Concept of Operations for MAGiC

1 Introduction

1.1 Purpose of the document

The purpose of this ConOps is to provide a brief description of MAGiC, single crystal diffractometer dedicated to MAGnetIC systems, instrument, and in particular its basic concept. The description includes both a high level introduction to the science case of the instrument as well as providing the framework and context within which the instrument will be designed, operated and maintained through its life-cycle. However, as the scope for the instrument is not finally set yet, the document has to be regarded as preliminary.

The intended audience for this document includes everyone involved in the construction and operation of MAGiC, i.e. all central stakeholders. It will also serve the function as a quick overview of the instrument's purpose, construction and operation for both persons familiar with the field of neutron science and diffraction in particular and those that are not. The ConOps is intended to be updated several times to ensure its actuality.

2 High-level system requirements

The science case defined the high level scientific requirements and hence the operating mode that shall be supported by MAGiC. Making full use of the ESS strength, and hence ensuring the best scientific output, the following operating mode will be supported by MAGiC:

I. Half-Polarized Laue-TOF Diffraction. Reason: ESS will provide a flux at sample position orders of magnitude higher than the one available at current neutron sources allowing MAGiC to deliver the brightest thermal and cold polarized incident beams at sample position. Collects of flipping ratios over a large Q-range will be the day to day operating mode of MAGiC. This specificity will ensure the refinement of magnetic structures, spin densities and/or local anisotropy in X-ray sized crystals.

II. Polarized Laue-TOF Diffraction. Reason: polarization analysis of the scattered beam is an unbeaten tool allowing to discriminate between magnetic and nuclear contributions to the diffraction pattern. Most modern and challenging systems have weak magnetic contributions and/or presents only short range correlations characterized by a weak diffuse scattering that can only be revealed with polarization analysis.

Correspondingly the high level scientific requirements are:

1. The instrument shall provide a polarized incident beam over the $0.6<\lambda<6$Å wavelength range.
2. The instrument shall provide XYZ polarization analysis over a wide angle of 120°x6°.
3. The instrument shall allow data collection from crystals with a magnetic unit cell repeats of 100 Å.
4. The instrument shall allow data to be collected to a d_{min} of 0.35 Å.
5. The instrument shall match the size of the neutron beam to the size of the sample.
6. The instrument shall match the divergence of the neutron beam to the mosaicity of the sample.
7. The instrument shall allow data collection from crystals with volume lower than 0.001 mm^3
8. The instrument shall provide cryogenic capabilities in the 30 mK - 300K range and magnetic field capabilities in the 0-10 T range.
9. The instrument should maximise the signal-to-background (S/B) ratio of the Bragg reflections.

10. The instrument should provide pulsed magnetic fields > 50 T.
11. MAGiC should serve the user, science, and instrumental development program without interruptions during source operation.

3 System characteristics

3.1 System purpose

Single crystal neutron diffraction is a technique probing nuclear and magnetic periodicity in single crystals by collecting position sensitive intensities of the scattered beam. Thanks to the long pulse/high brightness of the ESS and the latest advances in neutrons optics, it is now possible to deliver a bright fully polarized neutron beam on sub millimetric samples. The pulsed nature of the source will give access to wavelength-resolved intensities through the neutron time-of-flight, yielding huge gain factor compared to today's state of the art instruments. This gain will enable the study of X-ray sized samples on a daily basis while staging diffraction into the thin-films scientist common workflow.

The full scope capability offers its users a wide panel of diffraction configurations, from « unpolarized » magnetic structure determinations to half-polarized spin densities refinement and longitudinal polarization analysis of weak magnetic components. The scientific areas covered by the full scope instrument encompass most of today's challenges from the quest of reliable and renewable energies or the need for new information and data storage technology, to the study of fundamental objects.

MAGiC is a versatile diffractometer intended to satisfy a wide range of scientific needs of which only a few examples can be given here:

1. Magnetism and metal-insulator transition : iridates.
2. Magnetism and superconductivity : cuprates and the Varma state.
3. Magnetism in frustrated and quantum magnetic insulators.
4. Magnetism and ferroelectricity : multifunctional materials, the quest of spintronics.
5. Magnetism in thin films and heterostructures : applied magnetism.
6. Novel long-length-scale magnetic structure.

3.2 High-level system requirements

In order to achieve the high level scientific requirements and to serve the outlined science case in taking best advantage of the ESS source the following high level system requirements have to be met. These are the central design requirements among the extensive functional requirements listed in the corresponding functional requirements document (MAGiC functional requirements).

From the Half-Polarized Laue-TOF Diffraction mode follows that all of the classical requirements for single crystal diffraction have to be taken into account from beam homogeneity, highest flux, tunable collimation from 0.6° down to 0.2°, tunable wavelength resolution from 15% down to 2%, wavelength bandwidth of 1.7 Å, wavelength range between 0.6 Å and 6 Å, a time resolution for pixels of 1 μs and incident beam polarization over the whole wavelength range.
From the Polarized Laue-TOF Diffraction mode follows that XYZ polarization analysis have to be available for wavelengths in the 2-6 Å range.

3.3 System Life-Cycle

The figure below shows the life-cycle of the MAGiC instrument on a high level, schematically and without the details of the corresponding further detailed development phases. Each phase of the instrument development is concluded with a TG review, with accompanying design review. The schematic process below is a simplified depiction as in reality there are overlaps between the seemingly distinct separations of the phases. For example the design of details will extend up to the end of the construction phase while long lead time items have to start tendering and production in the design phase and have to be developed with companies hand in hand with the final design. The Instrument Development process provides the framework within which the instrument will be developed with timely milestones in order to measure progress, still allowing for the overlap to exist. The controlling document for the instrument development is: Process for Neutron Instrument Design and Construction: ESS-0051706.

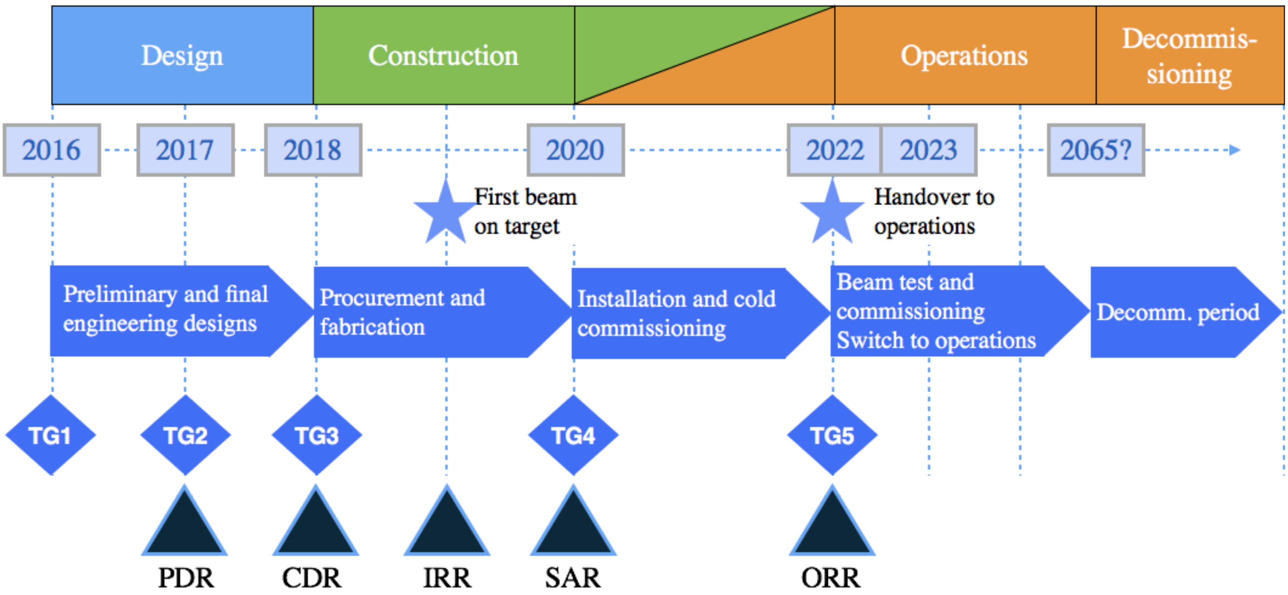

Figure 1. *Schematic Instrument Development process and its related life-cycle*

3.4 System overview

3.4.1 General

The MAGiC instrument is subdivided into the following generic main functional blocks:

- Neutron guides
- Shielding
- Chopper system
- Shutters
- Experimental cave
- Polarization elements
- Detectors
- Beam stop
- PSS
- Control hutch
- Instrument control
- Sample environment

All those have to be defined and designed such to enable to fulfill the high level requirements as the basis for the detailed functional and nonfunctional instrument and component requirements.

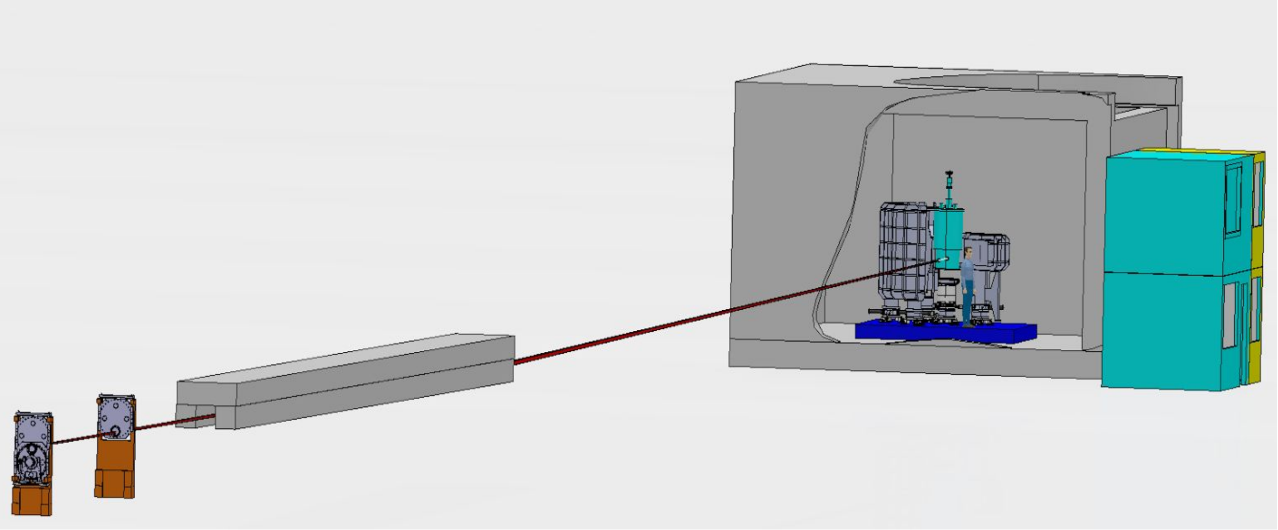

Figure 2. *MAGiC conceptual layout*

*3.4.2 Neutron Optics System (**LLB** WP)*

The neutron optics system is composed of 5 major elements ensuring the efficient transport of polarized neutrons from source to sample position (165 m) over a large bandwidth (0.6 to 6 Angströms), a ±0.3° divergence range in both directions and an illumination area of 5x5 mm². In this phase space, sample illumination has to be as homogeneous as possible.

Element 1 : the beam extraction system acting as a collimator. No supermirrors are necessary at this stage, so this part of the optics will be filled by shielding material as much as possible to limit noise and radiological level.
Element 2 : a 77 m long elliptical section of the supermirror neutron guide starts at 6.5 m from moderator surface and faces the thermal moderator maximizing thermal neutrons brilliance transfer. This section is inclined by 0.5° towards the ground in order to block direct line of sight and force polarizing reflections on Element 3 of the neutrons optics system.
Element 3 : a 3 m long FeSi coated polarizer, made of 6 channels and kinked by 0.25° in regard to the Element 2. It ensures an efficient polarization of thermal neutrons. The kink allows to lose direct line of sight while regaining horizontality of the guide.
Element 4 : a 77 m long elliptical section ending at 1.5 m of sample position. It is kinked by 0.25° in regard to Element 3 and regaining full horizontality of the guide system. As the first sections are inclined, this section will be at 30 cm of the E02 (guide hall) floor.
Element 5 : a 1 m long focusing device ending at 50 cm of sample position will be fixed to a vertical kinematic mount. This last element will increase neutron flux on small samples at the cost of a larger divergence.

The guide system outside of the monolith requires a vacuum system with less than 10^{-4} mbar pressure. The guide system is in principle a non-moving fixed installation, which in optimum case does not require maintenance. Settling of the ESS ground might however set a requirement for re-alignment at some point in time. The bunker section of the guide system will be unavailable for manual maintenance, therefore, a motorized re-alignment procedure should be implemented on this section of the beamline.

Other parts of the optics system are:
Divergence slits : a set of movable slits will be placed in the last 10 m of the guide system allowing to finely tune the beam divergence.

Slits : are to be installed in the last 1.5 m of the instrument to tailor the beam to the required size and shape.
Radial collimator : to reduce background from sample environment, an oscillating radial collimator will be installed in front of each detector.

*3.4.3 Shielding (PSI/**LLB** WP)*

The instrument operates with a very intense beam. Corresponding shielding requirements apply not only with respect to safety but also with respect to neighbouring instruments to reduce background as much as possible. Shielding optimisation is key and still on the way both with respect to cost and safety. The instrument shielding stretches from the bunker wall to the end of the instrument in the beam-stop and hence includes in particular the endstation. Current design is based on a 5 mm thick boron-plastic layer (with a boron carbide content of 80 %) enclosing the whole guide system and surrounded by concrete and steel elements of various thickness. The tunnel cross-section is of 50x50 cm and highly depends on the exact W6 angular sector design.

Outside of the bunker up to the polarizer position (28.5 - 83 m) the shielding will be made of 10cm of borated concrete (5%), 10 cm of steel and 50 cm of regular concrete walls. Additional steel blocks will be used at the instrument hotspot.
Extra care has been taken for the polarizer (Element 3 of the guide system) as more than 50% of the incoming beam will be lost at this stage of the instrument. In addition all fast neutrons propagating inside the guide have to be stopped at this position. For optimal guide performance the direct-line-of-sight is realized outside of the generic bunker. The current plan is to use 80 cm thick heavy concrete (d=5.2, 5% B4C) with an additional shielding block placed along the direct beam after the polarizer.
The second ellipse shielding will be made of 1 cm thick boron-carbide layers and 70 cm normal concrete walls up to the experimental cave (86 - 160 m).
Inside the experimental cave, the guide shielding will be made of 1 cm thick boron-carbide layer surrounded by 30 cm of steel. Boron-carbide layers will also be used to block the scattered neutrons outside of the detectors coverage.

*3.4.4 Chopper System (**JCNS** WP)*

The chopper system is a central part of the instrument as it has to fulfil the requirements of flexibility and efficiency of the instrument. This concerns mostly the requirements for wavelength bandwidth, wavelength range and wavelength resolution and their various combinations.

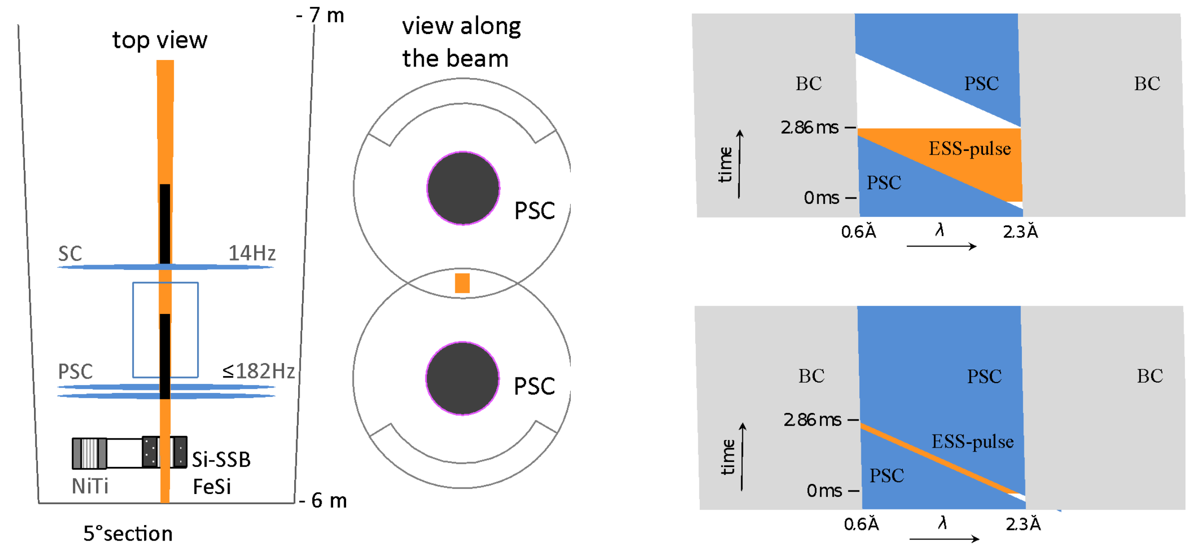

Figure 3 *: Pulse Shaping Choppers and Selection Chopper layout*

The choppers can be classified by their function as: bandwidth choppers (BC, 1 single disc) pulse shaping choppers (PSC, 1 pair, i.e. 2 single discs) and selection choppers (SC, 1 single disc). Together they allow tuning of bandwidth, wavelength range and wavelength resolution.

The chopper system is being optimized and specified with respect to the boundary conditions of the source time structure, the guide system, technical feasibility and failure modes and maintenance requirements. While the rotation speeds and disk diameters are low compared to the state-of-the-art choppers, the system has two peculiarities. The pulse shaping choppers are placed at 6.2 m to moderator surface. Their location close to the source is delicate and requires attention. The 14 Hz selection chopper, eliminating frame overlap, will be placed in the bunker, at 10 m from moderator surface. In addition the band chopper rotating at 14 Hz will be placed in the guide hall (E02 building) next to the polarizer (80m mark). Finally, the choppers close to the monolith require integration with neighbouring beamlines with respect to the space and access constraints in this region. This is in particular the case with the closest beamline MIRACLES presenting a similar chopper setup and being the closest beamline to MAGiC.

The choppers are foreseen to be connected with their vacuum housings with no windows to the guide system, hence sharing the same vacuum system. For removal of choppers for maintenance and in case of failures, it shall be possible to remove choppers without affecting the guide system.

*3.4.5 Shutters (**LLB** WP)*

As the instrument lose direct line of sight outside of the bunker, one heavy shutter will be installed before the bunker wall. The exact specifications of such shutter are still under development as it has to carry both the guide element and the associated guide magnetic field. Its main purpose is to allow guide maintenance while the proton beam is on target.
An experimental shutter and its associated fast shutter will be installed in the second guide section before the experimental cave to allow users access when the proton beam is on target.

*3.4.6 Experimental cave (**LLB** WP)*

The experimental cave is surrounded by a shielding construction. Its first part is a shielding insert hosting the last meters of the guide system and ending at 1.5 m of sample position. The second part is a large volume hosting all the secondary instrument : focusing device, sample table, sample environment, detectors and the polarization analyzer as well as any additional equipment required for the ongoing experiment.
The experimental cave also requires various utilities for gas, exhaust, electricity and corresponding surveillance equipment installations which are state of the art at other neutron sources or synchrotron. The experimental cave starts at 157 m from moderator surface and is 11 m long (outer) and 8 m wide (outer). The wall thickness is typically 0.8 m standard concrete. Only in beam direction a thicker shielding will be installed (up to 1 m). The exact dimensions will have to also adapt to the requirements of neighbouring beamlines in particular to one side (MIRACLES). The height of the experimental cave has to be decided with the height of the experimental hall and crane access in mind as well as taking into account the weight and bulkiness of equipment that will be added and removed through the top. As the weight footprint is limited to 20 Tons/m^2 the necessity of a shielding roof needs to be addressed. Access to the cave is currently foreseen through the back wall, offering no line of sight from inside to the outside. The main part of the experimental cave is the area of the instrument that is accessible for standard operation.

The control hutch, sample environment preparation area and storage area, sample preparation lab and user offices will be place on both the right and left side of the experimental cave (see picture).

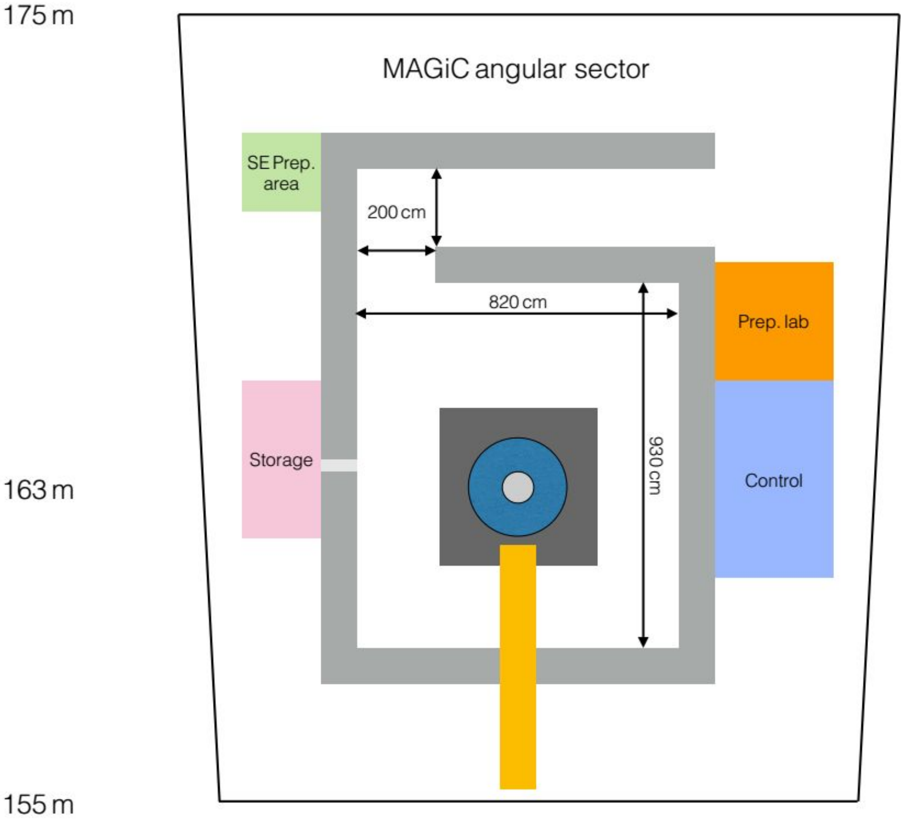

Figure 4 *: Experimental cave schematic layout*

*3.4.7 Polarization equipment (**PSI**/LLB WP)*

MAGiC will be the only permanently polarized instrument at ESS. Both thermal and cold spectra will be polarized, while polarization analysis will be possible on the cold spectrum only. Polarization management is made of :

1) cold neutrons polarizer: A solid state bender will be placed at the monolith exit, just after the service shutter. It consists of 150µm thick Si wafer coated with FeSi. Its dimensions are of 30x30x50 mm with a curvature radius of 3m. A saturation field of 1 kGauss will be permanently applied to maintain the SSB magnetization. This optional device will ensure the injection of cold neutrons into the guide system as well as their polarization. A kinematic mount will be installed to easily switch between the two configurations: thermal and cold polarized neutron beams. Shielding of the saturating magnets needs to be addressed as fast neutrons strongly deteriorate NdFeB magnetization.

2) guide fields : to maintain beam polarization, a guide field has to be applied along the full instrument. It is composed of Ni coated NdFeB-N52 magnets and soft iron ensuring an homogeneous guide field of 60 Gauss inside the guide. As reflections on super-mirrors can cause beam depolarization, the use of non depolarizing NiTi super-mirrors is mandatory.

3) super-mirror polarizer : thermal neutrons polarization will be ensured by the 3 m long section in the middle of the guide system. It is composed of three 1 m long straight guide elements (w80xh80 mm). Each element is a 6 channels guide with FeSi coating for top and bottom reflections, NiTi coating for left and right reflections. Like the SSB, it should be placed in a saturation field of 1000 Gauss to maintain super-mirrors magnetization over the instrument lifespan.

4) Flipper : an adiabatic spin flipper will be installed in the second guide section at distance from the instrument endstation to limit stray field effects from 10 T magnet. .
5) XYZ polarization : a set of magnetic coils will be installed at sample position to manipulate the guide field. It is usually done using a set of Helmholtz coils. The exact details of the device are still under discussion.
6) Polarization analysis : will be ensured by a solid state polarization analyser covering a 120° horizontal angular aperture and a 6° vertical aperture. Its design is similar to to the SSB one with 150 µm Silicon blades stack onto another. Remanent FeSi coating will be used to ensure stable operation nearby the detector. Furthermore a holding field of around 60 Gauss for the analyser will increase robustness.

*3.4.9 Detectors and monitors (**JCNS**/LLB WP)*

There will be two 1m radius cylindrical detectors, left and right to the beam axis. One of these will be a large detector with 160° horizontal and ±24° vertical acceptance, covering a solid angle of 2.3sr. The large solid angle is particularly important for the Laue-TOF method and is adapted to the opening of the vertical 10T magnet. The second detector will have a 120° horizontal and a smaller +/-3° vertical acceptance with 0.2 sr solid angle coverage, which adapts to the geometry of the supermirror polarization analyzer. The requested spatial resolution is 2x4mm^2 for both detectors.

The technology choice is a ^{10}B based volume detector with inclined geometry. The detector has a 3D grid of detection cells, working in coincidence mode of anode and cathode signals, rather insensitive to gamma-background. The cathode layers are coated with 1µm ^{10}B and are set in inclined geometry (10°), which with several layers are shown to yield measured detection efficiency larger than 50% at 1Å. There are favorable features of this volume detector: the distribution of counts into ~20 cm detector depth yields higher count rate capabilities, while the resolution can be appropriately chosen to ~4 mm (FWHM), the surface projection of the 3D cells provides an effective finer pixel mesh (~1x1 mm^2) and finally, the concept offers new possibilities to discriminate background from sample environment by the intrinsic collimation.

An additional square detector will be placed below the sample and sample table rotation stage giving access to the scattering intensities along the vertical axis. The technical specifications for this detector are still under discussion and will highly depend on the available space and superconducting magnet design.

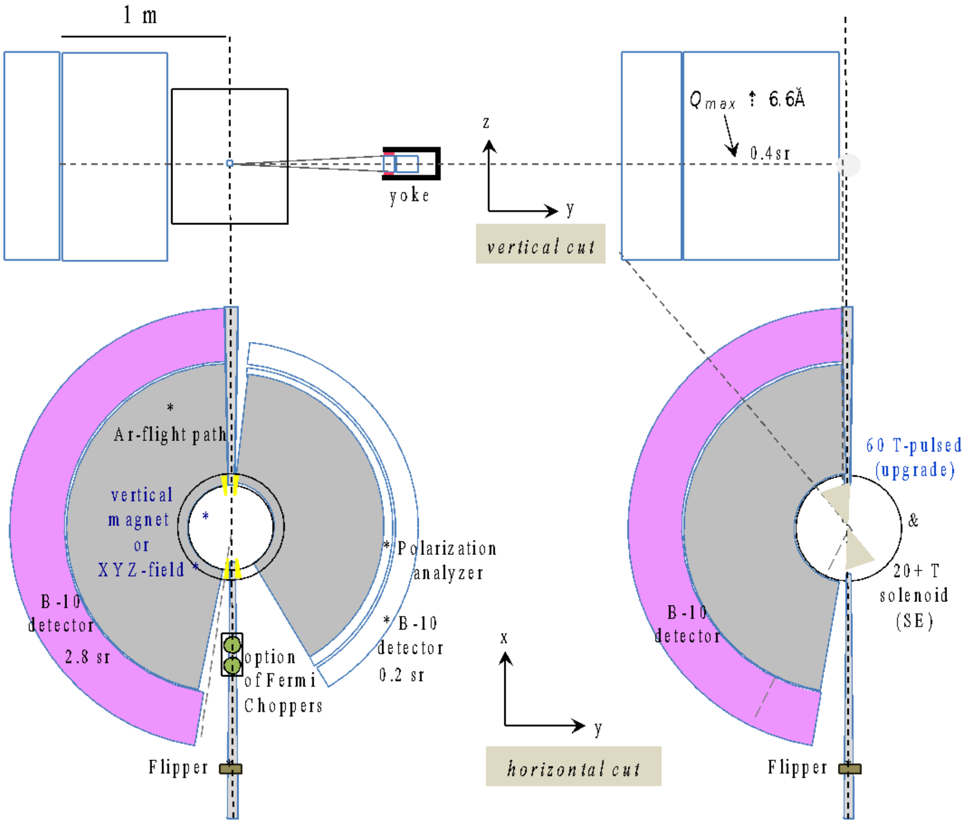

Figure 5: *Scheme of the secondary instrument and its components (1 m scale see top left). (left) vertical and (right) horizontal magnet and detector acceptance.; (top) vertical cut (bottom) horizontal cut.*

In addition three monitors will be installed on the beamline to characterize both the incident and transmitted beam. These monitors will be TOF Position Sensitive Detectors with low efficiency and will be located after the pulse shaping choppers in order to characterize the moderator beam quality, 50 cm before sample position in order to fully characterize (flux and shape) the incident beam and 50 cm after sample position to characterize the transmitted beam (flux, shape). The technology driving the monitors will follow the ESS standards.

*3.4.10 Beamstop (**LLB** WP)*

The transmitted neutron beam could be as intense as $1x10^{10}$ n/s. Therefore, a sufficient beam stop shall be design. The current design is a boron carbide block of $10x10x10\ cm^3$ enclosed in a lead housing and placed at 2.5 m after the sample position.

*3.4.11 Personnel Safety System, PSS (**LLB** WP)*

A PSS system will be designed and provided by ESS and the instrument team to allow safe operation with regards to access to the instrument and its components.

3.4.12 Control Hutch

A control hutch will host remote control equipment, computers and the experimentalists during measurement times. This control hutch will be a two floor $3x8\ m^2$ construction placed outside of the endstation on the right side and will enclose the sample preparation laboratory.

*3.4.13 Instrument control (**LLB** WP)*

Most instrument components will require remote control through specific electronics placed outside the shielding but connected to the components inside and to the control computers. Labyrinth in the endstation shielding walls will allow connection of corresponding patch panels.

*3.4.14 Sample environment (**LLB** WP)*

Magnets : A 10T split-coil magnet (NbSn based) with wide angular aperture (45° vertical, 300° horizontal) is part of the instrument scope and will be dedicated to MAGiC operation. It will make full use of the 2D detector and will be compatible with polarization analysis at ~1m distance. The cryogenic insert of the magnet will be equipped with a two axis piezoelectric goniometer for easy sample orientation. Additional magnets such as the horizontal 10T magnet will be used in coordination with the sample environment group.

Cryogenics: The sample station will be designed to accept cryogenic equipment from the sample environment group. All generic liquid ^{4}He cryostats, dilution fridges and furnaces will be used on occasion. Temperatures in the 50 mK - 1000K range will be available to users. Our dedicated superconducting magnet will use various inserts to match the experimental requirements. A dedicated dilution fridge will be specifically designed. These inserts will be part of the beam line budget. Temperatures in the range 30 mK - 300K will be available under magnetic field to the users.

High Pressure: MAGiC will be fully compatible with the use of various pressure cells. We do not plan to develop a specific pressure setup; however we will make full use of the "sample environment group" expertise on this matter to fulfill user needs.

3.4.15 Future upgrade possibilities

At present three potential major upgrade options have been identified:

Pulsed magnetic field : this is a very attractive option for the case of ultimate high field physics, which we aim to realize as early as possible. We plan to develop a **conical magnet** generating **60 T** horizontal field in collaboration with the LNCMI Toulouse . The use of a split-coil generating vertical field has been also considered, however, such magnets offer a reduced duty cycle as well as a lower maximum magnetic field. The proposed device is based on a resistive coil design made of high tensile wires. The wiring is made over a stainless steel double cone ensuring vacuum and thermal insulation between the sample volume and the coil/LN$_2$ volume. The magnet design provides a conical aperture of 60° for the scattered beam and of 30° for the incident beam.

Using 3 MJ capacitor bank, such coil can achieve 60 T with full pulse width of 140 ms and 10 mn repetition rate. Operating the setup at 50T will limit the total energy to 2MJ and increase the repetition rate to 1 pulse per 6 mn. Repetition rates are mainly limited by the coil cryo-cooling by liquid nitrogen. The duration of maximum field (>90%) is above 20 ms. Magnetic pulses will be fired through fully optical thyristors and triggering system and can be synchronized with the ESS pulse and wavelength spectrum.

This design is currently under operation at the ILL. The IN22 magnet is achieving 40 T at 1.1 MJ. The last 10 years have witnessed a doubling in pulsed magnets capabilities on synchrotron/neutron sources. The maximum achievable field will certainly increase by design, wire optimization and cooling improvements over the next 10 years. Construction cost of the magnet itself is rather moderate (<500 k€). Most of the pulsed magnetic field setup cost lies in the capacitor bank (1 M€).

Polarization analysis by ^{3}He filter cells: ^{3}He filter cells are relatively inexpensive (100k€) and should be considered if ESS will be able to provide the resources for operation. This will extend the polarization analysis capabilities of MAGiC to the thermal spectrum.

Increase of detection area/solid angle: increasing the out-of plane detector coverage naturally improves the instrument performance. A possible upgrade would be to increase the vertical angular coverage by 50% for 1 M€ increasing the Q-space coverage by an additional 30%.

3.4. Key System Interfaces

Key interfaces have to be considered carefully in order to embed MAGiC in an environment and context, which enables its optimisation and finally operation and efficient operation.

Key interfaces are to the following systems outside the scope of MAGiC:

- Target system: This interface concerns the beam extraction system and its interplay with the monolith in terms of geometry, cooling and atmosphere, the utilized moderator and its choice and influence on performance and guide optics as well as the service shutter as part of the target monolith.
- Bunker system: Key instrument components will be placed in the shared bunker which in MAGiCs instrument sector (west) extends from the monolith wall at 6m out to 28.5m with a wall thickness of 3.5m, which implies that no choppers can be positioned between 25 and 28.5m from the source. Interfaces with the structure, floor, columns, construction time plan etc. have to be considered and clarified with the bunker system in the design and construction phase.
- CF: This interface and external system defines parameters like the floor and ceiling heights, crane access, space for paths and infrastructure of the instrument etc. which are all of significant importance for the construction, operation and maintainability of the system.
- Neighboring instruments: There are significant physical interfaces with neighboring instrument systems in terms of space occupation which have potential impact on the performance, availability and maintainability as well as operational access of the involved systems in particular close to the monolith and in the area of the experimental cave. Additionally, the shielding of the instruments close to the bunker should be discuss as massive cost save could be obtained by simplifying and sharing some of the shielding elements.
- ICS: ICS is an important provider of key input and services for the instrument operation and in the current planning is hence vital to the instrument operation as it provides the source timing input as well as it takes up and transports key instrument data, without which the instrument becomes not operable.
- DMSC: The data management and software center also provides key services and systems for the instrument in the form of control, reduction and analyses software, without which the instrument cannot be operated and exploited for its central mission. It has to be hence guaranteed that the provided software and data solutions meet the requirements of the system to function in the foreseen and useful way also for third party users.
- SAD: The SAD provides the instrument with the indispensable services of the user office handling user requests and beamtime proposals, hence organizing the access of users required for the scientific productivity of the system according to its purpose. In addition SAD is administrating and maintaining the common sample environment, some of which will be required to perform specific experiments on MAGiC and the applicability of it in the context with the MAGiC system has to be ensured.
- Maintenance and Service Groups: The integration and application of standards and corresponding solutions as well as access strategies and maintenance requirements and schedules have to be agreed with technical groups as far as possible in order to enable the services needed or best possible enabled through these for a high availability of the instrument system.
- other: other interfaces of the system in construction (c) and operation (o) are amongst others with users (o), industry (c,o) and public relations (c,o).

4 System stakeholders

This paragraph is dedicated to the stakeholder analysis for MAGiC.

The MAGiC instrument consortium is leaded by LLB-CEA-CNRS in collaboration JCNS-FZJ and PSI. Its governance structure is not yet defined. At this stage, the stakeholder analysis is really generic and similar to that of all instruments who share interactions with external entities (potential users, institutions and government agencies, light blue) and ESS parts (dark blue). The following schematics and table present the existing/expected interactions in the design/constructions phases and during the full operations.

The generic stakeholder analysis for MAGiC is in the document ESS-16.3.18/SHA or following the link: **Stakeholder analysis**

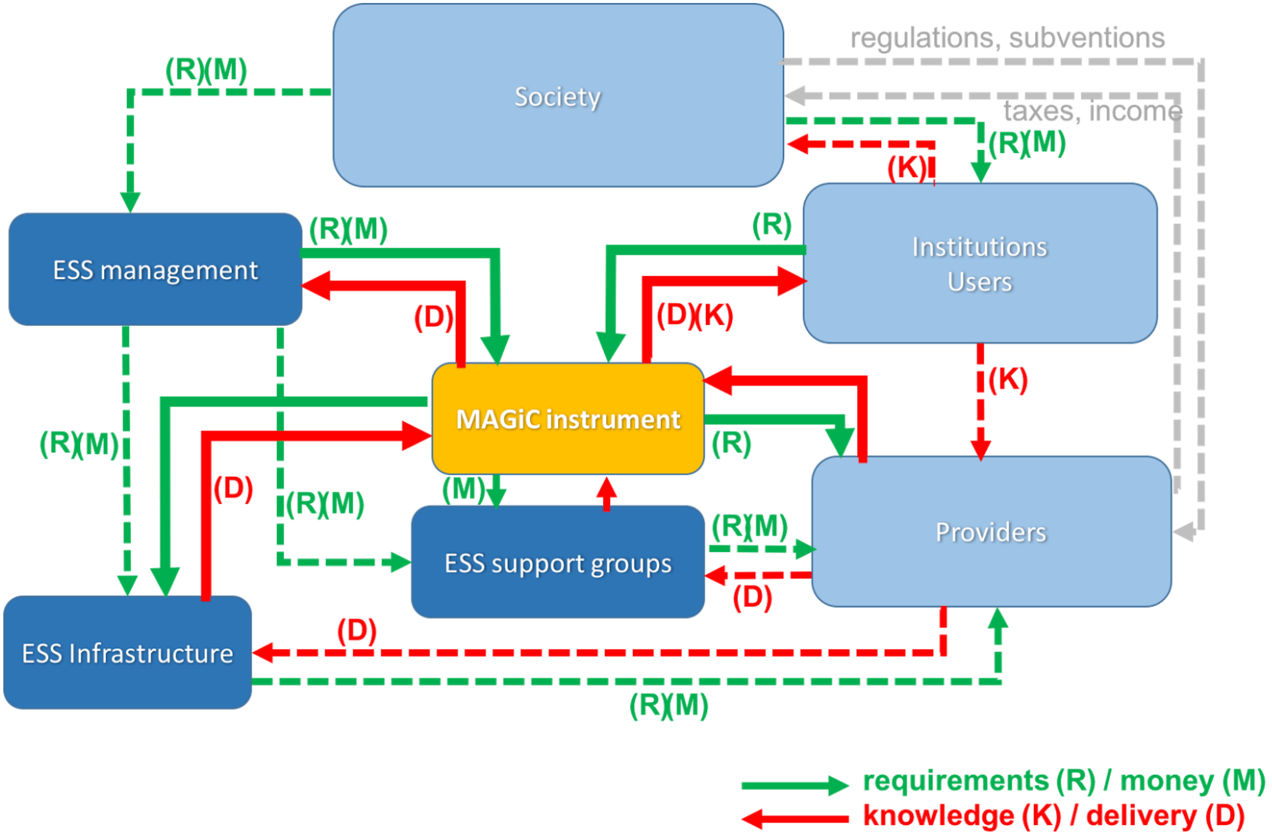

Fig. 6: MAGiC stakeholder diagram

5 Operational concept

5.1 operational environment

In the last baseline layout document, the beamport allocation for MAGiC is the W6 one, in the west sectors showed in Figure 7, below. MAGiC will extend over three different buildings : experimental hall 2 with building designation D01, the guide hall with building designation E02 and finally experimental hall 3 with building designation E01.

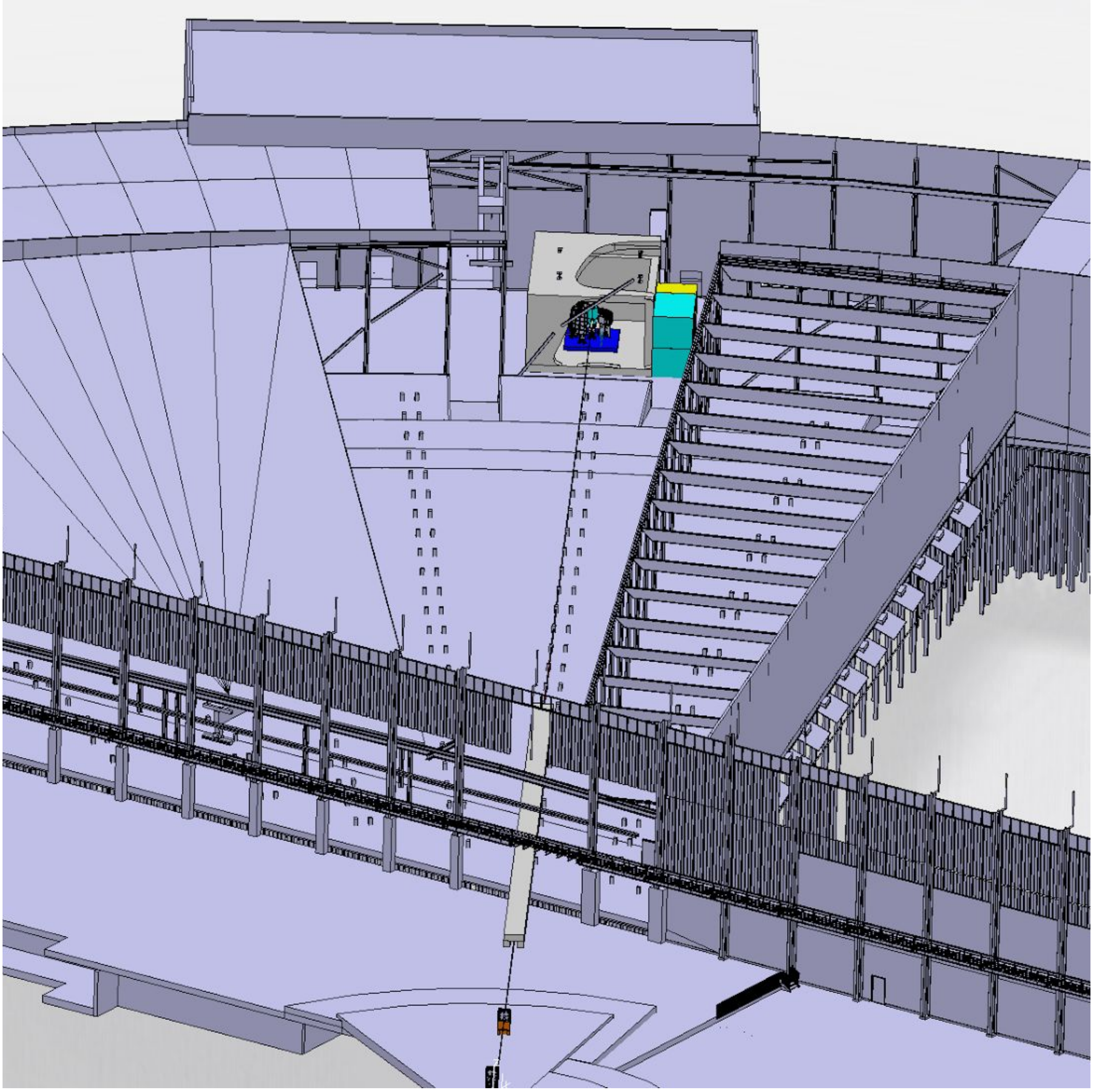

***Figure** 7: MAGiC in ESS west sector layout. MAGiC will be placed on beamport W6*

The instrument will be operated in a controlled environment with a temperature of 22±2 °C all year round. The floor height in experimental hall 2 is 2 meters below target centerline. The floor in the guide hall is 1 m below target center line and in experimental hall 3 it is 3 m below. Free height to lifting hook of the overhead gantry crane is maximum 7 meters in experimental halls 2 and 3. In the guide hall hook height is a maximum of 6 m above guide hall floor. Floor loading in the experimental halls 2 and 3 as well as the guide hall must not exceed 20 tons/m2. Floor underneath the bunker can accommodate a loading of up to 30 ton/m2. Floor stability in the halls is specified to be maximum 3mm w.r.t elastic movement and another maximum 3 mm due to creep/deformation.

Utilities and media are brought to the instrument from the gallery in case of experimental hall 2 and along the wall separating experimental hall 2 and the guide hall. Media include: N2, instrument grade compressed air, cooling water. Utilities include: office IT, office comms, Power, MPS, PSS, DMSC and ICS. For detailed and updated listing of requirements and/or specifications related to operational environment see the System Requirements Document. Details for e.g. maintaining the stable temperature in the experimental hall are still in development but one suggested solution could be to place ventilation hoods directly above instrument equipment generating most heat. Which then could have an impact on selection of location of such equipment and thus considerations for this need to be made.

The ESS facility has 5 different operating modes: Shutdown, Studies, Studies on Target, Startup and Production. These modes have various impact on instrument operations. Pure experimental work can only be conducted during ESS-mode Production. Access to instrument equipment for maintenance, calibration, cold commissioning is mainly done during shutdown, studies and studies on Target – naturally after due safety assessment and still possibly with some restrictions. During start-up instrument operations is limited to alignment, commissioning and calibration runs.

- When ESS has entered into a steady-state operations phase the following principal schedule will apply: 200 days/year of neutron Production for the ESS users after 2026,
- Proton beams will be on target for ~225 days/year,
- Two long Shutdowns, one in winter (~6 weeks) and the other in summer (~10 weeks) followed by Studies and Studies on Target periods,
- 3 Optional Studies Days every second week to avoid long down-time of instruments due to failures of activated components, followed by 2 days for Studies and Studies on Target,
- A series of Studies days to allow for fine-tuning of accelerator and target systems.

One goal of ESS is to ensure that at least 90% of the users receive a neutron beam allowing them to execute the full scope of their experiments. This is in accordance to the availability and reliability assessments made in ref [ESS-0017709 and ESS-0008886].
The MAGiC instrument is foreseen to be managed and operated by a team of 2 scientist and 2 engineers. ESS will be manned 24 hours/day, not all categories, but this manning will allow for flexibility for users when conducting experiments and making preparations or analyzing results. At the instrument team's and users' disposal for data collection, storage and analysis are the tools provided by DMSC, physically located in Copenhagen.

5.2 Operational scenarios

Although MAGiC can be operated in a vast variety of modes the following principal generic steps are required performing a measurement:

I. instrument preparation and cold verification (beam on or off, shutter closed, cave accessible)
  - setting the primary instrument parameters for a specific experiment including choppers, slits, etc. remotely via control computer and software
  - installing the specific required sample environment
  - setting up and connecting all auxiliary equipment required for a specific measurement modality within the cave.
  - Controlling all functions of the set-up devices as far as possible without beam.

Required staff: instrument scientist & technician, potentially also: technician(s), user

II. hot set-up verification (cave closed/opened, shutter open/closed, beam on)
  - checking spectra, flux and beam position by recording neutron images on the three beam monitors
  - checking alignment and functionality of auxiliary equipment in the beam, scanning parameters etc.
  - re-aligning remotely and manually when required

- calibration and characterisation of auxiliary equipment for readiness to measure (polarization quality, spin flipping efficiency, etc.)
- note these processes can be repetitive

Required staff: instrument scientist, potentially also: technician(s), user

III. prepare sample for measurement

- in diffraction, samples are usually glued on a sample holder. The specificity of the sample holder are to be defined, however it is most probable that both Kapton tube and Aluminium pins will be used as it is the solution of choice in other facilities. Due to the small sample size, this process will take place under binocular ;

Required staff: user, potentially some specific support personal or instrument scientist

IV. sample set-up (cave closed/opened, shutter open/closed, beam on)

- sample(s) mounting on beamline
- sample(s) position check and potential correction remotely
- signal check by recording first diffraction patterns
- decision on measurement protocol including exposure times, sample position, temperature and field range.

Required staff: user, first time(s) also instrument scientists, potentially also techn. support staff

V. measurement (cave closed, shutter open/closed, beam on)

- the sample is exposed to the beam
- data is collected
- a script is controlling the measurement parameters, which can be a single exposure or a complex scan of various parameters like temperature or magnetic field settings, but also only elapsing time
- the collected data of each individual step is stored, reduced and displayed in live on the computer screens in the control hutch or on whatever device connected
- the feedback of displayed or subsequently reduced data is suited to change the measurement steps or to interrupt a measurement to make changes with respect to one of the previous described steps and to re-enter the here described process at the corresponding point
- between exposures, when setting are changed according to the script remotely, an instrument shutter might close to reduce radiation exposure (cold/thermal) and corresponding sample activation as part of the measurement script or routine
- long measurement will run for significant times without human supervision
- exposure and data collection are interrupted in most cases when the source has downtimes but resumes when the source reaches a threshold neutron production again
- at the end of a script the shutter closes as last step of the script and data collection stops

Required staff: user, potentially in many cases and first runs also instrument scientist

VI. sample removal (cave open, shutter closed, beam on/off)

- sample removal, by hand or with remote tools (activation)
- the sample is scanned for activation
- potential waiting time for sample cool down under threshold activation
- sample storage (activated/non-activated)
- (at a later stage sample screening by radiation safety staff to decide upon sample removal from site)

Required staff: technician or instrument scientist, potentially user

VI. data analysis

Preliminary analysis might take place during a measurement campaign however, typically the real data analyses takes place elsewhere and is in its procedure and resources independent of the instrument system. However, due to the large amount of data to process, the data analysis tools shall be available on the beamline as well as remotely by users from their home institution.

5.3 Maintenance concepts

5.3.1 Levels of maintenance

Within ESS there are three identified levels of maintenance, see ref [ESS-0003640]:

1. Organizational maintenance: maintenance performed on site where the element is normally being operated,
2. Intermediate maintenance: maintenance performed on site at a dedicated workshop,
3. Supplier maintenance: maintenance performed off site at the supplier premises.

The term supplier includes In-Kind partners.

5.3.2 Maintenance categories

Maintenance can be divided into two categories: Corrective and Preventive. By utilising condition based monitoring, taking into account the overall ESS operational schedule, preventive maintenance on instruments is aimed to be conducted during the planned facility shut-down periods unless instrument reliability and availability are sacrificed. This will minimise disruption to user operation.

Preventive maintenance is part of scheduled maintenance which also include maintenance work to be conducted on equipment where condition based monitoring cannot be achieved. Performed instrument reliability analysis, part of RAMI work, should aim to ascertain that preventive maintenance on this type of equipment/components could be limited to periods of scheduled shutdown of the facility.

During scheduled maintenance access to components that are within e.g. common shielding bunker will require a cooling period before they are safe from a radiological view to handle.

Some components, (i.e detectors) can be maintained without removing them from their installed position, but other (e.g. choppers) will have to be removed for maintenance. To remove a component typically requires that the surrounding radiation shielding (including the common bunker shielding for components within the bunker) is either removed or opened by a hall or local crane. The time taken for removing the shielding is often a major part of the maintenance time and crane availability may become limiting, particularly for the work that can only be done after the proton beam has been off target for a sufficient time. The removed shielding elements have to be stored in the hall during the maintenance time. When the maintenance is completed the shielding has to be replaced and its radiological integrity verified by e.g. an interlock procedure.

Some of the component maintenance can be done on site, but some components may have to be sent to manufacturers, which incurs a longer lead time, but also imposes stricter radiological constraints as the equipment has to leave the site.

The components requiring more frequent maintenance include constantly moving parts such as choppers, vacuum pumps etc. The maintenance schedule will be developed to ensure a minimal need for unscheduled maintenance and consequent loss of user beamtime. As the lead time for maintenance varies strongly depending on the position of the component, the components in less easily accessible locations have less frequent maintenance.

Corrective maintenance will mainly apply when an event happens forcing maintenance to be done unscheduled. This occurs when either a component failure or detection of an issue that requires immediate action during user operation. The instrument will have to stop user operations for the duration of repairs or maintenance. The unscheduled maintenance of components that are not accessible when the proton beam is on target will have to wait for the next facility shutdown, which may cause significant loss of beam time. To minimise this type of maintenance a great deal of consideration needs to go into the design of each piece of equipment of the instrument to facilitate for swift and safe corrective measures to be made, to the greatest extent possible.

5.3.3 Maintenance philosophy

MAGiC's maintenance philosophy is in line with the approach of the facility to utilize condition based preventive maintenance as much as possible. In order to minimize resource requirements and potential instrument downtimes inspectability and accessibility, but also failure mode instrument operation and application of facility standards are in the focus of a sustainable instrument design. However, performance and in particular cost against the background of a very limited instrument budget are major constraints also in this regard and hence balanced cost-benefit solutions are indispensable.

As the most critical components with regards to maintenance, all moving parts within the bunker and instrument shield upstream of the endstation can be identified easily. For MAGiC this conveys choppers including, the translation stage of the solid state bender and the heavy shutter. The following philosophies apply to those in the MAGiC design.

Choppers:
- choppers are accessible and removable vertically from the top, and when required by remote handling; however, up to date there is no information available on expected activation and radiation situation within the bunker, which follows a new concept of large free space, i.e. with limited material to get activating and posing an irradiation source apart from the beamline components themselves. Better knowledge of the situation to be expected is essential in order to plan resource efficiently and under correct assumptions. This is important in particular with respect for the remote handling requirements that have to be met, designed and which impact cost, complexity, space demand etc.
- choppers are removable without impact on the guide system; this implies a state of the art split housing approach for choppers which are connected to the guide vacuum system, which is a design driver with respect to performance in order to keep guide interruptions as small as possible ;
- choppers are removable independently ;
- chopper solutions with minimum maintenance requirement (magnetic bearings) are preferred where affordable, final choice requires cost-benefit analyses; failure mode operation enables maintenance with certain frequency.

Translation stage of Solid State bender:
- removal of the stage shall not affect the guide system
- vertical removal and remote handling are foreseen
- radiation hardness of motors and movability have to be considered carefully; if this cannot be guaranteed sufficiently an alternative solution without stage but impact on cost and performance of the instrument should be available

Heavy shutter:
- the heavy shutter has to be fail-safe; failure of the component disables any instrument function; hence, the design has to be extremely robust and reliable;
- removal of the shutter disables any instrument function, hence the component has to be designed as maintenance-free as possible
- removal is vertical, with remote handling as required and with no impact on neighbouring components

The guide system should not require maintenance, but in case of failures partial removal follows similar principles as for the choppers. Partially choppers might need to be removed as well. Realignment requirements of the guide are to be considered in the general design of the system and the guide design shall be as robust against misalignment as possible with affordable means in terms of cost and performance. All other components are accessible, should be quickly replaced (standards) or allow failure mode operation, partly through replacement by alternative components (e.g. different detector to be used). Regular maintenance and check shall prevent failure.

6. Consequences of the concepts

6.1 General design considerations

General design considerations concern all functional and nonfunctional requirements and are/will be documented in detail in the corresponding documentation.

6.1.1 Upgrade options

During the development work identified upgrade options shall be considered and be catered for if possible in the design solutions. This is in particular mandatory for the pulsed magnetic field setup requiring specific adaptation of the experimental cave utility supplies.

6.1.2 Robust design

The current preliminary design can be considered robust with respect to the scientific and technical aspects raised. This is supported by the flexibility and various available failure modes of the instrument, which allow for efficient operation in nearly all cases of single component failure. However, careful provisions have to be made in particular also during final design and especially the performance and respective corresponding issues of the extraction guide and the heavy shutter have to be considered carefully. The final design of the guide including its alignment and support as well as choices still to be made on details of choppers and their support will be of significant importance.

However, robustness has to also be considered with respect to viable systems that MAGiC is connected to and relying on. This concerns particularly the ICS and data streaming functions coupled with it. In order to guarantee best possible availability it is foreseen that MAGiC is able to operate in a stand-alone mode in case of difficulties of the ICS and data streaming systems. The only precondition required for most instrument modes, namely time-of-flight modes is receiving a trigger signal from the source pulses, which MAGiC hence demands to get supplied with through a hardware solution. All choppers can usually, just like other motion control be addressed locally either through internal hardware connection or in the worst case by directly approaching the specific electronics or controls. For the case of detectors, an alternative local storage solution with sufficient storage has to be implemented in order to limit the instrument downtime.

6.2 Training of personnel

The organisation for operating instruments at ESS is yet to be decided. Based on the potential experiment output of the instrument, the team would likely include at least two instrument scientists who are knowledgeable in magnetic diffraction using polarized neutrons and can translate scientific needs to technical requirements. The instrument scientists have to maintain a research profile and dedicate time to scientific research in order to understand the needs of the future user community. Post-docs working at the instrument can support the operation by engaging in methodological developments and participating in user support.

The technical support of the instrument would include mechanical, electrical, software and other specialty engineer and technician personnel, who could be part of the instrument team and/or in specialised technical groups.

The users arriving at the instrument to perform experiments will be supported by a local contact such as one of the instrument scientists. The more experienced users should be able to operate the instrument independently after a short (< 1h) introduction by the ESS instrument team and the less experienced users who would require more support would be expected to establish a collaboration with ESS scientists.