Preface

The use of neutrons to investigate the fundamental properties of materials began with the search for new ways of exploiting the knowledge and instrumentation acquired during the all-out scientific efforts of the Manhattan Project in the 1940s. Neutron applications were explored in the 1950s by Bertram N. Brockhouse at the Chalk River Laboratory in Ontario and by Clifford G. Shull at the Graphite Reactor at Oak Ridge National Laboratory (ORNL) in Tennessee. When the Royal Swedish Academy of Sciences awarded them the 1994 Nobel Prize in Physics, for pioneering contributions to the development of neutron scattering techniques, the citation noted that they had between them helped to answer the questions of where atoms "are" and what atoms "do." The saying "neutrons see where atoms are and what they do" has become the motto of neutron scattering science.

Brockhouse's and Shull's pioneering applications were essentially limited to studies of the physical properties of matter, and in particular to phase transitions, magnetic structures, phonons, and especially the hydrogen bond. In the last 20 years or so, the use of neutrons has expanded tremendously following the development of new technology for the production of cold, thermal, and epithermal neutrons. This has resulted in orders-of-magnitude improvements to brilliance, energy resolution, and detector efficiencies compared with the original sources and measuring devices. Many of the scientific applications that now employ neutrons were quite unanticipated. Neutrons, with wavelengths on the order of angstroms, are capable of probing molecular structures and motions and increasingly find applications in a wide array of scientific fields, including biochemistry, biology, biotechnology, cultural heritage materials, earth and environmental sciences, engineering, material sciences, mineralogy, molecular chemistry, and solid state and soft matter physics.

This volume surveys the diversity of present day applications of neutron methods in the fields of Earth, Energy, and Environmental Sciences. Neutron applications in Earth sciences, including mineralogy, petrology, geochemistry, volcanology, structural geology, and sedimentology, are presented first for structural studies. The second set of applications is in the area of energy, particularly the sources of energy, upon which our modern civilization depends. In view of the inevitable exhaustion of natural fossil fuels, energy alternatives are needed for sustainable advancement. The last aspect of the Earth system dealt with, the environment, of course, becomes prominent in any of the studies addressed under the other two denominations, for energy use is linked to impacts to the natural environment of the planet Earth.

The book intends to provide the novice with an inspiring introduction to the use of neutrons in material science and technology and to stimulate the expert to consider these non-conventional techniques as readily available problem-solving tools in the fields of application considered. The International Year of Planet Earth, as declared by the United Nations Educational, Scientific and Cultural Organization and the International Union of Geological Sciences for 2008, testifies to the increased awareness of the strong ties linking these three fields.

The international scientific community has been engaged in a major effort to produce the next generation of large-scale neutron sources and instruments, along with the newest synchrotron-based X-ray facilities, in response to an ever growing demand for knowledge of the fundamental properties of materials (natural or man-made, organic or inorganic) and their scientific and technological implications.

The coming on-line of a new generation of spallation neutron sources, for example, at Oak Ridge National Laboratory (ORNL) (Fig. 1) in the United States and at Tsukuba, Japan (Fig. 2), represent the most tangible aspects of this effort. Additionally, the construction of ISIS-TS2, the second target station at the spallation neutron source (ISIS) of the Rutherford Laboratory in the United Kingdom, is well on its way to completion (Fig. 3); and construction is expected to begin soon for the Chinese source (CSNS) in Dong-guan, People's Republic of China. At the same time, efforts have been completed to renew the reactor-based neutron sources for the ORNL High-Flux Isotope Reactor and the research reactor at Grenoble, France (Fig. 4). The latter, supported by the Institut Laue-Langevin Millennium Programme (www.ill.fr), provided an order-of-magnitude gain at the experimental stations. The European Spallation Source has been planned for over 12 years, and construction seems imminent. This project is to build and operate the world's most intense

Fig. 1 Arial view of the pulsed Spallation Neutron Source at Oak Ridge National Laboratory, USA, completed and in operation in 2008. *Photo courtesy of ORNL*

Fig. 2 The new Japanese pulsed Spallation Neutron Source (JSNS) close to completion as a Materials and Life Science Facility at J-PARC, Tsukuba, Japan. *Photo courtesy of JAERI*

Fig. 3 Aerial view of ISIS and TS2 (the *box-shaped* building in foreground *right*) at the Rutherford Appleton Laboratory, UK. Part of the new synchrotron ring Diamond is visible on the *upper right side. Photo courtesy of RAL*

neutron source. It is currently one of the largest research and development infrastructures slated to be built in Europe during the next 10 years, with an estimated construction cost of 1.0–1.5 G€.

The editors—in the hope that these present day neutron applications in studies of the Earth, energy, and the environment help stimulate novel uses of neutrons to unveil otherwise unobtainable information—are grateful to all the contributors whose insights, diligence, and timeliness made this volume possible. Our thanks also go to the ORNL and Springer editorial staff: D. Counce, V. J. Ewing, C. Horak, E. Tham, and L. Danahy, whose assistance is critical to this volume. We are indebted to the following reviewers and the series editors (Ian Anderson, Alan Hurd, and Robert McGreevy) whose suggestions helped us maintain balance and accuracy: Alberto Albinati, Muhammad Arif, Miguel Ángel Castro Arroyo, Craig Brown, Michele Catti, Jack Carpenter, Gabrial Cuello, Wulf Depmeier, A. N. Fitch,

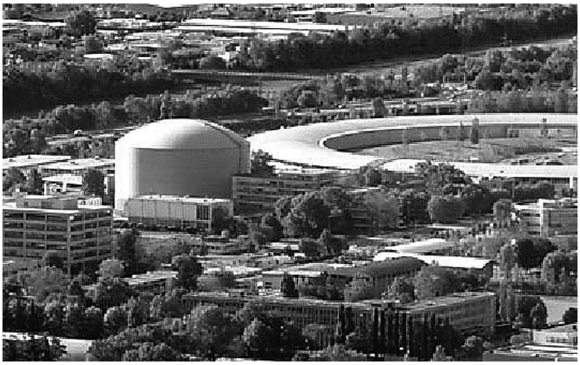

Fig. 4 Aerial view of the Institut Laue-Langevin reactor building, Grenoble, France. Part of the European Synchrotron Radiation Facility ring is visible to the *right* of the reactor dome. *Photo Courtesy of ILL*

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