Between legacy and innovation - the history of automation on Neutron Scattering Instruments

DENIM 2016,

19th September

Thomas Gahl

ESS Motion Control & Automation Group

Overview

EUROPEAN SPALLATION SOURCE

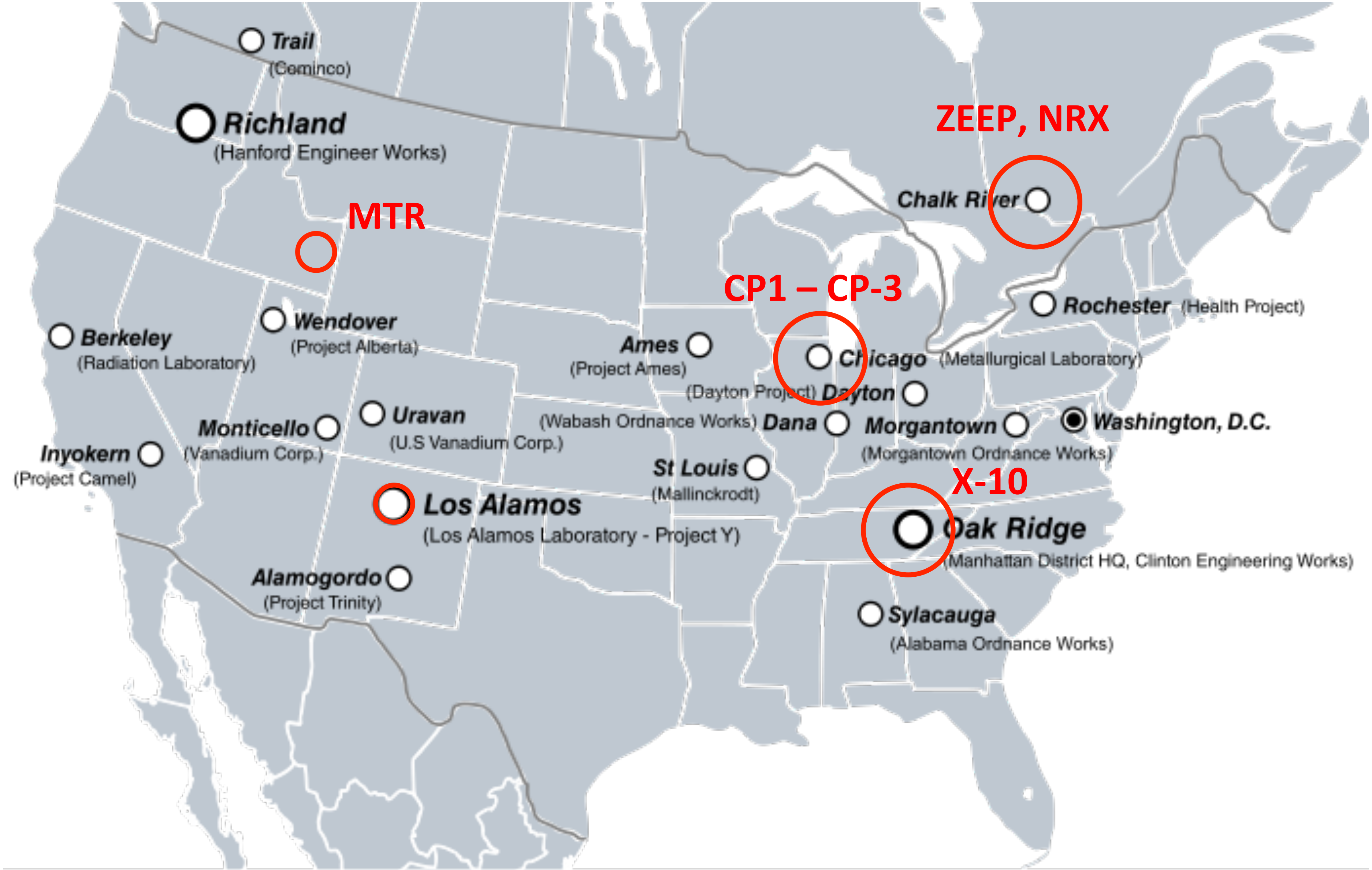
- Neutron Sources
  - The Manhattan Project
  - First reactors for neutron scattering experiments
  - European research reactors
  - The Hi-Flux sources of the 60s and 70s
- History of Automation
  - Fermi's chopper control
  - Motors, transmissions, cam shafts and a lot of switches…
  - Constant Q scan on Triple Axes
  - From paper tape punching to control computers
  - The stepper motor arrives
  - Customised control units to support the computer
  - The advent of PLC & Co
- What's next?

The Manhattan Project

EUROPEAN SPALLATION SOURCE

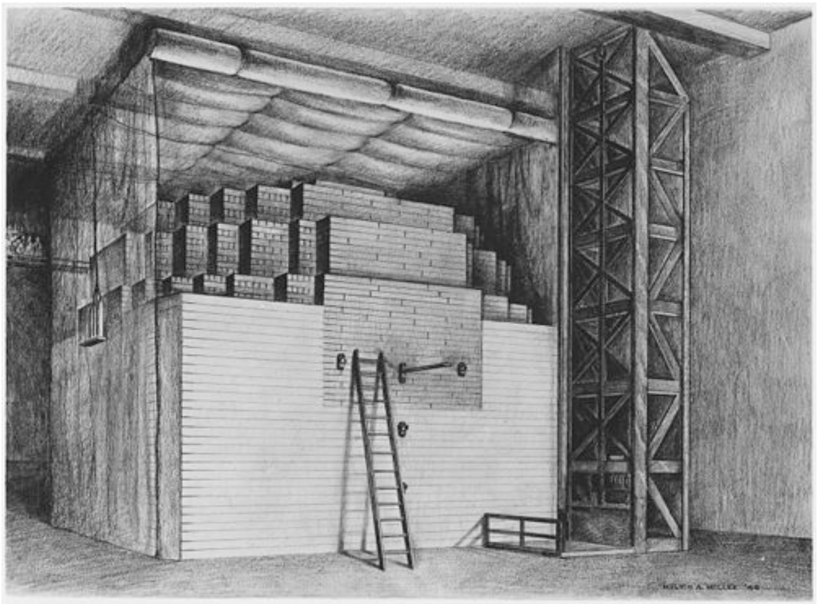
The Manhattan Project

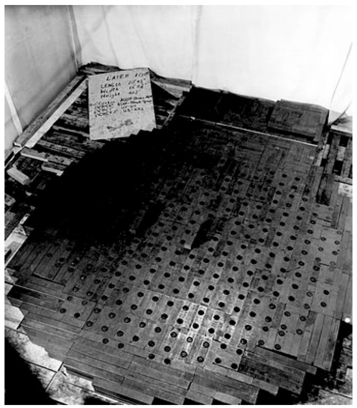
The Manhattan Project

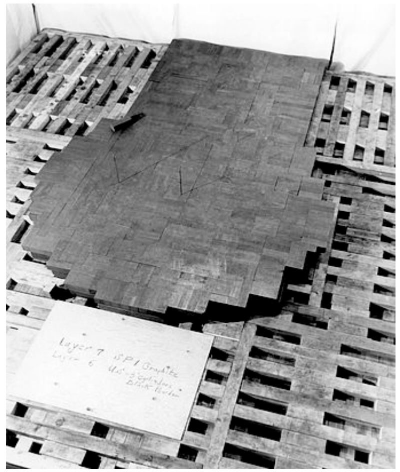


1. Chicago pile CP-1 1942

- 200 Watt, Enrico Fermi (University of Chicago)
- 1943 rebuild in Red Gate Woods as CP-2 (Argonne)

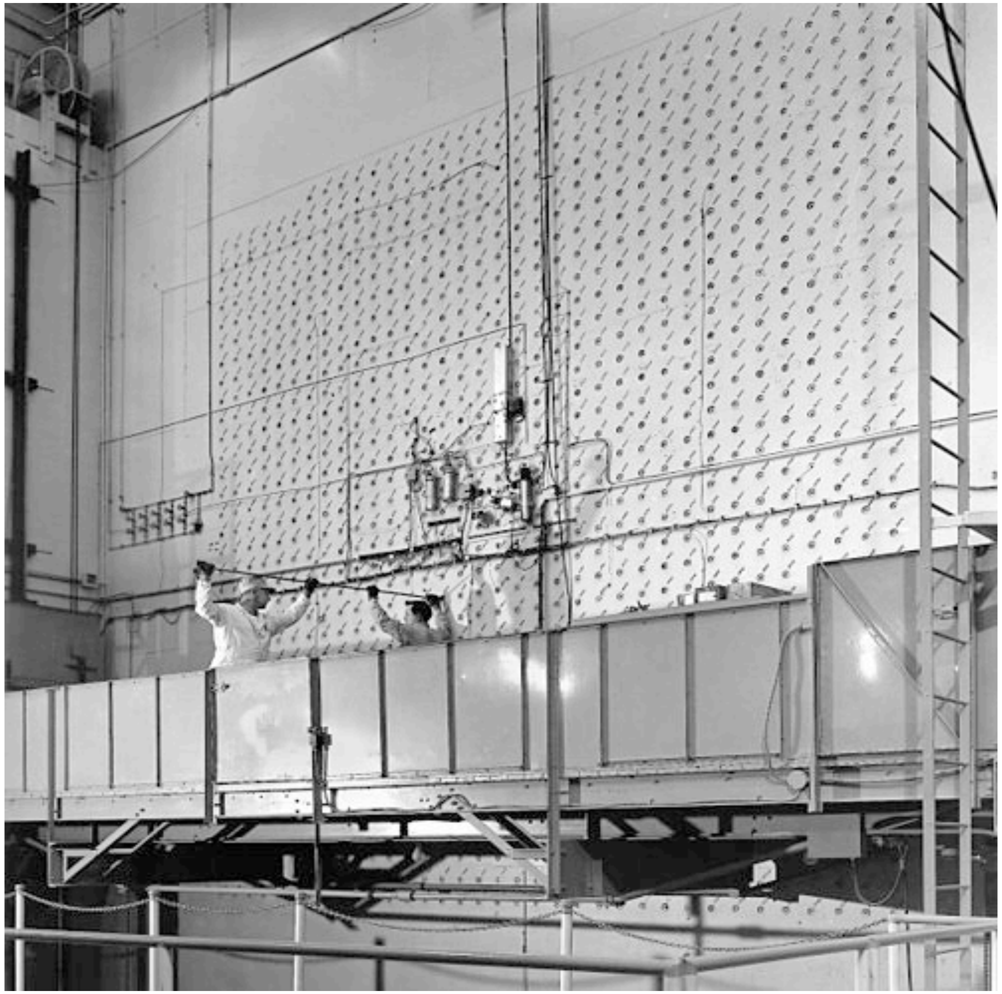






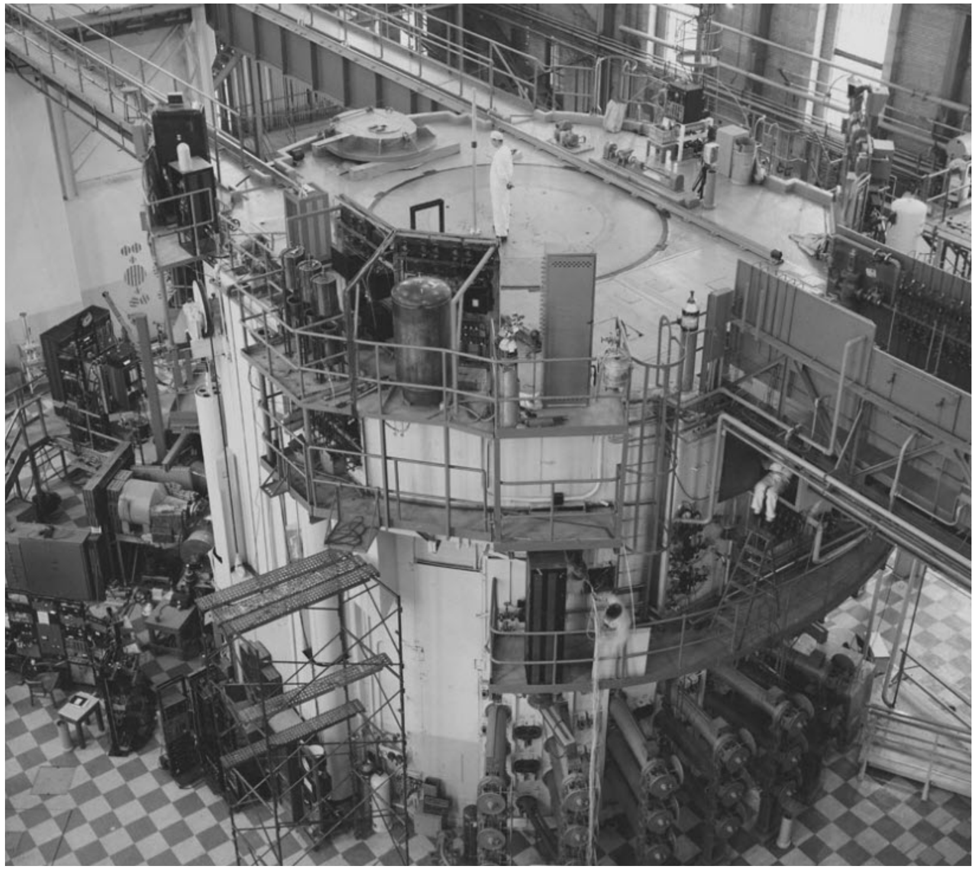
2. Clinton Pile (X-10 Graphite reactor) 1943

- 500 kW >> 4 MW, Clinton Engineers Work > Oak Ridge



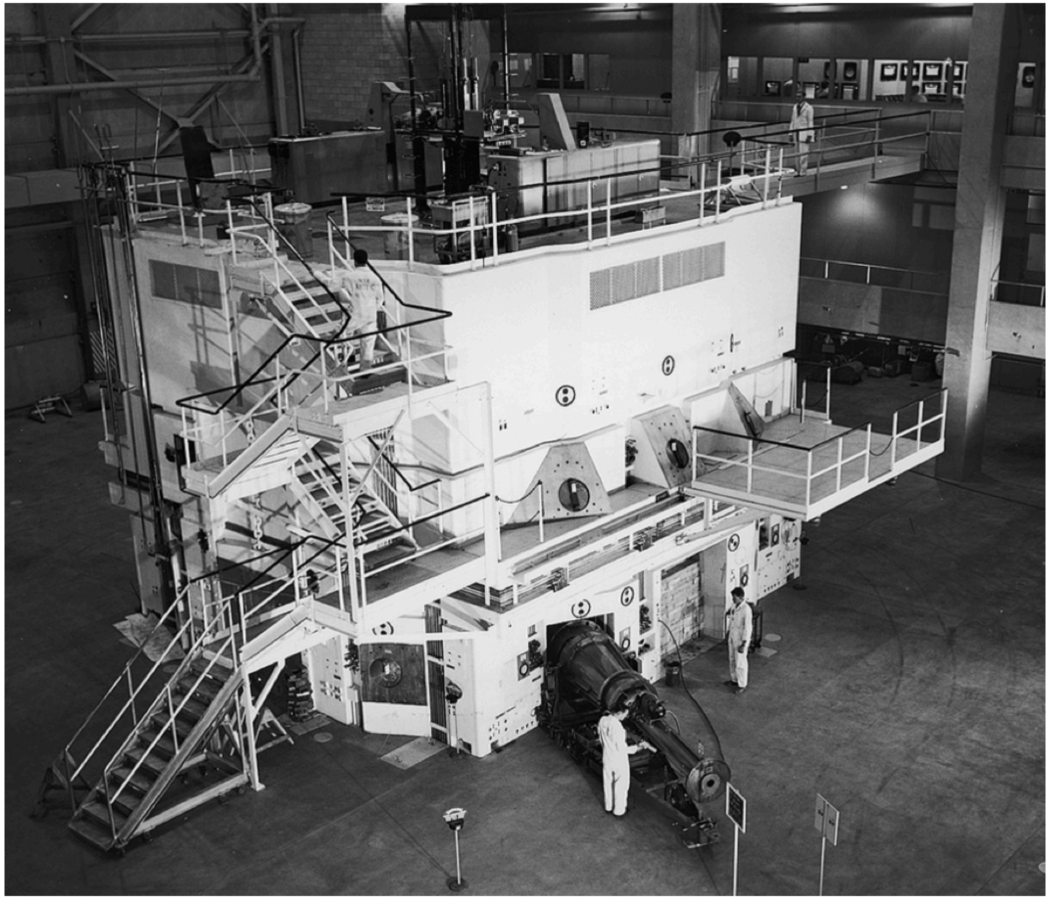
National Research Experimental NRX 1947

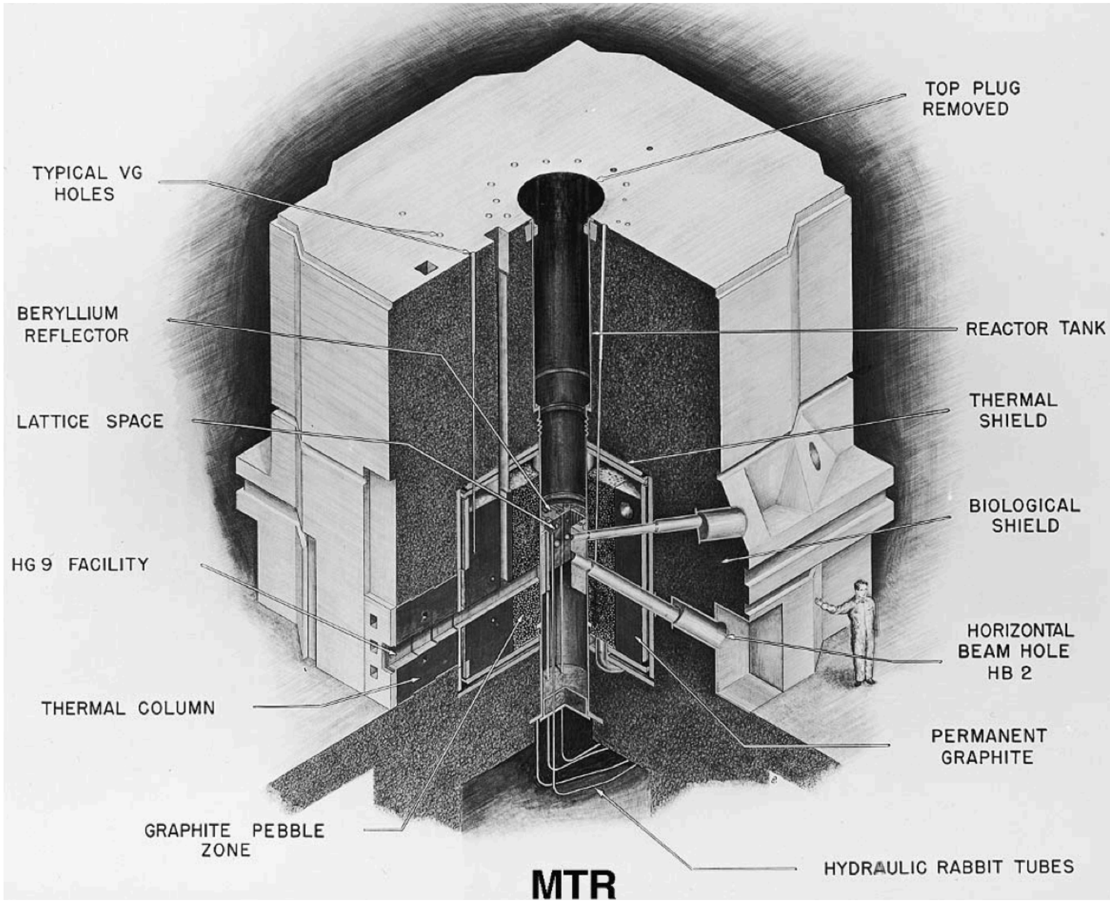
- 20 MW >>42 MW, Chalk River, Ontario, Canada
- Highest neutron flux at time



Material Test Reactor MTR 1952

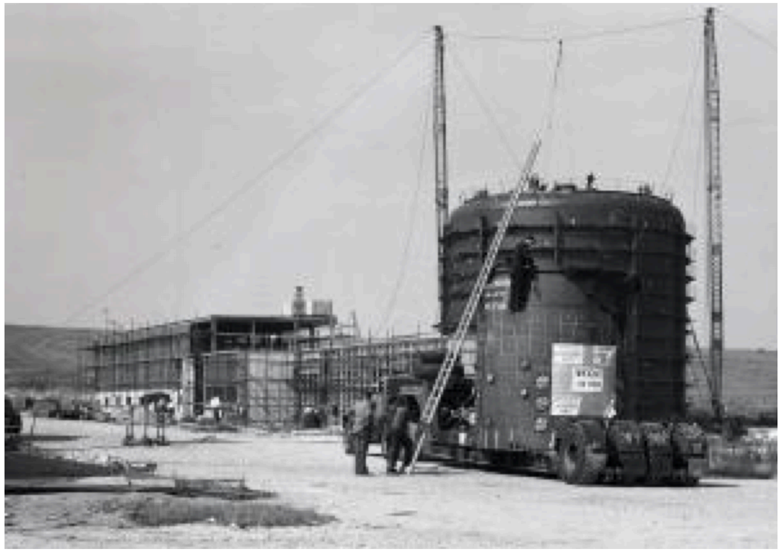
- 30 MW >> 40 MW, National Reactor Test Site Idaho (INL)
- Core and control design ORNL, construction ANL)





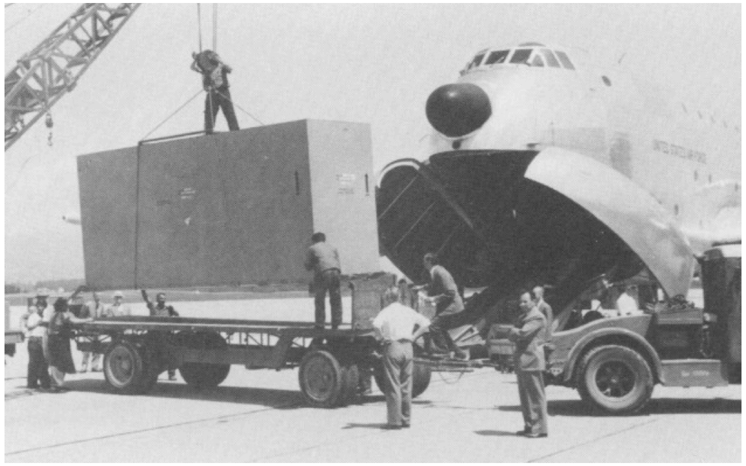
WWII Allies build Research Reactors in Europe

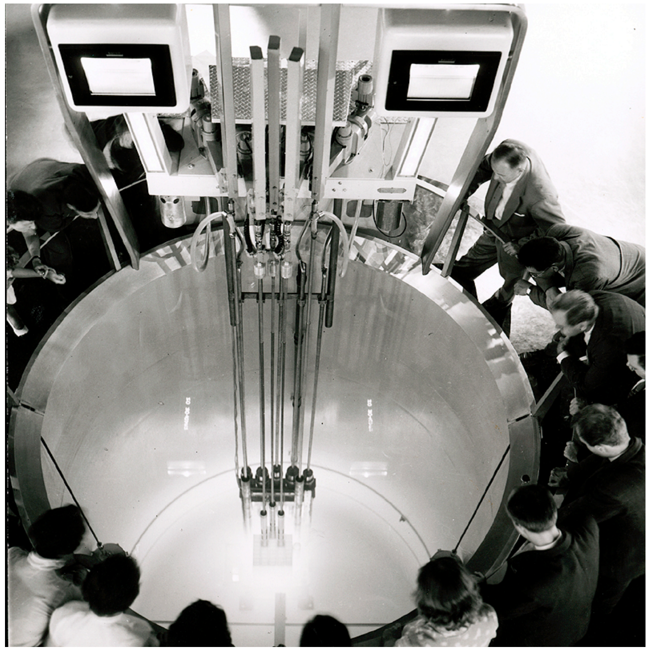
- AERE Harwell > RAL > ISIS
  (3kW GLEEP 1947; BEPO 1948;
  26MW: DIDO 1956, PLUTO 1957)
- CEA Saclay > LLB
  (EL-2, EL-3 1952, OSIRIS)
- Russia > Dubna
  (1kW IBR 1960)



1. Geneva atom conference 1955 (CH)

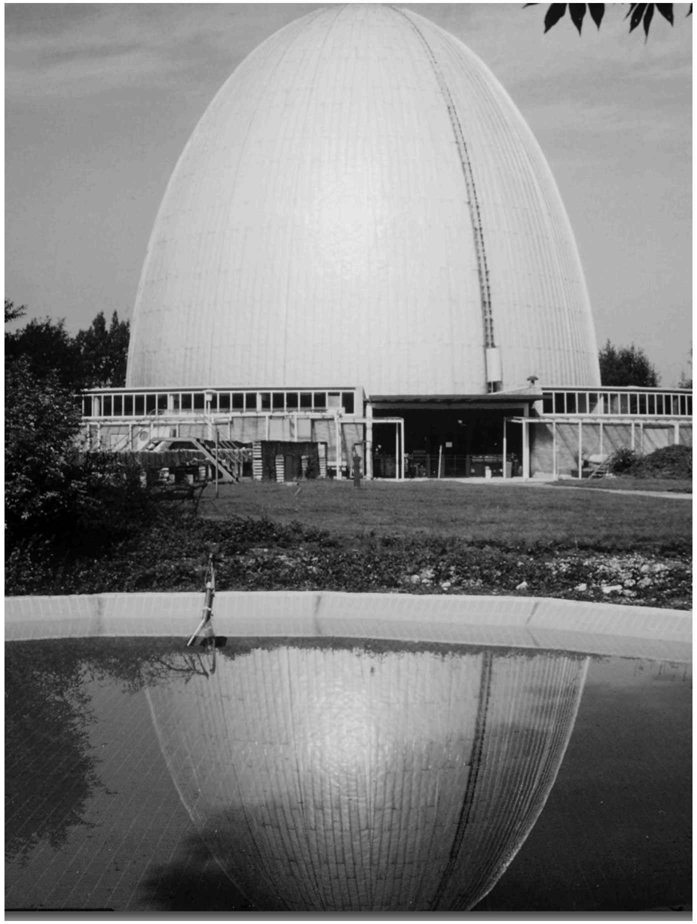
- Eisenhower “Atoms for peace”
- 4000 participants, 1 reactor
- “Waste Disposal” >> 1957 First Swiss Reactor “Saphir”, EIR, Villigen >> PSI





Cold War Race in Germany 1959

- 31. October FRM “Atom-Egg”, Munich, West-Germany

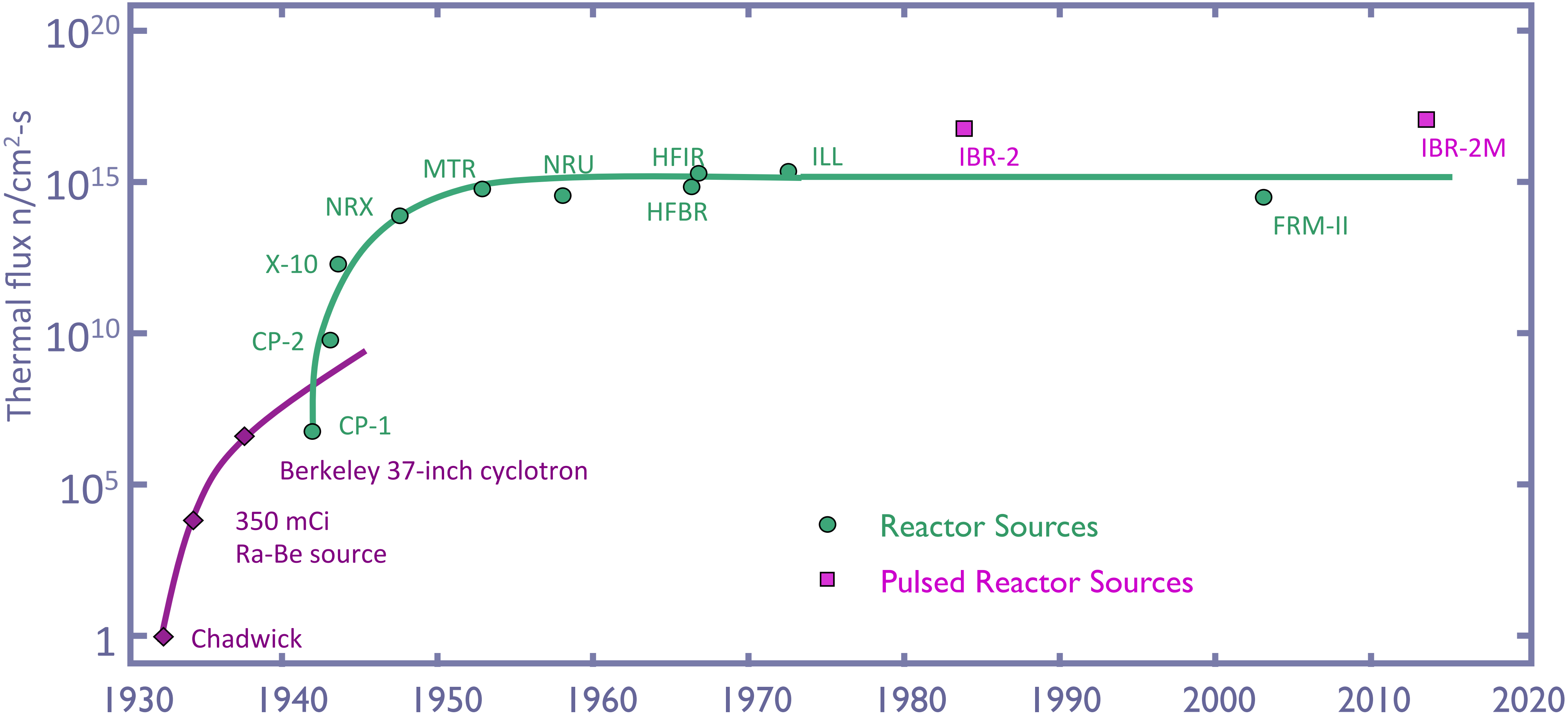


- 16. December, RFR, Rossendorf-Dresden, East-Germany

1960/70s: Era of the Hi Flux Reactors

- Canada: Chalk River NRU, 200 MW, 1957
- USA: BNL Brookhaven HFBR, 60 MW, 1965
- USA: ORNL Oak Ridge HFIR, 100 (85) MW, 1965
- GB: Harwell HFBR 1960 – 1970, canceled >> ISIS
- F: ILL Grenoble HFR, 58 MW, 1972

Evolution of neutron sources



(Updated from *Neutron Scattering*, K. Sköld and D. L. Price, eds., Academic Press, 1986)

1947 Chopper Speed Control and DAQ Gating

PHYSICAL REVIEW VOLUME 72, NUMBER 3 AUGUST 1, 1947

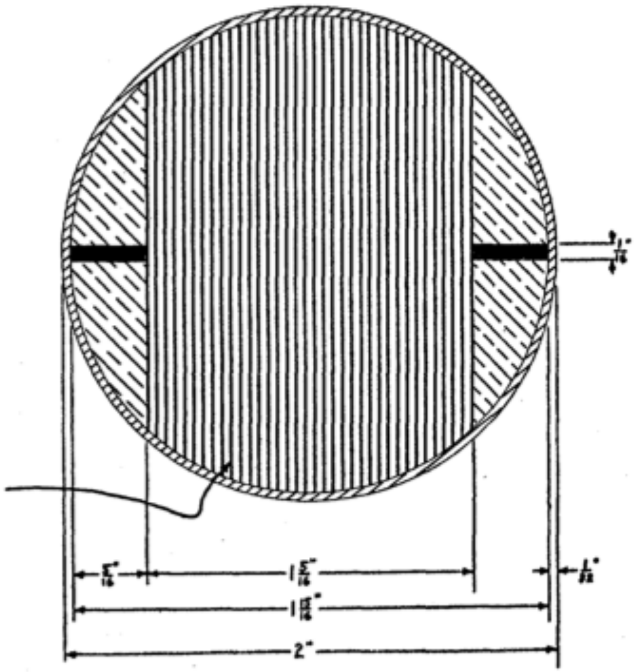
A Thermal Neutron Velocity Selector and Its Application to the Measurement of the Cross Section of Boron

E. Fermi, J. Marshall, and L. Marshall
Argonne National Laboratory, University of Chicago, Chicago,** Illinois*

(Received April 25, 1947)

A mechanical velocity selector for the study of monochromatic neutrons in the range of energies below 0.3 ev is described.

The instrument has been applied to the measurement of the cross section of boron, which is found to be 703×10^{-24} cm² for neutrons of 2200 meters per second velocity.

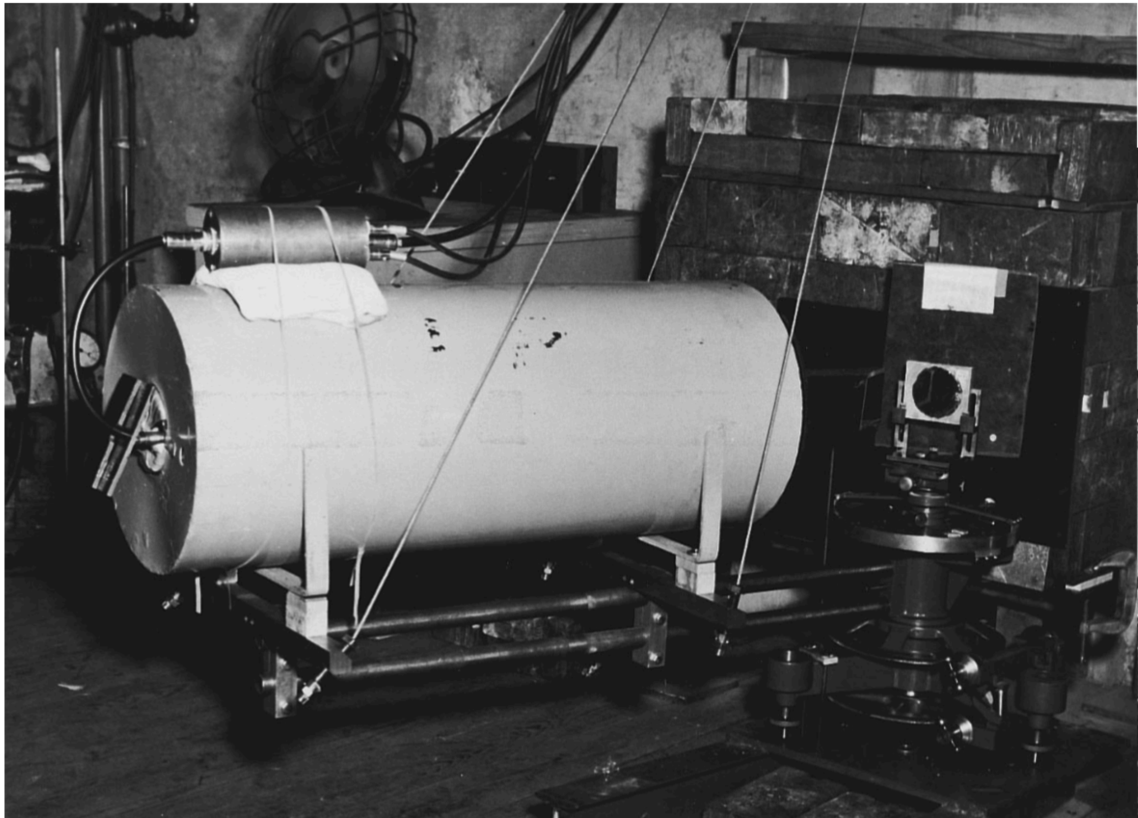


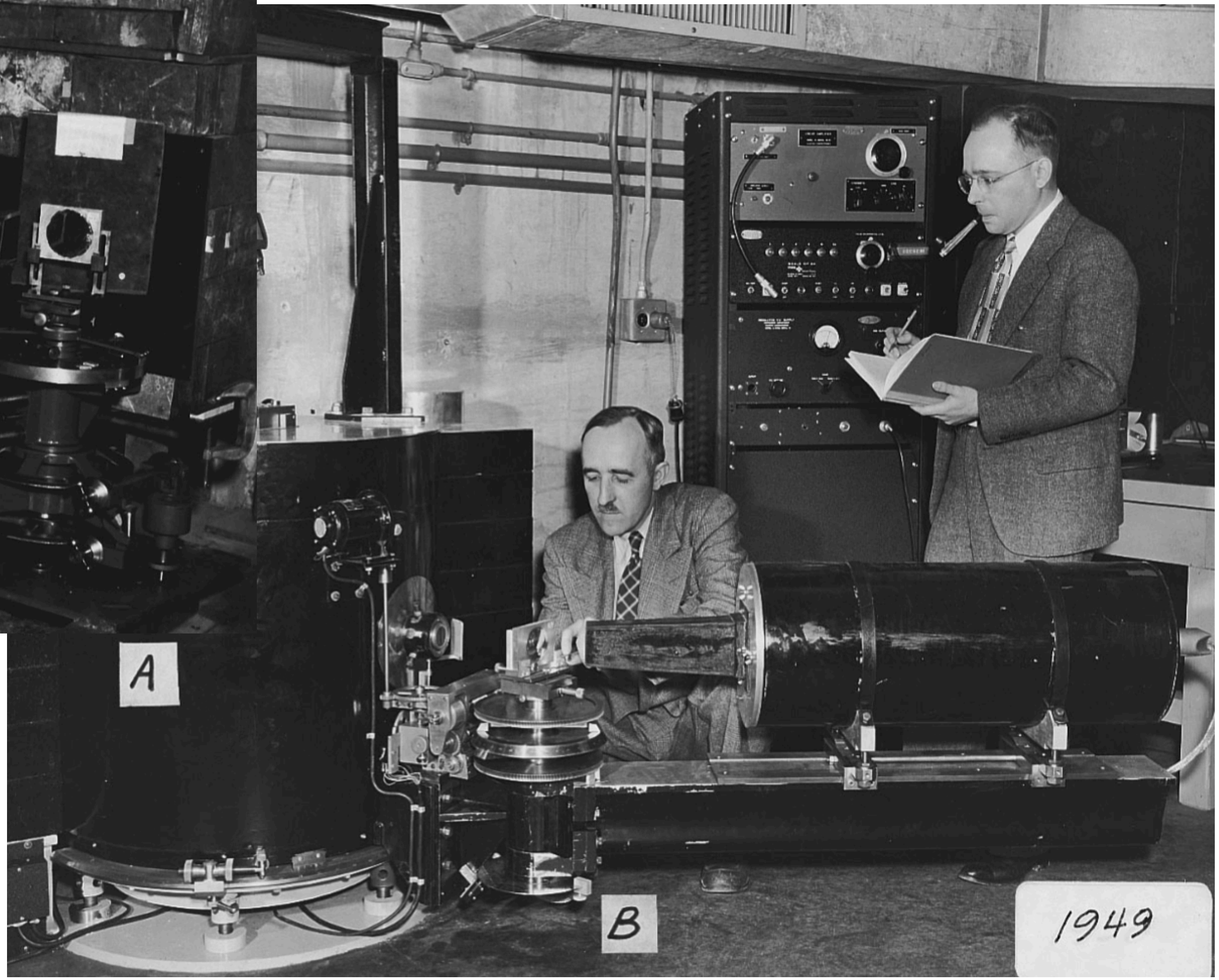
Through one end of the shutter was inserted a steel rod with its axis perpendicular to the axis of the shutter and with a minor surface ground and polished perpendicular to its axis at each end. Light from a projection lamp and lens system was reflected from these surfaces onto two photo-cells so placed that each photo-cell was illuminated twice during each revolution. One of the photo-cells was used with an amplifier and scaling circuit as a revolution counter. The other, adjustable and calibrated as to angulars position, was connected to an electronic switch circuit which allowed pulses from the proportional counter to be recorded only when the photo-cell was illuminated.

1946 Two-Axis-Powder Diffractometer (Oakridge, USA)

EUROPEAN
SPALLATION
SOURCE

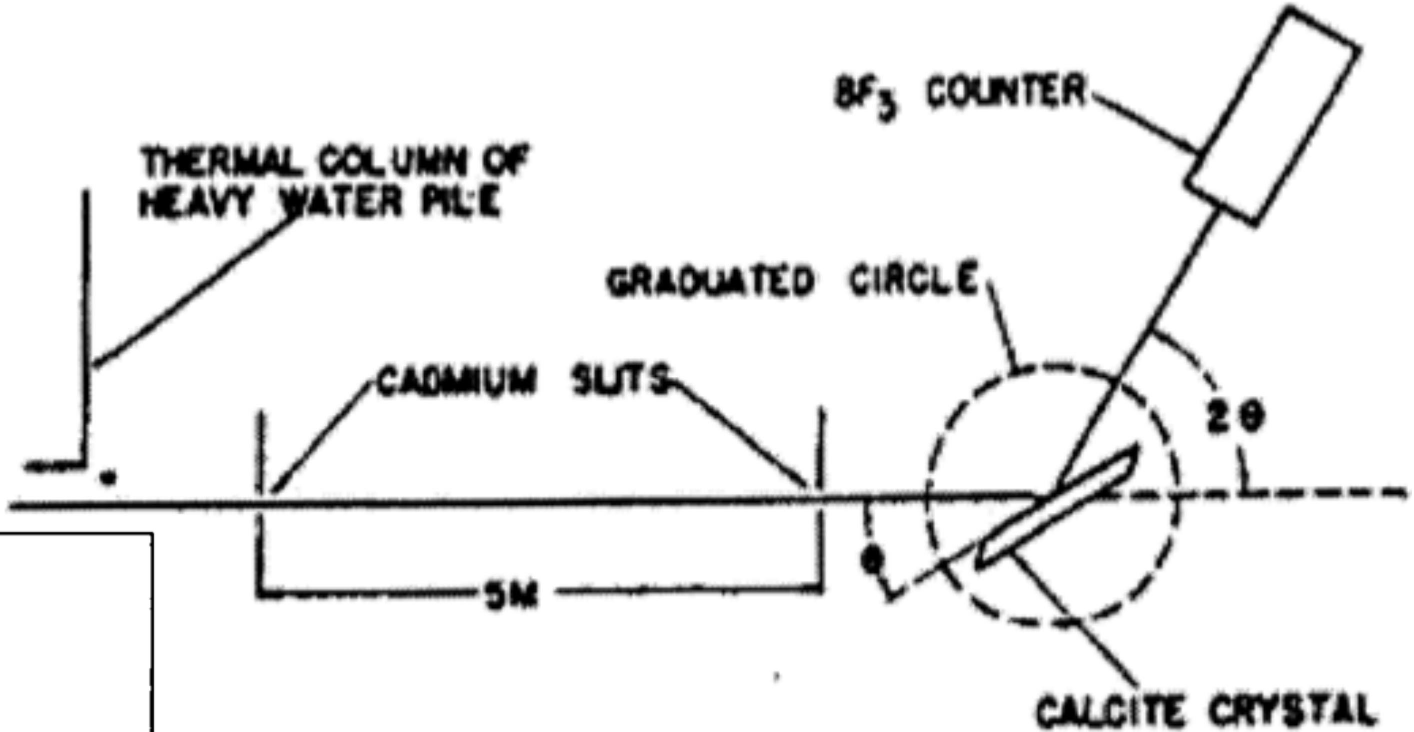
- Automated scans around the sample axis
- (Ernest Wollon, Clifford Shull)

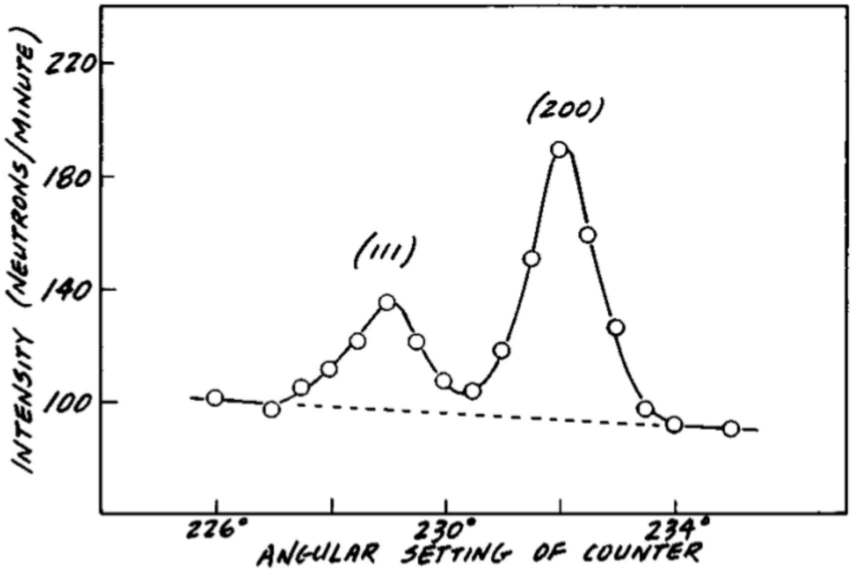




- Refurbished X-ray diffractometer, cables support for detector
- Equipped with motor drives, cam wheels, micro switches, data recorder

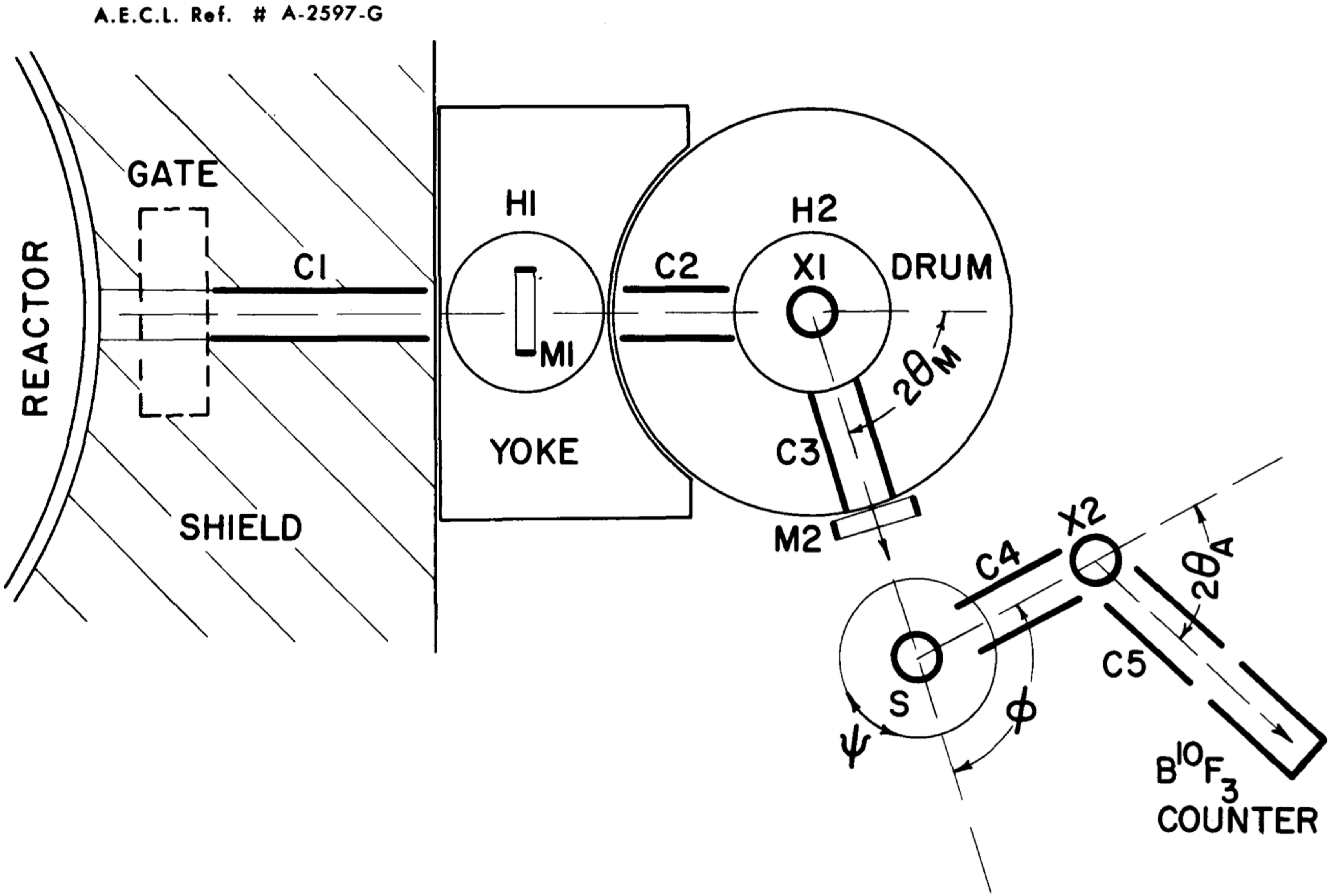
1946 First Automated Step Scan



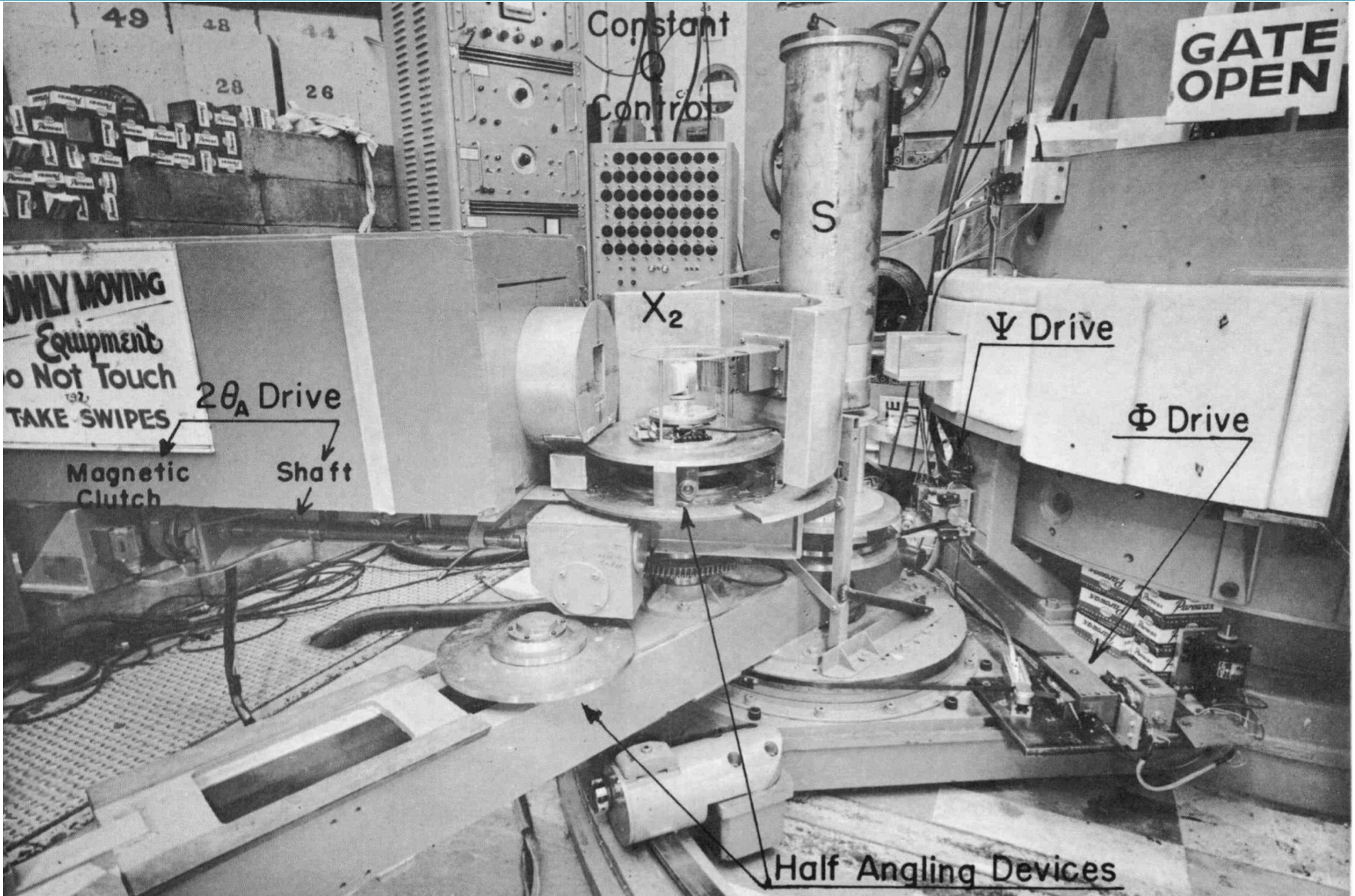


- Control of the angular position in a sequence of fixed, mechanically defined positions
- Recording of neutron counter intensity measurements with a printout recorder

1958 Triple Axis Spectrometer (Chalk River, CA)

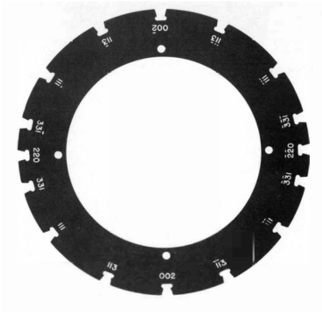


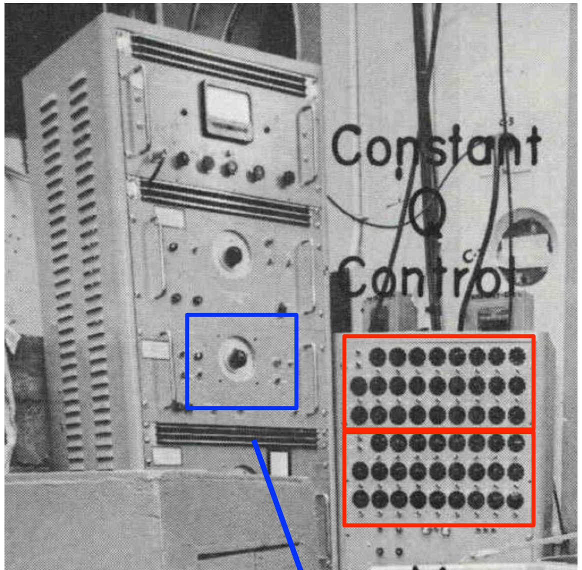
1958 Constant Q scan (Chalk River)



1958 Constant Q scan (Chalk River)

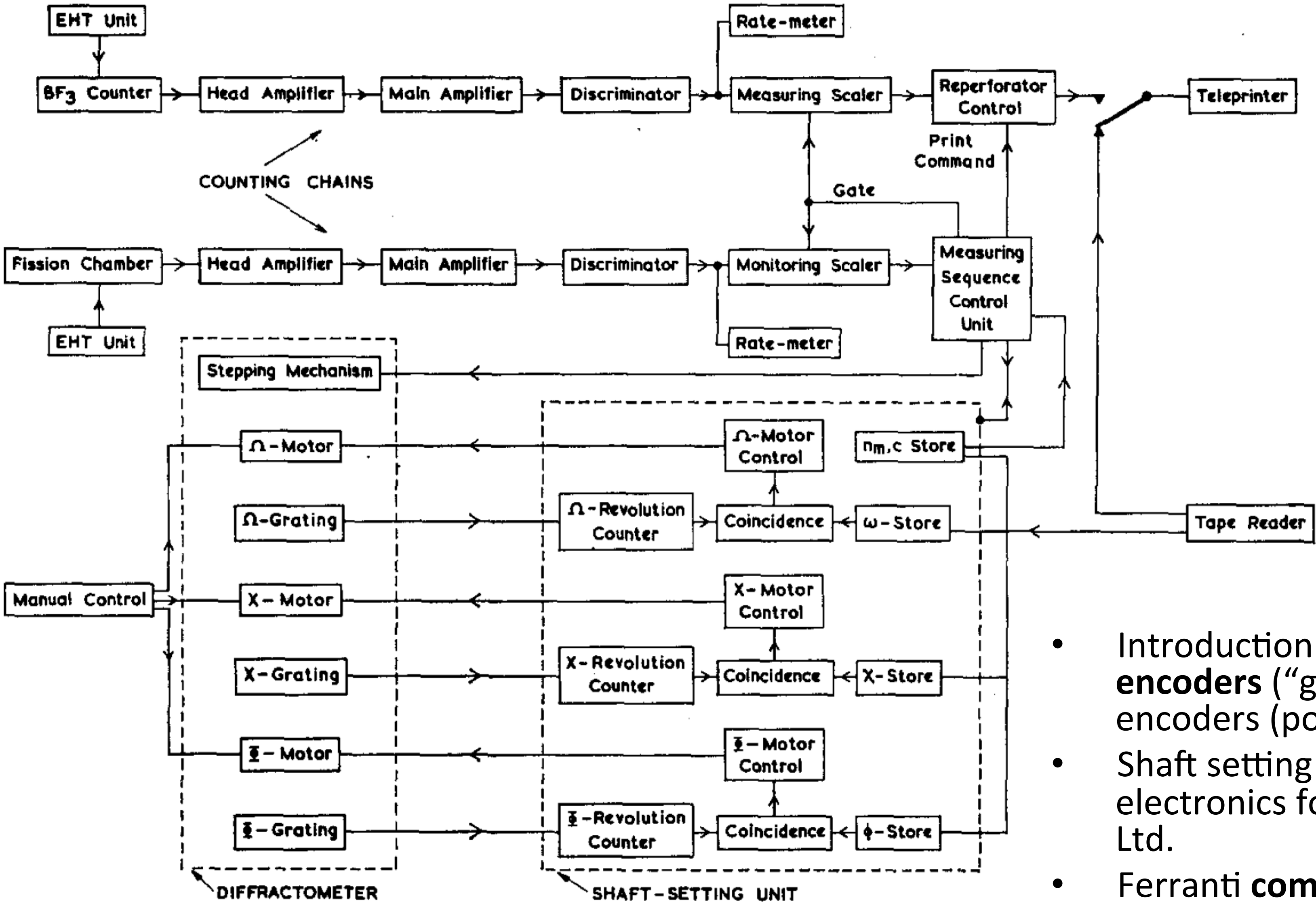
- Scan with 26 positions
- Positions of A3 and A4 are calculated beforehand and transferred to the 26 switches

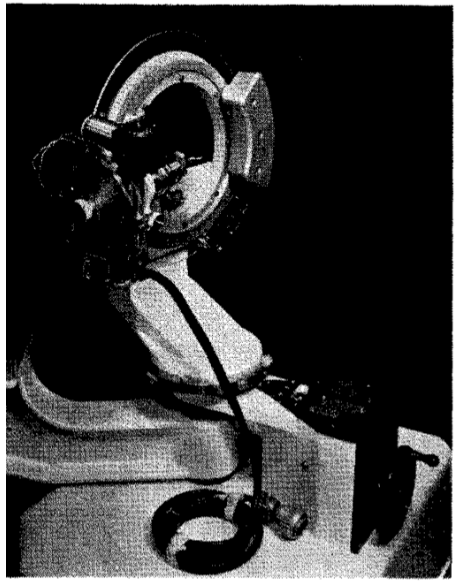




- Axis 1 (monochromator)
  - A1: $2\theta_M$, constant (k0)
  - A2: X_M, follows A1 with ratio 1:2
- Axis 2 (sample)
  - A3: ϕ, follows A5 in non-linear steps
  - A4: Ψ, follows A5 in non-linear steps
- Axis 3 (analyser)
  - A5: $2\theta_A$, linear inc. steps (-k')
  - A6: X_A, follows A5 with ratio 1:2

1962 4-Circle Neutron Diffractometer (Harwell, GB)





v of Φ-X assembly showing the circular gratings and motors. The pickup head of the Φ circle only is visible.

- Introduction of fine incremental optical **encoders** (“gratings”) and coarse analog encoders (potentiometers?)
- Shaft setting unit is a modified electronics for machine tools by Ferranti Ltd.
- Ferranti **computer** is used for full automatic control of the instrument

1967 Computer Controlled Instruments (Harwell, GB)

EUROPEAN SPALLATION SOURCE

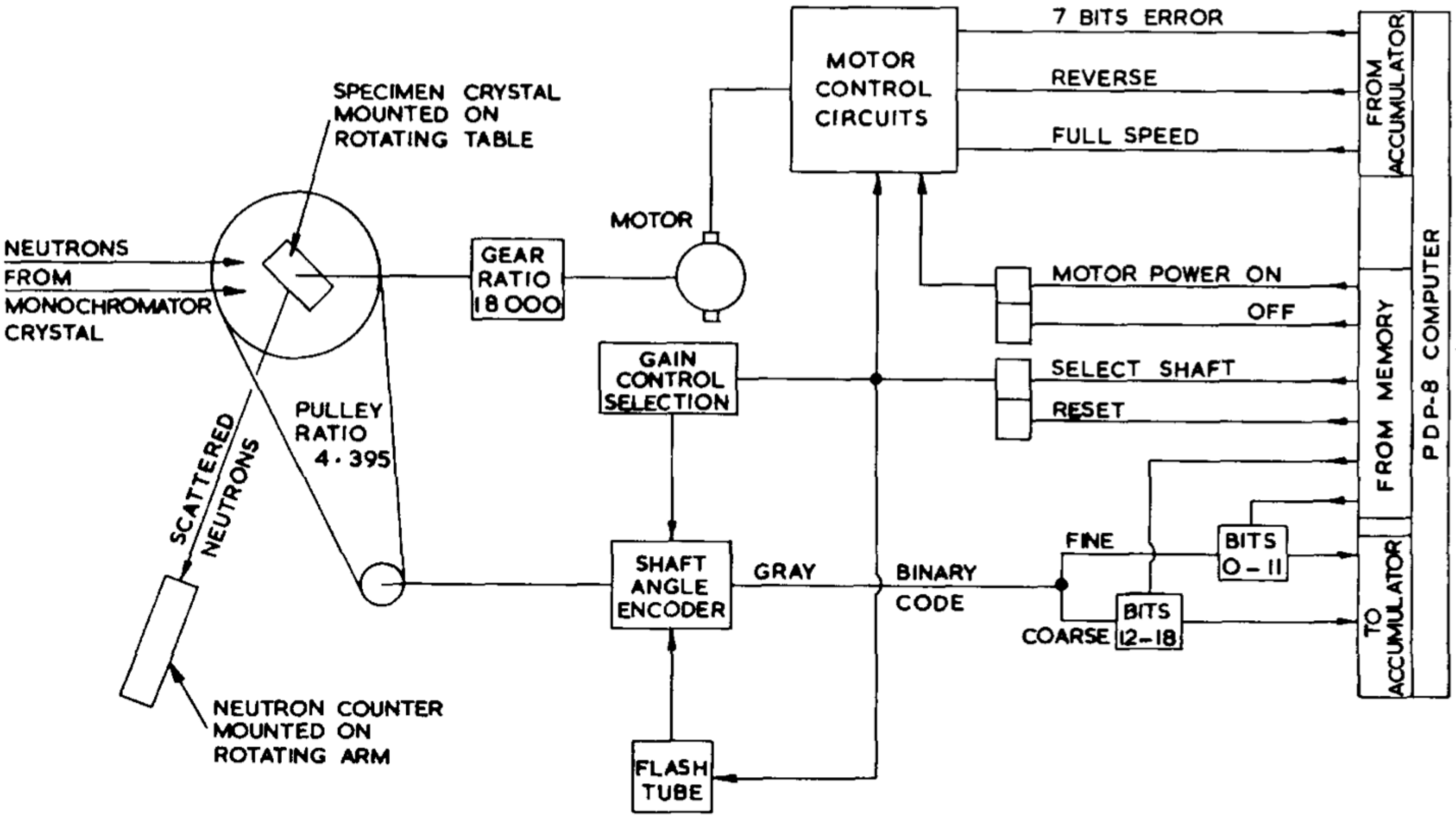
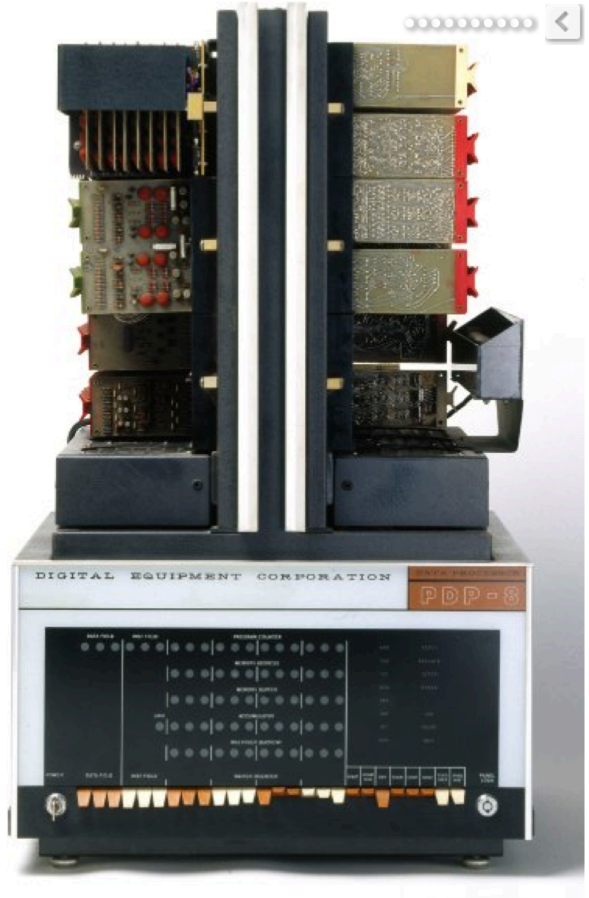


Fig. 3. Connections from computer to one of the six shafts.



1967 Computer Controlled Instruments (Harwell, GB)

The inputs to the computer are mainly paper tape punched instructions, compiled with the aid of the computer, which are then run into a magnetic tape store. The key-board of the machine is used for typing simple coded instructions from time to time which call up appropriate stored programs which control the course of experiments. The inputs from hardware are:

1. The 6 shaft angles.
2. Position of neutron shielding sectors on the drum, which go up and down as it rotates, so allowing the neutron beam to reach the monochromator.
3. The operation of relays which control the environment of the sample.
4. Program skips and interrupts.
5. An override push button control which stops all motors.
6. Microswitches which operate when the counter shield approaches an obstacle.
7. Counts from neutron detectors.
8. Clock pulses for measuring the duration of counting.

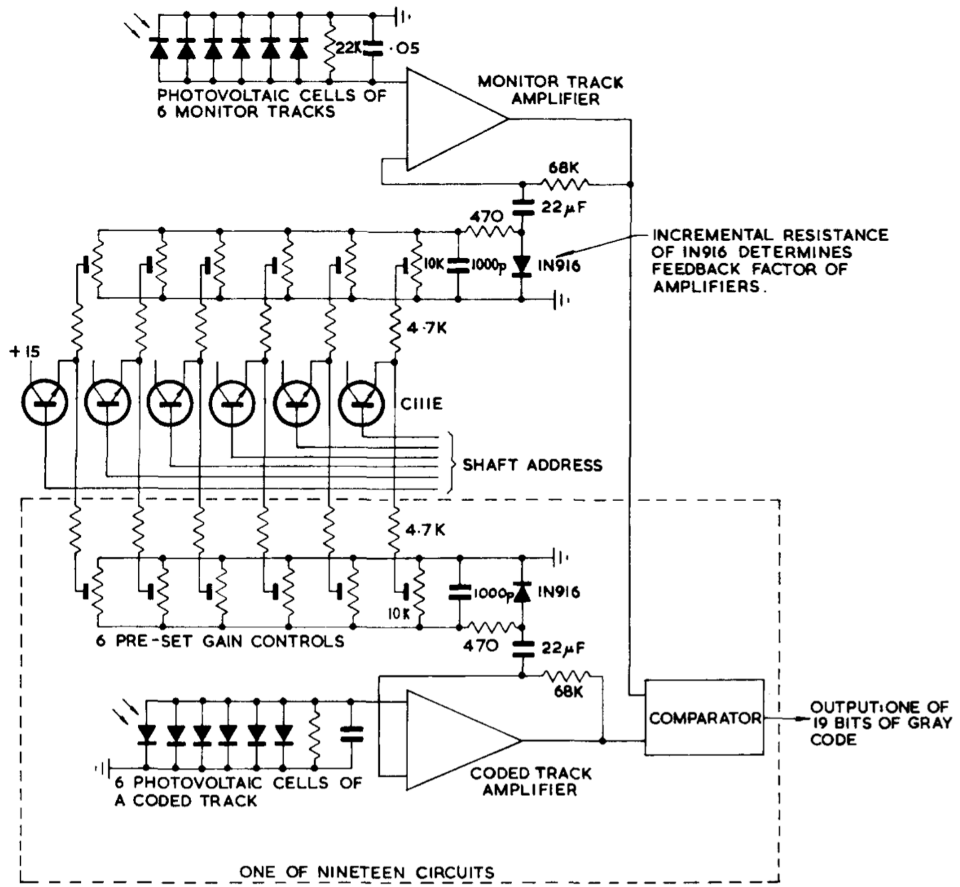


Fig. 5. Shaft angle encoder: photovoltaic cell amplifiers.

1967 First Stepper Motor Control (AAEC, Australia)

J. Appl. Cryst. (1968). **1**, 272

A Computer-Controlled Neutron Diffractometer

By A. W. Pryor, P. J. Ellis and R. J. Dullow
A.A.E.C. Research Establishment, Lucas Heights, N.S.W., Australia

(*Received* 27 *June* 1968)

A computer-controlled 4-circle neutron diffractometer is described. The axes are driven by pulsed stepping motors and all operations are under on-line control of a PDP–8 computer. Details of preliminary operating experience are given.

Introduction

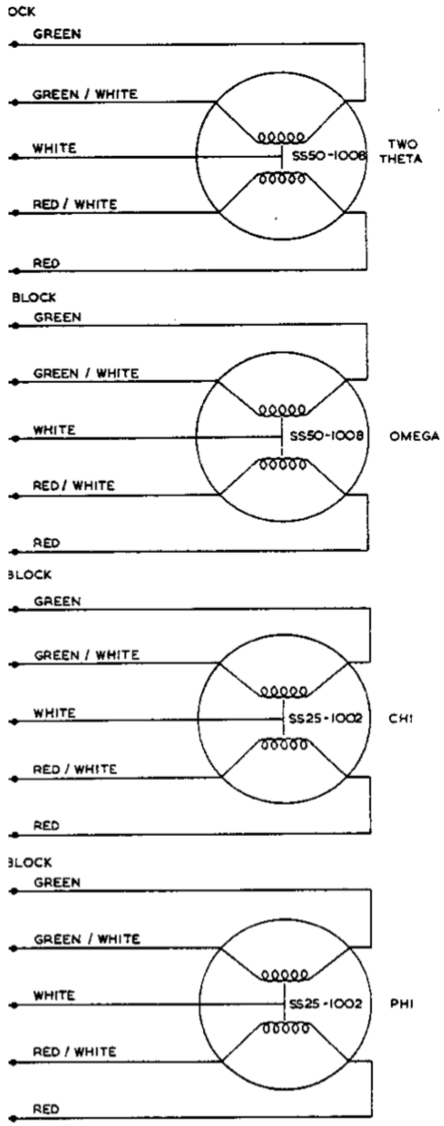
With the advent of small, moderately priced computers, it seems expedient to use such a machine entirely for the on-line control of one diffractometer – or, perhaps, as described below, of a few program-identical diffractometers. The availability of pulsed stepping motors has provided a cheap and convenient method of achieving digital control of angular rotations.

Both developments were exploited in the X-ray diffractometer described by Busing, Ellison, Levy, King & Roseberry (1968); an instrument assembled at Lucas Heights is similar in basic concepts, though different

The main operating programs, with approximate storage requirements, are:

(i) *Motor moving* (514 words)

The motors are supervised continually through 'Clock-Interrupt'. Slow starting is employed, with overshoot in the negative direction, so the final setting is approached from the one direction. The current position is checked, and rectified, at each crossing of the motor axis zero. If an error greater than 20 motor pulses is encountered, or 10 errors greater than 1 motor pulse, all four motors automatically seek and check the axis zeros.



1983 Customised Computer Interfaces (MURR, USA)

Nuclear Instruments and Methods 213 (1983) 333–342
North-Holland Publishing Company

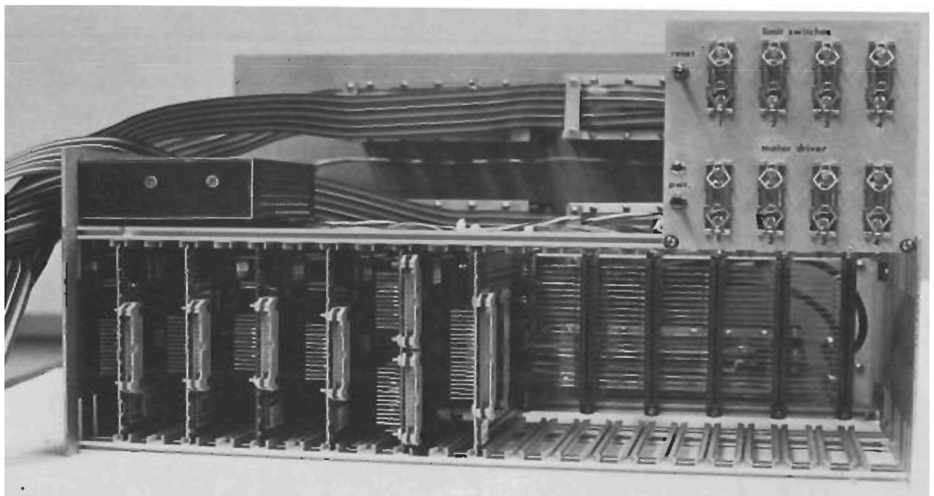
A MULTI-MICROPROCESSOR NEUTRON SPECTROMETER COMPUTER INTERFACE SYSTEM

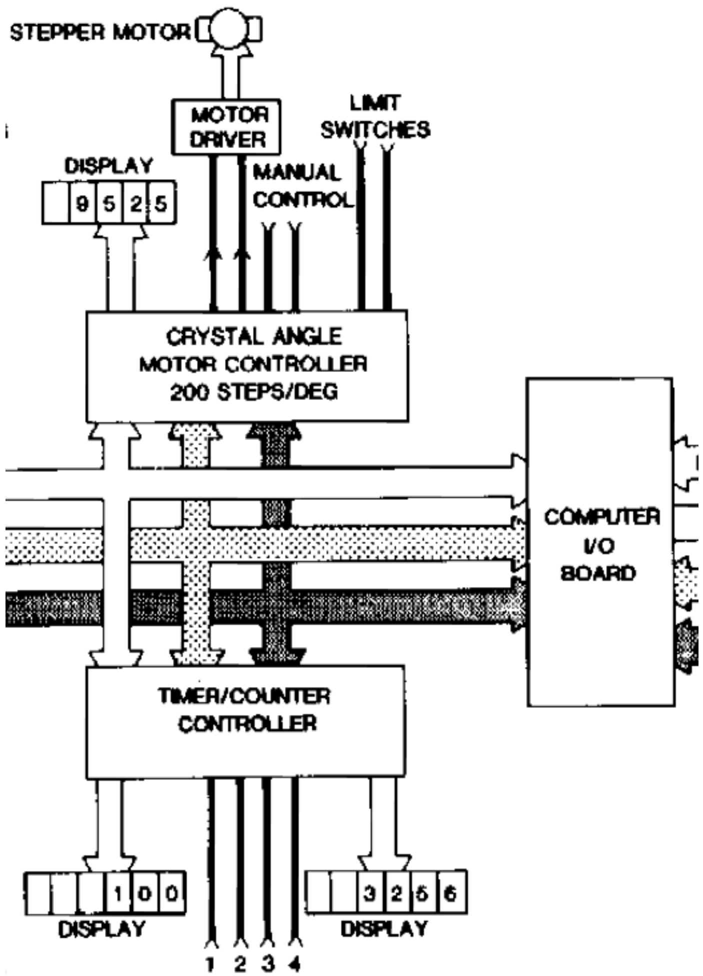
R. BERLINER and J. SUDOL
University of Missouri, Research Reactor, Columbia, Missouri 65211, USA

G. MOUM
University of Missouri – Columbia, Academic Computing Center, Columbia, Missouri 65211, USA

Received 30 November 1982

A novel computer interface system for neutron or X-ray diffraction instrumentation is described. Consisting of a set of microprocessor controllers, it provides a simple and flexible means of instrument control.





1997 PC-based Motion Control (ORNL, USA)

EUROPEAN SPALLATION SOURCE

Closed-Loop Step Motor Control Using Absolute Encoders

by

J. Steven Hicks

Michael C. Wright

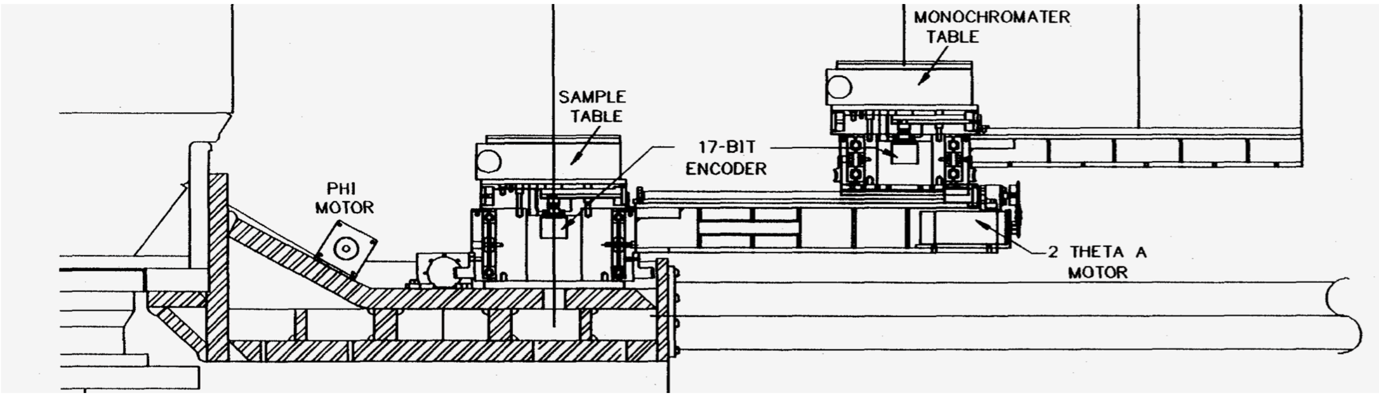
Oak Ridge National Laboratory

Instrumentation and Controls Division

Oak Ridge, Tennessee 37831

Abstract - A multi-axis, step motor control system was developed to accurately position and control the operation of a triple axis spectrometer at the High Flux Isotope Reactor (HFIR) located at Oak Ridge National Laboratory. Triple axis spectrometers are used in neutron scattering and diffraction experiments and require highly accurate positioning. This motion control system can handle up to 16 axes of motion. Four of these axes are outfitted with 17-bit absolute encoders. These four axes are controlled with a software feedback loop that terminates the move based on real-time position information from the absolute encoders. Because the final position of the actuator is used to stop the motion of the step motors, the moves can be made accurately in spite of the large amount of mechanical backlash from a chain drive between the motors and the spectrometer arms. A modified trapezoidal profile, custom C software, and an industrial PC, were used to achieve a positioning accuracy of 0.00275 degrees of rotation. A form of active position maintenance ensures that the angles are maintained with zero error or drift.

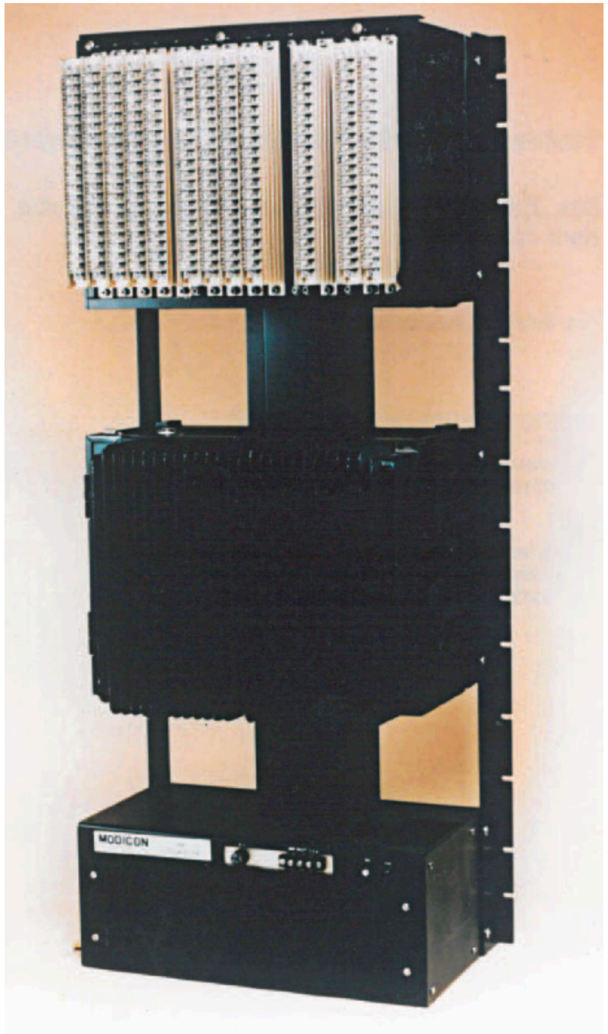
- Triple axis with 17bit absolute encoder and closed loop control
- PC and dedicated ISA stepper motor and SSI encoder cards as motion controller
- VAX and CAMAC modules for instrument control and data collection



Industrial Control Systems, PLC Systems

EUROPEAN SPALLATION SOURCE

- First needs for flexibility in automotive industry with short production cycles
- 1968: Modicon 084 + Allan Bradley
- 1970: First European: Telemecanique
- 1975/78: Siemens S3/S5
- 1990s: Introduction into Instrument control



What's next?

- Decentralized Systems
- Intelligent control units based on industrial standards
- Synchronisation for distributed real time control

- High-performance control layer systems (SCADA) like EPICS or Tango
- Transfer of all available process variables into that layer
- Data storage in cloud-like environments for remote access and control

- "Industry 4.0"

Thank You!

Gerry Lander: Repository on History

1. http://neutronsources.org/about/history.html

Search | Jobs | Press contacts | Contact

Neutronsources.org

Your entry into the neutron world

Home | About | News | Neutron centres | Resources | Calendar

About NeutronSources | Science with Neutrons | History

Literature | References | People | Timeline

References

A number of authors have compiled important information on neutron scattering and its history, so that we can keep track of the main events and discoveries.

Here you can find references to articles and books on the history of neutron scattering as well as neutron sources, and a list of the first conferences. By clicking on the title, you can read further information on the reference and find your way to the original publication.

When looking through the history articles please be aware that we have to respect copyright laws. If the article in question appeared *only* in a Journal, rather than on the web and a Journal, then we are not allowed by copyright laws to publish the full article on our website. Hence this page on “references”. This includes, of course, books.

James Chadwick (left) with Major General Leslie R. Groves, Jr., the director of the Manhattan Project. Picture by LANL, c. 1945

Are you aware of missing articles, books, or conferences to complete this list? Please contact us at info@neutronsources.org.

References

1. http://www-llb.cea.fr/spectros/pdf/3axis-llb.pdf
2. https://www.ncnr.nist.gov/instruments/bt7_new/
3. Brockhouse, Slow neutron spectroscopy and the grand atlas of the physical world, RevModPhysik 67 (1995), 735-751
4. Shull, Early development of neutron scattering, RevModPhysik 67 (1995), 753-757
5. Fermi et.al., Theriacal Neutron Velocity Selector and Its Application to the Measurement of the Cross Section of Boron, PhysRev 72 (1947), 193 -196
6. Neutron Scattering with a Triple Axis Spectrometer: Gen Shirane, Stephen M. Shapiro, John M. Tranquada
7. http://cins.ca/neutron-beams/brockhouse-and-the-nobel-prize/
8. Russel et.al., On-line computer control of a triple axis neutron diffractometer, NIM 60 (1968), 237-245