

## **IPNS UPGRADE-A 1 MW SPALLATION NEUTRON SOURCE**

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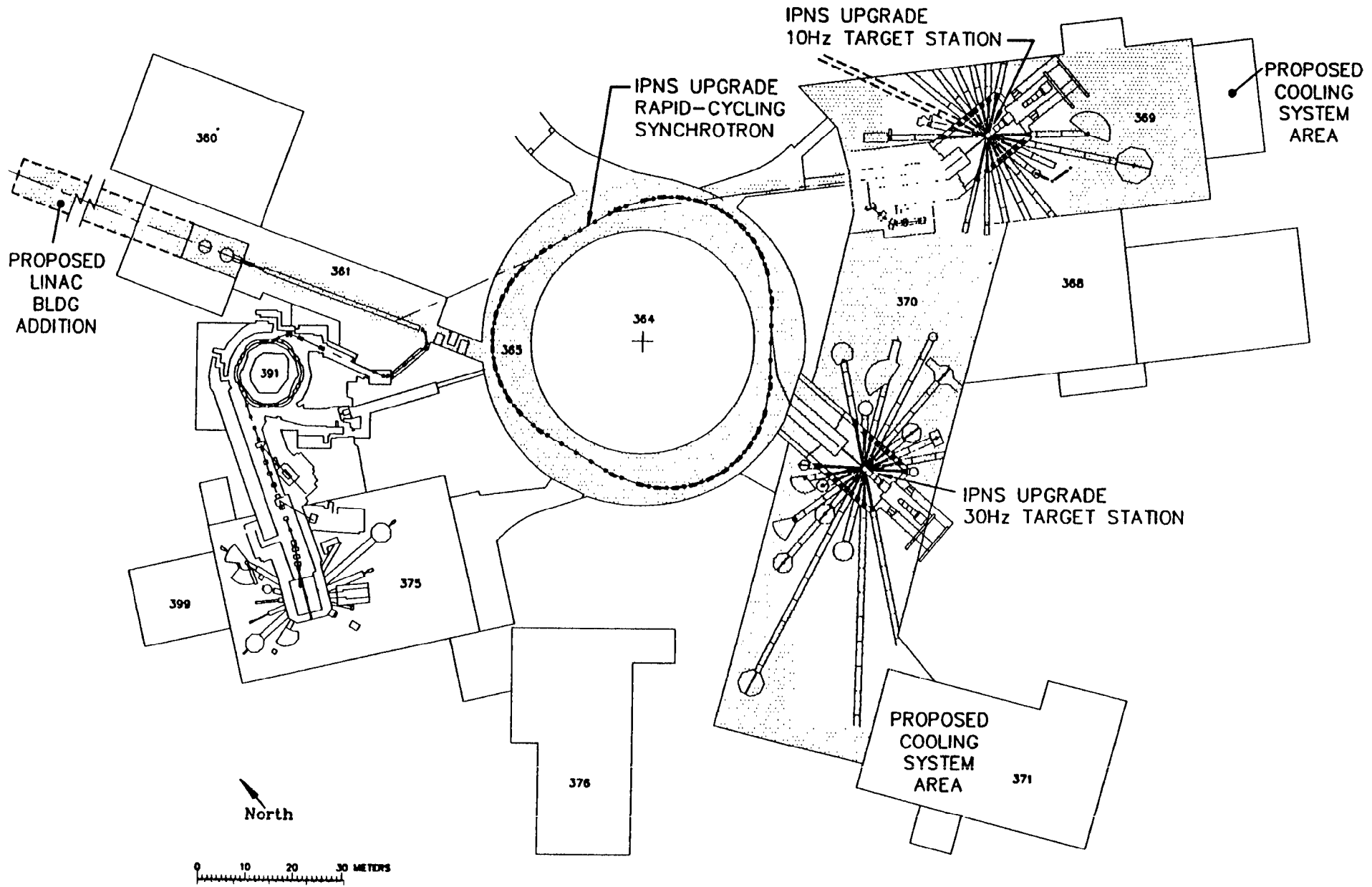
A feasibility study of a new 1 MW pulsed neutron source, the Intense Pulsed Neutron Source (IPNS) Upgrade, has recently been completed. The source will consist of a 400 MeV Linac injecting 500 microamps of protons into a Rapid Cycling Synchrotron, which accelerates to a final energy of 2.2 GeV. The beam will be delivered to two target stations at 10 and 30 Hz. Six moderators (water, liquid hydrogen or liquid methane) provide 18 beamlines from each target. Radiation effects facilities and neutron activation capabilities will be available. The use of existing buildings will result in a savings of more than \$100M. The preliminary results of this study are discussed in this paper, and covered in further detail in 6 other papers at this ICANS meeting.

### **Introduction**

Accelerator based pulsed neutron sources have been performing neutron scattering research for over ten years. During this time, beam intensities have increased by a factor of 100 and there are now more than 50 spectrometers operating world-wide. The pulsed neutron sources have proven 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. The need for more intense neutron sources has been the subject of many meetings and reports. Major workshops took place at Shelter Island, NY, in October, 1984; Abingdon, UK, in February 1992; Oak Brook, IL, in September, 1992; and Argonne National Laboratory in May, 1993. The conclusion of the workshops is that 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. It was also concluded that there are unique scientific opportunities at both the next generation reactor and next generation spallation neutron sources as well as a broad middle ground where both are able to make significant contributions. A conceptual design for the Advanced Neutron Source (ANS) has recently been completed which will result in the most powerful steady state neutron source in the world. The complementary nature of pulsed and steady state neutron sources argues strongly for also developing advanced pulsed source capabilities. This was one of the major recommendations of the BESAC Panel on Neutron Sources (1992) chaired by W. Kohn.

The potential for significant increases in the near future in neutron scattering capabilities at accelerator-based spallation neutron sources is great. The IPNS Upgrade would represent a factor of 6 gain over the present level of ISIS (UK), the world's most powerful spallation neutron source, which has operated since 1985. A source with an increase by another factor of 5 is being proposed for the European Spallation Source (ESS). In addition, there is significant potential for future enhancements in advanced spallation sources since there are no fundamental limitations for even further improvements in the technology.

Argonne is proposing that the capabilities of pulsed neutron sources be further pursued by means of an advanced spallation source that will produce 500  $\mu\text{A}$  at 2.2 GeV (a nominal beam power of 1 MW). Some of the present IPNS system and facilities will be incorporated in the design. The new neutron source, named the IPNS Upgrade, will be the most powerful pulsed source in the world and also act as a test bed for concepts for more intense sources in the future. This facility (shown in figure 1) represents the next advance in spallation neutron sources and can be accomplished soon with modest extensions of existing technology.



The IPNS Upgrade would require approximately 4 years from the design decision to completion and would be site specific and use existing Argonne infrastructure (buildings, water and electrical systems, shielding, etc.) which will result in a cost savings of more than \$100M. The total project cost is estimated to be less than \$500M assuming that the project is initiated in FY 1996. Capabilities are included for 36 neutron scattering beam ports, radiation effects facilities in both targets, rabbit tube irradiation and activation facilities; and other capabilities are being considered. As part of the design process, joint workshops were held with Los Alamos on Accelerators for Future Spallation Neutron Sources in Santa Fe on Feb. 16-20 and on Scientific Opportunities at Future Spallation Neutron Sources at Argonne on May 13-16, 1993.

Feasibility studies have begun on the various components of the IPNS Upgrade. These studies, including cost estimates, are directed by:

Accelerator systems-Y. Cho  
Targets and moderators-J. Carpenter, A. Knox  
Instrumentation-K. Crawford

Table 1 summarizes the design specifications for the IPNS Upgrade. The major subsystems are discussed briefly in the following sections. Additional details of the IPNS Upgrade are given in papers presented at this ICANS meeting on:

- **Neutronic Studies for a High Power Pulsed Spallation Neutron Source**
- **Conceptual Design of the Target Station the IPNS Upgrade**
- **Proposed Instrument Complement for the IPNS Upgrade**
- **Conceptual Design of the Accelerator System for a 1 MW Spallation Source at ANL**
- **RF System for the IPNS Upgrade Rapid Cycling Synchrotron**
- **Study of 1 MW Neutron Source Synchrotron Dual Frequency Power Circuit for the Main Ring Magnets**

## **Neutron Scattering Instrumentation**

The decision on the repetition frequency of the accelerator was based on the optimal frequency for the neutron scattering instruments. A survey of opportunities and an evaluation of preliminary designs for neutron scattering instruments for a 1 MW pulsed source led to a table of the various requirements that they place on the neutron source, which have fundamentally affected the definition of the project. A repetition frequency of 30 Hz was found to be clearly preferable to 60 Hz.

Two roughly equally populated categories of instruments emerged from the study of scattering instruments, those for which 30-Hz pulsing (but not much higher) is satisfactory, and those which require lower frequency of pulsing and for which 10 Hz is satisfactory. Serving these two categories of instruments led to the requirement of two separate targets. The total number of instruments and correspondingly the number of neutron beams and, in addition, the number of differently optimized moderators needed exceed the number that can be arranged around a single shielded target station; and this also spells the need for two target stations to provide for the required number of moderators and beams. Therefore the accelerator delivers one out of three pulses to a low frequency station at 10 Hz, the high frequency station normally receiving the remainder of the 30-Hz pulse train in iambic pattern.

**Table 1 --IPNS Upgrade Parameters**

**Accelerator**

<b>Linac Energy</b>	<b>400 MeV</b>
<b>Synchrotron Energy</b>	<b>2.2 GeV</b>
<b>Pulsing Frequency</b>	<b>30 Hz</b>
<b>Current</b>	<b>500 <math>\mu</math>A</b>
<b>Extraction</b>	<b>Single turn extraction, 300 nanosec pulses</b>

**Target Stations**

<b>Operating frequency</b>	<b>One at 10 Hz One at 30 Hz (with every third pulse missing)</b>
<b>Target Material</b>	<b>Tantalum</b>
<b>Target Cooling</b>	<b>Water</b>
<b>Moderators</b>	<b>6 at each target Liquid water, methane and hydrogen plus water premoderators</b>

**Instrumentation**

<b>Beam ports</b>	<b>18 on each target station, 36 total</b>
<b>Neutron scattering instruments</b>	<b>Initial complement of 27</b>
<b>Other capabilities</b>	<b>Radiation effects Neutron activation</b>
<b>Capabilities under consideration</b>	<b>Muon spin rotation Neutrino studies Isotope production</b>

The IPNS Upgrade will provide 36 beam ports for neutron scattering instruments, 18 each at the 30-Hz and 10-Hz target stations. Neutron beams for more than one instrument will be extracted from a single beam port in some cases, so more than 36 neutron scattering instruments can be supported at this facility. There will be a total of 12 moderators, one for every three beam ports, so the moderator characteristics can be optimized to the requirements of the individual instruments. A representative set of 27 instruments that would occupy 24 of the beam ports and would provide a well-balanced initial instrumentation complement is given in the accompanying ICANS paper, **Proposed Instrument Complement for the IPNS Upgrade**. The remaining 12 uninstrumented beam ports will be available for later development and installation of new state-of-the-art instruments, as well as for the installation of specialized instruments developed by Participating Research Teams (PRT's). This representative set of instruments has been used in selection of the target station parameters, in laying out the locations of the target stations within the experimental halls, and

in providing the cost estimates. This is certainly not the exact set of instruments that will be built, and considerably more input from the user community will be solicited before deciding on the actual instrument complement to be included as part of the project. It is anticipated that up to 10 instruments that are currently operating at IPNS would be refurbished and transferred to the IPNS Upgrade as part of this initial instrument complement. This will provide a core of proven instruments ready for operation on day one. The neutron scattering instruments will be located in existing experimental halls, which can provide internal space for beamlines up to 50 m long (see figure 2). Beamlines can easily be extended outside the buildings if necessary, since much of the external space is parking lots.

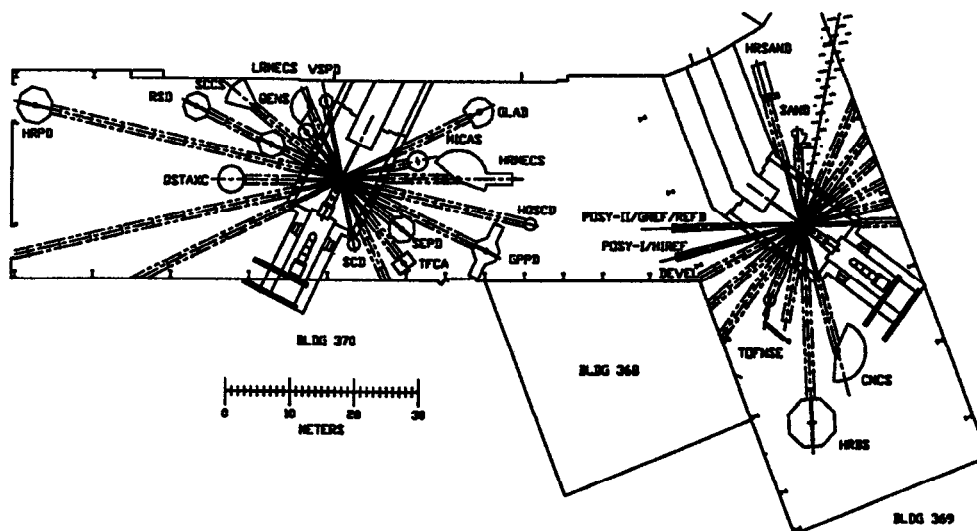


Figure 2. Location of the reference set of instruments on the neutron beamlines.

Most of the neutron scattering instruments will use the neutron time-of-flight (TOF) principle for determination of neutron wavelengths. Of these, the majority require good wavelength resolution, and for such instruments the IPNS Upgrade target stations will provide roughly 50 times the intensity available at IPNS. However, for those instruments which do not require good wavelength resolution, for example small-angle-scattering instruments, the moderators can be optimized to provide roughly 200 times the intensity available at IPNS.

However, the IPNS Upgrade will be sufficiently intense that it will no longer be necessary that all instruments be based on TOF techniques. With moderators optimized for total neutron output rather than for sharp neutron pulse structure, time-averaged thermal or cold neutron fluxes will be equivalent to those at a medium flux reactor. (A cold neutron flux of  $5 \times 10^{13}$  n/cm<sup>2</sup>/s has been calculated for one of the liquid hydrogen moderators at the IPNS Upgrade.) Thus, any instrument that would work at a medium-flux reactor can be made to work at least as well at the IPNS Upgrade. Furthermore, even a moderator optimized for high time-averaged flux will have a pulse width of less than one millisecond, and so will have a duty factor of 1:30 or less. This time structure can be used to significant advantage even on nominally steady-state instruments to reduce background, eliminate unwanted orders from crystal monochromators, etc. A cold-neutron triple-axis spectrometer operating in this "quasi-steady-state" (QSS) mode is proposed as one of the initial complement of the IPNS Upgrade instruments, and several other types of QSS instruments are under consideration which might have unique advantages for particular types of experiments.

Although the primary function of the IPNS Upgrade is neutron scattering, the facility can provide many other types of capabilities as well. Some of these, such as neutron

radiography, could utilize one or more of the neutron beam ports. Although no such use is included among the instrumentation for the first 24 beam ports, the feasibility study will discuss several potential uses of this type.

The IPNS Upgrade is well suited to the performance of neutron irradiations for radiation damage studies, isotope production, and neutron activation analysis. Facilities for these purposes are included as part of the IPNS Upgrade project. Space is available for other experimental facilities not included in the scope of the project, such as pulsed muon spin rotation, nuclear physics, neutrino physics and medical isotope production.

## Accelerator

In September 1991, there was a gathering of accelerator builders, neutron generating target builders and neutron source users-near Jülich, Germany organized by KFA-Jülich and Rutherford-Appleton Laboratory, UK to discuss the next generation European neutron source. Concepts for the 5-MW European Spallation Source (ESS) were formulated in this meeting. Within several months of the initial meeting, there were three accelerator meetings, a target workshop and a meeting on scientific utilization of the proposed ESS.

In parallel to these activities in Europe, IPNS and Advanced Photon Source (APS) personnel at Argonne have been reviewing design studies that had been developed during the 1980's relating to accelerator based sources along with other state-of-the-art accelerator and target capabilities. Specific items reviewed by this study group were:

1. What is the optimum beam power of the accelerator system?

A design goal of 1 MW was chosen for a detailed study. The most powerful spallation source available today is ISIS at Rutherford-Appleton Laboratory, UK, operating at 800 MeV and 0.2 mA, giving 160 kW of beam power. The design goal of 1 MW is about 6 times the power of ISIS, and 5 MW is 30 times. Extending accelerator capability by a factor of 6 is a reasonable approach with minimal risk in attaining the performance goals.

2. What is the best machine energy to provide 1 MW of beam power? Should the machine configuration consist of a high energy linac and a pulse compressor or should it consist of a lower energy linac and a circular accelerator which raises the beam energy and at the same time compresses the pulse length?

The decision was made to inject into a circular machine at the lowest possible energy and to accelerate to the highest possible energy. The considerations were based on future operational ease and the possible impact of beam loss during the capture, acceleration and extraction of the protons from a circular machine. It is generally accepted that the most significant beam losses occur during the injection and capture processes, and there is very little loss during the acceleration and extraction processes. Beam loss can cause not only radiation around the facility but also can produce residual radioactivities along the machine. If beam loss is unavoidable, then the preference would be losses at lower energy than higher energy because remedial action at lower energy loss is easier than that at high energy.

3. Could the former Argonne Zero Gradient Synchrotron (ZGS, a machine used for high energy physics operating at 12 GeV) infrastructure be used to save construction costs? If so, what would be the energy of the machine comfortably fitting into the structure?

The ZGS was decommissioned in 1980 and the complex has some 500 thousand square feet of building space, with a replacement value of more than \$100M. The ZGS tunnel can house a 1 MW, 2.2 GeV rapid-cycling synchrotron comfortably. In order to achieve the required 1

MW of beam power, the machine has to deliver a time-averaged current of 0.5 mA. Space charge limits in a circular machine dictate that the injection energy of the machine should be about 400 MeV. The result of these considerations is that the accelerator system consists of a 400 MeV linac operating at 30 Hz and providing a pulse current of 33 mA and pulse width of 0.5 msec and a 30 Hz rapid-cycling synchrotron.

It is important to note that the \$100M savings could also be realized utilizing the high energy linac-storage ring concept. The former ZGS buildings can accommodate either design, and the present choice for a lower energy linac-synchrotron is based on technical considerations, and not the necessity to build around an existing accelerator. All of the accelerator components in the IPNS Upgrade will be new and state-of-the-art.

Various concepts developed so far will be optimized further to meet the proposed performance goals with emphasis on reliable operations. The accelerator system consists of:

- Negative Hydrogen Ion Source
- A 2-MeV radio-frequency Quadrupole
- Beam Chopper
- 70 MeV Drift Tube Linac
- Matching Section
- Coupled Cavity Linac (70 MeV-400 MeV)
- Low Energy Transfer Line
- 30 Hz Synchrotron (400 MeV to 2.2 GeV)
- Single turn extraction with 300 nanosec pulses
- High Energy Transfer Lines.

Studies will include both theoretical analyses as well as some prototyping of the hardware. The following is a list of studies being proposed:

- Lattice Optimization
- Injection and Capture
- H<sup>-</sup> ion source
- Acceleration
- Beam Stability
- Physics Design of Magnets
- Ring Magnet Power Supplies
- Radio-frequency Acceleration System
- Vacuum System
- Injector Linac

For further information, see the accompanying ICANS papers:

- **Conceptual Design of the Accelerator System for a 1 MW Spallation Source at ANL**
- **RF System for the IPNS Upgrade Rapid Cycling Synchrotron**
- **Study of 1 MW Neutron Source Synchrotron Dual Frequency Power Circuit for the Main Ring Magnets**

## **Target Stations**

Shielded proton beam transport lines carry two extracted proton beams to the two target stations, where the protons are injected horizontally into the targets. Each station contains a neutron-producing target consisting of water-cooled tantalum plates in two sections. The proton beam power of 1 MW incident on the IPNS Upgrade target will be 6 times that presently incident on the ISIS target. Although it is determined in the feasibility study that no radically new target concepts are necessary, such as rotating or liquid targets, significant

R&D will be necessary. Areas include neutronics, metallurgical studies and tests, thermohydraulics, safety, shielding and target monitoring.

Six differently-optimized moderators positioned close to each target slow down neutrons from the primary source energies (about 1 MeV) to useful energies (less than about 10 eV). Moderators, all flowing systems, will be of normal water, liquid methane and liquid hydrogen. Reflectors of beryllium metal surround the moderators to enhance the intensities of the neutron beams. Decouplers and heterogeneous poisons within the moderator-reflector system tailor the spectra and pulse characteristics to the neutron beams. Each moderator provides three slow neutron beams, for a total of 18 beams for each target station. Massive steel and concrete shields surround the targets and moderators and provide multiple levels of confinement of radioactive materials within. Beam holes equipped with movable gates lead the neutrons to the instruments. R&D areas are neutronics, hydrocarbon production, cryogenic systems and control, safety, and changing of moderator components.

Targets and moderators will have finite service lifetimes in the proposed facility. Furthermore, it can be expected that it will be necessary to change the moderator-poisoning-decoupling-reflector arrangements from time to time as changing instrument requirements demand. To enable changes to be made with minimal impact on operations and minimal radiation exposure to personnel, each target station has a shielded hot cell with high density windows, manipulators and associated remote handling equipment.

For further information, see the accompanying ICANS papers:

- **Neutronic Studies for a High Power Pulsed Spallation Neutron Source**
- **Conceptual Design of the Target Station the IPNS Upgrade**

## **Conventional Facilities, Cost and Schedule**

A newly constructed extension of the existing linac enclosure will house the new linac. The synchrotron will be in the existing shield formerly used to house the 12-GeV ZGS accelerator. The targets and instruments are located in existing large buildings that formerly housed high energy experiments at ZGS, a use very similar to the new use. System control rooms, maintenance facilities, and laboratory and office space for resident personnel and for visitors will be provided in existing buildings. Water systems, cooling towers, main power and transformer systems, roads, sewers, and general infrastructure items already exist, which the new project will employ. Thus there will little need for new construction of conventional facilities, and this will result in a savings in construction time and cost of more than \$100M. The project contains an allowance for the cost of refurbishing these existing facilities.

Construction of the new components and refurbishment of the existing parts will not interfere with IPNS operation until the very end. Then, an interval about one year's duration will be required for installing the new linear accelerator and for reworking the scattering instruments that are to be transferred and installing them in their new locations. A commissioning period of about six months for the accelerator systems would then lead to the commissioning and use of the instruments.

## **Acknowledgments**

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