1. Schematic layout of double monochromating spectrometer.

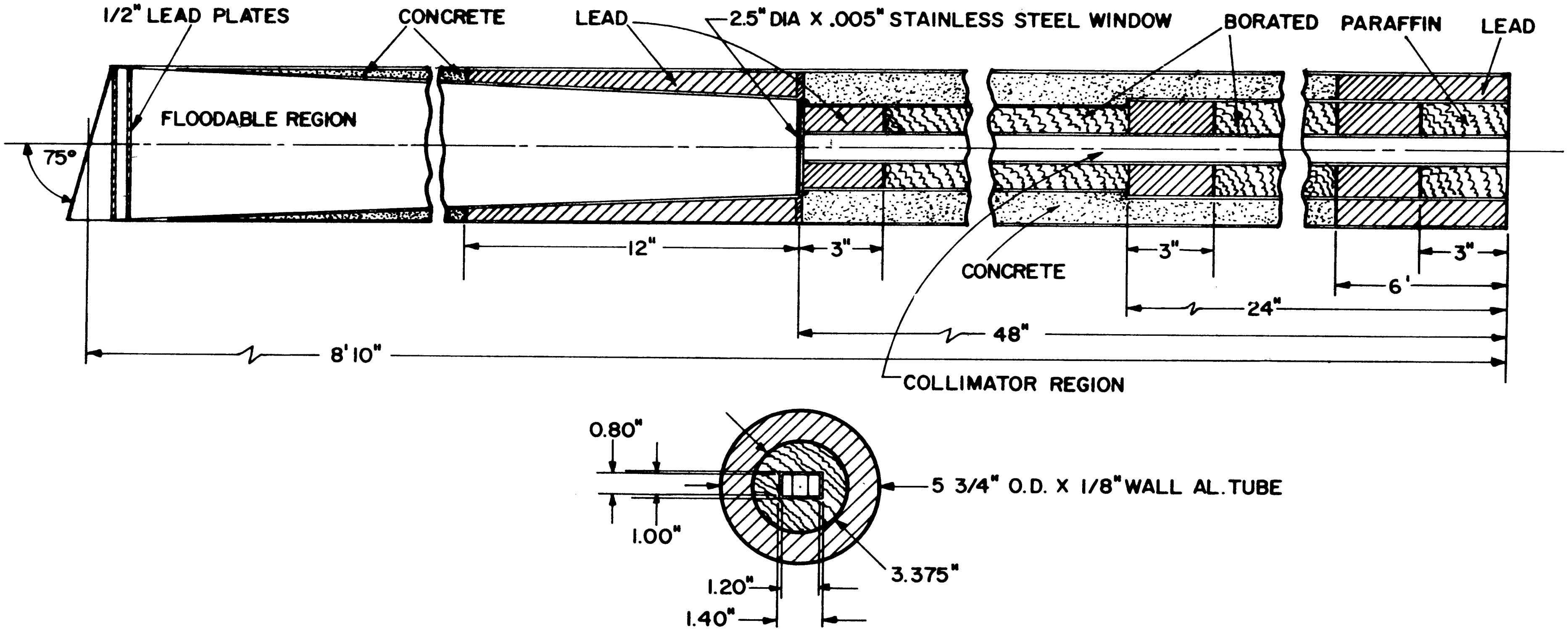

Fig. 2. Beam port plug assembly.

Fig. 3. First Bragg arm and rotating shield.

Fig. 4. First Bragg arm and rotating shield with shield partially removed.

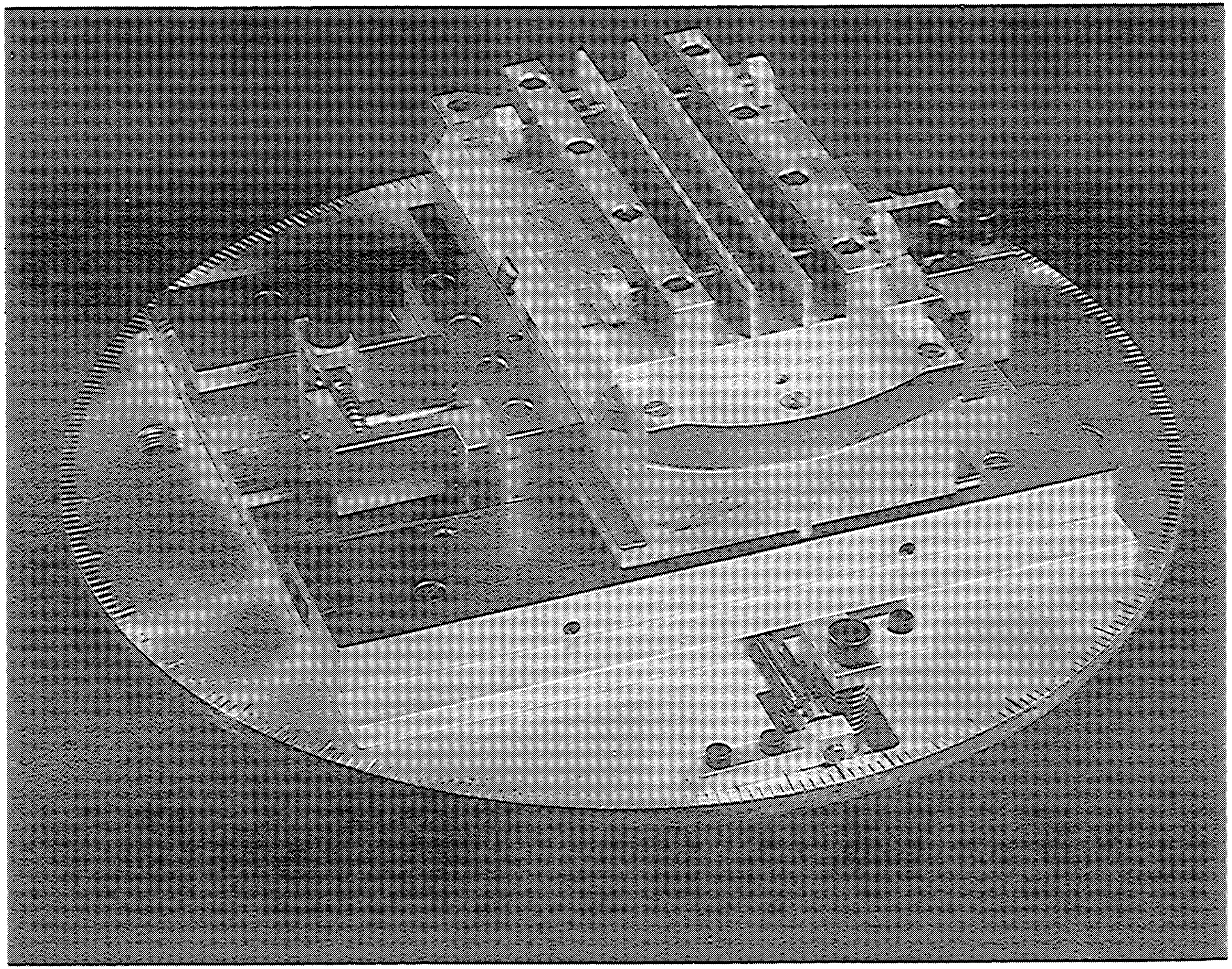

Fig. 5. First crystal table.

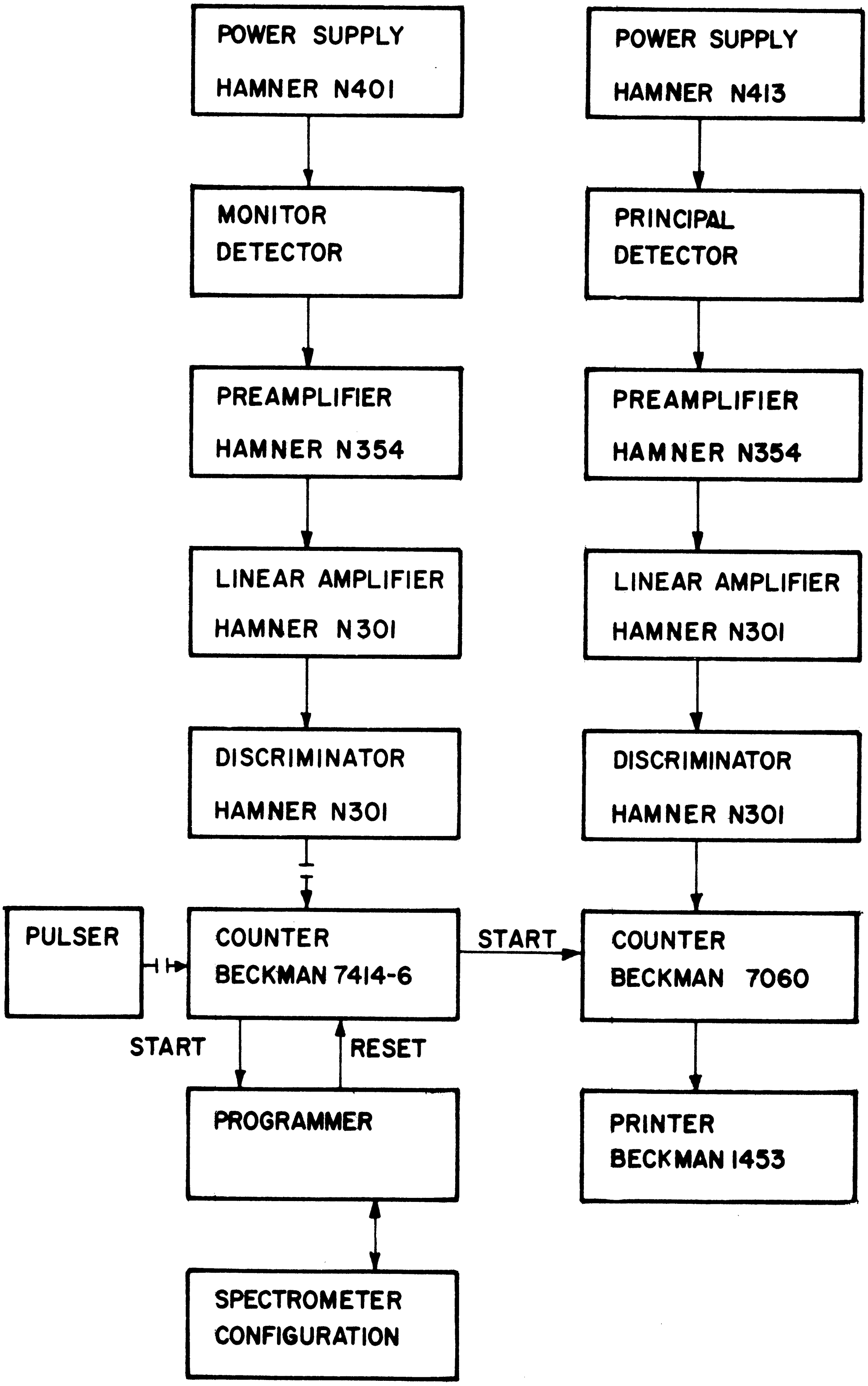

Fig. 6. Data-taking and control system.