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Intense Pulsed Neutron Source Status Report

B. S. Brown, D. E. Bohringer, F. R. Brumwell, J. M. Carpenter,
R. K. Crawford, A. V. Rauchas, A. W. Schulke, and T. G. Worlton
Argonne National Laboratory
Argonne, Illinois 60439
USA

Abstract: The status and future plans of IPNS will be reviewed. At the celebration of our 10th anniversary in 7 months, IPNS will have performed over 2000 experiments and has over 230 scientists visiting IPNS annually. Plans for a new spallation source concept using a fixed field alternating gradient synchrotron will be presented.

Introduction

Seven months after the ICANS-XI meeting, IPNS will celebrate its 10th anniversary, a significant milestone and a tribute to the hard work and dedication of the scientists, users, and technical support at IPNS. The 10-year anniversary of the first delivery of the proton beam to the IPNS target will be the cause for the Fifth IPNS User Meeting, a grand celebration, and a special IPNS Progress Report.

Another milestone was recently passed with the delivery of 3×10^9 pulses to the IPNS target in July, 1990. It seems like only yesterday that we had our 2-billionth-pulse party, but then milestones such as these come quickly when operating with 95% reliability.

Our motto for the past 2 years could well have been "IPNS Keeps Chugging Along." The past 2 years have seen some large budget fluctuations (+21% and then -25%, 6 months later); some surprising personnel changes; a never-ending series of audits on safety, environment, security, etc.; and a huge effort for the scheduled visit to Argonne of the Tiger Team, a 5 week audit on Department of Energy (DOE) regulations and policies. Despite these, IPNS continues to operate successfully and in a productive manner scientifically:

- 323 experiments were performed in Fiscal Year 1989 (FY89), which began October 1988, 25% more than the previous year (FY88).
- 220 scientists visited IPNS for one or more experiments during FY89, a 10% increase over FY88.
- A second neutron reflectometer, POSY II, to be used primarily for polymer research, was commissioned in December 1988.
- The Glass, Liquid, and Amorphous Material Diffractometer (GLAD) was commissioned in April 1990.
- A proposal to DOE for manpower and instrument support for a second Small Angle Diffractometer was funded.

- A multitude of workshops were held, ranging from Momentum Distributions to the Determination of Residual Stress in Engineering Materials.

- By far the largest group of visiting faculty and high school and college students came to IPNS this past summer.

And on and on ...

A most exciting prospect for the future is the conceptual design for an advanced Pulsed Neutron Research Facility (PNRF). The goal is to build a pulsed neutron source that is as powerful as any now operating in the world which will also act as a test bed for a Fixed Field Alternating Gradient accelerator that could increase the proton current by a factor of 30, up to 3 mA. Given the very likely scenario that none of the existing DOE neutron sources will be operating in 10 years, we feel that it is very important to have a plan for the future for pulsed neutron sources as well as the very exciting prospect for the advanced steady-state reactor, the U. S. Advanced Neutron Source (ANS).

Scientific results and highlights can be found in the recently printed IPNS Progress Report, 1988-1990.

Operating status of the accelerator system

The three-billionth proton beam pulse was delivered to the IPNS target on July 16, 1990. This was less than 3 years after the last major milestone, the two-billionth pulse on target, and shows what 95% reliability can do.

The average beam current on target is continuing to increase, showing another 5% increase over the average since the previous ICANS report. Most of the increase occurred in the last six months as some nagging problems affecting accelerator system components were solved.

The reliability, already high by accelerator standards, increased to a phenomenal 95.3%. Coupled with the record-setting average beam current, this period was the most productive for the accelerator system in IPNS history. As shown in the table below, even though 161 fewer hours were scheduled between July 1988 and April 1990 than during the August 1986-June 1988 period, the accelerator was available an additional 60 hours for neutron experiments.

Table 1 Accelerator operating summary.

	11/81-7/83	10/83-2/85	3/85-7/86	8/86-6/88	7/88-4/90
Average beam current (μA)	8.65	11.90	12.89	13.47	14.12
Operating efficiency (%)	89.6	89.3	93.9	91.9	95.3
Scheduled operating time (h)	7191	5567	5263	6237	6076
Available operating time (h)	6443	4973	4942	5732	5792
Total pulses on target (x 10^8)	6.27	4.91	6.02	6.21	6.03
Total μA hours	55,732	59,179	63,702	77,210	78,865
Total protons on target (x 10^{21})	1.08	1.22	1.54	1.73	1.77
SDI linac operation (h)	0	0	1000	3125	768

Figure 1 is a plot of weekly average proton current on the neutron target since turn-on in 1981; each point represents, on average, about 148 hours of

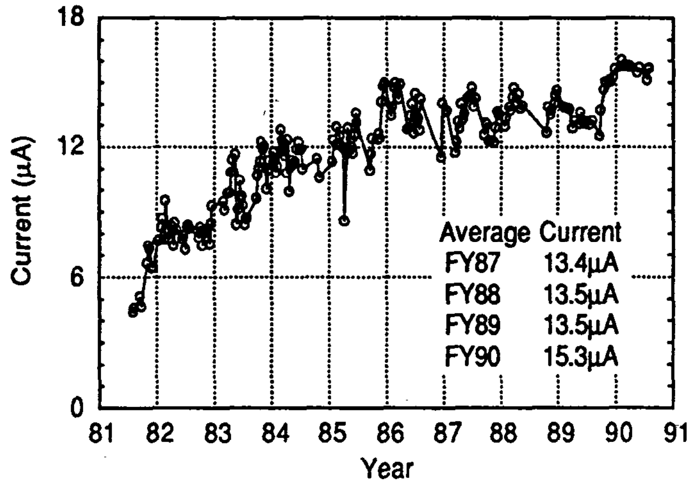

Fig. 1 Average target current of IPNS.

operation. It is clearly evident from the plot that during 1989, the average proton current had decreased after reaching a near record-setting monthly average of 14.5 μA in December 1988. In the beginning of 1989, an intermittent instability appeared in various accelerator system components. The instability was evident in numerous power supplies from the linear accelerator to the proton transport line and from the synchrotron to the neutron target. It was most prevalent in the ring-magnet power supply, which could not maintain the stability of the injection field. The worst problem was that the instability was intermittent; it would appear for several hours, disappear for another several hours, reappear again, and then disappear for several days. During the periods of instability, it would be necessary for the accelerator operators to reduce the operating current so that the imposed beam loss limit would not be exceeded. This prevented the accelerator from running at the peak level and limited the "gentle" tuning required to increase the performance. All accelerator operations personnel began investigating for possible sources of this instability. Since some intermittent problems were being experienced by the neutron chopper systems, significant investigation was centered on the variable-frequency master clock system which tracks the frequency variations of the power line and controls the phase relationship between the chopper systems and the synchrotron. This system was described in detail in the IPNS Progress Report 1983-1985.

The problem was located during June 1989 and was found to be an instability of the incoming power line. Voltage variations of a few percent and lasting only several 60-Hz cycles were affecting many of the accelerator power supplies. These power supplies are generally well-regulated, but the regulators do not have the bandwidth to respond to such short duration voltage transients. The power company was notified, and with their assistance, we were able to confirm that the noise source was not located within the laboratory, but was coming in through the power grid supplying Argonne. The power company began its own investigation in an attempt to isolate the source. Although never confirmed, the source appears to have been an industrial arc furnace facility which had converted from manual control to computer control early in the year. This would explain the appearance of the fast voltage transients on the power line. In October, the power company rearranged power grid feeders and removed the offending facility from the feeder supplying power to Argonne.

The improved accelerator stability was a major factor in the average current improvement which began in October 1989. Other contributing factors, although much more difficult to evaluate, were the replacement of the ion source, which appeared to improve the source emittance, and the repair of a vacuum leak in an injection diagnostic in the synchrotron. Beam size measurements in the synchrotron indicated that the beam was occupying less of the injection aperture, and therefore, more beam could be injected successfully.

The real bright spot of the IPNS accelerator operations continues to be the operating reliability, that is, availability to deliver protons as scheduled. Figure 2 is a plot of this availability; each point represents the availability for a one-week period. From July 1988 to April 1990, the lowest weekly availability has been above 88%; the average for the entire period is 95.3%. This excellent performance has to be attributed to the performance of the technical personnel responsible for the accelerator system. A great deal of effort is expended in isolating potential problem areas and correcting them. Many years of accelerator operations experience provides a firm basis for extensive preventative maintenance.

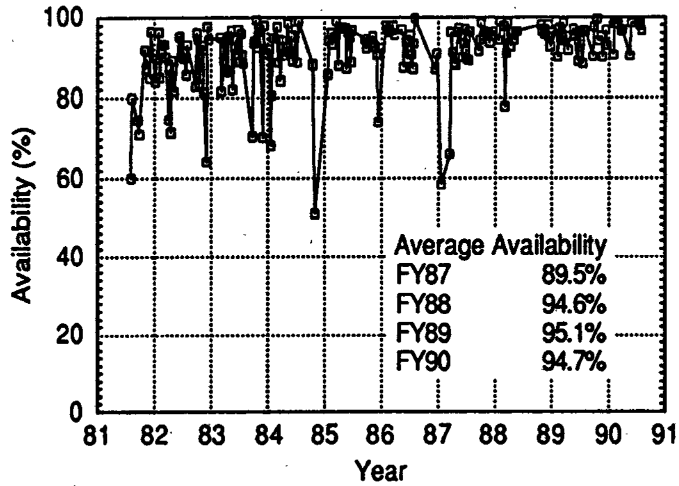

Fig. 2 Realibility of IPNS.

Achieving this high level of availability with a complex system such as an accelerator also requires some luck. There have been a few instances where equipment failures have "waited" until after the scheduled shutdown time. An example of one was a cooling hose that failed two hours after shutdown; had it occurred during operation, this would have cost six hours of downtime.

The only potentially significant problem occurred in December 1988, when a linac quadrupole magnet power supply failed to shut down when the substation feeding the linac vacuum and cooling water systems tripped off on a ground fault. It took 14 hours to repair the damage to insulation, solder joints, and current shunts. Neutron experiments lost only eight hours of beam time, since a six hour machine research period had been scheduled and was used for the repairs.

At a user facility such as IPNS, operating time is at a premium, and limited time and resources are available for major accelerator improvements. Most of the effort is used for minor upgrades. Accelerator research has been minimal and has concentrated on areas which could, with little effort, improve the accelerator performance. One area receiving attention has been the 50-MeV beam transport line from the linac to the synchrotron. Studies are underway to better characterize the beam transport system with the purpose of improving the beam matching into the synchrotron.

Another area receiving considerable attention has been the synchrotron loss monitoring system. Since the IPNS accelerator system operates loss-limited, eliminating the loss of a single proton in the synchrotron will enable an additional nine protons to be delivered to the neutron target. Studies are ongoing to improve the sensitivity and linearity of the loss monitoring system, so that the accelerator can be tuned "more precisely", thereby "squeezing" every available proton out of the synchrotron.

IPNS activity on behalf of SDI

One of the facets of the nation's Strategic Defense Initiative (SDI) program is the use of high-energy particle beams to discriminate between real and dummy warheads and to disable the real devices if necessary. Charged particle beams traveling long distances would be missteered and defocussed by the Earth's magnetic field and, of course, the electric forces between particles in the beam would tend to diffuse the beam, thus reducing its energy density. Beams of neutral particles would not suffer these deficiencies. Neutral particles cannot be accelerated, but negatively charged beams can and then, partially at least, neutralized after acceleration. It is imperative that the neutralization process does not add to the angular divergence of the beam.

While the SDI goal to put an operating 50-MeV H^- linac into space has been delayed, limited research and development is still underway. The only operating 50-MeV H^- linac in the U.S. today is the one feeding H^- ions to the IPNS RCS. Due to Department of Energy budgetary constraints, IPNS runs only one-half of the time; therefore, the IPNS linac can easily serve other users many weeks during the year.

As described in the IPNS Progress Report 1986-1988, design and construction of the larger ANL-SDI beam line started in late 1986, and the first test beam was sent down this new line on April 22, 1987. The beam optics design was supplied by members of the Argonne Engineering Physics Division, while IPNS personnel supplied much of the hardware design, installation planning, and about 90% of the installation labor and initial testing effort. Since that time, IPNS personnel have participated in the installation of a new type of electromagnetic beam expansion telescope designed at the Los Alamos National Laboratory (LANL). It includes trim multipole magnets to reduce higher order magnetic aberrations, and thus, it further decreases beam divergence. Another LANL addition to the beam line was the Wire and Fluorescent Fiber Optical Grid (WAFFOG) assembly which measures the performance of the beam expansion telescope. IPNS personnel were involved heavily in the installation and in the operations support for these tests.

However, as is evident from the Accelerator Operation Summary, the amount of SDI operation has decreased significantly. During the period July 1988-April 1990, 768 hours of SDI operation have occurred, only 25% of the time used during the August 1986-June 1988 period. Operation of the SDI facilities at IPNS will almost certainly terminate within the next year.

Instruments

Figure 3 shows the instruments now operating at IPNS, the specifications of which are given in Table 2. Although the use of epithermal neutrons (energies greater than ~100 meV) has been an important aspect of the science performed at IPNS, we are also aware that spallation sources can cover the whole useful neutron spectrum, which is why cold moderators are so important.

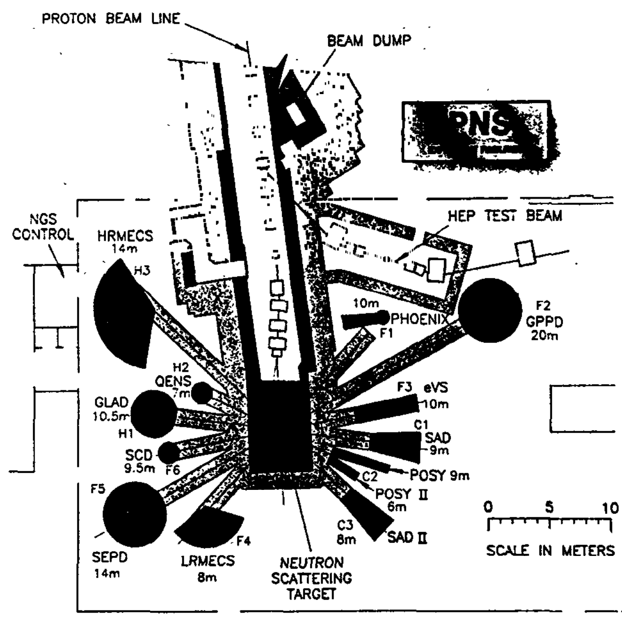

Fig. 3 IPNS neutron scattering instrument layout.

The instruments for elastic or total scattering consist of two powder diffractometers (SEPD - Special Environment Powder Diffractometer, GPPD - General Purpose Powder Diffractometer), which have excelled at high resolution and special environment work, coupled with the on-line capability of the Rietveld method and also have proved useful for amorphous systems. As one might expect, these instruments are now used increasingly with furnaces, cryostats, and pressure cells. Over the past few years, there has been considerable work on the powder diffractometers on structural and defect studies of the high-T_c superconductors and the determination of residual strains in composite materials. The Single Crystal Diffractometer (SCD) is based on the Laue technique with a two-dimensional (30 cm x 30 cm) position-sensitive scintillation detector based on the Anger method, designed and built at Argonne, and has investigated crystal structures and a variety of problems involving superstructures, diffuse scattering, and recently, texture determination and magnetic structures. The Glass, Liquid, and Amorphous Material Diffractometer (GLAD) was commissioned recently. This instrument features high intensity with low-to-moderate resolution and emphasis on low-angle detector banks to simplify inelasticity corrections. The Small Angle Diffractometer (SAD) also includes a two-dimensional position-sensitive detector and is used to investigate metallurgical, polymer, and biological systems. The broad scientific interest in the SAD and large oversubscription have resulted in the decision to build a second small angle diffractometer, SAD II, which is being designed to optimize capabilities for chemical and polymer studies.

The two chopper spectrometers (LRMECS - Low Resolution Medium Energy Chopper Spectrometer, HRMECS - High Resolution Medium Energy Chopper Spectrometer) have proved exceptionally versatile in a variety of problems involving measurements of S(Q,E). Experiments on amorphous materials, electronic transitions, and momentum distributions have all made use of the abundant epithermal spectrum. A low-temperature spectrometer, PHOENIX, is operating by a Participating Research Team (PRT) consisting of scientists from Argonne, the Pennsylvania State University, Harvard University, and the University of Illinois - Urbana for momentum density, n(**p**), measurements in quantum liquids and solids.

Table 2

IPNS NEUTRON SCATTERING INSTRUMENTS

Instrument (Instrument Scientist(s))	Beam Line	Range: Wave-vector* ($Å^{-1}$)	Range: Energy (eV)	Resolution: Wave-vector ($Å^{-1}$)	Resolution: Energy (eV)
Special Environment Powder Diffractometer (SEPD) (J. Jorgensen/K. Volin)	F5	0.5-50	**	0.35%	**
General Purpose Powder Diffractometer (GPPD) (J. Richardson/R. Hitterman)	F2	0.5-100	**	0.25%	**
Single Crystal Diffractometer (SCD) (A. Schultz/R.Goyette)	F6	2-20	**	2%	**
Glass, Liquid, and Amorphous Material Diffractometer (GLAD) (D. Price)	H1	0.05-45	**	~ 2%	**
Small Angle Diffractometer (SAD) (J. Epperson/P. Thiyagarajan)	C1	0.006-0.35	**	0.004	**
Quasielastic Neutron Spectrometer (QENS) (F. Trouw)	H2	0.42-2.59	0-0.1	~ 0.2	0.02 E_o
Low Resolution Medium Energy Chopper Spectrometer (LRMECS) (C. Loong)	F4	0.1-30	0-0.6	0.02 k_o	0.05 E_o
High Resolution Medium Energy Chopper Spectrometer (HRMECS) (C. Loong)	H3	0.3-9	0-0.4	0.01 k_o	0.02 E_o
PHOENIX (P. Sokol/Y. Wang)	F1	0.3-30	0.1-0.8	0.01 k_o	0.02 E_o
Electron-Volt Spectrometer (eVS) (P. Sokol)	F3	0.1-50	0-4	0.7%	0.08 E_o
Polarized Neutron Reflectometer (POSY) (G. Felcher/R.Goyette)	C2	0.0-0.07	**	0.0003	**
Neutron Reflectometer (POSY II) (W. Dozier)	C2	0.0-0.25	**	0.001	**

* Wave-vector, $k = 4\pi \sin\theta/\lambda$.
** No energy analysis.

Table 3

ANCILLARY EQUIPMENT AVAILABLE AT IPNS

Device	Instrument(s)	Can Be Used With	Temperature Range	Computer Control
Low Temperature				
Displex refrigerator	SEPD, GPPD, SCD, GLAD, SAD, QENS, LRMECS, HRMECS, POSY		10-300 K	yes
Helium cryostat	SEPD, GPPD, GLAD, SAD, QENS, LRMECS, HRMECS		2.5-300 K	
HeliTran	SCD		4.2-300 K	yes
^{3}He refrigerator	PHOENIX		0.3-4.2 K	
Dilution refrigerator	PHOENIX		0.03-4.2 K	
High Temperature				
"Miller" furnace	SEPD, GPPD	Controlled atmosphere	RT-1400°C	Furnace
"Howe" furnace	SEPD, GPPD, GLAD, QENS, LRMECS, HRMECS, POSY		RT-1000°C	yes
"Coffee Can" furnace	SEPD, GPPD, HRMECS		RT-400°C	yes
"Routbort" furnace	SAD	Controlled atmosphere	RT-1750°C	Furnace
"1000°C" furnace	SAD	Controlled atmosphere	RT-1000°C	Furnace
High Pressure				
0-20 kbar piston cell	SEPD, GPPD		RT	
0-7 kbar gas cell	SEPD, GPPD	Displex	10-300 K	Displex
0-5 kbar gas cell	SCD	Displex	10-300 K	Displex
0-5 kbar gas cell	GLAD		RT	
0-1.5 kbar cell	SAD	Furnace	RT-80°C	Furnace
Magnetic Field				
0-10 kG magnet	SAD		RT	
0-5 kG magnet	SAD	Displex/Furnace	10-1025 K	Displex/Furnace
0-14 kG magnet	POSY		RT	
0-8 kG magnet	POSY	Displex	10-300 K	Displex
Sample Changers				
10 position	SEPD, GPPD, GLAD		RT	yes
5 position	GLAD	Displex	10-300 K	Displex/Changer
7 position	SAD		RT	yes
Sample Positioners				
Single-axis orienter	SEPD, GPPD, GLAD, QENS, HRMECS, LRMECS	Displex	10-300 K	Displex
"x-y-z-ϕ" translator	GPPD		RT	yes

The Quasielastic Neutron Scattering Spectrometer (QENS) performs studies on molecular spectroscopy and diffusion. It takes advantage of good energy resolution (~70 μeV), coupled with the ability to measure energy changes as a function of momentum transfer.

The Polarized Neutron Reflectometer (POSY) has become a state-of-the-art instrument for obtaining magnetic information in thin films or near the surface of bulk materials. The very interesting basic information is coupled with some very promising applied interest, for example, magnetic hysteresis in materials for recording heads. A second reflectometer (POSY II) was commissioned in 1988 and was funded in part ($150,000) by IBM. This unpolarized version of POSY is primarily for studies of interfaces and interdiffusion in polymers, taking advantage of the large scattering contrast of hydrogen and deuterium. The Electron-Volt Spectrometer (eVS), designed to measure energy transfer to many eV, is used for momentum density measurement of hydrogen in various media and due to a recent reconfiguration, now functions as a high intensity, low-resolution diffractometer.

At the present time, five of the instruments at IPNS - Phoenix, GLAD, QENS, eVS, and POSY - are operated in a PRT mode. Members of a PRT supply financial support to build and operate the instrument in return for beam time (75%) that is distributed among the members. The remaining beam time is given to users that are not members of the PRT, based on proposals reviewed by the Program Advisory Committee.

Over two thirds of the experiments performed at IPNS involve some kind of special sample environment, e.g., low temperature, high temperature, controlled atmosphere (at high temperature), or high pressure. Table 3 shows the various ancillary equipment available at IPNS for use in the experimental program.

Booster target and cryogenic moderators

IPNS now operates three moderators, all cold; two of flowing liquid methane (90K) and one of static liquid hydrogen (20K). Deterioration of one of the liquid methane systems had been observed, which was due to the accumulation of radiolytically produced hydrogen. A palladium based separator has been installed which removes the hydrogen. Future plans include returning cold solid methane to the now-liquid-hydrogen system.

We were in the process of installing the Booster target at the time of the last ICANS meeting, in October 1988. In fact, one of the authors (JMC) left the meeting early for testing prior to final installation. The target has performed excellently since then, resulting in an increase in neutron beam line flux by a factor of 2.5, and is described in the IPNS Progress Report 1988-1990 and in another paper in these proceedings.

Remote examination of target growth

Previous experience has shown that enriched uranium disc materials can exhibit uranium crystal grain growth due to irradiation ("irradiation growth"). Neutron diffraction experiments at IPNS showed that the method used to fabricate the original IPNS <u>depleted</u> uranium discs (slicing discs from a water-cooled cylindrical mold) produced crystals with relatively small grains. Because of the small grain size and the lower neutron flux levels, irradiation growth of the discs over the predicted life of the depleted uranium target assembly was considered negligible. The process used to form the <u>enriched</u> uranium discs required slow cooling of the slab, which resulted in a larger grain size and an undesirable preferred crystal orientation. Due to the larger grain, perferred crystal orientation, and higher neutron flux levels, irradiation growth of the discs became the major factor in limiting the useful lifetime of the enriched uranium target assembly. As a result, direct measurement of disk irradiation growth within the housing over the operating life of the target assembly has become highly desirable.

A test method was developed that uses ultrasonic waves to measure target growth, the distance between two metal surfaces, i.e., the top of a uranium target disc cladding and the inner wall of the housing. A sound wave is injected into the side of the vessel that contains the target. Part of the wave penetrates the vessel wall and the water that flows around each of the uranium clad target disks. The wave reflects off the disk surface and returns to the surface of the vessel. The time delay from injection to return indicates the position and, therefore, the growth of the disks. Periodic measurements of the growth permit comparison between target swelling and model predictions. The axial-length change can also be monitored using a tang that reflects the ultrasonic beam at right angles to the initial beam path so it reflects from the target spring housing. The details of the measurement and results will be published in Journal of Testing and Evaluation (D. Bohringer, et al.).

To carry out a measurement, the transducer is lowered approximately 10 ft. through a 1-in. tube (an access port), placing it in contact with the outer wall of the housing. Movement of the target back and forth under the access port tube permits monitoring of different sections of the target. A borescope inserted into the access port tube is used to align etched markings on top of the target with the tube. The etched markings identify the location of each disc and the deflection tang. The ultrasonic transducer is suspended and lowered through the tube by a signal cable attached to the back of the transducer. A weighted collar installed over the transducer provides stability and the appropriate contact pressure when the transducer is resting on the target housing. A conventional glycerol couplant is used to couple the ultrasonic wave pulse to be transmitted through the buffer, housing wall, and water. The pulse then strikes the outer surface of the disc-cladding at normal incidence and returns to the transmitting probe by the initial path.

Numerous echoes are evident in the typical oscilloscope tracing. The first echo in the train is from the housing-outer-wall buffer interface, and the second is from the housing-inner-wall/water interface. Multiple echoes from the housing-inner-wall/water interface follow. After several reverberations in the housing wall, the interface between the disc-cladding-outer-wall and the water is seen between housing wall reverberations. Establishment of the time, t, between the first echo from the housing-inner-wall/water interface and the first echo from the top of the disc, allows separation to be established from $d = v \cdot t/2$, where v is the velocity of sound in water. Calibration and a check on this measurement is carried out with a standard of the target assembly.

The gaps between target discs and housing were dimensionally inspected before the discs were finally installed. The gap between the tang and the spring housing wall was also measured during final assembly. Measurements of disc-to-housing and axial gaps obtained with the micrometer and those obtained by ultrasonic testing after final assembly are within the expected cumulative errors of micrometer measurement.

The most recent ultrasonic examination of the target pucks was carried out on July 5, 1990. Absolute estimates of gaps were on the order of 90-115 mils (1 mil = .001 in. = .0254 mm) except for puck 2 which showed an anomalous result of 128 mils for the gap. In all cases except puck 2, the results are consistent with the initial gap measurements made on these pucks in October 1988 and the changes measured since. Total gap reductions (1988-1990) of 3-7 mils with an uncertainty of ±4 mils were observed. Average behavior is shown in Fig. 4. A clear ultrasonic signal was obtained from the reflector designed to measure axial growth. In this case the total reduction in gap (1988-1990) is about 30 mils (out of about 750 mils) with an uncertainty in change for this test of about ±9 mils.

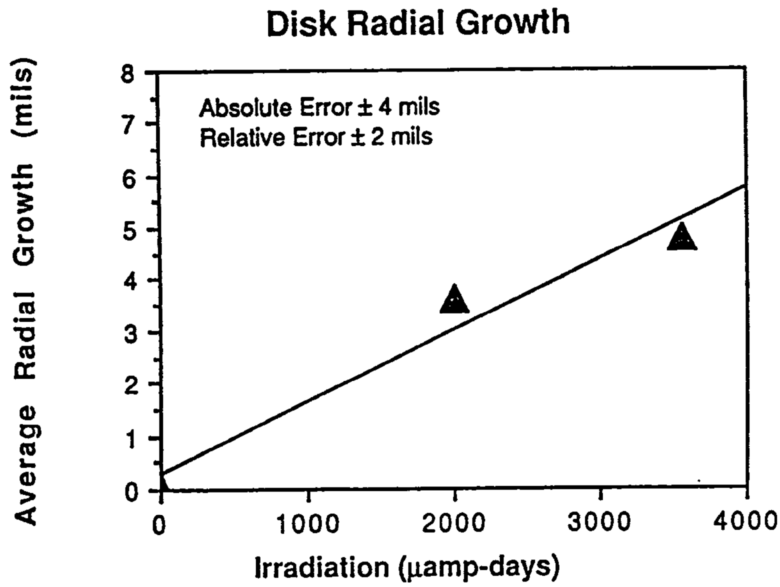

Fig. 4 Average radial growth of enriched uranium disks from October, 1988, to July, 1990.

The measurements are significant for two reasons:

1. A relatively sophisticated ultrasonic technique has been applied to a very important problem under severe test conditions. The test was performed through shielding from a distance of 3 m, on a very radioactive target (>100,000 R/hr. at the vessel surface), under corrosive conditions and requiring accurate and reproducible positioning.

2. In order to receive permission from the DOE to operate on the enriched target, very conservative estimates of growth were made, resulting in a predicted lifetime of approximately 3 years. The measurements confirm more realistic estimates of a growth rate that is less than half of the conservative estimate. The confirmation of the lower growth rate should result in installation of a new target, costing ~$1M, being delayed--for an annual savings of $300K.

Data acquisition

Introduction

Since the 1988 ICANS-X Meeting, we have continued to make improvements to the data acquisition system (DAS). Improvements to the existing system include replacement of the VAX-11/780 computer by a cluster of faster computers, conversion of additional front end computers from PDP-11's to VAXstations, installation of a 125 GB juke box library for 8 mm helical scan tape cartridges, improvement of our high-level graphics routines for the GKS graphics system, and installation of TCP/IP networking software to give increased access for our outside users.

The PDP-11 computers used for control of the data acquisition process and the VAX-11/780 used for data analysis were based on the Unibus which is no longer produced by DEC. Communication with the microprocessors controlling the actual data acquisition was originally through a Unibus controller. As these systems were replaced by Qbus PDP-11's and VAXstations, we used a Qbus to Unibus converter so we could continue to use the same communications controllers. The communications board which we had been using has now gone out of production and there have been changes in the VMS software which have caused problems with the Unibus to Qbus conversion. Because of this we have converted our software to work with another controller board which goes directly on the Qbus.

We are gradually replacing the PDP-11 computers with VAXstations. We currently have VAXstations as front end computers on the Glass, Liquid, and Amorphous Material Diffractometer (GLAD), the Neutron Reflectometer (POSY II), and the Small Angle Diffractometer (SAD). We are in the process of installing VAXstations on the High-Resolution Medium-Energy Chopper Spectrometer (HRMECS), the other neutron reflectometer (POSY), the Single-Crystal Diffractometer (SCD), and the General Purpose Powder Diffractometer (GPPD). Replacement of the remaining PDP computers with VAXstations is expected to continue, but there may need to be additional changes in our communications with the DAS microprocessors since it appears that future DEC VAXstations will not include the Qbus, but will be busless systems. VAXstations are also being used to increase the data analysis capacity at IPNS.

Data analysis computers

The VAX-11/780 computer originally purchased for analysis of IPNS data has been replaced with a cluster of two microVAX 3500 computers and one VAXserver 3400 computer. In addition, we currently are using the GLAD2 VAXstation 3520 computer for data analysis in the IPNS computer cluster, and the GPPD VAXstation II/GPX computer is being used for analysis of powder diffraction data. A microVAX 3100 will soon replace the GPPD VAXstation for data analysis and the GPPD VAXstation will be put into service for instrument control.

The replacement of the VAX-11/780 has resulted in an increase by a factor of eight in the processing speed available for data analysis. It has also given us improved reliability since the two microVAX computers are connected in a dual-host arrangement with the system disk and one user disk on a Digital Small Systems Interconnect (DSSI) so that either system can access files on these disks when the other microVAX is shut down. Currently access to one of the disks will be lost when it is necessary to shut off power to the microVAX housing that disk in order to replace interface boards, etc. This problem will soon be solved when the disks are moved to a separate cabinet. We will also add an additional DSSI disk and reorganize files to keep critical files on the DSSI disks. We still lose access to disks directly connected to one computer when that system is shut down and expect to convert additional disk space to dual-host access as the budget allows.

Use of VAXstations

All of the initial eight IPNS instrument computer systems were based on DEC PDP-11 computers. These computers are difficult to program because of memory size limitations and give us the burden of supporting an additional operating system. Several IPNS instruments also need greater on-line computing capabilities and disk storage capacity than is available on the PDP-11 systems.

Finally, the PDP-11 systems are starting to show their age (the oldest have been in continuous operation for more than 9 years) and their failure rate is increasing. For these reasons, we have begun purchasing VAXstations to replace the PDP-11 computers. We currently have four DEC VAXstation-II GPX workstations, each with at least 300 Mbytes of disk storage, one VAXstation 3200, and one VAXstation 3520. Another VAXstation 3200 is on order. The VAXstations procured as instrument computers initially were used very successfully for data analysis. Now they are being used as instrument computers and additional microVAX and VAXserver computers have been bought for data analysis. The addition of the VAXstations has not only improved the instrument computer situation, but has also increased the total computing capacity available for data analysis since the VAXstation instrument computers place significant computing capacity at each instrument. It is expected that in the future more data analysis will be done directly at the instrument as the data are being collected, rather than on one of the central computers in the system. Our central VAX systems will continue to be used by the VAXstations for data storage and archiving as well as program development and network services.

Graphics improvements

A package of high-level graphics routines (GPLOT) for use with the GKS graphics package has been developed at IPNS. This was originally developed to provide greater access to graphics capabilities at IPNS since we did not have the budget for the expensive commercial graphics package (DISSPLA) used on the VAX-11/780 to be put on all the workstations. There also was a need for a lower cost graphics package for use by IPNS users who did not have and could not afford DISSPLA. Most of our graphics routines have now been converted to utilize GKS graphics, which is available on all of our computers. The use of GKS has allowed us to develop device-independent graphics software that can be run on the VAXstation as well as our other graphics devices. The VAXstations produce high resolution color graphics very quickly, which allows users to interact effectively with data collection and data analysis. This will also enable more interactive modes of data analysis.

One of the limitations which prevented us from using GKS for all of graphics was the lack of a 3-dimensional plotting capability. This has now been added to our GPLOT package, so we expect to continue conversion to the use of GKS, which will result in a large cost saving to both IPNS and our users.

Other improvements to GPLOT include an improved user interface with data-driven menu routines for plot device selection at run time. This will greatly simplify the installation and customization of GPLOT, and will allow individual users to create their own device menus. We have also added a plot routine which allows the user to interactively add text and vectors to the plot and to label data points. This routine also provides a continuous display of the cursor position in data coordinates on the VAXstation.

Improvements have also been made in graphics hardware. Postscript laser printers are now available in several locations, and we have added additional graphics terminals and a color ink-jet plotter.

Networking and clustering

A number of improvements have been made in the Argonne lab-wide Ethernet and more improvements are in progress. All VAX computers at the lab are now on the Ethernet and many IBM-compatible and Macintosh personal computers are now connected via Ethernet. ANL has added a Cisco router which handles both DECnet and TCP-IP network traffic, and has purchased a site-wide license for Multinet software to provide TCP-IP capability on ANL VAX computers. We have installed Multinet software on our two microVAX 3500 computers and will add it to other computers as the need arises.

As our computer needs grew it was necessary to add a number of disk drives for users and to add additional processing power. The most cost-effective way to do this was to add MicroVAX and VAXstation computers. To simplify access and connection speed among our computer systems and many disks, it was necessary to join them together in a cluster. This has made it simpler to manage the computer systems and more efficient to store files centrally without the necessity of keeping multiple copies of files. Some of the new instruments which are now on-line have strained our computing and data storage capacity, and demand also increased with the Booster target, so a considerable expansion of the cluster has been necessary. The expansion of the cluster is expected to continue.

IPNS has now added a number of IBM-compatible personal computers and Macintosh personal computers. The IBM-compatible PC's have been networked with the VAX computers using DEC PCSA (Personal Computer Systems Architecture)/Lanworks for DOS networking software. This has improved printer sharing and will be used to improve file sharing for PC's and security of files. One of our Macintosh computers has been connected to the Ethernet and we expect to add Lanworks for Macintosh in the near future.

Future improvements to the Lab-wide network include additional connections to outside networks and the installation of a high speed (100 Mb/s) FDDI (Fiber Distributed Data Interface) fiber optic network. ANL has already installed FDDI cable between some buildings and has plans for expansion of FDDI capability. We expect to improve networked graphics through the use of X-Window terminals and will begin experimenting with this technology shortly.

Data backup, archiving, and retrieval

The large amount of data and other files on disk has required several improvements to our system for backup and archiving of data. The problem of disk back-up to tape has been solved by the use of high capacity helical scan cartridge tapes. The first drives of this type used standard VHS video tapes for backup and each cartridge could hold 2.5 GBytes compared to 0.14 GBytes on a high density 9-Track tape. This allowed us to back up two or three large disks on one tape cartridge instead of using several tapes to back up each disk. This gave us a considerable saving in operator time for changing tapes, cost of media, and storage space required.

The next generation of helical scan drives used 8 mm video tape cartridges which hold 2.2 GBytes each. These cartridges are several times more compact than the VHS cartridges and the cost of drives is lower than for the VHS units. These have been widely accepted in the industry and are starting to be used for data interchange. As we have converted to the use of VAXstations we have also put large disk drives on the front-end computers. Backup of these large disks to TK50 cartridge drives which hold 0.1 GByte proved to be unfeasible, and 8mm drives have been added to all VAXstations as well as computers used for data analysis.

Because of the cheaper and more compact storage, we are able to do weekly full backups of cluster disks and keep monthly full backup tapes permanently, instead of re-using the tapes after one year.

Another problem is the archiving of data to tape in order to keep sufficient space available on the disks. We have been using file expiration to select files for automatic removal from the disks and have used 9-Track tape to save these files. The problem with this method is that operator intervention is required to mount tapes whenever files need to be restored to disk.

We have recently purchased a juke box library system which holds 54 8mm data cartridges which can be mounted in one of two tape drives through remote commands. We have converted most of our archived files to 8 mm cartridges and have developed software for backup, archiving, and file restoration using the jukebox. This will eliminate the need for operator intervention for mounting tapes.

Current needs and future plans

IPNS has a need to continue upgrading and improving its computer systems and software. Developments in technology are very rapid in some areas and IPNS has formed a committee of users to recommend improvements to computing at IPNS. Two areas identified by this committee as primary concerns are improved interactive graphics capabilities using personal computers or workstations, and improved document production capabilities using a true What You See Is What You Get (WYSIWYG) software/hardware package. We are examining various commercial software packages in these areas for use on a Macintosh or IBM-compatible personal computer. We also plan to investigate the use of X-Windows terminals for achieving these capabilities on a shared system.

User program

Figure 5 shows that the number of requested and available days dropped off somewhat in 1985 and has been steady since that time. This is due to the decrease in operating funds which has resulted in fewer weeks of operation. This has been partially compensated by the installation of the Booster target and increase in average proton current, meaning fewer days are required per experiment.

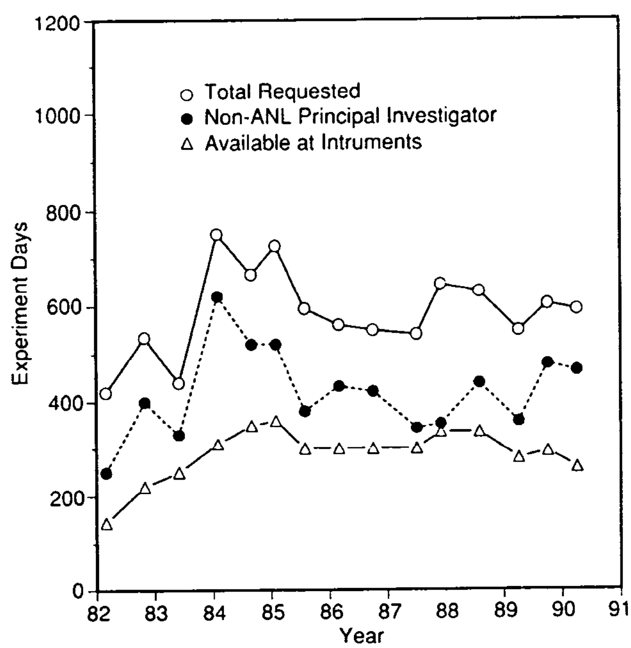

Fig. 5 IPNS statistics since 1982.

With the availability of significant fluxes of long wavelength neutrons, the Small Angle Diffractometer (SAD) has become a highly versatile and attractive instrument for research in many areas, viz., biology, metallurgy, and polymer science. This has resulted in making the SAD one of the most oversubscribed instruments for the past 4 run cycles. To alleviate this oversubscription on the SAD, a proposal to build a second SAD was developed and recently funded by the DOE; construction is underway, and the goal is to complete the instrument in collaboration with S.-H. Chen of the Massachusetts Institute of Technology by mid-1991.

The breakdown of statistics on visitors and their experiments is shown for the first 8 (fiscal) years of operation. Due to funding restrictions, the total weeks of IPNS operation decreased after fiscal year 1984 (FY84). However, since operation before FY85 included the now-defunct Radiation Effects Facility, the number of weeks for neutron scattering has been nearly constant. In addition, with the installation of the Booster target and increases in proton current and the number of instruments, the number of experiments continues to grow.

Table 4 IPNS user program statistics for FY82-FY89*.

	FY82	FY83	FY84	FY85	FY86	FY87	FY88	FY89
Experiments performed	94	110	210	180	212	223	257	323
Visitors to IPNS for at least one experiment:								
Argonne	37	41	49	44	52	55	57	60
Other government laboratories	8	9	8	7	11	15	18	16
Universities	27	33	45	51	79	78	89	94
Industry	5	5	9	7	13	24	20	24
Foreign	12	18	39	35	27	24	17	26
	89	106	150	143	182	196	201	220
User Instruments	4	5	6	6	6	6	6	7
PRT Instruments	1	1	1	2	3	3	4	4
PRT Instruments	1	1	1	2	3	3	4	4

*Fiscal Year (e.g., FY89 = October 1, 1988 to September 30, 1989, inclusive).

Recent conferences and workshops

We continue our strong commitment to sponsor conferences and workshops in connection with our efforts to spread the news about neutrons in general, and the capabilities of IPNS in particular. Financial and technical assistance from both the University of Chicago and Argonne's Division of Educational Programs is greatly acknowledged.

October 24-26, 1988
Workshop on Momentum Distributions

November 14-15, 1988
Fourth IPNS User Meeting

November 16-18, 1988
Short Course in Powder Diffraction and Rietveld Analysis

June 14-15, 1989
Neutron Scattering in Molecular Sieve Research

April 16-17, 1990
Workshop on Glass and Liquid Diffraction

May 22-23, 1990
Application of Neutron Diffraction to the Determination of Residual Stress in Engineering Materials

August 23-25, 1990
Workshop on Neutron Reflection Data Analysis

Pulsed Neutron Research Facility (PNRF)

The need for more intense neutron sources has been the subject of numerous meetings and reports. The most thorough workshop took place at Shelter Island, New York, in October 1984. The major findings of the workshop were:

1. The case for a new higher flux neutron source is extremely strong, and such a facility will lead to qualitatively new advances in condensed matter science.

2. To a large extent, the future needs of the scientific community could be met with either a $5 \times 10^{15} n\text{-}cm^{-2}\text{-}s^{-1}$ steady state source or a $10^{17} n\text{-}cm^{-2}\text{-}s^{-1}$ peak flux spallation source.

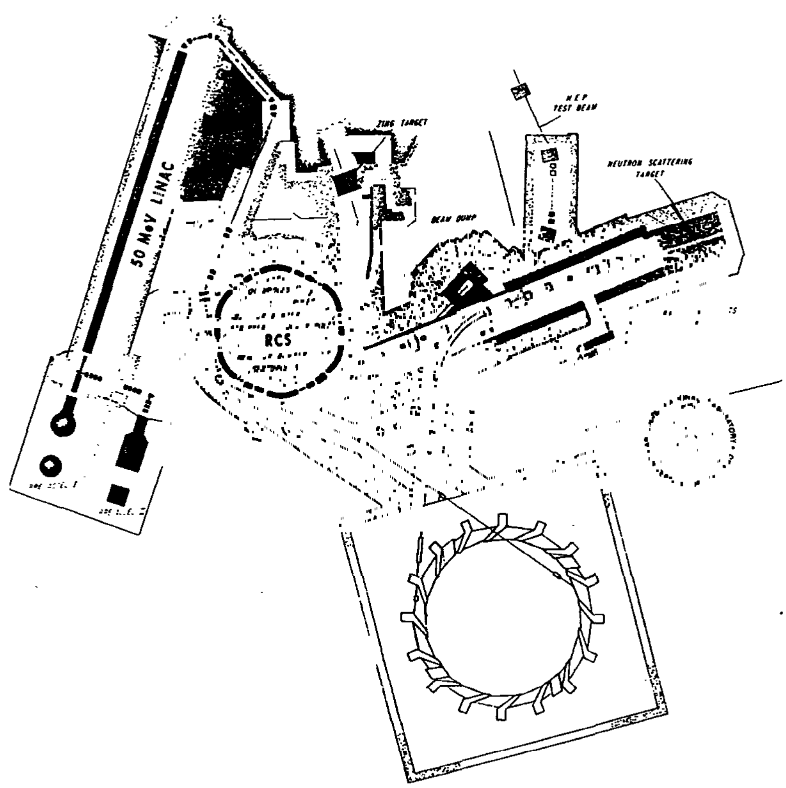

Fig. 6 Pulsed Neutron Research Facility.

Accelerator-based pulsed neutron sources have been performing neutron scattering research for just over ten years. During this decade, beam intensities have increased by a factor of 100, and there are now more than 50 spectrometers operating worldwide. The pulsed neutron sources have proved to be highly effective and are complementary to reactor-based sources in that there are important scientific areas for which each type of source has unique capabilities. We have proposed to the DOE that the capabilities of pulsed neutron sources be further pursued by means of a Fixed-Field Alternating-Gradient synchrotron concept. The program in this proposal will do the conceptual research and development for the accelerator and target systems that will produce 100-200 μA at 500-1000 MeV. Much of the present IPNS system will be incorporated in the design as shown in Figure 6. The accelerator, named Pulsed Neutron Research Facility (PNRF), will be a source comparable to the most powerful pulsed sources now operating in the world and also will act as a test bed for the basic Fixed Field Alternating-Gradient synchrotron concept for more powerful sources in the future. A preliminary conceptual design was developed in 1984 for a 100 μA, 500 MeV machine. Details of this proposal appear in the Proceeding of the Enrico Fermi Summer School on Industrial and Technological Applications of Neutrons; Lerici, Italy, June 19-29, 1990.

Acknowledgements

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Q(A.D.Taylor): Is your quoted thermal flux of 10^{14} n^{th} cm^{-2} mA^{-1} consistent with estimates that a 5mA SNQ would be equivalent to ILL?

A(G.S.Bauer): Yes, it is. SNQ had twice the proton energy (effectively, because of the 120MeV threshold) compared to SINQ and five times the current, which reach to somewhere around 10^{15} $cm^{-2}sec^{-1}$. Of course, the fine structure would have mach SNQ superior to the ILL-reactor by an order of magnitude or more with proper instrumentation.

Q(N.Watanabe): What are the major reasons for large difference in estimated target life compared to that of ISIS?

A(B.S.Brown): The ISIS target lifetime is determined by cladding fatigue and our by growth. The reason for the difference is in the details of target design, beam intensities, U-235 vs U-238, etc.

Q(?): Why are ISIS and IPNS target lifetime so much different?

A(J.M.Carpenter): The differences depend on details of stress distribution in the cladding. The disk designs differ substantially, so the comparison is difficult to make. Furthermore, the failure mode is in fatigue; fatigue life is a very strong inverse function of stress.

Q(Y.Endoh): I would like to ask your comment on the anisotropic growth of booster target because you showed only one direction data.

A(B.S.Brown): After 2 years of operation, the average radial disk growth was .127mm and the axial growth for the stack of 11 disks was .762mm.

Q(N.Watanabé): How can you measure the radial growing of U-235 target disk?

A(B.S.Brown): The growth is measure by an ultrasonic technique that measures the time for a signal to reflect off the outer surface of the disk.

Q(A.D.Taylor): Would you retain a ^{235}U booster target with the 100μA accelerator concept?

A(B.S.Brown): The present 80% enrichment would be very difficult at 100μA. Options include lower enrichment, 2 target stations with a booster target for low frequency operation, or a return to ^{238}U.