Day 1 SPIRAL2 Phase 1 Experiment Template

Dead-line for submission :
July 20th, 2009

Title:
Study of the pre-equilibrium process in the (n,xn) reaction.

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Brief summary of the physics goal (detailed description and counting rates should be given on separate pages) max. 1/2 a page:

The particle-nucleus reactions codes are made of several models (optical model, direct interaction, pre-equilibrium and evaporation) to reproduce the whole reaction mechanism and resulting observables. Among these processes, the pre-equilibrium is clearly the less well known. Actually some of the existing models reproduce integrated observables but rarely the differential ones.

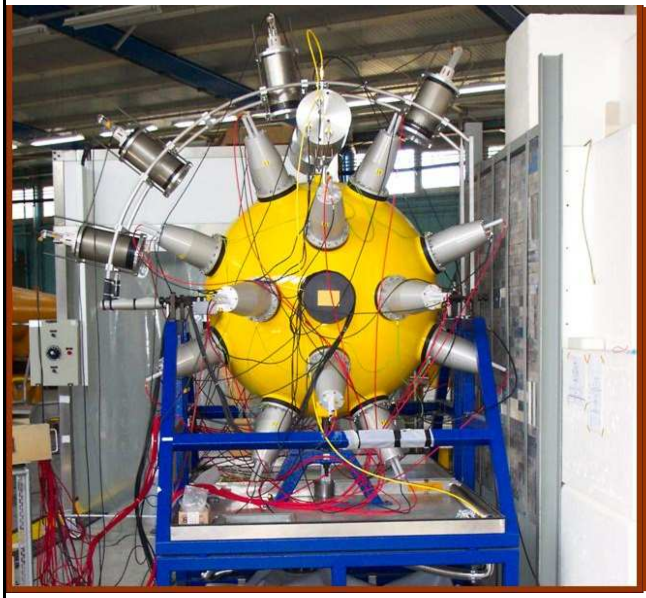
In order to constrain strongly the pre-equilibrium process we plan to measure the energy spectra of neutrons in the (n,xn) reactions in coincidence with the neutron multiplicity. Contrary to “classical” (n,xn) reaction measurement, where all the channels emitting at least one neutron are taken into account, double differential cross-section in (n,2n), (n,3n), (n,4n)… tagged reactions will be measured. The first experiments of this type were realized at Bruyères-le-Châtel between 8 and 13 MeV validating the experimental set-up and analysis procedure. This study showed also that the measurement has to be pursued at higher energy (typically from 20 to 50 MeV) to increase the pre-equilibrium importance. The set-up, composed of NE213 cells and the 4π neutron detector CARMEN is operational and the NFS facility will be perfectly adapted for this program. Again, one could start the measurements with “easy” targets as iron, lead, uranium and thorium.

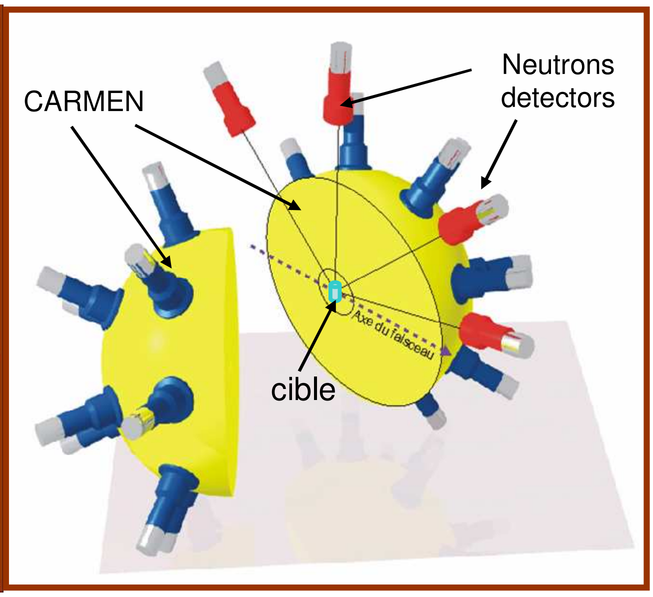
	Ion(s)	Energy (MeV/nucl.)	Intensity (pμA)	Number of beam UT (1UT=8hours) per beam	Requested time structure (if different from parameters given in the attached table) Δ t(ns): Beam on: Beam off:
LINAC Primary Beam(s) ***(see beam parameter table at the end of template)***	**p**	**33**			**F < 1 MHz**

Total estimated number of beam UTs (1 UT=8hours):	Approximate time for setting up the apparatus: 2 weeks Approximate time required for off-beam calibration and dismounting: 1 week
When the experiment might be ready to run (month, year):	The experimental apparatus is ready to run, but a entire characterization of the neutron background is required before running this experiment

Beam Line (NFS or S3): **NFS**

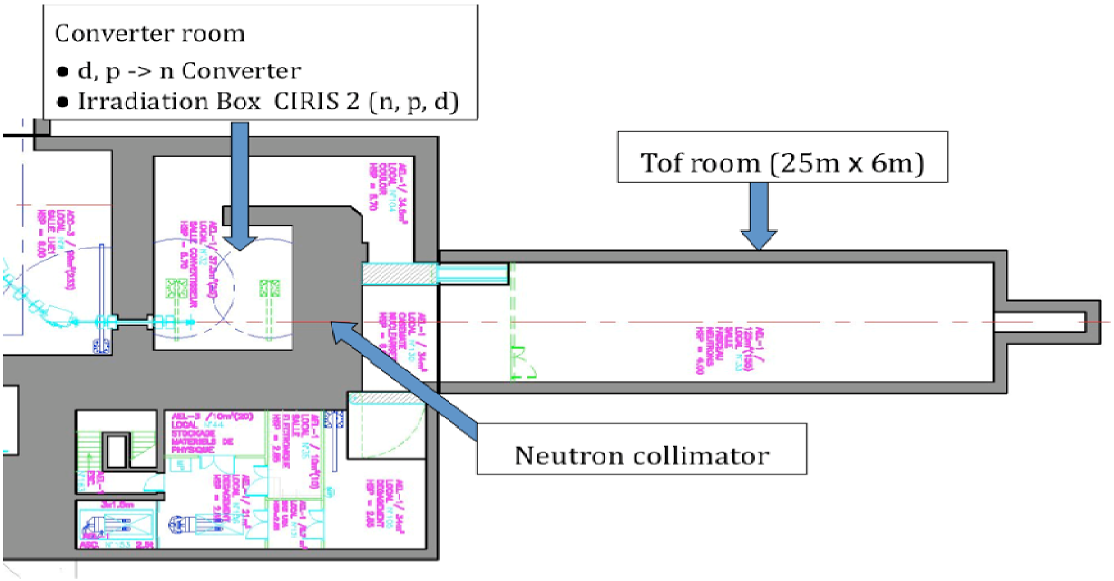
Detectors to be used (provide a sketch of the setup):
CARMEN, set of neutrons detector NE213





NFS parameters *(for the experiments using the NFS beam line):*

Type of neutron converter (Li, Be, C)	Neutron collimator (diameter in cm)	Distance collimator - target (m)	Use of irradiation Box CIRIS 2 (Y/N)
Li	2	2 m	N

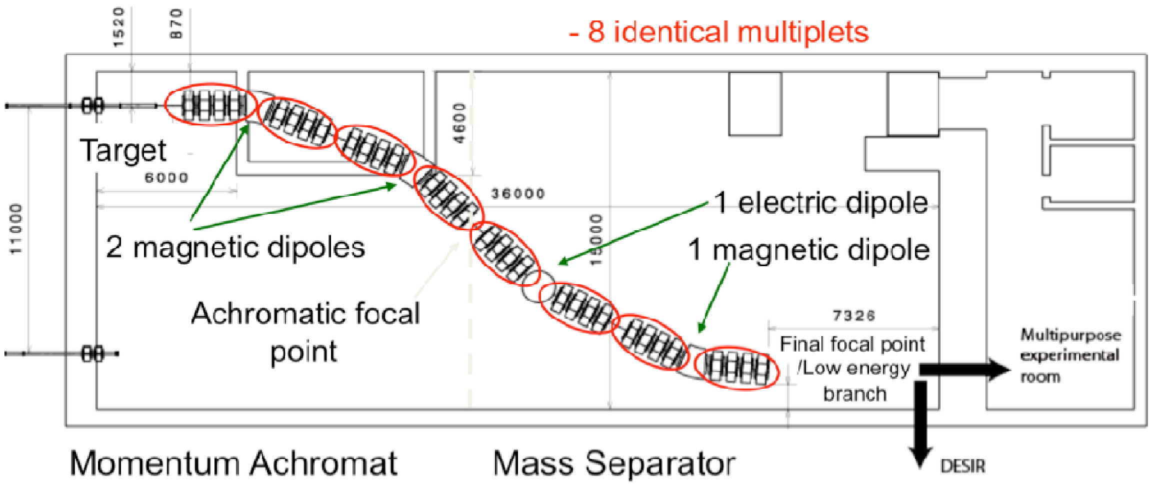


Schematic layout of the NFS facility

More information on the NFS facility can be found at:
http://www.ganil.fr/research/developments/spiral2/collaborations.html
For further questions on NFS please contact spokesperson of the collaboration:
xavier.ledoux@cea.fr

S3 parameters *(for the experiments using the S3 beam line)* **:**

	Material	Thickness	
Primary target(s)			
Stripper(s)			
Devices needed Mark with X	Momentum achromat	Mass separator	Low energy branch
Setup at achromatic point	Secondary target	Ancillary detectors (specify)	
Setup at Mass separator Focal Plane	Implantation decay station	Gas cell	Other devices (specify)



Schematic layout of the S3 spectrometer/separator

More information on the S3 spectrometer/separator can be found at:
http://www.ganil.fr/research/developments/spiral2/collaborations.html
For further questions on S3 please contact spokesperson of the collaboration:
savajols@ganil.fr

Acquisition system (present GANIL or specific one if yes specify):
The acquisition system dedicated to this experiment exists and is available.

Electronics system (type of electronics - provide a reference if possible, estimated number of racks, necessary electric power, other requirements) and its location (ex. located close to the detector/spectrometer or in a separate room) :
All the electronic already exists, is available, and will be placed is the electronic room.

Security, use of hazardous equipment :
(Radioactive target, liquid nitrogen, explosive gas etc.)
CARMEN liquid sintillator : 1000 l of BC 521

Remarks : CARMEN will also be used for other measurements like those related to the study of fission.

LINAC beams available for the Day 1 SPIRAL2 Phase 1 experiments*$^{)}$

Ion(s)	Energy Range (MeV/nucleon)	Maximum Intensity (pμA)	Approximate date of availability***$^{)}$	Remarks
$^{1}H^{1+}$	20-33	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{2}H^{1+}$	10-20	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{4}He^{2+}$	10-20	2-10	December 2012	NFS beam line; Intensity with fast chopper 1/100
$^{18}O^{6+}$	4-14	80-160**$^{)}$	February 2013	S3 beam line
$^{20}Ne^{7+}$	4-14	25-140**$^{)}$	February 2013	S3 beam line
$^{36}Ar^{12+}$	4-14	15-50**$^{)}$	February 2013	S3 beam line
$^{40}Ca^{14+}$	4-14	10-40**$^{)}$	February 2013	S3 beam line
$^{48}Ca^{16+}$	4-14	2-10**$^{)}$	February 2013	S3 beam line
$^{58}Ni^{18+}$	4-14	1-2**$^{)}$	February 2013	S3 beam line

Remarks:
Beam time structure: acceleration (or bunch) frequency 88 MHz, Δt for each bunch typically 1 ns (depends on beam energy and target position)

*$^{)}$ The parameters indicated in this table are the first and the best approximations that can be done today. They may be different from those available in reality at the beginning of operation of SPIRAL2. User's request of different beams and specifications supported by recommendations of the Scientific Advisory Committee for the Day 1 SPIRAL2 Phase 1 experiments might be taken into account. The SPIRAL2 project will update the list of parameters periodically.

**$^{)}$ Based on the order of magnitude of the expected best currents extracted from a high performance, fully operational, 28 GHz ECR Ion source.

***$^{)}$ These dates assume that: installation of equipment in the NFS and S3 areas can start in July 2011, commissioning of the LINAC can begin in the first quarter of 2012 and commissioning of the instrumentation in the S3 and/or NFS halls with the LINAC beam(s) would begin in September 2012.

Detailed description of the experiment:

1. Motivations

Neutron induced reactions are very important for many applications like Accelerator-Driven Systems, fast-neutron reactors or medical applications. Among the inelastic processes, the (n,xn) reactions are predominant for fast neutrons. For example in the 7-20 MeV energy range the (n,2n) reaction is one of the most important nuclear-reaction channels for non-fissile nuclei. For such energies the reaction codes need several models (optical, direct interaction, pre-equilibrium and evaporation) to be able to calculate the cross sections. Among the corresponding processes, the pre-equilibrium is clearly the least known. Actually some of the existing models reproduce integrated observables but fail in describing differential cross-sections.

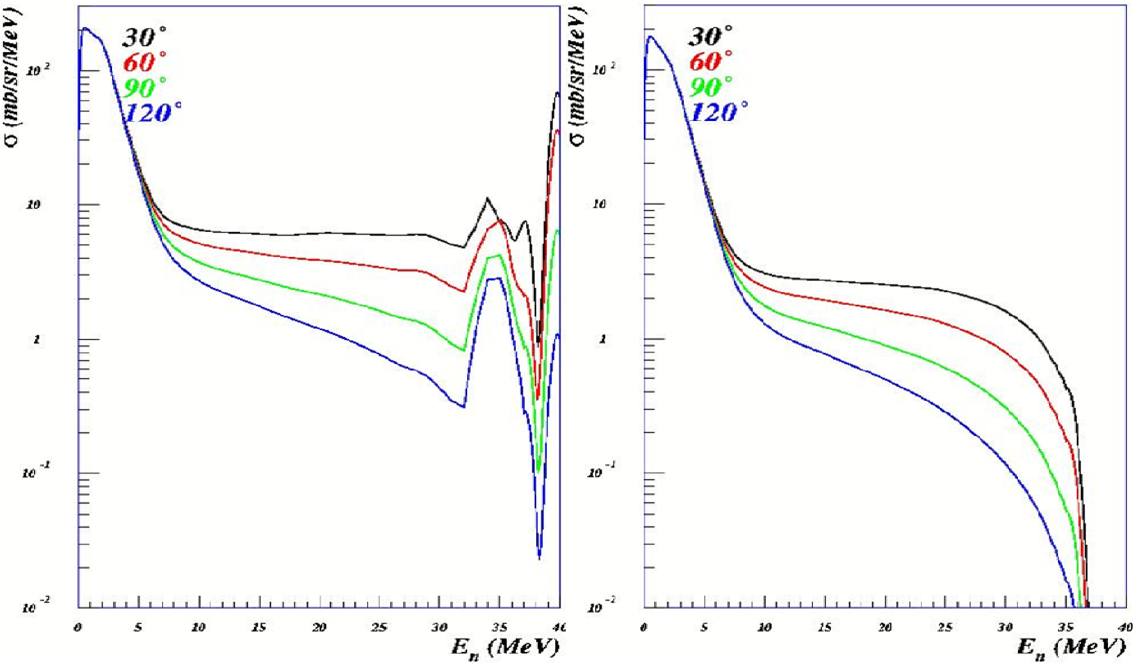


Figure 1: Talys [1] simulations of the neutron spectra emitted in 40 MeV ^{208}Pb(p,xn) (left) and 40 MeV ^{208}Pb(n,xn) (right) reactions.

In order to constrain strongly the pre-equilibrium models we propose to measure the neutrons energy spectra in the (n,xn) reactions in coincidence with the neutron multiplicity. The energies of interest range from 15 to several tenths of Mega electron Volts. This domain corresponds to an increase of pre-equilibrium process effect as illustrated in the figure 1. This energy range is also characterized by the opening of new reaction channels like (n,3n), (n,4n), (n,5n).... The measurement of the double differential cross-section in tagged (n,xn) reactions would be innovative, and would provide data of prime importance for the nuclear data bases and modeling improvements. The quasi-monokinetic neutron beam available at NFS will allow to perform this experiment at 30 MeV incident energy.

2. Experiment description

The detection set-up (Fig. 2) can be divided into two main parts.

The first one consists of a set of neutron detectors between 1 and 3 m far from the studied sample at angle from 10° to 120° with respect to the beam direction. They are NE213 liquid scintillator cells (r=12.5 cm and L=5 cm) coupled to Photonis XP4512B phototubes. A pulse shape analysis allows neutron-gamma discrimination while the neutron energy is determined by time-of-flight (TOF). The detection threshold is tuned at 500 keV to ensure good n-γ discrimination. The efficiency is about ε=15% in the 2 MeV – 30 MeV range.

The second part of the set-up is the 4π neutron detector CARMEN (Cells Arrangement Relative to the Measurement of Neutrons) [1]. It is a large spherical neutron detector operating like the BNB [2,3] or ORION [4, 5]. This kind of detector was already used in the past for (n,2n) integrated cross-section measurements [6]. It consists of two independent vertical hemispheres, 60 cm in outer-radius, 15 cm in inner-radius, each one filled with less than 0.5 m^3 of gadolinium-loaded scintillating organic liquid (BC521). A small space, about 10 cm, between the hemispheres allows double-differential cross sections measurements with the external NE213 detectors previously described. The 15 cm in radius area at the centre of the detector defines the reaction chamber. A horizontal channel, 5 cm in radius, allows the neutron to reach the reaction chamber, the beam exit being ensured by a rectangular wide-mouthed channel. Twelve phototubes surrounding each hemisphere collect the light produced in the scintillator. When a neutron enters the scintillating liquid it interacts with a proton whose recoil produces a so-called prompt light signal. The neutron is then slowed down by loosing its energy by inelastic and mainly elastic scattering on hydrogen and carbon nuclei. Since the neutron slows down to the thermal energy it can be captured by a gadolinium nucleus whose de-excitation produces a delayed light signal. Due to the low gadolinium concentration, 0,5 % by weight, 50 μs following the first interaction are necessary to capture 99% of the total number of captured neutrons in the scintillator. Several neutrons emitted simultaneously from the primary nuclear reaction are captured at different times and can be counted independently. For each event, two 50 μs gate signals (separated by 50 μs) are generated to measure the neutron and the background multiplicities respectively. In this configuration the detection efficiency of an evaporated neutron is $\varepsilon_c \approx 70\%$.

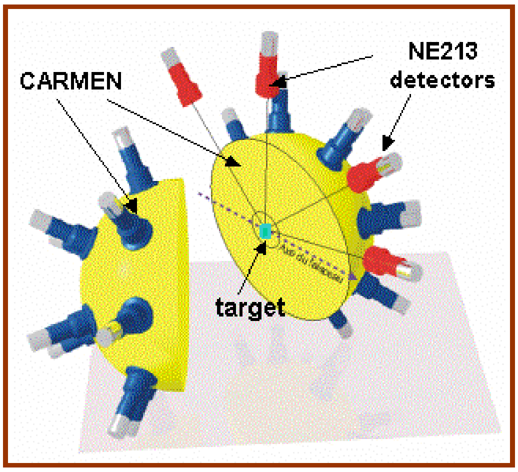


Figure 2: Sketch of the detection set-up

The data acquisition is triggered by 1 neutron detected by a NE213 cell while CARMEN detects the (x-1) other neutrons of the reaction.

The neutrons are produced by p+^{7}Li reaction, the pulsed beam is absolutely request.

3. Counting rate estimation:

The experiment will be performed with a proton beam intensity of I=5 μA, the sample, surrounded by CARMEN placed in the TOF hall at 2m from the collimator exit (i.e. D=600 cm from the production converter). The target is a lead cylinder of 2 cm in radius and 2 cm in height (m=283 g and S= 12.56 cm^2).

The goal is to obtain at least 500 events, produced in (n,4n) reaction, in a bin with of ΔE=1 MeV in the 20 to 25 MeV range. At 30 MeV (n,4n) represents roughly half of the (n,xn) cross-section at the same level than the (n,3n) and largely higher than the (n,2n). The cross-section can be evaluated to $d^2\sigma/d\Omega dE \approx 0.2$ mb/sr/MeV (see fig 1). For (n,4n) reaction measurement, 3 neutrons have to be detected in the CARMEN detector, so the CARMEN detection efficiency is ε_c^3.

Neutron beam flux:

Neutron cross-section production at 0 degree, by p+^{7}Li reaction:

$(d^2\sigma/d\Omega dE)_{pLi} = 2.10^9$ n/sr/MeV/μA [7]

Flux on the sample: $\Phi = (d^2\sigma/d\Omega dE)_{pLi}\ I / D^2 \approx 2.8e^4$ n/s/cm^2

Detection efficiency:

NE213 detector global efficiency $\varepsilon_g = \varepsilon * \pi r^2 / d^2 \approx 2e\text{-}4$

CARMEN efficiency for (n,4n) reaction: $\varepsilon_c^3 = 0.35$

Number of neutrons detected per second:

$N_d = \Phi\ S\ (m\ N / A)\ (d^2\sigma/d\Omega dE)\ \Delta E\ \varepsilon_g\ \ \varepsilon_c \approx$ 4e-3 count per second

Beam time to obtain 500 counts: t =125000 s ≈ 4UT for 1 target.

During an experiment, we plan to study 3 targets and 4 UT should be used for empty frame m measurement. The total time is estimated to 16 UT.

References

[1] I. Lantuéjoul, PhD Thesis, University of Caen (2004).

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[3] U. Jahnke, C.-M. Herbach, D. Hilscher, V. Tishchenko, J. Galin, A. Letourneau, B. Lott, A. Peghaire, F. Goldenbaum and L. Pienkowski, Nucl. Inst. and Meth. A 508 (2003) 295.

[4] Y. Périer, B. Lott, Y. El Masri, J. Galin, Th. Keutgen, J.H. Le Faou, M. Morjean, A. Péghaire, B.M. Quednau and I. Tilquin, Nucl. Inst. And Meth. A 413 (1998) 312.

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[6] J. Fréhaut, Nucl. Instr. and Meth. 135, (1976) 511.

[7] C. J. Batty et al., Nucl. Inst. and Meth. 68 (1969) 273.