

How Argonne's Intense Pulsed Neutron Source Came to Life and Gained Its Niche: The View from an Ecosystem Perspective

Office of the Director

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by
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Author's Note

As I was completing the final processing of this paper, Argonne director Robert Rosner regretfully announced on January 3, 2008, that “effective immediately, IPNS is to be shut down....” Rosner explained that although Argonne management “expected this to happen in the next few years, the suddenness of this directive from DOE” came as a consequence of surprisingly drastic funding cuts in December 2007. Jack Carpenter, the first director and long-standing Technical Director of IPNS, noted that the decision ended “a great era in the scientific history of Argonne National Laboratory” and “the development and applications of neutrons for the study of materials” stemming “directly from Enrico Fermi’s demonstration of the first self-sustaining fission reaction at the University of Chicago’s Staff Field in 1942.”

One of the most gratifying aspects of serving as laboratory historian is the opportunity to get to know and learn from hard-working, dedicated, creative staff members who have made history. One of the saddest parts of my job is that some who share their memories die before my work is finished. Indeed, this time we all suffered the loss of James Jorgensen, who passed away on September 7, 2006. The IPNS community also lost James W. Richardson on March 7, 2008.

This paper is, in part, a memoriam to both Jims. I also dedicate this history to the entire IPNS staff, past and present.

Catherine Westfall
Argonne, Illinois
April 2008

**How Argonne's Intense Pulsed Neutron Source Came to Life and Gained Its Niche:
The View from an Ecosystem Perspective¹**

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At first glance the story of the Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory (ANL) appears to have followed a puzzling course. When researchers first proposed their ideas for an accelerator-driven neutron source for exploring the structure of materials through neutron scattering, the project seemed so promising that both Argonne managers and officials at the laboratory's funding agency, the Department of Energy (DOE), suggested that it be made larger and more expensive. But then, even though prototype building, testing, and initial construction went well a group of prominent DOE reviewers recommended in fall 1980 that it be killed, just months before it had been slated to begin operation, and DOE promptly accepted the recommendation. In response, Argonne's leadership declared the project was the laboratory's top priority and rallied to save it. In late 1982, thanks to another review panel led by the same scientist who had chaired the panel that had delivered the death sentence, the project was granted a reprieve. However, by the late 1980s, the IPNS was no longer top priority within the international materials science community, at Argonne,

¹ The author would like to thank Bruce Brown, Don Geesaman, Gerry Lander, Simine Short, and Sunil Sinha for many helpful corrections, comments, and suggestions. Special thanks go to Jack Carpenter, who was central to my understanding about the IPNS and its history and lent a hand at every stage in the preparation of this manuscript. I am also grateful for the help of Rhonda Carpenter, who lent her professional skills to editing this manuscript.

or within the DOE budget because prospects for another, larger materials science accelerator emerged. At just this point, the facility started to produce exciting scientific results. For the next two decades, the IPNS, its research, and its experts became valued resources at Argonne, within the U.S. national laboratory system, and within the international materials science community.

Why did this Argonne project prosper and then almost suffer premature death, even though it promised (and later delivered) good science? How was it saved and how did it go on to have a long, prosperous life for more than a quarter of a century? In particular, what did an expert assessment of the quality of IPNS science have to do with its fate? Getting answers to such questions is important. The U.S. government spends a lot of money to produce science and technology at multipurpose² laboratories like Argonne. For example, in the mid-1990s, about the time the IPNS's fortunes were secured, DOE spent more than \$6 billion a year to fund nine such facilities, with Argonne's share totaling \$500 million.³ And an important justification for funding these expensive laboratories is that they operate expensive but powerful scientific tools like the IPNS, generally considered too large to be built and managed by universities. Clearly, "life and death" decision making has a lot to tell us about how the considerable U.S. federal investment in science and technology at national laboratories is actually transacted and, indeed, how a path is cleared or blocked for good science to be produced.

Because forces within Argonne, DOE, and the materials science community obviously dictated the changing fortunes of the IPNS, it makes sense to probe the interactions binding these three environments for an understanding of how the IPNS was threatened and how it survived. In other words, sorting out what happened requires analyzing the system that includes all three environments.

² A multipurpose laboratory supports many different types of research in contrast to a single-purpose laboratory like Fermi National Accelerator Laboratory, built primarily to support a single line of research.

³ Jack Holl, *Argonne National Laboratory, 1946-96* (Urbana: University of Illinois Press, 1997), Appendix 2, p. 506. Holl's history is an excellent general source for Argonne history that spotlights the relationship between laboratory managers and government officials. The other multipurpose laboratories were Brookhaven, the National Engineering Laboratory in Idaho, Lawrence Berkeley Laboratory, Lawrence Livermore Laboratory, Los Alamos, Oak Ridge, the Pacific Northwest Laboratory, and Sandia Laboratory.

In an attempt to find a better way to understand its twists and turns, I will view the life-and-death IPNS story through the lens of an ecological metaphor. Employing the ideas and terms that ecologists use to describe what happens in a system of shared resources, that is, an ecosystem, I will describe the IPNS as an organism that vied with competitors for resources to find a niche in the interrelated environments of Argonne, DOE, and the materials science community.⁴ I will start with an explanation of the Argonne “ecosystem” before the advent of the IPNS and then describe how the project struggled to emerge in the 1970s, how it scratched its way to a fragile niche in the early 1980s, and how it adapted and matured through the turn of the 21st century. The paper will conclude with a summary of what the ecosystem perspective shows about the life and death struggle of the IPNS and reflect on what that perspective reveals about how research is produced in the laboratory.

The Argonne Ecosystem Before IPNS

Although Argonne always sponsored multiple lines of basic research, the laboratory began life in 1946 focused on the research and development of civilian nuclear power reactors, and for more than forty years reactor research and development defined Argonne’s place in scientific and technical realms as well as the U.S. as a whole. From the beginning Argonne physicists, chemists, and others doing basic research chafed at their place in the scheme of laboratory life, and indeed, they were lower on the food chain at Argonne than their basic research colleagues were at other laboratories in the national laboratory system, like Brookhaven National Laboratory and Lawrence Berkeley Laboratory.⁵

⁴By niche I mean the response to the distribution of resources and competitors. For more on niches in ecology, see Colin Townsend, Michael Begon, John L. Harper, *Essentials of Ecology* (Malden: Blackwell Publishing, 2003), pp. 106-108.

⁵For Brookhaven history, see Robert Crease, *Making Physics: A Biography of Brookhaven National Laboratory, 1946-1972* (Chicago: University of Chicago Press, 1999). For the beginnings of the Berkeley Laboratory, see John Heilbron and Robert Seidel, *Lawrence and His Laboratory: A History of the Lawrence Berkeley Laboratory* (Berkeley: University of California Press, 1989). Since this laboratory has had many names, I will use Lawrence Berkeley Laboratory, the name used for most of the period under discussion. For a history of the development of the U.S. civilian nuclear power industry, see Brian Balogh, *Chain Reaction: Expert Debate & Public Participation in*

It wasn't until the mid-1950s that the first serious steps were launched so that basic research was more prominent within Argonne and that Argonne was more competitive in large-scale basic research within the national laboratory system.⁶ The impetus for change came from exciting discoveries in the blossoming field of high energy physics, the building pressure in the region for a very large Midwestern accelerator, and the desire of Argonne high energy physicists to harness the winds of change to create a premier accelerator that would put them – and Argonne – on the map in the prestige-rich world of high energy physics.⁷

Making the change would require smart experts with ideas for creating a machine capable of new, more incisive explorations of matter as well as the resources for testing accelerator ideas and eventually building the machine and related equipment. Argonne had such resources, and by the mid-1950s plans were being laid for the Zero Gradient Synchrotron (ZGS). In 1957 the Atomic Energy Commission (AEC) authorized construction of this machine – a 12.5 GeV proton synchrotron injected by a 50 MeV linear accelerator -- for \$27 million.⁸ High-level managerial assistance is always helpful in creating a dominant place for a big project; the ZGS got such assistance when Albert Crewe was promoted from director of the particle accelerator division to laboratory director. As historian Jack Holl explains, Crew “placed basic research foremost among Argonne’s priorities,” pushing “basic research budgets ahead of spending for reactor development and other technical programs for the first,” and until 1961 the “only, time in Argonne’s history.”⁹

As far as Argonne’s materials scientists were concerned, the ZGS would not by itself provide the full range of research resources necessary for maintaining a healthy multipurpose laboratory. They seized on the promise by the Joint Committee on Atomic

American Commercial Nuclear Power, 1945-1975 (Cambridge: Cambridge University Press, 1991).

⁶Other types of cutting edge research were performed during this period, for example, the Nobel Prize winning work of Maria Goeppert Mayer on the nuclear shell model.

⁷ For a history of the development of the Zero Gradient Synchrotron, see Elizabeth Paris, “Do You Want to Build Such a Machine?: Designing a High Energy Proton Accelerator For Argonne National Laboratory,” ANL/HIST-2, Argonne National Laboratory.

⁸ Elizabeth Paris, “Do You Want to Build Such a Machine,” p. 47.

⁹ Quote from Jack Holl, *Argonne National Laboratory*, p. 223. Also, pp. 196, 208.

Energy, the powerful group of Senators and Congressmen who shepherded funding for large research projects through Capitol Hill, to provide Argonne with the “essential tools” to keep “pace with new developments and new needs.” Competing laboratories were slated to get new research reactors (for Brookhaven, the High Flux Beam Reactor or HFBR, for Oak Ridge the High Flux Isotope Reactor or HFIR) to advance materials science, an up-and-coming research endeavor aimed at investigating the relationship between the properties of materials and their structure. Materials scientists at Argonne, they argued, needed their own major research tool.¹⁰

Crewe did his part to promote the project they wanted, the Argonne Advanced Research Reactor (A^2R^2), which was meant to extend the productive line of research that had grown alongside reactor development begun when Enrico Fermi created the first self-sustaining chain reaction for the atomic bomb effort using Chicago-Pile 1 (CP-1). CP-1 and subsequent reactors CP-2, and CP-3 did double-duty, testing concepts for power reactor design as well as providing neutrons to scatter off a variety of materials to study the dynamics and structure of matter. CP-5, which started operating in 1954, was the first reactor in the series built strictly as a research tool. Advancing this line of research required higher and higher neutron fluxes, which would allow the study of subtler effects, shorter time scales, and smaller samples with higher resolution. From the Argonne point of view it made sense that a new research reactor would continue the laboratory’s prominence in reactor development; accordingly, at a cost of \$25 million, A^2R^2 , the successor to CP-5, was slated to be the top competitor in neutron scattering with higher neutron fluxes than any other research reactor in the world, exceeding the capabilities of both HFBR and HFIR.¹¹

The ZGS and A^2R^2 proposals enjoyed an abundance of internal resources – not only did they have Crewe’s support, but also Argonne had considerable expertise in building both accelerators and reactors. However, both encountered adverse conditions in the scientific communities that formed their external ecosystems. Although the ZGS

¹⁰ As quoted in Jack Holl, *Argonne National Laboratory*, p. 236. On the development of materials science, see Bernadette Censaude-Vincent, “The Construction of a Discipline: Materials Science in the United States,” *Historical Studies in the Physical and Biological Sciences*, 31 (2001), p. 223-248.

¹¹ Jack Holl, *Argonne National Laboratory*, p. 111-113, 235.

was built and began operation in 1963 (at an ultimate cost of \$50 million), Cold War pressures to build a machine quickly to compete with the Soviets and the strain of squabbling within the high energy physics community as well as power struggles over Argonne management rendered the machine vulnerable to “interference competition,”¹² that is, a crippling fight for resources with other facilities. Unable to place highly in the competition for resources, the ZGS was relegated to an inauspicious niche in the high energy physics world. The weak-focusing, 12.5 GeV ZGS had out-dated technology, and although it had high intensity, it had lower energy than the already operating strong-focusing 30 GeV synchrotrons at Brookhaven and CERN, as well as the soon-to-operate 20 GeV Stanford Linear Accelerator Center, in a field in which achieving the highest possible energy was deemed most important.¹³

While the ZGS settled into what ecologists call a “realized niche,”¹⁴ that is, a niche made narrower because of more successful competitors, A²R² also suffered interference competition: the project lost in the competition for resources with other materials science tools and thus failed to find a place in the AEC budget. Although the AEC authorized funds for the project in June 1964, A²R² remained mired in difficulties. From 1965 to 1967 the project suffered cost overruns and resulting complaints from the AEC and the Bureau of the Budget, arguments over core and control rod design that led to the forced adoption of an Oak Ridge reactor core design, and a mismanaged safety review, all of which annoyed the powerful Milton Shaw, head of the AEC’s reactor division. As Holl notes, for Shaw and his staff “the A²R² controversy was an annoyance that diverted energy and funds from their principal mission to develop breeder-reactor technology” for civilian nuclear power “for the AEC.” In the meantime, Argonne’s engineers had been sidelined from this project after losing a show-down with Shaw who

¹² In an ecosystem, interference competition involves a fight or other active interaction among organisms in a way that threatens the survival of the weak. Colin Townsend, Michael Begon, John L. Harper, *Essentials of Ecology*, p. 104.

¹³ Jack Holl, *Argonne National Laboratory*, p. 204. For more on the development of the Alternating Gradient Synchrotron at Brookhaven, see Robert Crease, *Making Physics*, p. 219-225, 219-225. For more on the development of the Proton Synchrotron at CERN, see Armin Hermann, John Krige, Ulrike Mersits, Dominique Pestre, *History of CERN, Vol. II: Building and Running the Laboratory, 1954-1965*, p. 95-137 (Amsterdam: North Holland, 1990).

¹⁴ Colin Townsend, Michael Begon, John L. Harper, *Essentials of Ecology*, p. 192.

criticized the way they were running the Experimental Breeder Reactor-II and disagreed about the best breeder design. By 1967 Argonne's Fast Reactor Test Facility had been cancelled and money diverted to Pacific Northwest Laboratory's Fast Flux Test Facility. Even worse, Argonne lost its autonomy in planning and managing the laboratory's signature project, research and development for Liquid Metal Fast Breeder Reactors (LMFBR).¹⁵

At this point Crewe resigned and was replaced by Robert Duffield. Duffield was an experienced manager who had worked with both research and power reactors. In addition, he had successfully worked with Shaw while overseeing the construction of the Peach Bottom nuclear power plant in Pennsylvania.¹⁶

Despite his high qualifications, Duffield was not able to shield Argonne from the severe adversities that hit within months of his appointment. In April 1968, even with frantic last-minute efforts by the new director, A²R² was cancelled. At the same time the prestigious High Energy Physics Advisory Panel (HEPAP) made a ruling that threatened to slam shut the ZGS's already narrow niche. HEPAP chair Victor Weisskopf told Duffield that it was unacceptable for the ZGS to soak up resources, including scientific personnel and technicians and other local technical resources, that should be reserved for the nation's premiere highest energy proton machine which was being built at what would be called Fermi National Accelerator Laboratory (Fermilab). He argued, in fact, that the ZGS should operate only as long as it took for that lab's 200 GeV accelerator to get up and running. Clearly, by assuming its top niche, Fermilab stripped Argonne of any claim that it provided a top-notch regional high energy physics tool and at the same time made the ZGS's relative national standing even lower than it had been earlier in the decade.¹⁷ The ZGS would escape the squeeze for the time, but as the HEPAP judgment made clear, the machine was low enough in the high energy physics pecking order that it would fast become extinct, and in the meantime, it would not bring the prestige and related resources to Argonne that its planners had expected.

¹⁵ As quoted in Jack Holl, *Argonne National Laboratory*, p. 239. Also, pp. 231, 235-238 and Catherine Westfall, "Vision and Reality: The EBR-II Story," *Nuclear News*, February 2004, pp. 25-31.

¹⁶ Jack Holl, *Argonne National Laboratory*, pp. 240-241.

¹⁷ Jack Holl, *Argonne National Laboratory*, pp. 259-262.

Argonne continued to be defined by the LMFBR, but that project languished as well, its problems compounded as the 1970s began when the national civilian nuclear power program faced mounting public criticism and concern over safety issues. It was a bad time for Argonne to lose a secure niche in the high energy physics and power reactor realms: at just this point the national budget for research and development was tightening. From 1968 to 1971, for the first time in its history, Argonne had to cut its workforce, losing a whopping 17% of its staff.¹⁸ To survive interference competition from other DOE laboratories, Argonne would have to find a way to adapt to an environment within the national laboratory system that had grown harsh and inhospitable.

The IPNS Seed Forms

Although A²R² was never built, the project did draw people and ideas that would later seed new growth. Particularly fruitful was the January 1968 gathering of neutron scattering experts convened by Donald W. Connor of Argonne's Solid State Science Division to develop ideas for instruments for A²R². The meeting brought John (Jack) Carpenter, a young nuclear engineering professor at the University of Michigan, to Argonne. Although the group did not get very far before the reactor was cancelled in April, Carpenter made a good impression on his colleagues. A month later he was asked to serve on the Argonne Committee on Intense Neutron Sources that Duffield commissioned.¹⁹

The committee assembled accelerator and neutron physics experts like Lowell Bollinger, who was interested in improvements for Argonne nuclear physics accelerators, and Ronald Martin, who was interested in upgrading the ZGS, as well as neutron scattering experts like Carpenter. The object was to come up with new machine ideas that would help Argonne secure its future by developing a new, large research tool. From

¹⁸ Jack Holl, *Argonne National Laboratory*, pp. 257-262, 279-280; Brian Balogh, *Chain Reaction*, pp. 221-301.

¹⁹ John M. Carpenter, "Living With Neutrons: A Personal History – 40 Years or so in Neutron Scattering," Shull Prize Lecture, June 2006; Jack Carpenter, "Pulsed Neutron Source Development at Argonne," IPNS Progress Report, 10th Anniversary Edition, Argonne National Laboratory, p. 2.

the beginning, along with others, Carpenter was interested in figuring out a way to get around the limitations of reactors. Reactors are less efficient for producing epithermal (0.1 to 1 eV) neutrons, and in addition, the neutrons they did produce did not have a well-defined time of origin. Because it is difficult for detectors to directly measure the total energy of neutrons, reactor researchers had to use time-of-flight measurements to measure the neutron energies using “chopping” techniques that reduced flux, or they had to prepare a beam in a small band of energies, which also reduced flux. In addition, reactors had almost reached maximum neutron flux given costs and the heat transfer problems inherent in the technology then employed. Moreover, the accelerator neutron production process (spallation) is much more efficient than the reactor process (fission).²⁰

As Carpenter remembered, the assembled group surveyed “some really wild schemes, but we looked carefully at all of them.” One promising line of inquiry involved the use of “spallation,” a term borrowed from geology and stoneworking.²¹ In this case the idea was that the particles in the beam from an accelerator would hit the heavy nuclei in a metal target, dislodging numerous light particles, mostly fast neutrons, like chips flying from a stone hit with a “spalling” hammer. Researchers at the Canadian Intense Neutron Generator (ING) had produced a study of a steady (reactor-like) spallation source at the Chalk River National Laboratory. Even though Chalk River researchers had not found the right technology for exploiting this promising line of work, John Frazer and others had measured the spallation neutron yield from various target materials hit with protons of different energies. In addition, Ralph Fullwood had plans for a pulsed spallation source to be used for weapons research that would be driven by protons from the 800-MeV Los Alamos Meson Physics Facility. Researchers at the Nevis

²⁰ “Schedule 44 -- Construction Project Data Sheet,” Intense Pulsed Neutron Source (IPNS), 1977. “Spallation Source for Neutron Scattering,” *Physics Today* 35 (1982), pp. 19-21.

²¹ Quote from Catherine Westfall interview with Jack Carpenter, October 8, 2001. The term spallation was first used in science by W. H. Sullivan and Glenn T. Seaborg at Lawrence Berkeley Laboratory to refer to nuclear reactions in which a struck nucleus emits a rather large number of nucleons or fragments. Bernard G. Harvey, *Progress in Nuclear Physics*, 7 (1959).

synchrocyclotron came up with a potentially more efficient experimental set-up, a uranium spallation target that produced more neutrons per incident proton.²²

Spallation-related ideas were not the only ones considered. A particularly important development was reported by Martin, who returned from his visit to the Budker Institute in the Soviet Union with the news that Gennady Dimov and others there had developed an efficient proton beam using a negative hydrogen ion source employing a stripping technique. The advantage of starting with negative hydrogen ions (that is, a proton with two electrons) instead of protons is that the stripping process that removes the electrons changes the charge sign and facilitates proton injection into a second accelerator to get around a severe theoretical constraint, Liouville's theorem, which otherwise limits beam concentration in phase space. Dimov's successful demonstration of the process inspired Martin's idea of increasing the intensity of the ZGS (and thus providing additional experimental capabilities for high energy physics research) by adding to the accelerating system a 500-MeV rapid-cycling booster synchrotron injected by stripping negative hydrogen ions.²³

All this news was exciting to those interested in advancing neutron scattering research because it opened new possibilities for using synchrotrons in their work. Synchrotrons naturally produce pulsed beams that can create greater instantaneous flux than do steady sources, as demonstrated by the pulsed electron linear accelerators then operating. These electron machines, however, had managed to produce only modest neutron fluxes because the electrons interact with nuclei more weakly than protons, producing fewer neutrons while producing mostly heat; moreover, they had already reached the limits of beam power that their targets could tolerate. Negative ion stripping made a pulsed proton synchrotron seem practical. Such a machine (if it could be built) promised to provide greater fluxes than those produced in pulsed electron accelerators. Although a proton synchrotron would likely produce a lower neutron flux overall than could be produced in a reactor, the spallation process promised to create short bursts of very high-flux neutrons over a very broad energy spectrum (including the epithermal

²² Jack Carpenter, "Pulsed Neutron Source Development at Argonne," IPNS Progress Report, 10th Anniversary Edition, Argonne National Laboratory, p. 2; "Spallation Source for Neutron Scattering," pp. 19-21.

²³ Jack Carpenter, "Pulsed Neutron Source Development at Argonne," p. 2.

range) with a well-defined time of origin so that all the neutrons could be used in time-of-flight-based instruments. In other words, such a machine promised to produce more *useful* neutrons so that neutron scattering researchers would have the benefit of better resolution and the ability to use smaller samples. This sort of pulsed neutron source, in fact, might be just the tool to circumvent the limitations of reactors and become the new, top-of-the-food-chain tool for neutron scattering.

The fact that Martin wanted to upgrade the ZGS by building a booster synchrotron with negative-ion stripping injection – and that the machine could potentially be used for both neutron scattering and high energy physics experiments -- created a particularly golden opportunity for those interested in advancing Argonne’s neutron scattering capabilities. Thus, a key recommendation in the formal report of the Committee on Intense Neutron Sources stated, in part, that Argonne’s “objective should be consciously aimed at the goal of construction at Argonne of a pulsed neutron source of unequaled research capability.”

As Carpenter later explained, when he returned to the University of Michigan from Argonne, ideas for a practical design for a pulsed neutron source were forming in his imagination, aided by Frazer’s data developed in support of the Canadian ING project, which provided a sound basis for estimating neutron production. The envisioned machine would use a synchrotron that would accelerate protons to hit a heavy-metal target, creating a stream of fast neutrons. The stream of neutrons from this pulsed spallation source would be slowed with a moderator to energies that could be measured with specially designed instruments. As Carpenter continued making calculations and rough designs, he saw the possibility that the spallation process would produce “neutrons with much less heat than the fission process in a reactor.” In pulsed operation, because heat flows continuously from the target, high instantaneous power comes with low average power. The more he thought about it, the more he was convinced that his pulsed neutron source could rival – or even exceed -- the experimental capabilities of a reactor.²⁴

²⁴ Quote from Catherine Westfall interview with Jack Carpenter, February 14, 2007. Also: John M. Carpenter, “Living With Neutrons.”

Although Carpenter's pulsed neutron source was highly promising, the proposed mode of experimentation was novel and relatively untried. As he later recalled, the consensus of the committee was that priority should be given to proton-driven systems and target development, with the proviso that "much more needed to be learned about moderator design and science and instruments appropriate for pulsed neutron sources."²⁵

In the meantime, the ideas that would later facilitate the growth of that new accelerator first took root at the ZGS, even though ZGS researchers were focused on making their accelerator as competitive as possible within the environment of high energy physics rather than finding a way to replace the capabilities of the defunct A²R². Competing in their contest hinged on finding a new niche. Since the ZGS design prevented them from achieving the most coveted capability of the highest energy, ZGS scientists persevered in their attempt to prevail in the contest for the highest beam intensity and to add to other unique capabilities such as aligning the spins of the protons and measuring polarized proton interactions. Although ZGS advocates had originally beaten out proponents of all other accelerators in beam intensity, this triumph was brief. In 1966 due to limitations in AEC funding and the top priority Argonne managers placed on other, more pressing priorities, they did not manage to get a \$20 million linear accelerator injector that would have further improved intensity. As in the wild, in the high energy physics world those at the top of the food chain usually get fed first and most, allowing their continued domination: to the chagrin of ZGS researchers, in that same year Brookhaven obtained \$50 million for a 200 MeV linear accelerator as part of an Alternating Gradient Synchrotron (AGS) upgrade so that the AGS – which already topped the ZGS in beam energy -- also assumed top honors in high intensity (CERN's Proton Synchrotron would soon install a similar upgrade so that it had a similar beam intensity and energy as the AGS).²⁶

In Martin's words, what he saw in Novosibirsk in 1968 left him feeling nothing short of "elation," because "if one could develop practical foil stripping at 50 MeV," then they could go on to build a "500 MeV rapid cycling synchrotron" that "could be a useful

²⁵ John M. Carpenter, "Living With Neutrons."

²⁶ Ronald Martin, "Early History of the Argonne 500 MeV Booster," in *History of the ZGS 500 MeV Booster*, ANL-HEP-TR-05-44, p. 10.

injector for the ZGS.” Argonne could get around the difficulty of competing with other higher ranked facilities for upgrade funding because the Novosibirsk device “could be built at a small fraction of the cost of a 200 MeV linear accelerator – just what was needed at Argonne to improve the intensity of the ZGS beam.” However, when Argonne submitted a \$5 million proposal to the AEC in 1969 for the synchrotron, it was rejected.²⁷

The winds of chance would soon further elevate Argonne’s prospects. In 1969 the 2 GeV Cornell electron synchrotron was no longer needed there and became available. Martin, then director of the Accelerator Research Facilities Division at Argonne, calculated that with some relatively minor changes, including the introduction of stripping injection, the discarded accelerator could be modified into a 200 MeV proton accelerator and used to test the feasibility of the new injection scheme. This would pave the way for a much larger booster that would allow higher intensity ZGS beams. Plans were quickly made to move the machine to Argonne. (There was poetic justice in this inheritance; the Cornell synchrotron, central to hopes to elevate the ZGS’s place in the high energy physics ecosystem, had been built by Robert Wilson before he went to lead construction of the Fermilab accelerator, the very facility that relegated Argonne to a low ranking in the high energy physics world.)²⁸

First David Nordby then Jim Simpson led the “rebirthing” of the Cornell machine at the ZGS site, a task complicated by the many aging components, particularly the vacuum system, that were “unbelievably fragile” after being shipped from New York. While this work proceeded on what came to be called Booster I, Martin worked with the ZGS source expert John Fasola to make the first tests of charge exchange (or stripping) injection. In 1970 they successfully injected negative hydrogen ions into the ZGS at 50 MeV. Although intensities were low, calculations indicated this type of injection would likely serve their purposes.²⁹

²⁷ Ronald Martin, “Early History of the Argonne 500 MeV Booster,” pp. 11-12.

²⁸ Jim Simpson, “History of the ZGS Booster (1969-1978),” in *History of the ZGS 500 MeV Booster*, pp. 2-3. As Jack Holl, explains, Wilson himself was fully supportive of the ZGS and helped lobby for its continued funding. Jack Holl, *Argonne National Laboratory*, pp. 261-262.

²⁹ Jim Simpson, “History of the ZGS Booster (1969-1978),” pp. 4-5. Stripping injection later became standard in high intensity synchrotrons and storage rings.

When Simpson later described the 1972 Booster I beam tests, he exclaimed “What a chore!” Because most of the accelerator time was devoted to experimentation, only two weeks twice a year was allowed for beam testing. Poor vacuum was a particular problem given the poor condition of many of the components. In addition, the Booster group did not enjoy high status among those running the ZGS because by this time some figured (correctly as it turned out) that booster injection would not be implemented quickly enough to help ZGS experimental prospects, given the limited lifespan of the machine. As a result, at least in Simpson’s opinion, they were “often not well supported by the mainstream groups in the ZGS Division.” Nonetheless, the tests proved that stripping injection was practical at 50 MeV, and Martin proceeded on a shoestring with the construction of the 500 MeV Booster, Booster II, which was operating by 1977.³⁰

Mutualism with the ZGS Host

In the meantime Carpenter continued to work on the design of a spallation source from his university post in Ann Arbor, at the same time keeping in close touch with developments at Argonne. He knew from the Canadian ING results obtained while he worked with the 1968 Committee on Intense Neutron Sources at Argonne that spallation neutrons were produced in large numbers from protons, and he knew that a key technical hurdle was finding a moderator to slow neutrons to energies suitable for materials science neutron scattering studies. His student, Kingsley Graham, worked on what was the biggest problem in this regard at the time: determining the intensities and the response times of the slow neutron beams when extracted from the moderator. The ZGS Booster was central to his plans. He intended to form a symbiotic relationship with the ZGS project; that is, based on what is called “mutualism” in an ecosystem, the new project would attach itself to the ZGS host, but neither project would suffer in the deal.³¹ As Carpenter later noted, in 1969, based on Graham’s work, he made “a preliminary estimate of the intensities available” from a ZGS Booster-driven proton spallation source, but the resulting figures were rather low and quite uncertain.” That did not stop

³⁰Quotes from Jim Simpson, “History of the ZGS Booster (1969-1978),” pp. 4-5; “The Booster Project Checks Off Another Milestone,” *Argonne News*, February-March 1972, p. 2.

³¹ Colin Townsend, Michael Begon, John L. Harper, *Essentials of Ecology*, p. 225.

him from coining a snappy name for the device. With a nod toward the Canadian effort, he dubbed it the ZGS Intense Neutron Generator, or ZING for short.³²

Carpenter was close at hand to hear about the Booster I tests because he came to Argonne for a sabbatical in 1971-1972. As he later recalled, during the sabbatical he was encouraged by the Solid State Science division head Oliver Simpson “to work more on the neutron source ideas.” He knew from the beginning that securing a niche would not be easy. European competitors were breathing down their necks – the world’s highest intensity neutron research reactor had just started operation at the Institute Laue-Langevin (ILL) in France.³³

Although Carpenter and his colleagues reviewed “all the crazy schemes” they could think of, “the spallation source still came out on top.” With further encouragement from Connor, who then headed the Solid State Science division neutron group, and help from other Argonne benefactors, he obtained the “stock of beryllium blocks that were left over from A^2R^2 criticality experiments,” a “calibrated californium spontaneous fission source,” space in the still-standing A^2R^2 mock-up bay, and assembled “cadmium-filtered ^{235}U -foil track-etch detectors” and “learned to count fission-fragment tracks under a microscope.” Thus armed, he “built a mock-up moderator with a beam port and cadmium decouplers inside a beryllium reflector, which seemed to be the best material.”³⁴

With the reflector they got about 10 times more neutron flux than they did in the then-standard arrangement without the reflector. “It was a Eureka! Moment. The gain would not be that great in practice” because the arrangement in the real source would be more complex. However “we knew.” Working with engineer Robert Kleb, Carpenter then worked out a basic concept for ZING, the seed that would later grow into the IPNS, in the process realizing that with improved moderators and targets, the Booster II synchrotron being devised by Martin and others could produce peak thermal fluxes

³² Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 2.

³³ Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 2.

³⁴ Carpenter realized that to preserve the rapid time response of pulsed-source moderators, it was necessary to prevent long-lived slow neutrons from the reflector from getting into the moderator. A thin sheet of cadmium metal, the decoupler, served this purpose. Personal communication, Jack Carpenter, February 15, 2006. Text quote Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 2.

comparable to those at ILL. As Carpenter noted in a 1972 summary of his work, the envisioned “facility would be one of the most intense pulsed neutron sources in the world.” In an arrangement with Argonne, in 1973 Carpenter got a patent for the reflector idea, receiving a sum total of \$26 for the time and effort.³⁵

The environment continued to provide resources. Working with Argonne’s David Price, in spring 1973 Carpenter convened a conference at Argonne to evaluate how to use ZING. As the conference report noted, the new device facilitated unparalleled studies using epithermal neutrons, a type of research that could not be conducted in the U.S. at HFIR or HRBR, which produce mostly neutrons with the temperature of their moderators, or even at the high-flux reactor at ILL, which was starting operations in France.³⁶ In addition to considering how the device could be used for radiation damage studies on materials, the report explored various types of experiments that could be performed using ZING: high- and low-energy transfer inelastic scattering and diffraction from single crystals, powdered crystalline materials, and liquids and glassy solids. Although the report presented ideas for optimizing the device, it judged that there were no apparent problems with the targets, moderators, or other pieces of the experimental equipment. “It seems,” the report noted, “that the final limitations of the facility will come only from the absolute intensity of the proton beam available.”³⁷

The report clearly described a niche for ZING; its conclusions both confirmed and expanded upon Carpenter’s initial positive assessment of the device. The report noted that “the proposed ZING facility would be more powerful” in the epithermal neutron range “than any existing reactor,” also “that the flux would be comparable to ILL in the 0.2-0.5 eV region,” and that “the pulsed feature of the ZING source offers significant design advantages for some types of experiments.” Therefore, the report suggested “that the U.S. develop a capacity for this important field of neutron beam research in the near

³⁵ Quotes from John M. Carpenter, “Living With Neutrons” and J. M. Carpenter and G. M. Marmer, “Evaluation of the ZGS Injector-Booster as an Intense Neutron Generator,” ANL/SSS-72-1 (1972), p. 1. Also: U. S. Patent, 3,778, 627, December 11, 1973.

³⁶ The ILL reactor at the time did not have a higher flux than the U.S. reactors but did provide greater research opportunities because of the design of its neutron transport system. Personal communication, Gerard Lander, October 14, 2007.

³⁷ “Applications of a Pulsed Spallation Neutron Source,” Report of a Workshop held at Argonne National Laboratory April 29-May 4, 1973, ANL-8032, p. 88. Also, p. 5.

future and that pulsed accelerator-driven spallation sources” were “the most promising candidates for obtaining such capability.”³⁸

An important attendee was Japanese nuclear physicist Motoharu Kimura, who had experience with an electron linear accelerator-based neutron source as well as neutron scattering experiments at Tohoku University. As Carpenter later recalled, for the sake of testing the design ideas that emerged from the conference, Kimura insisted: “You must build a prototype!” Kimura returned to Argonne after the conference to help build it, bringing along his protégé Noboru Watanabe.³⁹

In his memoir, Kimura described the reception his ideas got among Argonne researchers. He remembers “encouraging support” from those in the Solid State Science and Chemistry divisions. From the Solid State Science division, he singled out Price, as well as “Sunil Sinha, a brilliant and powerful Indian physicist” and “the late Aneesur Rahman, almost a saintly figure.” In addition “younger physicists,” for example, in the field of magnetism, “waited for the construction with high expectations.” Jack Williams and others in the Chemistry division, “especially organic chemistry, put importance on the determination of hydrogen positions in hydrogen-containing crystals, feeling that they absolutely needed the pulsed neutron facility.” Selmer Peterson “dedicated himself and substantial effort of his group to the construction of a single crystal diffraction instrument,” even though at first he was not convinced “that the method would be effective.”⁴⁰

Argonne came up with \$30,000 and a great deal of surplus materials for this first phase of the project, dubbed ZING-P because it was a prototype.⁴¹ Thomas Banfield,

³⁸ “Applications of a Pulsed Spallation Neutron Source,” pp. 6-7.

³⁹ Quote from personal communication, Jack Carpenter, February 15, 2006. Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 3.

⁴⁰ Motoharu Kimura with John M. Carpenter, *Living With Nuclei: 50 Years in the Nuclear Age – Memoirs of a Japanese Physicist* (Sendai Japan: Sasaki Printing and Publishing Company, 1993).

⁴¹ The surplus equipment included battleship armor for shielding that had originally been brought to the site for shielding for the ZGS. Carpenter later remembered that when Argonne Deputy Director Michael Nevitt saw markings on the armor he cried: “BB58! That’s my ship! That’s the battleship *Indiana*.” Indeed, he had previously served as a naval officer on that very ship, the *Indiana*. Personal communication, Jack Carpenter, February 15, 2006.

then head of CP-5, would provide Argonne oversight of the project, which would involve building a small, shielded enclosure above the ZGS Booster I beam line as well as a target in a lead-shielded beryllium reflector that was designed with the help of Kimura and Bob Kleb. ZING-P was fed protons from the booster accelerator, which was just then being completed. The protons from Booster I hit a target consisting of “one half of a lead brick” with “a copper tube” soldered to it to “carry off the heat.” The resulting neutrons would then be slowed in polyethylene moderators and proceed through “two, nearly vertical beam holes.” These beam holes supported two instruments, a time-focused powder difffractometer and a crystal analyzer inelastic scattering instrument that were placed, in Carpenter’s words, in “a tiny shielded house.” ZING-P was finished by January 1974 and “built on top of the earth-mound shield between the Booster and the ZGS in an area called ‘Skunk Hollow.’” Carpenter and those helping him “had to scurry up and down the muddy bank that winter to get to the instruments.” The device operated three times for several-month periods during 1974 and 1975 before Booster I was shut down.⁴²

During this time a large number of researchers, including Carpenter and Kimura, made and published measurements that were aimed at showing the experimental viability of the device. Carpenter later noted that an important initial result was that in the course of experimentation, the intensities measured were as expected, which gave the green light to continue to the next incarnation of ZING, ZING-P', which was similar to its predecessor except it had an improved target and three horizontal beam holes and would operate with the upgraded ZGS booster synchrotron, Booster II.⁴³

⁴² Quotes from Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 4. Also: J. M. Carpenter, “Pulsed Spallation Neutron Sources for Slow Neutron Scattering,” *Nuclear Instruments and Methods* 145 (1977) pp. 91-113.

⁴³ Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 4; J. M. Carpenter et al. “Neutron Diffraction Measurements on Powder Samples using the ZING-P Pulsed Neutron Source at Argonne,” *Proc. Neutron Diffraction Conferences*, Petten (1975); M. H. Mueller, et al., “Structure of Th₄D₁₅ from Measurements at the Argonne ZING-P Pulsed Neutron Source, *J. Applied Crystallography*, 10 (1977), p. 79; A. Rahman et al., “Photon Spectra of Non-Stoichiometric Palladium Hydrides,” *Phys. Rev B14* (1976), pp. 3630-3634; J. Roziere and C. V. Berney, “Neutron Scattering Study of Cesium Hydrogen Dinitrate,” *Journal of the American Chemical Society* 98 (1976), pp. 1582-1583.

Growing to Fit a Niche

In the mid-1970s, environments evolved, both at Argonne and in Washington. The AEC was disbanded in 1974. Its regulatory functions were shifted to a new agency, the Nuclear Regulatory Commission, and the rest of the AEC turned into the short-lived Energy Research and Development Agency (ERDA), which became the Department of Energy in 1977. While these changes were taking place, Robert Sachs, an eminent theoretical physicist, served as Argonne director. Although LMFBR continued to be the laboratory's main initiative, it shrank in 1977 to only 40% of the total Argonne budget. The energy crisis was raging, and energy-related programs were flourishing at Argonne as elsewhere. But such work did not use a single, central tool, and national laboratories had traditionally been defined (and their funding justified) by large, state-of-the-art instruments. With Argonne reactor projects languishing and the ZGS on its last legs, a niche appeared: Sachs and others seeking Argonne's best interests were open to ideas for a new, large machine.⁴⁴

In response to these changes, in 1974, as Carpenter later recalled, "the powers," that is, officials in Washington as well as administrators at Argonne, "encouraged us to think up a larger-scale facility – ZING was not powerful enough." As Carpenter and others began scaling up their spallation source plans, they were encouraged, in particular by officers of the laboratory's operating contractor, the Argonne Universities Association (AUA). AUA President Paul McDaniel took Carpenter aside and gave him a piece of advice: "the new higher powered facility" should be called "by a name that could not be pronounced. Make them say what it is." Besides, "ZING was too cute." Turning to a simple description of its function, Carpenter renamed the project the Intense Pulsed Neutron Source, and the name stuck.⁴⁵

⁴⁴ Jack Holl, *Argonne National Laboratory*, pp. 291, 314. Alice C. Bush, *A History of the Energy Research and Development Administration* (DOE/ES-0001, Washington, 1982), p. 2,14; "New Energy Department: Who Will Champion Research?" *Physics Today* 30 (1970), p. 110.

⁴⁵ Quotes from Jack Carpenter, "Pulsed Neutron Source Development at Argonne," p. 5-6 and Catherine Westfall interview with Jack Carpenter, December 19, 2006.

Price, head of the Solid State Science division, offered Carpenter a full-time staff position at Argonne. Tired of commuting from Ann Arbor to Chicago and excited about the prospects for the IPNS, Carpenter resigned from his position as Professor of Nuclear Engineering at Michigan. Just as he arrived in January 1975, he heard the news that a previously submitted Energy Research and Development Agency funding request has been approved. They now had \$175,000 to develop a conceptual design.⁴⁶

T. Khoe, Kimura, and Carpenter laid out basic plans for proceeding to the larger machine the times seemed to call for. The pulsed neutron source originally conceived as the final incarnation of ZING would be IPNS-I, which would provide experience for building a larger IPNS-II. As planned, IPNS-I would have 5×10^{12} protons per pulse, a proton energy of 500 MeV, 20 neutrons per proton, and a peak thermal flux of 10^{15} n/cm²-sec. IPNS-II would have a 5×10^{13} protons per pulse, 800 MeV proton energy, 30 neutrons per proton, and a peak thermal flux of 10^{16} n/cm²-sec. Both versions would use a ²³⁸U target.⁴⁷

Along with Sam Werner, a University of Michigan physicist working there at Ford Scientific Laboratory, Carpenter convened another workshop in June 1975 to evaluate the potential of the IPNS within the context of other neutron sources in the materials science ecosystem, meanwhile identifying potential scientific applications and acquainting would-be users with the IPNS. The workshop had nine panels of scientists who “were charged with two tasks – to compile scientific problems” and “to propose and evaluate the instrumental means to accomplish the measurements.” Since the new pulsed source promised higher resolution and the ability to use smaller samples, those planning the IPNS wanted to explore the many ways that a wide variety of scientists (that is, not just condensed matter physicists) could use this tool to explore the properties of different materials. Thus, in addition to a panel on neutron sources and one on radiation effects, the workshop included panels on biology; chemical spectroscopy; chemical structures in

⁴⁶ Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” pp. 5-6.

⁴⁷ T. Khoe and M. Kimura, Feasibility Studies of an Accelerator for the Intense Pulsed Neutron Source, ANL/SSS-74-1 (1974); J. M. Carpenter, “Uses of Advanced Pulsed Neutron Sources,” Report of a Workshop held at Argonne National Laboratory, October 21-24, 1975, ANL-76-10, p. 4.

crystalline solids; chemical structures of disordered solids and inhomogeneous systems; dynamics of solids, liquids, glasses and gases; and magnetism.⁴⁸

As the workshop report noted, numerous “advanced pulsed source systems were emerging.” These included “the present and the scheduled new Harwell electron linear accelerator sources in the U.K., the series of Soviet pulsed fast reactors, IBR-I, IBR-30, IBR-II; the Soviet electron linear accelerator source at Kurchatov; the Japanese electron linear accelerator source operating at Tohoku; the proposed Japan Linac Booster; the operating electron linear accelerator source at Toronto, Canada; the studied application of the Oak Ridge Electron Linear Accelerator for neutron scattering; the nearly completed Weapons Neutron Research Facility (WNR-PSR) at LAMPF; and the Argonne pulsed neutron sources.” The report also highlighted the “High Flux Reactor at the Institut Laue-Langevin,” noting that it represented the highest evolution of the steady state research reactor” and provided “a thermal neutron flux of about $1.2 \times 10^{15}/\text{cm}^2\text{-sec.}$ ”⁴⁹

According to the report, within the ecosystem of neutron sources there was a fertile niche just waiting to be filled: neutron scattering was “the most general experimental technique in condensed matter research.” It could yield “direct microscopic information which is inaccessible by any other technique and in many other cases produced results which are completely complementary to the information obtained from other physical measurement methods.” So far, the technique had found applications in “biology, chemistry, physics, and materials science,” and applications were “growing constantly.” The perfect fit for this empty niche was, of course, the IPNS. “It is clear from the panel reports of this workshop that the construction of an advanced pulsed neutron source, such as IPNS, would expand the realm of scientific problems accessible to neutron scattering enormously in many directions.”⁵⁰

To further boost the growth of the budding new project, in January 1976 IPNS promoters called a Pulsed Neutron Source Users Group meeting to let potential users know of ongoing plans and to invite proposals.⁵¹ In the meantime, Carpenter, Kimura,

⁴⁸ Quotes from “Uses of Advanced Pulsed Neutron Sources,” p. 1. Also, pp. 11-15.

⁴⁹ “Uses of Advanced Pulsed Neutron Sources,” p. 3.

⁵⁰ “Uses of Advanced Pulsed Neutron Sources,” p. 6.

⁵¹ J. M. Carpenter, D. L. Price, and N. J. Swanson, “IPNS – A National Facility for Condensed Matter Research,” ANL-78-88, November 1978, p. 32.

and others were preparing to build and use ZING-P' to fill in the gaps of their knowledge so that they could bring to life the envisioned larger, more powerful IPNS.

Mutualism Turns to Scavenging

ZING-P' began operation in 1977 with the completion of Booster II and ran for three years. Before this milestone was reached, however, the ZGS's death sentence became official. In 1976 ERDA announced that funding for the machine would be cut in the next few years.⁵² Since the facility's death had long been eminent, this came as no surprise to anyone. As a matter of fact, for IPNS planners, the timing of this tragedy for the high energy physics group could not have been better. In 1977 and 1978 they were presenting their funding and design plans to the funding agency. For the first time they were free to openly engage in appropriating what they needed from the ZGS; that is, they took resources (in this case accelerator components) that the ZGS had used to stay viable, in the process saving time, money, and effort. Thus began a role-reversing turning-point: instead of being a small attachment living off the ZGS host without harming it, the spallation neutron source was slated to itself become the host, scavenging the parts of the dying ZGS as it lapsed into extinction.

Another advantage was that ZING-P', which, after all, had been built as a design tool, was just the right device available at just the right time to provide information for the emerging stand-alone IPNS design. IPNS designers were particularly focused on moderator and target design. Carpenter remembers trying out liquid-hydrogen moderators developed by Kleb and Bob Stefiuk. The moderators did not work well but did reveal some unanticipated problems. Nonetheless, with the help of David Mildner from the National Institute of Standards and Technology and Argonne's Ted Postol they were able to do measurements with cold neutrons (that is, neutrons cooled to near absolute zero), an important demonstration. Scientists already had realized that spallation neutrons provide a greater flux of epithermal neutrons useful for studying high energy excitations and determining precise atomic positions. Cold neutrons, on the other hand, provided greater opportunities for diffraction studies of large-scale structures and for high-resolution measurements of low-frequency excitations. Measuring the pulse widths and spectra for

⁵² Jack Holl, *Argonne National Laboratory*, p. 330.

different moderators produced data that would be essential to instrument design for the IPNS. Kleb and Henry Thresh designed and Thresh produced a Zircaloy-clad uranium target that worked well, though the prospect raised safety issues that were challenging to work through. From 1978 to 1979, besides doing research measurements, Carpenter, Kimura, Kleb, and Al Knox of Argonne's Engineering Division measured the energy deposition in the uranium and tungsten targets and developed other technical data needed for the IPNS design.⁵³

IPNS designers also had other concerns. For example, they wanted to know how much heat was generated in the moderators so they could design a cooling system. They also wanted to build flexibility in ZING-P'. Before the ZGS closure was announced, Bob Kleb, who was considered by most to be Price's best engineer, had developed a pneumatically driven actuator to allow sharing of the proton beam with the ZGS. Although that target feature was never used, the design included drawers in a reflector-shield assembly that allowed them to easily exchange moderators and to insert various items near the source for tests.⁵⁴

The IPNS group also needed more experience in building and using the novel instruments necessary for making measurements with the groundbreaking accelerator. This job was assumed by Argonne experimenters, mostly those who had been performing neutron scattering on CP-5. There was some grumbling. For one thing, IPNS measurements, which were performed on pioneering, untried equipment, diverted researchers from on-going, more reliable CP-5 measurements in a field in which careers are made with steady, weekly accumulation of solid data. In addition, Argonne did not have the scientists or support staff to support both CP-5 and the IPNS; inch by inch, the IPNS was taking over CP-5's niche at Argonne. Despite the sacrifice – and the risk that it would be in vain if the IPNS did not pan out – the group built a number of new instruments that would form the basis for the equipment used for the IPNS. To lend a hand and to help jump-start their efforts to recruit IPNS outside users, the budding IPNS group invited colleagues outside Argonne and set up its scientific proposal system to

⁵³ Jack Carpenter, "Pulsed Neutron Source Development at Argonne," pp. 5-6; Catherine Westfall interview with Jack Carpenter, December 19, 2006.

⁵⁴ Jack Carpenter, "Pulsed Neutron Source Development at Argonne," pp. 5-6.

share the use of the new instruments. Even though ZING-P' was mainly a testing device, the new instruments produced many publishable experimental measurements. James Jorgensen, who built a time-focused diffractometer at ZING-P' and later instruments at IPNS, would later note that this was the best diffractometer he had ever used.⁵⁵

When ZING-P' began operation in the fall of 1977 the IPNS's prospects for gaining funding also seemed promising, although from the beginning it was apparent that they would have to compete for its niche. The National Research Council of the National Academy of Sciences, which was charged with assessing research facilities and scientific opportunities using low-energy neutrons in condensed matter physics, declared that "major scientific achievements" could be made "in both present and unexplored areas with new-generation pulsed-spallation neutron sources with their very-high-peak neutron flux and readily tailored neutron spectra." The panel accordingly recommended that the funding agency (by then the newly formed DOE) make "an immediate commitment" to procure "such high-flux sources." The panel specifically suggested that DOE support the very course that the IPNS group – and the Los Alamos group designing the WNR-PSR -- were pursuing: "Design studies should be made and funding support should be scheduled for the phased development stages leading to the creation of a national center with a high-flux (10^{16} thermal neutrons $\text{cm}^{-2} \text{ sec}^{-1}$ peak) pulsed-spallation neutron facility provided with the associated instrumentation required for effective use."⁵⁶

Norman Swanson, an Argonne engineer with experience in building nuclear facilities, was brought in as project manager, and Carpenter, Price, and Kleb provided

⁵⁵ Carpenter devised the time-focused technique used in Jorgensen's diffractometer. Kurt Sköld, Kent Crawford, and Sow-Hsin Chen (Massachusetts Institute of Technology) designed a crystal analyzer spectrometer. Selmer Peterson created the idea for and with Art Reis built a single crystal diffractometer, and Mel Mueller, with the assistance of John Faber and Chuck Borso, created a small angle scattering instrument that would share the same beam and the same detector. Frank Lenkzsus and Paul Day arranged software and hardware so that data could be recorded on the Sigma-5 computer in the Chemistry division. Chuck Pelizzari, George Ostrowski, and experts from the Solid State Science division build a chopper spectrometer. Jack Carpenter, "Pulsed Neutron Source Development at Argonne," pp. 4-6; M. Kimura and John M. Carpenter, "Living With Neutrons"; Catherine Westfall interview with Jack Carpenter, December 19, 2006; Catherine Westfall interview with Sunil Sinha, March 6, 2007.

⁵⁶ National Academy of Sciences, "Neutron Research on Condensed Matter: A Study of the Facilities and Scientific Opportunities in the United States," Washington D.C., 1977.

DOE officials with what Carpenter later characterized as an “innumerable” succession of planning and cost documents. In line with the National Research Council suggestion of phased development, DOE officials asked IPNS planners to give the cost of a prototype, IPNS-I, separate from the 10^{16} machine, IPNS-II. Carpenter later remembered that he and Price “recognized the risk that if we once separated the two components of the project, only IPNS-I might be funded.” They worried, however, that if they “did not respond,” they “might lose it all” and, therefore, complied with the request. They accordingly responded that although the total facility would cost \$70 million, they could build the IPNS-I for \$9 million. They carefully stipulated, however, that the low IPNS-I cost assumed IPNS-II construction; without the second phase, IPNS-I would cost more, since staff funded for the larger project would do double duty if both projects were carried out together.⁵⁷

In April 1977, Argonne sent the formal request for the two-staged project and the next year prepared a report giving details. The report explained that the IPNS-I would be an upgrade of ZING-P' and serve as a prototype for IPNS-II. It would employ the Booster II proton synchrotron, now called the Rapid Cycling Synchrotron (RCS), and use the same negative ion stripping injection scheme developed in Booster I. The ion source was mounted in the terminal of another ZGS component, a 750-kV Cockcroft-Walton preaccelerator. In such a system, ions are created in a hydrogen plasma. Electromagnetic fields then separate negative hydrogen ions, which are subsequently accelerated from the high-voltage Cockcroft-Walton terminal and swept into a linear accelerator that further accelerates them. The negative hydrogen ions then pass through bending and focusing magnets and enter into the RCS, where a polymer film “stripper foil” strips off the electrons to produce a circulating proton beam that electromagnetic forces then accelerate to produce a 500 MeV pulsed beam for IPNS-I. A heavily shielded beam line carries the pulsed proton beam to a target of depleted uranium to produce short pulses of fast neutrons by spallation. Moderators arranged around the target slow down the fast

⁵⁷ Quotes from John M. Carpenter, “Living With Neutrons” and Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 7. Also: Jack Holl, *Argonne National Laboratory*, p. 412.

neutrons to the desired (milli-electron-volt) energies. The resulting neutrons then pass through 12 beam holes to support a wide array of measuring instruments in IPNS-I.⁵⁸

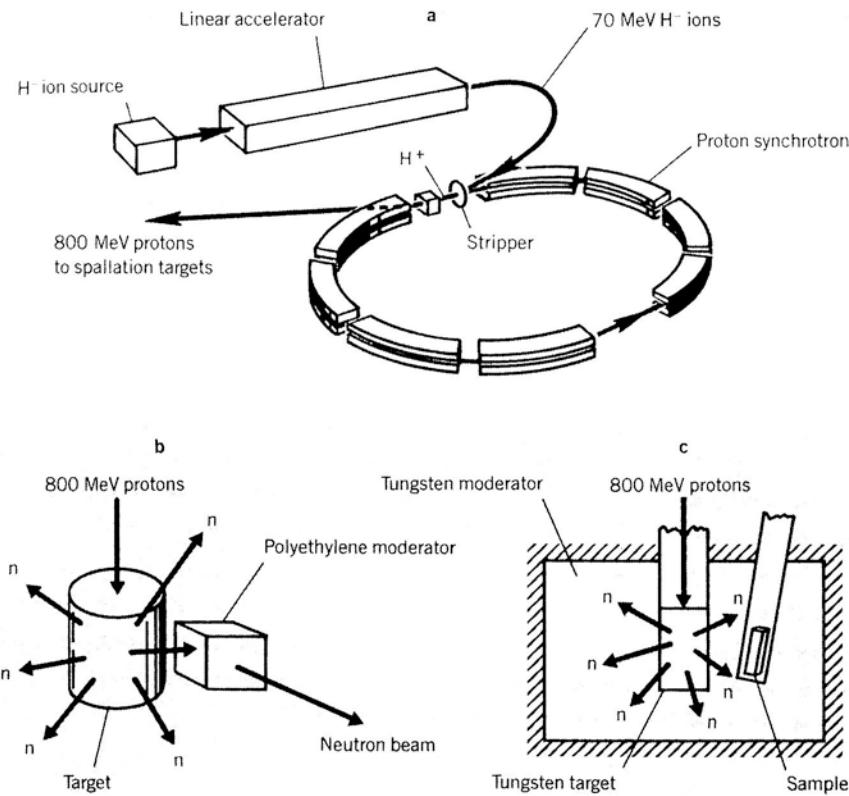


Figure 1: Early IPNS Plans. From: “Schedule 44 – Construction Project Data Sheet for Intense Pulsed Neutron Source (IPNS),” 1977. The lower left shows a source for slow neutron scattering; the lower right shows a fast neutron radiation effects facility.

The report also described IPNS-II (Figure 1), which would be a 800-MeV high-flux (10^{16} thermal neutrons $\text{cm}^{-2} \text{ sec}^{-1}$ peak) neutron source based on a new synchrotron called the High Intensity Synchrotron, or HIS. The larger and more powerful HIS would be placed in the abandoned ZGS main-ring tunnel, which would serve as its radiation shield. The pre-accelerating system consisted of a negative hydrogen ion source and a

⁵⁸ A beryllium reflector around the target and moderator enhanced the slow neutron flux. The original plan to cool the beryllium to liquid nitrogen temperature did not work out. Personal communication, Jack Carpenter, June 7, 2007. Text references: Jack Holl, *Argonne National Laboratory*, p. 412; J. M. Carpenter, D. L. Price, and N. J. Swanson, “IPNS: A National Facility for Condensed Matter Research,” pp. 67-78.

750-kV Cockcroft-Walton, like IPNS-I, but IPNS-II would employ a more powerful 100-MeV linear accelerator. The IPNS-II target would be made of steel-plated depleted uranium or a uranium-molybdenum alloy. The envisioned site also included a Radiation Effects Facility, which would continue work begun at CP-5 by a group led by Tom Blewitt. This facility would employ the IPNS proton beam with its own separate target, which would be surrounded by irradiation cryostats kept at helium temperatures (4 K).⁵⁹ (Figure 2)

By the time of the report, it was already clear that the project would benefit not only from the demise of the ZGS, but also by the death of CP-5, which, like the ZGS, would close in 1979. Scavenging equipment was a substantial advantage. Initial estimates indicated that the savings gained from using existing ZGS equipment would save at least 25% of the cost of the facility.⁶⁰

⁵⁹ J. M. Carpenter, D. L. Price, and N. J. Swanson, “IPNS: A National Facility for Condensed Matter Research,” pp. 73-75; Department of Energy, “Schedule 44 – Construction Project Data Sheet for Intense Pulsed Neutron Source (IPNS),” 1977.

⁶⁰ Department of Energy, “Schedule 44 – Construction Project Data Sheet for Intense Pulsed Neutron Source (IPNS),” 1977.

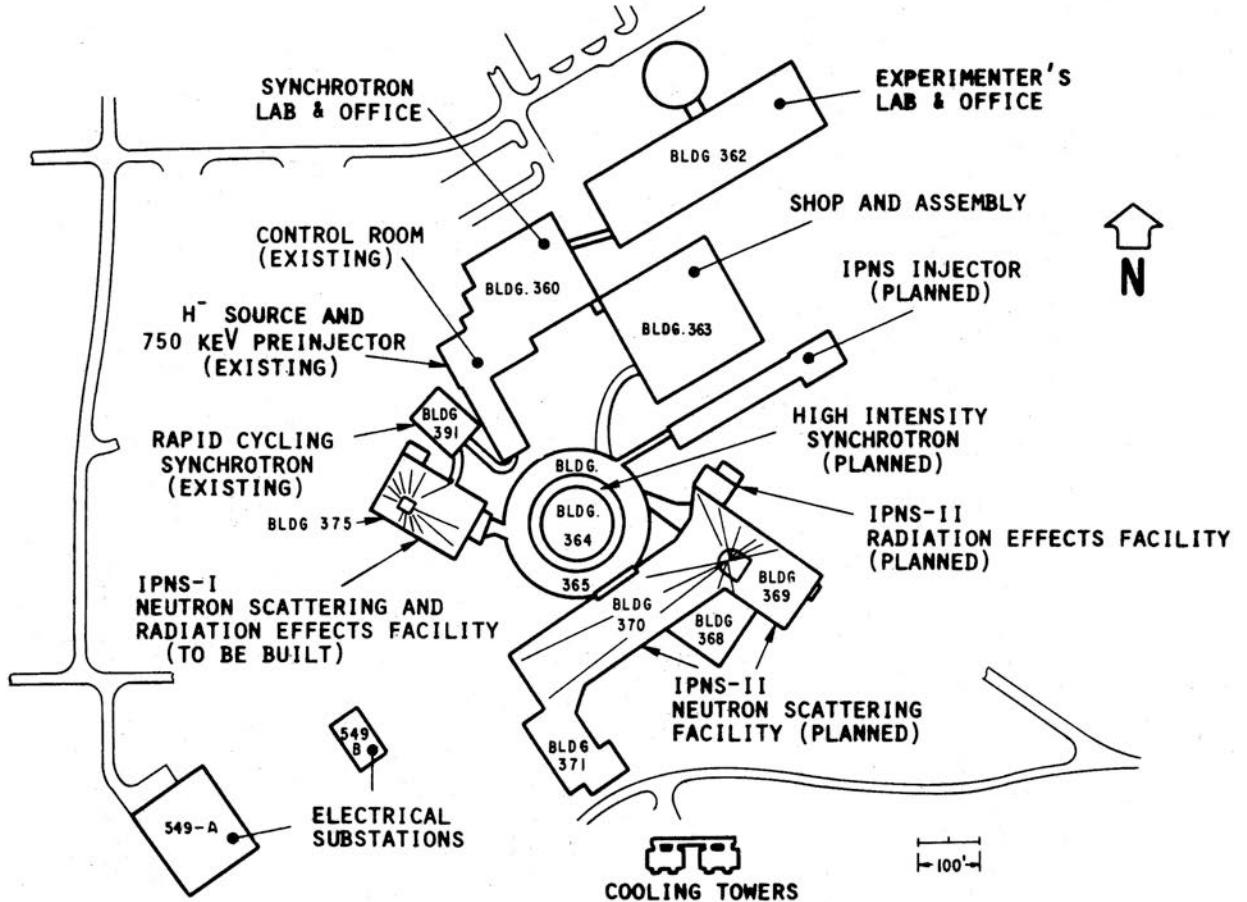


Figure 2: IPNS Facility as described in J. M. Carpenter, D. L. Price, and N. J. Swanson, "IPNS – A National Facility for Condensed Matter Research," ANL-78-88, November 1978.

At this stage IPNS designers reaped another benefit from the ZGS – they would take traditions as well as equipment. ZGS scientists had been among the first in high energy physics to stress the importance of outside user access when it began operation in 1963. Carpenter and Price would later judge that one of the greatest resources obtained from the ZGS was the user-friendly tradition for operating the IPNS. Although this approach is key in gaining the constituency political support and the funding of a large instrument – and by this time it was the approach expected by DOE for nuclear and high energy physics facilities -- up until this time it had not been the usual practice at U.S. neutron facilities because of their relatively modest size. An extra advantage of early

IPNS outside user involvement was that only a small percentage of materials scientists used neutron scattering devices. By publicizing their efforts, they could hope to educate potential users about the capabilities of the device, thereby building interest and creating a larger user community to advocate for continued resources for the machine.⁶¹

IPNS designers highlighted their plans for operating the accelerator in their 1978 report. In a section devoted to explaining the “policy and for operation and use” of the IPNS, they announced that the accelerator would “be a user-oriented national facility available to all interested and qualified scientists,” noting that they expected a “majority of users … to come from outside ANL, representing universities, industrial corporations, and government-sponsored research laboratories throughout the nation.” They were not shy about touting the novelty of their plans: they stressed that the “user orientation” of the IPNS would represent “a unique mode of operation for neutron facilities in the U.S.”⁶²

User response to the 1978 document was good. In the year of its distribution proposals streamed in from around the world. In addition to a proposal for inelastic-scattering and diffraction studies, one proposal was submitted for neutron-damage studies on materials for the Tokamak Fusion Test Reactor.⁶³

⁶¹ Catherine Westfall interviews with Jack Carpenter, October 8, 2001, and David Price, November 16, 2001. Edwin Goldwasser, who headed the users group at the ZGS, would later say that his ZGS experience was key in the late 1960s in setting up policies for assuring access at Fermi National Accelerator Laboratory, where he served as the first deputy director. For more on how the push for outside user access shaped the development of Fermilab, see Lillian Hoddeson, Adrienne Kolb, and Catherine Westfall, *Physics, the Frontier, and the Rise of Megascience*, forthcoming, University of Chicago, 2008. For more discussion on the importance of gathering interested users for large projects, see Robert Smith, *The Space Telescope* (Cambridge: Cambridge University Press, 1989). Gathering a constituency would also be important for the experimental program of the Advanced Photon Source in the 1990s, as described in Catherine Westfall, “A Different Laboratory Tale: Fifty Years of Mössbauer Spectroscopy” *Physics in Perspective*, 8 (2006), pp. 189-213.

⁶²J. M. Carpenter, D. L. Price, and N. J. Swanson, “IPNS: A National Facility for Condensed Matter Research,” p. 174.

⁶³ J. M. Carpenter, D. L. Price, and N. J. Swanson, “IPNS – A National Facility for Condensed Matter Research,” p. 34.

Times Get Hard

Even though plans for the IPNS rose along with the promise of resources, the project faced a series of adverse conditions just as its construction began in the late 1970s. The first blow came in late 1978 when DOE faced a tight budget that drastically narrowed the IPNS's niche. To the dismay of Carpenter and Price, DOE officials therefore decided to proceed with IPNS-I only and provided a mere \$6.4 million for the job. Although the IPNS-II was not formally killed, Argonne was forbidden from spending any money – even the director's discretionary funds – on its design. At that point, as Carpenter later recalled, they faced the “agonizing decision” of “whether to accept the project or not, realizing the difficulty of the funding shortfall.” After further negotiation, DOE agreed to the plan of using the allotted money for facilities construction only and allowed Argonne to submit a separate proposal for equipment. Although the IPNS group estimated that the equipment would cost \$3 million, with what they thought was the usual prudent contingency for the risk of unexpected or unusual circumstances, DOE balked. In the end IPNS received \$2.4 million for equipment funding and agreed to be ready for operation and use in spring 1981. According to their updated plans, the IPNS complex would include the Cockroft-Walton and a 50 MeV linear accelerator, the 500 MeV RCS, the spallation target, and the equipment needed for neutron scattering measurements, as well as the Radiation Effects Facility and its separate target, both in the same massive shield.⁶⁴ (Figure 3)

⁶⁴ Quotes from Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 7. “IPNS Newsletter,” May 1979, p. 1. Also, Jack Holl, *Argonne National Laboratory*, p. 413.

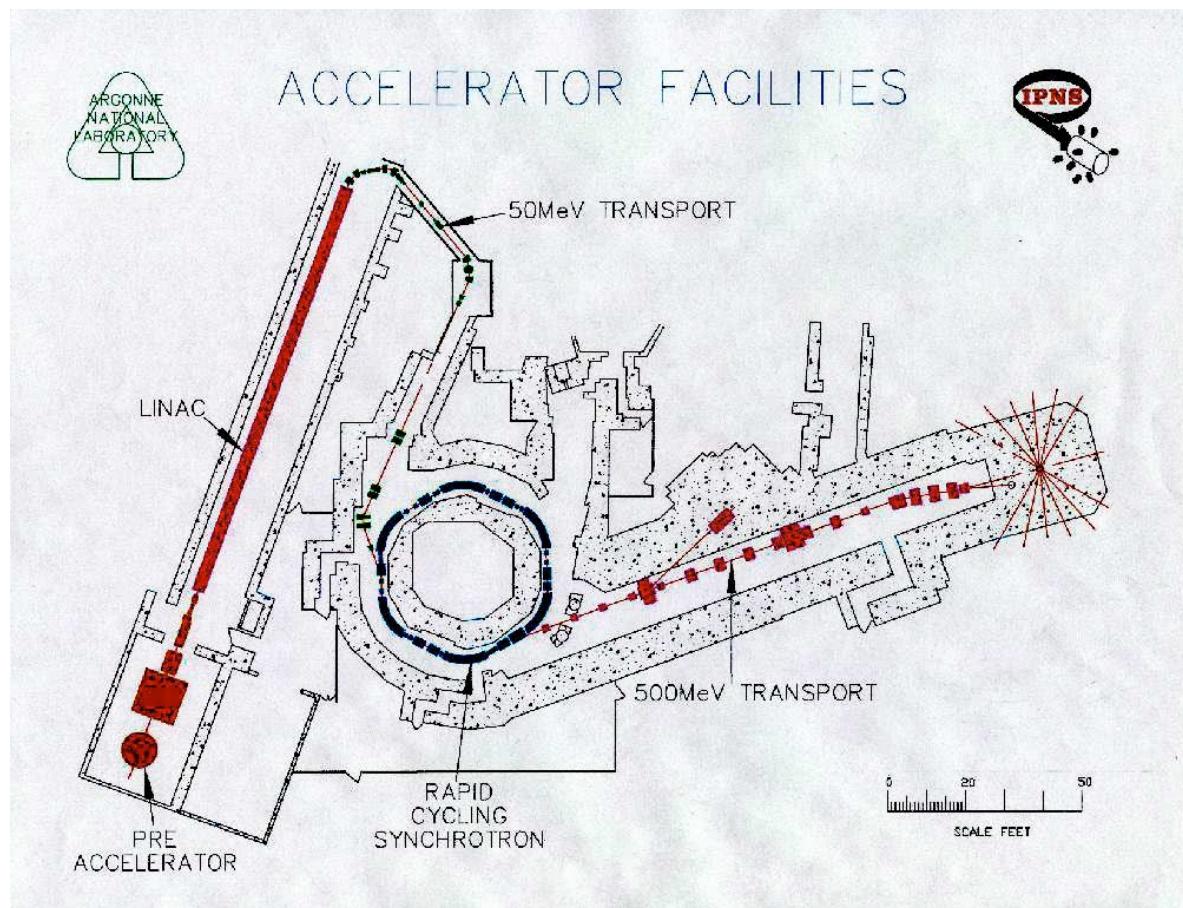


Figure 3. IPNS as eventually built. From: "Presentation to DOE Neutron Scattering Review Panel, August 3-4, 1980."

Construction began in May 1979 with, in Carpenter's words, the "grim determination" to adapt, despite the disappointment of their scaled-back plans and deep concern about the tight schedule and limited budget, which they had to meet regardless of rampant inflation. One advantage was that the Argonne environment yielded more usable resources than expected. Carpenter later calculated that about \$40 million worth of equipment was salvaged from the ZGS and CP-5. The ZGS "inheritances" included not only the accelerator system (the RCS, 50-MeV linear accelerator, and negative hydrogen ion source), but also buildings and infrastructure, including water, cooling towers, electrical power, and roads. For its part, the CP-5 provided an instrument and various instrument components as well as shipping casks, which became beam stops. As was

typical at Argonne, the most important resource was smart people. In this case, in Carpenter's words, those "with experience in accelerator and neutron source technology" and also those "with world-class expertise in neutron scattering."⁶⁵

Robert Kustom, long-time Argonne accelerator expert, assumed responsibility for the IPNS accelerator systems. He tapped veteran Argonne accelerator experts who were available to tackle the difficulties, including Yang Cho and Ed Crosbie, who had both been central to the development of the ZGS. Because Carpenter's skills lay more in design and construction than in administration, as IPNS construction was gearing up he opted for the job of technical director, a job that at this stage mainly involved development of moderators, targets, and instruments. A young research physicist, Bruce Brown, who had worked with Blewitt's group on radiation effects, agreed to be operations manager. Price agreed to become the project director. This team began construction of the IPNS alongside the ZING-P' run, which continued to provide engineering data and research until it was terminated in August 1980 to allow installation of the beam transport system connecting the RCS and the IPNS.⁶⁶

Although Kustom and his staff were valued additions to the IPNS effort, the times were not without strain. In their words, the staff consisted mainly of specialists who had previously worked on the ZGS and "had a high energy physics background." Seeing the IPNS build on the abandoned bones of the high energy physics machine could not have been easy for them. The process was further complicated by what Kustom later described as a "major culture shock and clash between the accelerator staff and the instrument, materials science, and condensed matter scientific staff." High energy physics experimenters at that time "tended to acquire and integrate data over long periods of time, sometimes years, and often were tolerant of frequent shut downs," especially since many of them had built accelerators early in their careers and understood that accelerators were being pushed to their limits to get the best possible performance. By

⁶⁵ Jack Carpenter, "Pulsed Neutron Source Development at Argonne," p. 7 and John M. Carpenter, "Living With Neutrons." For further analysis of the importance of smart people in the development of science at Argonne, see Catherine Westfall, "A Different Laboratory Tale: Fifty Years of Mössbauer Spectroscopy," pp. 189-213.

⁶⁶ J. R. Simpson, R. Martin, and R. Kustom, "Improvements of the IPNS Accelerator System," *History of the ZGS 500 MeV Booster*, p. 15, "IPNS Newsletter," September 1980, p. 1.

contrast, “materials science users previously got their neutrons from a nuclear reactor,” and because of safety concerns, reactors were built conservatively and operated very reliably. In addition, “many materials science and condensed matter users” performed experiments with “highly unstable crystals or samples.” Their data runs were short, and “unexpected shutdowns of a day or more often interrupted their data collection stream and forced the data collection to be aborted.”⁶⁷

Kustom later remembered feeling he had his work cut out for him. Potential IPNS users clearly had high expectations for the reliability of the accelerator, and given the tenuous beginning of the project, those building the project could ill afford to disappoint them. Kustom recollects that the accelerator availability when he took over in 1978 “was on the order of 65% or a bit worse,” a level of reliability that was typical for high energy physics research facilities but was sure to appall materials science users. Part of the problem was that “some hardware was forced to be hand-me-downs or compromised by limited funding,” but an additional problem was that they experienced “the kinds of infancy problems that occur when first-of-a-kind equipment that is not commercially available is brought on line.” In his opinion, the “most difficult hardware problems … were related to the pulsed extraction system magnet, the kicker magnet system, and the stripping foils.” The “basic machine parameters and the proof of design” had been successfully demonstrated by the ZING prototypes. However, there were also accelerator physics problems that needed to be solved, particularly beam losses at injection and extraction and in the extraction septum magnet.⁶⁸

Those constructing the rest of the facility had their own technical problems. Price remembered fighting to keep the ZGS shielding from being sent to the nearby Fermilab. To some in DOE and elsewhere it made more sense to shift resources from one high energy physics project to another rather than have resources from a high energy physics project shift to a condensed matter accelerator. After all, ZGS and Fermilab were both

⁶⁷ J. R. Simpson, R. L. Martin, and R. Kustom, “Improvements of the IPNS Accelerator System,” *History of the ZGS 500 MeV Booster*, pp. 15-16.

⁶⁸ Quotes from: J. R. Simpson, R. Martin, and R. Kustom, “Improvements of the IPNS Accelerator System,” *History of the ZGS 500 MeV Booster*, ANL-HEP-TR-06-44, p. 16. Also: “IPNS Newsletter,” March 1980, p. 1; “IPNS Monthly Report,” September 1980, p. 2.

high energy physics accelerators managed by the same DOE office. IPNS builders, who desperately needed to use whatever was available from the ZGS to keep to their very tight budget, ultimately prevailed. Carpenter remembered a long difficulty caused by faulty communication with the contractor supplying the cooling systems for the moderator. The problem was finally resolved when they realized the contractor had been told the systems were to be kept cold by using liquid methane but had somehow not been told that they not only needed to be cold, but also the systems must always be full of the substance. For his part, Swanson worried that the accelerator would not start on schedule in spring 1981 because of picketing by a union of electrical workers in March and April and again in October of 1980 due to a “jurisdictional dispute” that caused periods of time during which “no construction workers reported to work.”⁶⁹

Despite these challenges, IPNS builders made their promised deadlines. As Price announced “at 3 PM on Tuesday, May 5, 1981, the first protons were delivered to the radiation effects target in the IPNS-I facility,” and on “August 4, the 500 MeV proton beam hit the neutron scattering target for the first time.” Price went on to note that they had protons on the target exactly a year after ZING-P' was shut down, which he judged to be “a most creditable performance for all involved.” In addition, “The first four neutron scattering instruments were ready as planned to receive the first neutrons on August 4, as was the data acquisition system.” With construction complete, Swanson went on to other Argonne duties.⁷⁰

Preparations were also being made for the planned, large user program. In February 1981 Argonne issued a call for proposals and called together a users group meeting at the American Physical Society meeting the next month. In June, the first IPNS Program Committee – composed of eminent scientists from outside Argonne -- a milestone because, as Price noted, “This was the first meeting of its kind at a neutron facility in the U.S.” This program committee “received a total of 119 proposals submitted and selected 38 to run during the first round of user experiments.” Although

⁶⁹ Quotes from “IPNS Monthly Report,” October 1980, p. 1. Also: Catherine Westfall interview with David Price, November 16, 2001 and Jack Carpenter, “Pulsed Neutron Source Development at Argonne,” p. 8.

⁷⁰ Quotes from “IPNS Monthly Report,” May 1981, p. 1 and “IPNS Monthly Report,” August-September 1981, p. 1.

Argonne users conducted the initial research, by fall 1981 outside users were using instruments for measurements approved by the committee.⁷¹

Losing Their Niches?

Despite success and progress, as construction ended and the IPNS began operation, conditions became even more adverse. Although IPNS researchers did not know it at the time, the problem started with a DOE review panel led by William Brinkman from Bell Telephone Laboratories, which visited the laboratory in August 1980. The Brinkman panel was meant to follow up on the NRC recommendations. Subject to funding constraints, the DOE charge was to assess, first, “the continuing validity of the 1977 National Research Council recommendation for pulsed-spallation sources to complement existing steady state reactor sources and second, “the requirement for and necessary attendant resources (manpower and dollars) for a supporting materials research program located at and directly associated with currently authorized neutron-spallation sources.” DOE stipulated that “if the review determines that there is a continuing requirement for pulsed-spallation capability within the constraints of the present budget outlook,” reviewers should address “the performance characteristic of the best pulsed sources to meet program needs” and “the amount and specific source of funds within the DOE neutron scattering program required to support an optimum program at this facility.”⁷²

By this time, a panel of accelerator and neutron facilities experts led by Richard Neal of the Stanford Linear Accelerator Center had produced a report that provided, according to an IPNS monthly report, “a good picture of the plans, status, and problems” of the IPNS as well as the WNR-PSR at Los Alamos and concluded “that both projects should be able to reach their goals.”⁷³

⁷¹ “IPNS Monthly Report,” August-September 1981, p. 1.

⁷² “Presentation to DOE Neutron Scattering Review Panel, August 3-4, 1980.” In addition to Brinkman, the panel included John McTague from UCLA, John J. Rush from the National Bureau of Standards, Robert Birgeneau from the Massachusetts Institute of Technology, Borris Batterman from Cornell, and Frederick Vook from Sandia National Laboratory.

⁷³ “Presentation to DOE Neutron Scattering Review Panel, August 3-4, 1980.”

In October 1980 the Brinkman panel released its report. Panelists went out of their way to celebrate the importance of neutron scattering research, stating that the field “provides essential and unique information about the microscopic nature of a broad spectrum of phenomena occurring in fields as diverse as materials science and biology.” Panelists also made the case that the U.S. had lost its dominance in the field to Europe, where France, Germany, and the United Kingdom jointly operated the research reactor at ILL, which enjoyed more than twice the funding received by all U.S. neutron scattering research. The panel even requested a \$6 million a year funding increase for neutron scattering.⁷⁴

However, panelists had to take into account their charge as well as the tenor of the times. When discussing their report with *Science*, James Kane, who as director of DOE’s Office of Basic Energy Sciences was responsible for overseeing U.S. neutron scattering research, stressed his concern that “neutron scattering expenses” would “swamp his research budget at the expense of other energy-related programs” at a time of dwindling resources. Anticipating such sentiments, panelists drew sharp distinctions and made hard choices. They judged that the two existing 15-year old research reactors, Brookhaven’s HFBR and Oak Ridge’s HFIR – which were after all based on tried-and-true technology -- would “be the mainstays of our neutron scattering research programs” through the 1990s, and funding for these reactors had been too low in the 1970s “for continued vitality.” Therefore, they assigned “first priority to *increased* support of the two reactor facilities.”⁷⁵ The reactors were “exploitive competitors” that threatened to hobble the IPNS by reducing resources. Even worse, the Los Alamos project became an “enemy” that threatened “competitive exclusion”; that is, it was poised to steal the IPNS’s niche.⁷⁶ In light of funding constraints, committee members explained, only one pulsed neutron source could be supported, and Los Alamos’s WNR-PSR, a proton storage ring operating with facilities paid for by DOE’s Office of Military Operations, had a winning

⁷⁴ “Report of the Review Panel on Neutron Scattering,” October 22, 1980.

⁷⁵ Quotes from Arthur Robinson, “Will U.S. Skip Neutron Scattering Derby?” *Science* 211 (1981), p. 263 and “Report of the Review Panel on Neutron Scattering,” October 22, 1980. For more on Brookhaven’s High Flux Beam Reactor, see Robert Crease, “Anxious History: The High Flux Beam Reactor and Brookhaven National Laboratory, *Historical Studies in the Physical and Biological Sciences* 32 (2001), pp. 41-56.

⁷⁶ Colin Townsend, Michael Begon, John L. Harper, *Essentials of Ecology*, p. 197.

advantage: it would run as an offshoot to that program and therefore draw little money from the limited neutron scattering budget. Therefore, to the dismay of Argonne researchers, the IPNS fell prey to the Los Alamos machine. The Brinkman panel recommended supporting the Los Alamos pulsed source and terminating IPNS-I unless funding increased.⁷⁷

Argonne's IPNS had failed to justify its existence in the battle for scarce resources with neutron scattering machines at Brookhaven, Oak Ridge, and Los Alamos and therefore appeared to be on the brink of losing its niche in DOE's budget. The news could not have come at a worse time for the laboratory. Ronald Reagan had been elected President in 1980, and shortly after assuming office in 1981 he began trimming budgets in line with his policy of reducing government spending. Various reviews were ordered of the entire national laboratory system and the findings were not positive. Rumors swirled that the system might be closed. Argonne's situation seemed particularly precarious. The competition for research funding became increasingly cut-throat as laboratories, universities, and industry vied for diminishing federal funding. Under President Carter the crunch had been eased by increased funding for environmental programs, but the Reagan administration made clear that these budgets would also be slashed. And the laboratory would get no relief from the civilian reactor program: LMFBR continued to face a skeptical Congress and White House.⁷⁸

Walter Massey, who became Argonne's director in 1979, faced a rather frightening situation. Since the late 1970s, in light of the problems facing other laboratory projects, Argonne managers had declared the IPNS to be the laboratory's "highest priority."⁷⁹ The laboratory had been looking to the IPNS not only for funding, but also for users, prestige, and a continued rationale for existence. It was a perilous time, a time when it appeared only the fittest would survive. And the potential loss of IPNS's niche threatened the niche of the laboratory itself at a time when the fate of the entire national laboratory system was in doubt.

⁷⁷ "Report of the Review Panel on Neutron Scattering," October 22, 1980.

⁷⁸ Jack Holl, *Argonne National Laboratory*, p.398. For a discussion of budget problems of the time, see pp. 389-403.

⁷⁹ "DOE Project Review," Project Review with Director of Office of Energy Research," May 1980.

Securing a Niche?

In the wake of the Brinkman panel report, DOE decided to terminate IPNS funding in 1983. Thus, in early 1981, the IPNS team labored to bring to life a machine that was already slated for an early death. In the words of Brown, “it was a real struggle. There was nothing to do but try to hang in there and get the job done the best we could.”⁸⁰

In the meantime, Massey, together with Kenneth Kliewer who became the Associate Laboratory Director for basic research in early 1981, sprang into action to do what he could to save the fledgling project. Gerard Lander, a former CP-5 user who had left Argonne to work at the ILL, later remembered that Massey gathered him and others to help. In Lander’s words, the Brinkman panel judgment was “a devastating blow” to Massey, who “took it seriously and personally.”⁸¹

Massey wanted to overturn the Brinkman panel recommendations, but this was a difficult and risky task. Massey had done a postdoctoral fellowship at Argonne in the Chemistry and Solid-State Science divisions. Although he was therefore familiar with IPNS science, he was a theorist without particular expertise in neutron scattering. How could he possibly rebut the recommendation of expert peer review? Another problem was that George (Jay) Keyworth, a former Los Alamos manager, had just been appointed Reagan’s science advisor. IPNS supporters worried that a high-profile fight to oust Los Alamos from the single niche allowed for a U.S. pulsed neutron source would backfire.⁸²

Although they mentioned IPNS scientific potential, Massey and Kliewer ended up emphasizing an institutional and regional rather than a scientific rationale for continued

⁸⁰ Quote from Catherine Westfall interview with Gerard Lander and Bruce Brown, June 22, 2006. Also, Jack Holl, *Argonne National Laboratory*, p. 414.

⁸¹ Quote from Catherine Westfall interview with Gerard Lander and Bruce Brown, June 22, 2006. Jack Carpenter later remembered that he simply never believed during this period that the IPNS would die prematurely and simply re-doubled his efforts on the technical side. Personal communication, Jack Carpenter, October 5, 2007.

⁸² Jack Holl, *Argonne National Laboratory*, p. 352; Biographies of Aerospace Officials and Policymakers, National Aeronautics and Space Administration, NASA History Division, <http://history.nasa.gov/biosk-n.html>; Catherine Westfall interview with Gerard Lander and Bruce Brown, June 22, 2006.

IPNS operation. They started with the acknowledgement that Argonne would be damaged if the IPNS was terminated and then stressed the greater damage that would result. Argonne's "health and vitality" depended on the IPNS, Massey told the DOE. And as they argued in a September 1981 position paper to the laboratory's contractor, AUA, "Argonne, and the basic energy sciences effort in the Midwest, would be left without a major research facility, thereby adversely affecting a large segment of the university community and the relationship between the laboratory and the universities."⁸³

Lander remembered that they lobbied mid-level officials like Donald Stevens and Louis Ianniello of DOE's Materials Science division. However, they consciously avoided a large-scale letter-writing campaign and also did not press the issue with the Illinois Congressional delegation "because we were worried that doing so would inflame the situation and get Jay Keyworth involved."⁸⁴

Alongside Massey's behind-the-scenes lobbying, IPNS researchers pressed their case within the materials science community. They emphasized that pulsed neutron sources were the way of the future. All new and planned sources were accelerator-based, including the KENS spallation source that had begun operation in 1980, which Yoshikazu Ishikawa and Watanabe developed at the Laboratory for High Energy Physics, KEK, in Japan's Tsukuba "Science City"; a 1100 MeV linear accelerator with a storage ring, SNQ, being proposed by German researchers at Karlsruhe and Jülich that could produce a neutron flux of 10^{17} n/cm² -sec; and a British project (later named ISIS) employing a 800 MeV proton synchrotron at Rutherford Laboratory that was slated to provide a neutron flux of 10^{16} /cm²-sec and scheduled to begin operation at the end of 1984. Because the IPNS would be a little more powerful than the Japanese machine, it would be the most powerful pulsed source of its kind until Los Alamos and European facilities began operation. Thus, the IPNS would provide early scientific results, test the scientific utility of such a device, and also produce crucial technical data helpful to the development of the other projects.⁸⁵

⁸³ Quotes from Jack Holl, *Argonne National Laboratory*, pp. 414 and 415.

⁸⁴ Quotes from Catherine Westfall interview with Gerard Lander and Bruce Brown, June 22, 2006. Also, Jack Holl, *Argonne National Laboratory*, p. 415.

⁸⁵ Like the IPNS, the British machine rose from the ashes of an abandoned high energy physics accelerator. Gerard Lander, "IPNS: Pointing the Way to New Frontiers in

IPNS researchers also stressed the scientific potential of the machine and their ongoing efforts to make the IPNS available to outside users. A September 1981 *Science* article quoted Stevens explaining, “They’re fighting for their lives.” In the opinion of *Science*’s Arthur Robinson, to avoid this fate, Argonne “not only” had to “demonstrate the scientific productivity of its pulsed source,” but also had to “develop a user community in a land where researchers are generally uneducated as to the benefits of neutron scattering.” It was, he concluded, “a tall order to fill in a short time.”⁸⁶

At this point Argonne researchers were quick to point out their already developed user-friendly policies, which were unique in the U.S. Price and Carpenter told Robinson that in a departure from previous practice in neutron scattering, they had assigned “25 percent of beam time to the exclusive use of the research groups that develop and use the instruments.” They also got a bit of publicity about their experimental capabilities, which at this stage included uncooled, graphite-reflected polyethylene moderators and targets of depleted uranium. Robinson also reported that four instruments were operational: a single crystal diffractometer, two powder diffractometers, and a low-resolution, medium-energy chopper spectrometer. In addition, three more were being built: a high-resolution chopper spectrometer, a small-angle diffractometer, and a crystal analyzer spectrometer. (The choppers, which remove unwanted parts of the neutron spectrum, are not necessary for such applications as diffraction but are necessary for chopper spectrometers in pulsed sources. These applications require additional choppers or narrow-band energy selectors if used without a pulsed source.) Robinson also noted the activities of the June program committee. Less flattering was the report that due to budgetary restrictions, the IPNS was able to run only half the expected time, and thus only 39 proposals were accepted, 10 of which were for radiation damage studies.⁸⁷

Materials Science,” *logos*, TPD-LOGOS-1; Arthur Robinson, “Argonne’s Pulsed Neutron Source Turned On,” *Science*, 213, September 1981, pp. 1097-1099. For more on the development of the Japanese device, see Motohoru Kimura with John M. Carpenter, *Living with Nuclei*.

⁸⁶ Arthur Robinson, “Argonne’s Pulsed Neutron Source Turned On,” p. 1097.

⁸⁷ A chopper is a slotted, phased rotating device that defines a short pulse of neutrons. Quotes from Arthur Robinson, “Argonne’s Pulsed Neutron Source Turned On,” p. 1097. Also: “IPNS Users Bulletin,” October 1981, “IPNS Users Bulletin,” May 1982.

In November 1981 Price stepped down as IPNS director to be replaced by Lander, who brought valuable experience from ILL in running a robust users program. In Lander's words, for the next year they "did everything we could think of to save ourselves." For Lander's part that meant doing what he could to help the project adapt by continuing improvement of accelerator performance, instrument development, and building the user program. Lander and his team solicited another round of proposals, and in March 1982 the program committee assessed 79 proposals and accepted 37. In Lander's words, the proposals showed a particular interest in "spectroscopy at high energy transfer and low momentum transfer," an area "unique to pulsed sources." As IPNS experimenter Chun Loong later explained, the early round of experiments absolutely had to achieve two goals. "One was to prove that studies of the structure of crystals performed by Jorgenson and others using the IPNS and the powder diffractometers were equally good or better than such work performed by reactors." In addition, "we needed to show the promise for groundbreaking future work." An early example of the latter was the innovative polarized neutron reflectometer developed by Gian Felcher. Although the device was originally developed to measure the penetration depth of a magnetic field, it proved surprisingly well-suited for examining polymer and magnetic films and surfaces.⁸⁸

As Lander reported to users in May 1982, with the exception of difficulties with the innovative cryogenic moderator, which was redesigned and reinstalled,⁸⁹ "all systems have worked extremely well." He was particularly proud of accelerator operation, which improved so that they were able to perform "almost all the scheduled experiments" up to that point. Machine performance continuously improved so that by the end of the year, it had 90% reliability.⁹⁰

⁸⁸ Quotes from "IPNS Users Bulletin," May 1982 and interview with Catherine Westfall interview with Chun Loong, February 16, 2007. Also: "IPNS User's Bulletin," October 1981.

⁸⁹ As Carpenter later explained, the problem with the innovative cryogenic of "cold" moderators resulted from a design decision made in haste. For more on the details of the problems and how it was fixed, see Jack Carpenter, "Pulsed Neutron Source Development at Argonne," p. 9.

⁹⁰ "IPNS Users Bulletin," May 1982.

A stream of other visitors also came to see the facilities, including local politicians; Stevens, Ianniello, and Alvin Trivelpiece from DOE; National Science Foundation director John Slaughter; various congressmen; and Keyworth. As reported in the users newsletter, Brown and Lander had “become so expert at 25 minute tours that rumor has it they are being sought after as White House tour guides.” In the meantime, Massey met with the other laboratory directors, and Douglas Pewitt, acting director of DOE’s Office of Energy Research, stressing the political inadvisability of shutting down the IPNS so soon after its operation and on the heels of the ZGS and CP-5 closures.⁹¹

In the midst of these high-level negotiations, Stevens and Ianniello convened another review panel, again chaired by Brinkman, this time to focus exclusively on pulsed neutron sources. In June 1982 panelists visited both Los Alamos and Argonne.⁹²

This time the panel reported back with good news. In December 1982, Lander proudly quoted the panel’s finding that Argonne had made “outstanding progress in establishing a strong user program.” As *Science* noted, the second Brinkman panel also declared that “without question” the IPNS had “demonstrated its value in a variety of experiments and will be effectively used for research in condensed matter physics, materials science, and molecular biology for the next few years if funding is available.”⁹³

Thus by late 1982 the IPNS had two strong arguments for its continued existence. Massey had warned that damage would occur to the larger ecosystems of the national materials science community as well as the Midwestern research community if the IPNS were lost and Argonne suffered. (This argument undoubtedly resonated at least in part because the loss of Argonne would have damaged the national laboratory system and its patron, DOE, at a threatening time.) In addition, a group of materials science experts judged that the IPNS was a valuable research tool for their field. These arguments were

⁹¹ Quotes from “IPNS User Bulletin,” May 1982. Also: Jack Holl, *Argonne National Laboratory*, p. 415.

⁹² “IPNS Users Bulletin,” December 1982. Catherine Westfall interview with Gerard Lander and Bruce Brown, June 22, 2006.

⁹³ Quotes from “IPNS Users Bulletin,” December 1982. Second quote also in Arthur Robinson, “Pulsed Neutron Sources Okayed,” *Science* 217 (1982), p. 922.

persuasive enough that DOE approved a few more years of funding, although the facility continued to operate on a limited schedule.⁹⁴

The next two years brought change. In spring 1984 the National Academy of Sciences of the National Research Council convened a committee, led by the scientific elder statesman Frederick Seitz (then at Rockefeller University) and Dean Eastman at IBM, charged with assessing “priorities for major facilities for materials research.”⁹⁵ The recommendations of the committee made clear that the IPNS had not successfully made the case that pulsed sources were the way of the future. Committee members gave first priority to a 6-GeV synchrotron radiation source capable of producing an increase in brightness (flux per unit area) greater by orders of magnitude than any previously available, thus opening the possibility of studying material structure directly through imaging. With a nod to the argument that the materials science community still needed neutron sources as well as the photon-producing synchrotron radiation sources,⁹⁶ members gave second priority to a new high-flux reactor, the Advanced Neutron Source (ANS) to be built at Oak Ridge. Third priority went to a smaller light source to be built at Berkeley. The proposal for a new, larger spallation pulsed source that Argonne researchers hoped to build was at the bottom of the list at fourth priority.⁹⁷

On the heels of the Seitz-Eastman committee, DOE convened another panel chaired by Peter Eisenberger of Exxon to create a design for the first-priority 6 GeV

⁹⁴ John Walsh, “For Argonne, Criticism and a Comeback,” *Science* 218 (1982), pp. 354-357.

⁹⁵ Quote from National Research Council, “Major Facilities for Materials Research and Related Disciplines,” DOE-S-0037, Files of Klaus Berkner papers, Lawrence Berkeley National Laboratory, Archives and Records, Berkeley, CA 94720

⁹⁶ Unlike photons, which interact by electromagnetic interactions, neutrons interact primarily by the strong force and thus are only weakly affected by the electrons in atoms. This allows neutrons to probe deeply into a sample and also to distinguish atoms with the same number of surrounding electrons but different nuclei. The magnetic properties of neutrons also make them better probes of microscopic magnetism inside materials.

⁹⁷ National Research Council, “Major Facilities for Materials Research and Related Disciplines,” DOE-S-0037, Files of Klaus Berkner papers, Lawrence Berkeley National Laboratory, Archives and Records, Berkeley, CA 94720. Argonne researchers presented plans for a new machine that would replace the Rapid Cycling Synchrotron with a high-current accelerator, the Argonne Super-Pulsed Spallation Source (ASPUN) after first building a model, “Mini-Aspun.” “Major Facilities for Materials Research and Related Disciplines,” National Academy Press, 1984, pp. 411-432.

synchrotron radiation source. Under its auspices, this panel convened a workshop and created a site-independent cost and schedule study. By the time this work was finished, Kliewer and other Argonne managers outmaneuvered the competition, convincing DOE to site the facility, which they called the Advanced Photon Source (APS), at Argonne; the success of the IPNS as a user facility bolstered these arguments. Work on designing and constructing the project began in 1987 under the direction of David Moncton, who initially came on loan from Exxon but eventually agreed to head the facility. The project, which was eventually designed and built to operate at 7 GeV, had a high price tag (it would eventually cost more than half a billion dollars with related experimental equipment). However, from the beginning its financial prospects -- along with prospects for the national laboratory system in general – benefited from the “boomlet” in physics funding that accompanied Reagan’s defense budget in the mid-1980s. As the fortunes of Argonne’s civilian nuclear power program continued to decline, the APS became the large project that Argonne would look to for resources, prestige, and survival.⁹⁸

Adaptation, Maturation, and Spreading Seeds

During the next twenty years, the IPNS successfully adapted, establishing a narrow but sustainable realized niche within the international materials science community, at Argonne, and within the DOE budget. But the going continued to be rough. Starting in the 1980s and continuing through the beginning of the 21st century, the U.S. lost its edge in neutron scattering research. The ILL continued to be the top notch research reactor. In addition, the pulsed neutron source ISIS became the most powerful of its kind after it began operation in 1984 at the Rutherford-Appleton Laboratory near Oxford in Britain. Soon thereafter the experienced British neutron scattering community, which had been trained at Harwell (in Britain) and ILL (in

⁹⁸ “Reagan’s 1985 R&D Budget: Defense Boom, Physics Boomlet,” *Physics Today* 37 (1984), p. 55-60; “Key Decision Nears on Proposed Argonne Photon Source,” *Physics Today*, 40 (1987), p. 71; Holl, p. 472, Catherine Westfall interview with Daniel Lehman, January 24, 2001.

France), led neutron scattering research. The Japanese also built a strong research program on their smaller pulsed source, KENS.⁹⁹

There was no more talk of cutting Argonne or the DOE national laboratory system from the federal budget. In fact, DOE manager Alvin Trivelpiece and the directors at Brookhaven, Argonne, Oak Ridge, and Lawrence Berkeley Laboratory struck a deal in 1986 aimed at strengthening individual laboratories as well as the national laboratory systems by embracing mutualism and minimizing inter-laboratory interference competition. All agreed to support a major project for each laboratory. Brookhaven would get the Relativistic Heavy Ion Collider for nuclear physics research, and the other laboratories would each get one of the three top-priority materials science projects named by the Seitz-Eastman committee: the synchrotron radiation sources for Argonne (the APS) and Berkeley (the Advanced Light Source) and the ANS reactor for Oak Ridge.¹⁰⁰

Of course the IPNS could not have survived without Argonne, so in that way the Trivelpiece plan helped the IPNS. However, it did little otherwise to raise IPNS prospects. Within the materials science community the IPNS was a pulsed neutron source at a time when synchrotron radiation sources and a reactor project were favored, and the IPNS also faced potentially fatal competition from its enemy pulsed neutron source at Los Alamos. The situation was all the worse because of the nature of materials science research: advances in the field invariably require that the data from large facilities be combined with that from small equipment at university labs, which meant that the IPNS had to compete not only with the higher priority large facilities, but also with many university laboratories for U.S. materials science funding. The IPNS also faced other competitors in other venues: ILL and ISIS researchers had secured the top rung in the neutron scattering community while the APS had the edge at Argonne. Clearly, IPNS researchers could not command resources by arguing that their facility was the most capable machine in neutron scattering or materials science, and IPNS managers could not expect the laboratory management to go to the mat for them if funding dried up. After all,

⁹⁹ Martin Blume and David E. Moncton, “Large Facilities for Condensed-Matter Science,” *Physics Today* 38 (1985), pp. 70-73; private communication, Gerard Lander and Bruce Brown, July 26, 2007.

¹⁰⁰ Alvin Trivelpiece, “Some Observations on DOE’s Role in ‘Megascience,’” *History of Physics Newsletter*, IX (2005), p. 14.

Argonne's pulsed neutron source was no longer a do-or-die proposition for the laboratory.

Amid the continuous threat of closure, the IPNS managed to eke out a continued existence. Through the mid-1980s, Argonne's pulsed neutron source was saved thanks to an unexpected resource flow: funding from the burgeoning defense budget. IPNS generated approximately 10% of its funding from a special project led by Charles Potts, head of the accelerator group that used the pulsed source to measure neutral particle beams for the Strategic Defense Initiative. IPNS managers also saved money for neutron scattering measurements by eliminating the Radiation Effects Facility in 1985 and continuing half-time operation.¹⁰¹

Despite the limited funding and running time, the IPNS managers had to pave the way for scientific success, a goal that required a sizable and productive user community. Thus, first Lander, then Brown (who assumed the IPNS directorship in 1986 when Lander left for Europe) continued aggressive efforts to recruit users and enhance IPNS experimental capabilities. In addition to installing cryogenic methane moderators and a 77% enriched uranium target, IPNS personnel increased the beam current from 10-12 to 14-15 μ A and the number of neutron scattering instruments to 11. IPNS scientists, engineers, and technical staff continually improved instruments, notably by installing larger numbers of better detectors. Further, responding to users' needs, they developed a great variety of specialized environmental equipment for samples. Also, the accelerator staff managed to provide beam as scheduled 91% of the time. This record, they boasted, was "by far the world's record for pulsed neutron sources." This high reliability helped make the most of limited running time and, in addition, helped retain users, since most came to the laboratory to make measurements for only a few days and would not continue to use the facility if they went home empty handed. The figures told a success story: even though the hours of IPNS operation decreased from 1983 to 1988, the number of users and experiments increased.¹⁰² (Table 1)

¹⁰¹ "IPNS Progress Report 1986-1988," p. 1.

¹⁰² "IPNS Progress Report 1986-1988," pp. 1-4.

IPNS User Program Statistics for FY83 – FY88						
	FY83	FY84	FY85	FY86	FY87	FY88*
Weeks of Operation	26	29	21	22	21	18
Number of Experiments Performed	110	210	180	212	223	226
Visitors to IPNS for at Least One Experiment						
Argonne	41	49	44	52	55	54
Other Government Laboratories	9	8	7	11	15	17
Universities	33	45	51	79	78	79
Industry	5	9	7	13	24	17
Foreign	<u>18</u>	<u>39</u>	<u>34</u>	<u>27</u>	<u>24</u>	<u>16</u>
	106	150	143	182	196	183

*2 weeks to be run early in FY89

Table 1: IPNS Neutron Scattering Instruments. From: “IPNS Progress Report 1996-2001.”

By the end of the 1980s, the IPNS also had a high-profile scientific success story. When high-temperature superconductivity was discovered in 1986, Jim Jorgensen and others realized that their powder diffractometers were well matched to the structural complexity of the new superconducting materials. In 1987, Jorgenson and others published the solution of the structure of the first high-temperature superconductor – yttrium-barium-copper-oxygen – which would make the covers of magazines. In the words of Sinha, by then a researcher at Exxon, this and other IPNS work on superconductivity – over 175 papers in all -- “helped put IPNS on the map.”¹⁰³

Scientific success was necessary but not sufficient for continued survival. *Science* reported in 1996 that “other lab researchers give IPNS officials high marks for squeezing a lot of science from a relatively weak source.” Nonetheless, DOE rejected Argonne’s request for a megawatt-level IPNS upgrade, and DOE officials were “considering closing IPNS to help cover the costs of upgrades at other labs.”¹⁰⁴

¹⁰³Quote from Catherine Westfall interview with Sunil Sinha, March 6, 2007. The work of Jorgensen and his team made the cover of *Nature*, 327 (1987). J. D. Jorgensen, “Scientific Highlights of Argonne’s Neutron Scattering Program,” June 22, 2006, unpublished document, J. D. Jorgensen et al. “Oxygen Ordering and Orthorhombic-to-Tetragonal Phase Transition in $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$,” *Physical Review B* 16 (1987), pp. 3608-3616.”

¹⁰⁴ Andrew Lawler, “U.S. Neutron Scientists Settle for Less,” *Science* 272 (1996), p. 730.

The IPNS, however, proved a hearty survivor. As it competed for users, funding, and prestige, Argonne's pulsed neutron source gained some advantages because of the misfortunes of its competitors. In the wake of heightened public concern about reactor safety after the 1986 Chernobyl accident, the Oak Ridge and Brookhaven reactors were shut down for safety reviews (in 1986 and 1989 respectively), which limited running time for neutron scattering measurements through the end of the decade. Thanks to criticism from anti-nuclear critics, who worried that the ANS facility's highly enriched fuel could be stolen, and complaints from fiscal conservatives annoyed that the price tag tripled over original estimates, the ANS lost its niche. In early 1995, the DOE deleted the project from the federal budget. As the stock of reactors fell, the project that had threatened to steal Argonne's niche suffered its own difficulties. Los Alamos would upgrade and improve its pulsed source starting in the mid-1980s. However, as University of California Santa Barbara physicist Walter Kohn stated in August 1995, up to that time the Los Alamos facility (by then called the Los Alamos Neutron Scattering Center or LANSCE), had experienced "many problems, design conflicts, scheduling conflicts," and in addition, "its performance had fallen short of the original specifications."¹⁰⁵

In light of the difficulties at Los Alamos, the IPNS ended up squeezing into a niche alongside its competitor. By the late 1990s, the materials science and DOE ecosystems had developed sustainable niches for both the IPNS and LANCSE for the next ten years, in part because both projects had adapted to restricted resources and in part because both projects ended up providing an highly useful resource -- expertise. DOE insisted after the problems with the ANS that the next big machine for materials science would be a pulsed neutron source rather than a reactor. Although both Argonne and Los Alamos (along with other laboratories) vied to have the new facility (called the Spallation Neutron Source or SNS) built at their site, the 1986 deal struck by Trivelpiece (who in the meantime had become the Oak Ridge director) held: DOE made it clear that the new facility would be built in Tennessee at Oak Ridge. However, the IPNS and

¹⁰⁵ Quote as quoted in Jonathan Weisman, "Could Defense Accelerator be a Windfall for Science?" *Science* 269 (1995), 915. Also, Robert Pool, "Plea to Bromley: Save Our Neutrons," *Science* 246 (1989), p. 1553. Brookhaven's reactor would be closed permanently in 1999. For more on this episode, see Robert Crease, "Anxious History: The High Flux Beam Reactor and Brookhaven National Laboratory," pp. 41-56.

LANSCE were in a prime position to help researchers at Oak Ridge, whose experience was in building reactors, not pulsed neutron sources. In fact, Trivelpiece and Bill Appleton, a top manager for first the ANS then the SNS, brokered another deal, this one aimed at providing Oak Ridge with much needed expertise while reducing interference competition destructive to all concerned. In the end five laboratories agreed to help to build the SNS on the Oak Ridge site. Lawrence Berkeley Laboratory took responsibility for the ion source, Los Alamos oversaw the low-energy section of the linear accelerator, Jefferson National Accelerator Facility undertook the superconducting high-energy end of the linear accelerator, Brookhaven designed the accumulator ring, and Argonne handled instruments and experimental facilities. Oak Ridge and Argonne participated in a staff exchange -- some Argonne staff members, such as Kent Crawford, were detached to Oak Ridge and some Oak Ridge personnel came to Argonne for the duration of the instrument design effort. As Brown and Lander later concluded, the advent of the multi-billion dollar Oak Ridge project was crucial to "prolonging the life of the IPNS."¹⁰⁶

In 2001, the IPNS's 20th anniversary, Brown retired and Ray Teller, who had been a post doctoral fellow at Argonne but had spent the intervening period in industry, became director. It was a time for celebration. By this time the IPNS had delivered 6.5 billion pulses to neutron-producing targets and was operating with 95% reliability allowing 3550 users to perform 5000 experiments using 13 instruments.¹⁰⁷ (Figure 4)

¹⁰⁶ Quote from private communication, Gerard Lander and Bruce Brown, July 26, 2007. Also: Daniel Clery and Andrew Lawler, "The Looming Neutron Gap," *Science* 267 (1995), pp. 952-954; Andrew Lawler, "Neutron Scattering: Green Light for Long-Awaited Facility," *Science* 23 (1998), pp. 470-471.

¹⁰⁷ "IPNS Progress Report 1996-2001," p. 158.

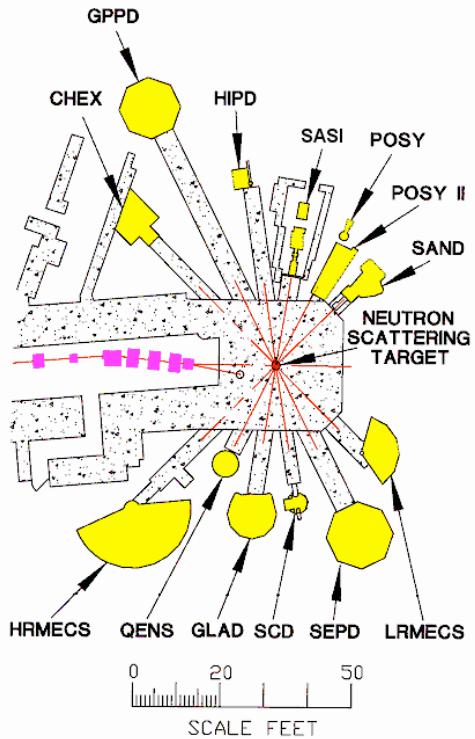


Figure 4. The IPNS and instruments in 2001. From: "IPNS Progress Report 1996-2001."

Meanwhile, the APS and other materials science facilities were stealing headlines. And in the end, the high-energy epithermal neutrons produced by the IPNS did not prove as dominant as initially expected in exploring materials for some branches of science. For example, the IPNS never produced fluxes high enough for many measurements of biological materials (although the introduction of cold neutron beams, highly efficient cryogenic moderators, and the installation of very effective small-angle scattering instruments went far to help this line of work). Nonetheless, by this time the pulsed neutron source had produced an impressive body of research. In addition to the contributions of such cutting-edge work as Felcher's measurements with neutron reflectometry and Jorgensen's measurements of the structural properties of high-temperature superconductors, IPNS researchers explored the momentum distributions in quantum liquids and solids, researched the static and dynamic structure of amorphous solids and liquids, worked on biological molecules and other materials, and conducted *in situ* structural studies at high pressure and studies on colossal magnetoresistive materials. As Brown would later summarize, "a lot of our success was steadily and continuously

building up the data base,” a major contribution in a field in which success is measured in the steady accumulation of diverse information.¹⁰⁸

At this point the fully mature facility also served an important function within Argonne. Along with other medium-sized facilities, such as the Argonne Tandem Linear Accelerator System (ATLAS) and strong programs across a wide range of scientific and technological disciplines (such as continuing work on reactor studies, a budding program in transportation-related work, and research in environmental studies, chemistry, and biology), the IPNS contributed to the laboratory’s reputation and multidisciplinary mix of expertise.¹⁰⁹

By this time, the IPNS had also made numerous contributions to the materials science community beyond scientific results. IPNS researchers established user-friendly operation as the standard for U.S. materials science facilities. In addition, their machine also served as a development center for neutron scattering instruments, moderators, and targets that were useful throughout the field. Also, although Argonne’s pulsed source was not the most capable of its kind, Carpenter and his team had pioneered the concept and were crucial to the successful construction and use of the cutting-edge tools of their day, first at ISIS, then at SNS, which began operation in 2006, and at the comparable Japan Spallation Neutron Source, JSNS, planned for 2008.¹¹⁰ Even though these machines were not at Argonne, their success proved that in the long run, Argonne had conceived and nurtured the right idea: spallation neutron sources, not reactors, were the right neutron scattering machines for the 21st century. Despite its rocky inception and continued struggles, the IPNS had taken root, matured, and spread seeds for the future.

¹⁰⁸Quote from Catherine Westfall interview with Gerry Lander and Bruce Brown, June 22, 2006. Also: “IPNS Progress Report 1996-2001,” pp. ii, iv, 2-3, 122, 156, 158; Jim Jorgensen, “Scientific Highlight of Argonne’s Neutron Scattering Program,” June 22, 2006.

¹⁰⁹ For an example of how the multidisciplinary mix of expertise and equipment facilitates small-scale research, see Catherine Westfall, “A Different Laboratory Tale: Fifty Years of Mössbauer Spectroscopy,” pp. 189-213. “IPNS Progress Report 1996-2001,” pp. 142-145; Jack Holl, *Argonne National Laboratory*, pp. 416-422, 446-452, 473-475, 483-488.

¹¹⁰ Private communication, Gerard Lander and Bruce Brown, July 26, 2007.

Reflections: The Ecosystems Perspective and the IPNS Story

The twists and turns in the IPNS story are less perplexing if we view the IPNS as an organism struggling to find a sustainable niche in overlapping ecosystems. As in the wild, survival required constant adaptation. Throughout its life the IPNS had to compete for resources in an ever-evolving environment. The project came to life when it appeared that Argonne, DOE, and the materials science community would happily provide resources (funding, users, prestige, institutional priority) to a new, premiere neutron scattering facility. But then DOE funding scarcity convinced the materials science community that it was best to fund existing reactor projects and a Los Alamos niche-stealing enemy with a separate, military income stream. Argonne scientists escaped extinction by trimming their project and its hours of operation, finding, for a while, their own source of military funding, developing new research instruments, and discovering efficiencies that allowed them to produce useful science on the cheap.

Did the quality of IPNS science play a role in its survival? Expert assessment of its quality certainly seemed to play a role. It seems unlikely that the second Brinkman panelists in 1982 would have stayed the IPNS death sentence if in their opinion the machine lacked scientific promise. And the IPNS surely would not have kept its funding through the 21st century if it had not lived up to that promise with cutting-edge research -- such as the work on high-temperature superconductivity as well as the steady flow of other useful measurements. On the other hand, the facility had faced extinction before it was given a chance to produce science and lived with the constant threat of death despite its successes and good reputation for productivity. Though necessary, scientific success was clearly not sufficient for survival.

As often happens in nature, luck played a leading role in the IPNS's struggle for survival. Even as Europeans began operating more capable neutron scattering machines and synchrotron radiation light sources gained top priority in the U.S. and at Argonne, the IPNS emerged as a crucial resource because technical problems limited productivity at Los Alamos and the reactors at Brookhaven and Oak Ridge were shut down for safety reviews in the wake of Three Mile Island and Chernobyl (and the Brookhaven reactor was eventually shut down). Like many a successful competitor in an ecosystem, the IPNS

scratched a niche through adaptation and then continued to survive, at least in part, because it was in the right place at the right time.

A particularly striking aspect of the IPNS story is the extent to which this story is linked with larger struggles for survival. The IPNS probably would not have survived the first Brinkman panel death sentence without the strong support of Argonne managers who were motivated by the threat to the laboratory's survival and of the DOE, which, in turn, was more responsive to Argonne because DOE's survival was also threatened. An ecosystem perspective is particularly useful in spotlighting the interdependence that linked Argonne, DOE, and the materials science community, as well showing as the potential fragility of the overall system. Due to the mesh of inter-relationships, the destruction of one relatively small element in an ecosystem can cause a cataclysmic chain reaction of ecological disaster that engulfs the larger surrounding systems. This is why scientific leaders repeatedly labored to cut deals so that every laboratory got a major project. They needed to avoid destructive interference competition that could have led to the competitive exclusion of them all. And this fact of laboratory life helps explain how the IPNS maintained its niche into the 21st century. As a mature facility, the IPNS was still useful as a scientific tool. In addition, IPNS researchers (and their once and future competitors) pooled their expertise so that the laboratories, DOE, and materials science community could continue to grow and prosper. In the end, successful adaptation required preserving the larger ecosystem that sustained their common scientific life.



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