The Neutrons for Science Facility at SPIRAL-2

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The Neutrons for Science Facility at SPIRAL-2

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Abstract. The "Neutrons for Science" (NFS) facility will be a component of SPIRAL-2, the future accelerator dedicated to the production of very intense radioactive ion beams, under construction at GANIL in Caen (France). NFS will be composed of a pulsed neutron beam for in-flight measurements and irradiation stations for cross-section measurements and material studies. Continuous and quasi-monokinetic energy spectra will be available at NFS respectively produced by the interaction of deuteron beam on thick a Be converter and by the $^{7}Li(p,n)$ reaction on a thin converter. The flux at NFS will be up to 2 orders of magnitude higher than those of other existing time-of-flight facilities in the 1 MeV to 40 MeV range. NFS will be a

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very powerful tool for physics and fundamental research as well as applications like the transmutation of nuclear waste, design of future fission and fusion reactors, nuclear medicine or test and development of new detectors.

Keywords: Neutron beam, time-of-flight, fission, fusion, cross section.
PACS: 29.25.Dz, 28.20.v, 25.85.Ec

INTRODUCTION

Neutron-induced reactions play an important role in a wide range of applications including nuclear power reactors, accelerator-driven systems (ADS), fusion technology, medical diagnostics and therapy, production of radio-elements, dosimetry concerning dose effects and radiation damage and upsets in electronic devices as well as basic science research. The data used in transport codes are embodied in evaluated data libraries, which are based on measurements and reaction models. As a matter of fact, the quality of the evaluated data depends on the accuracy of the measured data. Today there is still a large demand for data in neutron-induced reactions above 14 MeV. For many cases (n,fission), (n,n'γ), (n,xn) and (n,LCP) reaction cross sections are unknown or known with a very limited accuracy. The neutron energy range between 1 and 40 MeV is particularly well suited for the applications previously mentioned as well as for fundamental research.

NFS will be a very powerful tool dedicated to these studies. It will be a component of the future SPIRAL-2 facility [1,2], currently under construction at GANIL, Caen (France). SPIRAL-2 will produce very intense rare isotope beams (RIB) in the mass range from A=60 to A=140. These nuclei will be produced by the fission of ^{238}U induced by fast neutrons, which are generated by the break-up reaction of deuterons on a carbon converter. The LINAG (high-power superconducting driver LINAC of GANIL), delivering a high-intensity deuteron beam for RIB production, will also be used to produce neutrons in the NFS facility. NFS will deliver a well-collimated neutron beam in a long experimental area in order to perform in flight measurements at neutron energies up to 40 MeV. In addition, neutron, proton and deuteron induced reaction cross sections could be measured by means of activation techniques.

NFS DESCRIPTION

NFS will be mainly composed of two rooms: a converter cave and an experimental area separated by a 3 m thick wall of concrete (see Fig. 1). The converter room contains the primary ion beam extension and the converter to produce neutrons as well as the irradiation set-ups. A bending magnet is placed between the converter and the collimator entrance to separate protons from the neutron beam when a thin converter is used (see following section). Neutrons in the 0° direction are guided to the experimental room through a collimator consisting of iron and polyethylene.

The experimental area (30 m x 6 m) will allow in-flight measurements to be performed by using large experimental set-ups at desired distances from 5 m up to 25 m away from the converter point. This flexibility is very interesting in terms of flux and energy measurement resolution. The experimental area is designed for the use of radioactive samples up to 10 and 1 GBq for sealed and non-sealed samples, respectively.

The ion beam line in the converter cave will also be equipped with an irradiation box for cross-section measurements of proton and deuteron induced reactions by the activation technique. The use of light ions up to carbon is also envisaged to irradiate samples for material studies.

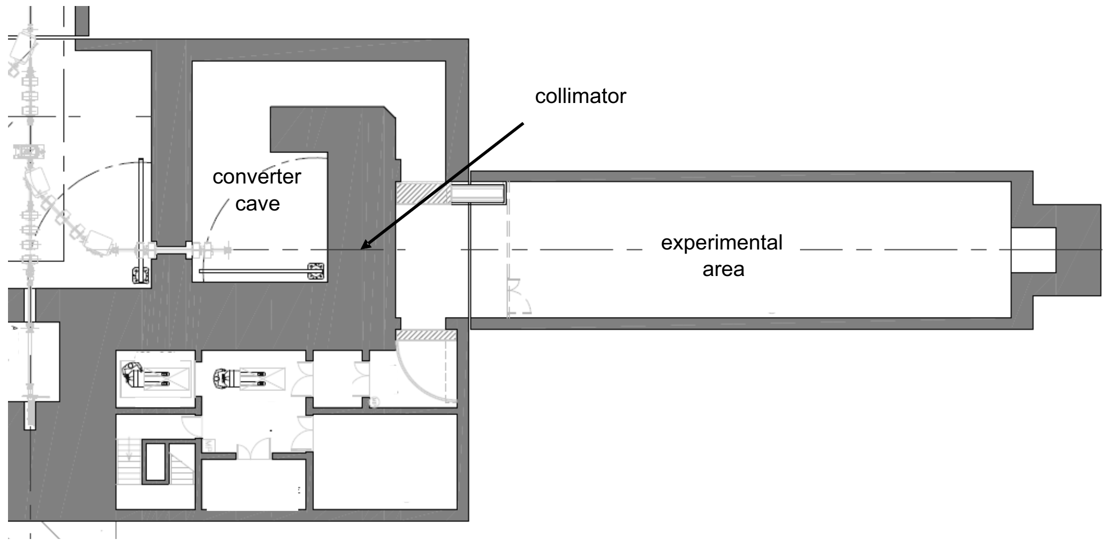

FIGURE 1. Schematic view of the NFS facility.

Two production modes will be used with the pulsed proton and deuteron beams delivered by the LINAG. First, the deuteron break-up reaction on a thick converter made of carbon or beryllium generates neutrons with a continuous energy distribution. At 0°, the spectrum extends up to 40 MeV with an average value of approximately 14 MeV as shown in Fig. 2.

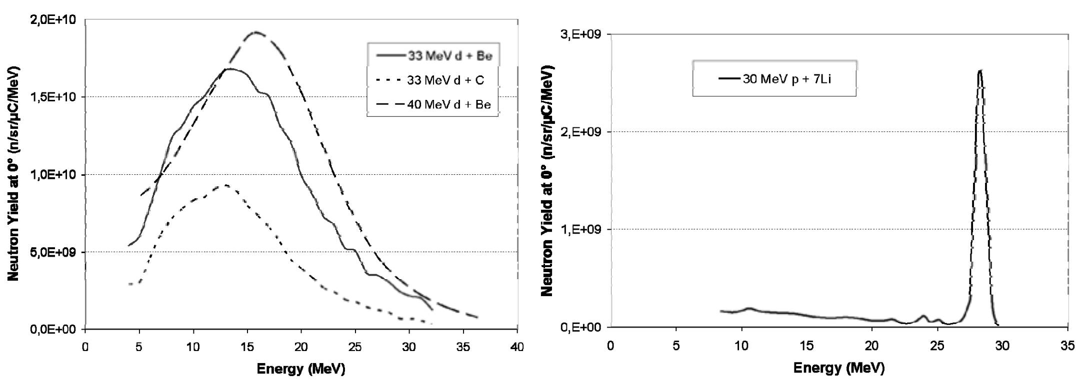

FIGURE 2. Neutron energy distribution at 0° produced by the deuteron break-up reaction on thick converters [3,4] (left panel) and by the $^{7}Li(p,n)^{7}Be$ reaction on a thin lithium target [5] (right panel).

Second, the $^{7}Li(p,n)^{7}Be$ reaction on a thin lithium converter (1 to 3 mm thick) produces nearly mono-energetic neutrons as shown; the neutron spectrum at 0° consists of a mono-energetic peak due to the $^{7}Li(p,n)$ process and a continuum which is attributed to the break-up process. After crossing the lithium converter, the protons are swept out of the neutron beam by a bending magnet placed downstream of the target.

By taking into account the neutron production yield [3,4], the beam division and the flight path, the neutron flux can be evaluated and compared to other major TOF facilities, namely n_TOF at CERN, WNR at Los Alamos (where neutrons are produced in a spallation reaction) and GELINA in Geel (where neutrons are produced by photo-reactions). The length of the TOF area allows either high-intensity flux (5 m) or high-resolution (20 m) measurements. It can be seen in Fig. 3 that NFS is very competitive in terms of average flux in comparison with n_TOF, GELINA or WNR between 1 and 35 MeV. Moreover, NFS presents some advantages thanks to the neutron production mechanism itself. In spallation sources, the high energy neutrons (up to hundreds of MeV), may imply challenges for both collimation and background. Secondly, the gamma-flash, which is known to be very penalizing especially because it induces dead time, will probably be strongly reduced at NFS. The energy of the incident neutron can be measured by the TOF technique with a rather good resolution thanks to a small time spread at the converter point (<1 ns) as well as to the length of the experimental area. The use of fast detectors ($\Delta t \approx 1$ ns) and slow detectors, like High Purity Germanium detector ($\Delta t \approx 8$ ns), allows for an energy resolution at 40 MeV of better than 1% and 5%, respectively.

The neutron flux measured very close to the converter in the converter room is presented in Fig. 4. By using the thick beryllium converter, a flux greater than 5×10^{11} n/cm^2/s can be reached. This very high flux can be used to measure reaction cross-sections by the activation technique with a small target.

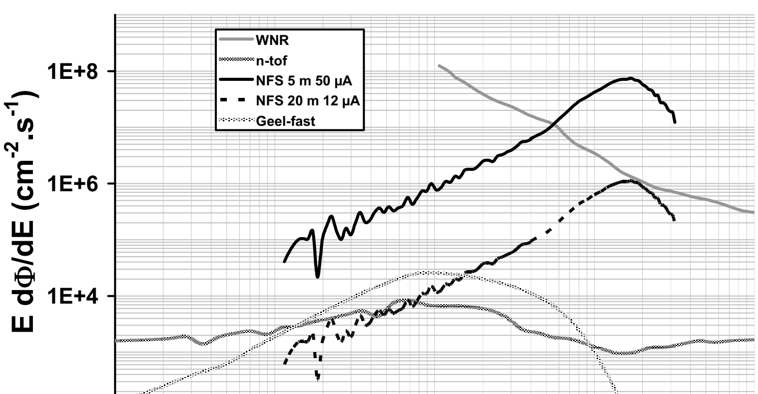

FIGURE 3. Neutron flux at NFS for two flight paths compared to three other neutron TOF facilities.

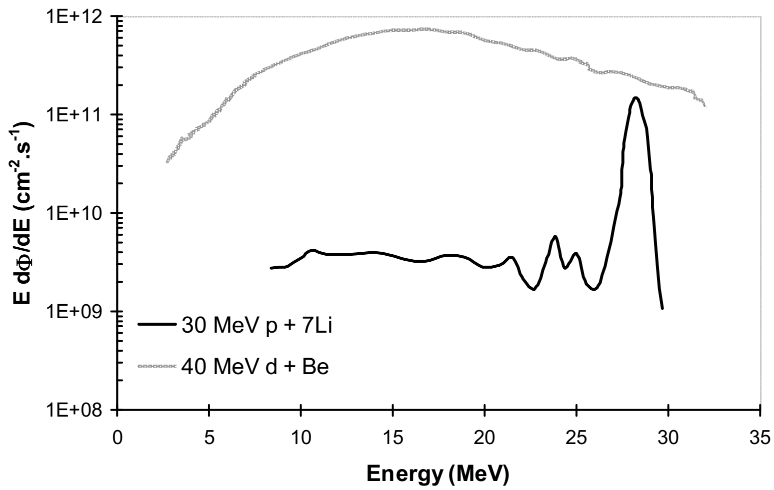

FIGURE 4. Neutron flux at 5 cm down stream of the converter for thick (Be) and thin (Li) converters.

NEUTRON TRANSPORT SIMULATIONS

Neutron transport calculations have been realized for several purposes like safety issues and background evaluation. All the simulations were performed with the MCNPX code version 2.5. The energy and angular distribution of the neutrons produced in the 40 MeV d+Be reaction have been calculated using the model described in Ref. [6].

The safety study was of prime importance for the design of the biological protections, the maintenance operations and the evaluation of the waste production for future dismantling operations. The most activated component in the NFS facility will be the beryllium converter, and a dedicated lead shielding has been designed to store the converter after use.

The background in the TOF area is a very important parameter for most of the detectors that will be used at NFS. The background originates mainly from two components, the collimator and the neutron beam dump.

The collimator is placed in the thick concrete wall separating the converter and the TOF rooms. The role of the collimation system is to define a well-collimated neutron beam; therefore its design is of special importance to the beam characteristics. The collimator will be composed of several materials arranged in ring fashion [7]. The inner part is a cylinder of iron (with a conical channel to define the beam), which would scatter away high-energy neutrons. The outer part (in concrete and borated polyethylene) would then absorb them.

The neutron beam is "stopped" at the end of the TOF room in a beam dump whose design has been optimized to reduce the neutron backscattering to the TOF room and to minimize gamma-ray creation. The beam dump is a hole 4 m long with 1x1 m^2 cross section centered on the beam axis. A borated polyethylene sheet (15 cm thick) in the bottom of the hall reduces the backscattering of neutrons. A tube at the entrance of the hole (composed of borated polyethylene in the inner part and concrete in the outer part) with a diameter greater than the beam spot allows for capture of the neutrons and the photons. Figure 5 shows the effect of the optimization on the neutron flux.

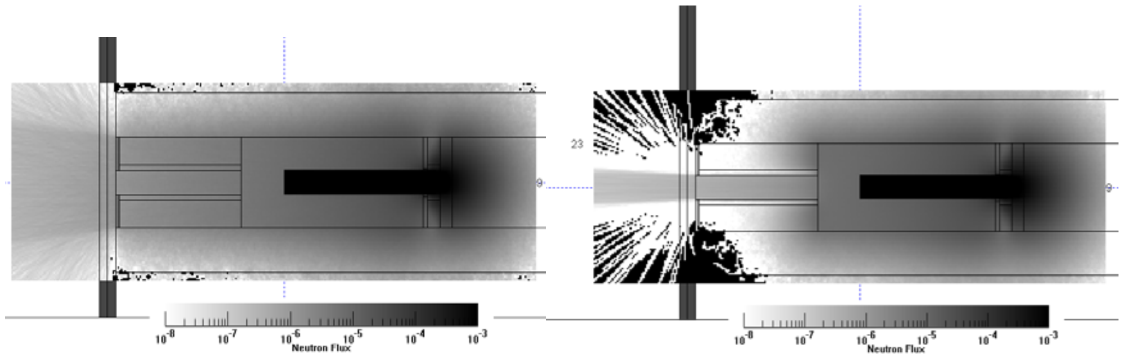

FIGURE 5. Neutron flux simulations in the beam dump zone; the dark rectangle represents the incoming beam. The left figure shows the basic design while the right shows the optimized design.

STATUS OF THE CONSTRUCTION

The SPIRAL-2 construction is split into two phases. The first one includes the accelerator building, the Super Spectrometer Separator (S3) [8] and NFS. The second one will be composed of the production building and the DESIR facility [9]. The design of the phase one buildings is now complete. The public enquiry was done in July 2010, and the construction permit was obtained in October 2010. The earthwork has been completed, and the first concrete works are scheduled for June 2011.

The major part of the facility, i.e. the LINAG, S3, the production building and NFS itself, will be placed underground at a level of -9.5 m (see Fig. 6). This solution leads to a lighter design of the biological protections. The buildings will be available for process installation at the beginning of 2013 and the first beam is scheduled in 2013.

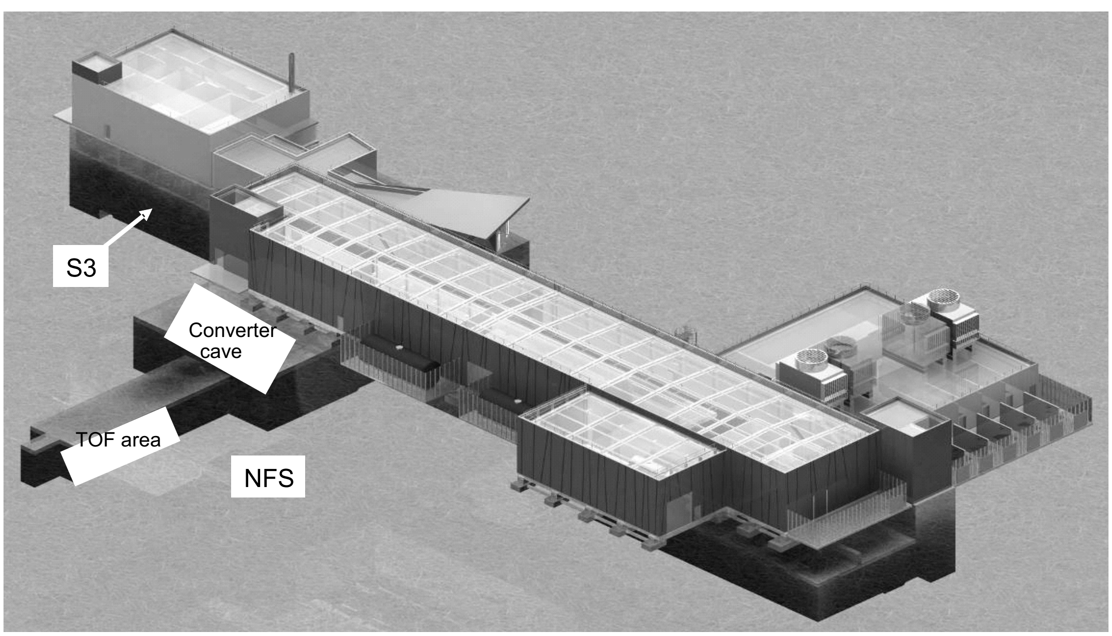

FIGURE 6. View of the SPIRAL-2 phase 1 buildings.

PHYSICS CASE

Neutron-induced reactions in the NFS energy range play an important role in numerous applications such as reactors of the new generation, nuclear medicine, describing the so-called Single Event Upset (SEU) in electronic devices, advancing fusion technology and development of nuclear model codes in general. Only very limited data exist for neutron induced reactions above 14 MeV, and for many cases, both fission and (n,xn) reaction cross sections are unknown. The above energy range corresponds also to the opening of new reaction channels such as (n,p) and (n,α), allowing for pre-equilibrium model studies, i.e. the transition between low (evaporation) and high energy models (intra-nuclear cascade). The NFS characteristics are particularly well suited for studying these reactions as well as deuteron and proton induced reactions.

The (n,xn) reaction cross sections can be measured at NFS by three different methods, namely the direct detection of neutrons, prompt gamma-ray spectroscopy or the activation technique. The beam properties (energy and resolution) will allow a precise measurement of the cross section from the threshold up to the maximum cross section for (n,2n), (n,3n) and (n,4n) reactions, where data are either unknown or known with only very poor accuracy.

Double-differential cross-section measurements for neutron-induced light-ion production (p, d and alpha particles) will also be performed. In fact, the light-ion production knowledge is essential in medical and electronic applications for accurate dose evaluation and for the prediction of gas production in windows or targets at these facilities.

The study of fission will be an important part of the NFS physics case. Actually, the probable development of innovative fast nuclear reactors requires new, high quality data for a large set of fissioning systems (from thorium to curium) for an energy range from thermal up to the fast (~2 MeV) region. Complementary to reaction cross-section data, the mass and charge distributions are needed with a high precision for burn-up calculations of the reactor fuel, since they are directly connected to the control and the safety of the reactor. A good knowledge of the cross sections is necessary for assessing the neutron balance or to predict radioactive waste inventories. The neutron multiplicity distributions as well as the energy released by gamma emission are also required.

Proton and deuteron induced activation reactions are of great interest for the assessment of induced radioactivity in accelerator components, targets and beam stoppers and are important for isotope production for medical purposes. The cross sections are needed in the energy range from the threshold of the activation reactions (2-10 MeV) up to 40 MeV for both incident ions: deuterons and protons. Present status of the measured and evaluated data needs urgent and strong improvement. The measurement of excitation functions can be performed at NFS in an energy domain (20-40 MeV) where data are either non-existent or known with poor accuracy. In the framework of the first-phase program of starting investigations (LoI Phase 1 - NFS), a development of the reaction chamber hardware incorporating a pneumatic sample transport system is under way within the NPI Řež and KIT Karlsruhe collaboration.

Nine Letters of Intents (LOI) for experiments which could be performed just after the commissioning of NFS have been submitted after request of the scientific advisory committee of SPIRAL-2. Some of the LOIs are available on reference [10].

Three LOIs are dedicated to the study of the (n,xn) reactions. A 4π neutron detector will be used for cross-section measurement and for the study of the pre-equilibrium process. Cross-section of (n,3n) and (n,4n) reactions will also be measured by in-flight technique thanks a set of germanium detectors.

Four LOIs are dedicated to the study of fission. For two of them, the goal is to measure the cross-section and the anisotropy of the fission fragment emission. For the two others, the physicists plan to measure the fragment distribution with a high resolution in charge.

One LOI is dedicated to the measurement of light ion production in neutron induced reaction.

Finally one LOI is dedicated to the cross-section measurement of proton and deuteron induced reactions by activation technique. The samples will be irradiated in a reaction chamber placed on the ion beam line and moved to the TOF area by a pneumatic system for counting.

CONCLUSION

Neutrons for Science is a component of the SPIRAL-2 facility under construction on the GANIL site at Caen (France). Its characteristics in terms of flux or energy resolution make it a very attractive and powerful tool for physics with neutrons in the 100 keV-40 MeV range. The high intensity neutron beam will allow cross-section measurements to be performed as well as fundamental physics experiments. This facility is fully complementary to other existing facilities based on spallation neutron sources or electron accelerators. The irradiation facility is particularly well adapted to cross-section measurements of neutron, proton or deuteron induced reactions which are needed for fusion technology. The NFS facility will be operational in 2013.

REFERENCES

1. "Report of the SPIRAL 2 Detail Design Study," available at http://www.ganil.fr.
2. "The scientific objective of the SPIRAL-2 project", available at http://www.ganil.fr.
3. M. J. Saltmarsh et al., *Nucl. Instr. Meth.* **A145**, 81-90 (1977).
4. J. P. Meulders et al., *Phys. Med. Biol.* **20**(2), 235 (1975).
5. C. J. Batty et al., *Nucl. Instr. Meth.* **68**, 273-276 (1969).
6. M. Majerle and S. Simakov, Karlsruher Institut für Technologie, Internal report, INR-Nr. 15/10 FUSION Nr. 368 (2010).
7. A. Takibayev, CEA/Saclay, Internal Report Irfu, 11-75 (2011).
8. A. Drouart et al., *Nucl. Phys.* **A834**, 747-751 (2010).
9. DESIR facility Letter of Intent, available at http://pro.ganil-spiral2.eu/.
10. Letters of Intent for Day-One experiment, available at http://pro.ganil-spiral2.eu/spiral2/instrumentation/nfs/lois/.