6.R3 Activity JRA3: Neutron Optics and Phase Space Transformers (NO-PST)

6.R3.1 Description and objectives of NO-PST

At present, Europe is the world leader in the number of powerful neutron sources as well as in the development of new techniques. However, in the US as well as in Japan, spallation sources with a projected power exceeding 1 MW are being built and are challenging the lead of Europe. One of the ways to cope with this situation is the development of more advanced focusing devices that play an increasingly important role in neutron scattering for the investigation of small samples as they occur often in the fields of soft condensed matter and in materials research. In addition, proper focusing allows often to increase the signal to noise ratio because the sample environment is not hit by neutrons that do not contribute to the signal. Last but not least, focusing is still the cheapest means to increase the performance of neutron scattering instruments.

It is clear that high flux can only be obtained by a combination of improvements of all parts of a neutron instrument. In particular, the combination of various focusing techniques alone may lead to large gains. In addition to focusing, it is also necessary to improve detectors with respect to spatial resolution, large areas and high rates. That topic is part of a separate JRA. This JRA will carry out several collaborative tasks between different partners (neutron scattering centres, universities) in the field of neutron optics and phase space transformers.

The participants have chosen the following four topics for a joint research activity:

Activity:	Task
• Honeycomb, multibeam, solid state devices	T1
• Focusing devices (not solid state)	T2
• Diffuse scattering, new sputtering techniques	T3
• Phase Space Transformers	T4

Most new developments in neutron optics have their origin at various research centres in Europe, putting Europe in a world leading position in this field. In fact, most of the advanced neutron technology is built in Europe. By joining the world leading laboratories in Europe in the actvities chosen we expect significant advances in the development of more powerful focusing and imaging techniques that will be used for elastic and inelastic neutron scattering as well as for technical applications like PGAA and radiography. In the following sections we provide an overview of the various research projects in neutron optics and phase space transformers.

Honeycomb, multibeam, solid state devices

Already under the Cold Neutron Optimization network (FP4, ended feb 2002), an initiative for thermal neutron beam conditioning in SANS applications concerned the development of prototype Honeycomb Collimators (HC). In addition, solid-state devices mostly based on the technology of supermirror coated Si-wafers were developed for focusing and polarization purposes.

The participants plan to improve the design and fabrication technology of the converging HC to get higher flexibility as to total length and hexagonal section. Different coatings of the profiles by neutron absorbing materials will be investigated (BNC-RISP). Tests of the collimator performances (ISIS/BNC-RISP) and insertion of it in a SANS instrument (BNC-RISP) will be carried out.

The technique of multiple-SANS is already being developed by collaboration between TUM and PSI. First tests have been performed on the SANS-II camera at PSI. Intensity estimates have been made and will be verified in the near future. It is planned to install a MSANS device at the MIRA beam line of the FRM-II of TUM (very cold neutrons). In a further project it is planned to built a neutron Si lens which can focus the neutrons after the end of a neutron guide.

Focusing devices (not solid state)

Many of the present day focusing devices (like anti-trumpets) suffer from producing a very inhomogeneous phase space. This is particularly disturbing for diffractometry and inelastic neutron scattering. In addition, it seems at present to be difficult to focus neutron beams to small sizes, except by using Kumakhov lenses. This is an expensive method; moreover due to the requirement that the area of the glass fibres is the same at the entrance and exit of the lens many neutrons are wasted. Preliminary simulations and tests in collaboration between TUM and PSI on parabolic flight tubes show that the spot of maximum intensity is quite far away from the exit of the device. Therefore, the technique of non-linearly shaped flight tubes is very promising. In particular it is possible to make full use of the neutron beam as delivered by a neutron guide using a multiple set-up of flight tubes. The participants plan to develop the technique further. For this purpose the participants plan to write routines for the Monte-Carlo simulation program McStas (in collaboration with JRA7: MCNSI). First simulations using linear interpolations suggest gains of a factor of 50.

Diffuse scattering, new sputtering techniques

Despite significant improvements in the technology of supermirrors it is important to improve further the quality and stability of the coatings in particular for mirrors with $m > 3$. For the increase of stability the in-plane strain has to be reduced, which requires an improvement of the preparation technique. The quality of coatings essentially depends on the properties of the interfaces. Especially, it is necessary to decrease the diffuse scattering from rough interfaces significantly in order to use supermirrors for focusing devices or as monochromators. In cases where sharp interfaces cannot be realised, we want to replace roughness by controlled interdiffusion to suppress diffuse scattering.

The participants plan to investigate systematically the diffuse scattering from supermirrors and to optimise the coating processes. For this reason the sputtering plant at PSI will be completely refurbished in order to reduce the interface roughness by co-sputtering and to be able to produce laterally graded mirrors. At the same time, the participants plan to re-design the cathodes at the sputtering plant at TUM to improve the stability of the plasma. For the investigation of the quality of the multilayers TUM have set up a D5000 x-ray diffractometer that is optimised and only used for thin film analysis. In addition, the participants will expand the codes for calculating supermirror sequences for the treatment of graded interfaces. The participants expect that the diffuse background can be reduced by at least a factor of 10 thus increasing the signal to noise ratio of SANS and reflectometry rather dramatically.

Phase Space Transformers

During the last few years it has become apparent that highly dense ultra cold neutrons can be produced using advanced cooling by a solid moderator and by using a proper pumping option at pulsed neutron sources. Densities above $\rho_{ucn} \cong 10^5$ cm^{-3} can be expected, which means an intensity gain of the order of 10^3 compared to the best existing UCN source at ILL, where the density is about 70 cm^{-3}. Such high densities are associated with a high phase space density, which can be transformed by a proper phase space transformer to produce highly monochromatic cold, and perhaps also thermal, neutron beams. The related monochromaticity is given by v_{ucn}/v where $v_{ucn} \cong 5$ m s^{-1}, and v denotes the velocity to which the neutrons are accelerated. The related intensity is $\rho_{ucn}\cdot v$. With v ~10^5 cm s^{-1} such monochromatic beams could exhibit an intensity of about 10^{10} cm^{-2} s^{-1} which is about three orders of magnitude above the present experimental situation at high-flux neutron sources (e.g., ILL and ISIS). Various loss factors, which have to be identified within the project, can reduce this performance parameter by a factor of 10, but this still means a remarkable gain factor.

The principle of phase space transformation has long been known to work. It has been demonstrated experimentally for thermal and cold neutrons. The objectives of this project are to

- design a UCN based phase space transformer
- optimise the design by analytical and Monte Carlo calculations
- construct a prototype
- carry out experimental tests of its performance
- minimise the intensity losses and optimise the resolution

Some topics which have to be exploited in detail before a dedicated UCN factory at a pulsed spallation source can be justified are:

(a) Measurement of various loss factors of the UCN trap and the adapted transformers.
(b) Is there a fast enough diffusion of UCNs towards the reflecting volume?

Detailed theoretical and experimental investigations concerning these topics will be carried out within the ongoing UCN project at PSI Villigen.

The crucial element of a phase space transformer is the moving monochromator system which accelerates the ultra-cold neutrons to the desired velocities. This can be achieved by the use of e.g. a rotating wheel with monochromator systems mounted at its circumference moving with velocities up to v = 10^5 cm s^{-1} (which is the technical feasibility limit at present). As monochromator systems both single crystals and multilayers may be used. Due to their finite size the moving monochromator systems experience a radial velocity gradient which decreases the monochromaticity of the scattered neutron beam. This effect can be lifted by tilting the crystals by a well defined angle which is in direct correspondence with the radial velocity.

An enhancement of the monochromatic neutron flux by two to three orders of magnitude through phase space transformation is just miraculous when compared with the moderate enhancement of the neutron flux by a factor of 4 from the very first research reactor (in Chalk River, Canada) to the presently most intense neutron source (ILL Grenoble). The gain factors will be tested first for very cold and cold neutrons and will eventually reach the thermal region successively. Only in the field of synchrotron x-ray sources are flux enhancements of several orders of magnitude usually reported. There are good arguments to believe that the setup of the UCN source plus the phase space transformer described above could revolutionise the field of cold neutron spectroscopy for condensed matter research. The project is therefore both technologically innovative and scientifically unique on a worldwide scale.

This JRA is also timely because of the project SUNS (Spallation Ultra-cold Neutron Source) which is under construction at PSI Villigen. The essential elements of SUNS are a proton beam with highest intensity (proton beam current ≥ 2mA), a heavy-element spallation target, a large moderator and converter system of about 4 m^3 heavy water, and 30 dm^3 of solid deuterium cooled to 6 K for the production of ultra-cold neutrons of energy ≤ 250 neV. Operating SUNS in a pulsed mode (pulse duration of a few seconds, pulse repetition approximately every 800 s) results in an equilibrium between the produced and re-absorbed UCN's in the storage volume of about 2 m^3, giving rise to an average UCN density $\rho_{ucn} \approx 3\ 10^3\ cm^{-3}$, which is two orders of magnitude above the density of the UCN source at ILL Grenoble. SUNS is expected to be operational in 2005, so that a prototype of a phase space transformer system can then be tested experimentally under the best possible conditions.

6.R3.2 Implementation plan of the joint research activity

Table 1. Partners of JRA3 – Neutron Optics and Phase Space Transformers		
P1	TUM	Technical University Munich
P2	CEA-LLB	Laboratoire Léon Brillouin
P3	PSI	Laboratory for Neutron Scattering, ETH & PSI
P4	HMI	Hahn-Meitner-Institute
P5	BNC-RISP	Budapest Neutron Scattering Centre
P6	INFM	Instituto Nationale per la Fisica della Materia
O7	ILL	Institute Laue-Langevin

Table 2. Objectives of JRA3 – Neutron Optics and Phase Space Transformers

Task	Partners	(Bold indicates the partner with main responsibility for the task. P1 is the coordinator.)
T1	P1 **P2** P3 P4 P5 P6	**Honeycomb, multibeam, solid-state devices:** Improvement of the design and fabrication technology of converging honeycomb (HC) collimators to get higher flexibility as to the total length and hexagonal section. Different coatings of the profiles by neutron absorbing materials will be investigated (BNC-RISP). Test of the collimator performances (ISIS/BNC-RISP) and insertion in a SANS instrument at BNC-RISP will be performed. Development and implemention of a multibeam technology for increasing the flux on SANS experiments. Recent tests in collaboration between CEA-LLB and BNC-RISP have demonstrated that the concept is actually working and provides the expected neutron flux gains. Within this task, the work will consist in designing an actual multibeam solution that can be implemented practically on a SANS spectrometer without compromising its configuration flexibility (varying wavelength, collimation length). The task will benefit from the experience developed at the BNC-RISP and CEA-LLB but the HC technology developed at INFM will also be used for implementation on a multiple beam SANS set-up. This HC technology allows the production of highly collimated beams without cross talk. In parallel, the technology of multiple holes SANS will be developed and implemented in collaboration between TUM and PSI. It uses the common SANS infrastructure except for the detector, which requires enhanced spatial resolution. The tests and characterisation will be carried out at PSI. A MSANS device should be implemented at the MIRA beam line for very cold neutrons at TUM (FRM-II). For several experiments such as strain analysis or neutron activation analysis a neutron lens with a short focus length of several 10 cm would be valuable. The participants will explore the possibilities of a solid state neutron lens which focuses the neutrons from a neutron guide to a spot. It will be composed of thin Si wafers coated with a reflected supermirror which are bent by an appropriate apparatus. This is a joint project of HMI and BNC-RISP.
T2	**P1** P3	**Focusing devices (not solid state):** Development of focusing devices using non-linear tapering. The goal of the research is the manufacture of a) elliptic devices to image a point-to-point source and b) parabolic devices for focusing neutron beams as delivered by neutron guides. The participants envisage designing large devices using technology similar to that for the transport of neutrons with glassy neutron guides. In particular ballistic guides with elliptically and/or parabolically shaped walls will allow i) the use of smaller cold sources thus reducing the flux depression, ii) increasing the S/N ratio by more than a factor of two, iii) to homogenize the phase space at the neutron scattering instrument and iv) decreasing the flux of fast neutrons and γ-rays. Therefore, an overall increase of performance of an order of magnitude is expected. In parallel the participants will develop the simulation program McStas (collaboration with JRA6: MCNSI) further in order to simulate and optimise guide components and neutron devices with arbitrary shapes of guide walls. A preliminary simulation/experiment has already given indications that parabolic

		guides can focus neutron beams down to an area of 0.7 mm, yielding flux gains of the order of 50. The new technology of non-linearly tapered guides will markedly increase the performance of neutron guides and make the expensive and fragile Kumakhov lenses obsolete.
T3	P1 **P3** P4 P5	**Diffuse scattering, new sputtering techniques:** Sputtered multilayers are used as neutron optical elements in a wide variety of applications. The weak points in the present technology are the limited angular or energy range and the appearance of diffuse scattering. In order to produce better multilayers this means that their total thickness and the quality of the interfaces have to be enhanced. The limiting factor for the total thickness of the supermirror is in-plane stress; hence strategies have to be developed to suppress its formation during the deposition. By a good quality of interfaces for neutron optics one understands a smooth and sharp change in the scattering length density. Smooth means that there is no lateral modulation (roughness), which leads to a reduction of the reflectivity and an increase of diffuse scattering. In many cases ideal interfaces cannot be realised. In these cases the strategy will be to control or induce interdiffusion in order to get non-sharp but smooth interfaces. The reflectivity then is still decreased, but diffuse scattering is suppressed. For certain applications such as monochromators this even opens up the new possibility of designing coatings with a sinusoidal scattering-length density with the consequence that no higher harmonics will be reflected. At the moment computer codes for the calculation of layer sequences are based on the concept of sharp interfaces, so new formalisms will be developed. These innovations will allow the design and production of supermirrors with larger angular range ($m > 3$), and monochromators where higher harmonics are suppressed. In addition, multilayer coatings with laterally graded layer-thickness will be produced for devices changing the divergence of the neutron beam, for example in phase space transformators.
T4	**P3**	**Design and construction of phase space transformer.** Optimisation of the coupling of the rotating monochromator system to the UCN storage vessel. Different technical solutions will be studied by both analytical calculations and Monte-Carlo simulations. These studies should also verify the expected performance of the PST instrument as well as identify (and cure) possible intensity loss factors. Development of fast rotating wheels with velocities at the circumference of up to 10^5 cm s^{-1} in order to achieve neutron energies ≤ 5 meV. Intermediate steps will be wheels with velocities of around 10^4 cm s^{-1}. Due to the finite size of the reflecting monochromator system there is a velocity gradient along the monochromator which worsens the resolution properties. This effect can be lifted by tilting the crystals by an well defined angle depending on the radial velocity.
		Test of phase space transformer at ILL. At the existing UCN-source at ILL a phase space transformer with tilting mechanism should be tested to shift UCN`s up to about 0.1 meV (corresponding to wheel velocities around 10^4 cm s^{-1}).
		Mechanical test of phase space transformer at PSI. The very fast rotating unit of the phase space transformer with automized tilting mechanism has to be tested according to the relevant safety regulations (2nd year to 4th year).

		Calculation of PST features. Various analytical and Monte Carlo methods will be used to calculate the PST features and to guide the experimental work.
		Development of alternative phase space transformers. Investigation of an alternative solution for neutron acceleration by linear velocity (rail gun) or high-frequency vibrating single crystals.
T5	**P1**	**Management and coordination.** Coordination of the JRA on Neutron Optics and Phase Space Transformers. The organization of regular meetings between participants of the six collaborating teams and an observer from the ILL twice a year. In addition, the dissemination of the results by regular reports and publications in the refereed literature is included.

Table 3. Milestones (M) and deliverables (D) of JRA3 – Neutron Optics and Phase Space Transformers.
Those falling within the first 18 months of the project are highlighted.

Task	Deliverables/ Milestones	
T1	D1.1	Fabrication of the 4 beams MB prototype, simulation for the Si lens, construction for a holder
	D1.2	Fabrication of the scalable MB prototype
	D1.3	Fabrication of the real device (4 beams), coating of wafers for the Si lens and assembling
	D1.4	Fabrication of the real multibeam device (4 beams), first test of the Si lens
	D1.5	Production of fabrication tools for HCs, design of improved Si lens system
	D1.6	Fabrication of HC prototype, production of improved Si lens system
	D1.7	Fabrication of absorbing masks for the multi hole SANS (MSANS) set-up prototype, test of improved Si lens system
	D1.8	Design and installation of the MSANS set-up at the MIRA beam line
	M1.1	Design of a SANS multibeam (MB) collimation prototype (BNC – INFM – LLB). Requirements are: no complicated mechanics, sturdy, proper absorbing coating this first prototype will be limited to 4 beams
	M1.2	Design of a scalable prototype for more than 4 beams (BNC – INFM – LLB) Requirements are: no complicated mechanics, sturdy, proper absorbing coating. The design will be based on a honeycomb layout.
	M1.3	Test of the actual 4 beams MB prototype (BNC), production of first Si lens
	M1.4	Design of an actual implementation (including the problems of collimation) (for the spectrometer PAXE at the LLB)), test of first Si lens
	M1.5	Test of the multibeam prototype on the USANS spectrometer at the LLB It provides very detailed imaging possibilities
	M1.6	Design of an actual implementation (problems of collimation) (for the USANS at the LLB)
	M1.7	Test an commissioning of the multibeam device on PAXE
	M1.8	Test an commissioning of the multibeam prototype on TPA

	M1.9	Development of absorbing coatings and non reflective coatings
	M1.10	Characterisation of the non absorbing and non reflective coatings
	M1.11	Design of a flexible and modular Honeycomb collimator, production of improves Si lens
	M1.12	Characterisation of HC performances
	M1.13	Implementation of the HC on an actual beam line (BNC)
	M1.14	Neutron test of transmission properties of masks for MSANS
	M1.15	Characterisation of the multi hole SANS set-up performance
	M1.16	MSANS experiments e.g. on a solution of latex spheres, test of improved Si lens
T2	D2.1.	Simulation software for the optimisation of non-linearly tapered guide structures (McStas)
	D2.2.	Concept for an elliptically shaped ballistic guide
	D2.3.	Technical specification for a “Kumakhov” like, parabolic focusing device. Design of multiple flight tubes for the measurement of dispersion less excitations and PGAA applications
	D2.4.	Optimisation of guide coatings for non-linearly tapered guides
	D2.5.	Manufacturing of multilayer devices using non-uniform *d*-spacing for parabolic mirrors and monochromatic focusing
	M2.1.	Performance calculation for an elliptic guide
	M2.2.	Prototype of a small elliptic guide tube and comparison with McStas simulation
	M2.3.	Prototype of a small parabolic flight tube and comparison with McStas simulation
	M2.4.	General concept of parabolic and elliptic guide tubes for the design of large guide systems
	M2.5	Concept for parabolic and elliptic imaging around the sample and detector area
T3	D3.1	Understanding of the influence of sputtering parameters (on several sputtering plants) on the performance of multilayers and supermirrors
	D3.2	Production of a stable $m > 4$ supermirror

	D3.3	Computer code allowing for graded interfaces for the design of multilayers and supermirrors
	D3.4	Functional monochromator with vertically graded interfaces
	D3.5	Functional focusing monochromators with laterally graded interfaces
	M3.1	Modification of sputtering plants
	M3.2	Supermirror with reduced in-plane stress
	M3.3	Layer sequence calculation paying respect to non-ideal interfaces
	M3.4.1	Control of interdiffusion
	M3.4.2	Decision of how to produce graded interfaces
	M3.4.3	Prototype of a multilayer with graded interfaces
	M3.4.4	Production and test of multilayers and supermirrors with graded interfaces
	M3.5	Mastering the production process for laterally graded layers
T4	D4.1.1	Construction of a fast (variable tilting) and a very fast (fixed tilting) rotating phase space transformer (24 months)
	M4.1.1	Detailed information available for the construction or purchase of a fast rotating wheel (9 months)
	M4.1.2	Detailed feasibility study available for the technical realisation of a PST instrument (12 months)
	M4.1.3	Conclusive answer whether a mechanical solution is technically feasible (12 months)
	M4.1.4	First mechanical tests of fast (≅ 10^4 cms^{-1}) rotating wheel (18 months)
	D4.2.1	Test of the very fast (≅ 10^5 cm s^{-1}) rotating wheel after 18 months including safety tests
	M4.2.1	Licensing of the PST unit to use it in a nuclear environment (after 18 months).
	D4.2.2	Test measurements at moderate velocities and automized tilting at ILL (after 24 months)
	D4.3.1	Test measurements at very high velocities with automized tilting at PSI (after 36 months)
	D4.4.1	Various calculations about PST-features
	M4.4.1	Optimised parameters for a high level PST-unit (after 24 months)

	D4.5.1	Detailed feasibility study available for an alternative solution of a PST unit based on a linear velocity device (rail gun) or high-frequency vibrating single crystals (24 months)
T5	D5.1	Annual reports

Table 4. Implementation plan for the JRA3 project. The detailed implementation plan for the first 18 months is outlined in bold.

		Quarter															
Task	Action Milestone Deliverable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T1	D1.1			■	■												
	D1.2					■	■										
	D1.3							■	■								
	D1.4									■	■						
	D1.5	■	■														
	D1.6			■	■												
	D1.7			■	■												
	D1.8											■	■	■	■		
	M1.1	■	■														
	M1.2			■	■												
	M1.3					■	■										
	M1.4					■	■										
	M1.5							■	■								
	M1.6									■	■	■	■				
	M1.7									■	■	■	■				
	M1.8													■	■	■	■
	M1.9	■	■														
	M1.10			■	■												
	M1.11	■	■														
	M1.12					■	■										
	M1.13									■	■	■	■				
	M1.14	■	■														
	M1.15					■	■										
	M1.16																
T2	D2.1	■	■	■	■	■	■										
	D2.2					■	■	■	■	■	■	■	■				
	D2.3	■	■	■	■	■	■	■	■								
	D2.4							■	■	■	■	■	■	■	■	■	
	D2.5								■	■	■	■	■	■	■	■	■
	M2.1					■											
	M2.2													■			
	M2.3								■								
	M2.4																■
	M2.5																■

Table 4. Implementation plan for the JRA3 project. The detailed implementation plan for the first 18 months is outlined in bold.

		Quarter															
Task	Action Milestone Deliverable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T3	M3.1				■												
	D3.1				■												
	M3.2							■									
	D3.2									■							
	M3.3					■											
	D3.3											■					
	M3.4.1								■								
	M3.4.2									■							
	M3.4.3											■					
	M3.4.4												■				
	D3.4														■		
	M3.5												■				
	D3.5																■
T4	D4.1.1	■	■	■	■	■	■	■	■								
	M4.1.1			■													
	M4.1.2				■												
	M4.1.3				■												
	M4.1.4						■										
	D4.2.1	■	■	■	■	■	■										
	M4.2.1						■										
	D4.2.2			■	■	■	■	■	■								
	D4.3.1							■	■	■	■	■	■				
	D4.4.1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	M4.4.1								■								
	D4.5.1	■	■	■	■	■	■	■	■								
T5	D5.1				■				■				■				■

6.R3.3 Management structure

The management of JRA3 will be assured by the JRA committee that is composed of one representative from each main partner (partners P1 – P6). The coordinator of the JRA3 (as defined to be P1) will act as chair of the JRA.

The partners of JRA3 will meet twice a year in order to discuss the status of the projects and distribute the new results. Every year JRA3 will submit a joint report to the General Assembly. JRA3 will design a web page in order to distribute the results.

6.R3.4 Exploitation of results

Neutron Optics

Considering that many important European neutron scattering facilities are involved in this JRA, there is a direct link, inside the project, between the designers of the new devices and the potential users. The flux of the neutron sources is always limited and as much as possible effort must be devoted to the improvement of the neutron instrumentation in order to exploit in all different research fields the benefits of the neutron scattering. The potentiality of the neutron scattering is enormous in almost all research fields concerning condensed matter, from life science to structural materials and from magnetism and magnetic materials to very basic condensed matter physics. However until now very little has been done in applications where only very small samples are available or can be used. Any improvement in this sector has an invaluable added value for many applied and basic research applications and the user community can be largely extended on increasing the instrumentation capability towards the use of smaller and smaller samples.

After the completion of the project it will be possible to supply good focusing devices to be used in all the applications which could benefit from Fresnel lenses.

The developments of JRA3 will contribute significantly to optimise the transport of the neutrons from the source to the sample position and to the detector. Four topics of JRA3 concern the focusing of neutron beams for cold and thermal neutrons. Some of the new types of focusing devices provide the maximum of intensity and the focal point away from the exit of the device. Therefore, these techniques are particularly suited for neutron scattering from samples that are contained in an advanced sample environment, in particular the use in high-pressure measurements. In addition, the divergence of the neutron beams will become more uniform thus simplifying the data treatment.

The projects on decreasing the diffuse scattering from supermirror coatings are, of course, a prerequisite to achieve good signal to noise ratios in particular in small angle neutron scattering and reflectometry. The new techniques to reduce roughness will significantly reduce the diffuse scattering of neutrons from the focusing and polarising devices.

Of course, the increase of intensity at the focal point goes along with an increase in divergence of the neutron beam. For many experiments this restriction is not really a serious one, for example in high-pressure studies, in measurements of excitations with weak dispersion, or in the more extreme case of activation studies. Therefore, the developments of JRA3 will be of interest to all neutron sources in Europe (and abroad).

The results of JRA3 will be published in the open literature and can be used by the scientific community as well as by private enterprise. Most major neutron scattering centres are involved in JRA3 and will directly profit from the results.

Phase Space Transformers

Any instrument for neutron scattering is designed so as to cover a particular part of the dynamical range which is a multiparameter space determined by the momentum transfer, the energy transfer, the resolution in the momentum space, the resolution in the energy space, and polarisation options. The UCN coupled PST instrument to be realised in the present project will have unparalleled energy resolution properties in the cold (and thermal) neutron range. Standard methods such as backscattering and spin-echo provide energy resolutions from μeV to neV. These techniques, however, are essentially restricted to quasielastic and low-energy inelastic scattering. For neutron spectroscopy involving energy transfers above 1 meV, where both triple-axis and time-of-flight instruments are commonly used, the presently available energy resolutions are typically of the order of a few tenths of a meV and thus hardly competitive for example with optical techniques. A PST spectrometer will contribute to an order of magnitude improvement of the energy resolution in cold (and thermal) neutron spectroscopy and thereby allow novel classes of experiments. On the one hand the intrinsic widths of inelastic lines associated with any kind of excitations can be measured with higher precision, on the other hand a series of inelastic lines occurring within a small energy interval can be completely resolved. Both achievements as well as the intensity gain factor (due to phase space compression) will be highly beneficial to significantly improve the quality of neutron spectroscopic work in many areas of science. The use of a PST spectrometer is evident for the study of magnetic and vibrational excitations in novel complex materials in the fields of magnetism, superconductivity, earth sciences and materials sciences.

The European community of 4000 scientists presently using neutron scattering techniques will benefit from the realisation of a PST instrument. Of course, an UCN based PST spectrometer requires the availability of a UCN source which in the foreseeable future will only be realised at PSI (the neutron density of the UCN source at the ILL Grenoble is too small for spectroscopic applications in condensed matter research). Nevertheless, the PST technique can be coupled equally well to a cold neutron source and thereby provide improved intensity and energy resolution for neutron spectroscopic work in the thermal energy range, i.e., a PST instrument can in principle be implemented at all major European neutron scattering facilities which have a cold source.

The expected outcome of the present project, the prototype of a PST spectrometer, is a novel instrument for neutron spectroscopy which will open new fields in many areas of condensed matter research.

6.R3.5 Risk assessment

Neutron Optics

The participants do not expect any particular risks in the proposed research projects. The tasks T1 and T2 will proceed on the basis of known and progressing technology (for example lithography). The success of task T3 depends partly on the technological development of sputtering techniques and a possible introduction of ion-beam sputtering techniques. Due to the collaboration of several laboratories that are running different sputtering facilities the participants expect significant progress by comparing and combining results from different plants.

Phase Space Transformers

Based on preliminary studies the participants are confident that the principal project goal can be achieved. However if it is concluded (see M4.1.3) that a mechanical transformer is not feasible, then all efforts will be moved to the search for alternative solutions (D4.5.1).

A certain "risk" of the project may be associated with the degree of optimisation of a PST instrument related to the expected intensity and energy resolution:

- Some neutron losses are probably unavoidable in conjunction with UCN, thus the JRA will study several methods of ultra-cold neutron extraction (e.g. direct extraction, extraction by transport through a neutron guide) and use the most efficient one for the construction of the PST prototype.
- The finite size and orientation of the monochromator system influences the energy resolution. The way to automatically adjust the monochromator to the radial velocity will be studied.