The Future of Neutron Scattering in China: Meeting Increasing Demand with New Facilities?

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Abstract. The China Advanced Research Reactor (CARR) and the China Spallation Neutron Source (CSNS), like other big national facilities for basic research in China, are viewed as vehicles for engaging in international R&D efforts, furthering the nation’s technological advancement, and facing arduous challenges such as energy and materials needs. In 2009, CARR—a 60MW steady-state reactor in Beijing—is expected to reach criticality while the CSNS—an 120 kW pulsed source in Dongguan—is to begin construction. In spite of the differing schedule, the road leading to full operation of the sources and productive utilization of the neutron instruments will be a long one. From the outset both projects benefit a great deal through interactions with the worldwide neutron communities. An even more trenchant task is to build a domestic user base, presumably from China’s numerous universities and research laboratories, to imbue new scientific ideas into using and exploiting of the neutron methodology. Arguably, a smaller neutron facility yet apt at flexibility and optimization for education and academic R&D is needed to bridge ‘big’ facilities and ‘small’ sciences. Here, we introduce the plan of a compact pulsed neutron source (driven by a 13MeV-proton accelerator system with a Be target and room-temperature and cryogenic moderators), to be built in about 3 years as a part of a Hadron Application Research Center at Tsinghua University. We discuss the mission of these neutron sources, the complementarity therein, and their synergetic relation with the academia and other facilities, and possible cooperation with international counterparts.

1. Neutron-source projects in China
During the last 10 years efforts to modernize China’s neutron-scattering capability have persisted, resulted in the undertaking of new neutron-source projects. The outstanding cases are the construction of the China Advanced Research Reactor (CARR) and the development of the China Spallation Neutron Source (CSNS). The basic design goals and the interim progress of CARR and CSNS have been previously reported elsewhere [1]. Very recently, a newly approved project—the Compact Pulsed Hadron (i.e., neutron and proton) Source (CPHS) as the Phase 1 of the eventual Tsinghua Hadron Accelerator Research Center (THARC) has been launched at Tsinghua University in Beijing, China.
The rationale behind these developments reflect the increasing demand of particle-beam experimental platforms for expansive applications. Here, we first update the recent activities at CARR and CSNS and introduce the CPHS project, then describe the inter-relation between these three neutron sources.

1.1. The China Advanced Research Reactor

The CARR of the China Institute of Atomic Energy (CIAE), located in the southwest suburb of Beijing, is to succeed the Heavy Water Research Reactor (HWRR) that retired in 2007 after 50 years of operation. Currently with all major construction completed, CARR is expected to reach criticality in 2009. It is a 60 MW tank-in-pool type reactor using a D$_2$O reflector for inverse neutron trap, designed to yield an optimal thermal neutron flux of 8×10$^{14}$ n/cm$^2$/s. The Neutron Scattering Laboratory (NSL)—a user facility—under CARR is to conduct neutron-scattering for fundamental research utilizing 7 horizontal beam tubes, each accommodating dual ports, of the reactor. Two of these beam tubes will transmit neutrons from a liquid-hydrogen cold source to the guide hall via four neutron guides that were purchased abroad. Installation of all major reactor components except the cold source has been completed. CARR currently carries out the final safety testing and is scheduled to reach criticality in 2009. Afterward, the thermal-neutron instruments (see below) will be commissioned while the reactor refines its operation. However, operation of the reactor has to be re-adjusted in conjunction with the installation of the cold source in ~2 years later.

From the outset NSL has promoted and maintained cooperation with the international neutron-scattering community especially in personnel training and instrumentation development. Through collaborative agreements a number of instrumental components have been relocated to CARR: a triple-axis spectrometer, a four-circle diffractometers and a texture diffractometer from Jülich Center for Neutron Science, Germany and a residual stress diffractometer from Studsvik Neutron Research Laboratory, Sweden. Participation research teams (PRT) also play a key role in development of additional beamlines and scientific programs. For example, a PRT from the Institute of Chemistry of the Chinese Academy of Sciences (CAS), through collaboration with the National Institute of Standards and Technology (NIST) of USA, is building a small-angle scattering instrument and a reflectometer. These beamlines, together with two (a high-resolution and a high-intensity) powder diffractometers and a radiography/imaging station under construction by NSL, will constitute a suite of instruments offering a broad range of capabilities to users starting in 2010. The layout of the instrument is shown in Figure 1.

![Figure 1](image-url)
NSL has a young staff to cover the installation, commissioning, and operation of the initial set of instruments. They work closely with the PRT scientists and the veteran researchers from the previous HWRR program. Furthermore, domestic and international advisory committees were set up to review NSL’s progress in instrumentation and scientific-program development and to communicate the findings to CIAE upper management. Thus far NSL has received strenuous support from CARR-CIAE. For example, the plan of a new building to provide office and laboratory facilities to users has been approved by CIAE. Nevertheless, mechanisms have yet to be identified and implemented for securing a long-term budget to ensure steady capital investments and sustainable programs for the NSL. Perhaps heightened awareness of CARR’s important role in neutron science R&D by the governing organization of CIAE—the China National Nuclear Corporation may improve the situation.

1.2. The China Spallation Neutron Source

The CSNS is a proton-accelerator driven short-pulsed neutron source (proton energy 1.6 GeV, repetition rate 25 Hz, beam average power 160 kW) to be built in Dongguan City of Guangdong Province in south China, see Figure 2. The proposed budget of 1.4B CNY (~$200M) becomes extremely tight after accounting for inflation. The strategy is to glean the knowledge and knowhow that are currently lacking through international cooperation so that the responsible organizations of the project, the Institute of High Energy Physics (IHEP) and the Institute of Physics (IoP) of CAS, can develop and test prototypes of all the major components. Eventually, the technology will be transferred to domestic industry for production at lower costs. Since 2005 active R&D and prototyping in key areas of accelerator system (ion source, RFQ, DTL, ceramic vacuum chambers, beam extraction, ring magnets and RF), neutron target station (target, reflector, and moderators), neutron instrumentation and beamline design have been carried out using discretionary funds provided by the Guangdong government and CAS. The project is benefited immensely by generous assistance from foreign neutron centers such as SNS, J-PARC, KEK, ISIS, and PSI and international advisory committees.

Figure 2. The schematic illustration of the linear accelerator system, the rapid cycling synchrotron and the experimental hall of the CSNS facility. Future upgrade and additional applications are also included.
In parallel to technical R&D, IHEP has conducted the environmental impact studies and responded to various reviews of the project mandated by the State Development and Reform Commission. In September of 2009, the Commission officially approved the CSNS site in Dongguan City. The remaining task is to finish the conceptual design and technical documentation. Final approval of the CSNS project is expected to materialize in the spring of 2010. Construction of the entire facility is to take 78 months. Currently, a major effort is underway to organize the IHEP personnel to be dispatched to Dongguan and to coordinate with the local government to prepare for construction. The most severe repercussion from the tight budget is the trimming the scattering instrument building down to 3 machines (a powder diffractometer, a small-angle scattering instrument and a reflectometer) out of the 18 available beamlines. It is hoped that as soon as CSNS construction begins, IHEP and IoP will establish a scheme to work with universities in seeking external funding for building additional world-class scattering instruments.

1.3. The Compact Pulsed Hadron Source of the Tsinghua Hadron Accelerator Research Center

The CPHS is a newly approved project led by the Department of Engineering Physics (DEP) of the Tsinghua University in Beijing, China. It is to be housed in an existing building on the Tsinghua campus, previously built and used for the now completed cargo-inspecting accelerator system. As illustrated in Figure 3, Phase I of the CPHS consists of a high-intensity proton linac (ion source, RFQ, and DTL), a neutron target station (Be target, reflector, and solid-methane and water moderators), and a small-angle neutron scattering instrument and an imaging/radiography station. Phase 2 will expand to include a proton research platform and additional neutron beamlines (for powder diffraction, reflectometry, irradiation/activation analysis, neutron therapy, and neutron optical devices R&D). The primary parameters of the CPHS proton-accelerator are: power on target 16 kW, energy 13 MeV, average and peak beam current 1.25 and 50 mA respectively, pulse repetition rate 50 Hz, and pulse width 0.5 ms. The rationale behind the CPHS-THARC is three-fold: 1) to establish a medium-flux, university-based neutron source for education of students and training of users, 2) to enable multi-disciplinary research and neutronics/device development, and 3) to pave the way for further R&D of innovative hadron technologies, from materials characterization to medical radiology to energy/environment applications. Since the CPHS adopts primarily mature accelerator and neutronic technology, requires a base cost much less than those of CSNS and CARR, and affords a fast-track construction, the facility even in the initial phase can advance scientific utilization and instrumental development of cold-to-epithermal neutrons that are much needed in China. CPHS will serve research partners and users from a large community, including but not limited to Tsinghua University.

After the launching of the CPHS-THARC project in February 2009, the university soon allotted the first-year budget of ~$3M. In April 2009 the Project contracted the construction of the ion source by the Institute of Modern Physics at Lanzhou, China. By virtue of the completed design of the RFQ and DTL, procurement processes for their fabrication and the associated power supply are now underway. The design and optimization of the neutron target station, on the other hand, requires considerable research, from understanding of the basic neutronics to Monte Carlo simulations. Not until an optimized design is achieved can engineering/construction of the target station commence. For this reason the DEP will convene the first international mini-workshop in June 2009 focusing on the neutron physics that governs the target-reflector-moderator performance and the processes towards the realization of an optimal configuration. Ad hoc meetings aiming at tackling problems in beamline optics and neutron-scattering instruments will be organized. The first goal is to complete Phase 1 of the project as well as to start R&D of Phase 2 in 3 years. Admittedly, such a timeline is rather ambitious. Therefore, the Project welcomes the participation of the international hadron-accelerator and neutron communities in advisory and collaborative activities with Tsinghua University and will actively take part in international collaborative such as the International Collaboration on Advanced Neutron Sources (ICANS) and symposia of accelerator and neutron moderation development. One of the top-priority items is assertive recruitment of young talented faculty, particularly in the area of
neutronics and neutron science/instrumentation. Since experienced researchers in these fields are scarce in China, attracting talent from overseas is a reasonable alternative. Concurrently, Tsinghua University will seek cooperation with the CSNS and CARR projects and with interested academic institutes in order to build an alliance for the development of hadron science and applications.

![Figure 3. The schematic layout of the CPHS. Phase 1 includes the ion source, RFQ, DTL, TMR, and the SANS and Imaging beamlines. Phase 2 adds more neutron instruments and the proton platform.](image)

2. Development of a domestic neutron user community and a network linking the international counterparts

Since 2005 four user meetings [2] and two US-China Workshops on neutron science and technology [3] were held. Attendants coming from 20-30 universities and ~10 laboratories nationwide listened to introductions of the CARR and CSNS and scientific applications of the neutron method from project scientists and foreign expert speakers. They also participated in discussions of possible outreach activities such as student training, joint research programs, and co-development of instruments. A nationwide survey of potential users has recently been conducted by CSNS. It identified the neutron-related research topics and priorities of desirable scattering instruments of ~30 research groups from universities and national laboratories. With continuing outreach efforts the assessment indicated that 30-40 user groups will conduct ~60 experiments per year using the 3 CSNS instruments. If all 18 instruments are available, the number of user groups will increase to ~100 with ~500 experiments performed per year. In the future the three neutron-source project will undoubtedly concert their efforts in user development, which will enhance the effectiveness of the scientific utilization of the facilities.

In the previous user meetings an informal alliance of neutron users was proposed but it came short of forming a national neutron science society. In contrary, neutron societies have been established in many countries in Asia-Oceania, Europe and America. For many years the neutron societies in each
continent/region have organized their own regional activities for promoting cooperation in neutron science and instrumentation such as topical schools, student exchange, international conferences, and prizes and fellowships. The establishment of a Chinese neutron science society will enable China’s full participation in the international events sponsored by the Asian-Oceania Neutron Scattering Association (AONSA) as well as effectively championing domestic support of neutron-related research through a coherent voice. The organization of a university-led neutron science society in China is currently under discussion.

3. Conclusions
The advent of three neutron-source projects in China accedes the fact of increasing demand for multidisciplinary R&D using neutrons, fueled by the rapid growth of international efforts in neutron applications versus the lagged behind status in China. The high-flux national projects of the CARR and CSNS have undergone different stages of development for a decade. Significant progress has been made yet arduous challenges remain in the next 2-7 years before fruits of the hefty investments are to be harvested. A medium-flux university-based source, owing to its relatively low cost and fast-track development, may play a pivotal role in user outreach within the academia and promotion of multidisciplinary applications of accelerator and neutronics technology. The CPHS of the THARC project may produce cold-to-epithermal neutrons for small-angle scattering and imaging in 3 years and expand neutron/proton R&D facilities in subsequent years.

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References
[1] D. F. Chen, Y. T. Liu, C. Gou, C. T. Ye, Development of neutron scattering on 60 MW research reactor in CIAE, Physica B385-386 (2006) 966.
   J. Wei et al., China spallation neutron source: Design, R&D, and outlook, Nucl. Instr. Methods A600 (2008) 10.
[2] Neuron News 16(1) 2005 and ibid 17(1) 2006.
[3] Neuron News 19(1) 2008 and ibid 20(2) 2009.