The case for a chip irradiation beamline at ESS

Presented by Giuseppe Gorini for CNR, Italy
27/1/2014

Introduction

The interest of CNR for the application of the large fluxes of fast neutrons expected from ESS was first formulated in 2011. Since then CNR, in close collaboration with ISIS and with the ESS Target division, has contributed to the neutronics simulation of the ESS fast neutron irradiation ports. Some of that work is summarized in chapter 3.3.10 of the ESS Technical Design Report. A workshop was jointly organised in 2013 by ESS, ISIS and CNR highlighting the opportunities for fast neutron research and applications at ESS (see http://plone.esss.lu.se/fast-neutrons-workshop). One of the most promising applications is chip irradiation, which is the subject of the present proposal.

As part of the collaborative development, the ComLayer code was applied to the ESS monolith. ComLayer is a tool for generating optimized input to MCNP. It also provides a framework for neutronic design optimization. The availability of a ComLayer model for the ESS monolith is a significant step forward in the design of a fast neutron beamline at ESS.

State of the art

Irradiation of electronic components or systems with fast neutrons is performed in order to simulate, at a much accelerated pace, the disruptive effect of atmospheric neutrons. The most common effect is the Single Event Error (SEE) resulting in flipping the logical state of a memory bit. A typical FPGA chip undergoes in the order of 10-100 SEE per hour when placed in the neutron beam of the VESUVIO instrument at ISIS. The number of errors will increase by about two orders of magnitude as a consequence of the flux increase in the CHIPIR beamline, which is the first beamline dedicated to chip irradiation at a spallation source. CHIPIR was built at ISIS with in-kind contributions from CNR. It will be brought into service in the coming months and will be fully operational in 2015.

It is worth pointing out that there is already a chip irradiation facility located in Scandinavia. It is the ANITA facility at TSL Laboratory, Uppsala, Sweden. This is part of an accelerator complex where the main application is proton irradiation therapy. The future of this facility is unclear but the reason is not the lack of chip irradiation users. Building ECHIR on ESS would allow for the ANITA users to migrate to ESS.

Currently there are few facilities operating around the world (e.g. TRIUMF, LANSCE at Los Alamos). A few more are considered for construction (CSNS in China or SNS in the USA).

Science case

The ESS Chip Irradiation (ECHIR) beamline has potential to provide fast neutron beams of higher intensity than available on CHIPIR. Is the provision of an additional single event testing facility a priority for ESS? Considerations on the higher possible fast neutron flux delivered at ESS indicate strong potential for SEE testing at ESS: looking ahead about 10 years one can expect that semiconductor devices will become more tolerant to radiation. As devices become more reliable higher fluxes will be required. This is what the ESS will be able to do that cannot be done now.

Additionally, ESS will have the highest energy neutrons. With 2 GeV, ESS will extend the neutron energy range beyond what easily available today; there are indeed cosmic ray neutrons extending to GeV energies. New materials may well introduce new problems at higher energies. There may be even new failure modes at high neutron energy that we are not aware of now. We envisage a totally new understanding of failure mechanisms will be opened by ECHIR.

A chip irradiation beamline can be accomodated on ESS in different ways. One option is to use the so-called Basement Port (Figure 1). This option was considered in the TDR and recently presented at a Conference [1]. The same port can also be used to enable access of irradiation samples inside the monolith (e.g. for material studies). The beamline is looking downwards which is not very convenient. However this is not a fundamental drawback since one of the irradiation options is to use a scatterer material to broaden the beam and irradiate large volume samples. The irradiation room would be in the ESS basement, i.e. away from the instrument hall. The calculated neutron energy spectra (Figure 2) are reasonably similar in shape to the reference atmospheric neutron spectrum. The agreement can be improved by neutronics design as was done on CHIPIR.

A second option that still needs to be assessed is to use one of the 22 beam lines in the current plan for chip irradiation. This could be, e.g., the beamline sketched in Figure 3. The layout would be similar to CHIPIR on ISIS in this case. The Beamline Port for ECHIR would look very much like the other ones except that it is laid in the taget midplane and the shielding must be adequate for stopping fast neutrons. CHIPIR will provide empirical evidence of the quality of the shielding design: indeed TS2 at ISIS is a low background area; any background from CHIPIR affecting the other beamlines will show up immediately.

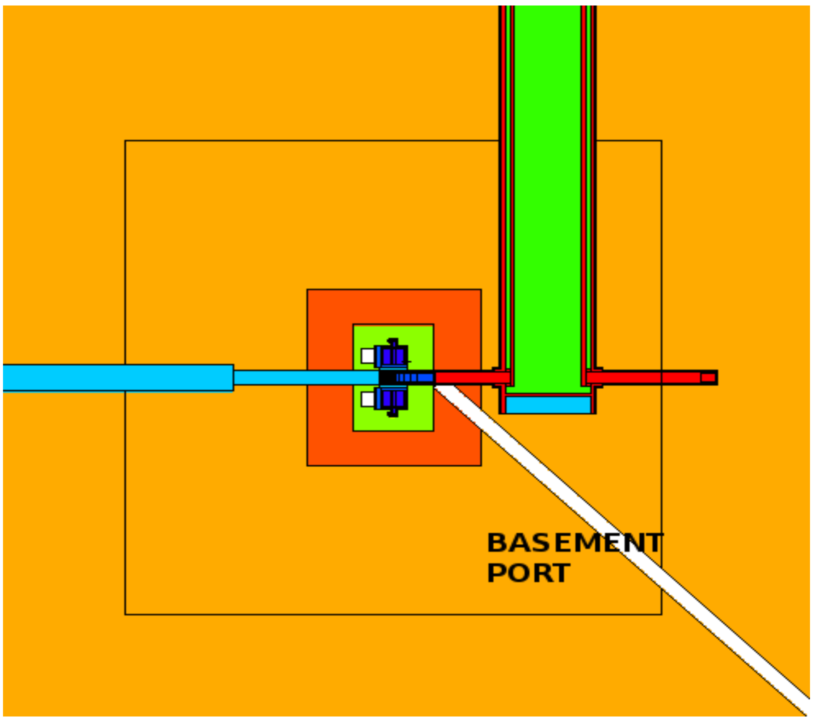

Figure 1. Layout of the 'Basement Port' extending to the end of the monolith

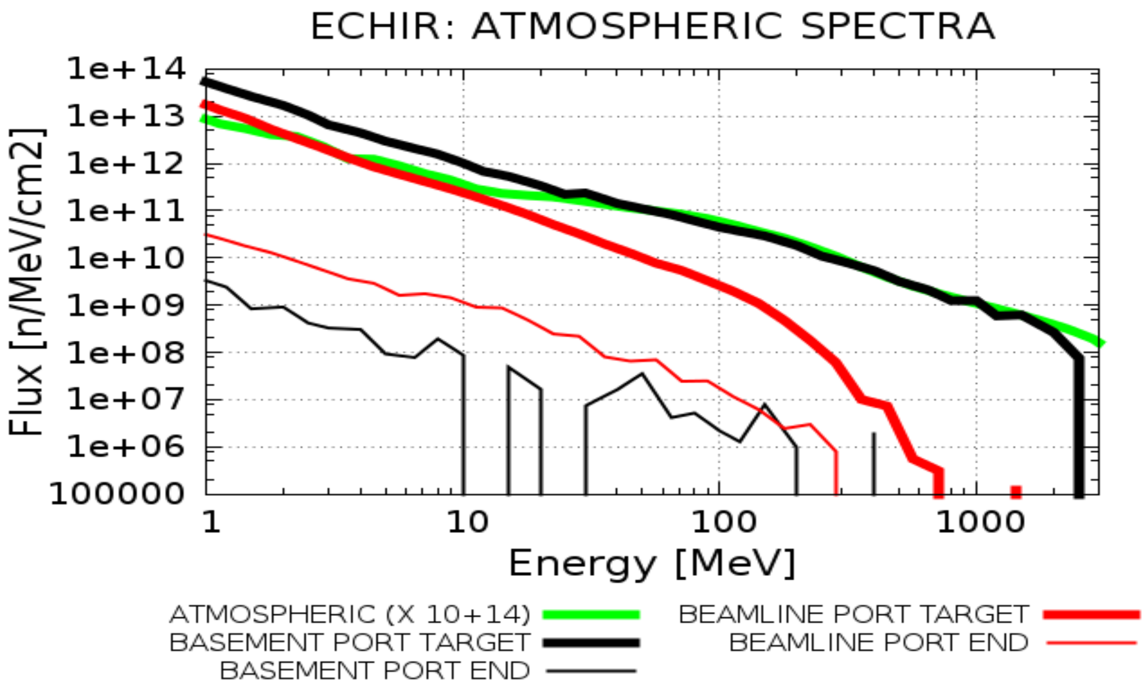

Figure 2. Comparison between a reference atmospheric Spectrum (Qinetiq model at 10 Km) and neutron spectra calculated in the 'Basement Port' and 'Beamline Port' in a position close to the target and at the end of the monolith: the simulations were performed with a nominal 2.5 GeV proton beam.

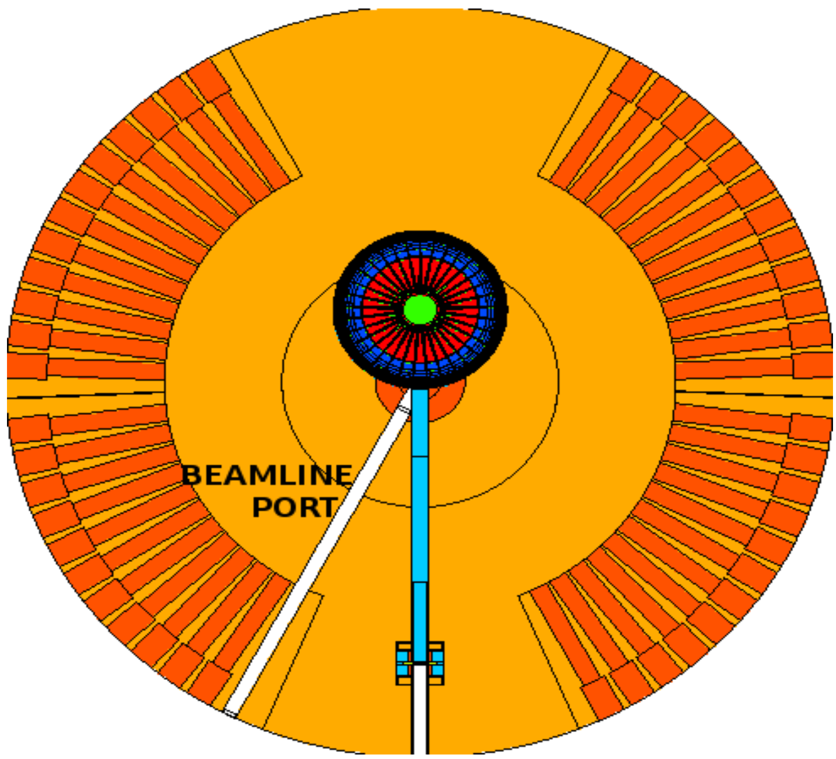

Figure 3. A new option for ECHIR port: it would substitute the first beamline on the left of the proton beam

Business case

The current provision of SEE testing was cited in a 2011 air accident report from the Australian Transport Safety Board as being inadequate, stating that *there were significant logistical difficulties in obtaining access to appropriate test facilities and developing test software and procedures"* [p146 of ATSB TRANSPORT SAFETY REPORT Aviation Occurrence Investigation, AO-2008-070, Final].

Further provision of facilities is perceived as a positive move as this will enable the field to expand from the current supply limited situation into one where adequate provision can be achieved. This will have several major effects:

- Single event testing could become a more routine 'tool' and a normal part of the development process of new devices
- It will allow expansion into emerging fields and sectors where single event effects have not been considered important
- It will allow authorities to specifically 'require' testing with neutrons rather than 'recommend' testing as part of a more generalized reliability requirement

Having many testing laboratories may help various industry sectors to further develop standards for radiation tolerance of semiconductor devices. Up to now, the setting of global standards has been limited by the number of suitable facilities, i.e. a lack of global capacity. As standards are developed, the demand for testing facilities will probably increase significantly and this has to be met with new facilities.

Thus we see no competition, but rather synergies in the future availability of CHIPIR at ISIS and ECHIR at ESS.

The business case for ECHIR can be further strengthened by a consultation with key stakeholders; this very much follows the process carried out during the development of the ChipIr beamline at ISIS. Key questions to be addressed:

- From the current perspective what are the expected problems to emerge in this field in the next 5,10,20 years and how will they be addressed.
- What does industry/academia do now and how does the provision of facilities shape this; i.e. look in detail how industry/academia works with facilities, the good and the bad.
- What would industry/academia expect/like to see over various timescales both in terms of beam provision and wider facility provision (in the context of additional facilities coming on line – i.e. ChipIr)
- Is the additional capability that ESS is proposing required and/or will it be required into the future (expect many different answers to this) and what is its expected impact.
- Are there any 'game changing' things that ESS could do?

In summary, ECHIR will be unique in terms of flux levels and energy range which will make it the top performing chip irradiation facility worldwide. The high flux can be used for testing rare events. It can also be used to test large electronic systems (e.g. from the cockpit of an aircraft) by spreading the neutrons over large areas. Users from both industry and academy are expected. The impact on SEE science and, more generally, on neutron effects on chips will be rather strong in view of what said above.

We foresee ECHIR will be part of a broader range of applications of fast neutrons bringing new user communities to ESS and expanding the ESS user base in directions that are not covered at present spallation facilities.

Comments

The main concern with this kind of beamlines is the potentially negative effect on nearby "standard" beamlines using (mainly) thermal neutrons. A fast neutron beamline is a gap in the monolith allowing fast neutrons into the experimental hall. Though ominous as it may sound, the effect on nearby beamlines can be controlled to the required sensitivity level by provision of adequate shielding. A large fraction of the CHIPIR cost is indeed the rather massive shielding used. The CHIPIR experience will be essential for the development of ECHIR: CHIPIR design choices can be readily adopted taking advantage of the ongoing multilateral collaboration between ESS, CNR and ISIS. CHIPIR engineering construction solutions can be transferred to ECHIR once they have been proven to work. Even the operational experience on CHIPIR will be beneficial for ECHIR, especially in the early operation phase.

The time scale of ECHIR development allows for a few optimization studies before embarking on the engineering design. Areas for optimization include

- measurement of the energy dependence of the neutron flux. The easiest way is by time-of-flight but that would require a mode of operating ESS with short (~1ns wide) pulses separated by a few microseconds (like Target-4 at LANSCE). It might be good to have the capability of short pulses even if it is used infrequently for calibration and diagnostic purposes. If we have several facilities testing semiconductor parts, we will need to come up with a way of accurately normalizing the fluxes between the facilities. Another possibility is to develop a Telescope Proton Recoil instrument. This is a compact spectrometer for fast neutrons that can be transported between facilities.
- choice of shielding material. Shielding costs can easily exceed 50% of the total cost of the beamline. We believe there is room for substantial savings if cost reduction measures are looked into. The analogy with building technology suggests looking into new concrete materials; extensive use of pre-fabrication; reduction in the number of components. Ideally, in line with the overall ESS approach, the new shielding material should be as eco-friendly as possible. Shielding cost considerations suggest that ECHIR be a rather short flight-path beamline, like CHIPIR.
- Spectra engineering. The neutron flux can be shaped using different techniques (filter insertion, dogleg-ducts, position change) according to those already employed for CHIPIR.

Conclusion

ECHIR will be a unique tool for chip irradiation studies at extreme flux and neutron energy conditions. It will enhance the capacity of chip irradiation making it possible for regulators to prescribe, rather than recommend, SEE testing. A timely decision is required in order to include a suitable penetration in the ESS monolith. Indeed one of the CHIPIR lessons is that early inclusion in the design allows for substantial cost reduction. The CHIPIR experience will also allow for optimized design and shorter delivery times.

[1] A. Milocco, G. Gorini, L. Zanini, F. Mezei, S.Ansell, '*Neutronic Design of Fast Neutron irradiation ports for the European Spallation Source*', Proc. Eleventh International Topical Meeting on Nuclear Applications of Accelerators, 5-8 August 2013, Bruges, Belgium