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STATUS OF THE INTENSE PULSED NEUTRON SOURCE*

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ABSTRACT

Since our last report, IPNS has continued to improve. We describe our recent experience and progress with the accelerator, targets, moderators, scattering instruments, data acquisition systems, ancillary equipment and the user program.

Operating Status of the IPNS Accelerator System

The IPNS Rapid Cycling Synchrotron just recently passed the ninth anniversary of the date when H^- ions were first circulated around the synchrotron. It is clearly improving with age! Of the 3892 hours scheduled since the last ICANS report, 93.2% were available. The average current over this interval was 13.39 μA. Since the last system improvement was completed in December 1985, current has averaged about 14.0 μA with weekly averages as high as 15.0 μA and peaks up to 16.7 μA. Figure 1 shows the weekly average current since user turn-on in 1981. Each point represents about 145 hours of scheduled operation.

There were no major system failures requiring cooldown before repair during this period, thus the large improvement in reliability of operation (see Figure 2). This factor has also allowed us to keep personnel exposure well under control. This smooth operation not only benefited the users but allowed IPNS accelerator personnel to participate in other ANL accelerator related activities. We discuss this briefly later.

As in the past, we have maintained a rigid beam loss limit of about 1.5 μA so necessarily the efficiency of trapping, acceleration and extraction have all improved slightly during the year. All but one of the system improvements responsible for the increased beam were discussed in our previous report.[1] The benefits of the most significant of these improvements, the new neutron chopper-accelerator synchronization system,[2,3]

Work Supported by the U.S. Department of Energy

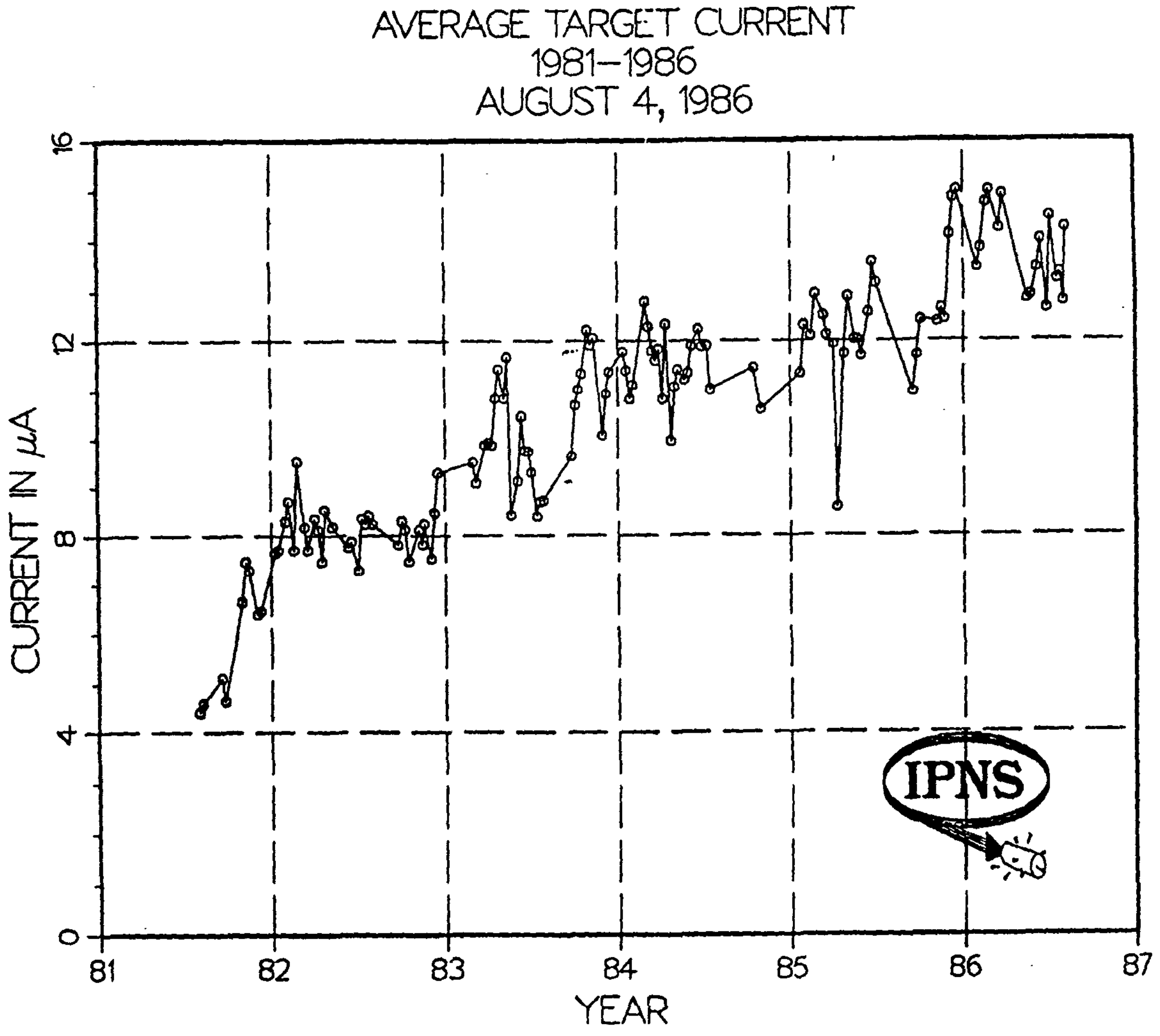


Figure 1: Average Target Current of IPNS

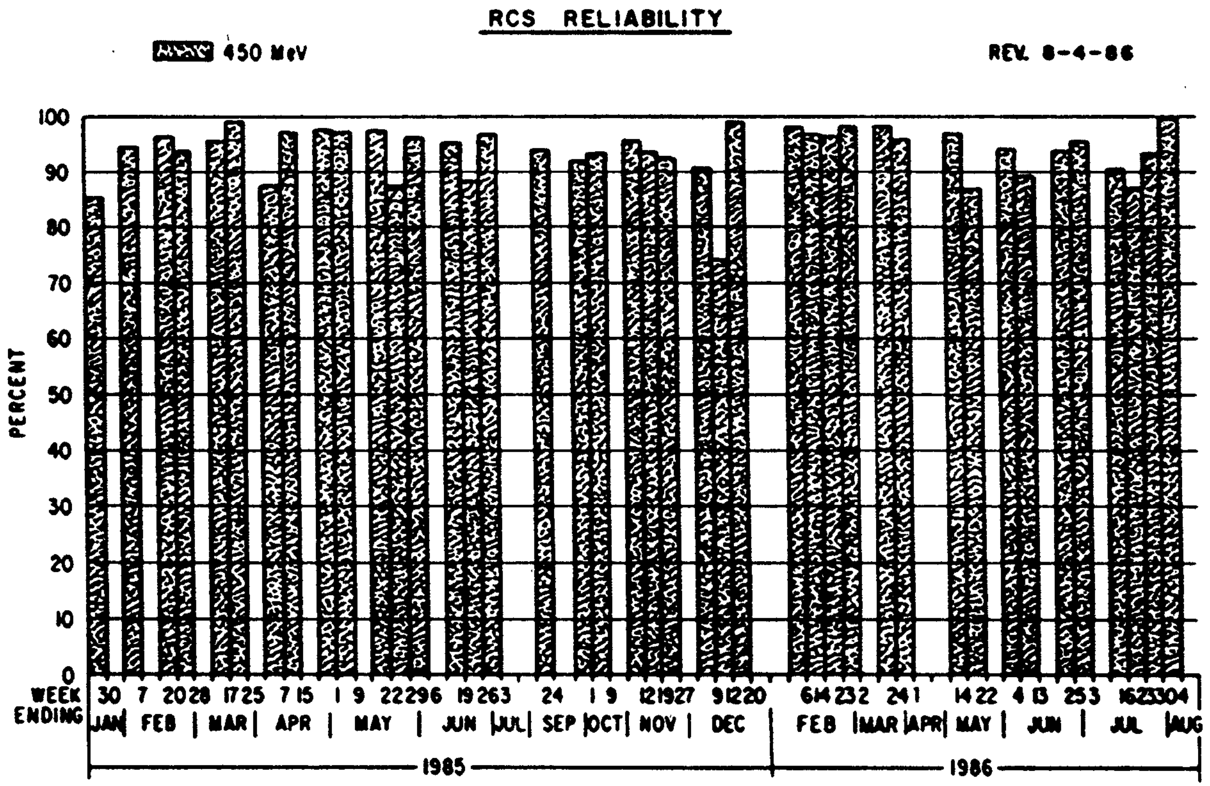


Figure 2: Reliability

were beginning to be harvested before the 1985 summer shutdown. This new synchronization scheme allowed about 0.8 μA increase in beam as expected but it had a side benefit in that it allowed us to study other systems more carefully while doing neutron science. A much improved regulator for the ring guide magnet power supplies resulted from these studies. This unit was installed in December of 1985 and was responsible for bringing the beam from the 14 μA to 15 μA level. This improved regulator is discussed in a companion paper[4] at this conference.

Both beam intensity and reliability were also enhanced by a complete switch over to commercially available 60-80 $\mu g/cm^2$ carbon stripping foils. Nine foils served us all year long. We estimate an average life of 42 million pulses per foil; about 5×10^{21} protons pass through each foil during its lifetime.

The reader will note from Figure 1 that beam improvement stagnated after January 1986. Due to the involvement of IPNS accelerator personnel in other ANL activities, accelerator research was less that 1% of scheduled time the remainder of the year.

Other Accelerator Activities

The most significant long-term activity was participation in the preparation of a proposal for a 6 GeV X-ray source to be built at ANL. The number of people involved was limited but their importance to accelerator improvement was great.

A far larger commitment in terms of personnel was IPNS involvement in the ANL portion of the U.S. Strategic Defense Initiative (SDI). Approximately one-half of our personnel have been working in this area since January 1986.

Neutral Particle Beam (NPB) systems are one facet of the SDI program. One goal of the program is to put a research 50 MeV H^- linac in space. The IPNS linac, though far from optimum for the NPB program, is the only operating 50 MeV H^- linac in the U.S. today and a large shielded beam hall exists nearby which formerly housed the Zero Gradient Synchrotron (ZGS). Since IPNS only runs about one-half time, the SDI program had an ideal opportunity - a H^- accelerator and a beam hall. The NPB program can only be run when the IPNS neutron operation is shutdown. Funding arrived in January to restore the beam line from the IPNS linac to the ZGS hall and to build two new test beams in the ZGS hall. The first of these test beams was brought into operation on April 30, 1986.

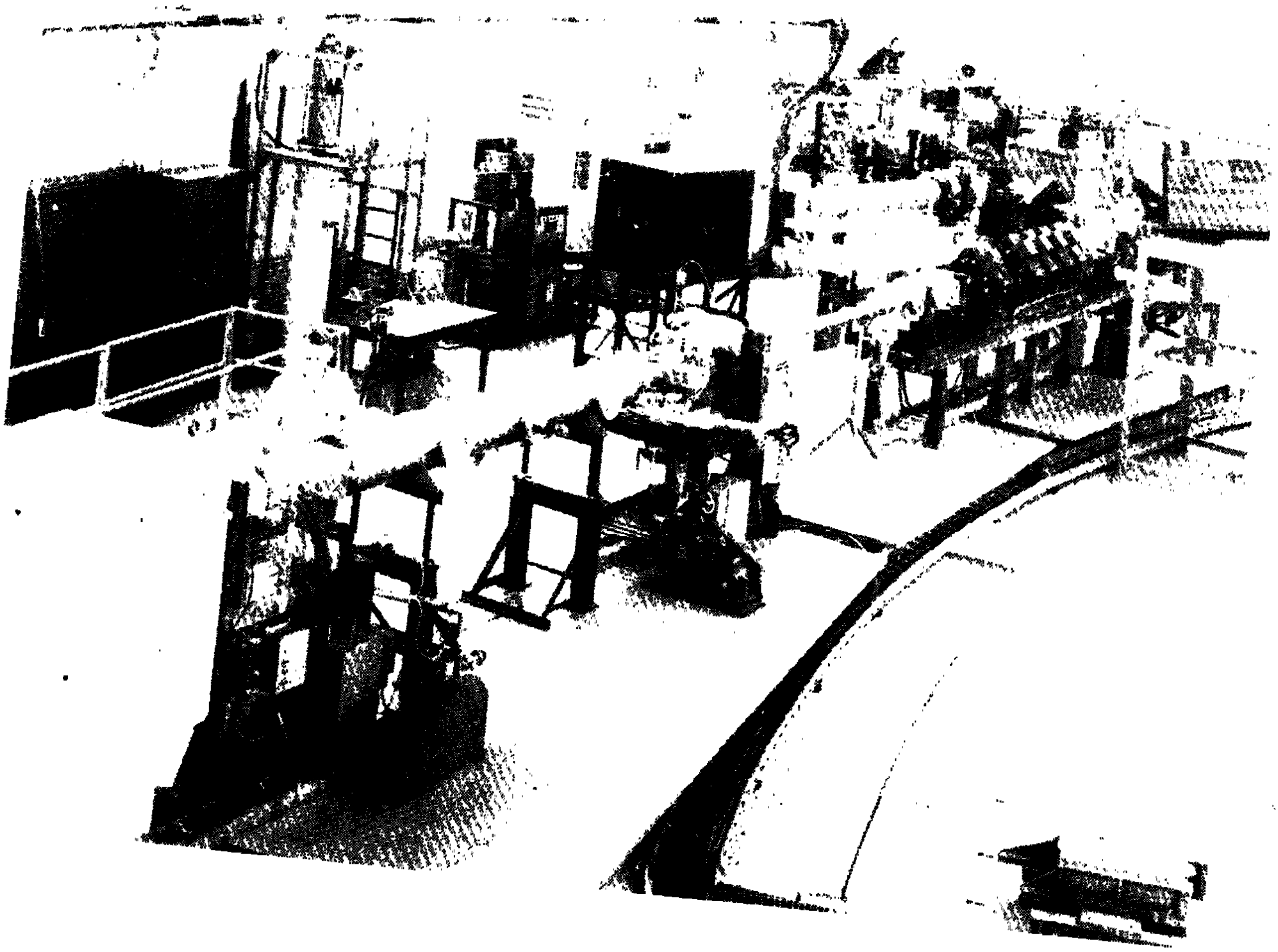
The SDI program is operated through the Engineering Division (ENG) at ANL but IPNS engineers and technicians took a leading role in the design and construction of the beam shown in Figure 3. Much of the equipment in this beam is IPNS and ZGS surplus. An effective collaboration between IPNS and ENG has been developed for the operation of this beam. A second beam, about three times as complex as the first, is now under construction and scheduled for completion in early 1987.

Some 1000 hours of NPB operation has now taken place with experiments on neutralization techniques, neutral beam sensing and target discrimination completed or underway. NPB users have come from industry, the military and other national laboratories and several ANL divisions. The second, yet to be completed beam, will perform similar experiments on large diameter beams as well as provide a test bed for specific prototype equipment evaluation.

Targets and Moderators

Most important among recent developments is the progress on the Enriched Uranium Booster Target. We have completed the design and the safety and security evaluations. The target and its various components and the needed facility modifications are nearing completion; we expect first operation this Fall. In its operating position, k_{eff} is 0.80; the enrichment is 77.5%. The new target will increase the intensity of all the neutron beams by a factor of about three. The expected increase in the primary source pulse width (to about 300 nanosec) will not significantly affect the performance of any existing IPNS instruments. We are assessing the impact of the increase in the fraction of delayed neutrons in the beams (to about 3%); most instruments will cope with this in data analysis software, but in addition we are designing choppers to reduce the effect in the powder diffractometers. Instruments will capitalize on the added flux by changing configuration to improve resolution, by concentrating on more difficult classes of measurements, or simply by accepting the higher data rates. Moderators are being changed to accommodate the greater nuclear heating power and the data acquisition systems are being upgraded to deal with higher data rates. We have recorded spectra from all the moderators under reproducible conditions, later to be compared with measurements with the Booster in place. With further modest improvements in the proton current delivered by RCS, we expect the Booster to elevate IPNS to a level of performance equivalent to that of a source with a 450. MeV, 48. μA proton beam and a depleted uranium target.

A separate report describes the Booster Target program in greater detail.[5]



Moderators

Partly as a result of studies which quantified the deterioration of polyethylene moderators under irradiation and partly in anticipation of the higher nuclear heating power in the moderators, we replaced the two polyethylene moderators with circulating liquid methane systems in January, 1986. Both operate at temperatures of about 100 °K; both have nominal dimensions of 10. × 10. × 5. cm^3 and are decoupled with boron-aluminum composite. Both include gadolinium heterogeneous poison; "H" at 2.5 cm (like the ISIS moderators), "F" at 1.7 cm on both sides (more severe than the ISIS systems). Figure 4 shows the time average spectrum of the "F" moderator. The fitted functions (corrected for attenuation by Aluminum in the beam) has the form

$$C(t) \propto E\phi(E) \propto \left(\frac{\phi_{Th}}{\phi_{epi}}\right) \frac{E^2}{E_T^2} e^{-E/ET} + \left(\frac{E}{E_{ref}}\right)^{\alpha} \frac{1}{\left(1 + \left(\frac{E_{co}}{E}\right)^{s}\right)}$$

with E_T = 10.70 meV, ϕ_{Th}/ϕ_{epi} = 1.087, α = .0235, E_{co} = 69.4 meV, s = 1.76. For "H" moderator, the parameters are E_T = 8.024 meV, ϕ_{Th}/ϕ_{epi} = 1.622, α = .125, E_{co} = 24.1 meV, s = 3.79. The CH_4 circulating systems are the same as were used in 1982, and have operated quite reliably - we experience some minor problems with clogging of small orifices in the cold systems.

For purposes of powder diffraction profile analysis, we are accommodating the changes in the spectrum and pulse shape by using spectrum and pulse shape functions described elsewhere.[6]

We continue efforts to understand and control the "burping" behavior of the grooved, cold solid methane moderator, which results in high stresses in the CH_4 container and has caused three failures which we now believe that we understand. A new system of improved design will be installed this Fall. Studies will continue with the goal of providing the lowest spectral temperature and the highest intensity of long-wavelength neutrons, consistent with long-term stable operation. Our analysis of the burping behavior is the subject of a separate report.[7] On the basis of experience with the new cold CH_4 moderator, we are planning to design and install a cold solid methane moderator, without grooves for higher resolution, for installation in the H position next Spring.

Data Acquisition Systems

One major improvement has been the development of a new microprocessor system which increases histogramming speed by a factor of ten without

liq CH_4 "F" Moderator
SEPD RUN 1385

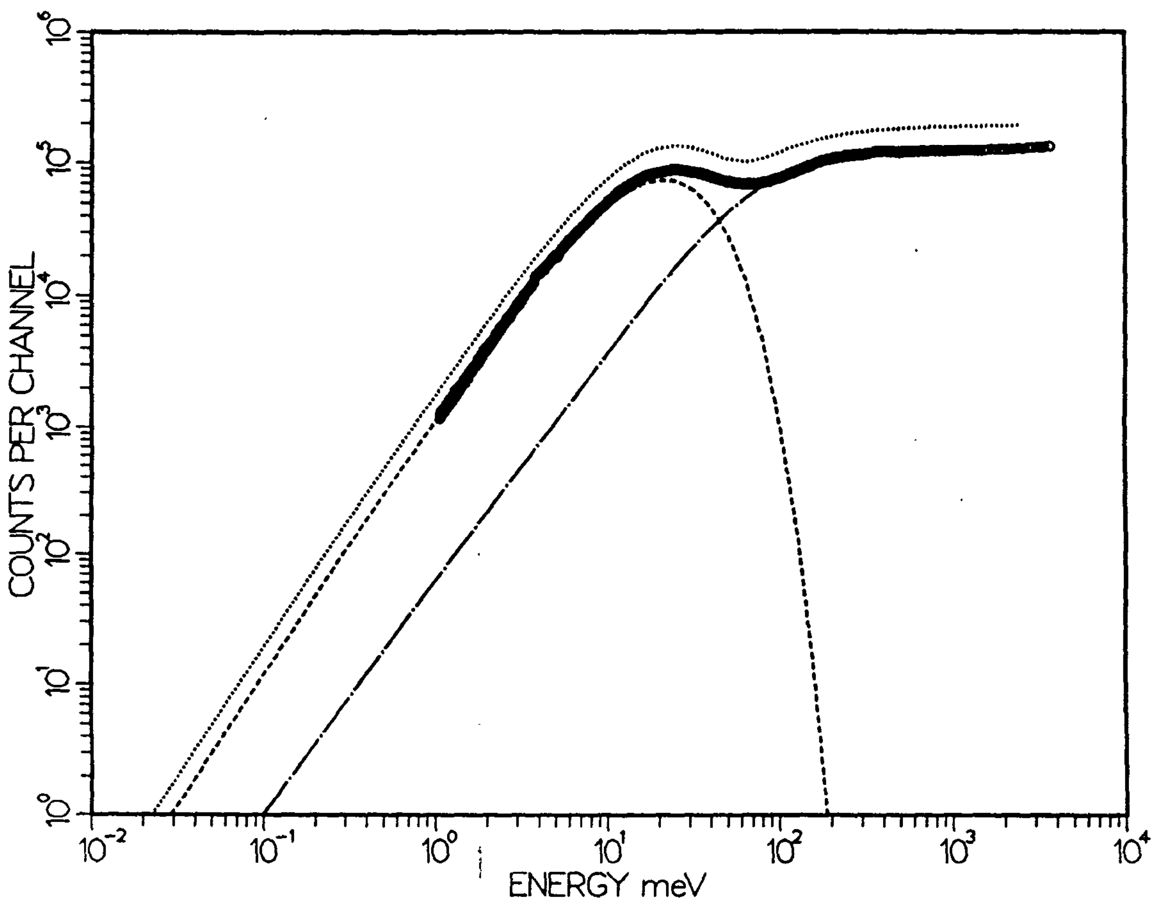


Figure 4: Time Average Neutron Flux Spectrum of the Liquid CH_4 "F" Moderator of IPNS

sacrificing any of the flexibility of the previous system. Refinements to the existing system include improvements in the interfacing of ancillary equipment to the instrument computers and to the VAXs, and the completion of networking of the instrument computers to the VAXs.

On the horizon are several other major developments. The instrument computer software will be converted to run on MicroVax computers, which will be used as the instrument computers on new instruments being developed. One of these new instruments (the glass diffractometer) will also require the development of encoding and histogramming hardware and software fundamentally different from that in use on current IPNS instruments, and this will involve a large fraction of the data acquisition effort over the coming year.

New Data Acquisition Microprocessor System

A multiprocessor data acquisition system has been developed and installed in all the IPNS instrument computer systems to replace the single microprocessor systems used earlier, in order to keep up with the data rates currently encountered on some of the instruments, as well as to cope with the large increase expected on all instruments as a result of the installation of the new booster target.

The old system used a dedicated Zilog Z8001 single board microcomputer on each instrument to histogram the data. Most of the histogramming operations were done in the software using this microcomputer. This permitted the on-the-fly time-focusing which has been so successful for the powder diffractometers and other instruments, as well as allowing a great degree of flexibility in the choice of channel widths, detector groupings, and other histogramming parameters. This flexibility was achieved at the expense of histogramming speed, which was limited to a maximum rate of about 3000 events/second. The new system maintains all this flexibility, and keeps all the histogramming algorithms used by the old system. However, this system uses improved hardware (National N32016 single board microcomputers instead of the Z8001) and the microcomputer software allows up to four microcomputers to be used in parallel. With these improvements the new system with a single microcomputer board can handle data rates a factor of 2.5 higher than the old system, a factor of 10 higher than the old system when four microcomputer boards are run in parallel. The new system has been running on several instruments since January, 1986, and installation in the remaining instruments is being completed in Fall, 1986.

Ancillary Equipment

Work has been continuing on the interfacing of ancillary equipment to the front end computer systems. Nearly all the instrument Displex systems now have controllers interfaced to the instrument computer systems, and the computer interfacing of some of the furnaces has now matured to the point where automated operation is becoming more useful. The sample changer interfacing works well, and the SEPD/GPPD changer is in such great demand that a second unit is being constructed. All the displex, furnace, and cryostat temperature controllers now can communicate with the VAXs as well, providing a means for device testing and development when the instrument computers are otherwise occupied. VAX software also provides communication with several multichannel analyzers and data loggers, permitting rapid transfer and storage of data from these devices.

Networking

All the instrument computer systems have now been connected to the Ethernet network, and can communicate with the VAXs via the DECNET software. This system is used primarily for transfer of data files, and for remote inquiry into the status of the instrument computer systems and/or the experiments running on them. The VAXs are connected to the ANL lab-wide system, thence to the outside world; they are called ANLPNS (780) and ANLPN2 (750).

Microvax Computers

All the instrument computer systems installed to date have been based on DEC PDP-11 computers (eight such computers currently support ten instruments). These computers have performed reliably and have met the needs of most of the instruments. However, two new instruments which are currently being considered at IPNS (glass diffractometer and new small angle diffractometer) have major needs for on-line computing capabilities and for greater disk storage capacity than is available on the current PDP 11/23 and 11/34 systems; we have selected DEC MicroVax-II computers for use with these instruments. We will soon begin to convert our instrument operating software for use on the MicroVax computers, and expect to have working MicroVax-based systems in 1987. In the longer term, it is expected that some of the existing instruments will be converted to MicroVax-based systems as well.

We are also exploring the use of MicroVax computers as part of the data analysis system, operating in a 2-4 user mode, dedicated to the analysis of data from a single class of instruments.

Data Acquisition for the Glass Diffractometer

This proposed new instrument, which is currently under development, will involve extensive use of linear position-sensitive detectors with different encoding requirements than any used in our present systems. Data rates on this instrument are potentially much larger than found on any of our other instruments, and will probably exceed the capabilities of even our new microprocessor system with the current histogramming algorithms. Thus this instrument will require a radically different approach to data encoding and histogramming than that used in all the current IPNS instruments. This approach will probably involve doing more in hardware and less in software than on the present systems, thus achieving speed at the expense of flexibility. This instrument will also involve very large data sets (preliminary estimates suggest something like 2-5 million channels), so the on-line data storage and analysis capability to be provided by the MicroVax computer will be very important. Data sets of this size may also require some serious rethinking of how the data analysis and archiving is to be handled.

Furnaces, Cryostats, Pressure Cells

Work on furnaces has concentrated on high temperatures and on controlled sample environments. A controlled-sample-environment furnace for SEPD and GPPD is now operating reliably to 1400 C. This furnace can be used with the sample in a vacuum or under different partial pressures of a variety of gases or gas mixtures. A controlled-sample-environment furnace has also been used on the SAD at temperatures up to ~ 1000 C. Table I summarizes currently-available equipment for special sample environments.

Table I

Equipment for Special Sample Environments at IPNS

Low Temperatures

(Adaptable to most instruments)

Displex Refrigerators	$T \geq 10K$
^{4}He Cryostat	$1.5 \leq T \leq 200K$

High Temperatures

Diffractometer and Chopper Spectrometer Furnaces	$T \leq 1400$ C
Small-Angle Diffractometer Furnace	$T \leq 1000$ C

High Pressures

(Special Environment Powder Diffractometer, $2\Theta = 90°$)

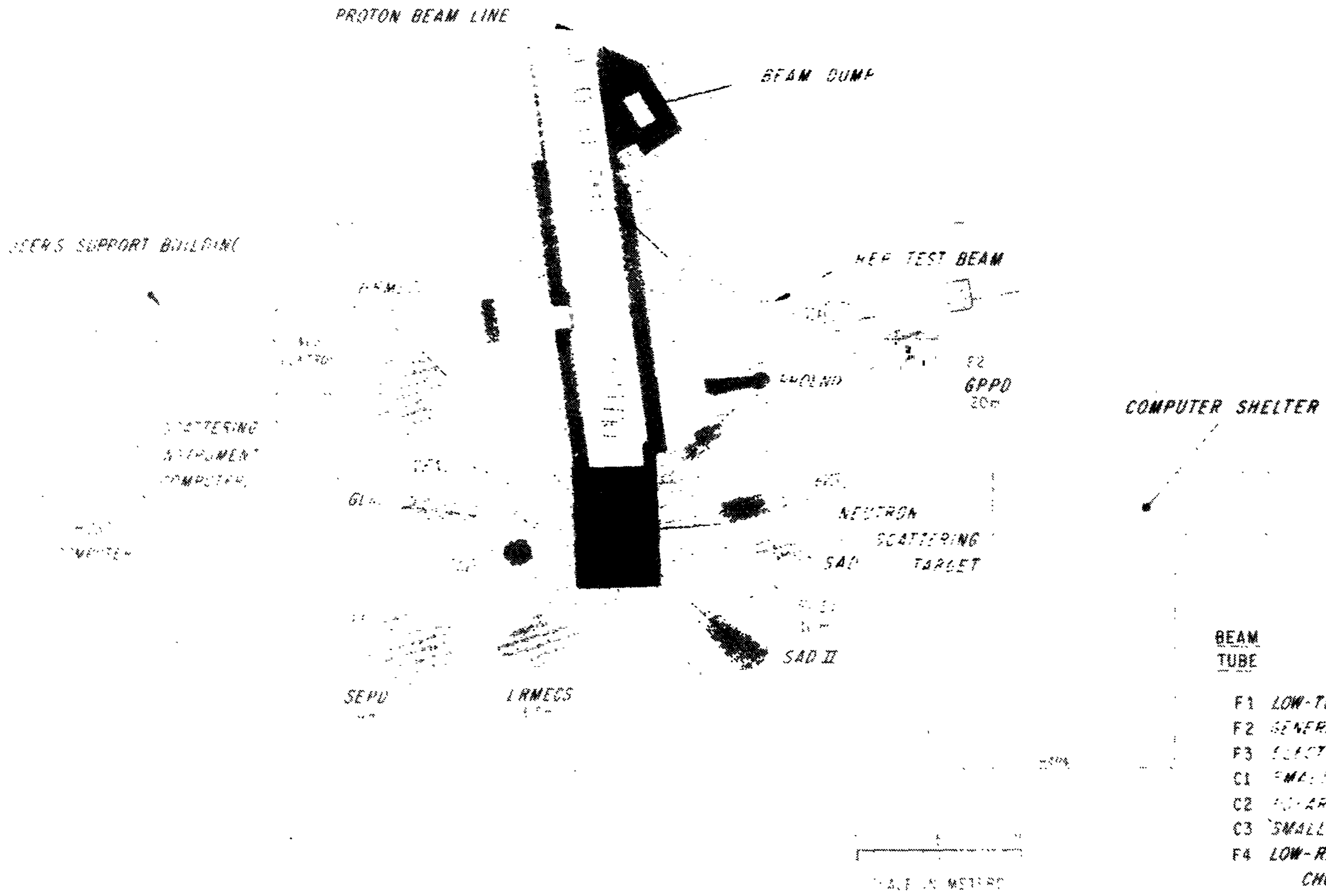
	Pressure	Volume	Temperature
Piston-Cylinder	35 Kbar	0.25 cm^3	300 K
Gas-Pressurized Cells	6 Kbar	2.0 cm^3	10 K
Clamped Piston-Cylinder	25 Kbar	1.5 cm^3	10 K
(Single Crystal Diffractometer)			
He Gas Pressure Cell	5 Kbar	1.5mm diam.	10K-300K

Scattering Instruments

We have rearranged the IPNS scattering instruments somewhat, partly as a result of introducing new ones, and partly as a result of phasing out the Ultralow Temperature Diffraction Experiment, formerly at the C3 beam. Figure 5 shows the new arrangement. The QuasiElastic Neutron Spectrometer (QENS) is a new instrument, located at the previously vacant H2 beam. It is the result of a collaboration between ANL, LANL, MIT, EXXON and Schlumberger-Doll Research. Figure 6 shows a diagram of the new machine. First tests show that the resolution is 65. μeV for quasielastic scattering about 3.7 meV, as designed. Background in the detectors is already acceptably low. The Single Crystal Diffractometer (SCD) is being moved from H1 to the F6 beam. There, with the higher resolution moderator and with the moderator-sample flight path increased to 9.5 m, the resolution will improve to about $\Delta Q \approx .03$ $Å^{-1}$. The overall data rate will increase by a factor around 1.4, and the instantaneous data rate will be about the same with the Booster as it was before. A new Glass Diffractometer (GLAD) is under design, in a collaboration between ANL, LANL, University of Houston and Willamette University to be placed at H1 beam. The instrument will feature a small angle detector array of moderate resolution, and a large array of detectors extending to 90.° scattering angle.

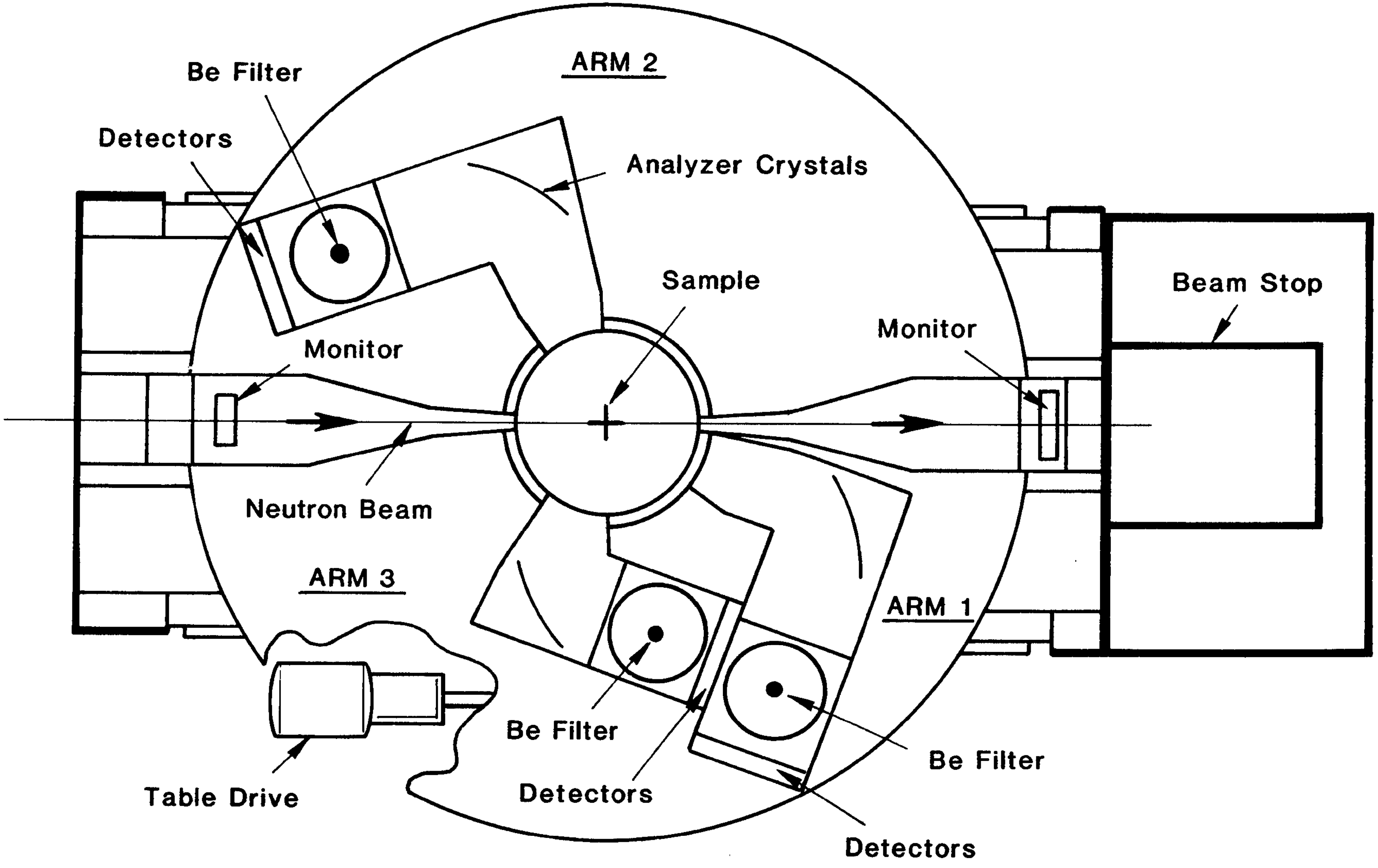
The Special Environment Powder Diffractometer (SEPD) will remain as is, but its capabilities for high pressure measurements are being enhanced by construction of new pressure cell. At the Low Resolution Medium Energy Chopper Spectrometer (LRMECS), the chopper shielding is being improved on the basis of better understanding of the origin of personnel background radiation. A new 10 meV chopper is being designed for use in LRMECS and in the High Resolution Medium Energy Chopper Spectrometer (HRMECS), to extend their ranges to lower energies and higher resolution.

IPNS
EXPERIMENT FACILITIES



BEAM TUBE	UTILIZATION
F1	LOW-TEMPERATURE CHOPPER SPECTROMETER
F2	GENERAL PURPOSE POWDER DIFFRACTOMETER
F3	ELECTRON-VOLT SPECTROMETER
C1	SMALL ANGLE DIFFRACTOMETER
C2	POLARIZED NEUTRON REFLECTOMETER
C3	SMALL ANGLE DIFFRACTOMETER (PROPOSED)
F4	LOW-RESOLUTION MEDIUM-ENERGY CHOPPER SPECTROMETER
F5	SPECIAL ENVIRONMENT POWDER DIFFRACTOMETER
F6	SINGLE CRYSTAL DIFFRACTOMETER
H1	GLASS LIQUIDS AND AMORPHOUS DIFFRACTOMETER
H2	QUASIELASTIC NEUTRON SCATTERING SPECTROMETER
H3	HIGH-RESOLUTION MEDIUM-ENERGY CHOPPER SPECTROMETER

QENS


ARM 2
Be Filter
Detectors
Analyzer Crystals
Sample
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Beam Stop
Monitor
Neutron Beam
ARM 3
ARM 1
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Table Drive
Detectors
Detectors

We plan to install a second Small Angle Diffractometer at the C3 beam; its detailed design depends on experience yet to be gained on the existing SAD. Meanwhile, we will install the Doppler shifter ultracold neutron apparatus, which is back from its round of experiments at Los Alamos. The Polarized Neutron Reflectometer at the C2 beam has developed into a highly productive instrument.[8] Figure 7 diagrams the instrument, while Figure 8 shows a recent measurement of the reflectivity of a layered, magnetically-biased permaloy structure. Recently, an electronic spin-flip chopper has been installed to improve the resolution and reduce the delayed neutron background.

The Small Angle Diffractometer (SAD) at C1 beam continues to improve. Recently we have installed a single crystal MgO filter which reduces the fast component of the delayed neutron background and the sensitivity to the prompt fast neutron and gamma flash. We are purchasing a new, larger (45 cm vs. 17 cm diameter) detector in the coming year. The Electron Volt Spectrometer (eVS) at F3 beam is the subject of a separate report.[9] The General Purpose Powder Diffractometer (GPPD) at F2 beam remains highly effective, especially for high temperature and residual stress measurements; no significant changes are envisioned for GPPD. We have replaced the Crystal Analyzer Spectrometer (CAS), formerly at F1 beam, with the QENS at H2, and have erected a new, special-purpose chopper spectrometer, the Pulsed High Energy Neutron Inelastic Chopper Spectrometer (PHENICS), dedicated to low temperature momentum distribution measurements. The new instrument uses the dilution refrigerator from the disassembled Ultralow Temperature Diffraction Experiment, formerly at C3, and has a single detector bank at a scattering angle of 150.°. The instrument is the result of a collaboration between ANL and Harvard University, and will begin operating at the time of the Fall startup. Table II summarizes the parameters of the present IPNS neutron scattering instruments.

User Program

The operating statistics shown in Table III clearly indicate an increase in the number of experiments and scientists at IPNS despite a small decrease in operating time. The increase from BY85 is due to the proton current increase and the coming to maturity of the Small Angle Diffractometer and the Polarized Neutron Reflectometer. The large increase in university users is due to the establishment of a number of groups consisting of faculty, post-doctoral appointees and graduate students which focus their research at IPNS. Particularly active research groups exist at Harvard University, University

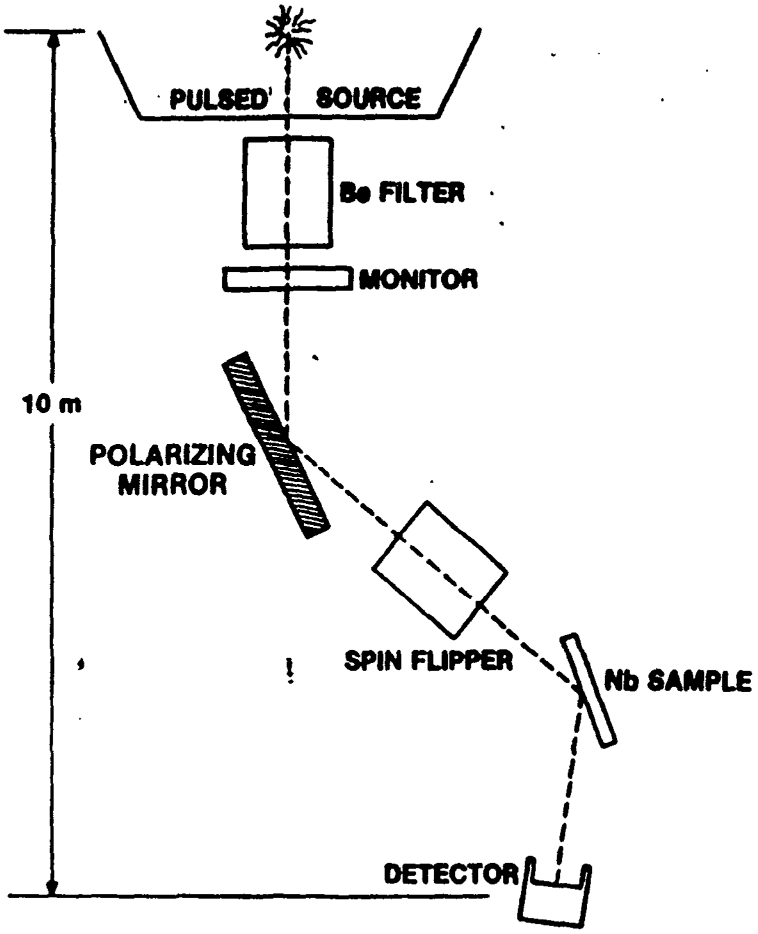

Figure 7: Schematic Diagram of the Polarized Neutron Reflectometer

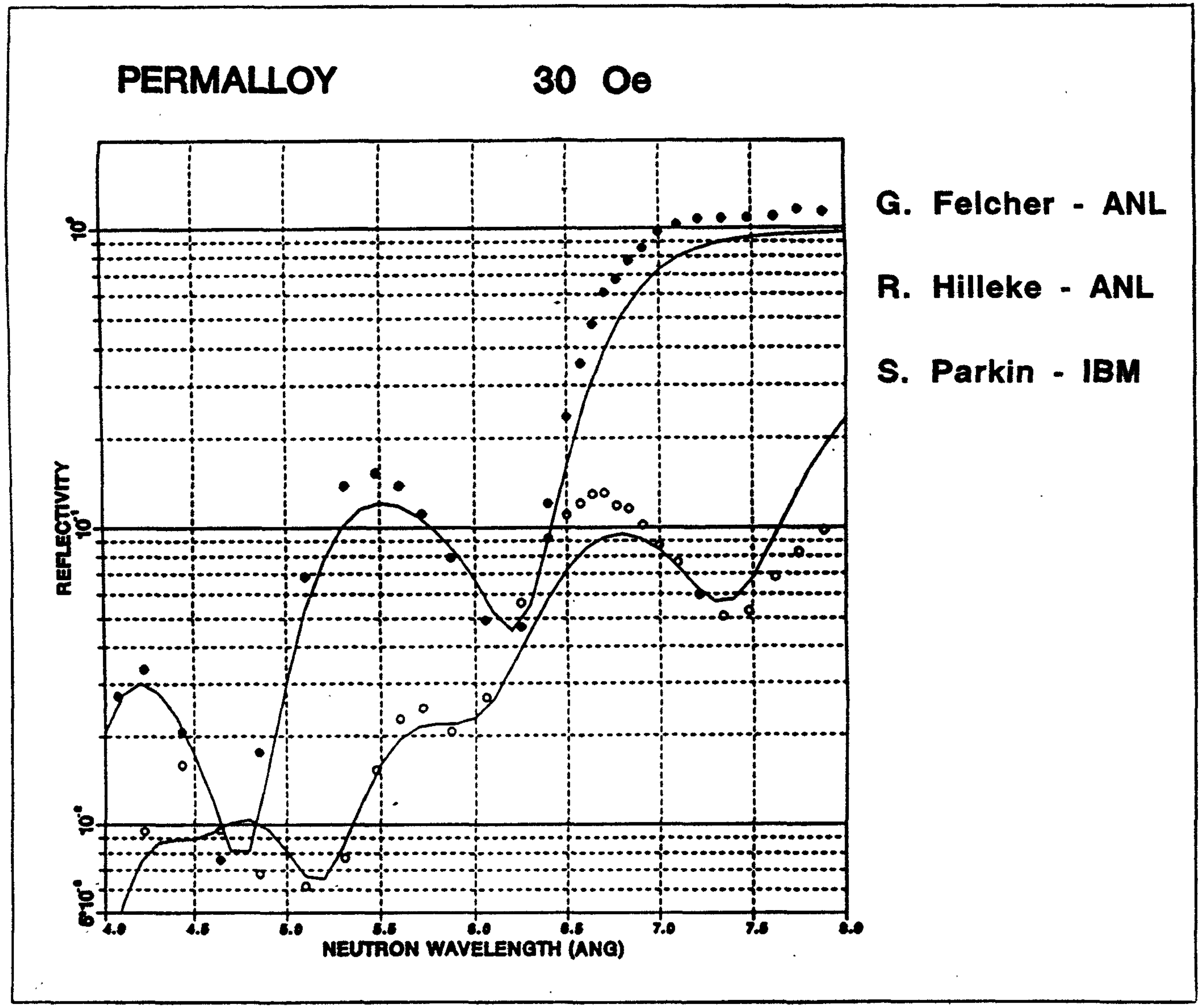

Figure 8: Polarized Neutron Reflection Spectrum of Magnetically Biased Permalloy

Table II
IPNS NEUTRON SCATTERING INSTRUMENTS

Facility (Instrument Scientist)	Assignment	• Range Wave-vector	Range Energy	Resolution Wave-vector	Resolution Energy
Special Environment Powder Diffractometer (J. D. Jorgensen/K. Volin)	F5	0.5–50 Å^{-1}	*	0.35%	*
General Purpose Powder Diffractometer (J. Faber/R. Hitterman)	F2	0.5–100 Å^{-1}	*	0.25%	*
Single Crystal Diffractometer (A. J. Schultz)	F6	2–20 Å^{-1}	*	2%	*
Low-Resolution Medium-Energy Chopper Spectrometer (C.-K. Loong)	F4	0.1–30 Å^{-1}	0–0.6 eV	0.02 K_o	0.05 E_o
High-Resolution Medium-Energy Chopper Spectrometer (D. L. Price)	H3	0.3–9 Å^{-1}	0–0.4 eV	0.01 K_o	0.02 E_o
Small-Angle Scattering Diffractometer (J. E. Epperson/P.Thiyagarajan)	C1	0.006–0.35 Å^{-1}	*	0.004 Å^{-1}	*

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* No energy analysis

• Wave-vector, $K = 4\pi\sin\theta/\lambda$

NEUTRON BEAMS FOR SPECIAL EXPERIMENTS

Beam Tube	Current Use	Flight Path Length (m)
F3	eV Spectrometer	10.0
C2	Polarized Neutron Exp.	10.0
F1	n(p) Spectrometer	13.6
H1	Glass Diffractometer (planned)	10.0
H2	QENS Spectrometer	8.0
C3	Ultra-Cold Neutrons	10.0
	New SAD (planned)	

Table III

IPNS USER PROGRAM

	FY83	FY84	FY85	FY86
WEEKS OF OPERATION	26	29	21	22
NUMBER OF EXPERIMENTS PERFORMED	110	210	180	212
VISITORS TO IPNS FOR AT LEAST ONE EXPERIMENT:				
DOE LABS - SAME SITE	41	49	44	52
DOE LABS - OTHER SITES	7	7	6	10
OTHER GOVERNMENT LABS	2	1	1	1
UNIVERSITIES	33	45	51	79
INDUSTRY	5	9	7	13
FOREIGN	18	39	34	27
	106	150	143	182

of Illinois, Northwestern University, Penn State University, University of Wisconsin, University of Chicago and University of Pennsylvania.

In addition to the basic research done for free under the proposed system, experimental time can be bought for proprietary research. Instrument time (primarily on the powder diffractometers) was sold this past year to Standard Oil (SOHIO), Amoco Oil, Canadian Hydro and Chalk River Nuclear Laboratory.

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