Name of the device **SPEG**

Name of the group leader

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Date **30/09/2008**

This template is the expected out-put of the various groups working on the future of a specific device of the GANIL facility.

1 History of the device

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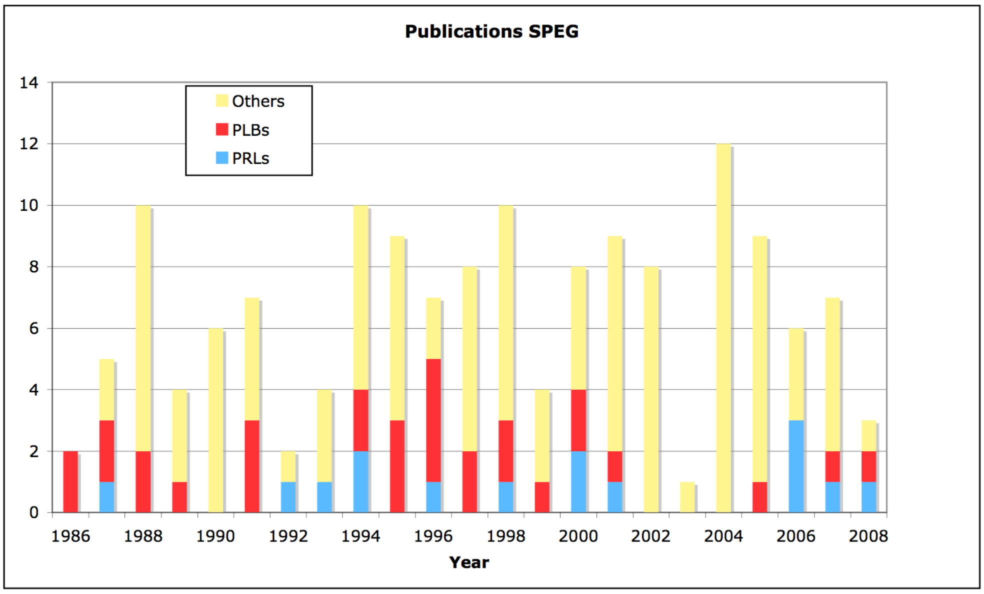
1.1 Short presentation and history of the device

SPEG (Spectromètre à Perte d'Energie du Ganil) is a high-resolution instrument, initially designed with the aim of precisely measuring the momentum of high-energy stable beams. To achieve the required performance (10^{-4} or better in momentum resolution), and given the momentum dispersion of the incident beam (a few 10^{-4}), an energy-loss spectrometer (see description in 2.1) with a high focal dispersion was built. Details are given in L. Bianchi et al., Nucl. Instr. Meth. A 276 (1989) 509. The detection ensemble around the focal plane allows the measurement of the trajectories (thus the position at the focal plane), the energy of the particles and the timing with respect to a reference detector placed upstream (or the RF of the accelerating cyclotrons).
The first experiments, in the '80s and beginning of the '90s, concerned mainly two topics: a) measurement of the angular distributions from the elastic and inelastic scattering and transfer reactions induced by stable heavy ions (^{12}C, ^{16,17}O, ^{20}Ne, ^{40}Ar, ^{86}Kr…) on various targets (Si, Zr, Pb), with particular interest in the excitation of giant resonances; and b) the mass measurement of exotic nuclei, produced by fragmentation in a target placed after the extraction from the second cyclotron (CSS2), via measurement of the time-of-flight and magnetic rigidity of the ions. The second topic has remained a highlight of the activity of SPEG throughout the years and to this day.
The mechanism of energy dissipation in heavy-ion reaction was investigated in a series of experiments by detecting high-energy photons emitted in the collisions.
In the mid-90s the first measurements on the spectroscopy of unstable nuclei took place, with the elastic scattering, charge-exchange and transfer reactions on exotic beams (of ^{6}He and ^{11}Be) and multi-nucleon transfer reactions to produce unbound systems (^{11}N). In particular elastic scattering and reactions on light targets in inverse kinematics have been extensively used for the study of exotic nuclei, and have driven the development of ancillary charged-particle detectors such as MUST and MUST2.
From the end of the '90s in-beam gamma-ray spectroscopy started to be performed by coupling SPEG with gamma-detector arrays placed around the target position. Exotic nuclei were produced by fragmentation, transfer or knock-out reactions. In such cases, SPEG was mainly used for the identification of the projectile-like fragments and thus the reaction channel. Recently, the method evolved to employ exotic beams, produced in turn by fragmentation at SISSI and selected in the ALPHA spectrometer. In one case (^{46}Ar) a post-accelerated beam from SPIRAL was used.

1.2 Statistics about experiments run at/with this device

In the last ten years, about 25 runs for a total of ~20 experiments have been performed using the SPEG spectrometer. The load decreased noticeably in the last two years with only one experiment in the beginning of 2007, due to the problems with the production of fragmented beams by the SISSI/ALPHA device.
Since the beginning of operations, which took place in 1985, about 160 refereed publications directly report results obtained using SPEG, totalling around 2500 citations. Among the publications there are 15 PRLs with more than 420 citations, and 30 PLBs.
In the last ten years (1999-2008) the publications are 67, with 8 PRLs and 7 PLBs.



1.3 Presentation of passed results and highlights

Experiments performed at the SPEG spectrometer cover a wide range of topics:

- Measurement of atomic masses of very exotic nuclei (1 PRL, 5 PLBs) – see also the LISE/SISSI “GANIL 2015” report, section 1.3.a.2.a (“Measurement of ground state properties: masses”)
- Total reaction cross sections of exotic nuclei
- Accurate measurement of elastic and inelastic scattering of stable heavy ions (3 PLBs)
- Study of giant resonances in stable and exotic nuclei using inelastic scattering and charge-exchange reactions (3 PRLs, 4 PLBs)
- Study of the reaction mechanism at intermediate energies through hard-photon emission (4 PRL, 1 PLB)
- Spectroscopy of stable and exotic nuclei using transfer reactions
- Multi-nucleon transfer to produce and investigate new dripline systems
- Proton elastic and inelastic scattering to investigate matter and transition densities of dripline nuclei
- Spectroscopy of exotic nuclei using (double) fragmentation and knock-out reactions, and in-beam gamma-ray detection – for an extensive presentation see

the LISE/SISSI “GANIL 2015” report, section 1.3.a.3.b (“Detailed spectroscopy: in beam spectroscopy and knockout reactions”)

- Measurement of Gamow-Teller strengths using charge-exchange reactions
- Electron emission induced by fast heavy ions in a semiconductor crystal (atomic physics).

2 Present activity

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2.1 Description of the present device.

The SPEG spectrometer is situated in the hall G3. The complete device consists in an analyser (line with quadrupoles and a large dipole DA up to the target point) and in the spectrometer proper, situated after the target point. The target point is the image point of the analyser and the object point of the spectrometer.
Different target chambers can be mounted, according to the desired target-position detection setup. A very large, multi-purpose chamber is used to install charged-particle detection arrays (such as MUST2) in vacuum. A much smaller chamber is used in combination with gamma detectors (such as the BaF2 scintillators of the Chateau de Cristal, or Ge detectors) and neutron detectors.

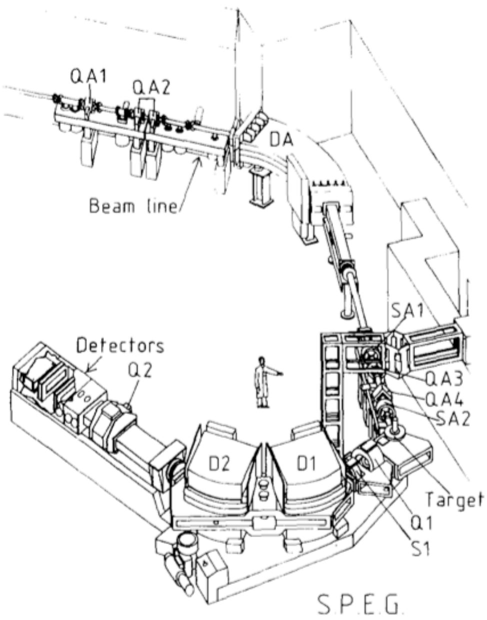


Fig. 1. Aristic view of SPEG.

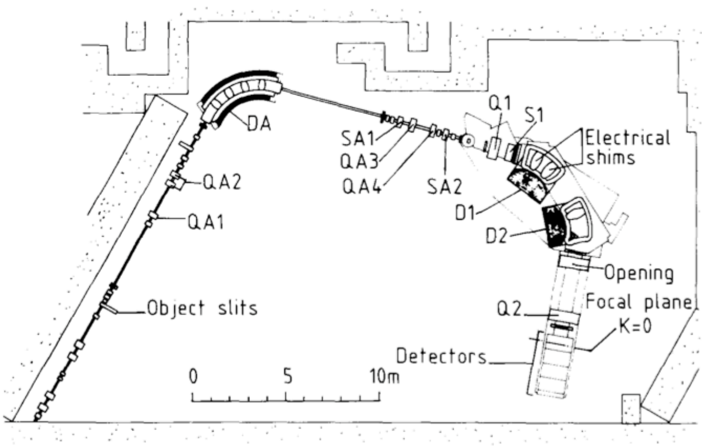


Fig. 2. Overall drawing.

The ensemble of the device is achromatic, i.e. the focal image is not affected by the momentum of the incident particle.
SPEG is an energy-loss spectrometer, it achieves the separation of projectiles based on their energy loss in a target. In presence of material in the target position, the interacting particles changing their momentum by a quantity Δp are separated at the focal plane by the quantity:

$\Delta F = D \times \Delta p/p$

where D is the dispersion of the spectrometer. The beam particles that did not interact are stopped inside the spectrometer before reaching the focal plane.

Characteristics of the analyser

Dispersion	10 m
Horizontal magnification	0.175
Vertical magnification	1
Mean radius of trajectory in the dipole	3 m
Dipole deviation angle	75 degrees
Angle entrance face dipole	23.5 degrees
Dipole maximum induction	1 tesla
Weight	33 ton
Dipole structure	"Window-frame"

Characteristics of the spectrometer

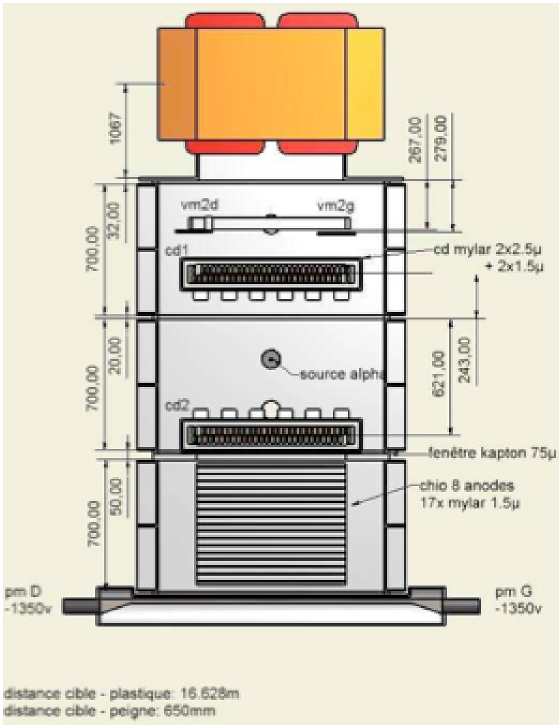
Nominal dispersion (adjustable)	8.1 m
Horzontal magnification	0.8
Vertical magnifcation	4.7
Maximum aperture, horizontal	+/- 2 degrees
Maximum aperture, vertical	+/- 2 degrees
Maximum solid angle	4.9 msr
Mean radius of trajectories in dipoles	2.4 m
Deviation angle of each dipole	42.5 degrees
Angle of exit face of second dipole	24 degrees
Momentum acceptance	7%
Focal length	60 cm
Angle of focal plane	8 degrees
Dipole maximum induction	1.2 tesla
Weight	200 ton
Structure of dipoles, entrance quadrupole and sextupole	" C"
Exit quadrupole	Collins type

Detection ensemble in the spectrometer

The detectors, placed after the spectrometer dipoles, allow identifying the products of the reactions, but also the reconstruction of the momentum distribution (parallel and transverse) and the associated diffusion angles.
The setup is composed of 1) two drift chambers (CD1 and CD2 in the figure) for the measurement of the position (in x and y); 2) an ionisation chamber (CHIO) for the measurement of the energy loss ΔE; 3) a plastic detector for the residual energy E and the time-of-flight (with respect to a beam detector, usually placed immediately before the target).
The focal plane is situated between the two drift chambers.

<u>Remarks</u>

The SPEG spectrometer is fully operative, its performance being very good and up to specifications. With respect to the initial configuration, changes have been made to improve the detection setup, keeping however the same scheme of position- and energy loss measurement.
The design allows for a rotation of the spectrometer between -10 and +105 degrees; at present this is limited between -10 and +15 degrees, due to land movements that changed the floor plane. However, in the history of the device no measurement has been performed requiring a rotation of more than +10 degrees; and in fact this latter reason led to a new design of the detection chambers (which are however replaceable), that already limits the possibility of a rotation of the instrument, favouring on the other hand their overall performance.



2.2 Present pressure and present use of the device, recent experiments, list of proposed experiments and backlog

SPEG is a high-resolution spectrometer, limited in angular acceptance and thus designed to work with high-energy beams, either stable or produced by fragmentation at SISSI. Since the latter is not available, <u>basically no measurements</u> are programmed at SPEG at the moment.
For some approved experiments using fragmented beams, that included the use of a spectrometer (SPEG but also VAMOS), a study has been made to verify the possibility of performing them using the LISE separator, thus on another beam line, instead of the SISSI-ALPHA device. These are experiments that do not require the measurement of the energy of the forward-scattering reaction fragment, and for which an isotopic identification (for example with an ionization chamber) could be sufficient.
Only one experiment is currently in the SPEG backlog: the mass measurement E418, aimed at neutron-rich nuclei around N=40, produced through the fragmentation of the primary ^{76}Ge beam in SISSI.

At the PAC in December 2008 a new proposal has been entered for a measurement with the stable beam ^{40}Ar (E582, J.A. Scarpaci). If accepted, it could be carried out in 2009 or 2010. Also, an LOI has been submitted for the use of a polarized target; the programme focuses on SPIRAL and SPIRAL2 beams, the use of the latter in combination with SPEG is addressed in section 3.3.2 (physics case).

2.3 Planned improvements and evolution

The SPEG spectrometer is fully operative, its performance being very good and up to specifications. At present there are no major improvements planned.
However the electronics of the detection ensemble is rather obsolete, and thus difficult to maintain because of missing spare parts. A renovation will soon be necessary.

3 Future activity

This part is the most important since it presents the scientific prospective for GANIL 2015.

3.1 Interesting improvement of the device

List of interesting improvements for the device and improvements (if identified) related to interfaces with SPIRAL 2 (ex. additional beam line, use of detector developed for SPIRAL2) described here and synthesized in a table. (Priority ordering)

3.1.1 Improvement of the device 1

Related to physics case 1: Physics with beams of fragmented ions.
The spectroscopic studies of very proton-rich nuclei would extend easily to systems where the populated states are proton-unbound. The protons would be emitted in flight at very small angles, entering the spectrometer. The possibility of placing charged-particle detectors at very small angles, inside the spectrometer, should be studied.

3.1.2 Improvement of the device 2

Related to physics case 2: Physics with SPIRAL2 beams.
The detection setup around the focal plane of the spectrometer need be changed to detect the heavy, low-energy nuclei of the SPIRAL2 beams; typically, detectors based on Secondary Electron Detection (SED) should be used (A. Drouart et al., NIM A 579 (2007) 1090).
For some reactions, it may be necessary to improve the momentum acceptance. The present limit, 7%, is dictated by the size of the focal plane detectors. These could however be advanced and placed after the second dipole, thus increasing the momentum acceptance. However the optical properties of SPEG would change; it would be necessary to study if the information (identification, energy, scattering angle of the particles) could still be extracted. In the most extreme case, one could verify if it was possible to rely completely on trajectory reconstruction, using appropriate codes. Even the constraints posed by the small angular acceptance could be lifted by moving the target position downstream – however this would imply a change of the optical mode of the whole beam line.

3.1.3 Improvement of the device 3

Related to physics case 3: mass measurements
Improvements to decrease the uncertainty of the measurements are difficult to achieve: even improving the timing resolution, the uncertainty on the magnetic rigidity (10^{-4}) is a limit of the spectrometer.

3.1.4 Interfaces 1 with SPIRAL 2

Detectors, which are being developed in the framework of the SPIRAL2 project, could be coupled to SPEG for some of the physics cases described in section 3.3. In particular:

- AGATA (gamma detection) is of interest for both fragmented and SPIRAL2 beams.

- GASPARD is mainly meant for the study of direct reactions in inverse kinematics, thus physics case 2 (3.3.2).
- ACTAR is a very versatile instrument. Like GASPARD, it could be placed at the target position of SPEG and used in reaction studies with very weak beams, where the heavy ejectile is then identified in SPEG (the low energy of the SPIRAL2 beams may however pose problems). Or, it could be placed at the focal plane of SPEG to accept a purified beam, obtained using SPEG as a separator; this could be achieved using the dispersion capability of SPEG, provided different ions have different charge states (use of a stripper foil).

3.1.5 Synthesis

	Number	Description	Comment
Interesting modifications	1.	Charged-particle detection at very small angles.	Possibility of placing detectors inside SPEG, after the first quadrupole or the sextupole, to be studied.
	2.	Focal plane detection to be adapted for the heavy, low-energy nuclei from SPIRAL2 beams.	Use of SED-based detectors such as the ones in VAMOS.
	3.	Change of the “normal” SPEG optical modes with the intent of improving on the momentum and angular acceptance: Move the focal plane detectors upstream; Move the target position downstream.	Trajectory reconstruction to be used to extract information: to be verified. To move the target position (focal point) the optics of the entire beam line need be recalculated.
Interfaces with SPIRAL 2	1.	Detector arrays at target position: AGATA, GASPARD, ACTAR.	No particular problems. Maximum acceptable beam intensity would be low for ACTAR (~10^5 pps) and probably limited in GASPARD too.
	2.	ACTAR at the focal plane, SPEG used as separator.	Different nuclei in the beam need to have different charge states to achieve separation. Radioactivity possibly an issue with very intense contaminants (general SPIRAL2-related issue).

Table 1: Possible improvements of the device (priority ordering)

3.2 Interesting improvement of the GANIL facility

List of interesting improvements of the GANIL beams (including SISSI2) described here and synthesized in a table that follows.

3.2.1 GANIL Beam improvement A, B

The most interesting improvement for GANIL (fragmented) beams, for experiments to be performed at SPEG, concern the intensity. SPEG allows measurements in conditions of extremely low background, thus the limitation is most of the times represented by the count rate. Higher beam intensities could allow a better precision (better statistics).
In addition, a larger Bρ of the SISSI-ALPHA device would allow a wider range of available beams on the neutron-rich side of the chart of nuclei. Among other cases, mass measurements would benefit from an upgrade.

3.2.2 SPIRAL Beam improvement C, D

The SPEG spectrometer is not the most suited instrument at GANIL to be used with *light* SPIRAL beams, because of its low angular acceptance. Improvements of SPIRAL beams are therefore not relevant. For heavier beams, see below the case for SPIRAL2.

3.2.3 Interesting SPIRAL2 Beam in GANIL existing caves E, F

Beams of fission fragments from SPIRAL2 could be used in SPEG for the measurement of direct reactions in inverse kinematics (3.2.2 Physics case 2).
Very intense beams could possibly be used; in this case the primary beams would be stopped in one of the existing Faraday cups mounted on retractable arms (also at zero degrees). Residual activity from long-living decay products is here a concern. Each mass case should be studied.
To perform study of the most exotic nuclei, for which intensities are predicted in the order of ~10^5 – 10^6 pps, it is essential that the beams be as isotopically pure as possible, in principle already before injection in the CIME cyclotron.

3.2.4 Synthesis

	Number	Description	Comment
Interesting GANIL beam improvements	A.	Increase in intensity of the most neutron-rich and neutron-deficient stable beams.	Each improvement reflects directly on the recorded statistics.
	B.	Increase the max Bρ of the SISSI/ALPHA device and the beamline.	Wider range of secondary beams on the neutron-rich side.
Interesting SPIRAL beam improvements	C.	---	---
	D.	---	---
Interesting SPIRAL2 beam	E.	Intense beams of fission fragments, provided the residual activity is acceptable.	To be evaluated case-by-case for each mass.
	F.	Weak beams of the most exotic nuclei for a total intensity of ~10^5-10^6 pps	Need isotopic purification, most probably before CIME. Acceptable contaminants of the order of 50%.

Table 2: Possible improvements of GANIL beams (priority ordering)

3.3 Physics case

Analysis of the interesting future physics case associated with the present device and present beams and future improvements (described here and synthesized in a table). This analysis should include an evaluation of the importance of the proposed physics case and a proposition of priorities should be made.

Preliminary considerations

These remarks are based on the replies to the questionnaire sent to users, and to the feedback/discussion which took place in the occasion of the "GANIL 2015 Workshop" on October 23 and 24, 2008.

Use of SPEG

SPEG is an instrument initially conceived to work with stable beams and reactions in direct kinematics. It ensures the complete identification of the reaction products (and thus the reaction channel), together with a very accurate measurement of the energy and angular distributions of the products.
It has then proven very effective using the high-energy beams, produced by fragmentation reactions in the SISSI device and analysed in the ALPHA separator. Two typologies of measurements were carried out:

1. Inverse-kinematics measurements with light beams; the channel of interest was identified in SPEG, which was at the same time used to measure angular distributions – which was essential for these measurements. Transfer, knock-out, elastic, inelastic and charge-exchange reactions were used for spectroscopic studies (of the projectile or the reaction product).
2. In-beam gamma spectroscopy of nuclei produced by fragmentation (in front of SPEG) and double fragmentation (of beams produced by SISSI). In this case, SPEG was only used for the identification of the produced nuclei (to perform a coincidence measurement).

For measurements as in 1., SPEG offers the best performances at GANIL. In reactions of type 2., even though the full capabilities of SPEG are not exploited, the identification of a nucleus is obtained among a large number of isobars and isotopes produced at the (second) fragmentation point. To achieve this goal a spectrometer is necessary.

Replies to questionnaires

- Several researchers and research groups (IPNO, Bordeaux, Milan, Saclay, Liverpool…) insisted on the importance of fragmentation at GANIL. Among them, those who indicated physics research programs which would require a spectrometer such as SPEG were:
  - Milan, for the study of pygmy resonances with inelastic scattering (also with stable beams);
  - Liverpool, for spectroscopy using knock out reactions;
  - IPNO, for complete kinematics detection of the reaction products using p-rich nuclei and the search for excited 0^+ states via inelastic and transfer reactions (see below 3.3.1 Physics case 1).

  The measurements above require the measurement of the energy and/or angular distribution of the products, thus a spectrometer.

- Some replies pointed to the possibility of installing a spectrometer behind LISE if it was not possible to replace SISSI, and use LISE as primary separator ("SPEG behind LISE").

- It was pointed out (Bordeaux, IPNO) that it is likely that SISSI/ALPHA will not be competitive in a few years. Proposed alternatives varied, with suggestions for replacing SISSI/ALPHA with something much more powerful on one side; and requests to concentrate directly on SPIRAL2 and the post-acceleration of radioactive beams to high energies (and, in future, fragmentation of such beams), on the other. Clearly, SPEG would only benefit from the first solution.

- Some groups (Milan, IPNO) mention the possibility of using SPIRAL2 beams in SPEG for the same physics topics mentioned above for fragmented beams. See 3.3.2 Physics case 2.

In summary, there were indications of a) the necessity of keeping fragmentation at GANIL, b) some physics programmes that would require a powerful spectrometer. This could be SPEG if SISSI is replaced, however the possibilities look somehow limited if the new SISSI/ALPHA is not improved significantly. An alternative scheme is to build a spectrometer behind LISE.
Independently from this, SPEG remains available for measurements with stable beams (Milan, J.A. Scarpaci proposal at the PAC in December) and SPIRAL2 beams (but see below).

3.3.1 Physics case 1

Spectroscopic studies of exotic nuclei using fragmented ion beams

The production of radioactive ion beams using fragmentation gives access to the most exotic species of the chart of nuclei. Spectroscopic studies are often possible using different methods; for such cases, the SPEG spectrometer is the best instrument available at GANIL for the measurement of the projectile-like particle. Because of limitations in the Bρ that can be attained, very neutron-rich nuclei are however difficult to reach.

- *In-beam gamma spectroscopy of proton-rich nuclei.*

  Reactions of beams on a secondary target positioned at the object point of SPEG can be used to produce proton-rich nuclei at and beyond the dripline. Such reactions include fragmentation, proton removal (knock-out), and inelastic scattering. Nuclei are created in excited states, which may decay either by gamma or proton emission. The structure of such states (position, gamma- and proton-decay widths), have implications for both nuclear structure (i.e. mirror symmetry) and nuclear astrophysics. For proton-unbound resonances, especially for systems beyond the dripline, the detection of protons emitted in flight may reveal peculiar decay modes (correlation between two-proton emission).
  The detection of the gamma rays would be ensured by a large and efficient array, ideally AGATA. In the case of proton decay, depending on the energy available, protons may be emitted at very small angles and thus enter SPEG: a system should be envisaged in order to detect such protons in the spectrometer. By detecting the energy of the heavy fragment in SPEG, the invariant mass method can be applied.
  The most neutron-deficient primary beams are the ones of interest here (^{40}Ca, ^{36}Ar, ^{32}S, ^{24}Mg).

- *Search for excited 0^+ states in neutron-rich nuclei by using two-nucleon transfer and/or inelastic scattering.*

  Pair transfer reactions around zero degree are in principle the perfect tool to populate excited 0^+ states in even-even nuclei. This type of reactions could be used in inverse kinematics with exotic beams in order to search and locate excited 0^+ states in even more exotic nuclei. Appropriate light targets (Li, Be, B, C) could be used in order to have the most favourable reaction Q-value for two nucleons stripping or two nucleons pick-up reactions. Besides the general study of pairing vibration modes and their evolution in loosely bound nuclear systems, the location of 2p-2h excited 0^+ states in some regions of nuclei, such as neutron rich around N=20 and N=28, should allow to establish the concept of shape coexistence resulting from the weakening of these spherical shell effects. In addition, the location of higher lying 2p-2h excited 0^+ states in unstable nuclei should give some insight on shell gaps between unoccupied orbitals otherwise inaccessible. SPEG will be used in a dispersive mode in order to single out excited states in the outgoing A+2 or A-2 projectile and study their angular distribution around zero degree. Light particle detectors (for better selection of the reaction channel and background reduction in the SPEG spectrum) and gamma-ray detectors (for the increase of the resolving power for individual excited states) could be used in conjunction with SPEG.

- *Charge exchange reactions to study GT strength in proton-rich nuclei.*

  Charge-exchange reactions using high-energy proton-rich beams is a tool of significant interest for nuclear structure and, indirectly, nuclear astrophysics. Of particular interest are the (n,p)-type reactions which enable GT strength to be probed above the Q_β window. Indeed, in nuclei such as ^{56}Ni, very strong or "super" GT transitions are predicted in this region of excitation energy. Such measurements are also of importance for deriving electron capture rates in supernova core collapse.
  Reactions of the (p,n) type would allow more proton-rich nuclei to be reached and the selection-rules governing the reaction should provide some insight to be gained on the structure of the levels populated.
  Experimentally the highest energy (90 MeV/nucleon) proton-rich beams would be employed with the heavy fragment resulting from the reaction being detected and momentum analysed in SPEG. SPEG operated in dispersion-matched mode would be sufficient for mapping the main features of the GT strength. Coupling with a gamma-array such as EXOGAM or, eventually AGATA, enable 10 keV or better resolution to be derived.

3.3.2 Physics case 2

Reactions with post-accelerated beams

With the availability of intense post-accelerated beams, the whole range of nuclear reactions can be used as spectroscopic tools on the radioactive ions. Elastic and inelastic scattering, but also transfer reactions (as they already are used with the light nuclei produced by SPIRAL). One-nucleon transfer reactions are particularly powerful: they give access to information such as position, spin and single-particle structure of states. We investigate here the possibilities of using SPEG in these measurements.
The SPEG spectrometer has a lower acceptance than other instruments at GANIL. However, the disadvantage is not important when the mass of the incoming beam is large, because the kinematics of the reaction is very forward peaked. For example, for (d,p) reactions at the energies of SPIRAL2 beams (6 MeV/nucleon), and masses of the incoming beam larger than about A=60, both the angular (+/-2 degrees) and momentum acceptance (7%) of SPEG are sufficient to detect the reaction ejectiles in the full centre-of-mass angular range.
SPEG could then offer the advantages of a) an effective primary beam rejection (a beam with given A and Q remains localised), and b) a relatively simple operation mode for the identification of the particle Z and A.
We can picture two modes of operation:

1. For transfer reactions on light targets, such as (d,p), the light recoil is detected in highly segmented detectors (MUST2, GASPARD). The angular distribution of the cross section is extracted from the light particle spectra. SPEG is used to identify the heavier partner (A and Z identification only).
2. Inelastic and transfer reactions could be performed on heavier targets (for example C, possibly heavier). In this case, coverage of the whole angular range would be obtained by placing SPEG at different angles. SPEG would provide

the identification of the exit channel (particle identification and its energy) and the angular distributions, of course with a limited resolution (few points only for the whole c.m. range). Simpler detectors around the target would be sufficient to additionally tag the reaction channel.

The following considerations need be made:

- In both cases, improvements would be necessary concerning the detection setup at the SPEG focal plane, in order to ensure the detection of the heavy ejectiles at relatively low energies.
- The rejection of the primary beam can be achieved in SPEG by stopping it in the existing Faraday cups mounted on retractable arms at several positions (including zero degrees). This method has been extensively used with stable beams. With radioactive beams, while activation should not be a problem given the low energies involved, a residual activity could be of concern in case long-living isotopes are present in the decay chain. This is strictly related to the mass of the incoming beam, and it has to be carefully studied.
  As an alternative to perform reactions with very intense (10^9, 10^{10} pps) radioactive beams, one could choose to measure only with the most exotic isotopes, at the limit intensities (10^5 pps) for such studies. It would then be mandatory to realise an isotopic separation at a stage prior to the post-acceleration in CIME, to reduce the isobaric contamination of the beam sent to the SPEG area.
- With all the above, the use of SPEG in this configuration remains to be proven. The presence of different possible charge states in the heavy beam-like ejectile could seriously modify the efficiency of the spectrometer for this kind of measurements. Problems in this sense were already notice in occasion of the ^{46}Ar(d,p)^{47}Ar measurement (L. Gaudefroy et al., PRL 97 (2006) 092501).
  A test using a heavy beam from SPIRAL (Kr or even Xe) could be performed, however an upgrade of the detection system at the focal plane is required first.
  A code for the calculation of trajectories of ions in electric and magnetic fields (ZGOUBI) is being considered to perform detailed simulations.

3.3.3 Physics case 3

Mass measurements

The measurement of masses of nuclei far from stability is of fundamental interest for our understanding of nuclear structure. At SPEG, this is made possible by combining high-resolution time-of-flight and accurate momentum measurements of beams produced by projectile fragmentation. Results have been obtained both on the neutron-deficient and neutron-rich side of the chart of nuclei. The high number of citation of the articles reporting the results proves the vast interest in these measurements.
It would therefore be desirable to continue with these measurements in the future. An experiment is already approved, aiming at the exploration of neutron-rich isotopes close to the N=40 sub-shell closure, obtained by the fragmentation of a ^{76}Ge primary beam. It would require the SISSI device as in its previous configuration.
To proceed further, however, upgrades would be necessary on SISSI, the ALPHA separator and possibly the beam line to increase the maximum Bρ, to values beyond 3 Tm. For example, by using a ^{48}Ca primary beam at 60 MeV/nucleon and with a Bρ = 3.3 Tm, one could produce ^{44}Si (1.4 x 10^{-4} pps, i.e 4 cts/UT), ^{31}F (8 cts/UT) and ^{22}C (200 cts/UT).

3.3.4 Physics case 4

Ion emission induced by fast heavy ions in a semiconductor crystal

The aim is to study the sputtering of a semiconductor crystal due to the impact of an energetic ion beam. The sputtering effect due to electronic stopping power is known in

insulator materials, but there is no experimental evidence of such a phenomenon in semiconductors such as Si or Ge.
The measurement is performed by impinging with an ion beam (typically Pb at the energies attained at the exit of CSS1 and CSS2) on a thin semiconductor crystal, and measuring the ions sputtered from the front face of the crystal as function of the impact parameter of the incident ion. The latter is related to the energy loss of the ion traversing the crystal, and the energy loss can be measured by the SPEG spectrometer.

3.3.5 Synthesis

			Possible device improvements				
			Present device	Improvement 1	Improvement 2	Interface 1 SPIRAL 2	Interface 2 SPIRAL 2
Possible Beams	Present Beams						
	GANIL beam improvements	A					
	SPIRAL beam improvements						
	SPIRAL2 beams						

Table 3: Table of possible physics cases