Eur. J. Mineral.
2002, **14**, 195-202

Neutron scattering in Mineral Sciences: Preface

ROMANO RINALDI*
Dipartimento di Scienze della Terra, Università degli Studi di Perugia, I-06100 Perugia, Italy

Abstract: The recently renewed activity related to the planning and construction of the next generation of neutron sources in the USA, Japan, and Europe, has prompted the birth of this Special Issue where the main applications of neutron-scattering techniques in Mineral Sciences are reviewed. The collection gathers a series of stand-alone but coordinated articles intended to provide a panoramic view of all fields of interest on the subject with a tutorial approach.

This preface provides a general scientific framework intended as an introduction to the subject for the novice and as a guide for the whole Special Issue. An Index of the ten papers collected and an Appendix on the existing European Neutron Facilities are given together with many references for further documentation mostly available from the World Wide Web.

Key-words: neutron scattering, mineral science techniques, mineral science applications, European neutron facilities.

Introduction

The Earth Science community has recently shown considerable interest for neutron-scattering techniques, mostly in the field of chemistry and physics of minerals and particularly for *in situ* studies carried out at temperatures and pressures typical of the Earth's interior environments. Furthermore, in recent years, in conjunction with the development of the project for a next-generation neutron source to be built in Europe (the European Spallation Source – ESS), a number of studies have been undertaken by several science and technology groups, in order to review the existing interest for neutron scattering and to investigate the scientific opportunities offered by this new kind of neutron source to the advancement of Science. A thorough idea of this scenario can be gleaned from the following five documents: i) "Scientific Prospects for Neutron Scattering with Present and Future Sources", ESF Framework Studies into Large Research Facilities; ESF Special Publication, 1996, ISBN 2-903148-90-2 – http://ensa.web.psi.ch/ensa/autrans.pdf -. ii) "ESS, A Next Generation Neutron Source for Europe, Vol. II. The Scientific Case", ESS Council, 1997; ISBN 090 237 6 500 and ISBN 090 237 6 608 – http://www.ess-europe.de/documentation/ESSvol2b.pdf -. iii) "Survey of the Neutron Scattering Community and Facilities in Europe", prepared for ESF by the European Neutron Scattering Association (ENSA) August 1998, ISBN 2-912049-00-8 – http://ensa.web.psi.ch/ensa/survey.pdf -. iv) "The Scientific-Strategic Case for a Next-generation European Spallation Neutron Source for Science and Research (ESS Project)", ESF Studies on Large Research Facilities in Europe, Interim Report 2000, ISBN 2-912049-20-2 – http://www.esf.org -. v) ESS-SAC Workshop Engelberg (CH), 2001 - http://www.ess-europe.de/search_ess.html -.

Reviewing the interest of Mineral and Earth Sciences for neutron scattering with present-day and future neutron sources in the context of the ESS project (Artioli *et al.*, 1996; Dove *et al.*, 1997; Price *et al.*, 2000; Rinaldi *et al.*, 2001), has prompted the idea of this Special Issue. The Editors' and contributing Authors' intention is to provide a timely review, with a tutorial approach, of the state-of-the-art of neutron-scattering applications in Mineral Sciences and related fields, covering the most established approaches, at the time of a renewed interest for these investigation techniques, once uncommon in this field, and with an eye to the future.

The latest generation of diffractometers and spectrometers at modern neutron sources, such as ILL in France, in the category of steady-state reaction sources, and ISIS in the UK, in that of pulsed spallation sources, has recently allowed the accurate determination of subtle, yet very important, structural details in minerals, also as a function of temperature and pressure. Neutron-scattering techniques are particularly versatile as they allow the investigation of both structural details (through diffraction) and structural dynamics (through spectroscopy) of the atomic arrangements in materials, and because they allow measurements of coherent and incoherent scattering and absorption processes. As a result, a wide range of phenomena can be studied using neutron scattering. Neutrons are scattered by the atomic nucleus and by atomic magnetic moments, and therefore have a complementary role to X-ray scattering operated by the electrons. Neutron scattering has an additional advantage over some other techniques in that it allows good data to be obtained under a wide range of

*e-mail: rinaldi@unipg.it

DOI: 10.1127/0935-1221/2002/0014-0195
0935-1221/02/0014-0195 $ 3.60

sample environments. Hence the potential of neutron-scattering methods for the solution of Earth Science problems, including many environmental problems, is extremely promising. The traditional drawbacks connected with the need for relatively large samples, imposed by the modest neutron flux at measuring stations, are being overcome by present-day and especially future neutron sources and instrumentation.

The first review in this monographic Collection (Dove, 2002) deals with the fundamental aspects of neutron-matter interaction with an eye to Mineral Science and Earth Science applications, and is also aimed at providing an overview of the advantages (and disadvantages) connected with the use of neutron-scattering techniques in the solution of mineralogical issues of fundamental importance for the Earth Sciences.

The second review in the Collection (Winkler, 2002) is aimed at providing the necessary background on the generation of neutron beams and on the instrumentation employed in order to contribute to the understanding of the experiments described in the following reviews devoted to the various applications.

The following list of ten points of merit from Rinaldi *et al.* (2001), describing some of the many features of neutron scattering that makes it a method of choice for studying natural materials, integrated with a brief account of each of the reviews in that Monograph, is intended as a guide for the novice in this field and as a guide for this Special Issue itself.

Points of merit for neutron scattering in Mineral and Earth Sciences and the contents of this Monograph

1. Hydrogen in minerals

Neutrons, as opposed to X-rays, are efficiently scattered by hydrogen ^{1}H and deuterium ^{2}H atoms. Many minerals contain hydrogen, often in the form of bound or free hydroxide ions, or in the form of bound or free water molecules within either structurally active sites, or interstitial cavities in the crystal structure. Water in minerals and rocks is extremely important in regulating a large variety of behaviours and properties of interest to the Earth Sciences spanning from the atomic to the continental scale. Because hydrogen has an extremely large cross-section for incoherent scattering, neutron scattering can be used to study the motions of individual hydrogen atoms. Slow motions of the hydrogen atoms, such as diffusion or reorientational motions, can be probed by quasi-elastic scattering, and fast motions by high-energy spectroscopy. On the other hand, since deuterium has a reasonable cross-section for coherent scattering and no appreciable cross-section for incoherent scattering, deuterated samples can be used in diffraction studies for the location of hydrogen sites in crystal structures and their modifications under inner earth conditions.

The articles by Artioli (2002), Dove (2002), Pavese (2002) and Redfern (2002) and the literature cited therein, provide a large number of examples of the application of neutron scattering for the location of hydrogen in the crystal structures of minerals and the characterisation of their hydrogen bonds.

2. Scattering cross-section

The fact that the scattering cross-section for neutrons does not change with scattering vector, whereas with X-rays it falls off more-or-less as the inverse of the atomic radius, means that neutron scattering allows the collection of diffraction data up to large scattering vectors. This is useful for a number of reasons. First, for investigating complex crystal structures and crystal chemistries, such as occur in many minerals, it provides a significant increase in the amount of information available in a diffraction pattern. Second, for information about thermal motion a wide coverage of the scattering vector is essential. Third, to extract information about site occupancies, and to decouple this information from the thermal motion, it is again essential to have data over a wide range of scattering vectors.

These three fundamental properties find a large number of applications as described in the examples reported in the papers of this Collection dealing with diffraction. For example, Artioli (2002) shows the unique advantages offered by neutron scattering for the accurate determination of the thermal components of atomic displacement parameters presenting an unpublished work on cuprite (Cu_2O). Furthermore, in crystals with considerable disorder, or in amorphous materials or liquids, there is a lot of information about short-range order contained within the total scattering, S(Q). The paper on total scattering by Dove *et al.* (2002) deals with this last point and reports, besides the fundamental principles involved in the technique, the unequivocal results obtained in a number of key examples of mineralogical importance such as the silica polymorphs and sulphur hexafluoride.

3. Scattering contrast is not electron-dependent

The contrast between the neutron-scattering cross-sections of mineralogically common atoms or cations which have equal or similar numbers of electrons, such as Ti^{4+}, Ca^{2+} and K^{+}; or K^{+} and Cl^{-} or Na^{+}, Mg^{2+}, Al^{3+} and Si^{4+} or Fe^{2+} and Mn^{2+}, allows neutron diffraction to be used for the direct determination of their site occupancies and order-disorder distributions. Untangling the ordering of these cations by X-rays can only be achieved indirectly by the analysis of bond lengths, but these are not definitive since bond lengths are affected by factors other than the specific site occupancy. Neutron diffraction allows the direct determination of site occupancies for these frequently coexisting cations in minerals. Furthermore, although synchrotron X-ray resonant scattering can certainly be achieved to enhance scattering contrast in favourable cases, it cannot be performed systematically being dependent on available edges and bonding features.

Figure 1 in Dove (2002) provides a good illustration of the non-systematic variations, with atomic number, of the coherent-scattering lengths, the incoherent-scattering

cross-sections, and the absorption cross-sections, throughout the periodic table of the elements.

Many examples of these applications are being reviewed in the papers by Artioli (2002), Pavese (2002) and Redfern (2002) dealing with the techniques of both single-crystal and powder neutron diffraction at both ambient and non-ambient conditions. This latter aspect is actually addressed in the next point of merit for neutron scattering as it deserves a particular mention.

4. *In situ* experiments

"Natural occurrence" for a mineral often means high temperature and high pressure, hence, to study the behaviour of minerals requires the reproduction of their "natural" environment and thus the need for simultaneous high temperatures and high pressures. *In situ* studies are best suited for a thorough knowledge of the relations between thermobaric variables and structural properties such as phase transitions, cation partitioning, bond valence, electronic structure, *etc*. Traditionally high pressures have been easier to work with by using X-ray diffraction and diamond anvil cells, but the use of time-of-flight neutron techniques has lately allowed considerable progress in high-pressure mineralogy. The low attenuation of neutron beams by many materials can effectively make extreme sample environments (HT, HP, Reaction Cells, differential loading frames, *etc*.) easier to work with for neutron scattering than for other experimental techniques.

Examples of frontier applications of neutron diffraction are nowadays mostly in the field of *in situ* studies where mineral structures are investigated while the sample is kept at high temperature and/or high pressure. The paper by Pavese (2002) reports a brief account of the most significant work carried out in the last 15 years or so by neutron powder diffraction both at ambient and non-ambient conditions. Redfern's (2002) paper gives an up-to-date account of the latest progress made in high-pressure and high-temperature mineralogy by powder neutron diffraction and provides clues as to the technological challenges posed by these techniques as well as to the scientific opportunities they will provide in the near future.

5. Spectroscopy and modes

Fundamental structural properties of minerals can be investigated by Inelastic Neutron Scattering (INS). Unlike spectroscopy with electromagnetic radiation, inelastic neutron scattering is not subject to tight selection rules on mode symmetries and wave vectors. For this reason neutron scattering can be used to determine phonon-dispersion curves and phonon densities of states, providing a fundamental understanding for the prediction of mineral behaviour and phase transformations of minerals under pressures and temperatures of the Earth's interior.

Extension to the inelastic and quasi-elastic scattering of *in situ* techniques is very promising. Such measurements, although requiring highly sophisticated means of data interpretation, offer a unique opportunity for solving fine structural details (atomic and protonic dynamics, soft modes, *etc.*) and allow better modelling and interpretation of fundamental thermodynamic parameters. Limiting factors are mainly associated with the availability of large enough and homogeneous natural single crystals of the phases of interest. Powder inelastic neutron scattering could also provide a viable complementary route, especially when associated with non-ambient techniques.

The review by Chaplot *et al.* (2002) reports all major advancements achieved by INS techniques and quantum-mechanical calculations in the last decade or so on most of the rock-forming minerals as well as on model systems of the oxides MgO, FeO, Al_2O_3 and of the SiO_2 polymorphs. Dove (2002) reviews the use of INS on hydrous minerals particularly focusing on the contribution of incoherent scattering to measure both fast and slow dynamic processes.

The limitations in INS studies of minerals can be essentially ascribed to the lack of large pure samples as both single crystals and powdered pure specimens. An increment in neutron flux, as expected from ESS-type sources, will extend INS to smaller purer samples of many more mineral species and phases, also at non-ambient conditions.

6. Magnetic properties

Neutron scattering is still the best probe for microscopic ordering of magnetic moments, and can be used to determine magnetic structures, collective magnetic excitations, and crystal field energy levels of many magnetic elements. The magnetic structures and transitions of Fe minerals present in high-pressure environments in the deep Earth is of paramount importance to elucidate their physical properties and behaviour. Although magnetic X-ray scattering can certainly be performed with synchrotron radiation, it is practically limited only to resonant species (*i.e.*, Fe and a few REE), therefore the use of the ESS neutron source will allow much better measurements, especially under pressure.

Relatively few mineralogical studies have been recently undertaken in this field as mentioned in the introductory article by Dove (2002). More studies are to be expected, especially under high pressure and temperature, when the next generation of neutron sources and instrumentation will become available (Rinaldi *et al.*, 2001).

7. Direct imaging

Neutron penetration and the time-structure of a pulsed source can be advantageously exploited for time-resolved neutron-absorption measurements to determine viscosity and density of magma-type melts at high pressure and temperature. Despite the absolute novelty of this field, very interesting results are to be expected by the development of the technique. For example, neutron imaging experiments at pressures up to 5-10 GPa and temperatures of 1300-1500°C in a cm scale cell can provide precise *in situ* measurements that may be extended to the study of reaction fronts in silicate crystallisation. More readily available measurements are those related with the inner fabric of

materials and artefacts, beyond the reach of less penetrating probes, for applications in many fields including archaeology and the preservation of cultural heritage artefacts.

Winkler *et al.* (2002) give a number of examples illustrating the potential of this new non-destructive technique which offers the promise for many new developments in fields of application ranging from experimental mineralogy and petrology to cultural heritage studies and preservation.

8. Mineral surfaces

The breakdown, weathering and transformation of minerals on the Earth inherently involves the migration of hydrogen through the mineral surface and into the subsurface of the crystals, thus changing the physical properties of the minerals in the surface region. As these reactions occur at the mineral/mineral, mineral/fluid or mineral/biota interface, the study of these protonation reactions is fundamental to our understanding of weathering and mineral breakdown. Currently, X-rays are used in reflectivity mode to investigate mineral surfaces, but as previously mentioned, in order to investigate protons, neutrons are far superior to X-rays.

Novel applications are to be expected in this field as accounted for in the article by Schäfer (2002) dealing mostly with aspects related with the next point of merit.

9. Texture and stress analysis *(using the penetrating power of neutrons to extract the geological history from rocks)*

Texture, defined as preferred orientation in a crystalline material, carries a fingerprint of the rock‘s history. The complexity of geological texture analysis results mainly from the overprinting of different textures upon several mineral components from different periods of geological activity. Quantitative texture analyses provide fundamental information for the modelling of rock anisotropies and the reconstruction of tectonic events.

The high penetration capability of neutrons and the availability of wide beams allow the investigation of large specimens which produce global volume textures with high grain statistics even on coarse-grained materials. Using position-sensitive detectors and time-of-flight techniques, texture can be analysed from reflection-rich diffraction patterns of polymineralic rocks containing low-symmetry mineral constituents.

Residual stress analysis of geological material is crucial because natural effects on rocks are orders of magnitude smaller than in technological materials and drilling gives rise to stress relaxation. Furthermore, transient stresses and strains can be directly observed through *in situ* measurements at various pressures and temperatures.

The review by Schäfer (2002) gives a full account of the technique and its recent applications to several cases of mono- and polymineralic rocks and with an eye to future advancements in both texture and stress-strain analyses with next generation neutron sources and instrumentation. Future prospects are in fact promising for performing simultaneous phase, structure, texture, and stress analyses.

10. Non-destructiveness

In general, the non-destructive nature of many neutron-scattering experiments makes the technique well suited for handling large, undisturbed samples, and/or rare and unique objects, natural and man-made, encompassing areas as diverse as, for instance, sediment layers, meteorites, and historical artefacts.

The present collection of articles is therefore aimed at considering the advancements recently achieved, and further expected, through this modern approach to neutron-scattering applications in Mineral Sciences. To this effect, the plan for this Special Issue can be subdivided into five broad areas collecting contributions from leading experts in each field according to the scheme (and Index) given below. Each article is effectively a stand-alone review addressing the subject with a tutorial approach. Care has been taken by the Editors in order to minimise overlaps and to provide a balanced coverage of all areas of interest although inevitably favouring the prevailing and most recent applications. One slight note of disappointment remains for having not received sufficient response from the experts in the field of the magnetic structure of minerals in order to cover the subject with a dedicated article rather than finding it dispersed throughout the collection.

Overall scheme of the Special Issue and Index

A look into the future

As the facilities for collecting high-quality data are further developed, so our ability to resolve scientific issues pertaining to these fields increases. As a matter of fact there are many areas in the Earth and Environmental Sciences for which the present sources and instrumentation still need further development. Examples include measurements of the structural changes in minerals at very high pressures and simultaneous high temperatures, locations of light elements in complex structures, and studies of the dynamical properties (neutron spectroscopy) also at non-ambient conditions. This information will eventually enable the modelling of fundamental processes in the Earth, ranging from large scale phenomena such as deep-focus earthquakes and volcanic activity, through to the transport (and disposal) of pollutants in the Earth's crust and to stone preservation in monuments. The new neutron sources at various stages of planning (SNS in the USA – http://www.sns.gov/brochures/newSNSBrochure.pdf -, JAERI-KEK Joint Project JKJ in Japan – http://jkj.tokai.jaeri.go.jp/MatLife/en/science.html - and ESS in Europe – http://www.ess-europe.de/search_ess.html -) promise a large increment of potentiality in these areas in the next decades.

Acknowledgements: Many thanks go to all contributing authors for making this endeavour possible. Thanks are also due to the following colleagues for acting very promptly as referees of the submitted articles, often providing valuable suggestions for the improvement of the manuscripts: G. Artioli, W.D. Carlson, M. Catti, D. Chateigner, N. Choudhury, B. Dorner, R.S. Eccleston, D.A. Keen, K.S. Knight, L. Lutterotti, S.A.T. Redfern, K. Stähl, I.P. Swainson, M.D. Welch, C.C. Wilson, I.G. Wood.

A sad thought goes to the memory of Jean-Michel Besson of Paris University whose enthusiastic and fundamental contribution to the Autrans Workshop (1996) has been one of the determining factors for this undertaking.

References

Artioli, G. (2002): Single crystal neutron diffraction. *Eur. J. Mineral.*, **14**, 233-239.

Artioli, G., Besson, J.-M., Dove, M.T., Geiger, C.A., Rinaldi, R., Schäfer, W. (1996): Neutron Scattering in the Earth Sciences. *in*: "Scientific Prospects for Neutron Scattering with Present and Future Sources"; European Science Foundation (Strasbourg), *Framework Studies into Large Research Facilities* Special Publication, 1996 Autrans (F) Workshop, ISBN 2-903148-90-2, pp. 94108. - http://ensa.web.psi.ch/ensa/autrans.pdf

Chaplot, S.L., Choudhury, N., Ghose, S., Rao, M.N., Mittal, R., Goel, P. (2002): Inelastic neutron scattering and lattice dynamics of minerals. *Eur. J. Mineral.*, **14**, 291-329.

Dove M.T. (2002): An introduction to the use of neutron scattering methods in mineral sciences. *Eur. J. Mineral.*, **14**, 203-224.

Dove, M.T., Tucker, M.G., Keen, D.A. (2002): Neutron total scattering method: simultaneous determination of long-range and short-range order in disordered materials. *Eur. J. Mineral.*, **14**, 331-348.

Dove, M.T., Price D., Artioli G., Besson, J.-M., Geiger C.A., Rinaldi, R., Schäfer, W., Winkler, B., Redfern S.A.T. (1997): Earth and Environmental Sciences. *in*: "ESS: A Next Generation Neutron Source for Europe." Vol. II, The Scientific Case, pp. 37-40. ISBN 090 237 6 500 – http://www.ess-europe.de/documentation/ESSvol2b.pdf

Pavese, A. (2002): Neutron powder diffraction and Rietveld analysis: applications to crystal chemical studies of minerals at non-ambient conditions. *Eur. J. Mineral.*, **14**, 241-249.

Price, D., Dove M.T., Artioli G., Besson, J.-M., Geiger C.A., Rinaldi, R., Schäfer, W., Winkler, B., Redfern S.A.T. (2000): ESF Studies on Large Research Facilities in Europe, Interim Report : "The Scientific-Strategic Case for a Next-generation European Spallation Neutron Source for Science and Research (ESS Project)" pp. 229-240. ISBN 2-912049-20-2 – http://www.esf.org -.

Redfern S.A.T. (2002): Neutron powder diffraction of minerals at high pressures and temperatures: some recent technical developments and scientific applications. *Eur. J. Mineral.*, **14**, 251-261.

Rinaldi, R., Artioli, G., Dove, M.T., Schäfer, W., Schofield, P.F., Winkler, B. (2001): Neutron Scattering in Mineral Science, Earth Science, and Related Fields with the European Spallation Source (ESS). In: "ESS-SAC/ENSA Report 1/01 on Scientific Trends in Condensed Matter Research and Instrumentation Opportunities at ESS", pp. 91-106. http://www.ess-europe.de/documentation/ESS_SAC_ENSA_2001.pdf

Schäfer, W. (2002): Neutron diffraction applied to geological texture and stress analysis. *Eur. J. Mineral.*,**14**, 263-289.

Winkler, B. (2002): Neutron sources and instrumentation. *Eur. J. Mineral.*, **14**, 225-232.

Winkler, B., Knorr, K., Kahle, A., Vontobel, P., Hennion, B., Bayon., G. (2002): Neutron imaging and neutron tomography as non-destructive tools to study bulk rock samples. *Eur. J. Mineral.*, **14**, 349-354.

Received 1 October 2001
Accepted 12 October 2001

Appendix

European Neutron Facilities: main characteristics, instrumentation and contacts.

Adapted and updated from: "Survey of the Neutron Scattering Community and Facilities in Europe", prepared for ESF by the European Neutron Scattering Association (ENSA) 1998, ISBN 2-912049-00-8, http://ensa.web.psi.ch/ensa/survey.pdf . Other information can be gathered at the www page: http://www.iaea.org/worldatom/rrdb/ listing all research reactors available in the World.

Atominstitut Vienna (A)
Facility: TRIGA MARK II
Type: Reactor. Thermal power 250 kW. Flux: 1.0 x 10^{13} n/cm^2 /s (Thermal) ; 1.7 x 10^{13} n/cm ^{2}/s (Fast)
Type of instruments available to external users:
SANS, Interferometer, Depolarisation, Transmission Expts, neutron radiography.
Address for information:
ATOMINSTITUT OESTERREICHISCHEN UNIVERSITAETEN
Stadionallee 2 A-1020 WIEN

PROF. DR. H. RAUCH
Phone: 43-1-58801 14168
Fax: 43-1-58801 141199
boeck@ati.ac.at
www.ati.ac.at

Budapest Neutron Centre BRR (H)
Type: Reactor. Flux: 2.0 x 10^{14} n/cm^2/s
Number of instruments available to external users: 9
Type of instruments available to external users:
1 powder/liquid diffractometer
1 single crystal diffractometer*
1 SANS
1 reflectometer*
2 3-axis spectrometers
2 Neutron/gamma radiography
Prompt gamma activation analysis
* Under construction
Dates for proposal submission: June 15/November 15
Dates for selection process: July/December
Related scheduling periods: August-December/January-June
Address for application forms:
Dr BORBELY Sándor, KFKI Building 10, 1525
Budapest, Pf 49, Hungary
E-mail: Borbely@power.szfki.kfki.hu
WEB page: http://www.iki.kfki.hu/nuclear

FRJ-2 Forschungszentrum Jülich (D)
Type: Dido reactor. Flux: 2 x 10^{14}n/cm^2/s
Number of instruments available to external users: 15
Type of instruments available to external users:
2 powder/liquid diffractometers
2 single crystal diffractometers
2 SANS
1 double crystal diffractometer
3 3-axis spectrometers
1 quasielastic spectrometer
1 TOF (MET)
2 backscattering spectrometers
1 β-NMR
Dates for proposal submission: no formal selection process
Informal proposals to:
Professor Dr D Richter, Forschungszentrums
Jülich GmbH, Institut für Festkörperforschung,
Postfach 19 13, 52425 Jülich, Germany
Telephone: +49-2461161 2499
Fax: +49-2461161 2610
Email: d.richter@kfa-juelich.de
WWW page: http://www.kfa-juelich.de

FRG-1 Geesthacht (D)
Type: Swimming Pool Cold Neutron Source. Flux: 8.7 x 10^{13}n/cm^2/s
Number of instruments available to external users: 10
Type of instruments available to external users:
1 four circle texture diffractometer
2 residual stress diffractometers
2 SANS
2 reflectometers
1 TOF spectrometer for basic research
1 Double crystal diffractometer for high resolution SANS
1 3-dimensional polarisation analysis diffractometer
Polarised neutrons available on 5 instruments
Dates for proposal submission: Any time
Dates for selection process: Within 4 weeks of submission
Address for application forms and information:
Contact name: Reinhard Kampmann
Contact address: Institute for Materials Science,
Div. Wfn-Neutronscattering, GKSS
Research Centre, 21502 Geesthacht, Germany
Telephone: +49 (0) 4152 87 1316 / 2503
Fax: +49 (0) 4152 87 1338
Email: reinhard.kampmann@gkss.de
WWW page: http://www.gkss.de

HMI Berlin BER-II (D)
Facility: BER II, BENSC
Type: Swimming pool reactor. Flux: 2 x 10^{14}n/cm^2/s
Number of instruments available to external users: >17
Type of instruments available to external users:
2 powder/liquid diffractometers
3 3-axis spectrometers
4 single crystal diffractometers
1 quasielastic spectrometer
1 membrane diffraction
2 TOF (MET)
2 SANS
1 spin echo
1 reflectometer
1 neutron interferometer
~1 β-NMR
1 cold source
NB: For many instruments options include polarisation, high fields, high pressures and low temperatures
Dates for proposal submission: 15 March /15 September
Dates for selection process: May/November
Related scheduling periods: July-December /January-June
Address for application forms:
BENSC, Office of the Scientific Secretary,
Hahn-Meitner-Institut, Glienicker Str 100,
14109 Berlin, Germany.
Download from the Web at http://www.hmi.de/grossgereate/bensc/BENSC-form.html
Contact name: Dr Rainer Michaelsen
Contact address: BENSC Scientific Secretary,
Hahn-Meitner-Institut, Glienicker Str 100,
14109 Berlin, Germany
Telephone: +49 30 8062 2304 / 3043
Fax: +49 30 8062 2523 / 2181
Email: michaelsen@hmi.de
WWW page: http://www.hmi.de/

IBR2 Dubna (RU)
Type: Pulsed Reactor. Flux: 3 x 10^{16} (thermal n in core)
Number of instruments available to external users: 12
Type of instruments available to external users:
4 powder/liquid diffractometers
1 single crystal diffractometer
1 SANS
2 reflectometers
1 quasi-elastic spectrometer
2 TOF (MET)
1 spin echo
Dates for proposal submission: 16 October/16 May
Dates for selection process: 30 January/15 September
Related scheduling periods: February-June/October-February

Address for application forms:
Scientific Secretary, Frank laboratory of Neutron Physics,
Joint Institute for Nuclear Research,
141980 Dubna, Moscow Region, Russia
Contact name: Dr Vadim Sikolenko
Contact address: Frank Laboartory of Neutron Physics,
Joint Institute for Nuclear Research,
141980 Dubna, Moscow Region, Russia
Telephone: +7-09621-65096
Fax: +7-09621-65882
Email: sikolen@nf.jinr.dubna.su
WWW page: http://nfdfn.jinr.dubna.su/

ILL Grenoble (F)
Type: 58MW High Flux Reactor. Flux: 1.5 x 10^{15}n/cm^2/s
Number of instruments available to external users: 36
Type of instruments available to external users:
5 powder/liquid diffractometers
7 single crystal diffractometers
2 SANS*
3 reflectometers*
5 polarised neutron instruments*
2 Nuclear Physics
6 3-axis spectrometers
2 backscattering spectrometers
3 TOF (MET)
2 spin echo
2 Fundamental Physics
*some double counting
NB: 7 of the above instruments are operated and supported by Collaborative Research Groups (CRGs)
Dates for proposal submission: 15 February / 31 August
Dates for selection process: April /October
Related scheduling periods: July-December / January-June
Address for application forms:
Scientific Coordination Office, ILL, BP 156,
38042 Grenoble Cedex 9, France
Contact name: Dr H Büttner
Telephone: +33 4 76 20 7179
Fax: +33 4 76 48 3906
Email: buttner@ill.fr
WWW page: http://www.ill.fr

IRI Delft (NL)
Type: 2MW light water swimming pool. Flux: 1.5 x 10^{13} n/cm^2/s
Number of instruments available to external users: 5+2*
Type of instruments available to external users:
2 powder/liquid diffractometers*
1 reflectometer
1 small angle scattering spectrometer*
1 TOF (MET)
2 polarised neutron instruments
*instruments located at ECN Petten
Dates for proposal submission: no formal selection process
Contact one of the following:
M Th Rekveldt (Head of Polarised Neutron Group);
I M de Schepper (Head of Neutron Scattering Group) or
A A van Well (Coordinator of Neutron Beam Facilities)
Address for application:
Interfacultair Reactor Institut, Delft University of Technology,
Mekelweg 15, 2629 JB Delft, The Netherlands
Contact name: Dr A A van Well
Telephone: +31 15 2784738
Fax: +31 15 2786422
Email: VanWell@iri.tudelft.nl
WWW page: http://www.iri.tudelft.nl

ISIS Didcot (UK)
Type: Pulsed Spallation Source. Flux: 2.5 x 10^{16}n fast/s
ISIS operates at 200 μA in 0.4 μs pulses at 50 Hz
Number of instruments available to external users: 24
Type of instruments available to external users:
3.5 powder diffractometers
1 single crystal diffractometer
1 SANS
2 reflectometers
1 Cold neutron test VESTA
1 Single crystal alignment ALF
5 muon instruments
1 neutrino facility
1 3-axis spectrometers
1.5 quasielastic spectrometers
4 TOF spectrometers
1 eV spectrometer
1 strain/pressure diffractometer
Dates for proposal submission: April 16 /October 16
Dates for selection process: First week of June / First week of December
Related scheduling periods: Sept to Jan / April to August
Address for application forms:
ISIS User Liaison Office, Building R3,
Rutherford Appleton Laboratory,
Chilton, Didcot, Oxon OX11 0QX
Telephone: +44 (0)1235 445592
Fax: +44 (0)1235 445103
Email: uls@isise.rl.ac.uk
WWW page: http://www.isis.rl.ac.uk/

JEEP-II Kjeller (N);
Type: D 2 O moderated 3.5% enriched UO 2 fuel. Flux: 2 x 10^{13}n/cm^2/s
Number of instruments available to external users: 5
Type of instruments available to external users:
2 powder/liquid diffractometers
1 single crystal diffractometer*
1 SANS
1 3-axis spectrometer*
1 quasi-elastic spectrometer (TOF)
*The 3-axis instrument may be used as a single crystal diffractometer
Dates for proposal submission: No special dates
Dates for selection process: No special dates
Address for application forms:
INSTITUTT FOR ENERGITEKNIKK
K. H. BENDIKSEN, MANAGING DIRECTOR
Box 40, 2007 Kjeller, Norway
Telephone: +47 -63-806000, 806275
Fax: +47 63-816356
E-mail: kjell.bendiksen@ife.no
WWW page: www.ife.no

LLB ORPHÉE Saclay (F)
Type: Reactor Flux: 3.0 x 10^{14}n/cm^2/s
Number of instruments available to external users: 24
Type of instruments available to external users:
6 powder/liquid diffractometers

2 single crystal diffractometers
1 Strain diffractometer
1 Texture diffractometer
3 SANS
3 reflectometers
5 3-axis spectrometers
1 TOF (MET)
1 spin echo
1 polarised neutron instrument
Dates for proposal submission: September
Dates for selection process: November
Related scheduling periods: January to December
Address for application forms:
Laboratoire Léon Brillouin, CEA-Saclay,
91191 Gif-sur-Yvette Cedex, France
Contact name: Mrs Claude Rousse
Telephone: +(33 -1) 69 08 52 41 / 54 17
Fax: +(33 -1) 69 08 82 61
Email: rousse@bali.saclay.cea.fr
WWW page: www-drn.cea.fr

PSI-SINQ Villigen (CH)
Type: Steady Spallation Source. Flux: 2.0 x 10^{14}n/cm^2/s
Number of instruments available to external users: 10
Type of instruments available to external users:
2 powder diffractometers
1 single crystal diffractometer
1 SANS
1 reflectometer
2 3-axis spectrometers (one for polarised neutrons)
1 TOF (cold neutrons)
Radiography
Prompt gamma analysis
Dates for proposal submission:
Starting in 1998
Dates for selection process: Spring, Autumn (details to follow)
Related scheduling periods: January to June, July to December
Address for application forms:
Secretariat, Laboratory for Neutron Scattering,
ETH Zurich and Paul Scherrer Institute,
CH-5232 Villigen PSI, Switzerland
Contact name: Professor Dr Albert Furrer
Telephone: +41-56-310 20 88
Fax: +41-56-310 29 39
Email: albert.furrer@psi.ch
WWW page: http://lns.web.psi.ch/

NFL Studsvik (S)
Type: 50MW reactor. Flux: >10^{14}n/cm^2/s
Number of instruments available to external users: 5
Type of instruments available to external users:
1 powder diffractometer
1 liquids diffractometer
1 single crystal diffractometer
1 Residual stress diffractometer
1 TOF (MET)
Dates for proposal submission:
1 Dec/1 April /1 Aug (for LSF programme only)
Dates for selection process:
Decisions before 1 Jan /1 May/1 Sept (LSF only)
Related scheduling periods:
January-April / May-August / Sept-Dec.
Address for application forms:
Dr R McGreevy, NFL Studsvik,
S-611 82 Nyköping, Sweden
Telephone: +46-155-221000
Fax: +46-155-263070/263001
Email: kklingfeldt@studvik.se
WWW page: www.studsvik.uu.se

NPI Řež (Prague) (CZ)
Type: 10 MW research reactor
Address for information:
Nuclear Research Institute Řež plc
250 68 Řež,
Czech Republic
Tel. exchange: (+420 2) 66171111,
or 20940885, 20940351, 20940179
Fax: (+420 2) 20940840, 20941155
E-mail: last_name@ujv.cz
Director General
František Pazdera
Tel.: (+420 2) 20940619, 66173532
Fax: (+420 2) 20940840
E-mail: paz@ujv.cz
Scientific Secretary
Zdeněk Kříž
Tel.: (+420 2) 20941177, 66173428
Fax*:* (+420 2) 20941155
E-mail: krz@ujv.cz
Email: brv@nri.cz
WWW page: www.nri.cz

TU Munich FRM, FRM-2 (D)
Type: Compact 20 MW Reactor.
Thermal peak flux 8 x 10^{14}n/cm^{2}s
Number of instruments available to external users: 14
Type of instruments available to external users:
1 powder diffractometer
1 soft phase boundary diffractometer
2 single crystal diffractometers
2 single crystal spectrometer
1 Small angle spectrometer/diffractometer
2 Spin-echo spectrometers
2 Three-axis spectrometers
1 Radiography-tomography
2 TOF spectrometers
Address for information:
Prof. Dr. Winfried Petry
FRM-II - Lichtenbergstraße 1
85747 Garching
Sekretariat: 089 289 14701
Fax: 089 289 14666
wpetry@frm2.tum.de
Address for cooperation:
TUM-Tech GmbH
Management
Saarstraße 7
80797 München
Telefon: 089 306695-00
Fax: 089 306695-66
info@tumtech.de
www.tumtech.de
http://www.frm2.tu-muenchen.de/
http://www.frm2.tu-muenchen.de/e/index.html