GANIL
PROPOSAL FOR EXPERIMENT

EXP # : (Do not fill in)	Scheduling period : **June 2005 – May 2006** Dead-line for submission : **September 17th, 2004**

- If Be or Ni production targets are to be used, indicate the maximum beam intensity the target can handle.
- Fill in the Security section if you intend to use LN2 or explosive gas (even in Speg chambers or germanium detectors).
- If you need to accelerate more than one beam or energy (stable or Spiral), include the beam tuning time in your requested number of beam UTs. If not, the experiment will not be scheduled all at once.

Please contact Gilles de France if you want to use the Exogam germanium detectors.
Parasitic beam time is not always possible. If it is essential for you experiment, it should be included in the requested number of UTs.

Title[*]**: Level density parameter determination for different isotopes**

Is it a follow up experiment? No

Spokespersons (if several, please use capital letters to indicate the name of the contact person):
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Other Participants or Organisations:

See the proposal for the participant list

Abstract : The advent of radioactive beams, coupled to judiciously chosen targets, allows for the very first time to explore the properties of a large number of isotopes of compound nuclei of a given Z, and in correlation, to test the mass asymmetry of the entrance channel on the fusion cross section. The aim of this experiment is to explore the deexcitation properties and thus level density parameters with N/Z of hot nuclei when going from the proton drip line to stable nuclei.

Beam Line: **G1**	If Lise is requested, Wien Filter? No Yes

	Ion(s)	Energy (A.MeV)	Intensity (nAe)
Primary Beam(s)	**^{36}Ar**	**95**	**max**
Beam(s)	**^{36}Ar^{10+}** **^{40}Ar^{10+}**	**11.5** **11.1**	**5 10^7 pps** **5 10^7 pps**
Spiral Beam	**^{33}Ar^{10+}**	**11.7**	**>5.10^4 pps**

Will you need Sissi ?	No	If yes, Sissi Target(s) and Thickness(es):
Lise production target ?	No	If yes, Lise Target(s) and Thickness(es):

Requested number of beam UTs (1 UT=8h): **53 UTs**	Time required for setting up the apparatus: Time required for offbeam calibration and dismount:

On what date would you be ready to run: 2006 Excluded periods: 2005

Acquisition system: Ganil Specific

Security, use of hazardous equipment :
(Radioactive target, liquid nitrogen, explosive gas etc.)

Comment : We need to move out the INDRA multidetector into G1 and to couple it with the Vamos spectrometer

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[*] If needed, to unlock this form, point to "Unprotect Document" on the Tools menu

Level density parameter determination for different Pd isotopes

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1 Motivations

Deexcitation of hot nuclei formed by fusion reactions (complete or incomplete) has been widely studied in the past. Experimental observations put some constraints on statistical model parameters, which depend not only on the characteristics of the exit channels, but also on the characteristics of the entrance channels which lead to fusion (critical angular momentum, preequilibrium). Thus incomplete fusion, linked to the fast emission of nucleons before the compound nucleus reaches thermal equilibrium, already occurs at 6 or 7 A.MeV for light systems [1].

To our knowledge experiments performed up to now on this subject consisted in inclusive measurements, determining either the mass (charge) distribution of evaporation residues, and eventually fission products or multiplicities of light charged particles associated with fusion. Compound nuclei formed by reactions between stable medium-mass to heavy projectiles and targets were all proton-rich. The advent of radioactive beams, coupled to judiciously chosen targets, allows for the very first time to explore the properties of a large number of isotopes of compound nuclei of a given Z and, in correlation, to test the influence of the mass asymmetry of the entrance channel on the fusion cross section.

In this experiment we aim at obtaining highly exclusive data by detecting event by event the residue and all the associated charged particles. The fundamental goal is to explore the variation of deexcitation properties and thus level density parameters with the N/Z of the compound nucleus when going from the proton drip line to stable nuclei.

2 Level density parameters

Nuclear level densities are fundamental quantities which govern the statistical decay of excited nuclei and determine the properties of hot nuclei (many-body effects). Knowledge of the level density is thus highly needed at low and high excitation energy and for the largest possible range of N and Z, from β stability to the drip-lines.

2.1 Experimental determination of level density parameters

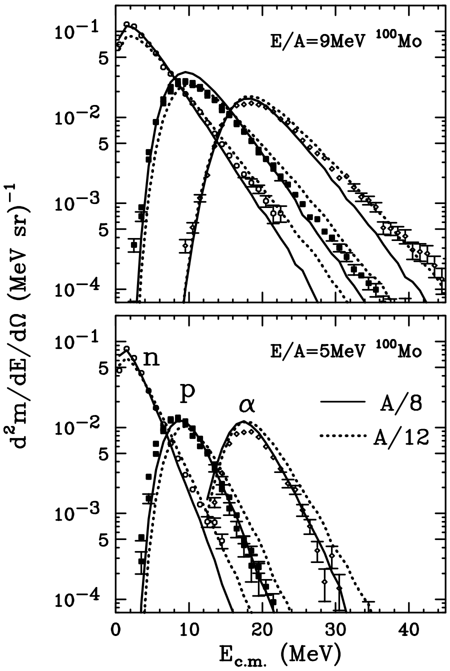

FIG. 1 – *Comparison of experimental energy spectra with calculation using level density parameter of A/8 and A/12, from [2]*

The density of states can be related to the excitation energy E* and the level density parameter $a = \alpha A$ by: $\rho \simeq exp[2.\sqrt{a.E^*}]$. This is the Fermi-gas expression, obtained in a single particle-model and used in most statistical model calculations. Collective effects (many body and effective mass) can be included by using an effective a which depends on excitation energy. While a cannot be directly measured at high energy, the temperature T and $\frac{1}{T} = \frac{dln\rho}{dE^*}$ can be extracted from the exponential slope of kinetic-energy spectra of evaporated particles. Multichance emission is taken into account by comparison with statistical model calculations like GEMINI. Comparison with calculations [3] will constrain the dependence of a with E* and T and verify the consistency with other data for known isotopes, see fig 1. INDRA is able to measure such kind of variation on the slope of the kinetic-energy spectra for all reaction products. An additional strong constraint on the values of a for nuclei along the deexcitation chain will be provided by the correct weighing of the different exit channels, which was never measured up to now. All decay chains will be measured (isotopic composition of emitted particles and their multiplicity added to the residue characteristics (A, Z) and their kinetic energies event by event) and we will obtain the percentage with which different chains lead to the same residue. The energy spectra (slope) of all deexcitation products will provide information on temperature for all decay chains. As a simple example, in our experiment the Ni(Ar,αxn)Ru channel will be distinguished from the Ni(Ar,2p(x+2)n)Ru and Ni(Ar,pd(x+1)n)Ru channels and correctly weighed.

2.2 N/Z effects

The predicted isospin dependence of level density parameter is very small in the Fermi-gas model, $a \simeq mA[1 - \frac{1}{9}(\frac{N-Z}{A})^2]$. A significantly larger dependence would have important implications for other fields (r-process). Experimental data far from the valley of stability are very scarce; Different extrapolations starting from stable nuclei lead to empirical parametrisations of the form $a = \alpha A/exp[\beta(N-Z)^2]$ [4]. Those parametrisations lead to quite important variation on the estimated values of the level density parameter, see figure 2. The availability of stable and radioactive beams at Ganil offers a great chance to perform precise measurements on a large range of isotopes. [5].

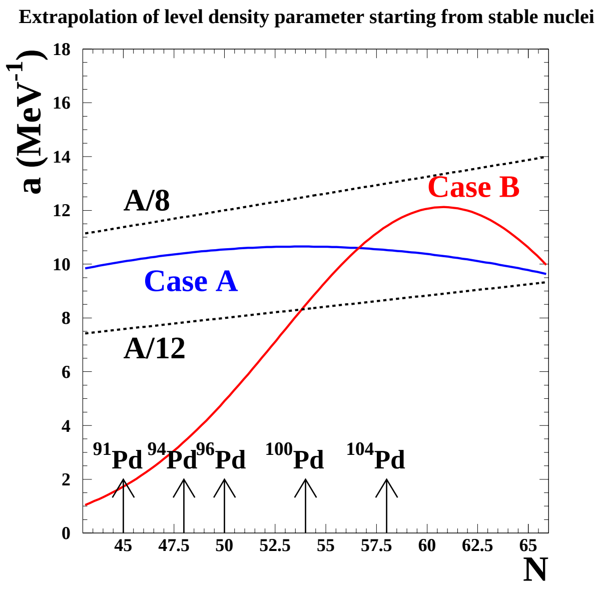

FIG. 2 – *Evolution of the level density parameter according to two different parametrisations for different Pd isotopes, see [4].*

We want to strongly underline that for the very first time, SPIRAL beams offer the unique opportunity to study complete deexcitation properties of several isotopes formed in the same conditions. In the context of the future program of multifragmentation studies with isospin (EURISOL, FAZIA, CHIMERA-PS...), information on the basic thermodynamical properties of nucleus (level density parameter, limiting temperature...) from the neutron-poor to the neutron-rich side are of fundamental interest.

3 Experimental details

3.1 Colliding systems

We propose to study the deexcitation properties of Pd nuclei formed in collisions between different Ar projectiles from ^{33}Ar to ^{40}Ar and three Ni targets (^{58}Ni, ^{60}Ni and ^{64}Ni) at incident energies around 11 A.MeV. This energy is a compromise between not too large preequilibrium effects and sufficient recoil energy for nuclear charge identification of residues.

91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	$_{46}$Pd
33UT			3UT		3UT				3UT				3UT							
^{33}Ar +			^{36}Ar +		^{36}Ar +				^{40}Ar +				^{40}Ar +							
^{58}Ni			^{58}Ni		^{60}Ni				^{60}Ni				^{64}Ni							

The ^{33}Ar beam is extremely important since it allows to touch the p-drip line in forming ^{91}Pd.

Depending on model the drip-line is predicted to be between masses 84 and 89 [6]. In this case special deexcitation properties might be observed. With the stable ^{36}Ar beam coupled to the ^{60}Ni target the semi-magic nucleus ^{96}Pd is made. Finally the easy made ^{36}Ar and ^{40}Ar coupled with two targets will provide some intermediate isotopes (and will be mandatory to tune the experimental device). Five Pd isotopes will thus be sampled.

The exact incident energies will be chosen to get the same excitation energy per nucleon of compound nuclei while the angular momentum ranges should not vary too much. Recoil energy criteria should allow to determine whether the observed reactions are mostly complete or incomplete fusion [1]. It will be interesting in this latter case to see if we can distinguish the particle(s) emitted before equilibrium (linear momentum criteria?) and then obtain information about their properties.

Producing with SPIRAL ^{33}Ar beams with good intensities is certainly a challenge, but it gives GANIL a unique opportunity to reach and study nuclei which could not be produced before.

3.2 Experimental set-up

We will couple INDRA (for light charged particle identification) and the VAMOS spectrometer (for evaporation residue detection). The detection efficiency is maximized thanks to the 4π angular coverage, which allows the use of low intensity beams. Indeed a 4π multidetector works in all cases with low intensities $\leq 10^7$ pps. Complete events (detection of the total charge of the incident system) will be selected, the charge and mass of the residue given by VAMOS and those of all light charged particles and fragments by INDRA. The multiplicity of the undetected neutrons will be obtained by mass difference. The 4π angular acceptance allows to differentiate more easily fusion reactions from deep inelastic collisions.

Keeping INDRA in its own reaction chamber and removing only the first three rings (angular acceptance 7-176^o) allows to set the entrance of the first VAMOS quadrupole at $\sim$130 cm of the target. We may need different angular positions of the spectrometer to cover the residue angular distribution ($\sim 0-20^o$) and to avoid any bias of the relative weights of the different exit channels. VAMOS will give the mass and the atomic number of the residue with a good accuracy provided that the ΔE resolution of the focal plan detection is $\simeq$3%. Concerning the residues charge state we will use a carbon foil of about 70μg/cm^2 at a distance of about $\sim$50 cm from the target in order to reach the equilibrium charge state distribution [2], independently of the compound nucleus production position within the target. The mechanical coupling between INDRA and VAMOS allows the rotation of VAMOS but reduces the angular acceptance for the residue to $\Delta\theta=\pm 4^o$.

4 Required beams

Target			^{58}Ni			^{60}Ni			^{64}Ni
Beam	E$_{beam}$/A	pps	c.n.	E$_{beam}$/A	pps	c.n.	E$_{beam}$/A	pps	c.n.
^{33}Ar	11.7	5.10^4	^{91}Pd						
^{36}Ar	11.5	10^7	^{94}Pd	11.5	10^7	^{96}Pd			
^{40}Ar				11.1	10^7	^{100}Pd	11.1	10^7	^{104}Pd

Tab. 1 –

In addition to stable ^{36}Ar and ^{40}Ar beams, we want to use radioactive beam of ^{33}Ar, see table 1. It is important to note that, for the very first time, we are able to study the thermodynamical properties of different isotopes in quite the same conditions of formation and detection. The 10$^+$ charge state will be necessary to reach the required beam energy and should reduce the amount of polluants for all requested beams. This may drastically affect the intensity (12% for ^{40}Ar charge state 8$^+$ against 6% for 9$^+$ and 2% for 10$^+$) and thus preliminary machine tests are necessary to establish the available intensity of ^{33}Ar^{10+}.

With ^{58}Ni, ^{60}Ni and ^{64}Ni targets we expect fusion residue cross sections of $\simeq$0.8-1 barn, similar to experimental results for ^{40}Ar+Ni [7] and ^{32}S+^{59}Co [8]. Target thicknesses of 300μg/cm^2, leading to an energy loss of about $\simeq$0.12 A.MeV for the considered residue, appear as a good compromise between a large enough number of events and a still sufficient residue velocity for identification. According to GEMINI residue calculations an amount of about $\simeq$ 40-50 isotopes are produced for typical excitation energies of $\simeq$2.5 A.MeV.

Moreover a small beam emittance is necessary to enter in INDRA (1-2 π mm.mrad) which will require to check the background rate with a target frame only. Tape recording will be triggered by the detection of a residue in VAMOS and at least one coincident particle with INDRA.

4.1 Counting rate and beam time

According to GEMINI simulations the entrance window opening between INDRA and VAMOS ($\Delta\theta=\pm 4^o$) limits the detection to one third-one fourth of the residues produced, so three angular positions of the VAMOS spectrometer will be needed. For a good study of 25 of the most produced different deexcitation channels a statistics of about 10^3 events per isotope is required meaning $\simeq$2.5 10^4 events by beam. Up to now few tests have been done on the Ar radiocative beam at GANIL. We have calculated that for minimum beam intensities of the order of 5.10^4 particles per second, with fusion cross sections of about 1 barn our predictions lead to about $0.7\text{-}1.10^3$ events/TU. Thus a request of 33 UT for ^{33}Ar beam seems to be a minimum, including the different VAMOS Bρ settings needed. For the stable beams ^{36,40}Ar we have estimated, that for a minimum beam intensity of 10^7 pps, one day per beam will be sufficient. So an amount of 11 days + 4x1 days=15 days, 45 UT are requested (11 days, 33 UT for radioactive beam). Moreover 2 beam changes at 2 UT, 1 UT for background measurement and also calibration beams for INDRA (3 UT) are necessary, leading to $\simeq$8 additional UT. For calibration we foresee to use the primary beam of ^{36}Ar at 95 A.MeV (necessary for ^{33}Ar radioactive beam) impinging on a ^{58}Ni target and use this reaction for comparison with the data registred during the first INDRA campaign, used as reference, for the same system. An amount of 53 UT is requested.

Références

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