Document Type	Preliminary system design, CSPEC
Document Number	
Date	2017-06-19
Revision	2
State	Review
Confidentiality Level	Internal

Preliminary System Design for CSPEC, the cold chopper spectrometer of the ESS.

	Name	Role/Title
Owner	Pascale Deen Joseph Guyon Le Bouffy Wiebke Lohstroh Stephane Longeville	Instrument Lead Scientist Instrument Lead Engineer Scientific coordinator (TUM) Scientific coordinator (LLB)
Reviewer	Shane Kennedy, Ken Andersen, Oliver Kirstein, Arno Hiess, Gabor Laszlo, Peter Sångberg	Science Directorate
Approver	Shane Kennedy	Science Directorate

1. Table of Contents

Document Type	Preliminary Design Description of CSPEC
Document Number	
Revision	1
State	Review
Confidentiality Level	Internal

2. SUMMARY

This document describes the preliminary engineering design of the CSPEC spectrometer in detail. The document provides an overview of the instrument and describes technical solutions. The expected performance of the given technical solutions with respect to the functional requirements is discussed, followed by an evaluation of the scientific performance.

3. INTRODUCTION

The preliminary System Design Description document of the CSPEC instrument describes the system architecture and the physical layout of the instrument. The hardware and software description arise from the design of the instrument addressing the functional requirements, as well as the constraint requirements that have been identified at this point. The purpose of this document, together with the "System Requirements" and "Concept of Operations" document is to:

Provide a documented description of the design of the instrument that can be reviewed and approved by the stakeholders in a Tollgate 2 review.

Provide a detailed enough description of the instrument so that its components can be designed in detail ("design-to specification").

Provide a description of the hardware and software solutions in sufficient detail to assess whether they fulfill the functional requirements.

Discuss the expected scientific performance of the instrument.

The detailed description in this report considers the scope of the instrument as agreed as a result of the CSPEC scope setting meeting. Any consideration of upgrades of the instrument with respect to the budget set in the scope setting meeting are clearly defined.

System characteristics

System purpose

The CSPEC instrument enables characterisation of low energy dynamics (0.005-20meV) in a wide range of materials from proteins to functional materials. Particular emphasis is placed on enabling one to probe phenomena in-situ and in-operando. The science case is outlined in detail in the CSPEC instrument proposal, operational scenarios are described in the "Concept of Operations" and the "Initial Operations and Staging Plan" documents.

System overview

The instrument consists of three main technical subsystems: beam transport and conditioning system (BTCS), sample exposure system (SES) and scattering characterisation system (SCS). In addition, as described in the instrument product breakdown structure (PBS), the instrument includes the structures that house and support these subsystems. The hardware description in this document does not strictly follow the PBS, but rather provides a functional breakdown of technical components along the neutron beam path. This makes it easier to map the specifications to the high level scientific requirements. The PBS numbers are given for reference where appropriate.

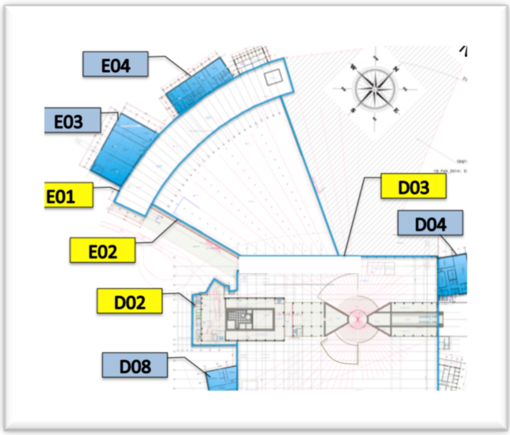


Figure 1: Overview of the ESS with the names allocated to various buildings.

Instrument layout

The conceptual CSPEC instrument is subdivided into the following main functional blocks:

- Neutron optics
- Chopper system
- Shielding
- Shutters
- Detector tank
- Detectors
- Sample environment
- Beam monitoring
- Beam stop
- Control hutch
- Instrument control
- Personnel Safety System, PSS

All components have to be defined and designed to fulfill the high-level requirements as the basis for the detailed functional and non-functional instrument and component requirements.

CSPEC within ESS.

CSPEC is positioned in the west sector on beamport W3. The spectrometer will extend over four different areas across three buildings – inside and outside of the bunker in the experimental hall 2 with building designation D03, the neutron guide hall with building designation E02 and finally the experimental hall 3 with building designation E01. Experimental laboratories, available to CSPEC users, are situated in E03 and E04.

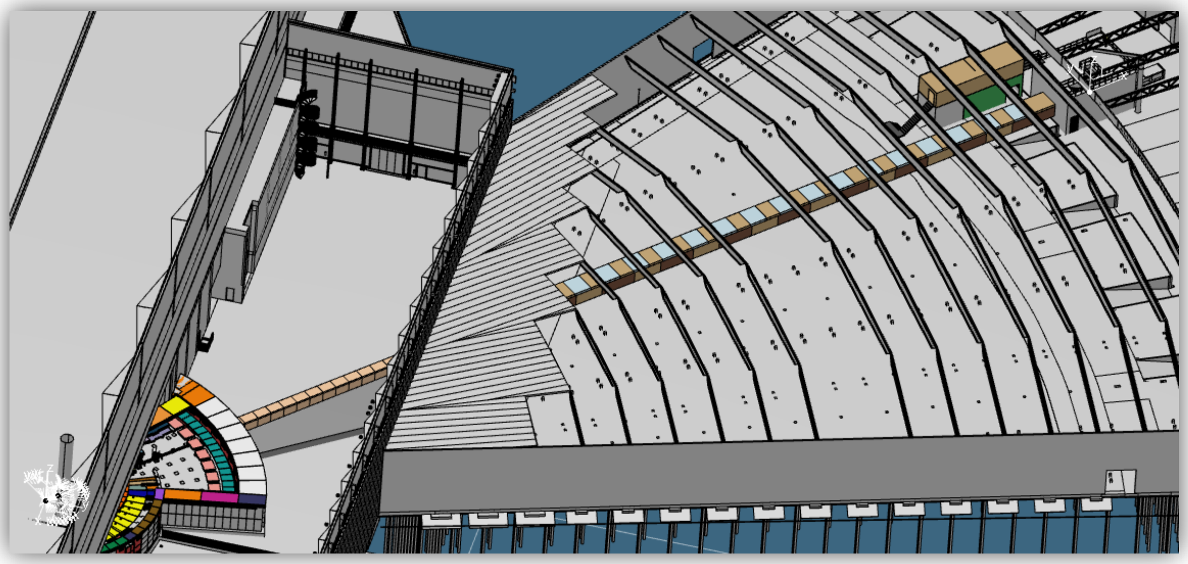


Figure 2: Overview of CSPEC from moderator to experimental cave.

Neutron optics (13.6.10.1)

Beam extraction (13.6.10.1.1)

The beam extraction system is located in the west sector and is oriented to view the top moderator. The beamport of the instrument is W3 with the guide rotated 0.5^{o} laterally to view the cold moderator which is offset from the Beam Port Coordinate System (BPCS) West. In addition to the rotation a slight lateral move is also required (Δx=0.016) to access the maximum cold neutron flux (at 3 Å). The guide is separated from the moderator by an Al neutron window the thickness of which is currently under review and is understood to be approximately 4 mm thick. A solution optimised for each beamport window would be much appreciated to limit flux losses. The first optical element is the guide in the beam extraction unit, the monolith insert, NBOA. Figure 3 (left) shows the CSPEC guide in the monolith insert of beamport W3 (top housing has been removed for ease of viewing). The ESS light shutter is positioned at the end of the monolith insert, see Figure 3(right).

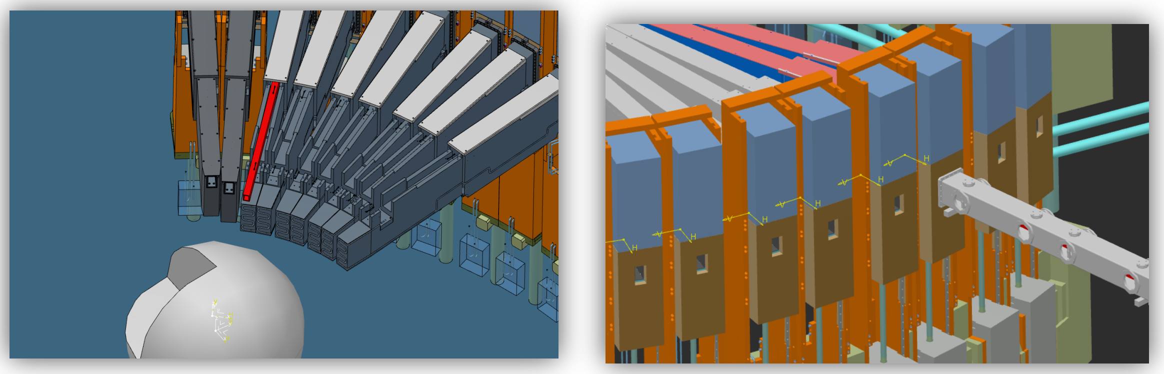


Figure 3: (left) Monolith insert for the CSPEC guide. (right) ESS light shutter system at the end of the monolith.

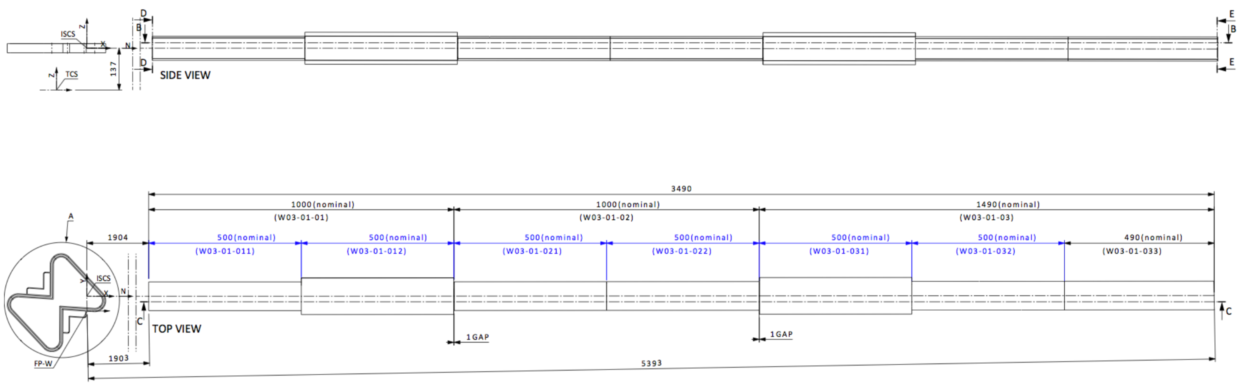


Figure 4: Beam extraction unit for ESS and CSPEC. The dashed lines show the CSPEC guide with a rotation of 0.5° and a translation of 0.016 m with respect to the instrument axis, ISCS, required to view the cold moderator and remain within the beam extraction unit.

Neutron Guide Design (13.6.10.1.2)

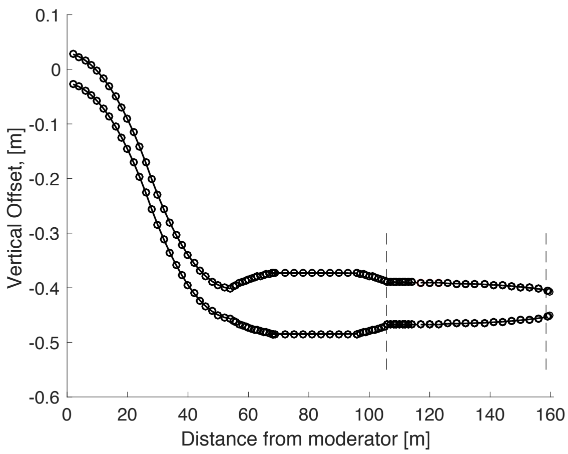


Figure 5(left): Vertical guide overview, distances are McStas coordinate system. The dashed lines show the position of the pulse shaping and monochromating choppers.

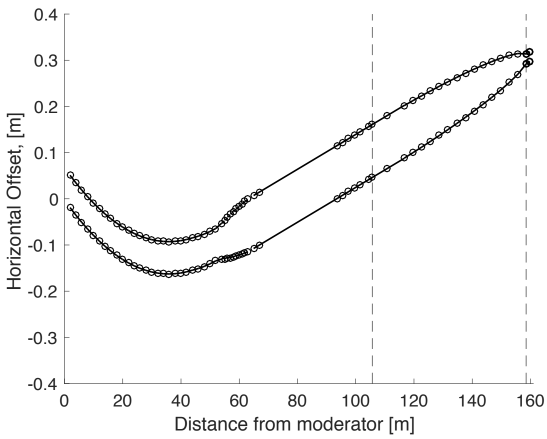


Figure 5(right): Lateral guide overview, distances are given in McStas coordinate system. The dashed lines show the position of the pulse shaping and monochromating choppers.

The instrument length, moderator to sample ~160 m, provides a 1.72 Å wavelength bandwidth. The beam transportation system is optimized using the following parameters:

- Guide must transport $2 < \lambda < 20$ Å.
- Beam dimensions vary from 4 x 2 cm^2 (height x width) at the sample position to 1 x 1 cm^2.
- < 10 % intensity variation across the sample position, necessary to extract the correct neutron scattering cross sections.
- The guide will transport at least ±1^{o} divergence at 3 Å but can transport more if possible, especially at higher wavelengths.
- The divergence profile must be smooth to facilitate scattering from single crystals.
- The guide dimensions at the pulse and monochromating chopper positions must be consistent with the requirement for $\Delta E/E_i = 1.5$ % for $\lambda \geq 4$ Å .
- The guide must be optimised for signal to noise.

The resultant guide is shown in Figure 5 and has been calculated both analytically and using ray tracing methods, McStas 2.3. McStas simulations have been performed using realistic guide pieces, 1-2 m straight sections, to create the curved and elliptical sections. Substantial effort has been made to reduce technical difficulties and this has resulted in optimised long straight sections. In addition, costs were carefully considered upon suggestion of the NOSG group. The CSPEC guide limits divergence over large regions of the guide making it possible to reduce the m-values and subsequently the costs.

	Description	Distance from moderator McStas ISCS coordinates (m)	Height	Width	m-values (top, bottom, left, right)
A	Bender Section	(0.016,0,1.9): (-0.092,-0.423,53.92)	Height: 0.055 m ROC: 1600 m	Width: 0.07 m ROC: 4000 m	3.0,3.0,3.5,3.5
B	Elliptical opening	(-0.092,-0.423,53.92): (-0.054,-0.423,63.93)	0.055: 0.101 m	0.07:0.1146 m	2.0,2.0,2.5,2.0
C	Elliptical opening	(-0.054,-0.423,63.93) (-0.039,-0.423,67.929)	0.101:0.111	0.1146:0.1146	2.0,2.0,2.0,2.0
D	Straight	(-0.039,-0.423,67.929): (-0.0575,-0.423,93.487)	0.111:0.111 m	0.1146:0.1146	2.0,2.0,2.0,2.0
E	Elliptical to PS	(-0.0575,-0.423,93.487): (0.1034,-0.423,105.661)	0.111: 0.0739 m	0.1146:0.1146 m	2.0,2.0,2.0,2.0
F	PS Chopper	(0.1034,0.423,105.666)	0.0739 m	0.1146 m	
G	Straight	(0.1034,0.423,105.671): (0.15629,-0.423,119.676)	0.0739:0.0739 m	0.1146:0.1146 m	2.0,2.0,2.0,2.0
H	Elliptical in width	(0.156,-0.423,119.676): (0.168,-0.423,122.677)	0.0739:0.0739	0.1146:0.1112	3.5,3.5,3.5,3.5 (3.0,3.0,3.0,3.0)
I	Elliptical in Height	(0.168,-0.423,122.677): (0.303,-0.423,158.495)	0.073746: 0.048874	0.1112:0.021844	3.5,3.5,3.5,3.5 (3.0,3.0,3.0,3.0)
J	Mono Chopper	(0.303,-0.423,158.5)	0.0488	0.021844	
K	Tapered	(0.303,-0.423,158.505: (0.303,-0.423,159.805)	0.0488:0.0415	0.021844:0.021844	5.0,5.0,5.0,5.0

Figure 6: CSPEC guide parameters.

The guide can be subdivided into components A-K (McStas coordinates):

- Component A (1.9 – 53.92 m): Beam extraction designed to extract the divergence required, at least ± 1 ° at 3 Å, that develops into an s-curved guide vertically with a simple curved guide horizontally, radius of curvature R = 1600 m vertically, R = 4000 m horizontally. The guide looses the first line of sight (LOS) at 26.53 m, within the bunker, with the second LOS at 53 m. The horizontal curvature ensures the guide remains on the piling corridor in E02 and ensures that there is sufficient space around the sample, at 160 m, to provide access for the ramp from E02 into E01, see Figure 7.
- Component B,C (53.92 – 67.93 m): An elliptical opening in the horizontal and vertical direction.
- Component D (67.92 – 93.48 m): Straight horizontal and vertical sections 0.111 x 0.115 m (height x width)
- Component E (67.92 – 105.661): Elliptical closing in the vertical direction, straight guide horizontally up to pulse shaping chopper.
- Component F (105.671 – 122.677): Elliptical closing vertically. Straight horizontally.

- Component G,H,I (122.677 – 158.495): Elliptical closing vertically & horizontally, up to monochromating chopper, 0.0488x0.0218 m (height x width).
- Component K (158.505 – 159.8): Tapered nose for the unfocussed guide. The focussed guide will be optimised in phase 2.

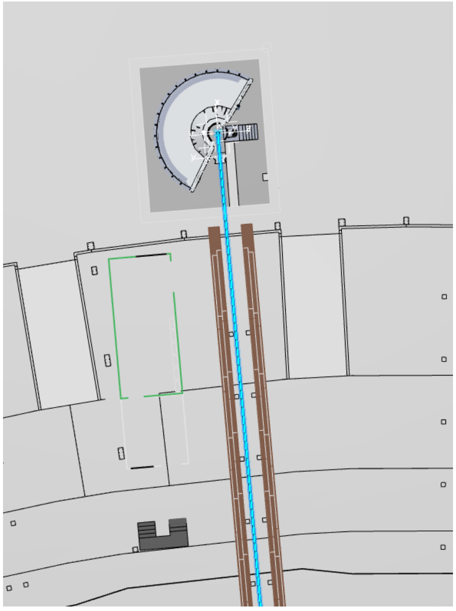


Figure 7: Engineering drawing of the CSPEC guide in E02 and E01. Particular focus has been paid to ensure the ramp is not blocked.

The brilliance transfer (BT) for this guide (taken as the ratio of the neutrons with ±1 ^{O} degree divergence impinging on the sample area (4 x 2 cm^2) to the number of neutrons with the same divergence leaving the moderator across the same sample area) is excellent with BT = 0.35 at 3Å that rises to 0.7 beyond 7Å, see Figure 8(left). Figure 8 shows comparisons between various guides that have been studied and are further outlined in document: **Overview of CSPEC guide: P. P. Deen, W. Lohstroh, S. Longeville, J. Guyon Le Bouffy. June 5th 2017.** Guide 2, as described in the above document, is the guide that we have chosen for the CSPEC instrument. Position sensitivity and divergence profiles are presented in Figure 9 matching the requirements. Guide 2 shows the required intensity uniformity (~ 10%) across the sample area with a clean cut off beyond the sample area to limit background scattering.

The CSPEC team show that downward curvature of a guide does not negatively impact the transport properties of the guide. We show excellent transport properties for the guide proposed, fully fulfilling the CSPEC requirements. Curving vertically allows the CSPEC team to benefit from the expected reduction in fast neutron flux in addition to providing cost savings for the shielding solution, the reduced the beam height in D02, D03 and E01 with respect to the nominal beam height, a reduction of 42 cm over 130 m, makes the shielding solution less costly and complex.

A detailed overview of the signal to noise parameters for the aforementioned guide and comparisons with the NOSG guide presented at TG2 are provided in the CSPEC guide document. Using the currently available information on the fast neutron background spectra, the decision to curve downwards is wise. Nevertheless we have requested further and more up to date information from the NOSG group that provide quantitative estimates of the background contributions at the bunker wall with no vertical offset and with a vertical offset. If these results contradict current information then the CSPEC team will certainly take this into account.

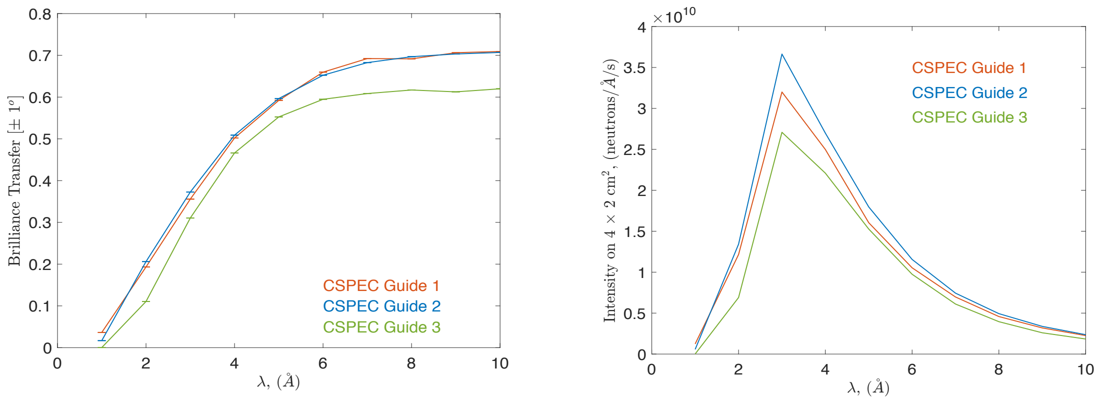


Figure 8: Figures showing comparison between various guide concepts leading to the decision to choose guide 2 for CSPEC.

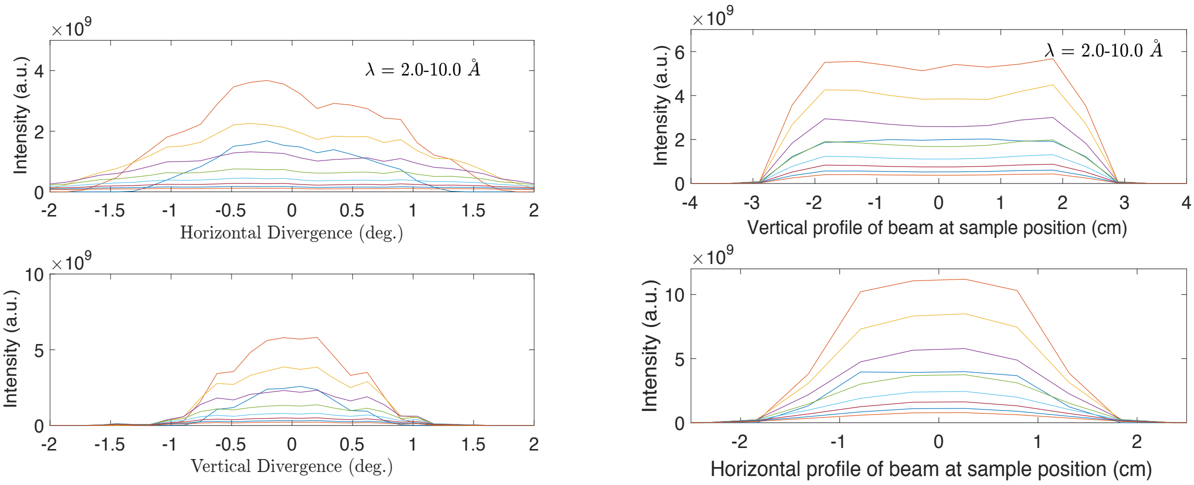


Figure 9: (left) divergence profile for a range of wavelengths 2 - 10 Å (+/- 0.5 Å) onto the sample position (4x2 cm^2) (right) intensity profile at the sample position (4 x 2 cm^2).

Neutron guide substrates (13.6.10.1.2.1.1)

The guide will be subdivided into several components that include: metallic substrate in the bunker, borofloat substrate along D03/E02 and final guide components that contain the focusing nose. It is foreseen that these various components will be manufactured separately. The TUM optics facility shall, as much as possible, manufacture in-house CSPEC guide components.

The guide substrates within the bunker will be metallic with Cu subtrates in the monolith, any collimators and the bunker wall to scatter as many neutrons into the surrounding material. Al. substrates will be used elsewhere in the bunker.

The lifetimes of various glass substrates has been studied in detail by Boffy *et al.* [5]. The results are documented in Figure 10 and indicates that Borofloat has a much lower radiation limit than the Borokron, N-ZK7, counterparts. These results led to the decision by the ESS optics group to request Borokron guides beyond the bunker. Upon calculation the CSPEC team feel that this is quite conservative and would lead to unnecessary costs.

	Radiation limit (beam fluence) (n/cm^2)	Radiation limit (effective fluence on the sample) (n/cm^2)	Beam number and spectrum
Borofloat (mean value)	$2.8 \pm 1.0 \times 10^{16}$	$2.0 \pm 0.7 \times 10^{15}$	H21 – Thermal
Borofloat (lowest value)	$7.5 \pm 2.5 \times 10^{15}$	$5.6 \pm 1.9 \times 10^{14}$	H21 – Thermal
N-ZK7	$3.7 \pm 1.3 \times 10^{17}$	$2.8 \pm 1 \times 10^{16}$	H112 – Cold
N-BK7	$> 2.0 \times 10^{18}$	$> 1.5 \times 10^{17}$	H112 – Cold
S-BSL7	$> 2.0 \times 10^{18}$	$> 1.5 \times 10^{17}$	H112 – Cold

Figure 10: Figure from Boffy et al. [5]. Beam fluence needed to splinter multilayer substrates upon scattering with thermal neutrons. Heterogenous irradiation with a mean incident angle of 4.3°.

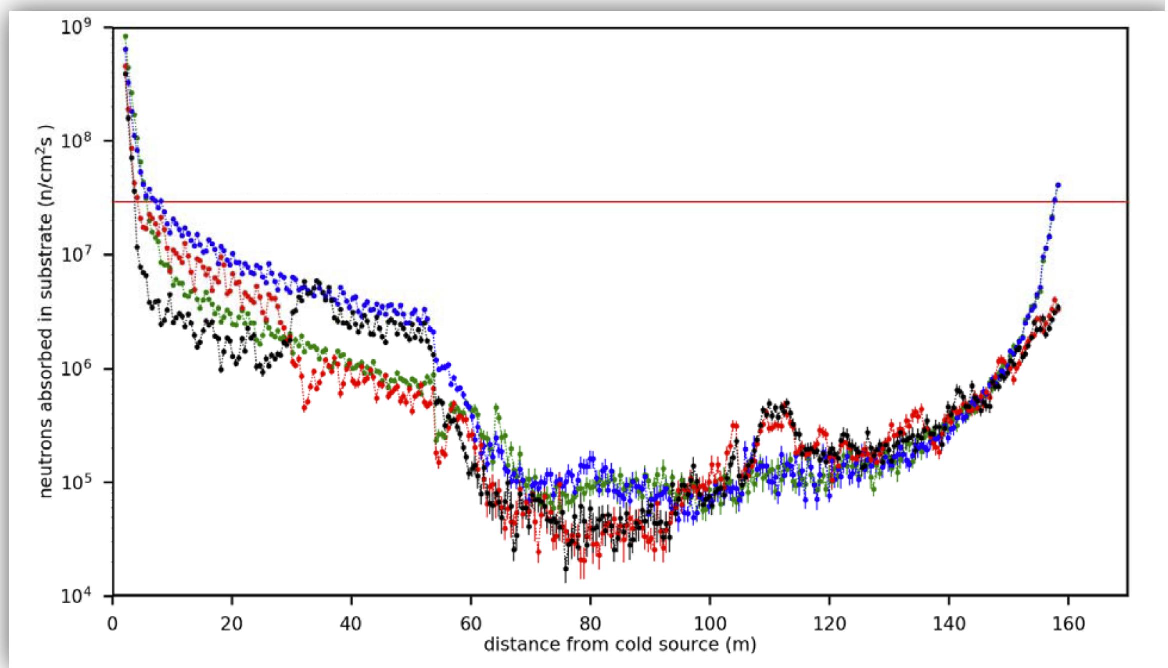


Figure 11: Result of the McStas Simulation for the CSPEC guide, 13.6.10.1.2. Plotted is the wavelength integrated neutron flux absorbed by the substrate for the left (green) and right (blue) side wall seen in neutron flight direction, as well as the top (red) and bottom (black) mirrors. The red horizontal line depicts the estimated flux limit corresponding to a life time of 20 years of operation at ESS full power

McStas simulations have been undertaken to obtain an estimate for the neutron irradiation of the substrate material and thereby to determine the substrate requirements for the lifetime of CSPEC. Guide substrate splintering is the results of the interaction between thermal neutrons and the substrate glass with the subsequent emission of γ's. Boffy et al. [5] studied a variety of glass substrates and the neutron fluence these substrates could withstand before splintering. Figure 11 shows the wavelength integrated neutron flux absorbed on the substrate of the CSPEC guide. The red horizontal line depicts the estimated flux limit of a Borofloat guide before neutron transport is affected. The horizontal line corresponding to a life time of 20 years of operation (200 days a year) at ESS full power operating, 5 MW A neutron fluence limit is reached within 1 to several decades on the guide in the bunker section and before the guide curves out of line of sight (distance < 27 m). However since metallic substrates will be employed in this region, as requested for safety, there will be no concern about Borofloat lifetimes.

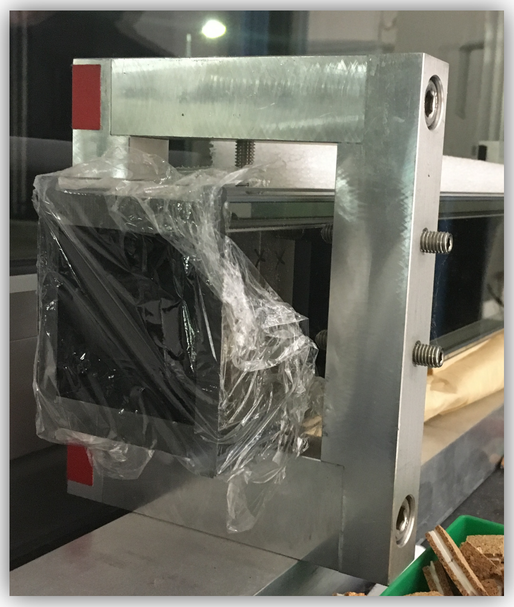


Figure 12: Guide and guide alignment as devised by the TUM Optics group.

Beyond the bunker and out of line of sight , x > 28 m, the CSPEC team envisage using Borofloat glass for which we show lifetimes that are in excess of 100 years. . Full information can be found in the MLZ Document: **Recommendation for neutron guide substrates: Dr. P. Link, 1st June 2017.**

There is some concern at the ESS that one should also consider the misalignment of the guides since that is, according to the ESS NOSG group, where most of the damage will occur. There has been no quantitative estimate for such damage reported, however the CSPEC team will carefully consider this and ensure that there are no guide edges protruding by, for instance, slightly narrowing the guide pieces at the end of the guide section so that the following guide piece is slightly larger and no protruding pieces show.

As the guide approaches the focusing nose the fluence increases once more and a decision on the exact substrate material will be made in the detailed engineering design phase.

Neutron guide alignment (13.6.10.1.2.1.4)

Neutron guide alignment procedures as devised by the TUM optics group will be followed, see Figure 12. This alignment procedure has been employed on several beamlines at FRM2 and allows for alignment greater than 50 µm. Fiducial markers will be used for guide alignment. ESS Optics group will monitor the beam performance and realign when needed, as outlined in the Optics handbook.

Neutron guide vacuum housing & support (13.6.10.1.2.1.2 – 13.6.10.1.2.1.3)

The CSPEC guide will be housed in an external vacuum, $p < 10^{-3}$ mbar, suitable to limit losses due to air scattering within the guide. In D03 the entire floor is piled and therefore subsidence should not be a concern. In E02, the support for the vacuum housing will rest on the piled corridor. The distance between piles in section E02 is 4 m, quite a distance. However, the TUM optics group is convinced that the vacuum housing will be strong enough to support themselves over 4 m and enable the correct alignment procedures. Of course extra support structures can be added underneath if there is doubt about the strength of the vacuum housing.

Exchange of guide end pieces (13.6.10.1.2.4)

Much consideration has gone into the requirements for the guide end pieces. The first requirements are variable focusing from 4 x 2 cm^2 to 1 x 1 cm^2. The second requirement, limiting flux losses, necessitates the guide end to be as close to the sample as possible, we estimate 20 cm but may reduce this once exact sample environment details are clearer in the detailed design phase. The third requirement originates from sample environments that are rather bulky in size, large bore magnets for instance, that require the guide exit to be further from the sample than 20 cm. As such 4 guide end pieces are envisaged:

(1) unfocused, guide end-sample distance = 20 cm
(2) focused, guide end-sample distance = 20 cm
(3) unfocused, guide end-sample distance = 50 cm
(4) focused, guide end-sample distance = 50 cm

A complete remote handling system was considered but the complexity of such a system would be very costly and rather unnecessary and as such manual changes of the focusing nose is envisaged.

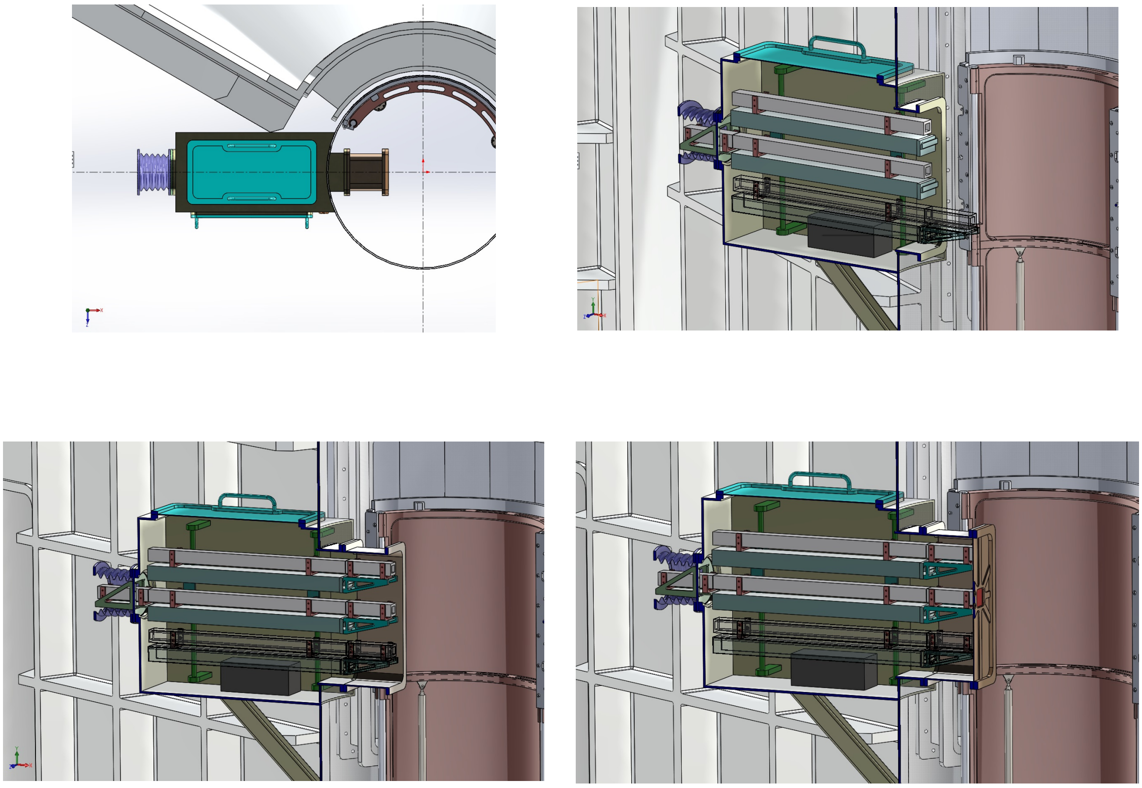


Figure 13: Preliminary Engineering drawings outlining the design for the exchange of the focused and unfocused nose. (top, left) Top view of the guide box within which the exchangeable guide pieces are housed. (top, right) two guide pieces with guide end to sample distance of 50 cm. (bottom, left) Extended guide pieces so that the guide end to sample position is reduced to 20 cm (bottom, right). Extended guide pieces with the final section in place.

Figure 13 provides an outline of the solution for the exchangeable guide. A guide box is integrated between the monochromating chopper and sample environment pot of the detector tank. Within this box there are two penultimate guide pieces that can be exchanged remotely (guide end – sample = 50 cm). The final guide pieces (guide end - sample = 20 cm) are positioned manually via the window in the sample environment pot. There are two experimental scenarios: (1) Cryogenic vacuum and (2) Gaseous environment. In the first scenario the last window before the sample will be placed just after the monochromating chopper position. In this case the guide box and the sample environment pot will both be evacuated to cryogenic pressures. In the second scenario a thin Al window will be placed at the end of the guide (in red in image) and will separate the sample environment pot from the guide box. As such the guide box can be evacuated while the sample environment pot will be a gaseous environment.

Future Proofing for Polarisation analysis.

A future essential upgrade path for CSPEC is the inclusion of polarisation analysis. The CSPEC team envisage using a polarising supermirror system and an adiabatic RF flipper before the monochromating chopper with He_3 analysis of the scattered beam. The length of the polarising system must be adequate to provide a uniform magnetic field. In addition the flipper must also be long enough to enable flipping of the incident neutrons. A 2 m exchangeable guide piece before the monochromating chopper is incorporated into the guide design.

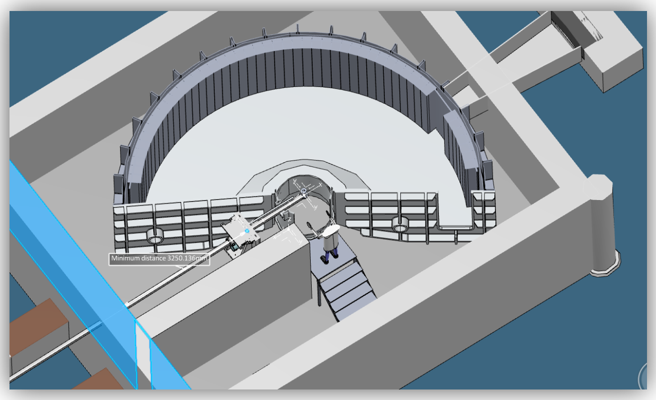


Figure 14: CSPEC secondary spectrometer showing, in particular, the distance available for a removable section before the monochromating chopper.

The polarisation system will be subject to stray fields and this must be carefully considered with respect to any magnetic field in the vicinity. Space is often an issue when trying to incorporate equipment for polarisation analysis. The CSPEC team provides a sufficiently long removable section before the monochromating chopper. Figure 14 shows the distance available for a removable section of which 2 m will be employed.

Slits (13.6.10.1.4.2)

Automated slits will be positioned after the final guide piece. The details of the slit design are not finalized however the slit design must be able to accommodate the variable 20 and 50 cm end of guide to sample distance as outlined in section 13.6.10.1.2.4 . $^{10}B_4C$ or Cd based coating will be used as an absorber.

Monitors (13.6.10.1.6.1)

Flux and time of flight monitors are required for instrument diagnostics and data normalisation. There will be provisions for monitors after each chopper set for guide and chopper diagnostics and furthermore a final normalisation monitor after the monochromating chopper. Typically monitors are made from scintillator materials (such as GS20 Glass). The ESS chopper group is developing a system to insert and remove monitors within each chopper housing.

Chopper Cascade (13.6.10.1.3)

The chopper cascade, in conjunction with the guide and detectors, must access the energy resolutions outlined in the CSPEC system requirements. In addition, the chopper cascade must ensure that the distance in time between adjacent RRM pulses can be adjusted so that the complete energy transfer region, energy transfer = $\hbar\omega = \infty < E_i < 0.8E_i$, can be measured. The technical choice for choppers considers, as a high priority, reliability. It is for this reason that:

- High speed choppers are symmetric.
- Chopper blade diameters do not exceed 700 mm.
- Frequencies do not exceed 350 Hz (most experiments will run at frequencies of 250 Hz or less.

A suitable technical and engineering solution for the bandwidth choppers has been found with two BW choppers in the bunker at 15.5 and 20.03 m from the moderator surface (McStas coordinates), see Figure 15 which shows the neutron flux after each BW chopper. Substantial work has gone into providing a solution with all BW choppers outside the bunker, in line with the strong suggestion of our advisory panel of experts, see document: **Bandwidth chopper system for CSPEC chopper spectrometer, P. P. Deen, W. Lohstroh, S. Longeville, J. Guyon Le Bouffy, 11th June 2017**. This solution, with three BW choppers outside the bunker, is favoured by the CSPEC team but we have been requested, by the ESS, to place the BW choppers into the bunker. This request is accepted however, we decline any responsibility due to potential failure (and loss of beam time) due to the presence of the BW choppers in the bunker that could delay the opening of the spectrometer to the user program.

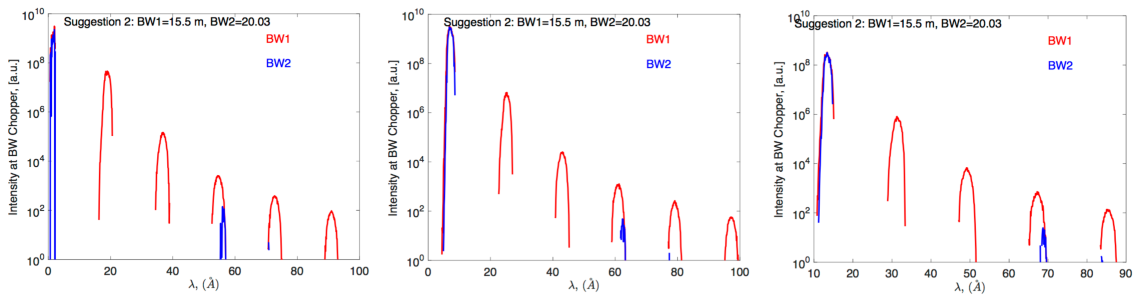


Figure 15: McStas simulations show the transmitted flux with the choppers focussed to an average wavelength of λ = (left) 2 Å, (middle) 8 Å and (right) 14 Å for configuration 2, 2 BW choppers in the bunker. The transmitted intensities after the BW choppers are colorcoded.

An overview of the concept of the entire chopper cascade is given in the CSPEC Concept of Operations. Table 1 gives an overview over the chopper system parameters and the characteristics of the various axes. The absolute positions may change slightly, particularly of the BW choppers, when engineering realities are considered.

Table 1: CSPEC chopper cascade and relevant parameters.

Chopper Name	Position (m) McStas ISCS coordinate system	Single Blade (SB) or Counter rotating (CR)	Diameter (mm)	Number of openings & slit width (angle)	Max Frequency (Hz)	Blade material (Absorber)	Bearing
BandWidth 1	(-0.077, -0.07, 15.5)	SB	700	1 & 34.30°	14	Aluminium (^{10}B coated)	Magnetic
BandWidth 2	(-0.1, -0.12, 20.03)	SB	700	1 & 44.32°	14	Aluminium (^{10}B coated)	Magnetic
Pulse Shaping	(-0.319, -0.423, 105.666)	CR	700	3 & 23.45°	175	Carbon fibre (^{10}B coated)	Magnetic
Mono_RRM	(-0.318, -0.423,158.450)	SB	700	1 & 4.15°	350	Carbon fibre (^{10}B coated)	Magnetic
Monochromating	(-0.318,-0.423,158.50)	CR	700	1 & 4.15°	350	Carbon fibre (^{10}B coated)	Magnetic

Bandwidth Choppers

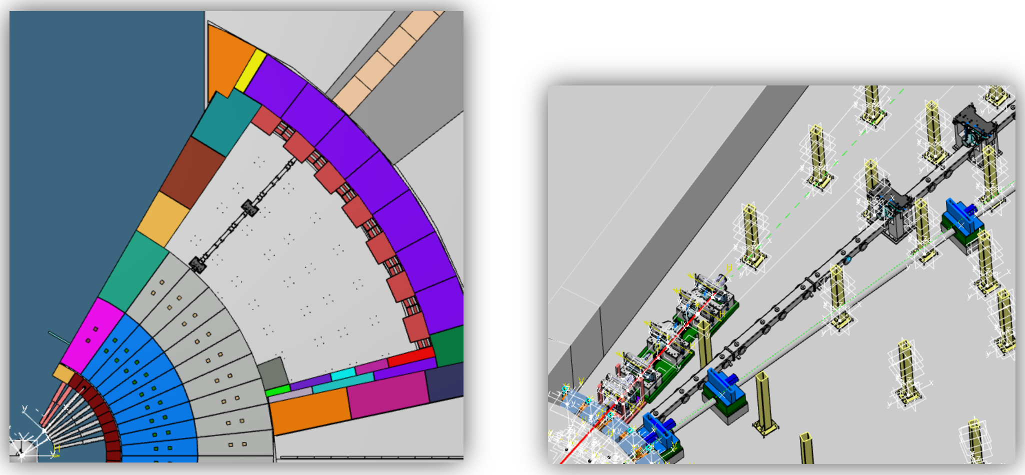


Figure 16: Catia drawings of the BW choppers within the bunker. (left) showing only the CSPEC guide and surrounding pillars. (right) CSPEC guide and BW choppers shown in the central guide with the adjacent instruments shown to ensure no overlap between components.

The BW choppers are shown in the CATIA engineering drawings, see Figure 16. The choppers used are generic 700 mm single disk choppers, from the ESS CATIA library, rotating at 14 Hz under a vacuum of 10^{-3} mbar and can therefore be integrated into the guide housing. Figure 16(right) shows the components of the adjacent instruments, there are currently no collisions. A precise overview how ESS envisages to facilitate technical work will be most appreciated.

High speed choppers

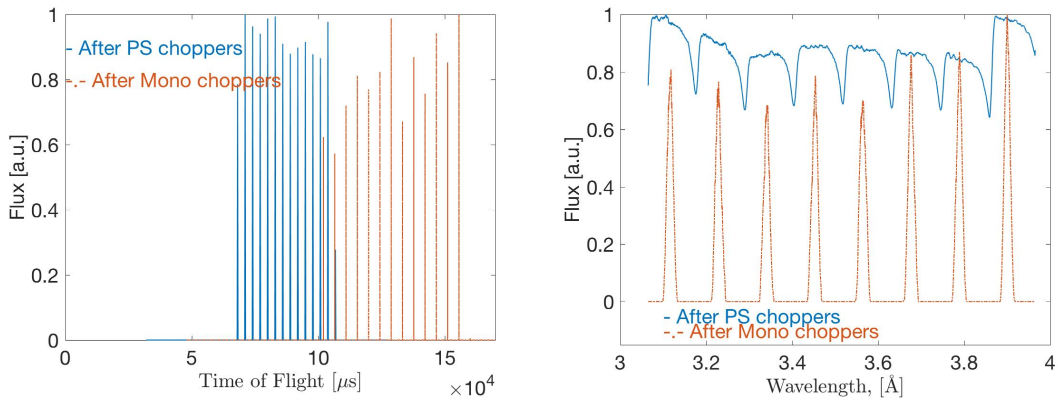


Figure 17: McStas simulations: (left) time of flight dependence and (right) wavelength dependence of neutron flux profiles after the pulse shaping and monochromating choppers for $\lambda_{central}$ = 3 Å with pulse shaping choppers rotating at a frequency = 112 Hz and RRM and monochromating choppers rotating at a frequency = 224 Hz.

The high speed choppers are the pulse shaping, RRM and monochromating chopper pair with frequencies up to 350 Hz. The pulse shaping chopper blades have 3 symmetric windows and run at a frequency of 1/2 "F" ensuring that the total frequency is a multiple of the ESS source frequency. The monochromating chopper blades run at a frequency "F", again ensuring a multiple of the ESS source frequency.

Frame overlap of RRM pulses is avoided via the use of the RRM chopper, an extra blade before the monochromating choppers (within the same housing) rotating at a frequency "F"/n (with n = integer) of the monochromating chopper frequency.

The narrow bandwidth of CSPEC, Δλ = 1.72Å, in conjunction with the cold nature of the neutron spectra, means that the time required to reach background levels, between subsequent pulses, does not vary substantially. The chopper cascade on CSPEC creates equally spaced, in time, incident pulses on CSPEC. A more elaborate solution to vary the time between pulses is not required.

Figures 17 shows a McStas simulation of the clean separation of the pulses, in time and wavelength, on CSPEC with the pulse shaping chopper frequency at 112 Hz and the monochromating and RRM choppers frequencies at 224 Hz.

The high speed choppers will rotate at frequencies up to 350 Hz and therefore must be placed in a ultra high vacuum environment, 10^{-6} mbar. The separation between the guide and the chopper unit will be an Al window (~ 0.5 mm). These choppers are outside the bunker and will have large housings to facilitate technical work.

T0 Chopper

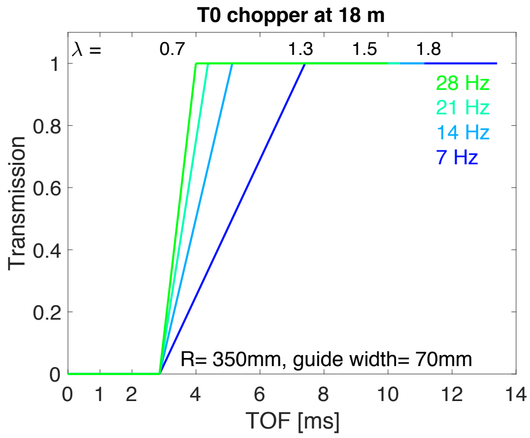


Figure 18 : Transmission of neutron flux through a T0 chopper positioned at 18 m from the moderator, rotating between 7 and 28 Hz across the CSPEC guide as a function of time (2.86 ms is the prompt pulse needed to shield). An alternative x-axis is given on the top of the graph that relates the positon of the T0 chopper to the TOF (lower x-axis) and the wavelength transmitted.

There remains substantial uncertainty about the background radiation levels. However the CSPEC team estimate that, curving the guide twice out of line of sight and with a sample position at approximately 160 m from the moderator, the background should provide a signal to noise of 10^5. Nevertheless the possibility to include a T0 chopper must exist in the case of high background levels due to unforeseen moderation of MeV prompt pulse neutrons and other high-energy particles. Figure 18 shows the transmission of neutrons, as a function of time, of a 700 mm T0 chopper blade rotating across the CSPEC guide at 18 m. The corresponding wavelengths that are transmitted are shown. A T0 chopper, rotating at 14 Hz, can therefore be placed at a position beyond 18 m. For shielding purposes, if an upgrade with a T0 chopper is required, it would be placed within the bunker avoiding any extra shielding.

ESS plans to develop a standard T0 chopper, a description of which can be found in ESS-0068110 that requires a guide opening of 50 cm. The loss of flux at 3 Å at the sample position due to the replacement of 50 cm guide with a T0 choppers is ~ 13 %: flux on the sample is 3.89e10 n/s/Å while the guide system with the T0 chopper produced flux on the sample of 3.41e10 n/s/Å.

Failures

Failures of the chopper system can be forewarned via the recording of operational parameters. Operational parameters recorded for each chopper axis include:

- Cooling water flux and temperature
- Chopper vessel vacuum (Pressure, Vacuum pump on/off)
- Status of the magnetic bearings
- Vibrations of the chopper vessel
- Rotation speeds and phases
- Temperature of the disks

These parameters will signal the onset of a failure and will enable the team to intervene immediately.

Shielding (13.6.10.1.10)

The General Safety Objectives (GSO) for the ESS, define the radiation hazards and the radiation dose objectives. This is based on the legislative requirements in Sweden as well as good practices from research reactors and similar facilities all over the world. GSO criteria are given for workers and for the public and for different event classes.
The table below summarizes the dose levels for different event classes.

Table 2: Categorisation of radiation risk events at ESS.

Classification	Event	Frequency/Year	Effective dose: Radiation Worker [mSv]	Effective dose: General Public [mSv]
H1	Normal Operation		< 10 per yr	< 0.05 per yr
H2	Anticipated Events	$<10^{-2}$	< 20 per event	< 0.1 per event
H3	Unanticipated events	10^{-2} - 10^{-4}	< 50 per event	< 1 per event
H4A	Improbable events	10^{-4} - 10^{-6}	< 50 per event	< 20 per event
H4B	H2-H3 events combined with multiple failures	$< 10^{-4}$	< 50 per event	< 20 per event
H5	Highly improbable events		< 500 per event	< 100 per event

The shielding requirements are such that the shielding solution must be sufficient to deal with a H2 event. The radiation levels must not exceed 3 μSv/hr in the supervised areas: D03, E02 and E01.

The ESS optics group consider examples for a H2 event as:

- Full beam under normal operation, scattering of worst case sample environment equipment.
- Full beam under normal operation, scattering of a worst-case sample.
- Full beam under normal operation, hitting the beamstop/downstream end of the instrument cave.
- Misaligned sample environment equipment.
- Sheet of cadmium in the sample location.

In the case of a H2 scenario the dose to the worker cannot exceed 2 mSv/event.

The calculations that have been performed consider (a) normal operation with all choppers running as required optimised for the highest flux (~ 3 Å) and (b) operation with all choppers in the open position, optimised for the highest flux (~ 3 Å with $\Delta\lambda$ = 1.72Å), this is the case for a white beam event that will be a regular occurance when aligning single crystal samples. We consider these two events as H1 and H2 events, respectively. Shielding is designed to allow all H1 and H2 events.

These calculations estimate the biological shielding requirements and not the stringent signal to noise requirements on the time of flight spectrometer. MCNPX calculations will be performed in the next phase to determine shielding requirements to further the shielding solution for CSPEC.

Guide shielding inside the bunker. (13.6.10.1.10.1)

The guide housing/guides will be covered with a Boron absorber to limit activation of these components. There is no further requirement for shielding within the bunker from a biological perspective however shielding within the bunker around the guide could help significantly lower the background and avoid cross talk between the instruments.

MCNP calculations were performed by D. DiJulio to estimate the flux of high energy neutrons emerging from a curved guide, once out of line of sight, at the bunker wall, see Figure 19. The open curve (yellow in figure) indicates no shielding within the bunker while the filled curve (orange in figure) indicates a completely concrete filled bunker region. The high-energy neutron level can be reduced by nearly two orders of magnitude by fully filling the bunker with concrete. The third calculation estimated the effect of a collimator around the guide. An Fe collimator is placed in the middle of the bunker around the guide, variable in length from 5 to 50 cm in lenght (along the guide) and 1 m wide with no further optimization. The collimated curves show the high-energy neutron level at the bunker wall after passing through the Fe collimator. An order of magnitude of high-energy neutrons are lost after the placement of a 30 cm long collimator in comparison to an empty bunker. Optimisation of such a collimator, by optimizing the length, width, material (Fe/Tungsten laminate), may reduce the background to the filled curve levels. As such this figure shows that some level of shielding around the guide is required in the bunker to limit background from fast neutrons. Further calculations are required to understand the noise levels on the instrument.

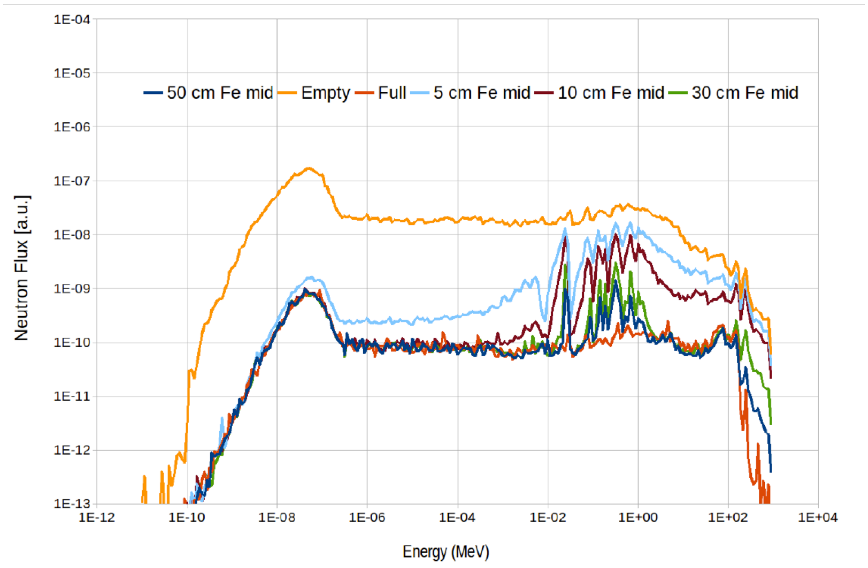


Figure 19: Energy dependence of the neutron flux, starting at 2m relative to source, at the bunker wall after a curved guide for a guide surrounded by collimators of various lengths and compared to an empty and a fully filled concrete bunker.

Guide shielding outside the bunker (13.6.10.1.10.2)

The neutron losses along the guide, see Figure 11, can be used to determine the shielding requirements considering a H2 event. Once the guide is out of line of sight, after the bunker, the γ dose from the neutron capture in the glass substrates is the leading term in the shielding requirements. The neutron losses are uniform along the majority of the guide once out of line of sight. For this reason the required shielding thickness along the guide can be uniform beyond the bunker.

The ESS optics group determined the shielding thicknesses required by calculating the photon emission spectra that resulted from neutron capture along the guide. Shielding calculations assumed a guide width of 8 cm and m–values of 2.5, these values are close to the current guide parameters and provide a good estimate. The calculations used a weighted average of Ni-58 and Ti-48 γ-rays. These isotopes dominate the photon emission spectrum. Ti-48 has a neutron absorption cross-section of 6.1 barns, Ni-58 =

4.43 barns. However Ni-58 has a density that is roughly half, 4.51 g/cm^3 compared to 8.90 g/cm^3 of Ti-48, with an atomic mass of 48 compared to 58 for nickel. This results in an almost equal macroscopic cross-section of 0.3459 cm^{-1} for Ti-48 and 0.4045 cm^{-1} for Ni-58 and these were used to weight the γ-rays. The biological shielding requirements are a concrete thickness of 95 cm for a H2 event. Currently the CSPEC team have taken 70 cm thickness concrete blocks with a thin steel shielding housing closer to the guide. These calculations remain preliminary and determine the requirements for biological shielding only.

Table 3: Beamline shielding requirements. Shielding thicknesses are for normal concrete. Flux numbers are flux at sample position. Parameter A is the fraction of neutrons absorbed in the walls of the guide (see Shielding Report)

Flux [n/cm^2/s]	m-value	Guide Height [cm]	A	Standoff [cm]	Dose conversion μSv/cm^2	Density [g/cm^3]	Attenuation [cm^2/g]	Concrete Shielding Thickness [cm]
4.3e9 (H2)	2.5	8	0.3	50	0.00001175	2.3	0.030625	95
4.3e7 (H1)	2.5	8	0.3	50	0.00001175	2.3	0.030625	33

In addition, extra care will be taken to limit any fast neutrons that are able to stream through the guide housing by using shielding collimators or collars closely placed around the guides at relevant positions.

The shielding concepts around the guide in the various halls must be varied due to the different floor heights: 1.75 m from floor to CSPEC beam center in D03, 0.714 m floor to CSPEC beam center in E02, and 2.58 m from floor to CSPEC beam center in E01. Figures 20 shows the proposal for the shielding in the halls D03 and E02 with a steel liner around the vacuum housing and further concrete blocks. The guide shielding in E01 will be similar to the proposal for shielding in E02 but is not yet finalised since it needs to be integrated into the experimental cave.

The chopper pits will be used to enable maintenance work but also to create large volumes in which multiple scattering events of the streamed fast energy particles will reduce their intensity and energy in the forward direction along the guide.

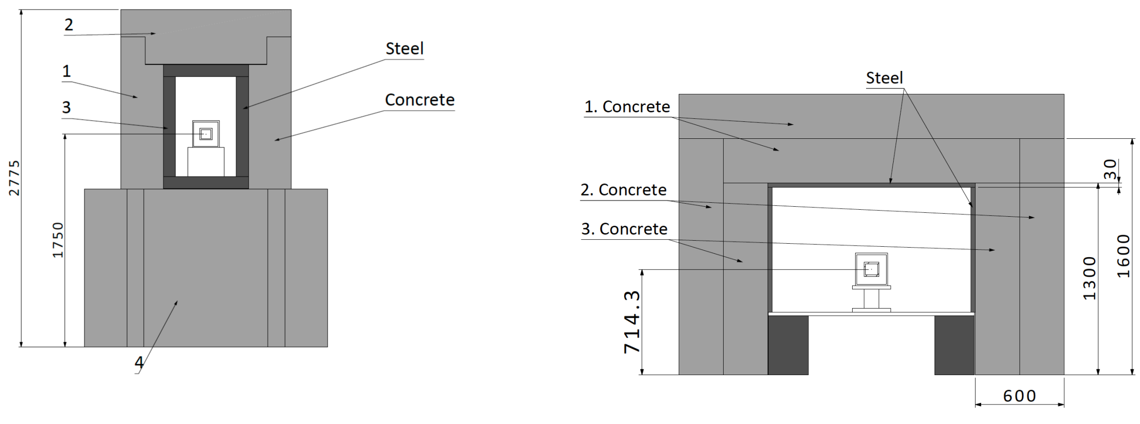


Figure 20: Cartoon showing the guide shielding solution in buildings (left) D03 and (right) E02.

Detector tank shielding (13.6.10.5.4)

The flux estimates for the detector tank are obtained by considering that all the neutrons absorbed are converted to 2 MeV photons as is the case for scattering of neutrons from hydrogen, which can be considered as a worst case sample, and emitted into 4π.

Flux [n/cm^2/s]	Area [cm^2]	Distance [cm]	Dose conversion µSv/cm^2	Density [g/cm^3]	Attenuation [cm^2/g]	Concrete Shielding Thickness [cm]
4e9 (H2)	8	315	0.0000065	2.3	0.04557	81
4e7 (H1)	8	266	0.0000065	2.3	0.04557	32

Table 4: Cave Shielding for the roof. Thicknesses are for concrete.

Flux [n/cm^2/s]	Area [cm^2]	Distance [cm]	Dose conversion µSv/cm^2	Density [g/cm^3]	Attenuation [cm^2/g]	Concrete Shielding Thickness [cm]
3e9 (H2)	8	297	0.0000065	2.3	0.04557	81
3e7 (H1)	8	248	0.0000065	2.3	0.04557	33

Table 5: Cave Shielding for the detector walls. Thicknesses are for standard concrete.

These preliminary calculations indicate that up to 81 cm of concrete is required to surround the detector vessel both for the roof of the cave shielding and the detector walls. In the case of the detector wall shielding the value is calculated considering the requirement directly behind the detector vessel. However there is a possibility to provide some extra space between the detector vessel and the shielding blocks, Figure 21. This (a) minimises the shielding thickness, (b) may reduce secondary scattering events since the distance are extended and (c) provides a suitably extensive region above the detector housing for technical work.

Several instruments have reported strong background scattering originating from beneath the scattering chamber, [AMATERAS, LET, WISH]. This can be avoided by covering the floor beneath the chamber with B_4C contained (25%wt) precast concrete, [7]. In contrast to floor shine, skyshine has not been reported to be a large issue for any large detector tank instrument. The roof of the scattering chamber will be covered with a thin layer of polyethelene/B_4C.

It should be noted that although we are now discussing concrete for shielding purposes, it is more likely that a laminate of other materials (boronated PE, steel cans containing Fe_3O_4 nanoparticles and a hydrogen rich fluid or wax) will be employed to optimise shielding and cost.

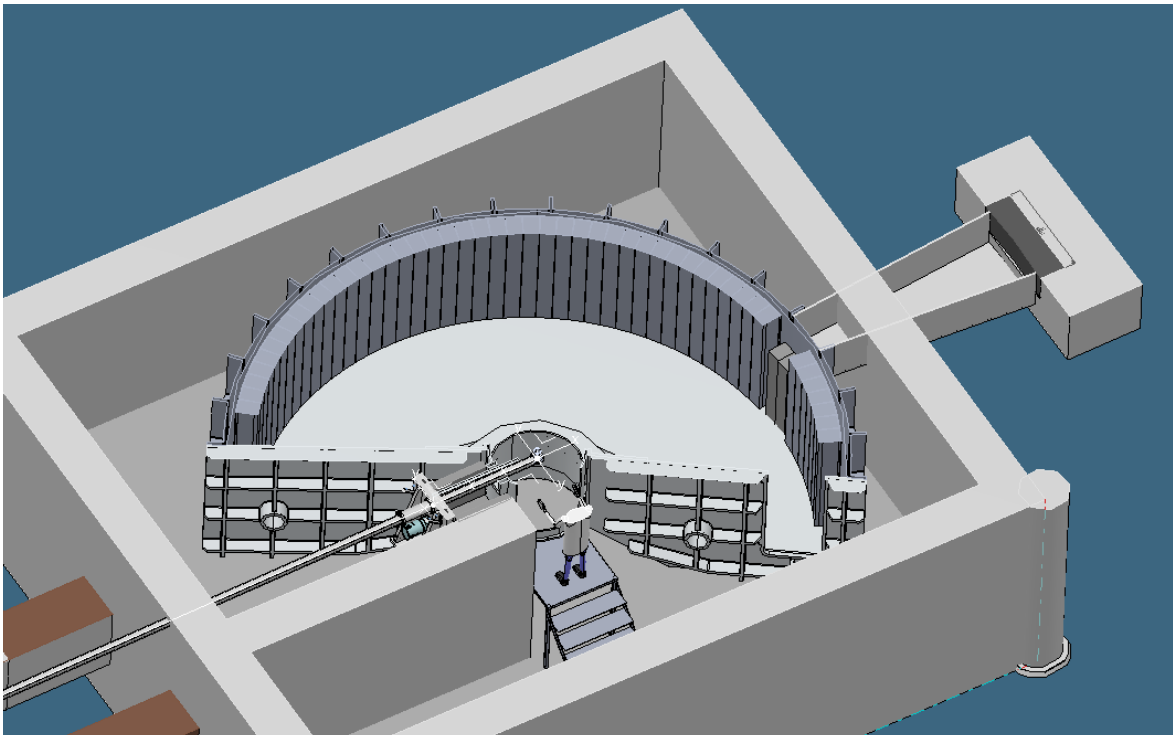


Figure 21: CSPEC Secondary spectrometer showing the shielding blocks around the detector tank, slightly offset, and the beamstop.

Beam stop (13.6.10.1.8.6)

CSPEC will require to access low Q regions to deliver its scientific case. A beam tube around the transmitted beam at 2θ = +/-3^{o} will be provided in the detector tank wall, covered in absorbing material, that will end in an opening surrounded by approximately 90 cm of concrete, see Figure 21. The exact width will be determined when the guide design is completely finalized. The get lost tube around the transmitted beam will be connected to the detector tank by an absorber that will be placed close to the detectors, thereby ensuring that the transmitted neutrons and associated gamma burst will arrive into the elastic line of the measurement. The get lost tube extends behind the detector tank, see Figure 21, the inner part of which will be covered with B_4C as an absorbing material. However any final decision can only be made after further MCNPX calculations. The CSPEC team are working towards a solution that will suitably incorporate the first absorbing sheet and the get lost tube in the detector design.

Detector tank (13.6.10.3.3.1)

The detector tank ensures detector coverage for -27^{o} to 140^{o} with +/- 26.5^{o} vertical coverage and with a sample to detector distance of 3.5 m for detectors in the equatorial plane. The detector tank includes the sample environment pot incorporated to provide a continuous cryogenic vacuum (10^{-6} mbar) around the sample, with a vacuum that extends to the monochromating chopper window, and up to the detector vessels housing the detector modules. The sample environment pot also incorporates an Al gate valve able to separate the sample environment pot from the rest of the detector tank and enabling atmospheric pressure or gassy environments in this region. A radial oscillating collimator is positioned outside the Al window of the sample environment pot. Figure 22 shows the detector tank surrounded by the detector cave. The detector tank must be non-magnetic, particularly for 1.5 m around the sample environment pot. Discussions are on-going with a number of detector tank manufacturers. In addition, there is a strong cost benefit to manufacture the whole detector tank in a single piece. Delivery logistics will need to be carefully considered including how the tank is placed in E01. Discussions are on-going with conventional facilities to ensure that this is possible, in particular discussions are on-going to provide a suitably large door into E01 (6 x 5 m).

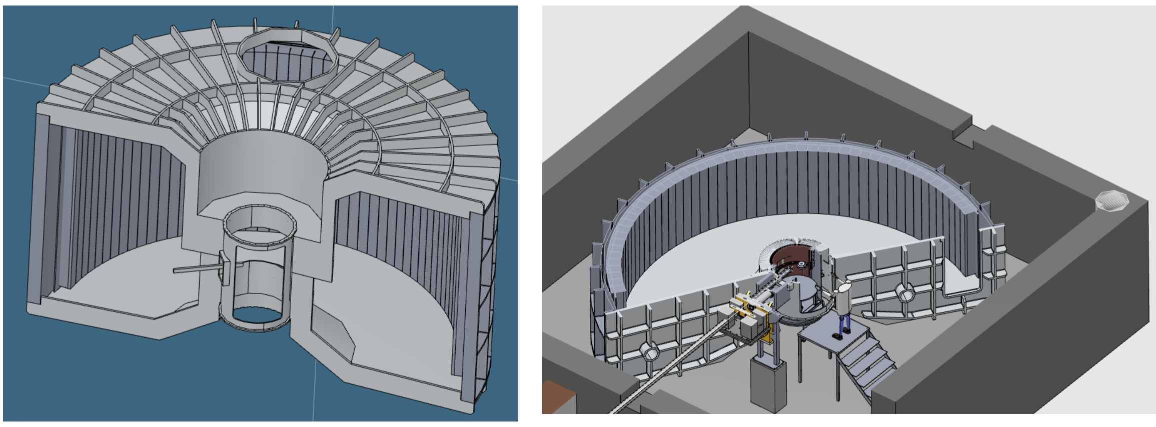


Figure 22: Engineering drawings of the CSPEC detector tank (left) the open detector tank with the detector modules at the edge of the tank (right) detector tank incorporated into the detector cave, half the height is shown. Beamstop is not shown.

The detector vessel housing the ^{10}B multigrid detectors, are shown at the edge of the detector tank, Figure 22. The detector vessels are required since a 250 – 400 mbar detector gas is essential for the operation of the detectors. The cables, incorporating the data cable and high/low voltage/gas flow, for each vessel will be extracted via a removable circular section in the top of the tank, see Figures 22 & 23.

The detector tank must provide a method for installation and extraction of the detector vessels. The solution most favoured at the moment is extraction via the top of the detector tank using the removable circular section in the tank, see Figure 22 & 23. In this case the detector vessels will slide forward from their nominal position on rails, are then able to translate along rails to under the circular section and removed using the E01 crane. This solution requires removable shielding blocks in the top of the cave housing, shown in Figure 23(right).

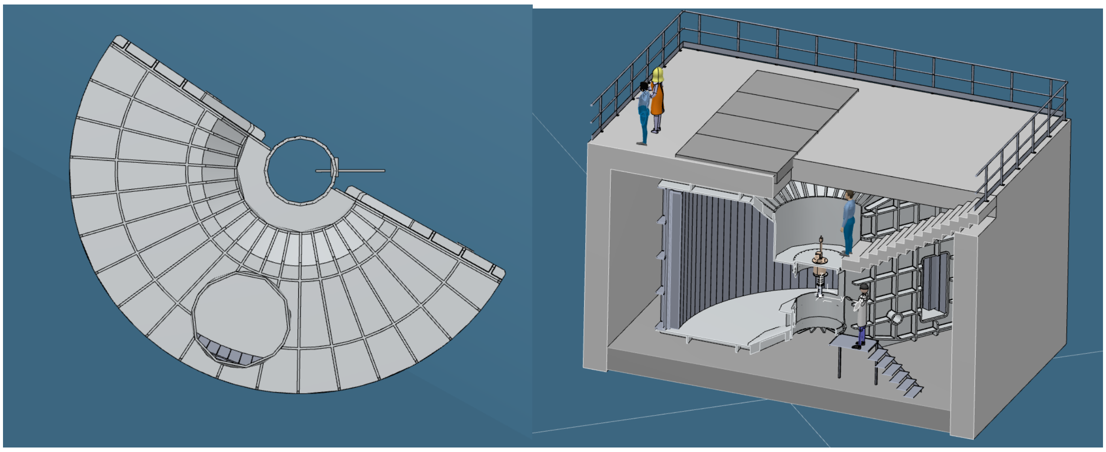


Figure 23: Engineering drawings of (left) the CSPEC detector tank from the top and (right) incorporated fully into the detector cave.

The detector tank will be evacuated to cryogenic pressure thus limiting the cryogenic shields between sample and detectors. Internally, the main tank will be covered in an absorbing material, either Cd or B_4C sheets, depending on vacuum limitations. The detector tank evacuation is the responsibility of the ESS vacuum group and details are under consideration.

Sample area (13.6.10.3.3.1.1)

The sample environment pot of CSPEC makes this instrument considerably different from its predecessors. The sample environment pot makes it possible to perform experiments under cryogenic environments with minimal aluminium windows (thus reducing the background) and under gas atmosphere.

Figures 24 shows the preliminary engineering design for the sample environment pot that will be incorporated into the complete final detector tank. In the image Figure 24(top, left) the window between the sample and the rest of the detector tank is open thereby working under cryogenic vacuum. In Figure 24(top, left) the window is closed to enable experiments under gas atmosphere or to access the sample environment region during sample and sample environment changes. The sample environment region is sealed from the cryogenic vacuum of the detector tank using a gate valve sealed by inflatable gaskets, shown in Figures 24(bottom), which expands the red region in Figure 24(bottom,right) thereby sealing the sample environment pot.

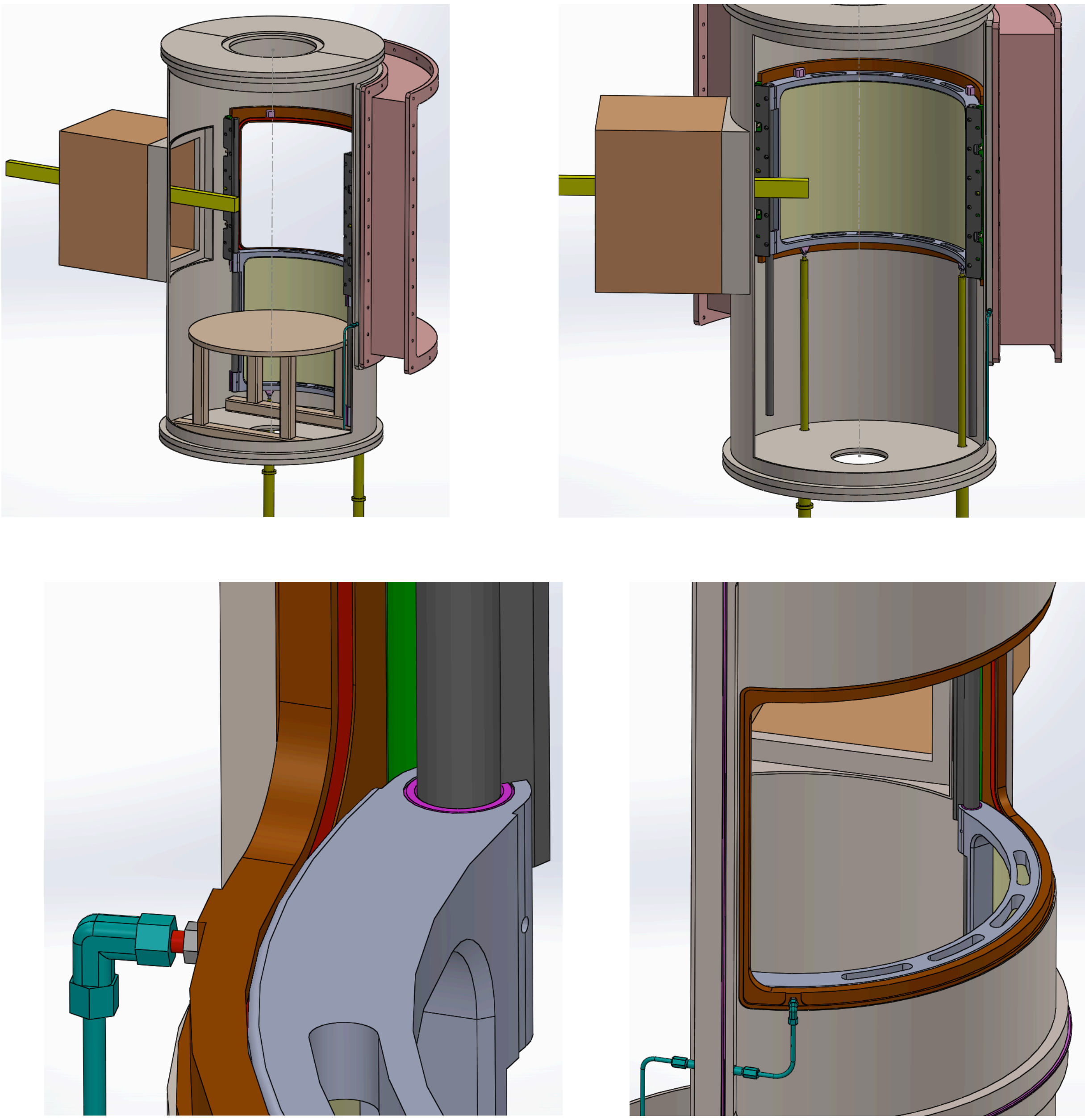


Figure 24: Sample environment pot showing (top, left) The window is open to the detector tank allowing a cryogenic environment at the sample environment. (top, right) The window is closed to enable gaseous

environments at the sample position or to change sample environments. (bottom, left) The window is made vacuum tight using a gate valve sealed by inflatable gaskets (red region in image).

A preliminary drawing shows the access available adjacent to the sample environment tank. It is possible to access the sample pot from sample height and from the top. .

Collimation (13.6.10.3.4)

A radial oscillating collimator is positioned behind the window of the sample environment pot with a collimator slit height that can extend up to 0.7 m, see Figure 22(right). We have been in discussion with Eurocollimators. Eurocollimators consider the collimator feasible with increased plate thickness of 45 mm using Cast 50mm 7022 T651 Aluminium (AlZnMgCu0.5), which is non-magnetic, with Tensile Strength 500/550 N/mm^2. The foil coating will be B_4C or Gd_2O_3, to be decided, and with an angular separation of approximately 2^o (defined by the dimensions of the collimator and the sample width), to be refined in phase 2.

Detector technology (13.6.10.3.2)

B10 Multigrid detectors (13.6.10.3.2.1)

The CSPEC team promised to make a decision on the detector technology that we would employ on CSPEC. As such we are fully committed to the development of the ^{10}B multigrid detector technology for CSPEC.

The recent results from the tests on the CNCS instrument with a ^{10}B multigrid detector technology are encouraging. The results are detailed in the document "CSPEC DETECTORS"

The requirements for the detector technology are:

- Efficiency: to use with spectrum from 1.5 to 20Å.
- Position resolution: 5 mm parallel to incoming neutron direction;
- Position resolution: 25 mm perpendicular to incoming neutron direction;
- Time resolution will be defined by the path length uncertainty.
- Electronic time uncertainty will not exceed 1 µs.
- γ-ray efficiency =< 1e-6.
- Solid angle coverage: polar angular range: -26.5 deg to +26.5 deg; azimuthal angular range: 5^o to +140^o.
- Gaps in the detector coverage are to be minimized as much as reasonably possible.
- Detector background: < 1e-5 n/voxel/s.
- Minimise secondary scattering effects.
- Vacuum level: evacuated flight path from sample to detector, 10^{-6} mbar.
- Count rate — peak count rate: 1e5 n/voxel/pulse (considering Bragg scattering from a cubic crystal.)

The relevant requirements for detectors are listed above and are based on the high-level system requirements. The completed instrument detectors will cover the vertical angular range from -26.5° to +26.5° and the horizontal angular range from +5° to +140° on day 1. Given the sample to detector distance of 3.5 m for the equatorial plane detectors, the detection area specified in the scope of the instrument is 29 m^2, with a full height of 3.5 m. In order to cover this area with Multi-Grid detectors, 80 modules will be needed, these can be grouped into detector vessels, containing a currently unspecified number of modules. The full height of 3.5 m can be covered using 140 grids in each Multi-Grid module, with no gaps in the vertical coverage. In the day-one configuration of the instrument, the full detector coverage is foreseen, however, only 50% of the electronics is included in the budget. The available electronics is to be configured so that the full horizontal angle is covered, while vertically, only -8 to +8 degrees are covered. The remaining readout units will be added at a later stage.

In order to achieve the expected scientific performance in terms of energy and **Q** resolution, the detectors shall provide 25 x 25 x 10 mm^3 (Width x Height x Depth) position resolution and the electronic time resolution shall not exceed 1 µs. The detector is comprised of modules of grids and anode wires, both grids and wires are readout in coincidence, thus defining the position of interaction to a voxel in 3 dimensions, whose area in the current proposed design is 25 x 25 mm^2 (and can be modified if needed) (this corresponds to the position resolution) and depth is 10 mm (meaning that the maximum neutron time of flight distance error is 5 mm). The readout will acquire data from each wire and grid channel independently, allowing a high rate acquisition. All events will be time-stamped with precision of at least 100ns, safely fulfilling the ToF requirements.

Around 16 detection cells, each equipped with two $^{10}B_4C$ layers, will be used in the depth dimension. This will require a single-side coated layer front-most in the detector, and 16 double-sided coated layers over the rest of the detector depth. The thickness of the $^{10}B_4C$ is chosen to maximize the detection efficiency for cold neutrons. In phase 2 the efficiency will be optimized to produce a good overall efficiency for cold neutrons while maintaining a reasonable thermal neutron efficiency, see Figure 25. The double-layer arrangement, where 6 blades have a coating thickness of 0.75 µm, 7 of 1.0 µm and 3 of 1.5 µm, fulfills this optimization for 4 Å. The exact details of the number of blades, and thus the depth of the module, which will optimise the neutron detection efficiency will be decided upon in

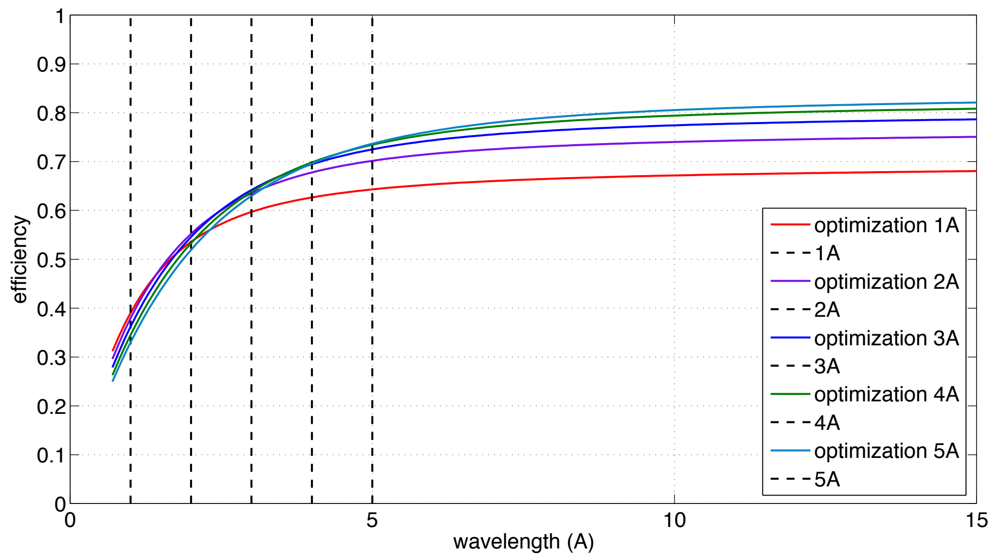


Figure 25: Multigrid detector efficiency optimised for a range of wavelengths.

phase 2.

γ-ray sensitivity has been measured in γ source tests and modelled using Monte Carlo methods, showing that a sensitivity below 1e-6 over the relevant range of γ energies can be achieved. This has further been demonstrated in time-of-flight measurements, ensuring the γ efficiency background is met.

The grids will be built using high purity Al, in order to minimize background rate. All other mechanical parts of the detector do not require pure Al and will not contribute to background. Recent measurements have shown a background rate (combining detector intrinsic background and ambient neutron background in a shielded environment) of 3e-5 counts/cm^2/s, thus meeting the detector background requirements.

The non-scattered incident beam will pass outside of the detector area, up to 2θ = +/-3^o and will not be detected in the Multi-Grid. The focusing of the beam combined with a final design of the beam stop and detector positioning shall address the minimum angle requirement.

There will be Cd shielding between grid modules as well as immediately after the last boron layer, in order to minimize detection of neutrons scattered in the detector materials. A radial collimator around the sample environment will further help suppress scattered neutron background.

The detector tank will be evacuated. The detector gas will be composed of only inert gases with no hydrogen content, Ar and CO_2. The gas pressure will be decided upon later but will be in the region of 200-500 mbar. The mixture will be flushed continuously at a rate of at most twice the detector volume per day. The gas pressure will be chosen to balance detector performance and the thickness of the detector window required. The detector and vacuum tank pressures will be controlled, so that (a) a constant pressure in the detector is maintained and (b) pressure differential on the window never exceeds the specification.

To determine the count rates we consider quasielastic scattering as the most appropriate scattering profile for CSPEC. On CSPEC the highest flux obtained is at 3 Å, ~ 4e10 n/s/Å onto the sample. A monochromatic pulse of approximately 100 µs extracted out of the 71 ms time period of the ESS, will provide a broad energy resolution at 3 Å, results in 5.63e+07 n/s on the sample for a single pulse.

A 10% isotropic scatterer will scatter 5.6e6n/s into the complete detector tank, 2.1 steradian, out of a complete 4pi steradian. The count rate on the CSPEC detector range is therefore 9.36e+05 n/s which results in a daily rate of 8.09e+10 n/day. A neutronic event requires 12 bytes of storage space and thus the daily requirement is 9.7e11 bytes which translates into 9.7027e11/(1024)^4 Tb = 0.8825Tb/day for a single incident pulse. However CSPEC will run in RRM mode with approximately 10 pulses per period and therefore the data rates will be approximately 8.8 Tb/day. This is typically an order of magnitude greater than data rates on current day chopper spectrometers.

The instantaneous count rate can be estimated considering a highly symmetric crystal that may scatter the incident neutrons into 10 Bragg peaks. Each Bragg peak will therefore contain 9.36e+04 n/s across approximately 50 cm^2 , considering +/1^o divergence. Each voxel, 2.5 cm^2, will receive 1.3e+04 n/s/voxel as an average rate.

However the peak flux on each voxel will be much greater. Even though CSPEC is an inelastic instrument, the detector must, nevertheless, be able to deal with these instantaneous rates and recover quickly from saturation.
Each voxel will receive a flux I (ns-1), which results in a flux of I/14 in 1 ESS period. In 1 pulse intensity the intensity is received across ~ 50 µs of the 71000 µs ESS period.
In these calculations the assumptions are made that the pulses in RRM can be separated in time. The peak intensity per voxel is therefore estimated to be (I/14)(71000/50) = (1.3e4*1/14)*71000/50 = 1e6 n/voxel. The current estimate for the saturation of the multigrid detectors is 1e5 n/voxel. However by considering the peak flux on only the first voxel in the multigrid detector, the multigrid detector depth is not taken into account. A multigrid detector will have a depth of approximately 10 voxels and this helps tremendously when saturation occurs. As such it is estimated that the peak intensity is closer to 1e5 n/voxel. The detector group considers that with these numbers a saturated voxel (1e5 n/voxel) will loose 10 % of the counting statistics in the peak. This is acceptable for CSPEC as long as the recovery time is limited to less than 4 µs. These estimates are preliminary and further information on the use of the multigrid detector will be gained in the next phase.

Each voxel will have an individual ASIC readout channel. The depth of the multi-grid detectors will help with saturation effects. Front-end electronics will be mounted in direct proximity to the detector modules reducing pick-up noise. The output from these will be digital and will be transported on compact cables to the standard data acquisition system, preventing further noise contributions. Data will be collected in an event format, where for each neutron, the time and position of the detection is stored. From this information, final energy and momentum and absolute time of detection of each scattered neutron is reconstructed. Further details on the latest results of the multigrid detector on CNCS can be found in the attached ArcXiv paper.

Detector housing (13.6.10.3.2.4.2)

Within the detector tank the ^{10}B MultiGrid detector will be housed in Al detector vessels with a 1-2 mm window thickness, facing the neutron beam. Some engineering simulations have been performed, using ANSYS 17.0, to acquire an understanding of the stresses that the window facing the neutron beam will be exposed to. The simulation assumes an Al vessel that houses 8 MultiGrid detector columns positioned radially around the sample position. Each MultiGrid detector column is 91.5 mm wide with 0.5 mm clearance on either side to place 1 mm Al stiffeners. The height of the detector vessels is sufficient to incorporate the complete MultiGrid detector and a further 20 cm to incorporate electronics. The vessel does not, currently, take into account further technical details. The depth of the vessel is 210 mm and the outer walls are assumed to be 5 mm thick. The simulations considered Al windows of 1 – 2 mm thickness, a range of stiffeners between the MultiGrid columns (from 1 between each column to 1 between every other column) and with a range of gas pressures in the box to mimic the stopping gas pressure for neutron detection (pressure differential between inside and outside of the housing = 100, 200 and 500 mbar). Table 5 shows the maximum stress experienced by the Al window as a function of number of stiffeners, window thickness and gas pressure. Stresses below 150 MPa are acceptable and lead to long longevity of the window. It can therefore be seen that stiffeners between each column with a 2 mm window can easily contain up to 500 mbar of gas. Figure 26 shows the stresses on the detector vessel and Figure 27 shows the relative deformations for 7 stiffeners, a 2 mm thick Al window and a gas pressure of 500 mbar. This pressure is acceptable and shows the feasibility of the design. The radial nature of the detector vessel will help strengthen the window with a 500 mbar pressure differential pushing inwards towards the detectors. In the case of a leak in the detector vessel the pressure differential will point in the opposing direction. Although not as yet calculated, it is estimated that a 500 mbar pressure differential in the opposite direction will also be within acceptable limits.

8-column radial	#	Stiffeners	Window	Pressure	Stress
	1	7	2mm	0.5bar	108MPa
	2	7	1mm	0.5bar	212MPa
	3	3	2mm	0.5bar	204MPa
	4	3	1mm	0.5bar	770MPa
	5	3	2mm	0.2bar	82MPa
	6	3	2mm	0.1bar	45MPa

Table 6: Variation of parameters affecting the maximum stress on the Aluminium window facing the neutron beam.

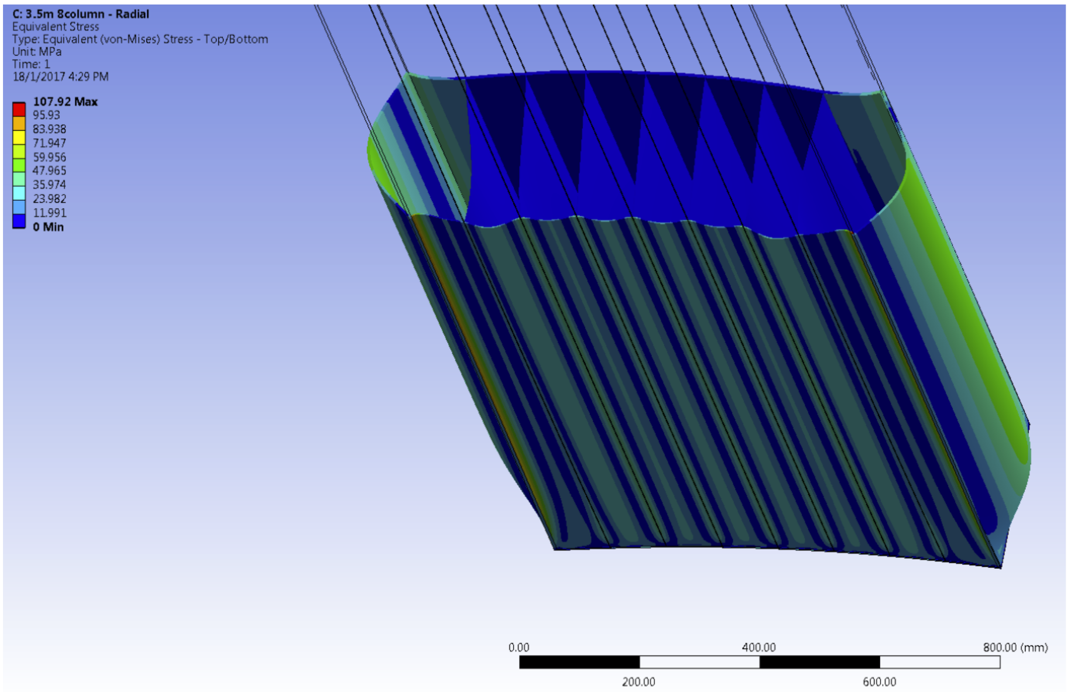


Figure 26: Stresses on the Al detector vessel. 2 mm Al window is at the front of the image. The stopping gas pressure is 500 mbar. There are stiffeners (in black) between each MultiGrid column)

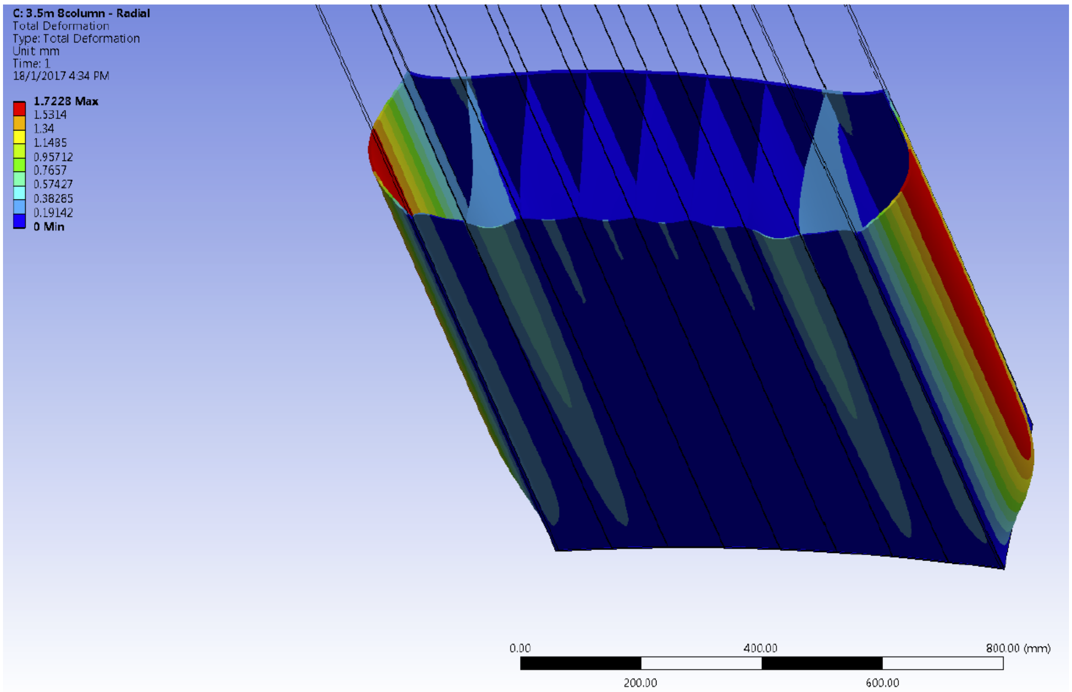


Figure 27: Maximum deformation of the Al detector vessel. 2 mm Al detector window is at the front of the image. The stopping gas pressure is 500 mbar. There are stiffeners (in black) between each MultiGrid column)

The exact width of each detector vessel will be defined in the next phase and will consider the requirements of collimation vanes between the vessels to limit secondary scattering events from one detector vessel to another.

Readout electronics

The proposed readout is easily and economically integrated into the overall ESS framework according to the ESS detector group. Half of the readout electronics are included in the first day scope of the instrument.

Support infrastructure and Utilities distribution (13.6.10.9 – 13.6.10.8)

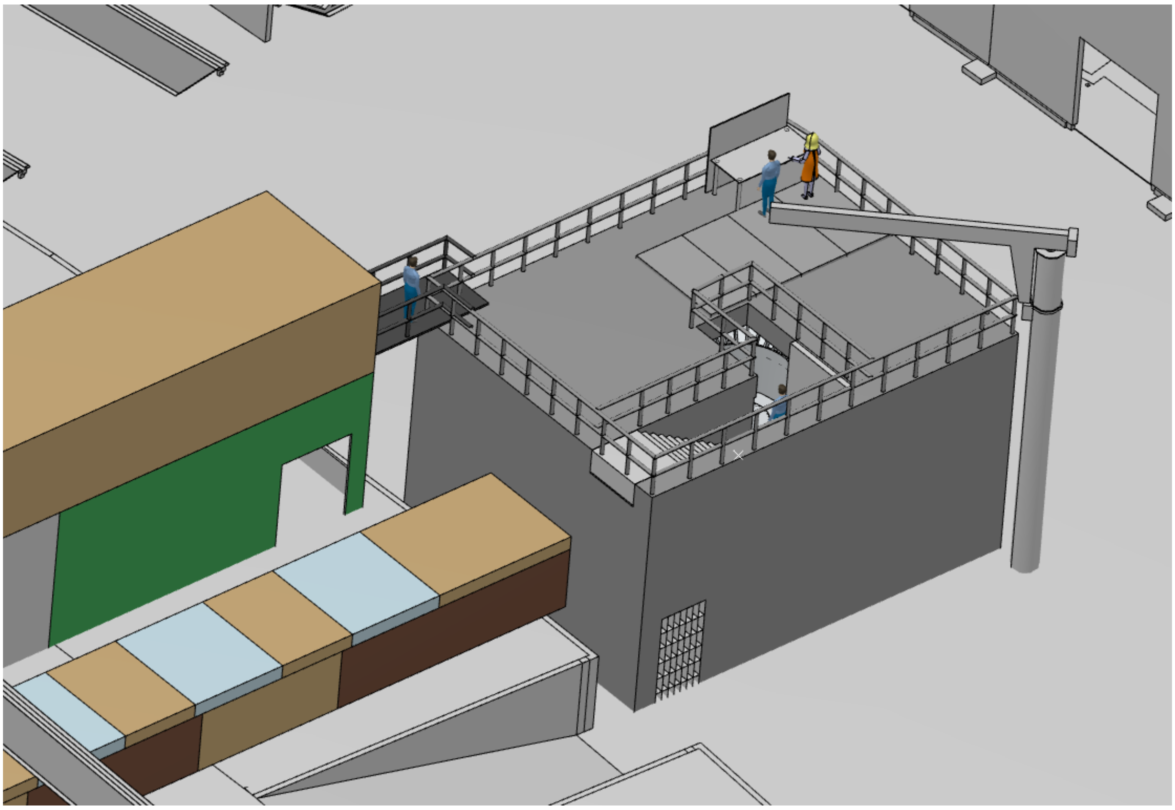


Figure 28: Engineering drawing of the region between E02 and E01 showing the experimental and technical cabin adjacent to the secondary spectrometer of CSPEC.

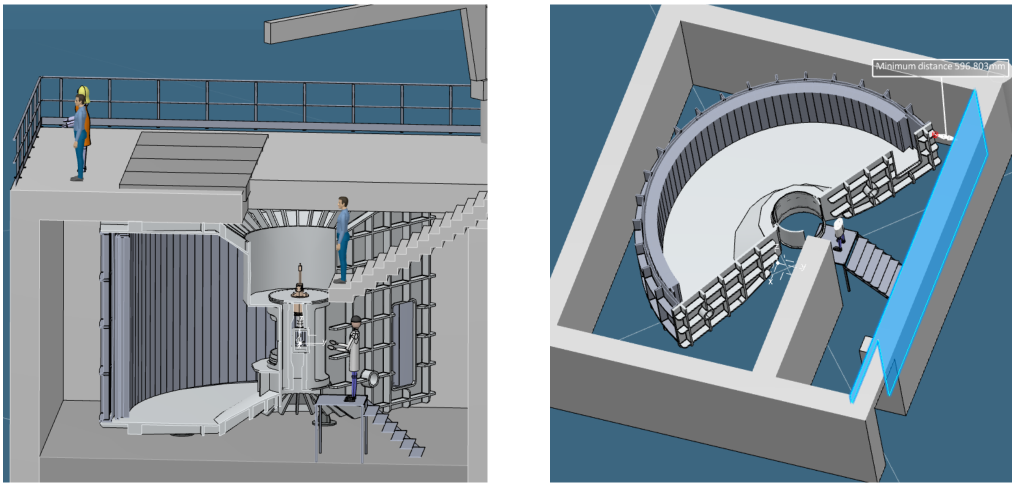


Figure 29: Engineering drawing of the region the CSPEC cave showing (left) the available space to work next to the sample (right) distance between detector tank and detector cave.

Figure 28 shows the control hutch (light brown) (13.6.10.6) and sample preparation area (dark green) (13.6.10.7), in addition to space around the sample environment area (orange) that will be used to change samples and equipment. In addition a sample environment laboratory with dedicated fume hoods can be found in E03.

It is imperative that the working conditions in the control hutch are conducive to sustained work over several days. Suitable working conditions, as stipulated in the Swedish Health, Safety and Welfare Regulations, include natural light, ventilation, low noise levels, sufficient space and workspaces for 6 people. (Handicapped access). The decision to place the experimental cabin in E02 allows us to extend the cabin to 52 m^2 without inconveniencing our neighbouring instruments. In addition, the E02 floor is higher than the E01 floor, which in addition to placing the experimental cabin on top of the technical cabin, ensures a well-lit environment, since the windows are at the top of the opposing wall in E01 which contains windows.

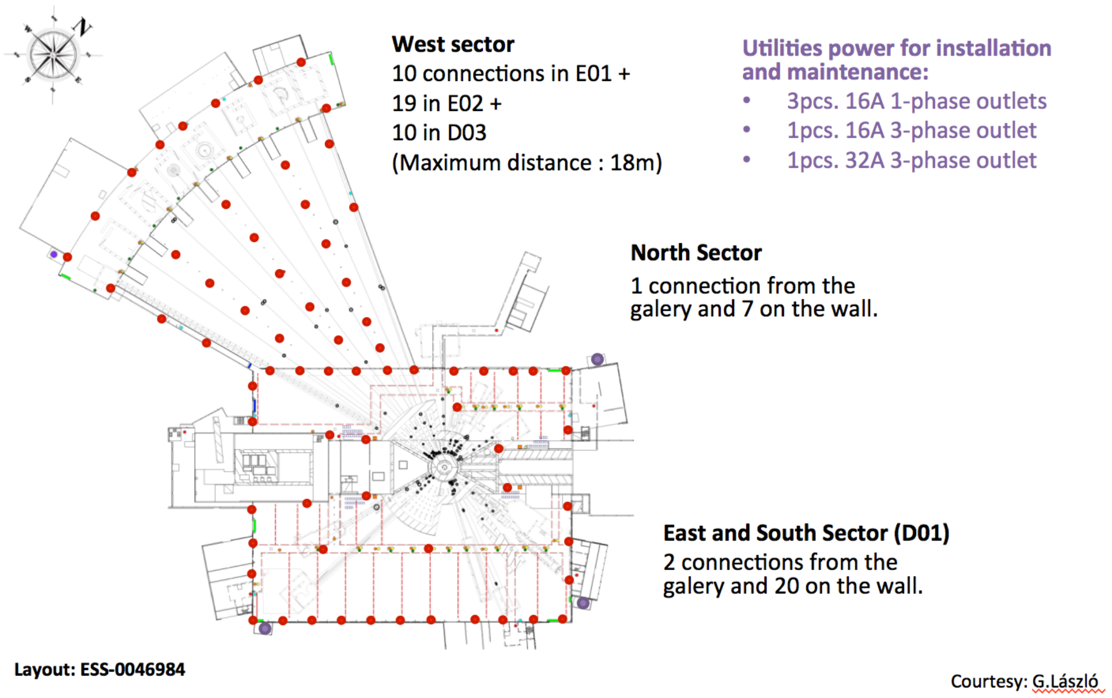


Figure 30: Power outlets across the ESS, G. Laszlo.

Utilities and media are brought to the instrument via utility connection points situated close to the instrument, Figure 30.The CSPEC team request that (a) electrical grounding is carefully considered and (b) that electromagnetic interference is minimised in particular close to the chopper positions.

The ESS will provide, via gas lines:

Nitrogen gas (10bar)
Deionized water (8 Bar)
Compressed air (6Bar)
Detector stopping gas (500 mbar)

The following gasses will be provided by ESS in cylinders:

Argon gas (Cylinder)
Helium gas(Cylinder)
Liquid Helium (Dewar)

A Liquefier and recovery point is provided at a collection point in the gallery.

Liquids provides are:
Liquid nitrogen (1 filling point / sector, sector = West)
Cooling water: 7Bar, 8°C with a Cooling capacity / average instrument: 27kW

Fume hoods (one for each instrument) and exhaust pipes for sample environments.

The instrument power distribution will be provided via CF Power outlets with 1 for each instrument. The design of the CF power outlets will be provided by ESS, the installation and material cost will be paid by the instruments. Further discussions to finalise the design must be had between the CSPC team and ESS since the design will be finalized according to the instrument designs. However there will be no central UPS system with the power distribution network will be planned according to our grounding rules. There will be power connection points similarly placed as the sample environment connections .

Cranes

A crane covers D03 with a capacity of 30 tonne and a hook height of 12 m from the floor. This is sufficient for our needs in D03. There will be mobile gantry cranes in E02 with a 10 tonne capacity. The size of the shielding blocks will be optimised to minimise removal time in the case that to the primary spectrometer is required. This results in up to 2 m long shielding blocks and can be manipulated in E02. However it is unclear whether the crane solution close to the E02/E01 region is currently suitable or whether the shielding blocks have to be optimised in this region. A 10 tonne crane is foreseen in E01 with a 10 m hook height from the floor.

A local crane, capacity 1500 Kg, will be positioned close to the sample environment to enable the manipulation of sample environment equipment.

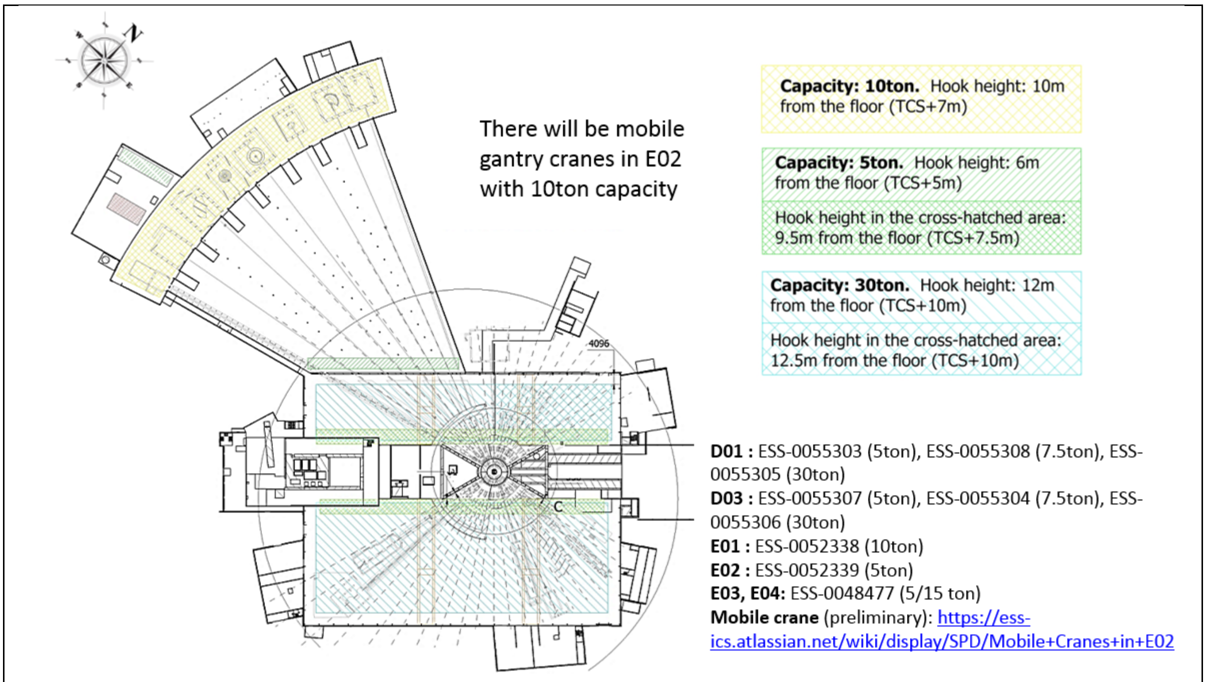


Figure 31: Crane coverage across ESS.

Sample environments (13.6.10.2.2)

The scope setting meeting allocated first day sample environment that is sufficient to run a high level experimental program as outlined in the scientific requirements of CSPEC, See "Concept of Operations". The first day sample environment includes

- Cryofurnace (3-600 K, $\Delta T = 0.1$ K) (CSPEC - in scope),
- multiple sample changer (up to 8 samples), possible collaboration between ESS and TUM (CSPEC – in scope),
- sample rotation stage and goniometer (CSPEC – in scope),
- Dilution insert (in-scope)
- Access to a 12 T magnet (ESS Pool – not in scope).
- In-situ capabilities (in-kind – not in scope).

The sample environment pot, diameter = 1000 mm, will provide suitable space and access to enable the full use of the equipment and drive development towards novel sample environments.

Motion Control and Automation

The motion control requirements on CSPEC are not extensive once the choppers are excluded. However, a particular requirement is that the slit system, the focussing nose exchanger and oscillating collimator must be compatible with a low magnetic environment.

Table 7: Table of motion requirements for CSPEC.

Axis Number	Device Description	WBS Element	Motion Type	Range (mm or °)	Accuracy (mm or °)
1	Sample Rotation	Sample Rotation	Rotary	360°	0.01°
2	Slit system	Slit system	Linear	50	0.05
3		Slit system	Linear	50	0.05
4		Slit system	Linear	50	0.05
5		Slit system	Linear	50	0.05
6	Oscillating Collimator	Oscillating Collimator	Rotary	10	0.1
7	Focussing Nose (Nose changer)	Focussing Nose (Nose changer)	Linear	100	0.05
8	Instrument shutter	Instrument shutter	Linear	ESS	ESS
9	Sample window	Sample window	Linear	600	0.1

4. PRELIMINARY SAFETY ANALYSIS FOR THE INSTRUMENT

The main safety hazard at the CSPEC for personnel or a user is ionizing radiation. The shielding design will protect the personnel outside the instrument from radiation hazards.

In the case of a sample change there must be access to the experimental cave close to the sample environment region. The radiation levels on the sample area must be low enough to eliminate any dangers due to radiation exposure, < 3 µSv/Hr. Equally, in the case of maintenance from the bunker onwards, the radiation levels must be low enough to permit interventions.

The required safety levels will be achieved using the light shutter and the secondary shutter shortly after the bunker. The light shutter immediately outside the target monolith stops radiation emanating from the target with the proton beam is not on the target. The instrument shutter, in conjunction with the out of line of sight nature of the instrument, will stop high-level radiation levels along the beamline.

The instrument shutter is connected to the Personnel Safety System (PSS) that interlocks the high radiation areas (such as the experimental cave) when the instrument shutter is open.

Upon opening the instrument shutter a search procedure will be implemented to ensure that no one is situated in a hazardous zone.

Additional safety systems will concern fire detection and automatic fire extinguishers and oxygen deprivation sensors.

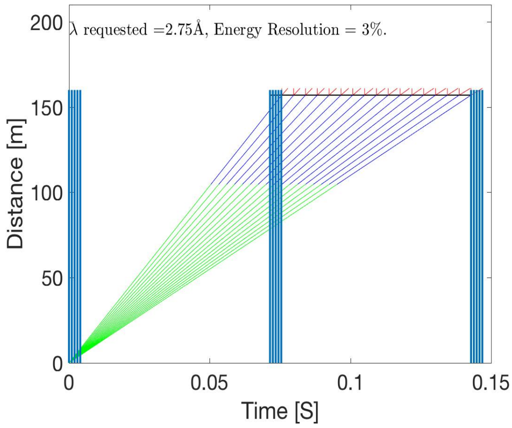
Warning signs indicating hazardous materials and high magnetic fields will be positioned around the instrument when required.

The instrument personnel will indicate the safety features and hazards of the instrument to every user.

Handling of activated samples:

Prior to the experiment the samples will be loaded into a solid sample container with an airtight lid using the ESS user lab and a designated fume hood (HEPA filter). After the experiment the samples radiation levels will be checked with radiation monitors. If the radiations levels are too high the Radiation Safety Group will be contacted and they will place the sample in the ESS storage area. If the sample radiation level is less than 100 µSv/hr the user will place the sample in a storage area on the instrument. Upon leaving, the sample will be radiation checked once more before taking it to Radiation Safety and checked at that level.

5. EXPECTED SCIENTIFIC PERFORMANCE OF THE INSTRUMENT.



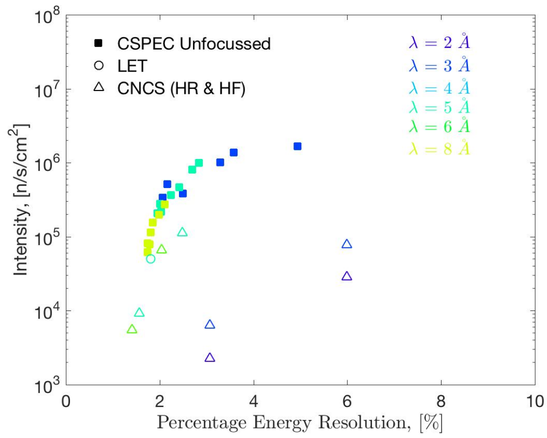


Figure 28: (left) Time-Distance diagram of CSPEC with a range of incident wavelengths within the ESS time period. (right) Unfocussed flux of a single incident wavelength on sample as a function of energy resolution and incident wavelengths, ESS Power = 5 MW and with complete detector coverage. Comparisons with CNCS and LET are made. Additional gains will be made through the cumulative use of RRM.

Figure 28(left) shows an example of the the range of incident wavelengths on the sample within the ESS time period on CSPEC. The flux of each incident wavelength on sample as a function of energy resolution, at the detector, for a range of wavelengths is shown in Figure 28(right). . These simulations are derived from McStas 2.3 simulations with ESS 5 MW power, scattering from an incoherent sample (0.01 m radius) at the sample positioned and probed at the detector position. In this figure comparisons with current high profile cold chopper spectrometers are made and this shows that an order of magnitude in flux will be gained for the complete and finalised instrument. In the day 1 scope of the instrument only 50 % of the detector coverage will be readable and it is expected that ESS will run at 2 MW thereby providing a 2-3 fold improvement, as opposed to an order of magnitude, for each incident wavelength. These improvements are valid for the case of inelastic scattering experiments.

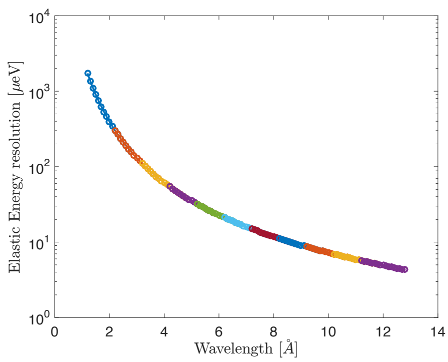


Figure 29: Range of energy resolution across the various bandwidths (different colours) on CSPEC.

In the case of quasielastic measurements it will be possible, in certain cases, to sum the incident pulses across the ESS time period. Figure 29 shows the energy resolutions across the bandwidth as the CSPEC chopper are phased to wavelengths ranging from 2 to 13 Å. The science case for CSPEC is focussed on in-situ kinetic measurements. In these experiments the dependence on momentum transfer, Q, is often neglected, to date, in favour of intensity of the energy transfer by integrating the complete detector area in Q. Information obtained from the Q-dependence is vital to understand the spatial behaviour of the relevant dynamics and is not available for many measurements on current chopper spectrometers. For wavelengths > 7 Å the energy resolution across several of the incident pulses will be comparable to the variation in Q resolution across the detector range. On CSPEC it will be possible to integrate some of the incident pulses across the CSPEC bandwidth, presented in Figure 28(left), and therefore provide a substantial increase in flux.

6. GLOSSARY

Term	Definition
BW	Bandwidth Chopper
RRM	Repetition Rate Multiplication
ConOps	Concepts of Operations
FOC	Frame Overlap Chopper
IRR	Installation Readiness Review
ORR	Operational Readiness Review
PDR	Preliminary Design Review
PSS	Personnel Safety System
SAR	Safety System Acceptance Review
TG	Toll gate

7. REFERENCES

[1] Process for Neutron Instrument Design and Construction: ESS-0051706
[2] Concepts of Operations for the ESS system: ESS-0003640
[3] Concepts of Operations for the NSS system: ESS-0005817
[4] Boffy. PhD. Thesis, ILL 2016.
[5] Hayter Z Physik B 31, 117 (1978).
[6] AMATERAS, personal discussions.

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	Pascale Deen	2017-01-01

Revision	Reason for and description of change	Author	Date
2	Second issue	Pascale Deen	2017-06-19