

# **Résumé of general recommendations of the Scientific Advisory Committee of SPIRAL 2**

The Scientific Advisory Committee (SAC) of SPIRAL 2 met on 19-20 October 2006. It considered the submitted letters of intent (LoI), which were presented by the spokespersons in the open session on Thursday, 19 October. During the closed session on Friday, 20 October Marcel Jacquemet and Marek Lewitowicz gave presentations of the technical and scientific aspects of the SPIRAL 2 facility, respectively. These were then discussed also in light of the submitted LoIs and the foreseen scientific programmes to be pursued at SPIRAL 2. The SAC made, in addition to the specific recommendations concerning each of the LoIs, general recommendations related to the LoIs as well as to focussing and strengthening the scientific collaborations. Furthermore, recommendations related to the various technical realisations within the SPIRAL 2 project have been made.

## **I. Recommendations related to the base-line project**

### **▪ Choice of the HI source and injector**

1. Phoenix V2 source should be available at the beginning of SPIRAL 2 operation. This should be accompanied by a vigorous development of metallic beams.
2. Second injector  $q/A=1/6$  (extension of the facility) is requested by an important part of the users community and it should be designed as soon as possible but without a negative impact on the construction of the  $q/A=1/3$  injector.
3. Choice of the best next-generation HI source (extension of the facility) in 2-3 years from now is recommended.

### **▪ LINAG Experimental Area**

1. Construction of 3 experimental halls is recommended. The  $S^3$  separator-spectrometer is seen as essential equipment for experiments with LINAG beams. The  $S^3$  device and corresponding experimental hall should be constructed with the highest priority.
2. Installation of the beam bunchers and the fast chopper necessary for the future n-tof facility and for interdisciplinary research is recommended.

### **▪ Design goal for number of fissions**

1. The number of fissions per second should be kept as close as possible to  $10^{14}$  fissions/s (limited only by safety and building costs). This goal is important for most of the proposed physics programmes and is necessary to preserve the competitive character of the SPIRAL 2 beams with respect to other RIB facilities (HIE-ISOLDE, ISAC II, etc.)

### **▪ RIB Production Building**

1. The use of selective  $1^+$ -ion sources (IS, laser, ECR) is recommended as essential for physics (beam purity) and safety requirements.
2. The SAC considers the production building consisting of two RIB production caves (one “red zone” & one “yellow zone”) as the optimal choice among the proposed options.
3. It is recommended to preserve the possibility to deliver in the future two simultaneous RIBs for DESIR & CIME
4. It is essential for the success of the physics programme with low energy RIBs to reserve space for an RFQ cooler and High Resolution Mass Separator (HRMS).

### **▪ DESIR RFQ Cooler & HRMS**

1. Construction of the DESIR facility is highly recommended. The DESIR building should be included in the SPIRAL 2 buildings construction phase.
- **CIME-GI/G2 Direct beam line**
  1. This new beam line allowing for the parallel operation of the GANIL and SPIRAL 2 facilities should be constructed as soon as possible and preferably before the SPIRAL 2 buildings

## **II. General recommendations related to the letters of intent and scientific collaborations**

The SAC acknowledges the high scientific quality of the presented letters of intent (LoIs). They reflect strong involvement and commitment of the community in the preparation of future experiments and theoretical developments necessary for the success of the scientific programme at the SPIRAL 2 facility. The oral presentations of the LoIs were well-prepared and provoked lively and informative discussions. A limited attendance during the open session of the SAC was pointed out.

The SAC formulates the following general recommendations:

- It is highly recommended to establish a coordination committee/platform, which will exploit all possible synergies between SPIRAL 2 collaborations and will suggest in the future the best use of the available resources necessary for the construction of new detectors.
- The SAC noticed an absence of LoIs related to the interdisciplinary aspects of the scientific programme at SPIRAL 2. A workshop dedicated to this topic should be organised as soon as possible. An organising committee of this workshop should be appointed before the end of this year.
- The SAC pointed out the limited number of LoIs proposing the construction of a new neutron detector as well as the lack of a strong collaboration with the aim to realise such a detector. The SAC would like to encourage collaborations aiming to use neutron detectors in their scientific programmes to join European-wide efforts to develop such detectors for use at different RIB facilities.

# Specific recommendations of the Scientific Advisory Committee regarding the letters of intent for SPIRAL 2

## 1. The DESIR facility (decay, excitation and storage of radioactive ions)

*Spokesperson: B. Blank*

The construction of an experimental facility to exploit the low-energy beams of SPIRAL and SPIRAL 2 has been discussed since long time. The proposal to construct a new hall and install the DESIR Facility there would provide an excellent supplement to the SPIRAL 2 physics programme with high-energy radioactive beams. The building of the hall and construction of an isotope separator with relevant experimental apparatus should be part of the SPIRAL 2 project from the beginning.

The LoI gives a very broad overview of the physics that might be feasible with such a facility in the coming years. The unique yields for a number of isotopes would give the possibility to perform several different experiments not feasible elsewhere. The main strength would be on the neutron-rich side of stability. There is a certain limitation due to the relatively few different elements available at present. The collaboration should help in the beam development as much as possible in the years before start of operation of SPIRAL 2. We also note that the large neutron detector (LoI-2) seems very suitable for the early phase of the experimental programme.

The SAC makes the following recommendations and observations:

- The experimental hall for DESIR should be built according to the proposal.
- The separator and at least one beam-line should be planned immediately.
- The Collaboration should focus on two to three experiments in the first phase.
- They should provide a detailed theoretical justification for the experiments in the early phase.
- Concentrate on developments of equipment that matches the initial experiments.
- Collaborate with LoI-2 for experiments on  $\beta$ -delayed neutron emission and discuss with LoI-7 for the need of  $\gamma$ -ray detection.
- Discuss maintenance and location of equipment in the Yellow Zone with the Project Management.
- The Collaboration should help and support the beam development group.

## 2. Decay properties of neutron-rich nuclei

*Spokespersons: Yu. Penionzhkevich, F. Ibrahim*

This LoI proposes studies of neutron-rich nuclei with  $\beta$ -,  $\gamma$ - and neutron spectroscopic measurements. The project is very well suited to the beams available at SPIRAL 2 especially at the proposed DESIR Facility. However, the success of the project is to a great extent dependent on the variety of beams available at SPIRAL 2. We recommend that this group work in close contact with the beam development group over the coming years.

It is a big advantage for the group that they can already start the experiments in 2007 at ALTO. Spectroscopic information about neutron-deficient isotopes is of interest in both nuclear physics and nuclear astrophysics and, as mentioned in the LoI, it is important to establish solid collaborations with theory groups as soon as possible. It is important that the neutron detection

system proposed in LoI-2 is seen clearly as part of the more general DESIR LoI since neutron spectroscopy will be of importance in studies of the most n-rich nuclei. It should be incorporated into the DESIR proposal.

### **3. S<sup>3</sup>: The Super Separator Spectrometer for LINAG beams**

*Spokespersons: A. Villari, A. Drouart, J. Nolen*

The SAC finds the experimental programme based on the use of high intensity stable ions accelerated by the LINAG interesting and worth to be developed as one of the priorities of the SPIRAL 2 project. The SAC emphasises that, although the highest priority for SPIRAL 2 is the production of RIBs, such a programme could be exploited especially before and during the commissioning phase of the facility. The SAC strongly supports the completion of the SPIRAL 2 facility with the second RFQ with  $A/Q=6$  but is aware that such a goal cannot be reached in the first phase of the project.

The SAC also finds that in order to exploit such experimental programme the construction of the S<sup>3</sup> spectrometer is of highest priority. Therefore, the SAC encourages to finalise the design of the spectrometer and to proceed with the definition of the MoU. Furthermore, it recommends that a few physics cases of highest priority focused on the LINAG beams available from the reference project should be merged into an experimental proposal.

The SAC therefore encourages the proponents of the S<sup>3</sup> LoI to present the experimental proposal for the selected physics cases, together with full simulations of the response of the spectrometer (for measurements using both the target and the focal-plane positions).

In particular:

- Super-heavy elements production: the goal of reaching cross sections of less than 1 pb is of high priority. Beams, production methods, background rejection etc. should be presented.
- Fusion-evaporation reactions: the study of proton-rich nuclei populated using especially fusion-evaporation reactions close to the Coulomb barrier is very interesting in particular concerning the investigation of the proton-neutron pairing phenomena and the isospin symmetry in  $N=Z$  nuclei. The use of secondary reactions is also envisaged. The SAC encourages developing such a programme into a specific proposal focusing on the new achievable frontiers.
- Multi-nucleon transfer and deep-inelastic reactions: the SAC finds such a programme very interesting for mainly producing moderately neutron-rich nuclei, provided the second RFQ with  $A/Q=6$  is available.
- Astrophysics and plasma collisions: The SAC finds that the energy domain of the LINAG beams could be only partly appropriate for the astrophysical experimental programme. It encourages the finalisation of the proposal both for astrophysics and for plasma collisions.

### **4. From actinides to super-heavy elements with SPIRAL 2: reaction dynamics and structure**

*Spokesperson: P. Greenlees*

The field of physics of heavy and super-heavy elements was presented in a well documented LoI. It described well and clearly the domains and conditions under which SPIRAL 2 is competitive in

this topic. The necessity of highest possible intensities for stable and secondary beams was demonstrated. A large and motivated community is supporting this programme.

The SAC makes the following recommendations and observations:

- A schedule provided by the SPIRAL 2 team for the construction of an RFQ for  $A/Q=6$  should become available before the date for submission of proposals of experiments. The recommendations concerning the RFQ for  $A/Q=6$  are also included in the general remarks of the SAC.
- Close discussion with other LoIs regarding, e.g.,  $\gamma$ -detection and upgrade of EXOGAM is recommended.
- No actinide beams will be available.
- The domain of subjects was very broad, as is needed for LoI. The collaboration is invited to work out the case for a 1<sup>st</sup> day experiment.

## **5. Fusion reactions: A probe of multidimensional tunnelling**

*Spokespersons: A. Navin, R. Raabe, A. Shrivastava*

The LoI aims to study the interplay between the reaction mechanisms and the intrinsic structure of nuclei far from stability in fusion near the Coulomb barrier in order to understand the multidimensional path to fusion. For that SPIRAL 2 will provide unique tools: beams of intense light radioactive beams and beams of fission fragments.

The LoI gives an excellent overview of the physics that will be addressed and will become feasible with such a facility in the coming years. The given priority using beams of  $^{15}\text{C}$  and  $^{130}\text{In}$  is particularly well suited with the physics programme and the future facility.

The SAC makes the following recommendations and observations:

- The physics programme is well focussed.
- The collaboration should look to possible upgrades of VAMOS and FULIS if needed to carry out the physics programme since the construction of a Recoil Mass Separator is out of the scope of the SPIRAL 2 project.
- The development of a  $^{15}\text{C}$  beam is recommended.
- The development of beams of high purity is important for these experiments. The SPIRAL 2 team should give as precise as possible information on this subject. The collaboration is invited to participate in the discussions in order to specify needs. .

Encourage the collaboration to discuss and coordinate the physics programme with LoI-6 and more specifically seek collaboration on theory with G. Pollarolo.

## **6. Nucleon correlations probed via multiple particle transfer and their influence on sub-barrier fusion**

*Spokesperson: L. Corradi*

The subject of this LoI is focused on the follow-up of a programme on nuclear transfer and fusion near the Coulomb barrier. It aims at studying the dynamics of such reactions, the nuclear potential landscape near the Coulomb barrier and the spectroscopy of unknown nuclei. This programme asks for the highest possible intensities of secondary beams (order of a few pnA!).

The SAC makes the following recommendations and observations:

- To have precise information on intensities that may be achieved contact should be made with specialists of the SPIRAL 2 team (e.g. M. Lewitowicz).
- The SAC encourages the collaboration to discuss with LoI-5, and coordinate efforts both regarding the scientific programme and the similar instrumentation that will be utilised by both.
- Physics at somewhat lower intensities should be considered, which would make it feasible for running some experiments after the commissioning of SPIRAL 2.
- Therefore, the SAC also recommends the collaboration to elaborate a proposal of initial experiments with a focussed physics programme.
- The SAC is positive about the theoretical support that the collaboration is seeking and would like to see an integrated ‘complete’ coupled-channel approach wherein all transfer and inelastic scattering channels are taken into account.

## **7. High-resolution $\gamma$ -ray spectroscopy at SPIRAL 2 (AGATA-EXOGAM II)**

*Spokespersons: J. Gerl, W. Korten, B. Wadsworth*

AGATA (the Advanced Gamma Tracking Array) is an international project with the object of pushing back the limits of  $\gamma$ -ray detection by several orders of magnitude compared to existing  $\gamma$ -ray multi-detectors. It is being constructed within the framework of a European effort and benefits from levels of finance and human resources that are unprecedented in this area of physics.

It is a mobile detector, which should be able to participate in experiments at several nuclear physics accelerators in Europe. According to current agreements it should be based at GANIL for at least a third of its lifetime, i.e. one year in every three. It is clear that experiments carried out with this detector combined with the radioactive beams produced by the SPIRAL 2 facility should lead to unprecedented breakthroughs in our understanding of the structure of the nucleus. The SAC urges the management of GANIL to do everything in its power to provide the best conditions for hosting this detector.

The SAC urges the community to refine the definition of the first physics experiments which will be carried out with SPIRAL 2 beams and it asks the community to explore possible synergies between the AGATA ancillary detectors (TRACE) and other detectors, the construction of which is foreseen within other LoIs, such as FAZIA or GASPARD.

Finally, the SAC urges the community to upgrade EXOGAM by providing it with digital electronics. There is a large range of experiments where the  $\gamma$ -ray multiplicity is low. EXOGAM was designed specifically for such experiments and will play a major part in much of the science programme at SPIRAL 2.

### **7.1 Proton drip-line studies and $N=Z$ nuclei**

*Spokespersons: M.A. Bentley, D. Rudolph, G. de Angelis*

This LoI gives a very broad overview of the physics which might become feasible with such a facility on the proton-rich side of the valley of stability in the coming years. The foreseen programme will be carried out with different types of beams (stable and radioactive) using different types of reactions. To perform this ambitious programme of physics, the collaboration mentions the need of a large number of instrumentation and detectors.

The SAC makes the following recommendations and observations:

- The Collaboration should focus in the first phase on two to three key experiments, which are particularly well suited for SPIRAL 2.
- Concentrate on developments of equipment that matches the needs of the initial experiments.
- Explore and therefore strengthen the synergy of TRACE with ancillary detectors of other LoIs
- Collaborate with other SPIRAL 2 LoIs for the definition of common instrumentation and also with NUSTAR HISPEC/DESPEC, for example, for neutron detection.

## **7.2 High resolution spectroscopy of neutron-rich nuclei with AGATA**

*Spokespersons: A. Gadea, G. Duchêne, U. Datta Pramanik*

This LoI sketches an ambitious programme to study neutron-rich isotopes. In view of the intense neutron-rich secondary beams expected from SPIRAL 2, the use of deep-inelastic and transfer reactions seems to be particularly attractive.

The SAC makes the following recommendations:

- The Collaboration should focus in the first phase on a few key experiments, which are particularly well suited for SPIRAL 2 and develop the associated instrumentation
- For the development of ancillary detectors, all synergies around SPIRAL 2, but also with all other facilities, should be explored.
- The use of actinide targets is for the moment not recommended.
- Detailed counting-rate calculations should be carried out to check efficiencies, etc. needed.

## **7.3 Nuclear shapes and high-spin spectroscopy**

*Spokespersons: A. Görge, N. Redon, J. Simpson*

The SAC found the LoI “Nuclear shapes and high-spin spectroscopy” (part of LoI-7) of interest and recommends to proceed to the submission of a full proposal. However, the SAC suggests that the full proposal be focused, at least initially, to one or two topics. In particular, the SAC found interesting the study of high-spin states in neutron-rich nuclei for which no experimental information is available. Problems that can be studied are the elusive Jacobi shape transition and the possible occurrence of triaxial shapes. Another aspect of great interest is that of shape coexistence in neutron-rich nuclei. The SAC finds essential for the latter study the development of conversion-electron spectroscopy. The theoretical support for the high-spin study appears to be good. For the shape coexistence study, the SAC suggests also the support of groups developing semi-microscopic models (Heyde *et al.*) in addition to that of groups developing mean-field methods.

## **7.4 Collective modes in the continuum**

*Spokespersons: S. Leoni, E. Khan, D. Pierroutsakou*

In exotic nuclei with large  $N/Z$  ratio, collective phenomena are expected that will be interesting to study in order to investigate the evolution of collectivity and redistribution of strength as a function of  $N/Z$ . The present LoI addresses collective modes that could be excited either by inelastic scattering or by fusion reactions. It is proposed to study the GQR and double-phonon

states in inelastic scattering of exotic nuclei from heavy target nuclei in coincidence with  $\gamma$ -decay. The exotic beams that will be delivered by SPIRAL 2 do not have the intensities to allow such studies in a reasonable period of time. Also, the bombarding energy is a little bit too low for such studies. The SAC urges the proponents to make an estimation of the yields starting from realistic exotic-beam intensities. If this turns out not to be feasible, the proponents should propose a different technique for identifying excited GQR strength.

With fusion reactions, the proponents want to address a number of interesting issues. One of these is the Jacobi shape transition where shape and deformation change at high angular momenta. The second is the dipole dynamical mode, which can be better manipulated with the availability of exotic nuclei with large  $N/Z$ . This will provide information on the charge equilibration time. The third is the study of collective rotation at finite temperature, and in particular the temperature at which the system makes the order-to-chaos transition. All these studies are interesting and will benefit from the availability of very exotic beams at low energy at SPIRAL 2. The SAC strongly advises collaborating with LoI-8 in which the same type of physics is addressed making use of the same  $\gamma$ -ray detector-array AGATA. A first experiment can be proposed in full consultation with LoI-8 collaboration.

## **7.5 Nuclear electromagnetic moments at SPIRAL 2**

*Spokespersons: G. Georgiev, D.L. Balabanski, A. Görge*

There exists a large variety of methods for determination of nuclear moments. Part of the DESIR LoI addressed such measurements while this LoI mainly concentrates on measurements involving  $\gamma$ -ray detection. It represents thus a complementary proposal for this kind of studies. The LoI presents a large pallet of different possible techniques like Coulomb excitation, lifetime measurements and tilted foil techniques. The SAC considers these kind of studies of key interest at SPIRAL 2 and DESIR. The scientific cases are strong and with EXOGAM and AGATA there are possibilities to make major progress. The theoretical interest and support seems also adequate. The SAC recommends that the collaboration writes a proposal based on this LoI but with a clear focus on one strong scientific case for the first round of SPIRAL 2 experiments.

## **8. High-energy $\gamma$ -rays as a probe of hot nuclei and reaction mechanisms**

*Spokespersons: A. Maj, J.A. Scarpaci, D. Jenkins*

This LoI represents a very broad and interesting programme to study hot nuclei and the reaction mechanisms leading to them through emission of high-energy  $\gamma$ -rays. All facets of hot GDR studies are addressed: Jacobi shape transitions, non-Jacobi shape phase transitions, emergence of soft dipole mode (pygmy resonance) in neutron-rich nuclei, isospin mixing at finite temperature, onset of fragmentation, reaction dynamics and heavy-ion radiative capture. A strong collaboration consisting of a large number of groups from many countries will pursue the broad programme at SPIRAL 2 employing high-energy  $\gamma$ -rays as probes of the various processes. In general, the beam quality and intensity requirements are within what could be delivered by SPIRAL 2. For instrumentation to be used in the various sub-programmes, a whole arsenal of equipment is proposed to be used. EXOGAM(2), AGATA (at different stages of construction), and a versatile  $\gamma$ -calorimeter (possibly consisting of two shells, the outer being Château de Crystal or HECTOR) are considered and the charged-particle spectrometer, INDRA, is also

envisaged to be used. For neutron detection, DEMON is considered, and for measuring the recoils the large acceptance VAMOS spectrometer or Recoil Filter Detector could be used. This is quite an undertaking.

The SAC looks positively at this broad programme but would like to make the following comments and suggestions:

- Considering the large arsenal of apparatuses that could be used, an early discussion with the collaborations exploiting these detectors will be necessary. It will be important to make at some point a selection of what will finally be used so that the collaboration has the instruments ready for a quick start when SPIRAL 2 delivers its beams.
- Contacts should be made with the group suggesting similar studies under LoI-7 (S. Leoni *et al.*) to have a common coherent programme.
- The investment of 1,8 M€ should be justified. A first design study of the inner-shell detector should be made with simulations encompassing the outer shell as well. Furthermore, a time schedule with milestones should be presented.
- Two to three experiments should be worked out which would be the flagship experiments at the start of SPIRAL 2.

## **9. Studying the r process nucleosynthesis with direct reactions**

*Spokespersons: O. Sorlin, K. L. Kratz*

The physics case of the present LoI is nicely laid out and the SAC acknowledges the high scientific interest of the subject. (d,p) and (d,t) reactions will be used to determine energies and spectroscopic factors of occupied and valence states near the  $N=82$  shell closure by means of  $^{130}\text{Cd}$  and  $^{132}\text{Sn}$  secondary beams. Through the knowledge obtained for the behaviour of shell closures, single-particle energies and spectroscopic factors, r-process abundances could be understood.

The SAC makes the following recommendations:

- The Collaboration should use the best possible instrumentation, which seems to be the GASPARD detector, and contribute to its development.
- Development of new beam tracking detectors seems to be necessary to make use of secondary beam intensities as high as  $10^6$  pps or beyond.
- To judge the experimental feasibility of this kind of experiments, detailed counting-rate estimates are required.
- To interpret the experimental data and determine, e.g., spectroscopic factors for neutron capture, collaborations with theoreticians should be considered.

Although an interesting option, the physics case for the construction of a gas-filled separator does not seem to be broad enough at present.

## **10. $\alpha$ -capture reactions in inverse kinematics relevant to stellar nucleosynthesis**

*Spokespersons: S. Harissopulos F. de Oliveira Santos*

The SAC considers that it is difficult to extrapolate the models which parameterise nuclear potentials to low energies, above all in the resonance region. The proposed experiments should be carried out with radioactive beams but also with stable beams.

The SAC suggests that the collaboration begins this type of study as soon as possible by using the

stable beams currently available at GANIL. This step should allow the collaboration to familiarise itself with the experimental techniques and to rapidly understand the problems associated with targets, which seems to be a major problem when low intensity radioactive beams are used.

### **11. Production of radioactive samples for astrophysical interest by (n,p), (n,<sup>3</sup>He), (n, $\alpha$ ) reactions**

*Spokespersons: F. Hammache, M. Heil*

This LoI proposes to produce radioactive targets of <sup>59,60</sup>Fe and other isotopes relevant for the (n, $\gamma$ ) studies needed to understand the s-process of nuclear burning. The goal of the LoI is well defined and valuable from the scientific point of view.

In order to assess fully the feasibility of the production of targets, simulations taking into account the realistic geometry and neutron energy spectra available at different irradiation positions (behind the carbon converter and UCx target) should be performed. Further evaluation of all safety and sample handling requirements is also necessary.

Taking into account the current status of the SPIRAL 2 facility it seems to be more appropriate to assume that the irradiated samples are directly sent to another site for further chemical and mass separation. This point requires also further investigations.

The collaboration is encouraged to contact the project management group and in particular those responsible for the production of RIB (M.H. Moscatello) and for safety (B. Rannou) in order to define all technical details before the submission of the full proposal.

### **12. Production targets of light radioisotopes for nuclear astrophysics and basic nuclear science studies**

*Spokespersons: M. Hass, D. Berkovits, T.Y. Hirsh*

The LoI sketches schemes for production of light radioactive nuclei by transfer-type reactions. The SAC recognizes that there is a clear need for intense light radioactive ions and therefore strongly encourages the development of these beams.

The SAC encourages the collaboration to write a detailed proposal and recommends that they take the following into account:

- A clear physics case of interest for SPIRAL 2 should be selected.
- Collaboration with groups developing target-ion source ensembles for SPIRAL 2 is strongly encouraged
- A development scheme should be worked out.

### **13. Improving effective forces, mean-field based methods and predictions: dedicated measurements**

*Spokespersons: M. Bender, K. Bennaceur, S. Péru*

The SAC considered with great interest this LoI and is very positive about the involvement of theorists in the definitions of the scientific programmes of SPIRAL 2 at the various stages, i.e. from performing calculations that guide the experimentalists in preparation of their experiments

to description and interpretation of the obtained data at a later stage. In this respect, the SAC wishes to encourage this group to perform calculations of properties of nuclei, which will be reached at SPIRAL 2 with sufficient intensity to study their spectroscopy. Discussions with experimental colleagues would be imperative to define some of these realistic cases. In particular, calculations of nuclear masses and of proton and neutron radii of even-even nuclei in the neutron-rich Sr,Kr and Sn,Te isotopes are of great importance, as well as calculations of the single-particle structure in odd-even nuclei and their spectroscopic factors in the same regions. If calculating collective properties is also feasible, it would be also interesting to study their evolution as function of neutron number. The SAC encourages strongly the coordination of the proposed theoretical effort with the experimental effort of LoI-14 and LoI-16 (direct reaction studies of neutron-rich isotopes).

#### **14. Direct reaction studies of exotic nuclear structure (GASPARD)**

*Spokespersons: D. Beaumel, R.C. Lemmon, I. Martel*

The SAC finds the study of direct reactions with radioactive nuclear beams of high priority for the SPIRAL 2 project since the beams and their energies are ideally suited to studies of the character of low-lying levels in exotic nuclei. The SAC encourages the proponents to finalise the design of the GASPARD detector and proceed with the definition of the MoU and the preparation of a full proposal. In particular it recommends also that the full case should concentrate on the physics cases of highest priority focusing on the SPIRAL 2 beams available from the reference project. Full simulations of the response of the gamma and particle detectors for the specific cases proposed should be carried out. The SAC also encourages the group to consider possible convergences in the developments of the gamma array as well as of the neutron detector with similar devices proposed in other LoIs.

In particular:

**Single-Particle Structure:** Such studies using transfer reactions are of high interest and very well suited for the beam and energy regime of SPIRAL 2. As in the case of other direct reactions the SAC strongly encourages the group to finalise the project and define the priority experiments.

**Nuclear Pairing:** The study of the evolution of pairing with isospin is of considerable current interest. The SAC encourages the proponents to present an experimental proposal for the selected physics cases. Moreover, it encourages this group to develop the necessary theoretical tools needed to extract the expected effects. It also recommends that full simulations of the response of the apparatus for the experiments of high priority should be carried out prior to submitting the full proposal. Thus in the case of the p-n pairing investigated through pn transfer it would be interesting to find out how much the change of seniority will impact on the expected enhancement in cross section.

**Spectroscopy of Very Neutron-Rich Nuclei:** The SAC finds spectroscopic investigation of very neutron-rich nuclei performed using transfer reactions of high interest and very well suited to the SPIRAL 2 radioactive beam facility. It strongly encourages its development.

**Nuclear Cluster and Nuclear Molecules:** The committee finds the study of cluster configurations in nuclei very interesting. It encourages the group to focus on a specific proposal and to define the specification of the proposed neutron detector. It encourages the group to find in such development, convergences with similar projects proposed in other LoIs.

**Direct Reaction Mechanisms and Application to Astrophysics:** The SAC finds direct reaction studies one of the major objectives of the SPIRAL 2 project due to the available energy domain

of the beams. The experimental and theoretical programme proposed is also very well suited for the characteristic of the GASPARD array. It strongly encourages the group to finalise the project and define the priority experiments.

### **15. Direct and resonant reactions with an active target**

*Spokespersons: M. Chartier, D. Cortina, P. Roussel-Chomaz*

The study of direct and resonant reactions far from the valley of stability will shed light on the evolution of shell structure and will yield information of importance for astrophysical processes. Especially in the case of the latter, important nuclear reaction rates have to be determined at low energies and often for the most exotic nuclei that are produced with low intensities at SPIRAL 2. The LoI presents an excellent and well-investigated hybrid of an active target-detector, which will have a low-energy detection threshold that will make it feasible to study nuclear reactions at very low energies. Furthermore, it can handle the low beam intensities for the most exotic nuclei to be studied and allow a good determination of the interaction point in the target. The latter would remove the uncertainties in the kinematical reconstruction and lead to a good energy resolution.

The SAC finds this LoI excellent and was impressed with the beautiful simulations indicating how well the reactions could be reconstructed. The SAC would like to receive a worked-out proposal for a first experiment wherein use is made of the first exotic beams that will become available at SPIRAL 2. For this a full simulation of the low-energy recoils should be made with a good estimation of the average charge state. Furthermore, the SAC would like to see the planning and time schedule for the design and construction of this solenoidal active target-detector. It is clear that this has to be based on some assumptions regarding financing. Finally, the SAC recommends strongly to collaborate with reaction theorists who will develop/improve the models for describing the direct reactions.

### **16. Unbound states of neutron-rich isotopes via direct reactions**

*Spokesperson: V. Lapoux*

The committee finds the objectives of the LoI very well suited for the specific characteristics of the SPIRAL 2 facility regarding both accelerated ion beams and the energy domain. The experimental programme proposed is of high interest and can uniquely be performed at SPIRAL 2. Moreover, the group has strong theoretical support for the interpretation of experimental results and for testing the predictive power of nuclear theories.

The SAC therefore finds the proposed study of highest priority. It encourages the proponents to finalise the design of specific detector set-ups for the priority experiments with full simulation of the response especially for what it concerns the radioactive ion-beam intensity and the required optimum energy. The SAC also encourages to merge the needed detector specifications with the detector requirements of LoI-14 and LoI-9 and to proceed with the definition of the MoU. The SAC encourages to proceed with the needed R&D programmes concerning, for example, the beam tracking detector technology and the mass and energy resolutions of the focal-plane detector of the spectrometer. This will be needed to push the resolution above  $A=100$  and  $Z=40$ . It also encourages to develop the necessary theoretical tools needed to calculate the expected effects, for example the aspects related to the coupled reaction channel analysis.

## 17. Neutrons for science

*Spokespersons: X. Ledoux, S. Simakov*

This LoI concerns the direct use of the neutrons produced in the breakup of the deuterons from LINAG on a carbon target. The proposal is to use these neutrons for a variety of purposes including inter alia nuclear astrophysics and the measurement of cross sections of importance for the transmutation of nuclear waste. The SAC for SPIRAL 2 recognised the considerable potential for the use of the intense neutron flux that will be generated in this way and was impressed by the wide range of science that could be addressed. It recommends that this LoI should now be developed fully. The case to be made should be refined with an emphasis on a few key experiments to demonstrate the full power of the system that could be set up. The SAC was concerned, however, at the relatively small number of scientists associated with this LoI. It was felt that they do not constitute the critical mass needed to attract the funding, design the facility and prepare the equipment. Final approval to build the facility will demand commitment from a larger community. The SAC recommends to the GANIL management that they should ensure that the space needed for this scientific activity is made available in the buildings dedicated to SPIRAL 2. It should be noted that a chopper will be required for the LINAG if this LoI is given the go-ahead. The SAC recommends that the proponents of the LoI should ensure that the SPIRAL 2 project team are fully aware of the design specifications for this chopper.

## 18. Dynamics & thermodynamics of exotic nuclear systems

*Spokespersons: F. Gulminelli, G. Poggi, G. Verde*

This LoI proposes a programme to study the (thermo)dynamics of excited exotic systems making use of fusion reactions and deep-inelastic collisions induced by exotic beams from SPIRAL 2.

The SAC considers the scientific objectives highly interesting. For example, the  $N/Z$  dependence of the limiting temperature, which should furnish information on the critical temperature,  $T_C$ , of infinite nuclear matter, is predicted by theoretical calculations to decrease significantly for large  $N/Z$ . This may be just within reach of SPIRAL 2 beam energies. However, the obtained results should be combined with the results obtained at higher energies at other accelerator facilities (e.g. FAIR and EURISOL in the future) to have a better picture of the limiting and critical temperatures. Other topics of interest are:  $N/Z$  dependence of nuclear level densities, two- and multi-particle correlation studies, fragment isotopic distributions and dissipative peripheral collisions. In all of these processes, the symmetry energy plays a central role and it may be possible to infer its temperature dependence as well as constrain the underlying isovector part of the nuclear effective interaction from these studies.

The proponents demand for their studies a variety of n-rich and p-rich beams with qualities and intensities that seem to be achievable with SPIRAL 2. However, no specifications of targets are given, possibly because they are standard.

The SAC is very positive about this LoI and would like to see a worked-out proposal for a first experiment. The SAC has the following remarks and suggestions:

- The SAC commends this collaboration on the strong theoretical support. This will be much needed in interpreting the data and understanding the mechanisms underlying the observations.

- Although many apparatuses are available at present, the new experimental demands require a new detector system, FAZIA, which will be indispensable in future studies at SPIRAL 2. The SAC was informed about the milestones on the road for construction of FAZIA. It would be important to be explicit about the deadline for constructing FAZIA after the green light is given in 2010 as expected. Would the commissioning be in step with the completion of SPIRAL 2?
- The SAC would like that the FAZIA collaboration discusses with the GASPARD collaboration concerning various aspects of particle and  $\gamma$ -ray detection.
- This programme needs neutron detection as many other programmes at SPIRAL 2 and FAIR. Coherent efforts should be put into developing neutron-detection techniques for general purposes.

### **19. Isospin non-conservation in nuclear states and its implication for the physics beyond the Standard Model**

*Spokespersons: N. Smirnova*

The SAC finds the research programme of this LoI very interesting both from the theoretical and from the experimental point of view.

The different aspects addressed in the LoI require very challenging experimental techniques and beam developments. These are necessary to reach the experimental sensitivity needed either to obtain meaningful results or to further constrain existing upper limits. It is therefore of high importance to clearly identify the objectives. The SAC strongly encourages this theoretical group to identify the cases of highest priority in conjunction with the beams available in the reference project of SPIRAL 2. Moreover, it encourages this group to merge with an experimental group in order to identify what experimental equipment is needed to test physics beyond the Standard Model and at the same time to develop the necessary theoretical tools needed to calculate the expected effects, for example isospin symmetry breaking corrections.