Background

A review of the ESS detector status, development plans and strategies was convened by Victoria García Sakai (ESS SAC Vice-Chair and lead here) and Michael Preuss (ESS SAC Chair), in response to the concerns raised at SAC-28 (and over the last years) on detector readiness, expected performance and plans for risk mitigation, necessary for the delivery of successful instruments to the user community. Information provided to the SAC had highlighted that neutron detection systems (detectors and monitors) for the ESS instruments continue to be a technical challenge. Of particular concern are the performance of the multi-grid detector technology for spectroscopy and the Jalousie detectors for diffraction instruments. In addition, the detector group is undergoing significant changes. As a result, communication of progress has suffered in a number of ways. The review is meant to provide more clarity on the status and the technical issues, and thus help the ESS to address and manage them well as the project approaches BOT and FS. It is also expected that this exercise will help ESS to inform better SAC and Council on these challenges going forward.

Review Panel Members

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Charge

1) Are the chosen detector systems at an appropriate level of maturity to enable meeting the requirements agreed by the ESS re-baselining exercise? Please provide comments and feedback.

2) Are the risks associated with neutron detectors and related correctly captured, and have appropriate mitigation plans and alternatives been considered? Please provide comments and feedback.

3) Are there any suggestions on additional courses of action that NSS should take in order to minimize the risks to scientific performance while taking into account the project schedule?

Feedback

We first would like to thank all the instrument teams at the ESS and the ESS management for providing the review panel with a very comprehensive set of documentation and for the very positive engagement with the review. Feedback was obtained by email from the reviewers, collated by the conveners and then discussed with the ESS management over a 2hr Zoom meeting on Friday 8th July 2022.

The first observation is around the complexity of the detector technology (and monitor) provision for the ESS project, including many new and previously unused technologies. This translates into the need for a wide range of expertise, a tremendous amount of development work, extensive system testing at all points of the pipeline, and an appropriate level of resourcing, management of work and risks.

The second observation was that the ESS management have a good understanding of the status of affairs, the challenges they face, both technical and in terms of resource, and that there is a sense of urgency around some of the matters discussed.

We now provide some comments on the charge questions and close with some recommendations for moving forward. Given the critical nature of some of the points discussed in what follows, we urge the ESS to take account of the recommendations given in this review and act as fast as possible. Finally, in an appendix we include a few extracts from the reviewers comments that we think will be valuable to the ESS as it takes the recommendations forward.

Question 1: Level of Maturity

The answer to this depends very much on the instrument and/or detector technology. The detectors chosen for the first 8 instruments already encompass most of the breadth of technologies to be deployed, and all are at different levels of development, testing and thus readiness. Below are a few comments on each instrument and the level of maturity labelled with a traffic light system (green, amber, red).

Green Category

LOKI is well tested with full acceptance tests successfully performed on LARMOR at ISIS, which included the full data acquisition pipeline, and should be commended. It will serve as a good process for other instruments to follow. **Bifrost** uses 3He detectors and is therefore also a low risk instrument. Similar technologies will be used for **Miracles** and **Vespa**, which are further ahead in the schedule than **Bifrost**. **Odin** will require a variety of imagining systems most of which are low risk with limited R&D work remaining for the ToF detector. However, the team have a good plan and good risk awareness identified for electronics and integration.

Amber Category

The instruments in the amber category show adequate progress, however, in some cases we still missed detailed evaluation with regards to performance. Issues may be encountered as the instruments proceed but sensible plans have been presented. **Dream** will use Jalousie detectors, which were successfully tested some time ago on Powgen at the SNS and on V20 at HZB. Encouraging diffraction patterns were obtained which provides some confidence. However, performance parameters, key to Dream's science case (such as detector efficiency, peak shape, signal-to-noise, cross-talk from the data), are still missing - a direct comparison with the data from the Powgen detectors would have been useful. In addition, no information on detector stability and long-term performance under realistic conditions were presented. Thus, it is plausible that issues will be encountered during commissioning and that the instrument requirements will not met with this set of detectors. It was surprising thus, to see that the team does not foresee any risks and that there is no back-up plan, also in view that the detectors have already been purchased and partially built for both Dream and Magic. Installation of the detectors on DREAM is planned for October 2022 and source testing planned straight away. This will inform on performance hopefully early in the schedule. Since **Magic** and **Heimdal** follow by a few months, they will benefit for the Dream acquired knowledge. Finally there was some concern around plans for knowledge transfer between CDT and the instrument team/ESS.

Initial tests on the **Beer** detector prototype indicate that the specification should be met, and the backup solution, although more onerous, is in principle feasible. However, it requires some more careful consideration of costs and schedule. The upcoming test at PSI should indicate whether to go ahead or not. **Skadi** will use Li-gas based scintillators developed through the SoNDe EU project. Several tests have been performed which indicate the system meets the instrument specifications. However, risks remain around integration. The development of the Gd detector for **NMX** is progressing well, however, it is not clear whether the performance is optimal. Although the resolution appears to be adequate, questions were raised around its low efficiency and sensitivity to gammas. Tests have been hampered by lack of front-end electronics and so further testing is necessary.

Estia and **FREIA** will use boron based multiblade detectors, as ^{3}He does not seem to be a viable option to match the instrument requirements. Good progress has been made in terms of the hardware and programme development, with testing at AMOR in PSI. However, full testing has been affected by the issues with the VMM electronics and supply chain. Plans moving forward appear appropriate.

Red Category

The biggest concerns for the review panel concerns 1) the **multi-grid detectors for CSPEC (and Trex)**, 2) the **monitors** and 3) the **VMM electronics**. These three areas are at a CRITICAL point and require URGENT attention given the status of the developments and the timescales associated with a successful delivery.

The development of the **multi-grid detectors for CSPEC** (and **TREX**) has been ongoing for many years, initiated as a necessary alternative to ^{3}He technology at a time of gas shortages. Multiple tests (e.g. SNS 2016) indicated that it is a promising technology albeit having some issues to be addressed around performance, such as sub-optimal signal:noise, peak asymmetry and some spurious features. Sufficient time was available to solve these issues, however, the shocking reports from the latest test on LET at ISIS (May 2022) reveals that these detectors are no longer a viable option for a day 1 instrument. A general degradation of performance with efficiency at 10% (a factor of 6 below specification), very low signal:noise, plus the lack of trustable data from the test and the issues encountered in preparation and during the test (vacuum, read-out electronics, grounding), indicate that the ESS in-house system is not ready for deployment at this time. Hence, a clear understanding of the LET results, a detailed and accurate proof of a performing prototype with final geometry including the full pipeline (electronics), and the expertise within the team around this technology need to be acquired first before construction can be considered. CSPEC and the ESS should, with urgency, ascertain if equipping CSPEC with ^{3}He detectors is a viable option, if they want it as a day 1 neutron spectrometer in their suite. ^{3}He is a well-tested technology with plenty of expertise within the neutron community, saturation risks are not envisioned as a major issue at the initial ESS power, and electronics integration will be relatively simple through collaboration with ISIS and ILL for example. Notwithstanding, work should continue on the development of the multigrids, as they will be necessary to meet the requirements of TREX.

A second area of real concern is the **monitors**. The common beam monitor project was a good initiative from the ESS to capture all instrument requirements, manage the range of technologies to ease operability and eventually maintenance. However, the choice and numbers of monitors per beamline appears as an after-thought in many instances, albeit beam characterisation at multiple points along the beamline and proper normalisation of the data, being crucial across all techniques. The report represents a comprehensive review of options and requirements and appears like 'work in progress' with no clear plan for taking things forward. This is particularly concerning since monitors will be essential in the early stages of commissioning. Decisions on appropriate monitor choices, presentation of a timeline for testing performance pre-deployment and for deployment, of a plan for integration and operability, of a strategy and engagement plan with the instrument teams, clear milestones, are missing completely. There appears to be no sense of urgency in this area. Finally, we note that not all instruments have signed up. With a number of them interested but not fully committed, we wonder why and what the implications of this is as we approach operations.

The final area is around the status of the **VMM electronics** which impact several instruments, a number in the first suite of 8. The review report (March 2022) provides a very comprehensive evaluation of the situation, pointing to several issues that could incur severe delay to instruments. It provided very detailed technical advice, suggestions for improvements and solutions, a sensible path forward, and we urge the ESS to take the advice very seriously.

Question 2: Risks

Like with the first question, answering question 2 very much depends on the instrument. Only Bifrost, Miracles and Vespa, are mostly risk-free from the point of view of the areas covered in this review. All other instruments have risks associated to performance and/or electronics, integration, delivery schedule. We were happy to see that the ESS management is aware of these risks on a per instrument basis. However, this awareness was not always in line with the risk assessment presented in the individual team reports. Only a few instruments have properly identified risks and considered mitigation plans appropriately. This raises some concern.

A common risk, that lies beneath many of the aforementioned issues, is the level of resourcing, expertise and morale within the detector group. The review has highlighted that there is an immense amount of work still pending to achieve a successful start of user operations, with complex technical and varied issues to resolve, which need an appropriate level of staffing with a broad range of skills and knowledge, and with varying levels of expertise. At the moment, it appears that the group lacks the rigor, quality assurance, testing protocols and criteria, knowledge and leadership that is required. Furthermore, in light of all these issues (large workload, understaffing, reprioritisation of work, possibility of underperforming instruments or even delays), people's morale needs careful monitoring – which brings additional risk.

Question 3: Additional suggested actions/Recommendations

Considering the responses to the previous two charge questions, we present here our recommendations which in our view are a matter of urgency:

1. Start the necessary procedures for the possibility of equipping CSPEC with ^{3}He detectors. Albeit multi-grids being advantageous in the long-term and indeed necessary for TREX, at present it seems very unlikely that they will be ready to meet the instrument requirements in time for commissioning. We recommend pursuing ^{3}He as the day 1 technology for CSPEC. We recommend ascertaining with utmost urgency whether supply, cost and schedule are appropriate to make this a viable alternative. In parallel and until this information is at hand, the multigrid detector development should continue, with the aim to deliver a module that can be installed and tested in parallel for final validation. To enable this, we recommend that the detector vessel design allows to accommodate both technologies. Note that if ^{3}He costs are too high to limit the angular coverage, we recommend optimising for science output.
2. Address the issues surrounding the detector group. We recommend that ESS recruits the necessary staff to address the immediate problems: a new group leader, a senior electronics engineer, some junior people to send to ISIS or ILL to learn, appropriate staff members to fill the competence gaps and do the most important tasks. It will be important to build a culture within the group that aligns to the mission and values of the ESS and the project and that works collaboratively towards its goals. The ESS will need to instil a sense of urgency but manage this carefully.
3. Review the realistic full list of tasks (in detail) at hand, prioritise in line with the new ESS delivery schedule and assign appropriate resource. One instrument report mentioned "Neutron test campaigns need huge human resources, time and significant budget"; We recommend that ESS reviews carefully the tasks list and doesn't dismiss delaying instruments if necessary. It is better to come online with fewer instruments that operate as competitive,

world-leading, scientifically successful instruments, even at the initial loss of the promised scientific breadth. (e.g. for CSPEC if budgets dictate a reduced detector coverage, consider matching to one subset of the science case, but ensure science will be impactful).

4. Evaluate ALL technical suggestions by the reviewers, prioritise and action with a concrete plan (e.g. VMM review report). As reviewers, we are here to provide an outside, unbiased view, to input with our knowledge and past experience, advice and ultimately help the ESS achieve success. Thus, we encourage the ESS to work openly with the reviewers, ask questions, collaborate. We are here as critical friends. We also ask and recommend that the ESS provides the SAC regular updates on progress (3 or 6 month to be decided).
5. Develop a detailed testing and commissioning plan, with clearly defined criteria, for detectors and monitors. Define clear timescales and milestones that can be monitored and adhered to.
6. Develop a strategy for operations. The end goal is not just the working detector or monitor, but a reliable, stable and maintainable one. We recommended testing the reliability and long-term stability and having a plan for steady state operations.
7. Produce a properly populated risk register (with mitigations) for all instruments, in terms of detectors and monitors. This should be a joint effort between the instrument teams and the ESS. We recommend that in all cases, there should be a plan B. In the words of one reviewer “You cannot make good business decisions if you don’t have alternatives to pick from.”
8. Specific to diffraction instrument detectors. Since the installation of the Dream detectors is planned for October 2022, we recommended starting source testing straight especially given the identified risks on detector performance.

Appendix- Extract from Review report from Bruno Gérard (ILL)

Simplified description of the MultiGrid detector

For convenience of the discussion, let's consider that there are two types of planes in a column of grids:

- a detection plane is composed of blades parallel to the entrance window, and located at the same distance from the entrance window
- a radial plane is composed of radial blades corresponding to the same detection angle

Both planes contribute to the detection efficiency and to the background. The thickness of the B^4C films in the detection planes is optimized for maximum efficiency (typically 1 µm for 30 films). The neutron absorber on the radial planes does not need to be high quality B^4C; actually, it is preferable to use an other material in order to better absorb scattered neutrons and to reduce the production cost. From the JINST article published in January 2019 (« suppression of intrinsic neutron background in the MultiGrid detector, E.Dian et al), different strategies of background reduction based on a GEANT4 simulation are presented, in particular side shielding, end-shielding, and inter-stack shielding.

Background reduction based on neutron absorption in the radial blades

One way to improve the actual ESS MultiGrid design would be to increase the shielding of the radial planes, which is too low in the current MG design (1 or 2 µm thick B^4C film).

During the CRISP and BrightnESS projects, ESS and ILL proposed to use 4 µm B^4C films coated on the radial blades, but this solution seems to be abandoned, maybe due to its cost, or because it is too challenging technically. Although the B^4C film thickness on the radial planes is an important parameter to reduce the background, it has not been studied in the simulation program, probably because other Boron coating techniques apart from DC magnetron sputtering were not considered.

Today I would propose another technique, much cheaper than DC magnetron sputtering, based on BNP (Boron Nano Particle) films like those the ILL developed in collaboration with NCBJ in Poland, or Tsinghua University in China. A thick (typically 10 µm) BNC coating on each side of the radial blades, will contribute in a much better way than 2 or 4 µm B^4C films to absorb scattered neutrons, as well as to increase the detection efficiency of non-scattered neutrons. Using this technique would allow to use blades made of standard Aluminium coated with 20-30 µm of Nickel on each side to absorb alpha radiations emitted by U and Th impurities contained in the Aluminium.

Background reduction based on the grid geometry

Let us distinguish the following cases for a neutron interacting in the grids. We consider now that the radial planes are black for neutrons (fully absorbing). We have seen that there is a simple solution to do it.

1/ captured in a detection plane —> **good event**

2/ captured in a radial plane (at grazing angle) —> **good event**

3/ scattered in a detection plane followed by ….

3.1/ captured in a radial plane —> **high probability of 0 event (depends on the angle between the radial plane and the neutron trajectory)**

3.2/ captured in another detection plane —> **bad event (background)**

A/ One way to reduce the impact of background events described in 3.2 on the tof spectrum is to reduce the path of the scattered events by reducing the distance between the **detection planes**. As we said, the thickness of the B^4C films has been optimized for maximum efficiency; another approach could be to optimize the B^4C film thickness for maximum SBR; by increasing the B^4C film thickness, the SBR would be increased at the cost of a slightly reduced detection efficiency. The detector would also contain less detection planes; hence it would be more compact and simpler to produce.

B/ On the other hand, reducing the distance between the **radial planes** would contribute to reduce the background by increasing the fraction of scattered neutrons absorbed in the radial blades.

Both A/ and B/ conditions can be fulfilled by reducing the section of the tubes. This was the approach followed by the ILL in the Brightness project; the tube section was reduced by a factor more than 2, from 10 mm x 20 to 6 mm x 15 mm. A similar factor of reduction of this source of Background can be expected. This solution was not considered at ESS, probably because of its higher mechanical complexity, but I think that it is acceptable thanks to the tolerant design the MG provides.

<u>Background reduction based on the thickness of the blades</u>

To reduce the thickness of the Aluminium blades from 0.5 mm down to 0.2 mm would be an efficient way to decrease neutron scattering, but it imposes a change in the fabrication process of the grids; during the B^4C coating, the blades undergo a temperature close to 400°C which results in mechanical distortions; for this reason, they should be machined after the coating to preserve mechanical precision. This solution would probably require some development.

<u>Background reduction based on a reduction of the pressure vessel material</u>

GEANT4 simulation described in the above mentioned article also showed that a 4 mm thick entrance window reduces the SBR by 10% at 4Å, and between 20% and 30% at other wavelengths. Although this simulation indicates that a reduction of the window thickness would not be decisive for the main wavelength (around 4 Å), it is always good to minimize it if the price to pay for it is acceptable.

During the BrightnESS project, the ILL proposed a solution to drastically reduce the neutron scattering induced by the detector vessel, as well as its complexity and cost. With this solution the pressure inside the detector and inside the vacuum chamber would be the same, around 50 mbar for example. The detection gas could be a mixture of Argon and CO_2, or CF_4 (if it turns out that Ar get too much activated, then we could use CF_4). We can anticipate that the scattering probability in the gas contained in the TOF chamber will be much less than in the 4 mm thick Aluminium detector window, but the exact benefit must be quantified by simulation or measurement. The gas would be circulated in a closed loop system at constant pressure, and cleaned to remove moisture. Tests have shown that the detector operation with 50 mbar gas pressure is more stable and less sensitive to gamma than at 1 bar. Using a low gas pressure inside the MG allows to reduce its gamma sensitivity by two means: the gamma interaction rate is reduced, and the difference of energy deposited in the gas for gamma and neutron events is increased. Another advantage is a reduced dead time, hence a higher counting rate capability. We also developed during the BrightnESS project a gas circulation system to operate the detector at 50 mbar, with the TOF chamber at 0 bar, hence the 2 options are possible, either 50 mbar, or 0 bar, in the TOF chamber. One advantage of using this 50 mbar pressure in both the detector and the TOF chamber is that the dead zones between the columns could be significantly reduced with a simplified design of the vessels; actually the pressure vessels would be used only for flushing clean gas through the grids.

<u>Benefit of the COG localisation</u>

Finally, we demonstrated that the spatial resolution could be significantly improved in the vertical direction by using a COG algorithm. This could be exploited to reduce the number of readout channels instead of increasing the spatial resolution.

Conclusion

The CSPEC detector design had to be frozen to start the production phase. Several solutions to optimize the detector performance could not be considered. The MG design proposed for CSPEC is based on the original design developed 10 years ago with some improvements like the end-shielding and, in some extent, the radial-shielding; it would strongly benefit from a more efficient radial-shielding, and from a smaller section of the tubes. This could be done without making the production of the detectors more complex. The low pressure option would be valuable for further improving the background, and for increasing the counting rate capability. The COG signal processing would be a simple way to reduce (by up to 30%) the number of blades, and it doesn't represent a technical risk either.

A detailed description of the manpower resources, equipment, and methods currently devoted to the production of the CSPEC detector, together with a risk analysis, would be needed in order to evaluate the risk of missing the production objectives. Depending on the current status of the MG production, it will be possible to know if, or how, the design modifications proposed here could be integrated.

Recommendations for CSPEC

- Progress rapidly in the negotiations with ^{3}He suppliers to better know the cost and availability of this gas. Purchase one bottle of 100 liter.bar to test.
- Ask Reuter Stokes to confirm that they have a secured source of ^{3}He.
- Provided the supply of 3He is secured (either from Air Liquide, or from Reuter Stokes); the priority for CSPEC should be given to ^{3}He PSDs, either commercial (Reuter Stokes) or ILL. One advantage of the ILL MultiTube is that the ^{3}He pressure can be changed without difficulties. CSPEC could be equipped with all the modules mounted on the instrument, and then filled at an intermediate ^{3}He pressure (for example between 1 and 3 bars). This intermediate gas pressure would allow to reduce the risk of a detector saturation, and to minimize the budget risk. A potential advantage of the Reuter Stokes solution, if they can provide ^{3}He, is that the cost of the ^{3}He might be lower compared to Air Liquide (or other suppliers if there are any).
- Invest in transfers of technology to complete existing equipments and methods at ESS. For example, a ^{3}He gas handling systems will be very useful in the future for the maintenance of different types of ^{3}He detectors.
- Ensure compatibility of the CSPEC tof chamber with the different detector options (this is going on) for a possible future detector upgrade
- Continue the development of the MG detector, as it will secure other ESS instruments (e.g. TREX) but produce a demonstrator MG_CSPEC optimized for minimum background. A possible MG_SCPEC demonstrator could have tube section reduced by a factor of 2, thick Nickel film + thick BNP films on radial blades, and a new pressure vessel design optimized for low gas pressure operation.
- Simulate CSPEC scientific measurements with 50 mbar of detection gas inside the TOF chamber and decide whether this option is acceptable or not.
- Use the CSPEC instrument with the MG_CSPEC demonstrator continuously in place
- Based on the experience from IN5 and PANTHER, it is worth considering Cd sheets between the PSDs (not used in the actual CSPEC design based on the ^{3}He Reuter Stoke version, which only has large Cd sheets between 32-tube PSDs modules).