Day 1 SPIRAL2 Phase 1 Experiment Template		Dead-line for submission : **July 20th, 2009**

Title: Fission fragment distributions and neutron multiplicities.		
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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:

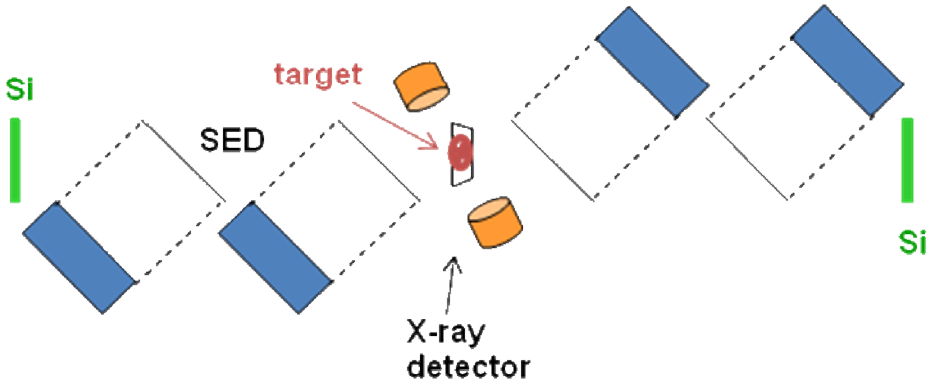
This experiment aims to provide accurate data on actinide neutron-induced fission fragment characteristics (mass and charge distributions, kinetic energy) and neutron multiplicities in the energy range between 500 keV and 20 MeV. For thermal neutron energies, a lot of data are available. Although some of them are partial or have an insufficient accuracy, the number of measured nuclei is relatively large. In the fast energy domain, only few data are available. This energy range is particularly important for the development of the fast reactor technology and the development of reactors dedicated to the incineration of minor actinides. Indeed, in these reactors, the nuclear fuel will be composed by a large proportion of minor actinides, inducing important incidence on the short-term radiotoxicity of the used-fuel, and on the neutron flux. For fission mechanism studies, the energy dependence of fragment mass, charge and isotopic distributions as well as the fragment kinetic energy and neutron multiplicities are important. Fission modes, even-odd effects, deformation energy, etc, can be studied with such measurements. Therefore, models will be improved and more precise predictions can be done for nuclei difficult to access experimentally.

The NFS facility will allow performing experiments in this energy domain with a good neutron energy resolution (2% at E_n=5 MeV). The fission fragment mass distribution will be measured using residual energy and time-of flight (TOF) technique. A good time resolution is expected using secondary electron detectors for the TOF measurement. Silicon detectors will be placed behind to stop the fragments and measure their residual energies. Information on the charge of the fragments will be provided by X-ray detectors. The combined measurements of velocity and energy loss provide information on the mass of the fragments before and after the neutron evaporation. Then the neutron multiplicity as a function of the mass distribution will be derived. The total kinetic energy (TKE) of fragments will also be determined. The proposed setup will use "conventional" detection systems and can be ready for the end of 2012. The setup will be first commissioned and characterized performing experiments with ^{238}U and ^{235}U targets. Other actinides, ^{239}Pu, ^{237}Np, ^{233}U and ^{232}Th, will be studied later on.
(detailed description at the end of the document)

	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)
LINAC Primary Beam(s) ***(see beam parameter table at the end of template)***	$^{2}H^{1+}$	20	**50**	36	Δ t(ns): Beam on: Beam off:

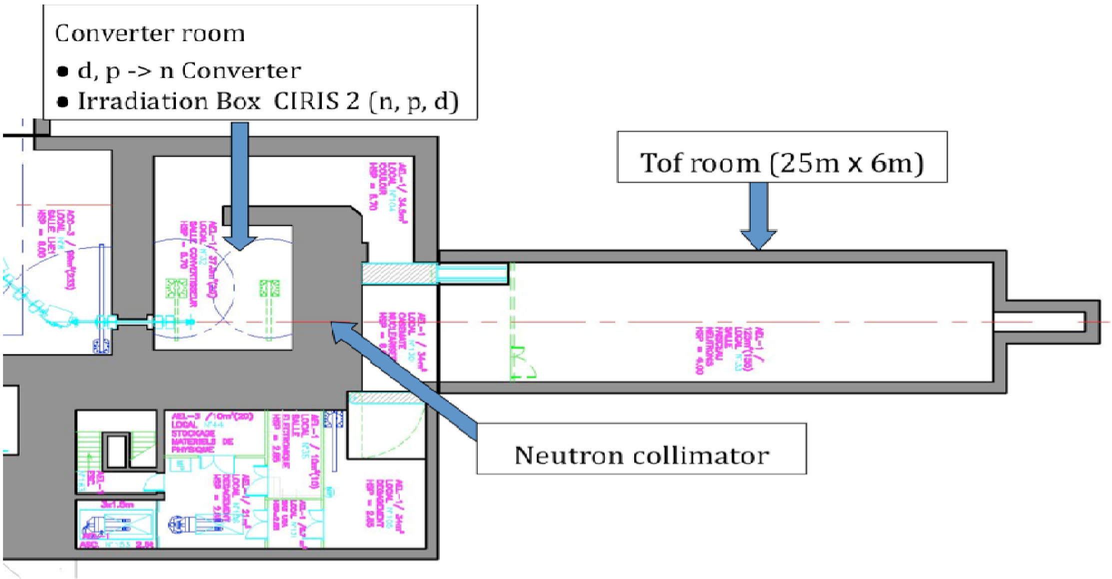
Total estimated number of beam UTs (1 UT=8hours): **36UT**	Approximate time for setting up the apparatus: 1 week Approximate time required for off-beam calibration and dismounting: 1-2 days
When the experiment might be ready to run (month, year):	January 2013

Beam Line (NFS or S3):
Detectors to be used (provide a sketch of the setup): **Side view of the first setup: Four secondary electron detectors (SED) + Silicon detectors and low energy photon detectors (only two of them are represented, the four others are out of plane). The beam direction is perpendicular to the sheet and points into the scheme. The target is tilted of 45 degrees with respect to the sheet plane.**



01NFS 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)
Be	4	2	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

Acquisition system (present GANIL or specific one if yes specify): Probably GANIL acquisition

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) : Gassiplex, Crams

Security, use of hazardous equipment : radioactive (actinide) targets (~150 $\mu g/cm^2$)
Isobutane (low pressure and low flux)

Remarks :

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.

Fission fragment distributions and neutron multiplicities

Motivations:

The present proposal is closely related to the Letter of Intent (Actinides fission fragment yields) presented in 2006. The goal is to provide accurate nuclear data for both applications and fundamental physics. Production yields of neutronic poisons (Gd, Sm, Xe, …) are particularly important for the design of new generation nuclear reactors. Neutron multiplicities ν are important for the control of the neutron flux inside the reactor. Fission fragment isotopic yields and neutron multiplicities, their evolution with neutron energy are relevant data for model developments. The high neutron intensity in the energy range available at NFS combined to the possibility to use radioactive actinide targets makes it a unique tool to study actinide fission.

The emitted prompt neutrons during the fission process is of great interest for the understanding of the mechanisms of fission, as their multiplicity as well as their energy reveals the total excitation energy that is gained during the descent from saddle to scission and shared among the two fragments.

The Los Alamos or Madland-Nix model [1] has been commonly and successfully used over the years to predict the spectrum and the average number of prompt neutrons, as functions of both the fissioning systems and its excitation energy. However, this model cannot reproduce more differential data as the multiplicity distribution or the dependence on the mass split, as it does not follow the neutron evaporation chain in detail, but instead averages over the decay chain.
Recent theoretical works based on Monte Carlo simulations have tempted a better approach by describing the prompt decay of the fission fragments with the Weisskopf-Ewing statistical prescription [2, 3]. This theoretical description is based on two main parameters, the total excitation energy and how the total excitation energy is shared between the two fragments.
The total excitation energy TXE gained in fission is defined as:

$$TXE(A_L, Z_L, A_H, Z_H) = Q(A_L, Z_L, A_H, Z_H) + B_n(A_c, Z_c) + E_n - TKE(A_L, A_H)$$

Where A_c, Z_c are the mass and charge of the fissioning nucleus, A_L,Z_L and A_H,Z_H the mass and charge of the light and heavy fragments, respectively. $Q(A_L, Z_L, A_H, Z_H)$ is the energy release in the fission, which is the difference between the fissioning nucleus mass and the sum of the two fission fragment masses. B_n is the binding energy of the incoming neutron, E_n its kinetic energy, TKE (A_L, A_H) is the kinetic energy of the fission fragments. If the kinetic energy of the fission fragments has been intensively measured [4, 5], the isotopic distribution is poorly known, and the energy release Q is deduced from the unchanged charge density assumption (Zc/(Ac-ν)=ZH/AH=ZL/AL). However, measurements of the isotopic fission fragments distribution [6,7] have shown that deviation from this behaviour is being observed, which induces important discrepancies on the estimation of the energy release, and consequently in the estimation of the emitted neutrons. In addition, in the most advanced version of calculations [8], the neutron multiplicity dependence on the mass distribution can be reproduced only introducing arbitrary parameters to simulate the unknown energy sharing between the two fragments.

The most prominent feature of fission of actinides is the asymmetry of the mass split, with the heavy peak remaining essentially constant in position as the mass of the fissioning nucleus increases. This feature is accounted for the influence of the strong neutron shell gap N~88 at large deformation, and to a less strong effect to the spherical neutron shell gap N=82. The energy available for neutron emission in each fragment is the difference in energy between the scission point and ground state shapes, plus any intrinsic excitation energy, rather limited compared to the deformation energy. Therefore, the multiplicity of emitted neutrons is a probe on the deformation energy at scission and the corresponding neutron numbers playing role in the deformation. This is well described by the Brosa model [9], which reproduces the number of emitted neutrons as a function of the mass of the fission fragment for spontaneous fission of Cf and Fm isotopes.

An exhaustive study of this correlation between neutron multiplicity and fragment masses or charge over a large range in energy and nuclei is the goal of the present proposal. The measure of the two velocities and two residual energies [10-11] has proven to be a very efficient method to deduce the multiplicity of the emitted neutrons as a function of the mass of the fragments. The proposal intends to use this method, and to add an array of X-rays detectors in order to determine the elemental yields [12], and provide a unique information on the multiplicity of emitted prompt neutrons for each combination of fission fragments determined isotopically (A_H, Z_H, A_L, Z_L). This will allow to determine the influence of both proton and neutron number in the asymmetric split and deformation of the fragments.

Experimental details:

The experiment is devoted to fission fragment mass and charge distribution measurements, in correlation with the neutron multiplicity. The 2V method (measurements of both fragment velocities) will be used to obtain fragment masses prior their neutron evaporation [10-11]. This method is meaningful only when the mass of the fissioning system is known. It is then foreseen to perform first measurements below the threshold of the second chance fission channel ($E_n < 6.5$ MeV). The velocities will be measured with two TOF (Time-Of-Flight) arms. The limitation of this technique is linked to the intrinsic dispersion brought by neutron evaporation which degrades the resolution.

Secondary electron detectors (SED) are good candidates to reach the desired resolution with a good efficiency [13]. Indeed, such detectors can have large dimensions with efficiency close to unity and excellent time resolution. The dispersion induced by the thin foils is small and the grids are almost transparent (90 %). The fission fragment detectors will then consist of two collinear arms equipped with two -SED detectors each. Two foils of 10 cm x 40 cm will be placed at 10 cm from the target and the two others at 50 cm. The geometrical acceptance is then ~ 0.5 %. The target will be placed at 5 m from the converter. The neutron flux at 5 MeV has been evaluated at 1.8×10^6 n/cm^2/s/MeV (**for deuteron intensity of 50 pμA**). The thickness of the target has been fixed to 150 μg/cm^2 in order to limit the energy straggling of the escaping fission fragments, leading to a fission rate of about 10 fiss/s for each neutron energy bin of 1 MeV. To calculate the beam time needed, a statistics of 500 events for a fragment yield of 1% is required. Taking into account the geometrical acceptance (0.5%), twelve days (36 UT) of beam-time will allow to reach the desired statistics.

The addition of silicon detectors to stop fragments and measure their residual energy allows for the 2E-2V method [10-11]. With this method, a resolution of 0.8% (dA/A) is expected assuming a resolution of 0.5 % for the energy and 50 ps for the time. The 2V method provides the velocity (the neutron emission does not modify the average fragment velocity). The initial masses will be deduced from these velocities. The final energy measurements (2E method) will provide the final masses. The neutron multiplicity will then be deduced from these two measurements. In addition, TKE measurements will be provided. Assuming two silicon walls covering approximately the same area than SED, the measurement would be achieved in parallel with the 2V experiment described in the previous paragraph.

The charge of the fragment will be identified using low energy photon (X-ray) detection. Six LEPS (Ge) detectors (10 cm^2) will be placed at 4 cm from the target. The geometrical efficiency will be 30% of 4π. The intrinsic efficiency being close to 1, a good statistics is expected for the charge distribution.

The beamtime request is fixed by the statistics needed for the 2E-2V experiment, knowing that in 30% of the events the isotopic identification will be achieved. Therefore the typical beamtime request is 36 UT per target.

NOTE: During the time that the deuteron beam is limited to 10 pμA (as mentioned in the present document), it is foreseen to run the commissioning of this experimental programme using ^{235}U and ^{238}U target. If the beam intensity is limited over a larger period, the proposed experiment (2V or 2V-2E) would need 60 days to reach the required statistics. Such experiment duration is typical for fission measurements providing data with good accuracy. Another possibility to keep the beamtime of the order of the proposed 12 days is to increase the neutron beam energy bin (from 1 MeV to 2MeV) and to decrease the statistical accuracy from 4 to 6 %.

Some discussions are ongoing for the medium-term program. A compact and very high performance setup is foreseen. The goal is to use the energy deposition in gas to evaluate the charge of the fragment and to combine the energy to a velocity measurement (TOF) to get the mass. The ensemble has to be compact to be placed close to or inside a high efficiency neutron detector like CARMEN (a liquid scintillator detector from CEA Bruyères-le-Châtel). This type of detector would provide the neutron multiplicity with a high accuracy. Experiments with such a detection system are foreseen for 2014.

References

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