GANIL 2015

Report on prospective study for GANIL 2015
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I. GANIL 2015 : CORE GROUP RECOMMENDATIONS

1. OVERVIEW

GANIL presently offers unique opportunities in nuclear physics and many other fields that arise from not only the provision of low-energy stable beams, fragmentation beams and re-accelerated radioactive species, but also from the availability of a wide range of state-of-the-art spectrometers and instrumentation. With the construction of SPILARL2 over the next few years, GANIL is in a good position to retain its world-leading capability even though it faces strong competition from new and upgraded ISOL and fragmentation facilities. In order to ensure that GANIL makes best use of available resources to achieve this goal, it has undertaken a study of the prospects for the laboratory, which will address its likely needs for the scientific programme up to 2015.

The study presents the scientific case, with priorities, for the future exploitation and possible upgrades for each GANIL experimental installation (including the various accelerators). The different experimental programmes under consideration can use SPIRAL2 beams in the present installations at GANIL, or are complementary to SPIRAL2 physics, or are independent of SPIRAL2. The study considers how the future requirements for SPIRAL2 beams into areas outside AEL and DESIR, and new SPIRAL1 beams/ stable beams/ fragmentation beams, will impact upon resources and technical developments, including safety licensing.

The study excludes considerations of requirements for the future research programme of SPIRAL2 that are being carried out by the SPIRAL2 Scientific Advisory Committee, but will provide advice to both the SAC and the GANIL Scientific Council that will enable the laboratory to make future plans for the total scientific programme.

The Core Group consists of members drawn from both the SAC and the SC: Nicolas Alamanos, Giacomo de Angelis, Bertram Blank, Angela Bracco, Peter Butler (chair), Fadi Ibrahim, Bill Lynch, Tohru Motobayashi, Gerda Neyens, Chistina Trautmann, Dominique Vernhet, Cristina Volpe, Ani Aprahamian, Muhsin Harakeh, Philippe Chomaz (up to June 2008), Patricia Roussel Chomaz (from July 2008), Sydney Gales, and Marek Lewitowicz. Two other committees have been set up to assist the group: the Forward Look Forum, chaired by Bertram Blank, and the Technical Advisory Board, chaired by Frédéric Chautard. The mandate of the Forum is to look across the range of beams and facilities and provide a perspective on future requirements, taking into account other facilities that will be available world-wide. The TAB is providing advice on the technical implications, including radio-protection and safety, of the future physics requirements and the possible large-scale maintenance needed. The reports of the Forum and the TAB are appended to this report, together with completed templates provided by the coordinators of the GANIL installations/facilities (Stéphane Grévy, Abdou Chbibi, Bruno Piquet, Riccardo Raabe, Gilles de France, Mauryce Rejmund, Jean-Charles Thomas, Navin Alahari, and Emmanuel Balanzat).

The underlying theme of our report is that GANIL should be ready, in 2015, to assume the mantle of the world-leading ISOL facility. This can be achieved not only by ensuring that the suite of instrumentation – spectrometers, separators and detectors - is able to accommodate the intense neutron-rich beams from SPIRAL2, but also the repertoire of radionuclides from SPIRAL1 should also be enlarged. In addition, GANIL has a distinguished record for exploiting energetic stable beams and it is recognised that - in addition to the low energy intense beams from LINAG - there is an energy regime (~ 50 MeV/u) for which the laboratory will continue to have a niche for many years to come. Beyond 2015, it will have, in particular, the opportunity to access the most neutron-rich nuclei by secondary fragmentation of fission fragments, and this...
possibility of realising the dream of EURISOL should be incorporated into any long range plans for the laboratory.

2. SPIRAL-1, SIRa and LIRAT

SPIRAL-1 uses the ISOL technique to produce radioactive ion beams which are post accelerated using the CIME cyclotron. The SPIRAL1 Target Ion Source (TIS) is based on a 10 GHz permanent magnet ECR ion source coupled with a projectile fragmentation graphite target (design is optimized for gas production.) Seven radioactive elements are now offered with 36 isotopes. The first SPIRAL radioactive ion beam produced was delivered in November 2001.

A large and interesting physics programme has been achieved with the available beams at SPIRAL1. The main limitation of SPIRAL1 is related to the small number of elements available (mainly noble gases), making clear the need for new beam developments. With the present configuration the insertion of new sources is complicated because of geometrical and safety constraints. According to the excellent results obtained at SIRa for $^{1+}$ radioactive beams, the development of new beams is likely to result from the insertion of a charge breeder outside of the SPIRAL1 cave 1.

As the highest priority, the core group strongly recommends the modification needed for the insertion of a charge breeder out of the cave of SPIRAL1 to be included in the safety file. A pre-separator should also be included between the $^{1+}$ ion source and the charge breeder. The Core Group recommends that a detailed study of the best solution for the $^{1+}/N^+$ implementation is performed by the new committee of physicists and engineers called GANISOL. The core group strongly encourages the management of GANIL to put sufficient human resources in order to achieve this major improvement. The core group encourages the GANISOL group to deliver a list of all the beams available within the new configuration including the $^{1+}$ and $N^+$ intensities.

The design of the surface or FEBIAD 1+ ion sources presents no major technical problem, but the laser ionization source requires significantly more effort compared to the other sources, and this is considered a second priority. Nevertheless the core group recommends that the possibility of using laser ion sources at SPIRAL1 should be included in the safety file.

The possibility to use targets other than Carbon and various types of sources for testing purposes in the SIRa cave should be considered in the future and included in the safety documents.

We agree with the Forum that the present limitations on permitted beams for LIRAT have to be overcome, particularly in the view of the use of SPIRAL1 for providing radioactive ions for DESIR. We recommend that the authorisation of extracting all SPIRAL1 beams for LIRAT should be obtained, in addition to the currently available beams. This will not require significantly additional resources and will make LIRAT attractive as an open access facility for a wider community.

Within the SPIRAL2 project, the LIRAT beam line should transport SPIRAL1 beams to the DESIR facility. LIRAT will not be a facility any more but just a beam transport line.

3. PROVISION FOR FRAGMENTATION STUDIES : LISE and SISSI

The Core Group has noted that the fragmentation community has asked that SISSI should be replaced by an identical SISSI2. However, there are implications on resources and doubt as to
how internationally competitive the facility will be for fragmentation studies, thus questioning the usefulness of this option. The Forum has concluded that the higher energies available in all other facilities place GANIL in a difficult position. For many radioactive isotopes, production rates at the exit of the fragment separators BigRIPS at RIKEN and Super-FRS at FAIR are expected to be a factor 100 higher than at GANIL. It is difficult for GANIL to compete with these new installations without a significant upgrade of the whole GANIL fragmentation facility. Indeed, the Scientific Council has concluded that while SISSI2 would provide some unique capabilities at non-relativistic energies for two-step reactions, its recommendation is that GANIL should concentrate efforts on SPIRAL2. We concur with this view and recommend that the in-flight secondary beam studies are focused on the LISE spectrometer. We recommend that a detailed study is initiated with the highest priority that considers upgrading the LISE beam line with a velocity filter and a magnetic spectrometer. The outcome of this study, together with the outcome of the on-going design study for SISSI2, will allow the expected performance of the two devices to be compared. An additional advantage of the LISE upgrade is that the second beam line of the spectrometer can be dedicated to zero degree studies with SPIRAL2 beams (see following section), thereby enhancing the coherence and efficiency of the whole facility.

We note that the community has enthusiastically endorsed the proposal for a new 100-150 MeV/nucleon post-accelerator that will allow fragmentation of neutron-rich fission products. While outside the scope of this report, we would like to see the launching of a preliminary, conceptual design study of such a facility and the associated instrumentation. This should not commit significant resources from the laboratory, and take advantage of related activity carried out within the EURISOL Design Study.

4. PROVISION FOR ZERO-DEGREE STUDIES: LISE, SPEG and VAMOS

The Core Group’s view is that it is essential that there is provision of spectrometers/ separators for the study of reaction products, induced by SPIRAL1 or SPIRAL2 beams, emitted at or close to the beam direction. In this section options are presented as to how best achieve this. An early consensus will allow the caves where the high intensity beams of SPIRAL2 will be sent to be specifically identified. Detailed studies will have to be carried out in order to determine the new experimental conditions, in terms of radiological environment, for the detection systems, electronics and operation conditions. For that purpose a working group should be nominated, including physicists, instrumentation and safety engineers. Sample experiments for simulation studies can be drawn from the Cluster and Forum reports, as well as from the SPIRAL2 Letters of Intent.

LISE

The Forum has stated in their conclusions: “GANIL possesses today three spectrometers: LISE, SPEG, VAMOS. All of them have been used with re-accelerated radioactive or low-energy stable beams. The velocity filter of the LISE separator was extensively used for fusion-evaporation reactions. However, this use implies a modification of the velocity filter as compared to the main use of LISE as a high-energy fragment separator. These frequent modifications are man-power intensive and most likely not compatible with ever increasing beam intensities and radioprotection issues coming along with them. Therefore, a solution needs urgently to be found.” We agree with the Forum that consideration should be given to the upgrade of LISE that will allow it to be used for both low energy fusion-evaporation reactions and high-energy fragmentation reactions. We recommend that, with highest priority, the detailed study that considers the enhancement of LISE for fragmentation studies should incorporate a parallel study for use for zero-degree operation with high-intensity RIB. This should allow the use of detector arrays at the target position. We appreciate that the most efficient solution would probably be a new zero-degree spectrometer specifically designed for
this application. However, the limited financial and technical resources particularly during the construction of S³ would delay the provision of this spectrometer well beyond the start-up of SPIRAL2.

**SPEG**

The SPEG spectrometer is a powerful instrument of GANIL, which has provided important physics results and which is planned to be used for high quality experiments in the next decade. The long-term usefulness of this instrument arises from its excellent performance and its versatility in application to different types of measurements. This, combined with the availability of new beams, could allow experiments at the frontier in nuclear physics be performed in the future. For future activities SPEG can be used in combination with γ-ray (EXOGAM, AGATA, and PARIS), charged particle (INDRA, FAZIA, MUST2, GASPARD) and neutron detector arrays. SPEG has produced important results addressing nuclear structure problems such as giant resonances, nuclei at the drip line, and unbound nuclei production, using fragmentation beams. If the SISSI device is not replaced, fragmentation beams will not be available for SPEG. Therefore the future experimental activity of SPEG would be made using the radioactive beams from SPIRAL1, SPIRAL2 and stable beams. The activity with stable beams will include applications in material science. The SPEG spectrometer will be used for measurements of inelastic and transfer reactions in inverse kinematics in order to study nuclear structure properties of unstable nuclei produced as fission fragments with SPIRAL2. This scientific programme will be complementary to that of VAMOS, because it will exploit the high resolution capability of the spectrometer.

The beams of interest would be the most exotic ones with intensities of $\sim 10^5$ – $10^6$ pps. To avoid problems related to radioactivity from the presence of more stable isobars, it is essential that the beams are as isotopically pure as possible, in principle already before injecting into the CIME cyclotron. Modifications of the detection system around the focal plane of the spectrometer, in order to optimize for heavy, low-energy beams from SPIRAL2, will be necessary. In addition, the effects on the detection efficiency of different charge states in the beam-like ejectiles need be evaluated. **In summary a strong recommendation is made for the implementation of all the changes to the focal plane detector setup which is required to perform reaction measurements with the heavy and low energy beams from SPIRAL1 and SPIRAL2.** The safety report should take on board the provision of radioactive beams of intensity up to $10^6$ pps in the SPEG cave.

**VAMOS**

VAMOS is a large acceptance device that can operate in different optical modes. It has been built to obtain sensitivity and selectivity for experiments using the radioactive ion beams provided by the SPIRAL1 facility. It has been extensively used coupled to other spectrometers: INDRA, EXOGAM, TIARA, and MUST2. The experiments have largely fallen into three categories: (i) fusion reactions using stable or radioactive beams; (ii) transfer reactions in inverse kinematics using radioactive beams and (iii) multi-nucleon transfer mostly using heavy stable beams. Transfer reaction studies of type (ii) and (iii) have been recently very successfully applied to studies of the structure of very neutron-rich nuclei. For type (iii) we agree with the Forum that higher intensities for the heavy beams like, Pb, Th or U would greatly help the physics programme carried out with those beams. However, we believe that VAMOS has to be ready for zero-degree operation for fusion evaporation and inverse-kinematics transfer (low-mass target) studies using intense SPIRAL2 beams. The outcome of the tests of gas-filled operation are eagerly awaited, but in any case **improvements to the existing Wien filter and a detailed study of the incorporation of a beam dump with a separate permanent beam-line are required as a first priority.** This study should include configurations that accommodate large-angle operation that allows grazing-angle studies on heavy targets carried out in a later phase of SPIRAL2 operation. The safety study should incorporate the request of the VAMOS cluster: “beams of neutron rich fission products with intensities between $10^3$ and $10^6$ pps of the rare species and up to $10^6$ pps or more of abundant species, with energies
ranging from 3 MeV/u to 10 MeV/u. The priority of beam development would be to first develop neutron-rich Xe, Kr, Ga and Sn beams and then subsequently increase the intensity of the most neutron-rich isotopes for these beams.

5. EXOGAM AND INDRA

EXOGAM

The CG considers that high-resolution γ-ray spectroscopy with a Ge detector array is a very important part of the scientific programme of GANIL and SPIRAL2. It agrees with the Forum who stated “For γ-ray detection, a high-performance array EXOGAM is permanently at GANIL. The electronics of this array urgently needs to be modified to cope with steadily increasing beam intensities. AGATA which will stay only for certain experimental campaigns at GANIL will be a new powerful tool for γ-spectroscopy. The upgrade of EXOGAM is also necessary to couple it with AGATA and other detectors.” It considers therefore of high priority the need for a dedicated gamma detector array (since AGATA is not a permanent installation). The CG therefore supports the completion of the EXOGAM2 project. The committee is also aware that such a development will improve the high counting-rate performance, which is already a limiting factor of EXOGAM in several applications at GANIL. The improvement of the Doppler-shift correction is expected to be marginal because of the limited improvement in position resolution. As first priority the electronics should be renewed using pulse processing based on digital electronics, funded by the international collaboration. This will allow the device to be operated at higher counting rates and possibly with improved position resolution. As second priority the available number of Ge detectors should be increased, again funded by the collaboration, to allow different and more complex configurations of the EXOGAM array as well as providing spare elements. For such developments the CG recommends that a) options should be considered that reduce the investment costs and human resources; b) a clear funding scheme should be defined within the present, or possibly extended, collaboration; c) an overall strategy should be established for the combined use of EXOGAM2 and AGATA at SPIRAL2.

INDRA

The Core Group considers it an important priority, for studies of neutron-rich matter, to complete the PHASE I - PHASE IV FAZIA implementation plans within the context of an international collaboration that will construct the device. This includes the required FAZIA modules and the thin-walled chamber that allows operation of INDRA/FAZIA as a standalone device and in conjunction with other devices at a variety of target stations. The group noted the requirement for the improved availability of rare isotope beams with intensities up to 10^{8} pps at 5 MeV/u. The user community and the laboratory have to consider the future location of INDRA/FAZIA if used as a standalone device.

6. INTERDISCIPLINARY RESEARCH ACTIVITIES, INDUSTRIAL APPLICATIONS

GANIL is one of the few facilities providing swift heavy ions for experiments in the fields of atomic physics, materials and condensed matter research as well as radio-biology and radio-chemistry. The attractiveness of GANIL is linked to the broad range of beams and experimental installations in combination with the local expertise offering optimal conditions for these communities. To keep the competitiveness for interdisciplinary activities, the Core Group considers it as essential that GANIL continues to provide in the future frequent beam access.
over a broad range of ion species, charge states and energies (from eV to GeV). In addition, the beam qualities and the installations in the experimental areas should be improved.

With respect to the rather diverse requests of the different user communities, the Core Group recommends the highest priority for the following upgrades:

For material sciences: moving the chopper behind the SME entrance and/or modifying intensity modulation by introducing pepperpots or other suitable devices in order to take full advantage of parallel beam times.

For radiochemistry: offering reliable operation of pulse suppression which is essential for pulsed radiolysis and provides a unique tool worldwide.

For radiobiology: improving the beam stability in order to avoid the large intensity fluctuations that occur at the extremely low intensities used.

For atomic physics: equipping the SME beam line in D1 with an analyzing magnet to enable charge state detection of the outgoing ions, which is essential in order to characterize collision processes.

In addition, it should be noted that the installation of GTS type sources on the C0 platforms could open new possibilities of experiments in the medium energy range, increasing the available currents of heavy ions. The Core Group encourages the TAB to carefully examine the possibility of reaching high-intensity beams of 500 W in the SME beam-line, which is presently accessible within the THI mode.

Regarding the industrial applications, the Core Group supports further exploitation of GANIL beams for the fabrication of ion-track membranes and for testing electronic systems and components. The GANIL management is encouraged to keep allocating beam access to industrial users and to study the possibility of providing “cocktail beams" i.e. rapid changes in ion species.

7. SUMMARY

The following are the recommendations of the Core Group that relate directly to enhancing the ISOL capability of GANIL for leadership in this area in 2015:

- The modifications needed for the insertion of a charge breeder out of the cave of SPIRAL1 should be included in the safety file, with sufficient human resources in order to achieve this major improvement. The possibility of using laser ion sources at SPIRAL1 should also be included in the file but their construction is considered to be a second priority. Authorisation for extracting all SPIRAL1 beams for LIRAT should be obtained.

- Detailed studies to allow the high intensity beams of SPIRAL2 into specifically identified caves have to be carried out, and for that purpose a working group should be nominated that includes physicists, instrumentation and safety engineers.

- Detailed studies should be initiated that gives GANIL capability for zero-degree operation with intense SPIRAL2 beams. This include improvements to the existing Wien filter of VAMOS and a study of the incorporation of a beam dump with a separate permanent beam-line; a study for upgrading the LISE beam line for zero-degree operation, that also allows use of target arrays; changes to the focal plane detector setup at SPEG which are required to perform reaction measurements with SPIRAL1 and SPIRAL2 beams.
The recommendations that relate to the ongoing capability of GANIL to exploit fragmentation beams and its long-term future in this area are:

- A detailed study should be initiated, in parallel with the upgrade for exploiting SPIRAL2 beams, which considers upgrading the LISE beam line with a velocity filter and a magnetic spectrometer.

- The launching of a preliminary, conceptual design study of a new 100-150 MeV/nucleon post-accelerator that will allow fragmentation of neutron-rich fission products; this study should take advantage of related activity carried out within the EURISOL Design Study.

Recommendations concerned with enhancing existing equipment maintained by large international collaborations are:

- For EXOGAM the electronics should be renewed using pulse processing based on digital electronics, funded by the international collaboration. As second priority the available number of germanium detectors should be increased, again funded by the collaboration.

- The PHASE I - PHASE IV FAZIA plans should be implemented within the framework of the international collaboration that will fund the construction of the device.

The following recommendation relate to the very important activities of GANIL in the areas outside of nuclear physics:

- For material science, radiochemistry and radiobiology: improvements in the beam quality and enhancements to the beam definition; for atomic physics: equipping the SME beam line with an analyzing magnet.
II. APPENDIX

1. APPENDIX n°1 : Summary of Cluster Reports

1. SPIRAL-1 & SIRa

SPIRAL-1 uses the ISOL technique to produce radioactive ion beams which are post accelerated using the CIME cyclotron. The SPIRAL1 Target Ion Source (TIS) is based on a 10 GHz permanent magnet ECR ion source coupled with a projectile fragmentation graphite target. Thus this design is optimized for gas production. Seven radioactive elements are now offered with 40 isotopes. The first SPIRAL radioactive ion beam produced was delivered in November 2001. Improvements of this system have been done constantly to reach better stability and reliability. At the same time, the increasing primary beam intensities achieved have made it possible to develop a 3 kW target for helium beams in 2005.

The scientific program at SPIRAL encompasses a large scientific program probing the existence of exotic states of nuclear matter like the existence of resonances in a 4n system or addressing fundamental questions like of how many neutrons can a proton hold. The goals in general are to study the evolution of nuclear structure as a function of isospin. This has been studied by using transfer reaction in inverse kinematics to study the single particle spectroscopy, Coulomb excitation and fusion evaporation reactions have been used to characterize the excited states of nuclei far from stability and to address the question of exotic shapes, open questions of np pairing etc. Resonant elastic scattering has been used for the spectroscopy of excited sates of nuclei of astrophysics interest. The influence of nuclear structure on reactions around the Coulomb barrier and studies of level densities in nuclei far from stability have also been studied.

The creation of detectors like MAYA , and the full exploitation of the EXOGAM array, the VAMOS spectrometer, the MUST arrays, TIARA specially created for SPIRAL1 and highly segmented annular silicon detectors combined with various detectors like the neutron wall array is an additional benefit which with their improvements and next generation detectors will take us towards the optimum utilization of Spiral2. It seems almost unanimously felt that the SPIRAL 1 needs to be continued taking into account the fact that it could provide beams (especially lighter beams) in a more optimum way and taking into account the fact that both accelerated and unaccelerated beams can be used. This assumes that the physics done with these beams will still be competitive and there is a strong user and development groups, which are there to use and improve it. A list of beams asked for by users in the earlier was given by the cluster group. This list is not complete and does not take into account the uniqueness and the competition with the other facilities which the forum group will look into. There were also discussions about new beams and increasing the intensity of existing beams in general. The increase of intensities of the existing beams can be a maximum of a factor of 1.5 to 2 by increasing the power of the primary beam. Such an increase will involve detailed studies and target modifications. The uniqueness of SPIRAL presently lies in highly intense beams of He isotopes and other light nuclei. The development of alkaline beams like neutron rich beams of $^{47}$K or Na, $^{8,9}$Li beams has/is been/being studied for the last few years but technical problems still exist. The efforts put into this development have to be taken to an endpoint and the priorities of these beams for physics have to be discussed. This was originally driven by beams of $^{11}$Li which appears to be not practical and not competitive with other facilities. The development of neutron rich beams of C, which also have been studied in a collaborative effort might yield an final intensity of around $10^9$/sec (for $^{15}$C on a dominant charge state, less for other C isotopes) and the interest of these beams has to be studied. To put into final priorities for the beam development, in addition to the
physics priorities, one also requires knowing the detailed plans for the beams at SPIRAL2 and the order of the priorities for the beam development including a rough time scale. This will facilitate the optimization of the current facilities to be best suited for the coming years and the time after the start of SPIRAL2. Below are given some possible pathway, the last one is the most general option which would remove the constraints in the development but the exact plans of which beams have to developed has to be decided by the physics priorities. It might be still worth considering for the final recommendations a detailed summary for the physics program at SPIRAL1 and their needs in terms of beams, detectors...

Given below are some suggestions to improve the quality and/or quality of beams at the SPIRAL1 facility. The suggestions are presented in order of increasing complexity. It should also be remembered that everything cannot be done unless there is sufficient manpower and financial support. The ideal solution would be to improve existing facilities while build the general option give in item C.

A) **Improvements of the existing system**

Improvements in vacuum, target geometry and the transfer line between the target and the ECR ion source. These relatively simple modifications are expected to lead to an increase in the present beam intensities, especially for the short-lived isotopes. A modification of the whole system is required to limit the number of different type of production systems and thus their management, (construction and dismantling). The present services are not visualized to require important modifications or major changes in the mechanical structure of the cave. The suggested modifications of the TISS (Target Ion Source System) can be tested on the test bench with stable beams before being used online. The required expertise is available at GANIL. The time required for the planned modifications is estimated to be around 1,5 year.

B) **Ongoing plans for new beams**

The direct 1+/N+ method for producing alkali ions is under development and the off-line tests are encouraging. The production of exotic neutron-rich Xe ions can be immediately started, owing to its low cost and to the simplicity of its principle, and similarity with the existing TISS of SPIRAL. Due to these reasons it should have a relatively large success rate. Its on-line test directly on SPIRAL I can be considered. No modification of the cave or of the handling system is required hence the safety studies should not be too involved. The production of neutron-rich carbon isotopes has already been tested at GANIL and the C release has been observed. Mainly thermal studies and mechanical design must be carried out before designing a TISS suitable to the primary beam of some hundreds of watts. Two solutions are possible: direct primary beam in an Oxide target or a combined target C + Oxide. A preliminary test on SIRa test bench is necessary. Its installation in the cave of SPIRAL I will not need any modifications. However, an authorization to put new material target is will probably be required.

C) **A charge breeder setup. 1+/N+**

As opposed to the compact ECR source which is now being used, a more traditional 1+ to N+ charge breeder setup (like the one used at CERN, TRIUMF and proposed for SPIRAL2) can be built. The technique and its performances are relatively well known. The charge state distribution produced is suitably matched for the requirements of the post-accelerator. In terms of Target Ion Source System, this solution is the most ambitious and general solution. Its use on SPIRAL I would strongly enlarge the choice of available radioactive beams. Since this system has already been build elsewhere and is currently under development for SPIRAL 2, it would seem to be possible to minimize the time of construction and delivering the first radioactive beam at SPIRAL I. This installation at SPIRAL I will require major modification, for which at least a minimum of 3 years are required if all the resources needed are available. The optical, mechanical, electrical and safety studies could be done in parallel, as with the construction of the source and the off-line test. Such a source may not have an optimal performance for light beams. Additionally if it has to replace the existing TISS this will cause the
break in delivery of the existing SPIRAL beams. In order to facilitate both the operation of SPIRAL1 and also to exploit the existing TISS an existing second irradiation cave at SPIRAL1 might be equipped. It is important to note that the choice of the charge breeding solution involves the development and the construction of 1+ TIS systems. The TISSs existing at GANIL could already be adapted or different TISSs developed for SPIRAL 2 and those used in other laboratories could be transformed or adapted to fit with the specific constraints of SPIRAL I. Among the solution the laser ion source is a very versatile choice but presents difficulties in term of installation at SPIRAL I. These need to be studied immediately, in parallel with its development on SIRa along with the requested authorizations. The third plan suggested here is a very general option which can be planned and constructed as per the physics demands. This general option should make the beam delivery at SPIRAL 1 competitive to other facilities and complementary after the starting of SPIRAL2 provided the physics goals and priorities are clearly defined.

2. LIRAT

The LIRAT facility was built in the period 2003-2004 to respond the physicists request to dispose of a low energy beam line at GANIL for experiments with the radioactive nuclei produced by the SPIRAL target-ion source system. The facility consists of one beam line in which, for authorization reasons, only four radioactive ion beams are available (\(^6\)He, \(^{19}\)Ne, \(^{32,35}\)Ar) at a maximum energy of 30 keV.

So far only one experimental set-up, the LPCTrap, has been installed there and used the LIRAT beams. This device consists of a RFQ cooler and buncher followed by a transparent Paul trap and is dedicated to the study of fundamental interactions via the beta decay of trapped radioactive ions. In this context only the decay of \(^6\)He\(^{1+}\) ions has been studied. The aim of the experiment is to look for a possible admixture of tensor like currents in the weak interaction. They are addressed by means of a precise measurement of the beta-neutrino angular correlation coefficient \(a\) in the pure Gamow-Teller decay of \(^6\)He. Fundamental interaction studies at low energy have furnished building blocks for our present understanding of elementary particles and their interactions and they shaped the Glashow-Weinberg-Salam model as we know it today. Nowadays measurements with radioactive nuclei keep being at the forefront in the search for new physics and are complementary to searches at much higher energies.

During the last three years the stability, the purity and intensity of the \(^6\)He\(^{1+}\) beam have been improved, as well as the overall efficiency of the low energy manipulation and trapping device. After several tests with stable beams, the beam line was first commissioned in 2005 with a \(^{35}\)Ar beam followed soon thereafter by the first \(^6\)He beam. Since then, several runs with stable beams have been performed to optimize the beam transport and two runs with \(^6\)He beams have also been carried out. The first data taking experiment devoted to the decay study of \(^6\)He was performed in 2006. A related article has been accepted in Phys. Rev. Lett. for publication while the technical developments have been published in 6 other articles.

During the 2006 experiment with the \(^6\)He beam, more than \(10^5\) coincidences between the beta particles and the recoiling \(^6\)Li ions have been collected. This corresponds to a relative statistical precision of 2% on the beta-neutrino angular correlation coefficient \(a\) which is 5 times more precise than the only beta-recoiling ion coincidence experiment performed so far. The LIRAT beam line will be devoted to the measurement of the beta-neutrino angular correlation coefficient \(a\) in \(^6\)He decay until the required level of precision (below 0.5%) will be achieved. A recent experiment has been performed (in October 2008) where more than \(4 \times 10^6\) coincidences have been collected, and which would enable to reach the statistical goal. Additional tests with \(^6\)He beams are already planned to assess the impact of possible systematic effects in the measurement of the angular correlation coefficient. These effects will further be studied by extensive Monte-Carlo simulations.
An upgrade of the LIRAT facility has been proposed in December 2006 and in July 2007, the so-called LIRAT2 project proposed the extension of the existing LIRAT facility, but this has not been funded.

A strong condition for the attractiveness of LIRAT as an open access facility for a wider community is the urgent availability of all the radioactive beams produced by SPIRAL. In the mean time, awaiting for the necessary administrative authorizations for the future use of all SPIRAL beams at LIRAT, it is being considered to measure with the LPCTrap set-up, or with other setups to be developed, different correlations addressing fundamental problems like: tests of CVC, the determination of the $V_{ud}$ element of the CKM matrix and the search for exotic couplings. Note that some of these measurements also bring crucial information on isospin mixing in nuclei and offer strong constraints to microscopic approaches. More specifically, the experiments concern:

- The measurement of the angular correlation parameter in the mirror decay of $^{19}$Ne. This decay appears to be an ideal case for an alternative determination of $V_{ud}$. There are several other mirror transitions where such measurements can be carried out. Considering the lifetimes and required statistics, intensities of up to $10^7$-10$^9$ pps in the $1^+$ charge state are needed.
- The measurement of the angular correlation coefficient in the Gamow-Teller decay of $^8$He, with a complementary technique based on beta-gamma coincidences.
- New correlation experiments, like the beta asymmetry measurement in mirror transitions with a MOT allowing the production of polarized samples.
- Other experiments with implanted low energy beams.

Within the SPIRAL2 project, the LIRAT beam line should transport SPIRAL beams to the DESIR facility. It would not allow the running of experiments in parallel.

3. LISE & SISSI

The LISE separator is one of the major equipments of GANIL. In conjunction with SISSI or in stand-alone mode it allowed many fragmentation type experiments as well as experiments at the Coulomb barrier to be performed. SISSI, until its break down mid 2007, allowed to serve all other high-energy experimental rooms of GANIL to be supplied with fragmentation beams. Between 2001 and 2008, a total of 1192 UTs of fragmentation beams was delivered to experiments, more than 900 of these UTs used the LISE separator, 436 UTs used SISSI. In addition, LISE was used in 358 UT with low energy beams. Since the break down of SISSI, LISE is extremely used (80% of the high energy beam time in 2008 - 90% forseen in the first part of 2009). In 10 years (1998-2008), 115 publications (15 PRLs) dealt with LISE and 73 (6 PRLs) with SISSI physics. The physics topics cover a variety of subjects such as “new isotopes”, “ground-state properties” such as masses, half-lives and decay properties, “isomers”, “exotic radioactivities”, “nuclear moments” “Coulex”, “knockout reactions”, “in-beam spectroscopy”, “transfer reactions”, “haloes and clusters”, “active-target type experiments”, and “super-heavy element studies”.

Since its initial installation LISE was upgraded several times: i) the addition of the velocity filter and the corresponding beam line and the possibility of using an angle on the target in 1991, ii) the addition of a vertical dipole in order to use the velocity filter and this dipole as a mass filter (1994), iii) the addition of a second beam line LISE2000 which uses the first LISE dipole, but a separate second dipole (2000), iv) the recently completed high-intensity target CLIM including a new target chamber and a target robot (2007), v) the $B_\rho$ detector CAVIAR.

The LISE separator was the first of its kind world-wide. Despite the upgrades just described new separators like the A1900 at MSU or the RIPS separator at RIKEN have today much better performances at more or less comparable energies. This is mainly due to the limited angular acceptance of LISE of only about ±15mrad (about a factor of 2 more for LISE2000, but without the velocity filter which is absolutely needed of an important number of experiments) compared
to ±45mrad (A1900) and ±40mrad (RIPS) for also a slightly larger momentum acceptance of the two other separators. This drawback was in part compensated with SISSI which increased the angular acceptance to ±60mrad, however, at the price of a reduction to ±0.5% in momentum acceptance as compared to LISE3 alone (±2.5%), the A1900 (±2.75%) and the RIPS (±3%). An additional prize to pay was the high focalization of the primary beam which created mechanical target stability problem for some targets due the heat deposited in the target on a rather small spot (0.2mm x 0.2mm).

The present limitations of LISE are the following:

- 400 W equivalent $^{12}$C at 95MeV/nucleon. For less energetic beams, the intensity can be increased following the relation $I_{\text{max}} = 8.1 \times 10^{29} \times E^{-8.8}$, yielding slightly higher intensities.
- 80 W of power deposited in the target. This is a rather severe limitation as it allows only 20% of the available beam intensity to be used for $^{58}$Ni at 75 MeV/nucleon. For $^{18}$O, almost a factor of 10 more beam intensity could be used without this limitation. It should be mentioned, however, that for selected experiments, the GANIL safety authorities can give the authorization to use higher beam intensities, since CLIM is used.
- The full momentum acceptance of LISE of ±2.5% can only be used for very light fragments as heavier fragments overlap in the time-of-flight identification parameter. As a rule of thumb, the momentum acceptance has to be smaller than the 1/(mass of the fragment), e.g. up to mass 20 one can use the 5% full acceptance. CAVIAR is meant to measure the $B_p$ in the LISE dispersive plane, which would allow to use the full momentum acceptance. However, this is only possible if the intensity in the dispersive focal plane is limited to about $10^5$ pps. It should be mentioned that, contrary to the momentum acceptance, the full angular acceptance can be used.

The short-term (2-3 years) improvements of the fragmentation facility at GANIL should consider the following possibilities:

- replacement of SISSI or a spectrometer behind a separator. The GANIL fragmentation beams are ideally suited to direct reaction like transfer. In particular, proton-rich fragmentation beams are more than competitive compared to other laboratories, largely due to the highest primary beam intensities. For other beams, the availability of equipment or combinations of equipment including SPEG, EXOGAM, MUST2 and TIARA render the possibilities offered by GANIL unique. Physics topics only possible with a combination of a separator and a spectrometer behind are e.g. mass measurements and two-step reactions.

option 1: replacement of SISSI :
- This would allow to send fragmentation beams in all caves of GANIL
- proton-rich beams are best produced with SISSI (compared to LISE)

option 2: spectrometer behind LISE2000 :
- n-rich beams will benefit from the highest $B_p$ of LISE2000
- This would allow to have two independent fragmentation beam lines at GANIL

- by adding one quadrupole in front of LISE (1m space needed) an increase of the angular acceptance could be achieved. Specially needed for p-rich nuclei if option 2 is choosen

Another proposal concerns the use of LISE3 as a $0^\circ$ spectrometer for low-energy beams (e.g. fission fragments from SPIRAL2) at the Coulomb barrier. However, the change from the standard LISE mode to this so-called FULIS mode requires a lot of mechanical work and will become more and more difficult with high beam intensities and in particular with radioactive beams. Therefore, it is felt that LISE might a solution if nothing else is available, but is certainly not state of the art. Rather a new separator/velocity filter should be considered.

On a much longer time scale, the fragmentation community wishes to possess a world-class fragment separator which could be used for stable beams from the CSS cyclotrons or
another machine which would in addition allow also to accelerate fission fragments to energies around 100MeV/nucleon. At this time, it would probably be needed to upgrade the LISE spectrometer in order to reach world-class specifications.

The physics program that will be followed at such upgraded fragmentation facility would be a follow-up of the present program, however, with improved intensities and, in particular, the availability of fission fragments from SPIRAL2 in LISE.

**SUMMARY OF THE “FRAGMENTATION” MEETING**

The objective of the meeting on December 4, 2008 at GANIL was to discuss the future possibilities for fragmentation at GANIL taking into account that SISSI is not reparable and therefore today the only possibility is to use LISE to produce fragments at GANIL. In this context, three possibilities have been discussed:

- The replacement of SISSI by an identical SISSI2. According to the information available, a detailed description will be established by March and sent to companies with an answer expected in the summer. This would probably mean that SISSI2 could go online in 2012.
- The extension of LISE2000 which includes the addition of a velocity filter and a spectrometer, possibly the BBS from KVI which could be available by the end of 2009. This option would keep the LISE3 beam line unchanged.
- The replacement of LISE3 and LISE2000 by a new separator “SUPER-LISE” which would consist of parts from LISE2000 (first dipole) and of LISE3 (the velocity filter). A new second dipole may be required.

These two options are shown below (figures 1 and 2).

![Figure 1: Extension of the LISE2000 beam by a velocity filter and the addition of a spectrometer.](image)

Both these solutions would allow to perform again basically all experiments performed in the past with the combination of SISSI-ALPHA-SPEG, except mass measurements for which the long flight path is no longer available. The first solution is probably more expensive, but would allow to use LISE3 at least to some extent during the modifications of LISE2000, whereas for
the second solution fragmentation would be completely stopped most likely for as long as 2 years. However, the second option is probably cheaper as most of the equipment exists either on LISE2000 or LISE3. In both solutions, the INDRA cave would vanish and INDRA would need to be installed else where. Both solutions require also to increase slightly the size of the D5 cave.

Figure 2: The new “SUPER-LISE” separator with the spectrometer behind.

All solutions have advantages and drawbacks. Some of them are listed in the following:

<table>
<thead>
<tr>
<th>Advantages</th>
<th>SISSI2 + ALPHA</th>
<th>LISE2000 extension</th>
<th>SUPER-LISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 2 target stations</td>
<td>• Two beam lines</td>
<td>• Advantages for production of p- and n-rich isotopes</td>
<td></td>
</tr>
<tr>
<td>• 2 beams lines</td>
<td>• Advantages for n-rich nuclei due to higher mag. rigidity</td>
<td>• Possibility to use velocity filter and spectrometer in “FULIS” mode (to be investigated)</td>
<td></td>
</tr>
<tr>
<td>• Advantages for heavier and in particular for p-rich isotopes</td>
<td>• Improvement of LISE2000 which is rarely used today</td>
<td>• Large acceptance of BBS</td>
<td></td>
</tr>
<tr>
<td>• Increased purity of beams due to distance between production and detection</td>
<td>• Possibility to use velocity filter and spectrometer in “FULIS” mode (to be investigated)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Project already started</td>
<td>• Large acceptance of BBS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Probably least man power needed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drawbacks</th>
<th>SISSI2 + ALPHA</th>
<th>LISE2000 extension</th>
<th>SUPER-LISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Maintenance of 2 target stations</td>
<td>• Probably little interest for SPIRAL2</td>
<td>• No 0° experiments possible any-more (e.g. DEMON)</td>
<td></td>
</tr>
<tr>
<td>• Small maximal Bρ of 2.9 Tm</td>
<td></td>
<td>• Probably little interest for SPIRAL2</td>
<td></td>
</tr>
<tr>
<td>• No interest for SPIRAL2</td>
<td></td>
<td>• Only one target station</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Only one beam line</td>
</tr>
</tbody>
</table>
The following table summarises the performances of the different configurations in terms of acceptances and magnetic rigidity.

<table>
<thead>
<tr>
<th></th>
<th>Angular acceptance (msr)</th>
<th>Momentum acceptance (%)</th>
<th>Max rigidity (Tm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LISE</td>
<td>1.0</td>
<td>± 2.5%</td>
<td>3.2</td>
</tr>
<tr>
<td>LISE2000</td>
<td>3.5</td>
<td>± 2.5%</td>
<td>4.3</td>
</tr>
<tr>
<td>SISSI</td>
<td>11</td>
<td>± 0.5%</td>
<td>2.9</td>
</tr>
</tbody>
</table>

One should, however, keep in mind that often the full momentum acceptance of LISE3/2000 can not be taken as this necessitates a measurement of the $B_0$ of the fragments e.g. with CAVIAR which limits the counting rates at the LISE dispersive plane at the degrader to about $10^5$ pps which is a strong limitation for many experiments. The full angular acceptance can always be taken to the experiments. The big disadvantage of SISSI is its low magnetic rigidity which severely hampers experiments with neutron-rich nuclei.

To compare the possible future spectrometer behind LISE2000 (which is supposed to be the Big Bite Spectrometer from KVI) the following table compares SPEG with the BBS in two different modes:

<table>
<thead>
<tr>
<th></th>
<th>SPEG</th>
<th>BBS mode A</th>
<th>BBS mode C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum acceptance (%)</td>
<td>7</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>Solid angle ( msr)</td>
<td>4.9</td>
<td>13</td>
<td>6.7</td>
</tr>
<tr>
<td>Horizontal acceptance ( mrad)</td>
<td>±35</td>
<td>±36</td>
<td>±30</td>
</tr>
<tr>
<td>Vertical acceptance ( mrad)</td>
<td>±35</td>
<td>±90</td>
<td>±56</td>
</tr>
<tr>
<td>Mean Radius (m) / Max induction (T)</td>
<td>2.4 / 1.2</td>
<td>2.2 / 1.4</td>
<td>2.2 / 1.4</td>
</tr>
<tr>
<td>Deviation angle</td>
<td>2.88 - &gt; 3.8</td>
<td>3.1 - &gt; 3.4(?)</td>
<td>3.1 - &gt; 3.4(?)</td>
</tr>
</tbody>
</table>

This shows that the performances of the solutions with BBS would be superior to SISSI-ALPHA-SPEG.

The meeting did not allow to take a decision on the choice. In order to converge quickly, each user of fragmentation at GANIL will be asked to compare the three solutions proposed for three typical experiments which represent their experiments performed at GANIL and give a preference for the different choices. From the technical side, a more detailed study about the feasibility, the costs and the delays of the two solutions with BBS should be performed in order to take a decision.

4. SPEG

Presentation of the device
The SPEG spectrometer is a powerful instrument of GANIL, which has provided important physics results starting from the '80s, and which may still deliver high quality results, depending on the available beams and beam line optics.

The long lasting activity of this instrument is strongly connected with its very good performances and the possibility of various types of measurement. This, combined with the availability of new
beams, would allow performing experiments at the frontier in nuclear physics also in the future.

SPEG has produced top-level results (67 papers during the period 1999-2008, including 8 PRLs and 7 PLBs) concerning, among others, the following topics:

a) Direct reactions (elastic, inelastic scattering and transfer) for nuclear structure studies, such as giant and Gamow-Teller resonances, spectroscopic factors, nuclei at the drip line, production of unbound nuclei;

b) Mass measurement of exotic nuclei produced by fragmentation, a topic which has been a highlight throughout the years and up to now;

c) Study of the reaction mechanism at intermediate energies;

d) Electron emission induced by fast heavy ions in semiconductors.

SPEG has been used in combination with gamma detectors (such as the BaF$_2$ scintillators of the Chateau de Cristal, or Ge detectors), charged-particle (MUST2, INDRA) and neutron detectors.

Thanks to the large dispersion, a very effective rejection of the primary beam can be achieved, by using the existing Faraday cups mounted on retractable arms at several positions, including zero degree: this allows measurements down to 0.5 degrees in the laboratory frame. This is an important feature when working in inverse kinematics.

SPEG works best with high-energy stable or fragmented beams. The latter are not available because the SISSI device is broken; a measurement with a stable beam was approved at the last PAC (December 2008). Only one other measurement (E418, mass measurement of n-rich nuclei produced via fragmentation of $^{76}$Ge) is in the backlog and cannot be programmed.

**Future activity – improvements of the device**

The space available around the target position at SPEG allows the use of most present and future detector arrays. For the physics cases of interest, the most probable couplings would be with EXOGAM, MUST2, AGATA and GASPARD. ACTAR could in principle also be placed at the target position, or behind the focal plane (SPEG would act as a separator).

The following improvements are relevant in relation with the physics cases listed further below:

1) The detection of protons emitted at very small angles during in-flight decay of proton-rich nuclei;

2) The modification of the detection setup around the focal plane of the spectrometer, to optimize for heavy, low-energy beams from SPIRAL2;

3) Moving the focal plane closer to the second dipole, increasing the momentum acceptance – this would imply a change of the properties of SPEG making it necessary to study if the performances would be still acceptable.

Improvements on the time resolution for mass measurements are not crucial since the uncertainty on B$_{p}$ is the limiting factor.

**Improvements of the GANIL facility (beams)**

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. In addition, a larger B$_{p}$ of the SISSI-ALPHA device would allow a wider range of available beams on the neutron-rich side of the chart of nuclei. Especially mass measurements could benefit from an upgrade.

Since SPEG, due to its low angular acceptance, is not the ideal instrument for SPIRAL beams, related improvements are not very relevant.

Beams of fission fragments from SPIRAL2 could be used in SPEG. The beams of interest would be the most exotic ones, at intensities of $\sim$10$^5$-10$^6$ pps, for the measurement of transfer reactions in inverse kinematics. The beams should be as isotopically pure as possible, in principle using a separation already before injection in the CIME cyclotron. The use of more intense beams (10$^5$-10$^{10}$ pps) does not seem justified by a physics case; it would anyway require a study to avoid using isotopes that have long-living daughters.
Physics cases for future experimental programmes

SPEG is an instrument initially conceived to work with stable beams and reactions in direct kinematics. It has then proved very effective using the high-energy radioactive beams, produced by fragmentation reactions in the SISSI device and analysed in the ALPHA separator. Part of the GANIL community at large, interrogated on possible future plans, has replied indicating the interest of keeping fragmentation at GANIL; in some cases, the programmes would require the use of a powerful spectrometer (study of pigmy resonances with inelastic scattering; knock-out reactions; complete kinematics measurements with p-rich nuclei). This would require the replacement of SISSI, or, alternatively, placing a spectrometer behind LISE. Discussions concerning the choice between the two solutions, and even the opportunity of keeping fragmentation at GANIL, have been held in several occasions, promoted by the “SISSI-LISE” cluster group, and are documented in their reports. We just mention that many aspects, strongly correlated, need be considered (the uniqueness of GANIL energies; competitiveness with other fragmentation facilities in a few years; time required for realising the installation; relation to the SPIRAL2 project; etc.).

We list here the physics cases, as identified by the SPEG cluster group, which would use the fragmented beams in combination with a spectrometer such as SPEG:

1) **Gamma spectroscopy of proton-rich nuclei**
   Double fragmentation techniques are used to produce nuclei at and beyond the proton dripline. The structure of such states has implications for both nuclear structure (i.e. mirror symmetry) and nuclear astrophysics.

2) **Search for excited 0⁺ states in neutron-rich nuclei**
   Pair transfer reactions around zero degree are the perfect tool to populate excited 0⁺ states in even-even nuclei. Inverse kinematics reactions on light targets (Li, Be, B, C) can be used to locate excited 0⁺ states in exotic nuclei. Besides the pairing vibration modes, the location of 2p-2h excited 0⁺ states in 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.

3) **Charge-exchange reactions to study GT strength in proton-rich nuclei**
   They are of significant interest for nuclear structure and, indirectly, nuclear astrophysics. Of particular interest are the (n,p)-type reactions which enable to probe the GT strength. For example in ⁵⁶Ni, very strong or “super” GT transitions are predicted. The highest energy (90 MeV/nucleon) proton-rich beams would be used. The coupling with a gamma-array such as EXOGAM or AGATA enables an energy resolution of 10 keV or better.

4) **Mass measurements of nuclei far from stability**
   These are possible by combining high-resolution ToF and momentum measurements of fragmentation beams. Experiments for neutron-rich isotopes close to the N=40 sub-shell closure, requiring the SISSI device, are already approved. To measure heavier masses, however, upgrades would be necessary to increase the maximum Bρp to values beyond 3 Tm.

The use of SPEG with SPIRAL2 beams was also considered. Transfer reactions are possible because of the strongly forward-focused kinematics. For example, for (d,p) at 6 MeV/nucleon and a projectile with A>60, both the angular (±2⁵) and momentum acceptance (7%) are sufficient to detect the reaction ejectiles in the full centre of-mass angular range. SPEG offers the advantages of an effective primary beam rejection, and identification of the recoil Z and A. However, the use of SPEG in this configuration is still to be proven: the presence of different possible charge states in the heavy beam-like ejectile, as already noticed in occasion of the ⁴⁶Ar(d,p)⁴⁷Ar measurement.

Measurements with stable beams remain possible, with applications also in material science.
5. VAMOS

Introduction

VAMOS is a large acceptance device that can operate in different optical modes. It has been built to obtain sensitivity and selectivity for experiments using the radioactive ion beams provided by SPIRAL1 facility. It has been used coupled to INDRA, EXOGAM, TIARA, MUST2 where the last three have also been used simultaneously. VAMOS has a variable distance from the target and can be also rotated around the target axis up to about 60 degrees.

Scientific Highlights:
• The existence of a low-lying negative parity state in $^{27}$Ne, which is a signature of a reduced sd–fp shell gap in the N=16 neutron-rich region, at variance with stable nuclei.
• The gamma spectroscopy of $^{25,27}$Ne and $^{26,27}$Na studied from the reaction of $^{26}$Ne with a deuterium target in inverse kinematics
• Results from the gamma spectroscopy of neutron rich isotopes around $^{46}$Ca exemplifying new limits of sensitivity
• First evidence of non-axial deformation near classical closed shells in $^{48}$Ar
• The absence of the predicted N=34 in $^{54}$Ca

Observed limitations

The main working modes of VAMOS are:

a) Focusing device (2 quadrupoles used)

b) Magnetic spectrometer with a possibility of a variable dispersion. In this mode the magnetic rigidity can be determined by using tracking detectors

c) Separator. Here the velocity filter (WIEN filter) is used.

d) Separator, gas filled mode (under study)

The unique advantages of VAMOS spectrometer imply a number of disadvantages and limitations:

1) Multi-nucleon, deep inelastic transfer reactions and fission reactions: operated in non-zero degree operation with the incident beam not entering the device. Modes a) and b) are possible and beams reaching 10-20 pnA can be used depending on the limitations of the auxiliary detectors

2) Transfer, multi-nucleon transfer etc. reactions: A zero-degree operation mode and/or beam and beam like particles entering the device. Mode a) is possible only if the beam intensity is smaller than $10^4$ pps. In mode b) the dispersion of the device will remove the main charge states of the beam (particularly for low energy heavy beams). For X(d,p) reactions such measurements would be limited to currents $10^4$ - $10^5$ pps.

3) Fusion reactions: zero-degree operation mode: Modes a) and b) cannot be used unless the current is below $10^5$ pps. It has been recently demonstrated that mode c) provides a beam suppression of around $10^7$ for very asymmetric reactions e.g. $^{22}$Ne + $^{197}$Au. More symmetric and inverse kinematics reactions in this mode are presently not possible. Mode d) might be used but this has not yet been tested (tests are planned in 2009).

In conclusion, measurements with the highest beam intensities available can be used only in certain cases. This suggests that a new device is required.
**List of planned improvements**
1) Increase of the momentum acceptance of the device by a factor of 2 by increasing the active area of the detection system
2) Electronics upgrade
3) Rotating target for high currents/melting targets
4) Gas filling of the spectrometer
5) Improvements of the vacuum near the target chamber
6) Development of the MUSETT detector for recoil tagging and recoil decay tagging
7) Coupling with AGATA

**Future use**
VAMOS will be the major instrument that will be required for most of the research programme using the secondary beams of fission fragments produced by the SPIRAL2 facility. VAMOS is expected to operate with future arrays like AGATA, PARIS, and GASPARD. The use of VAMOS will also reduce the effects of beam contamination and beam-induced activation.

**Desired improvements**
Change of accelerating gap of the Wien filter from 1 m in the horizontal direction to 15 cm in the vertical direction for studies of fusion reaction with high intensity stable beams. This will allow an increase in the dispersion by a factor of 6 allowing for an improved separation from the beam in the case of very asymmetric systems.

In order to exploit multi-nucleon reactions with the high intensity beams of SPIRAL 2 it is necessary to place a spectrometer near the grazing angle. For energies at 10-20% above the barrier this angle typically lies between 60 and 90 degrees. At present, the walls of the experimental hall constrain the limit to 50 degrees or less.

The beam dumping at VAMOS will be an important issue in all cases because of radioprotection issues and because of the large gamma-ray background. A new beam line inclined at 45 degrees relative to the present beam line will have to be installed. With this line VAMOS can be operated between 35 and 95 degrees. Zero-degree operation is achieved with the existing beam line. This solution will allow all working modes, and allows for the provision of a permanent beam line to the beam dump.

**Desired GANIL beam improvements**: Increase of the intensity of the heavy beams Pb, U up to 20 pnA at 8 MeV/u for studies using the deep inelastic transfer reactions and fission reactions in inverse kinematics; improvement of time resolution of the beam pulses to about 500 ps.

**Desired SPIRAL Beam improvement**: The time resolution should be improved to less than 1 ns without decreasing the beam intensity.

**Desired beam in existing caves**: Beams of neutron rich fission products with intensities between $10^3$ pps and $10^6$ of the rare species and to $10^3$ pps or more of abundant species, with energies ranging from 3 MeV to 10 MeV/u. The priority of beam development would be to first develop neutron-rich Xe, Kr, Ga and Sn beams and then subsequently increase the intensity of the most neutron-rich isotopes for these beams.

**New Separator**
To realize many of the future physics using high intensity beams from SPIRAL2, a new device is required which could be a large acceptance zero-degree device allowing the separation of reaction products from the incident beam.
6. EXOGAM

EXOGAM is an array of Ge detectors designed to exploit the beams from the SPIRAL1 facility. EXOGAM consists in an ensemble (16) of Ge detectors (Clovers), the associated anti Compton shields and the dedicated electronics, data acquisition system and infrastructure items. Each Clover has a photopeak efficiency of \( \sim 1\% \) at the closest distance and at a gamma-ray energy of \( E=1.3 \) MeV.

It has been used coupled to LISE, SPEG, TIARA, MUST2, VAMOS, DIAMANT, NEUTRON WALL, where the last three have also been used simultaneously. EXOGAM can be assembled in different configurations, maximising efficiency or Compton suppression. The EXOGAM detectors are also used in additional specific set-ups often coupled with the previously listed devices.

**Scientific Highlights:**

- Shapes and shape coexistence phenomena in the neutron deficient A~70 nuclei.
- Low spin collective behaviour in nuclei below \(^{100}\)Sn.
- Isomeric decay of excited states in exotic nuclei, both on the neutron rich and on the neutron deficient sides of the valley of stability and following beta delayed multi proton emission.
- Spectroscopy of nuclei around \( N=20 \) establishing the contour of the “island of inversion” by measuring g-factors, excited states and attempting to measure spin and parities.
- Shell structure evolution far from stability: the case of \(^{66}\)Ni; the shape evolution of sulphur isotopes along the \( N=28 \) shell closure and its interpretation in terms of “shell closure erosion”; the onset of deformation in \(^{44}\)Ar produced by SPIRAL1; the shell gap reduction in \( N=17 \) observed in Ne and Na isotopes. The new \( N=34 \) shell gap in the heaviest Ca and the spectroscopy of exotic nuclei produced in deep inelastic reactions.
- The heaviest element with \( Z>100 \): spectroscopy and single-particle structure of the odd-\( Z \) heavy elements \(^{255}\)Lr, \(^{251}\)Md and \(^{247}\)Es.
- Nuclear reactions: coincidences between EXOGAM, a Si detector and a neutron detector to allow an exclusive measurement of elastic scattering, transfer, fusion and break-up cross sections. This led to a better understanding of the role of the weakly bound neutrons of \(^{6,8}\)He.

**Improvements and evolution:**

**Observed limitations**

Limited number of available Clover detectors. This is especially critical in the case of the parallel operation with the additional set-ups. In particular, a rather generic setup consists in 4 or 5 Clovers installed in LISE for decay studies or coupled to MUST(2)/TIARA and VAMOS/SPEG for direct reaction studies. Sometimes the number of detectors required for such installations reaches 8. More detectors are therefore required in order to cope with 1) the necessary routine maintenance rate 2) the very large numbers of experiments using EXOGAM (with 12 detectors or more) and 3) the regular requirement of 4 to 5 Clovers.

Limited performances of the existing electronics in particular for what it concerns the count rate limitations. Also the maintenance of the existing electronics will become unaffordable on the long time scale.

**List of planned improvements**

1) Lack of detectors: Actions have been undertaken to improve the maintenance of the existing detectors.
2) Electronics upgrade. EXOGAM2 is an already identified project at GANIL. It corresponds to an upgrade of the existing electronics to a full digital, triggerless system and is technically fully specified.

**Future use**

EXOGAM will be one of the most used instruments for the research program using the secondary beams of fission fragments produced by SPIRAL2 facility. It is expected to operate coupled with the SPEG and VAMOS spectrometers at the target and at the focal plane positions as well as with most of the new instrumentation presently being designed for SPIRAL2. It is also expected to operate in conjunction with the S3 spectrometer at the intermediate focal plane for in beam spectroscopy and at the final focal plane for decay experiments.

**Desired improvements**

Increase of the number of detectors in use for EXOGAM as well as for the set-ups at LISE and SPEG (20%). Combined use of the AGATA segmented detectors.

Coupling EXOGAM with AGATA. Mechanics and Electronics need to be reconsidered.

Coupling EXOGAM to S3 at the intermediate focal (in- beam spectroscopy) plane and/or at the final focal plane (decay studies).

Coupling EXOGAM to SPEG or VAMOS, at the target position (in- beam spectroscopy) and/or at the focal plane (decay studies). Concerning the coupling to the VAMOS spectrometer, the combined operation with EXOGAM should be reconsidered according to the suggested developments required for the upgrade of the operation modes of the spectrometer (new beam line, new beam dump etc.).

Development of the infrastructure for the use of EXOGAM in the DESIR area.

**Desired GANIL beam improvements:**

Upgrade to higher energies (~100 A.MeV) for fragmentation of isotopic beams of medium mass \(^{96}\text{Zr},^{100}\text{Mo},^{104}\text{Ru},^{110}\text{Pd},^{130}\text{Te},^{136}\text{Xe},\text{etc.}\). Increase of the intensity of the heavy beams like Pb, U up to 20 pnA at 8 MeV/u for studies using the deep inelastic transfer reactions and fission reactions in inverse kinematics. In particular in the case of the use of EXOGAM with ancillary detectors, the improvement of the time resolution of the beam pulses to less than 1 ns is a necessary development.

Example of SISSI2 interesting beams: \(^{36}\text{Ca},^{32}\text{Ar},^{28}\text{S},^{24}\text{Si},\ldots\)

**Desired SPIRAL Beam improvement:**

Improvement of the beam quality from CIME (emittance, time structure etc.). In particular in the case of combined use of ancillary detectors the time resolution should be improved to less than 1 ns without decrease of the beam intensity.

**Desired beam in existing caves:**

Beams of neutron rich fission products with intensities between \(10^7\) pps for the rare species and \(10^9\) pps or more if available for abundant species, with energies ranging from 3 MeV to 10 MeV/u. The priority of beam development would be to first develop neutron rich Xe, Kr, Ga and Sn beams and then subsequently increase the intensity of the most neutron rich isotopes for these beams. Ar, Kr, Xe, Sn, Nd, p-rich nuclei, n-rich metallic beams, \(^{81}\text{Ga},^{62}\text{Ge},^{80}\text{Zn},\) Ar to Zn up to \(10^{8-9}\) pps
7. INDRA

Introduction

INDRA is a charged particle detection array designed for investigations of multi-fragmentation and the nuclear liquid gas phase transition. It covers approximately 90% of 4π with 336 telescopes arranged in 17 azimuthally symmetric rings. Except for ring 1, each telescope contains an ion chamber and a CsI(Tl) scintillator, allowing elemental identification at essentially all angles. At \( \theta_{lab} < 45^\circ \), the addition of silicon detectors between the ion chambers and CsI(Tl) scintillators provides isotopic resolution for energetic particles that penetrate through the silicon. At larger angles, one calibration telescope is installed per ring, providing isotopic resolution for \( Z > 5 \) with limited solid angle coverage. The INDRA electronics allows the utilization of INDRA as a standalone device or in conjunction with other complementary devices such as VAMOS or SPEG, enabling the exploration of a wide variety of physics topics.

Scientific Highlights:

1. Observation of nuclear vaporization and the production and identification of a real gas of fermions and bosons
2. Studies that characterize multi-fragmentation:
   a. Limitation of the internal excitation of fragments to 3 A MeV
   b. Determination of freeze-out properties such as the fragment charge distributions, collective expansion velocities, and total deposited excitation energies.
   c. Pioneering studies in phase transitions in finite systems and evidence for negative heat capacity, spinodal decomposition, fluctuations and bimodality.
   d. Exploration of scaling laws such as delta scaling, Fisher scaling and isoscaling.
3. Characterization of reaction dynamics at 20 MeV ≤ E/A ≤ 150 MeV:
   a. Isolation of aligned fission, pre-equilibrium and mid-rapidity emission.
   b. Definitive elliptical flow measurements.
4. Multiparticle correlation functions (structure of light nuclei)

Operating modes and limitations

The main working modes of INDRA are:

1. As a standalone device using all rings and detectors. INDRA has been used in this mode for much of its operating life. Large scale survey experiments using INDRA have delineated much of what can obtained without significant improvements in isotopic and angular resolution to the current array.
2. As an ancillary detector providing impact parameter selection and particle identification over a selected angular range in conjunction with more specialized or higher resolution devices. Recent measurements with VAMOS illustrate how INDRA can be used as an ancillary detector to provide impact parameter, event characterization and particle identification. In these experiments, VAMOS provided capabilities for isotopic resolution of heavy projectile fragments at forward rapidities that INDRA lacks. As an ancillary detector, INDRA has world leading capabilities.

INDRA limitations:

1. The INDRA telescopes do not provide isotopic resolution for many of the particles that must be detected to explore the isospin dependence of hot nuclei and nuclear matter.
2. Fast fragmentation beams from LISE, needed to explore the new physics, cannot be sent down the present INDRA beam line. INDRA has not been adapted to the LISE beam line; fast fragmentation beams cannot be used in an experimental setup involving INDRA and VAMOS.
3. The INDRA chamber is not suited for coincidence measurements with neutrons. A new chamber with thin walls would be needed in order to use INDRA as an ancillary detector to
define the centrality in an experiment where neutrons are measured. The present chamber is also not suitable for the future progressive replacement of INDRA modules with FAZIA modules.

**List of planned improvements**

1. Completion of the FAZIA PHASE I prototype in 2009
3. Completion of PHASE III FAZIA demonstrator in 2012 for experiments at SPIRAL2. Portions of INDRA are still required; PHASE III FAZIA has a limited solid angle.
4. Optimization of FAZIA PHASE IV in 2015, which is designed for experiments at EURISOL. Retirement of INDRA.

**Future use**

As the GANIL facility provides an expanding range of intense rare isotope beams, it will enable new experimental programs to probe the isospin degree of freedom in nuclei and nuclear matter and to constrain the Equation of State of neutron rich matter. Until the completion of Phase IV FAZIA, portions of the INDRA array will remain essential to such studies, where they will be used in conjunction with FAZIA modules and other devices, such as spectrometers or neutron detectors. These studies require the possibility to place INDRA/FAZIA at target stations that can receive rare isotope betweenes from LISE, SISSI2, SPIRAL1 and SPIRAL2.

**Desired improvements**

1. Completion of the PHASE I - PHASE IV FAZIA implementation plans.
2. Improved availability of rare isotope beams at target stations where INDRA can be used as a standalone device or in conjunction with other devices. This has several components:
   a. The ability to run with fast fragmentation beams from LISE and from SISSI2 (if it is constructed) with INDRA/FAZIA on its own line and in conjunction with a large solid angle spectrometer like VAMOS.
   b. The ability to run with new SPIRAL1 and SPIRAL2 beams as they become available.
   c. A moveable thin-walled chamber that allows INDRA to be used at other target stations. This chamber should be designed to allow the progressive implementation of FAZIA modules as they become available.

**Desired GANIL beam capabilities and improvements:**

**Fragmentation:**

1. GANIL continues to provide high energy stable beams suitable for fragmentation
2. Fast fragmentation beams should be available for experiments involving INDRA/FAZIA and a large solid angle spectrometer like VAMOS (before 2011).
3. SPIRAL2 beams should be post accelerated to E/A ≥ 100 MeV by a new accelerator. This new accelerator should also replace CSS1/CSS2 for the acceleration of stable beams. (~2020)
4. LISE separator should be upgraded to allow fragmentation of fission fragment beams.

**SPIRAL1:**

5. Development of new medium mass beams.

**SPIRAL2 (low energy radioactive beams):**

6. Development of intense $^{14-26}$O, $^{21-26}$Na, $^{64-80}$Zn and $^{112-132}$Sn, $^{78-95}$Kr, $^{112-132}$Sn and $^{124-144}$Xe beams.
8. INTERDISCIPLINARY RESEARCH ACTIVITIES

Current use of the different GANIL facilities:

Introduction
The current community using the GANIL beams for so-called interdisciplinary research is extremely broad including:
- atomic physics: concentrating on collisions with atoms, molecules, clusters, surfaces, and solids with special focus on dynamical interaction properties;
- material science: probing beam-induced defects and modifications, as well as testing radiation hardness and materials suitability for nuclear applications;
- radiochemistry: studying beam-induced radiolysis including kinetic processes;
- radiobiology: irradiating living cells and investigating subsequent repair processes.

In the past, swift heavy ions as well as slow highly-charged ions had been used by a large community active in these different fields. The number of scientists involved is enormous (more than 200 persons participated in at least two experiments per year). During the last 25 years, the interdisciplinary research activities produced 143 thesis and more than 1100 publications in 155 different international journals.

For the interdisciplinary community an important aspect is the availability of a broad set of beam parameters including different ion species (He up to U) and energies between eV/q to a few GeV (CSS2). Additional attractions are on-line instrumentations and special designed irradiation devices. For most projects, it is extremely important to be programmed rapidly and to perform rather short but more frequent irradiation experiments preferable with not too extended time intervals.

A selection of scientific highlights:

• Atomic Physics: interaction dynamics of atomic collisions for different targets either atoms or complex systems such as molecules, clusters, micro-droplets, surfaces or solid bulk have been investigated with unprecedented details, from low to high energy using the most powerful techniques such as COLDTRIM or multi-coincidences measurements of outgoing ions, fragments, electrons, and photons. GANIL experiments e.g.
  o provide kinematically complete determination of collision dynamics for atoms and polyatomic molecules,
  o elucidate the role of dielectronic correlations,
  o highlight the role of the potential energy of slow highly-charged ions for surface sputtering,
  o result in astonishing progress in the understanding of stability and relaxation of atomic edifices of complex systems,
  o improve the knowledge of individual processes and collective effects involved in ion-solid interaction, including evidence for Fermi-shuttle acceleration and wake field effects,
  o reveal the dependence of elementary atomic collision processes on impact parameter using channelling conditions.

• Material Sciences and Solid State Physics: Based on GANIL experiments, numerous beam-induced modification and degradation processes have been elucidated, including:
  o radiolysis of water on a nanosecond scale
  o track formation in metals and identification of specific defects and phase changes in insulators and polymers
  o characterization of track morphology, identifying threshold values of track formation, and discovery of velocity effect
  o MC calculations for electron cascade and thermal spike modelization for track formation
  o sputtering processes including jet-effects in the electronic stopping regime
  o characterization of suitable radiation resistant materials for nuclear application

1 upcoming at TBE (Très Basse Énergie) installation, keV/q are presently available at ARIBE (Accélérateurs pour les Recherches à Basse Énergie)
o use of ion tracks as efficient vortex pinning centers to better understand the phase diagram of vortices in superconductors

Facilities, beam lines and online equipments:
Since many years, proposals from the interdisciplinary community are evaluated by a special PAC providing expertise from the many fields involved. Around 10-15% of the overall GANIL beamtime is allocated to the interdisciplinary user community (overbooking factor ~2). The CIRIL (Centre Interdisciplinaire de Recherche avec les Ions Lourds) belonging to the CIMAP (Centre de Recherche sur les Ions, les Matériaux et la Photonique) laboratory provides local user support and develops new installations dedicated for irradiation experiments in e.g. atomic physics, material science, or biophysics.

At present, the main installations used by the community are:
- SME facility (medium energy 4-14 MeV/u (U - C)) located in cave D1, offering ion beams delivered by CSS1. The beamline houses various in-situ analysis tools and is the working horse of the solid-state physics community but also provides suitable conditions for selected atomic physics experiments.
- HE facility (high energy 24 – 95 MeV/u (U - C)) at the exit of CSS2 also located in cave D1. The beam line is predominantly used for radiobiology experiments.
- The IRRSUD facility (low energy 0.4 - 1 MeV/u (U – C)) at the exit of C0. This beamline is heavily used for high fluence irradiations in material science permitting independent selection of energy and ion species during 2 weeks per month.
- ARIBE (low energy, high charge states) facility directly connected to the ECR source in hall D (a few keV/q). Due to large demand, this facility has recently been expanded to 7 beam lines.

All the beam lines devoted to interdisciplinary research are equipped with dedicated irradiation chambers, which allow e.g. the exposure of large surfaces and irradiation at low or high temperature. Tools for in-situ analysis include various particle spectrometers (atoms, molecules, electrons), absorption spectrometry (e.g. UV-visible, infrared), X-rays diffraction, gas emission analysis, and conductivity measurements.

Besides the dedicated facilities, some other GANIL beamlines have been used in the past, in particular for experiments requiring extremely well defined beam optics and charge state analysis of the outgoing ions after collisions. This requirement mostly concerns atomic physics experiments which can be performed e.g. in the LISE or SPEG cave.

Improvements and evolution:
Existing limitations
- Some experiments at the medium energy beams in D1 fully suffer from the introduction of specific time-structures that unfortunately are introduced upstream.
- The very low energy installation (TBE) at ARIBE is still waiting for the safety authorisation and could loose its primacy in the international context which is very competitive.
- IRRSUD experiences an unexpected delay of the safety authorisation to irradiate nuclear materials. A huge backlog of accepted proposals concerns investigations that are essential for the future development of nuclear energy.

List of planned improvements
- The low-energy-beam production will be improved by the installation of the GTS source on ARIBE and of Supershypie on the TBE.
- IRRSUD and SME beam lines will be equipped with a small-scale device for continuous film irradiation.
- At IRRSUD an additional in-situ X-ray powder diffractometer (ALIX) is close to be installed. In addition, a time-resolved optical spectrometer is planned for the near future.
- Developments of mass-selected cluster beams and molecular beams produced by electrospray are currently in progress and in a first step, will be installed at ARIBE.
Two special devices concerning beam delivery are in preparation: DOSION for radiobiology dosimetry and "ion-by-ion" irradiation setup for the Ion Track Technology (ITT) applications.

Future use

The large feedback to the recent questionnaire (75 responses received), clearly demonstrates the great interest of this community and the important role of the GANIL facilities in the future. Without doubt, GANIL is expected to continue to be one of the main driving forces for the interdisciplinary research activities until 2015 and beyond. So far, the interdisciplinary community considers primarily stable beams for future GANIL experiments except two specific experimental programs that plan exploitation of high-intensity stable beams of SPIRAL2 in the target chamber of NFS and possibly on the S3 beam line. While the French atomic physics community presently orients mainly towards low energy ions, experiments in materials research and condensed matter are based on the availability of medium energy ions, i.e., beams from C0 and CSS1.

The following modest-scale improvements could have an extremely positive impact on the course of future experiments.

Desired beam improvements:

- Priority 1: On SME, the time structure (slow chopper) is sometimes set by the running experiment for decay studies, but much more frequently it is used to control the beam power on the target (e.g., SISSI, LISE or Spiral 1). This situation renders parallel SME experiments very difficult and leads to a major loss of potential beam time. The problem could be solved by replacing the chopper behind the SME entrance and/or modifying the intensity modulation by introducing pepperpots or other suitable devices.
- Priority 2: A reliable operation of the pulse suppressor is mandatory and corresponds to a unique tool worldwide. This equipment makes the GANIL beams very well suited for pulsed radiolysis studies and for specific investigations on collision dynamics in atomic physics.
- Installation of GTS type sources on the C0 platforms would be interesting to reach higher energies and currents for heavy ions, which will open new possibilities of experiments in the medium energy range.
- Improvements are needed to minimize beam position instabilities frequently occurring especially on the SME line. These instabilities do not apparently affect the transmission of the cyclotrons, but perturb in particular radiobiology experiments, which use extremely low intensities and for which intensity fluctuations are really problematic.

Desired improvements in cave D1:

- Priority 1: The different sectors of the SME lines are within the same cave. Experiments requiring good emittance but low background suffer from the radiation created in the first part of the line. A concrete wall inside D1 would be of great help in order to separate the stripping and slit area from the part of the beam line where experimental setups are installed.
- Priority 2: For ion-atom and ion-solid interaction studies, the installation of an analysing magnet at the SME line is of large interest for measurement in the CSS1 energy range where the outgoing ions need to be analysed.

9. INDUSTRIAL APPLICATIONS

Current use of the GANIL facility:

Introduction

For industrial applications, mainly two different domains are concerned:

- Irradiation of polymer films for realisation of microporous membranes
- Test and certification of components and electronic systems for space usage
The microporous membranes are primarily produced for micro-filtration purposes and gas sensors although in some cases, they are used in the realisation of micro or nanostructures. The researches on radiation hardness of electronic systems are also performed by industrial users, but aim to get a better understanding in the behaviour of the components under irradiation and in the mechanisms involved as well.

**GANIL beams and beam line:**
All industrial applications take place in cave G4, on a specific designed beam line, during 20 UT of beam per year shared among five or six experiments. Krypton, xenon and lead beams are commonly used for the fabrication of microporous membranes while 75% of the allocated beam time is dedicated to studies of components and electronic systems using predominantly xenon (50 MeV/a) or lead (29 MeV/a) ion beams.

The optic and intensity qualities of the beam enable the production of large quantities of membranes with a high density of pores while avoiding numerous multiple impacts. Providing beams with a wide LET variation in a range over 100 µm, relevant tests of components and electronic systems for space usage can be performed, taking full advantage of the very good resolution in energy and the stability of ion beams, even at very low intensity.

**Online equipments**
Two specific devices has been built since end of the 80’s and are currently updated to achieve these experiments: a roller for the polymeric films, which allows large production of membranes, and a sample irradiation device for components and electronic systems.

**Improvements and evolution:**

*Observed limitations*
- The ability to change the ion species in a short time to allow instigations of radiation hardness of electronic components for several consecutive ion beams within the same experiment.
- An easier access to the beam time which means higher reactivity in the allocation and more time slots available for the tests.

*List of planned improvements funded by the industrial users*
- A new sample device and the associated detection and control systems are currently under studied to allow characterisation of electronic components and systems at low intensity ($10^4$ to $10^5$ pps/cm$^2$). This new setup should be implemented in spring 2009.
- For irradiation of membranes, the detector is currently upgraded to be able to monitor beam of higher intensity (usually 1 to 2 A) on-line through secondary emission.

**Future use**

In both domains, the industrial users are fully satisfied by the good qualities of the GANIL beams and the reliability of the facility. They wish to exploit the same ion beams with the improved devices installed in cave G4.

The demand of allocated beam time is growing up and the foreseen growth factor is of two for the tests of components and electronic systems, but could reach four or five in the case of membranes production.
2. APPENDIX n°2 : Completed cluster templates

Please find enclosed the CD Rom with completed cluster templates.
3. APPENDIX n°3 : Report of Forward Look Forum

Contribution of the Forward Look Forum to the GANIL 2015 Project
March 2009


The present document collates together a series of brief reports on aspects of nuclear physics and interdisciplinary research at GANIL. The coverage is not exhaustive but is driven rather by the current and future interests of the community. Beyond briefly elucidating the physics interest, each report proposes example experiments and the related observables. The equipment and beams required to undertake such work is enumerated and, in many cases, where possible, a comparison is made between GANIL and the possibilities at competing facilities. In addition to defining where the limits of the current facility lie, indications are provided as to the improvements necessary to remain competitive. The possibilities offered by SPIRAL2, the S3 spectrometer, SISSI2 and other devices under study have also been included for completeness. Some observations regarding the longer term future of SPIRAL2, in particular increased reacceleration energies beyond those offered by CIME, are also made.

Collective Modes

Title: Low-lying collective states and response properties
Physics case: The systematic of low-lying collective states when going from magic to open-shell nuclei provides one of the first few key information about the transition from nearly pure two-quasiparticle excitations determined by shell structure to quadrupole and octupole collective states on the one hand, and about the transition from vibrational to rotational nuclei on the other hand. It additionally gives valuable benchmarks for the shell model and models treating large-amplitude collective motions. The comparison of the response strength distributions between nuclei having near-symmetric and asymmetric neutron and proton numbers gives constraints on the nuclear energy density functional, providing information about bulk properties of nuclear matter.
Key observables: gamma energies and reduced strength, angular distributions
Sample experiment: Coulomb excitation, fast timing, Doppler shift methods
GANIL facility: EXOGAM, AGATA, PARIS
Comparison / conclusions: With the exception of few cases (such as DIC studies), the present GANIL cannot compete anymore with other facilities like RIKEN, NSCL and the forthcoming GSI, as rates obtained by fragmentation or fission in these facilities are now exceeding the ones offered by GANIL. The high fission rates that are expected by the SPIRAL2 project will undoubtedly bring a revival of these studies at GANIL.
**Title: Collective excitations in neutron-rich and weakly-bound nuclei**

**Physics case:** Nuclei far from stability are expected to exhibit several soft collective modes located at low energy, as for the pygmy resonance: soft monopole resonance, proton pygmy, vortex mode... Apart from their importance for understanding nuclear dynamics their presence at low excitation energy will enhance neutron capture rates in stars as supernovae. All these modes require further studies. Besides these soft modes, the study of the Giant Monopole Resonance along isotopic chains will offer the possibility of studying the nuclear incompressibility with isospin. With some optimism, one can hope to extrapolate to pure neutron matter, thus bringing further constraint to neutron star calculations.

**Key observables:** Coulomb break-up for L=1 modes; inelastic scattering combined with angular distributions measurements to distinguish between L=0 and L=2 modes.

**Sample experiment:** Coulomb excitation followed by complete kinematics measurements for low-lying E1 strength; \( ^{1}	ext{ } \)' or \( ^{(d,d') \text{ inelastic scattering at small cm angles for compression modes.}} \)

**GANIL facility:** Absence of a large gap magnet and a neutron array as well as low fragmentation energies makes GANIL uncompetitive for Coulomb break up studies. Conversely the MAYA (and later ACTAR) active targets are unique instruments for GMR measurements. SISSI2 could be used to produce and select the ions of interest, although the LISE spectrometer can produce them as well, sometimes with smaller count rates.

**Requirements:** 50 MeV/A for \(^{38-50}\text{Ca, 56-70\text{Ni, 96,98,100}\text{Zr for GMR}}\)

**Other facilities:** GSI and RIKEN for Coulomb break-up. GSI + EXL will be the premier facility for this work but this is still many years in the future.

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**Nuclear Shapes**

**Title: Deformation properties and shape coexistence**

**Physics case:** The nuclear shape is very sensitive to the underlying shell structure and to the amount of available correlations. The study of shapes as a function of proton and neutron number reveals modifications of the shell structure in nuclei far from stability. In some regions of the nuclear chart, the low-lying excitation spectrum exhibits two or even more coexisting collective structures at low excitation energy, which can be associated with coexisting shapes that each can be related to different cross-shell excitations. States of same angular momentum in these coexisting structures are often strongly mixed. Nuclei showing shape coexistence or rapid shape changes with excitation energy, spin, or isospin are particularly sensitive and represent stringent benchmarks for nuclear theory as in particular for explaining the physics of intruder states and island of inversions.

**Key observables:** Excitation energy of \( 0^+ \) isomers, E0 transition moments, rotational bands, in-band and out-of-band B(E2) values, static quadrupole moments

**Sample experiment:** Multi-step low-energy Coulomb excitation with RIB, life-time measurement after deep-inelastic collisions (DIC), fusion-evaporation or fragmentation reactions, gamma and conversion electron spectroscopy after fragmentation, \( (p,t) \) or \( (t,p) \) reactions with medium energy beams to populate excited \( 0^+ \) states, beta-decays, fast timing.

**GANIL facility:** SPIRAL(1+2) beams, EXOGAM(2), AGATA, PARIS, VAMOS, SISSI, LISE, MUST2 (GASPARD), heavy stable beams \(^{208}\text{Pb, 238}\text{U} \) for DIC, neutron detector array, Plunger

**Requirements:** 3-6 MeV/A for RIBs for life-time measurements, stable beams up to 10 MeV/A for DIC, on targets like \(^{48}\text{Ca, 64}\text{Ni, 70}\text{Zn, 82}\text{Se, 96}\text{Zr}\)

**Other facilities:** a wide range of radioactive beams at these energies will be available at HIE-ISOLDE, while for ISAC-2 a more limited number of radionuclides will be offered to the user. For DIC studies, the Legnaro and ANL facilities can provide a wide range of stable beams.

**Comparison Conclusions:**

On the proton-rich side GANIL will have to make significant developments in its ISOL technology in order to compete with other facilities. On the neutron-rich side SPIRAL2 will allow access to the most exotic nuclei. The instrumentation available for Coullex studies or lifetime measurements is comparable worldwide (EXOGAM, MINIBALL, TIGRESS) although the
Title: Systematics of K isomers and bandheads of excited rotational bands

Physics case: one-quasiparticle, two-quasiparticle, and multi-quasiparticle K isomers in odd-A and even-even nuclei, and the rotational structures built on top of them, provide unique information on the underlying shell structure and its coupling to deformation and pairing degrees of freedom that is complementary to the analysis of purely collective states.

Key observables: excitation energies, lifetimes, multipolarity of transitions, spectroscopic quadrupole moments, magnetic moments, charge radii, transition moments and moments of inertia in the rotational bands.

Sample experiment: Z=104, 106, 178Hf and other hafnium isotopes, tungsten
GANIL facility: Wien filter of LISE3, VAMOS gas-filled, 94Kr + 164Dy -> 258No at 5 MeV/A, EXOGAM2, AGATA, S3 in the future,

Other facilities:

a) GSI: 54Cr is available, 50Ti is subject of source development and is planned to be available with the UNILAC upgrade – both at intensities around and above 1 particle µA. The separators TASCA and SHIP together with the particle and γ detectors already in place and to be upgraded are prepared for this type of experiments. The radioactive 94Kr is not available at low energies and for SHIP and TASCA.

b) JYFL: 50Ti is available at moderate intensities (100 particle nA). 54Cr should also be feasible. The separator RITU together with the particle and γ detectors already in place is prepared for this type of experiments. At JYFL radioactive beam species are not available.

c) ANL: 50Ti is available at moderate intensities (20 particle nA). The mass spectrometer FMA together with the particle and γ detectors already in place is prepared for this type of experiments. At ANL radioactive beam species are not available.

d) HIE-ISOLDE: For the study of isomers in the (Z~72, N~106) region, ISOLDE can prepare metastable beams selected using laser ionisation. The rotational bands built upon the isomeric state can then be Coulomb excited. Similar studies have been carried out for isomers in odd Cu nuclei using REX-ISOLDE.

Comparison Conclusions:
For the stable beam part GSI, Jyväskylä and Argonne are competitive, with the drawback of low beam intensities for JYFL and ANL. For the radioactive 94Kr beam, GANIL will be unique. Stable beam induced experiments of this type can ideally be performed at the planned S3 separator. However, to take profit of the intense radioactive beams from SPIRAL1 and SPIRAL2, a Zero-degree spectrometer is necessary. This could either be a velocity filter like LISE3, VAMOS in gas-filled mode or a new Zero-degree spectrometer.

Title: Fast nuclear rotation

Physics case: The existence of (in most cases many coexisting) rotational bands at high spin and the evolution of their properties with angular momentum, N and Z provides unique benchmarks for deformed shell structure, the deformation properties of the nuclear energy density functional, the so-called “time-odd part” of the energy functional that models the effective interaction between the spin and current densities induced by fast rotation, as well as the proton-neutron and like-particle pairing energy functional in the presence of aligned single-particle orbits.

Key observables: excitation energy of the band heads, moments of inertia, in-band and intra-band E0, M1 and E2 transition moments

Sample experiment: fusion-evaporation with stable and high-intensity radioactive beams
GANIL facility: SPIRAL(1+2), EXOGAM(2), AGATA, VAMOS, stable and radioactive beams from CIME and direct beam line to G1, neutron detector array, charged-particle detectors (Diamant etc.)

Requirements: 92Kr (5 MeV/A) + 164Dy in VAMOS gas-filled or a new zero-degree separator

Other facilities: Other RIB facilities can accelerate 92Kr beams but not at the predicted intensities of SPIRAL2 which is an absolute requirement for these studies.

Comparison Conclusions: SPIRAL2 used in conjunction with AGATA will be world-leading.
Title: Systematics of charge radii

Physics case: Charge radii provide fundamental information about the spatial extension of the charge distribution in the nucleus. Its variation when following isotopic or isotonic chains reflects the evolution of the underlying shell structure, the onset of collectivity and stable deformation, providing complementary information to the systematic of low-lying states and their transition moments.

Key observables: charge radii, isotopic shifts
Sample experiment: neutron-rich Be isotopes
GANIL facility: SIRa, LIRAT
Other facilities: ISOLDE and TRIUMF can provide neutron-rich Be beams of the necessary intensity

Comparison Conclusions: The other facilities have well developed instrumentation and are highly competitive. The DESIR facility with the variety of beams provided by the S3, by SPIRAL2 or SPIRAL1 will potentially make GANIL world leading.

Pairing and alpha correlations in nuclei

Title: Alpha-clustering and Bose condensation

Physics case: Clustering has long been known to be influential in the structure of ground and excited states of N=Z nuclei and its possible association to Bose condensates of quartets is an important theoretical challenge. Direct observation of multi-alpha clustering can be achieved measuring the correlations in the structure decays.

Key observables: Two- and many-particles correlation functions
Sample experiment: break-up of medium n-rich beams at medium energies
GANIL facility: MUST2 + EXOGAM (+ VAMOS or SPEG), GASPARD, PARIS in the future
Requirements: 10-40 MeV/A stable beams like \(^{36,40}\text{Ar}\) or radioactive N=Z nuclei + n targets like \(^{12}\text{C, 24Mg, 28Si, 40Ca}\) etc.
Other facilities: Some N=Z nuclei will be available at HIE-ISOLDE and ISAC-2 at energies < 10 MeV/u and intensities \(\sim 10^4\) /s.

Comparison Conclusions: GANIL will have to make significant developments in its ISOL technology in order to compete with other facilities. However, spectrometers for efficient heavy-ion detection do not yet exist at either facility (except TRIUMF with the EMMA project).

Title: Quasi Molecular and Cluster States

Physics Case: Momentum and spatial correlations in light nuclei give rise to quasi-stable subunits, or clusters, within nuclei. The exchange of neutrons between these clusters can be described in terms of molecular-like wave-functions for the neutron orbitals. Molecular orbitals are found to be of particular importance in exotic neutron-rich nuclei. The experimental challenge is to search for molecular structures in very neutron-rich systems where their binding effects are believed to be important. Examples of cluster states of interest are in carbon, oxygen magnesium and silicon isotopes. These all can be described in terms of alpha-conjugate subunits with valence neutrons. The role of the cluster in determining the behaviour of the valence particle orbit as a function of the number of valence neutrons is interesting. For example, \(^{24}\text{Mg}\) has been described as possessing an \(\alpha^{10}\text{O}+\alpha\) substructure, the exchange of neutrons between the three cores in principle would reduce the kinetic energy of the neutron enhancing the binding energy. To date, some limited understanding of the molecular/cluster behaviour of the beryllium isotopes has been reached, the challenge is to demonstrate that the effects are replicated in larger-mass nuclei.

Key observables: Excitation energies, spins, partial widths for the excited states close to cluster decay thresholds, either using resonant scattering or invariant mass spectroscopy techniques.
GANIL facility: Fragmentation and ISOL beams (LISE, LISE2K, SPIRAL1/2), neutron-rich Be, C, O, Ne, Mg, Si..... isotopes; detection systems ECLAN chamber+Charissa/MUST2, GASPARD

Requirements: High intensity light ion (3<Z<20) beams. For the resonant scattering 10^6 pps and for break up measurements 10^4-10^5 pps. Energy range of beams 4 MeV/u to 30 MeV/u.

Other facilities: Up until recently Louvain-la-Neuve has provided low energy, relatively high intensity “exotic beams”, e.g. ^6He, ^7Be and ^10C. These were of sufficient intensity for resonant scattering and transfer studies. This facility has now ceased to produce beams for general use. Some of the RIB beams are available at ISOLDE and TRIUMF. For example, ISOLDE produces an ^11Be beam of ~10^4-10^5 pps but contaminants are problematic. Suitably intense ^24Ne (10^6 pps) and ^28Mg (10^6 pps) beams are also produced at ISOLDE. TRIUMF has accelerated yields of ^10Be, ^11Be, ^24Ne, ^28Mg of 1.6×10^7, 2.8×10^5, 2.2×10^5, and 3×10^6 pps.

Comparison Conclusions: GANIL will have to make significant developments in its ISOL technology for production of neutron-rich C, Mg and Si beams – the key is to maintain a beam development programme which would allow the acceleration of isotopes other than noble gases from CIME. The advantage that GANIL offers is the wider energy range of the beams when combining both the ISOL and fragmentation branches. To attain an advantage in this area GANIL needs to produce beams of high purity with intensities comparable with those available elsewhere.

Title: Like-particle pairing correlations

Physics case: Like-particle pairing is essential to the description of (exotic) nuclei and the cooling of neutron stars. A fundamental, yet unresolved, question relates to the microscopic origin of superfluidity in infinite matter and finite nuclei. New experimental data in exotic nuclei are required to validate recent non-empirical calculations and to constrain semi-empirical pairing energy functionals that can be used for large scale calculations and extrapolations towards neutron rich matter present in the crust of neutron stars.

Key observables: Masses of nuclei located into the “next major shell”. Moment of inertia of normal and super-deformed bands in exotic nuclei; spectra and angular distributions associated to pair transfer reactions.

Sample experiment 1: Mass measurement of odd and even tin isotopes beyond ^132Sn with a precision better than 50 keV.

Sample experiment 2: Pair transfer (p,t), (t,p),(^α,^6He) for n-n pairing; (^α,^6He) would permit to explore the low-density surface region of the nucleus (in this case preferably higher incident energies with respect to expected SPIRAL2 energies).

GANIL facility: SPIRAL2, VAMOS, SPEG, MUST2, CHARISSA, GASPARD

Requirement: ^132,134,136Sn, ^144Xe (6-10 MeV/A) on t, p, targets

Other facilities: Other RIB facilities can accelerate ^132,134,136Sn beams (HRIBF) but not at the intensities of SPIRAL2

Comparison Conclusions: SPIRAL2 used in conjunction with VAMOS or SPEG will be world-leading.

Title: Proton-neutron pairing correlations

Physics case: While the presence of like-particle pairing correlations clearly affects most low-energy properties of nuclei, the fingerprints of proton-neutron pairing on data and on the choice of pertinent observables is still a matter of debate, making the requirements for its modelling also uncertain.

Key observables: Spectra and angular distributions associated to pair transfer reactions.

Sample experiment: Pair transfer (p,^3He), (d,^4He) for n-p pairing in Z=N nuclei

GANIL facility: Existing RIB produced by fragmentation (SISSI2) in combination with a spectrometer (VAMOS, SPEG) as a charged particle array (MUST2, CHARISSA, …). Nuclei like ^48Cr and ^56Ni can be studied with SISSI or LISE + recoil spectrometer. However, heavier nuclei (which are potentially more interesting) will suffer from charge states and from decreasing intensities. The possibility to accelerate radioactive nuclei to about 10 MeV/A after production in S3 is certainly interesting.
Requirement: $^{48}$Cr, $^{56}$Ni, $^{72}$Kr, $^{80}$Zr (4-10 MeV/A or 30 MeV/A) on t, p, targets
Other facilities: $^{48}$Cr, $^{56}$Ni, $^{72}$Kr will be available at HIE-ISOLDE and ISAC-2 at energies < 10 MeV/u and intensities ~ $10^4$/s. GSI and RIKEN can produce the nuclei of interest in large amounts, however, one would need to slow them down significantly and lose most of the advantage in production rate.

Comparison Conclusions: GANIL will have to make significant developments in its ISOL technology in order to compete with other facilities. In particular, the increase of the $^{72}$Kr intensity is important. This beam is expected to be produced in other ISOL facilities. $^{48}$Cr and $^{56}$Ni beams are already available and could be used already for experiments. However, the breakdown of SISSI makes their production rates probably not large enough.

**Nuclear structure far from stability**

**Title: Nuclear masses**

**Physics case:** Atomic mass measurements provide the very first information of the structural changes as modifications of shell gaps, the onset of deformation or pairing gaps. Accurate measurements are also very important to determine Q values in reaction, accurate log ft values, separation energies for astrophysics and more.

**Key observables:** atomic mass

**Sample experiment:** mass measurements for proton or neutron-rich nuclei

**GANIL facility:** The present GANIL facility, after the breakdown of SISSI, is no longer competitive. In particular the in-flight method commonly used with the SPEG spectrometer cannot be used anymore. The production of fission fragments with SPIRAL2, of proton-rich nuclei in S3 as well as the equipment of the DESIR experimental room with traps will certainly bring back GANIL to be competitive.

**Title: Evolution of shell closures away from stability**

**Physics case:** The evolution of shell closures away from beta stability is one of the major current issues in nuclear structure physics. The change of magic numbers is a direct consequence of the properties of nuclear forces, the properties of which can be tested in nuclear medium by studying evolution of single particle energies. Among these forces, the tensor and spin-orbit ones play essential roles. These studies will be used to validate theoretical approaches to predict the role of in-medium forces from bare NN ones. With this achieved a better predictability to regions so far not accessible in terrestrial laboratories will be obtained. This is absolutely necessary for a better understanding of the astrophysical r process.

**Key observables:** Excitation energies of low-lying states in odd-A nuclei adjacent to doubly-magic and semi-magic nuclei, angular distributions (to determine the spin, parity and the spectroscopic factor of the state).

**Sample experiment:** The determination of neutron single particle energies can be obtained by (d,p) and (d,t) or (p,d) reactions. $(\alpha,t)$, $(t,\alpha)$ (or $(d,^3\text{He})$) if high energy beams are available) transfer reactions will be used to probe proton single particle energies. The study of Isobaric Analogue States with resonant elastic scattering with neutron-rich beams at low incident energy is also an interesting tool to use. Alternatively neutron or proton knock-out reactions can be used in case of high energy RIB.

**GANIL facility:** present GANIL beams, SPIRAL1, SPIRAL2, post-accelerated SPIRAL2 in a far future. Charged particle array combined with a gamma array, such as MUST2/GASPARD with EXOGAM/PARIS. The use of a spectrometer as VAMOS or SPEG is certainly positive point for some experiments.

**Requirements:** Neutron-rich C isotopes, $^{56}$Ni, $^{80}$Zn, $^{130}$Cd, $^{132}$Sn (8 MeV/A and beyond) …

**Other facilities:** Other RIB facilities can accelerate some of these beams but most likely not at the intensities of SPIRAL2.

**Comparison Conclusions:** The development of new SPIRAL1 beams is certainly interesting near proton or neutron magic shells. The present GANIL is still offering interesting studies, even if the SISSI breakdown has led to restrict to inclusive studies. SPIRAL2 used in
conjunction with the forthcoming charged particle and gamma-ray detectors will be world-leading. The whole GANIL program will offer a wide range of beams and energies appropriate for transfer reactions.

**Title: Unbound states of neutron-rich isotopes via direct reactions**

**Physics case:** How do the shell gaps evolve for neutron-rich weakly-bound nuclei? We want to determine the shell effects in these nuclei which have low particle emission thresholds, few or no bound excited states. To extract the structure information relevant for the signature of new shell effects (modification of known magic numbers, new shell gaps in neutron-rich regions) the measurement should be as complete as possible (elastic and inelastic scattering, transfer reactions to the main channels) in order to fix the coupling between the main processes to be included in the coupled-reaction scheme. Experimentally, we require particle spectroscopy to have access to both bound and unbound states.

**Key observables:** low-lying spectroscopy, energy and width of the resonant states, angular distributions of direct cross sections giving access to the multipolarity L of the transitions. From L and when the initial ground state is a 0+, spin and parity Jπ can be inferred. Ideally measurements of transfer reactions should be performed using a polarized target to deduce Jπ.

**Sample experiment:** Direct reactions on proton and deuteron targets (p,d), (p,t), (d,p) of neutron-rich light and medium-mass nuclei on extended isotopic chains, towards the drip-line - reaching as neutron-rich beams as possible delivered by the facility. Transfer reaction measurements are feasible in a reasonable beam time period (~one week) if the beam intensity is of the order of 10^4/s.

Ex: the evolution of shell structure far from the valley of stability for the neutron-rich Tin isotopes, determination of the unbound states and configurations and spectroscopic factors for

\[ ^{133-138} \text{Sn} (p,p') (p,d) (p,t) \text{ and } (d,p) \]

**Possible experiments:**

\[ ^{134} \text{Sn}(d,p)^{135} \text{Sn}, \quad ^{134} \text{Sn}(p,p'), \quad ^{134} \text{Sn}(p,t)^{132} \text{Sn}, \quad ^{132} \text{Sn}(d,p)^{133} \text{Sn}, \]

\[ ^{134} \text{Te}(d,p)^{135} \text{Te} \text{ and the reaction channels } (d,d') (d,t). \]

**Energies:** angular cross sections for transfer reactions are of the order of few mb/sr in the low energy regime (5-20 MeV/n). An important point is the angular momentum matching window L. To have access to the excited states at least up to 6 MeV of excitation energies, with an angular momentum window L~3-4 we need incident energies above 10 up to 20MeV/n.

**Possible detection system:** particle-gamma spectroscopy using a MUST2-like array coupled to a gamma spectrometer (EXOGAM-like array) and a spectrometer (VAMOS, SPEG) for the identification of the heavy partners emitted at forward angles.

NB: Note also that, from the detection point of view, the higher the incident energies, the better the A,Z identification of the heavier fragment in the spectrometer focal plane. The problem of charged states is reduced as well.

**Needs for theoretical development:** In order to provide an accurate understanding of the reactions on a microscopic ground and to extract correctly the structure information, the microscopic models have to treat on the same footing bound and scattering states and to mix structure and reaction aspects. Constraints on the reaction-structure models (form factors of the entrance/transition/exit channels, potentials, coupling) are provided with improved sets of complete reaction data (elastic, inelastic, transfer) from neutron-rich nuclei.

**Title: Transfermium nuclei towards superheavy elements**

**Physics case:** The strong polarizing Coulomb field modifies the shell structure of transactinide nuclei and destabilizes these nuclei as a whole, such that they are solely stabilized by quantum shell effects against spontaneous fission. Pinning down the spectroscopic properties of deformed nuclides with A≈260 will contribute significantly to the understanding of the interplay of bulk properties and quantum shell effects in these nuclei. This aims also at a better extrapolation on the shell structure at sphericity in the “island of stability", predicted to be located at even higher mass and charge number.

**Key observables:** Qvalues, lifetimes, B(E2) and B(M1) transition moments, moments of inertia, fission barriers.

**Sample experiment:** Recoil-decay tagging after fusion-evaporation
**GANIL facility:** EXOGAM(2), AGATA, PARIS, VAMOS, MUSETT, stable beams from CSS1 and CIME (direct beam line to G1), high-intensity heavy-ion beams from LINAG + S3

**Requirements:** stable high-intensity beams ($^{28-30}$Si, $^{32-36}$S, $^{36-40}$Ar, $^{40-48}$Ca) at 5 MeV/A

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**Title:** Neutron skins in medium-mass neutron-rich nuclei

**Physics case:** The upper mass limit for the formation of neutron haloes, and more generally extended neutron density distributions, is an issue of interest. Within a naive picture, however, the increase of collectivity with mass and, more simply the fractional increase in the mass of the core, will decrease the tendency for the spatial de-correlation of the valence neutron distribution. The formation of less a diffuse distribution in the form of a “neutron skin” is, however, a possibility and is a prediction common to most models of the density distribution of medium-mass (A~50-150) neutron-rich systems. Interestingly a relationship has been shown to exist between the equation-of-state and the extent of neutron skins. More specifically, the thickness of the neutron skins in systems far from stability can provide a means of constraining the symmetry-energy term. The systematic study of the formation and extent of neutron skins in medium-mass, neutron-rich nuclei is thus of interest not only from a structural point of view but also in understanding the behaviour of neutron-rich matter. Ideally complete isotopic chains should be explored from the stable isotopes (where evidence for neutron skins has already been found in the heavier stable nuclei, such as $^{208}$Pb) out to the most neutron-rich systems accessible. The relatively high intensities projected for moderately neutron-rich systems at SPIRAL2 should allow for precise measurements of the neutron skin thicknesses which will complement the lower precision measurements close to the dripline possible at fragmentation facilities (most notably FAIR and RIKEN).

**Key observables:** Precise measurements of the angular distributions for the inelastic scattering of protons, the cross section to the isovector GDR populated in inelastic alpha scattering and the cross sections to the isovector Spin-Dipole Resonance populated in charge exchange.

**Sample experiments:** high statistics measurements of the $(p,p')$, $(\alpha\alpha'\gamma_0)$ and $(p,n)$ reactions at energies above 100 MeV/nucleon for the neutron-rich isotopes of Ni and Sn.

**GANIL facility:** high-energy, post-accelerated SPIRAL2 beams, GASPARD ($(p,p')$, $(\alpha\alpha'\gamma_0)$ reactions) and a low-energy neutron array ($(p,n)$ reaction) coupled to a zero-degree spectrometer.

**Other facilities:** Energies much higher than possible with SPIRAL2 using CIME are required. RIKEN and FAIR will be capable of probing the neutron-skin thicknesses for the more pronounced cases (i.e., in general the most neutron-rich systems) using some of the techniques noted above together, in some cases, with total reaction cross section measurements. The higher intensities projected for SPIRAL2 for somewhat less exotic systems, coupled to reacceleration to energies in excess of 100 MeV/nucleon (and preferably above 150 MeV/nucleon), will enable precise determinations of the skin thicknesses including cases where the effect is small. As such the different facilities will be complementary.

**Comparison Conclusions:** SPIRAL2 with post-acceleration to high energies will be more than competitive for providing precise determinations of neutron-skin thicknesses. As noted above, these studies will be complementary to similar work that will be possible with fragmentation beams at RIKEN, FAIR and FRIB.

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**Title:** Two-proton radioactivity studies

**Physics case:** Two-proton radioactivity studies allows to determine the masses of the most exotic nuclei, to test the wave function of the two protons emitted, to test our understanding of barrier penetration and the correlation of nucleons in the atomic nucleus.

**Key observables:** Precise measurements of the decay energy, the half-life and the branching ratio for two-proton emission as well as the angular correlation and the energy sharing between the two protons.

**Sample experiments:** determination of the key observables for nuclei like $^{48}$Ni, $^{59}$Ge, $^{63}$Se, $^{67}$Kr

**GANIL facility:** high-energy fragmentation of intense $^{58}$Ni or $^{78}$Kr beams with SISSI/LISE3

**Other facilities:** The conditions in terms of production rates and separation qualities at the MSU A1900 are, within maybe a factor of two in favour of MSU, comparable to SISSI/LISE3.
The FRS at GSI is not competitive today, however, the Super-FRS of FAIR will most likely deliver much higher intensities although the higher energies are certainly not an advantage. The best laboratories for these studies in the near future will be the BigRIPS facility at RIKEN. However, for the moment the beams needed are not available (\(^{58}\)Ni) or only with much smaller intensities than initially predicted (\(^{76}\)Kr).

**Comparison Conclusions:** Without a significant upgrade of the fragmentation facility at GANIL, the production rates at LISE3 for the nuclei to be investigated will be much lower than elsewhere in the near future.

### Nuclear Reactions

**Title:** Fission in inverse kinematics

**Physics case:** The isotopic distribution of low energy fission fragments is known for very few actinides and only in the light fragments part of the asymmetric distribution. However, the structure effects being responsible for most of the fission characteristics (asymmetry, deformation, neutron multiplicity,...) are observable in the heavy fragment part, where neutron richness allows for approaching magic numbers. Due to the unknown contribution of neutron and proton numbers, controversy exists on the interpretation of these characteristics and neutron or proton shells. Multi-nucleon transfer in inverse kinematics, combined with a spectrometer for the complete isotopic identification of the fission fragments, allows for producing exotic actinides. In the future, prompt neutron emission (kinetic energy and angular distributions) may be studied in coincidence (access to deformation and dissipation). The production of heavy fission fragments in coincidence with gamma detection may provide breakthrough data for spectroscopic studies near \(^{132}\)Sn as well.

**Key observables:** Kinetic energy, multiplicity and angular distributions of neutrons emitted in prompt fission. Mass and isotopic yields of fission fragments

**Sample experiment:** Multi-nucleon transfer induced fission of a \(^{238}\)U beam in inverse kinematics

**GANIL facility:** VAMOS spectrometer, a neutron array, EXOGAM-like detector.

**Requirements:** High intensity for a Uranium beam with good optical parameters. Thorium beams for production of additional actinides. Multi-detectors for neutrons (fission mechanism studies) and multi-detector for gamma radiation (spectroscopic studies).

**Title:** Fusion far below the Coulomb barrier and stellar nucleosynthesis

**Physics case:** Fusion of medium-heavy systems is strongly hindered at deep sub-barrier energies as compared to standard coupled-channels predictions, and the reaction mechanisms at such low energies are still waiting for a coherent description. New measurements at extremely deep sub-barrier energies for various systems are mandatory in order to explore the influence of the entrance channel on the fusion hindrance and get a deeper understanding of the underlying physics. \(S\)-factor investigations have shown the importance of such studies for astrophysical aspects like reaction rates and their consequences for stellar nucleosynthesis processes. First experiments for lighter systems (e.g. \(^{16}\)O+\(^{16}\)O, \(^{16}\)O+\(^{12}\)C and \(^{12}\)C+\(^{16}\)C) and systems at medium mass (e.g. \(^{60}\)Ni+\(^{83}\)Y, \(^{64}\)Ni+\(^{64}\)Ni, \(^{64}\)Ni+\(^{100}\)Mo and \(^{28}\)Si+\(^{64}\)Ni) seem to indicate a dependence of the fusion hindrance on the reaction Q-value. Measurements at lowest energies for some key reactions, however, are still missing. Examples for extreme Q-values among the reactions mentioned are: \(^{64}\)Ni+\(^{100}\)Mo with Q = -92.29 MeV and \(^{16}\)O+\(^{12}\)C with Q = 16.73 MeV. The question of (slightly) neutron-rich reaction partners has not yet been addressed in this context. It could be, however, of interest for reaction rates within the r-process scenario and here GANIL could offer unique opportunities. The region where hindrance effects can be observed in terms of deviations of the fusion excitation function from coupled channel calculation predictions and where the maxima in the derived \(S\)-factor curves are is at a cross section of \(\sigma_s\) from \(10^{-2}\) to \(10^{-6}\) mbarn.

**Key observables:** evaporation residue cross sections at low sub-barrier energies with high transmission separators

**Sample experiment:** \(^{64}\)Ni+\(^{64}\)Ni, \(^{64}\)Ni+\(^{100}\)Mo and heavier beams with high-intensity stable beams and thin targets. Lighter systems are of great interest for astrophysical purposes but would need...
low beam energies <2MeV/A: $^{16}$O+$^{16}$O, $^{18}$O+$^{12}$C and similar. Neutron-rich radioactive beams with high enough rates to reach sub-barn cross sections

**GANIL facility:** spectrometer S3, VAMOS in gas-filled mode

**Other facilities:**

a) **LNL:** $^{64}$Ni is a typical tandem beam and for stable beams an electrostatic deflector is available as a separator which has been used for similar studies in the past. A gas-filled magnetic spectrometer PRISMA would offer similar opportunities as VAMOS in gas-filled mode. With the new injector PIAVE higher intensities would facilitate this type of measurements.
b) **ANL:** $^{16}$O and $^{64}$Ni are both available from the ATLAS accelerator and have been used for similar studies together with the mass spectrometer FMA. Intensities for e.g. $^{64}$Ni are in the same range as at LNL with the new injector PIAVE (10-20 particle nA).
c) Other facilities: There are a few facilities like RIKEN and GSI where the stable beams are available together with suited separators. The need for a precise beam energy definition, however, puts up additional constraints.

**Comparison conclusions:**

(i) For the stable beam part the future set-up LINAG and S3 will be more than competitive due to the high intensities and the separation quality for the lighter beams and in a second phase with the M/q=6 acceleration capability put in operation.

(ii) For modestly neutron-rich radioactive beams in some cases with a high $\sigma_s$, GANIL with a gas-filled VAMOS could possibly enter the field.

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**Title: Consistent extraction of observables in weakly-bound nuclei**

**Physics case:** Nuclear reactions near the Coulomb barrier are characterized by a delicate interplay between mean-field, collective and nucleonic degrees of freedom. Intense beams of both light and heavy nuclei far from stability provide a unique opportunity to measure with a unprecedented precision, (for radioactive beams) the many facets of multidimensional tunneling and thus unravel and understand the delicate balance between the reaction mechanism and the intrinsic structure of the colliding nuclei. Such beams encompass exotic states of nuclear matter such as halos, skins, and sometimes almost decoupled 2-component nuclei. Key variables that determine the multidimensional potential energy landscape which controls the path to fusion have to be studied. This can be achieved by studies of fusion, elastic, inelastic and transfer mechanisms near the Coulomb barrier, each of which is influenced by different regions of the potential landscape. The consistent understanding of these processes will be a stringent test ground for new theoretical models being developed, motivated by recent experimental (often controversial) results obtained using low-intensity beams. The availability of light intense beams of neutron-rich nuclei could help in this direction and is supposed to be one of the highlights for SPIRAL2.

**Key observables:** low-lying spectroscopy, energy and width of the resonant states, angular distributions of direct cross sections. Measurements should be as complete as possible (elastic and inelastic scattering, transfer reactions to the main channels, neutron detection) in order to fix the coupling between the main processes to be included in the coupled-reaction scheme.

**Sample experiment:** Direct reactions on proton and deuteron targets of neutron-rich light and medium mass nuclei close to and at the drip-line: (p,d), (p,t), (d,p) reactions using as neutron-rich beams as possible for Z=6 to 18.

Ex: Unbound states and configurations and spectroscopic factors for $^8$Li, $^{14}$Be, $^{16-18}$C, $^{22-23}$O. Ex: Evolution of shell structure far from the valley of stability, for the neutron-rich isotopes of Ne, Mg, Si, S, Ar, Kr [possibly $^{27-28}$Ne, $^{30}$Na, $^{46-48}$Ar, $^{84-86}$Se, $^{88-94}$Kr].

**GANIL facility:** SPIRAL1, SISSI2; in heavier mass region: SPIRAL2, post-accelerated SPIRAL2; MUST2 device in VAMOS, SPEG or LISE area.

**Other facilities:** a wide range of radioactive beams at these energies will be available at HIE-ISOLDE, while for ISAC-2 a more limited number of radionuclides will be offered to the user.

**Comparison Conclusions:**

Apart from the gaseous beams, GANIL will have to make significant developments in its ISOL technology in order to compete with other facilities.
Nuclear Astrophysics

Title: Charged particle cross section reactions

Physics case: The energy generation in stars, the production of new elements, the timescales of the stellar quiescent or explosive burnings are constraints that can be provided by nuclear reaction rates. In exploding binary star systems as novae or X-ray bursts, many charged particle reactions remain to be measured or to be better determined. This is true in particular to estimate the possible observation of gamma-ray cosmic emitters from novae, and to explain the break out of the hot CNO cycle to develop a rapid proton capture process in X-ray bursts. To achieve these objectives, the combination of hydrodynamic models of the phenomena and of accurate nuclear cross sections is essential. If nuclear cross sections can hardly be measured for stable nuclei at stellar temperatures (due to the high Coulomb barrier), cross sections entering in explosive phenomena are in principle easier to determine, except the fact that they require RIB of lower intensity. Depending on the cases, direct measurements or indirect ones should be applied.

Key observables: Proton, alpha cross sections measured at low energy. Alternatively cross sections can be derived using: excitation energies, spin, partial widths of states, masses and half-life of nuclei.

Sample experiment: Direct measurements (at low energy) of cross sections reactions (most often with light nuclei A < 40). Indirect measurements (such as transfer reaction, resonant elastic scattering, inelastic scattering followed by break-up etc.) when direct measurements are too difficult (too low cross section). Few selected direct measurements should be enough to constrain nuclear models (optical model, density function etc.) for heavier nuclei.

GANIL facility: VAMOS, SPEG, LISE, MUST2, GASPARD, SPIRAL1 and SPIRAL2.

Title: Atomic mass measurements

Physics case: In exploding stars, the temperature and matter densities can be so large that an equilibrium between photodisintegration induced by the photon bath and the nucleons captures is established. In general nucleon capture rates are much shorter than beta-decays, so that the location of this equilibrium exclusively depends on reaction Q values for which captures and disintegrations balance. For these nuclei, the explosive process halts for a moment, and accumulate unstable nuclei. These called waiting-point nuclei become the major genitors of stable nuclei, as their beta-decay to the valley of stability leads to increase stable elements with respect to neighbours. For neutron-rich processes, these waiting-points nuclei form the r abundance peaks, whereas for proton-rich processes these nuclei influence the energy pattern of X-ray bursts.

Key observables: Atomic masses in the vicinity of the neutron shell closures N=50 and N=82 for the r-process, in the vicinity of proton (sub) shell closures and close to the drip line for X-ray bursts.

The requirements to determine atomic masses have been described earlier.

Title: Beta-decay studies of astrophysical interest

Physics case: As depicted in the previous paragraph, the waiting point nuclei play a crucial role for the nucleosynthesis and the dynamics of the explosion of binary stars. For the r-process nucleosynthesis which occurs on the neutron-rich side, beta-decay lifetimes and Pn values should be determined. For proton-rich nuclei, lifetimes of interest are almost all known. However, if existing at low excitation energy, isomers can play a role as well, as being thermally populated in hot stellar environments. Beta-delayed neutron emission can serve to determine the resonant states of interest involved for direct neutron capture measurements.

Key observables: Beta decay lifetimes, Pn values, beta-decay schemes in the vicinity of proton (sub) shell closures and close to the drip line for X-ray bursts.

Sample experiment: Neutron-rich nuclei in the vicinity of the neutron shell closures N=50 and N=82, ground state and isomers. Beta-delayed neutron spectroscopy of $^{81}$Cu, $^{82}$Zn, $^{130,131}$Ag, $^{133}$In. The possibility to study nuclei in the vicinity of $^{110}$Zr would also be interesting. Search for beta-decaying isomeric states close to proton drip-line.
Intensity > few pps.

**GANIL facility:** SPIRAL2 + DESIR + low-energy neutron detector + few gamma detectors.

**Title: Neutron-capture cross sections**

**Physics case:** Neutron capture reactions acting to produce or destroy the cosmic gamma-ray emitters $^{56,60}$Fe and $^{44}$Ti that are observed (or foreseen to be) from supernovae by space telescopes are important to be measured. Neutron-capture rates in the vicinity of the N=40, N=50 and N=82 shell closures play a role in the case of the weak r process, or when the classical r process falls out of equilibrium as the stellar matter expands and cools down.

**Key observables:** Radiative neutron capture rates on radioactive targets like $^{59,60}$Fe, if they can be produced. Alternatively or for other cases where nuclei involved are too short lived to be prepared as targets, cross sections can be derived using excitation energies, spins, partial widths of states, and reaction Q values.

**Sample experiment:** Direct measurements (at low energy) of cross sections using radioactive targets. Indirect measurements (such as transfer (d,p) reaction, beta-delayed neutron emission) for nuclei in the vicinity of neutron shell closures. In particular the location of low I states (leading to s wave resonances through E1 radiative capture) is to be searched for. Transfer reactions at the energy provided by SPIRAL2 will be suited for this, as the momentum matching will be optimized.

**GANIL facility:** SPIRAL2 beams, high neutron flux to produce radioactive targets, MUST2-like charged particle detector, EXOGAM. The addition of a spectrometer as VAMOS, SPEG can be useful as well.

**Title: Study of the unbound nuclei and their astrophysical interest**

**Physics case:** Unbound nuclei are heavily involved in several astrophysical processes. The properties of the unbound $^2$He resonance are directly linked with the proton-proton chain I reaction rate in the Sun. The unbound $^8$Be is involved in the triple alpha reaction. Several other unbound nuclei close to the proton drip line are at the origin of waiting points in hot hydrogen burnings. Nucleosynthesis and energy generation are depending strongly on bypassing or bridging reactions which occur through these unbound states. Sequential proton captures or simultaneous 2-proton captures are under studies. Other new reaction mechanisms were proposed like (p, beta) or (p, gamma beta) reactions.

**Key observables:** Nuclear spectroscopy, energies, spins, widths, spectroscopic factors

**Sample experiment:** Indirect measurements (transfer reactions, resonant elastic scattering...)

**GANIL facility:** VAMOS, SPEG, LISE, MUST2, GASPARD, MAYA, SPIRAL1 and SPIRAL2.

**Nuclear dynamics and thermodynamics**

**Title: Density dependence of the symmetry energy**

**Physics case:** We want to address the question of the energy functional of asymmetric nuclear matter, and specifically constrain its isovector part, the symmetry energy, at sub-saturation densities and finite temperature. This will constrain the EoS for neutron stars and supernovae as well as shed light on the possible late cooling scenario of neutron stars. Isospin diffusion in peripheral collisions between differently isospin asymmetric beam/target combinations can provide quantitative information about the symmetry energy, once confronted with transport model simulations.

**Key observables:** Isotopic composition of quasi-projectiles and quasi-targets, in coincidence with isotopically resolved light particles

**Sample experiment:** Different isotopes of medium and medium-heavy beams from n-deficient to n-rich nuclei including stable ones, in an energy range of 10-50 A.MeV

$^{106,112,120,132,136}$Sn$^{48,64}$Ni at E/A=10,15 MeV

$^{56,64,74}$Ni$^{48}$Ni at E/A=10,30,50 MeV

Intensity >=10$^6$ pps on target
Title: Limiting temperature and phase transition
Physics case: The fragmentation phase transition will be quantitatively studied as a function of isospin and charge and located in the phase diagram of asymmetric nuclear matter, bringing information about the importance of Coulomb interaction as well as on the short range correlations beyond the mean field. Scaling observables from sources differing in charge/isospin will be developed to control data selection criteria.
Key observables: Energy threshold for fragmentation, energy spectra, inclusive and exclusive charge scalings, IMF multi-charge correlations, charge fluctuations
Sample experiment: Different isotopes of medium and medium-heavy beams from n-deficient to n-rich nuclei including stable ones, in an energy range $10^{-100}$ A.MeV
$^{78,84}$Zn$^{64}$Ni, $^{94}$Kr $^{50}$Ti, $^{96}$Sr $^{48}$Ca, $^{72}$Kr $^{50}$Ti at E/A=5,10,15,20 MeV
$^{114-145}$Xe $^{40,48}$Ca, $^{122}$Cd $^{58}$Ni, $^{90}$Kr $^{90}$Zr at E/A=5,10,15,20 MeV
Intensity $>=10^6$ pps on target
GANIL facility: CSS1+CSS2, SISSI2+LISE, SPIRAL1, SPIRAL2, post-accelerated SPIRAL2, INDRA+FAZIA+VAMOS

Temperature dependence of the symmetry energy
Physics case: The different determinations of the density dependence of the symmetry energy $C_{sym}$ from reactions, giant modes, or differential n-p radii only address the T=0 equation of state. The temperature dependence of the effective mass induces a temperature dependence of $C_{sym}$ with important physical consequences on the supernova collapse dynamics. This latter can be calculated from the experimental knowledge of the neutron-rich nuclei density of states in the continuum region.
Key observables: coincidence yields, spectra, and angular distributions of evaporated particles and gammas with isotopically resolved evaporation residues
Sample experiment: neutron-rich medium-mass beams (ex: Fe-Ni), in an energy range $10^{-30}$ A.MeV: $^{40,48}$Ca at E/A=5,10,20 MeV; $^{58,64,74}$Ni at E/A=5,10,20 MeV;
Intensity $>=10^6$ pps on target
GANIL facility: CSS1, SPIRAL1, SPIRAL2, post-accelerated SPIRAL2, INDRA + FAZIA + VAMOS

Fundamental interactions
Title: CVC tests and searches for non-standard contribution to the weak interaction
Physics case: Both super-allowed decays and beta-decays of mirror nuclei can be used to test the Conserved-Vector-Current (CVC) hypothesis. In particular for the former, a precise knowledge of the isospin-symmetry breaking corrections is required. On the other hand, nowadays the experimental information is so precise that it can be used to put constraints on isospin-symmetry breaking interactions. Precise beta-decay and beta-neutrino angular correlation measurements allow searches for non-standard (ex. tensor or scalar currents) contributions to the weak interaction that can reach unprecedented accuracy. Such measurements are complementary to high-energy searches.
Key observables: angular correlation coefficient, half-lives, branching ratios, Q-values
Sample experiment: $^8$He, $^{16,18}$Ne, $^{34,36}$Ar
GANIL facility: LPCTrap, decay station for SPIRAL1 beams (or SIRa)
Other facilities: ISOLDE offers a wide range of nuclei of interest for these studies. More and more isotopes are now also being produced at ISAC. However, for the isotopes available at GANIL, SPIRAL1 offers for most of them the highest intensities, sometimes one order of magnitude higher than at ISOLDE or ISAC. In all cases, SPIRAL1 is largely competitive, in particular for proton-rich isotopes. A larger variety of isotopes from SPIRAL1 is needed.
Comparison Conclusions: GANIL with LIRAT or SIRa could play an important role at least for the isotopes which are presently produced, i.e. gaseous elements. However, only a few beams
are allowed in LIRAT and SiRa is not an experimental facility, but a test bench. DESIR will greatly improve these possibilities.

**Title: Neutrino-less double-beta decay**

**Physics case:** Nuclear structure measurements are necessary to constrain half-life predictions for the neutrino-less double-beta decay. This process can answer the crucial question of the neutrino nature (Majorana versus Dirac). Its observation would represent a strong evidence for physics beyond the Standard Model (lepton number violation). Nowadays the half-life calculations are plagued by significant discrepancies. Various experiments can improve present calculations as well as constrain the nuclear matrix elements of the isospin and spin-isospin excitations involved.

**Key observables:** single-beta decays, precise mass measurements, deformation.

**Sample experiment:** 1460 decay of intermediate nuclei, deformation of initial and final states by COULEX

**GANIL facility:** decay station, EXOGAM

**Requirement:** few MeV/A, >103 pps of the nuclei of interest (e.g. 100Mo)

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**Interdisciplinary Research using GANIL Beams**

**Atomic Physics, Materials Research, Radiobiology and -chemistry**

**Atomic physics**

**Title: Dynamics of ion-solid interaction**

**Physics case:** Interaction of fast highly charged ions in solids results on a femtosecond scale in the emission of X-rays, fast electrons and the production of highly excited and ionized target atoms. The experiments aim at a better understanding of the initial individual and collective processes which are followed on a much longer time scale by electronic and atomic rearrangements resulting eventually in various forms of radiation damages. Predicting specific damage processes from our knowledge of the first step features remains a very challenging task. Besides investigations in “random” conditions, using the subset of well-defined trajectories along low-indexed crystallographic axes, so called “channelling”, the periodicity of the potential as well as impact-parameter controlled multiple scattering can be exploited. Channelling has become a tool to perform atomic collision physics experiments under unusual conditions. Among those are the coherent driving transitions by the Fourier components of the crystal potential in a frequency regime not yet accessible by lasers and coherent X ray sources. Similarly, electron-ion scattering experiments with electron “beam” intensities well beyond the reach of any laboratory electron beam facility become possible. Lastly, for low ion velocities, the advent of intense sources opened up the possibility of exploiting processes dominated by the huge potential energy stored in these projectiles for highly localized surface excitation and modifications on a nano scale.

**Key observables:** charge-state distribution, energy loss, X-ray emission, electron emission, particle sputtering in channeling or random conditions

**Sample experiments:** production and transport of projectile excited states (core and Rydberg states); impact parameter dependent energy loss, charge exchange or electronic processes in channelling conditions and investigations of selective formation of multiply excited states; specific surface modifications

**GANIL facility:** CSS1, CSS2, SPEG (LISE) and ARIBE

**Other facilities:** Chiba, Riken, GSI.

**Requirements:** on-line experiments with highly parallel beam at high energy; use of different charge states. It would be of great interest to equip the SME line with an analyzing magnet.
Title: Multi-particle effects in atomic collisions
Physics case: In low density media, primary electronic processes such as capture, excitation and ionization in a few active electron systems (including small molecules) are still not well known in the intermediate velocity regime where the stopping power is maximum. The investigations of multi-electron correlation effects, interferences etc., is mandatory to provide stringent tests of theories. Furthermore, high Z projectiles allow to study dynamics of the interaction under atto-second ultra intense electromagnetic fields that are comparable to what can or will be reached with new powerful laser installations (FLASH, XFEL)
Key observables: recoil ion spectroscopy, X-ray emission, electron emission, ion fragments and electrons momentum, projectile scattering and charge state analysis
Sample experiments: determination of the full three-dimensional momentum vectors of all the final-state reaction products using COLTRIM Spectrometer; measurements of multi-differential cross sections using multiple particle coincidence techniques, Coulomb imaging
GANIL facility: CSS1, CSS2, ARIBE
Other facilities: GSI, KVI, KSU, TIFR (Mumbai), MPIK-Heidelberg, TMU-Tokyo, Lanzhou, Ahmadabad
Requirements: on-line experiments making use of the beam time structures that can be offered by GANIL (including pulse suppressor). Equipping the SME line with an analyzing magnet would be interesting.

Title: Stability and fragmentation of complex targets (clusters, biomolecules)
Physics case: Goal of the activities within this topic is the study of stability and fragmentation patterns of complex systems such as fullerenes, clusters of fullerenes, bio-molecules and micro droplets. Questions can be raised like 'how many charges can a complex system carry before falling apart' or 'what is the collision-induced damage of tissues on a bio-molecular level'. These classes of systems are of interest from a curiosity driven point of view but also of increasing importance for radio-biological and material science applications. From a conceptual point of view interesting analogies to nuclear complexes can be explored.
Key observables: mass spectroscopy and TOF; electron, X-ray and ion emissions.
Sample experiments: Investigations of Coulomb dissociation (Rayleigh limit), energy distribution in the different degrees of freedom, solvation effects on the radiation stability of large molecules, transition from atoms to solids.
GANIL facility: CSS1, ARIBE
Other facilities: The different types of ions sources (ECR or EBIT) of the ITSLEIF network: KVI, Aarhus, Belfast, Heidelberg, Stockholm as well as electrostatic rings.
Requirements: Key for these investigations is the availability of various sources for a wide range of ions and clusters. The development and improvement of size selected complex targets is of primary importance for these on-line experiments.

Materials Research

Title: Materials modification
Scientific case: Many solids exposed to high electronic excitations undergo drastic changes of their physical and chemical properties. The experiments in this field aim at a better understanding of track formation and ion-induced damage including the question how collective mechanisms induce atomic motion in the lattice. The investigations comprise irradiation studies on radiolysis of polymers in high-dose environments and on nuclear materials for safe storage of nuclear waste and identification of suitable materials for transmutation targets and generation IV or fusion reactors.
Key observables: Change of crystal structure and texture, interface mixing; modification of surface topography, sputtering, creation of point defects and defect clusters, radiation enhanced diffusion, gas release, swelling, and change of physical properties (mechanical, electrical, thermal, etc).
**Typical experiments:** Irradiations are performed for simple model targets as well as rather complex sample systems (e.g., multi-layers, controlled surfaces, specific alloys or compounds, embedded nanoclusters). It is important to vary the beam parameters (e.g., ion energy, charge state, electronic energy loss, fluence, flux) and experimental conditions such as irradiation temperature, applied pressure, etc. The characterization of beam-induced modifications are on-line (e.g., infrared or UV-VIS spectroscopy, gas release, x-ray diffraction, scanning probe microscopy, etc.) or off-line (e.g., transmission electron microscopy, Mössbauer spectroscopy, small-angle x-ray and neutron spectroscopy, ion-beam analysis, profilometry).

**GANIL facility:** Depending on the project, specific irradiation parameters (e.g., energy, ion range) are needed available at ARIBE (surfaces effects), C0-IRRSUD (e.g., simulation of fission fragments), CSS1-SME and CSS1&CSS2-HE (bulk modifications). Many experiments require access to irradiation chambers with on-line devices (e.g., CHEXPIR, ALIX, AODO, CASIMIR, CIGAL and CESIR).

**Title:** Ion-Track Technologies  
**Scientific case:** Fabrication of nanostructures using energetic ions, or combined with track-etching and radiochemical grafting.  
**Key observables:** Functional properties of ion-track membranes (electrical, magnetic, optical, biological, permeation) for application e.g. as fuel cells or special biomembranes.  
**Typical experiments:** Irradiation of polymer films under precise fluence control, followed by chemical track-etching (producing open channels) and radiochemical grafting (functionalization).  
**GANIL facility:** C0, CSS1  
Roller irradiation for continuous films, single-ion irradiation

**Radiobiology and Radiation Chemistry**

**Title:** Radiobiology and radiation chemistry  
**Scientific case:** Radiobiology studies ion-induced modification of biological matter and has strong relevance for heavy-ion tumor therapy. Radiation chemistry aims at understanding water radiolysis with special focus on the heterogeneous chemical kinetics induced by high LET particles in liquids. An important issue is the comparison of experimental results with Monte Carlo codes.  
**Key observables:**  
Radiobiology: single and double strand breaks, base modifications, cell survival, chromosome aberrations  
Radiation chemistry: time evolution of radical and molecular species.  
**Typical experiments:**  
In radiobiology biological matter (e.g., plasmids, DNA, cells, tissues, animals) are exposed to high LET beams with subsequent off-line analysis e.g. of the RBE via survival studies.  
In radiation chemistry, irradiation experiments are performed with liquid targets (water) using pulsed beams in combination with on-line ns-resolved optical spectroscopy.  
**GANIL facility:** CSS2  
Specific dosimetry (radiobiology) and in combination with pulse suppressor (radiation chemistry)

**Comparison with other facilities:**

The quality of the GANIL beams is regarded as excellent with respect to various parameters such as intensities, stability, emittance, optical definition and time structure of the pulse. These advantages in combination with special on-line instrumentation and the internationally recognized expertise of the scientific teams involved ensure an outstanding position and high visibility in the field.

In atomic physics using high energies (i.e. exit of CSS1 and/or CSS2), the LISE, SPEG, and SME installations offer excellent conditions. Significant activities are also performed abroad e.g. at GSI, Chiba and RIKEN and mostly with very high Z ions and/or at energies higher than what
GANIL can reach at the exit of CSS2. At low energies (i.e. a few hundred of keV and lower), ARIBE is one of the larger facilities worldwide, offering high-intensity beams of highly charged ions that can be delivered to 5 beamlines. The foreseen TBE line (Très Basse Energie) will provide multicharged ions down to a few eV which places ARIBE at a very competitive position in the international context.

Activities of most significant importance in the low-energy regime are performed within the European infrastructure network ITSLEIF for which CIMAP and the GANIL facilities play a key role.

In materials research, very similar activities using swift heavy ions in the inelastic stopping regime (above 1 MeV/A) are performed at Darmstadt (GSI). Both groups cooperate for many years and benefit from similar instrumentation and complementing beams and on-line analysis techniques. Also in Dubna (JINR), Lanzhou (IMP-HIRFL), Louvain la Neuve (CRC), Tokai Mura, Takasaki, and Riken (JAEA) irradiation experiments for materials research are performed. In addition, there exist numerous smaller facilities providing heavy ions around 1 MeV/A (e.g., Canberra (ANU), New-Delhi (IUAC), Orsay (IPNO)). Small facilities with lower beam energies are not considered, because the ion-target interaction is dominated by elastic collision processes.

Additional Comments:
GANIL has been one of the pioneering installations in the field of swift heavy ions in atomic collisions, materials research and condensed matter and still today is one of the few places where the facility and local expertise offers optimal experimental conditions for the broad activities of the interdisciplinary community. The excellent position is based on the fact that GANIL offers frequent beam access, a broad range of ion species, charge states, and energies (from eV/q to the GeV), excellent beam qualities and very powerful installations in the experimental areas. The users also greatly benefit from the expertise, support and the many (continuously up-dated) analytical on- and off-line methods provided by CIRIL.

The future situation of radiobiology is closely linked to the ARCHADE and ETOILE projects. If ARCHADE starts operation, the request for GANIL beams is expected to decrease and to be restricted to niche studies using ions heavier than C and with emphasis on lower energies.

Future activities in atomic physics and materials research will also be possible at FAIR and SPIRAL-2. The possibilities at these new facilities are not explicitly discussed here because they are characterized by rather specific beam conditions (completely stripped ions almost at rest, high ion ranges for pressure experiments, etc).
Conclusions

In many respects GANIL is a state-of-the-art facility for low and high energy stable beams and low to medium energy re-accelerated radioactive ions. These capabilities will be significantly enhanced with the advent of LINAG and SPIRAL2. In addition to reinforcing nuclear physics research at GANIL, the swift heavy ions physics and related programmes will remain competitive at an international level. Nevertheless, owing to the increasing international competition from new generation and upgraded facilities elsewhere, the position of GANIL has to be re-evaluated. The most important conclusions of the present document are given in the following.

To conduct their physics programme, experimentalists need modern detection setups to use most efficiently the available radioactive species and beam time. For charge particle detection arrays like MUST2 and TIARA are today state-of-the-art. Possibly this situation will even improve with the advent of the GASPARD array proposed in the frame of SPIRAL2. INDRA provides large solid angle coverage, but needs the FAZIA upgrade to be a world leading device for its planned program. For detection, the high-performance array EXOGAM is permanently available at GANIL. The electronics of this array urgently need to be modified to cope with steadily increasing beam intensities, to be more reliable, and to be compatible with the new electronics of ancillary detectors as well as with AGATA. AGATA, which will be available only for well defined experimental campaigns at GANIL will be a new powerful tool for \( \gamma \) spectroscopy. The PARIS detector, also under study within the SPIRAL2-PP, will be particularly well suited for experiments which require the highest efficiency at the expense of a somewhat reduced energy resolution. The active target concept, such as that pursued within the ACTAR project, is innovative and will provide access to new types of reactions in particular at very low recoil energies. This detection concept should be pursued. Given the increased range of neutron-rich nuclei that should be available with the advent of SPIRAL2, a low-energy neutron array would be highly desirable to pursue a range of studies from beta decay to reactions with reaccelerated beams.

The intensities available for selected isotopes at the SIRa test bench and at LIRAT compare rather well with other facilities. As such, these installations will continue to play an important role in ISOL-type physics. Consequently the present limitations for LIRAT (only a very few beams are currently authorised) have to be overcome, in particular in view of the use of SPIRAL1 to provide radioactive ions for DESIR. SIRa is probably needed as a test bench and therefore its routinely use as an experimental installation should not be envisaged. Selected experiments may, nonetheless, be run on this installation provided that they do not disrupt the developmental work.

GANIL possesses today three spectrometers: LISE, SPEG, VAMOS. All of them have been used with re-accelerated radioactive or low-energy stable beams. The velocity filter of the LISE separator has been used extensively for fusion-evaporation reactions – most notably in the heavy element programme. However, this use requires a modification of the velocity filter as compared to the principal functioning of LISE as a high-energy fragment separator. These frequent modifications are man-power intensive and not compatible with ever increasing beam intensities and related radioprotection issues. Therefore, a solution urgently needs to be found. This could be an upgrade of LISE allowing its use in the same configuration for low-energy fusion-evaporation reactions and high-energy fragmentation reactions. A second possibility could be the development of the gas-filled separator mode of operation of VAMOS. The most efficient, but also the most expensive solution would be the development of a new zero-degree spectrometer specifically designed for this type of physics. We believe that a much more efficient use of the radioactive beams from SPIRAL1 and SPIRAL2 will be possible regardless of which of the three solutions is implemented. The advent of S3, which is dedicated to the high-intensity stable beams from LINAG, is not in contradiction with this request.
In terms of beam development, it is believed that a much broader variety of radioactive species from SPIRAL1 (currently confined to the noble gases and one or two other elements) will greatly improve the potential of GANIL. Therefore, all measures necessary to achieve this goal should be put into place. For stable beams, higher intensities for the most heavy beams, in particular Pb, Th and U would greatly help the physics programme carried out with those beams.

As illustrated in appendix 2, GANIL possesses beam intensities for primary beams which are competitive with all other facilities. However, the higher energies coupled with fragment separators with characteristics specifically adapted to these energies and mass-to-charge ratios of the products (especially for neutron-rich beams) place GANIL in a difficult position. For many secondary beams, production rates at BigRIPS (RIKEN) and the Super-FRS (FAIR) are expected to be a factor 100 higher than at GANIL with or without SISSI. Moreover, for the most neutron-rich species rates of order $10^3$-$10^4$ higher will be available. SISSI2, as presently envisaged, will not improve the situation, in particular as it is expected to be online at the earliest in late 2011.

However, it should be kept in mind that GANIL has some unique fully operational detection systems (MUST2, TIARA, INDRA, EXOGAM, MAYA ...) which compensate in quality and/or solid angle to a large extent for the lower beam intensities. The use of these instruments would be clearly enhanced by installation in the short to medium term future of a spectrometer at the final focal point of LISE3. In the longer term (beyond 2015), it seems to be difficult for GANIL to compete with the fragmentation facilities currently coming online and under construction without an extensive upgrade or replacement of the existing separators (LISE3 and/or the SISSI+alpha spectrometer combination) and associated beamlines. Such an upgrade, as requested in many of the contributions to this report, would, however, be the sine qua non of the extension of the SPIRAL2 postacceleration capabilities to enable the fragmentation of the intense neutron-rich fission fragment beams (~100-150 MeV/nucleon). Such an upgrade would naturally also provide for the use of stable beams.

At the GANIL User’s Meeting which discussed the different upgrade possibilities for GANIL, the enhancement of the reacceleration capabilities beyond those offered by CIME was the most strongly supported proposal. Although this is clearly beyond the remit of the present study, it should be kept in mind in planning the evolution of GANIL up to 2015. It is worthwhile noting that the eventual provision of postaccelerated beams to around 100-150 MeV/nucleon would be the ideal precursor to the full implementation of EURISOL.

In the field of interdisciplinary research, GANIL has a very well established position and is world-leading in many areas. It is, however, important to maintain the large variety of beams and energies available at GANIL in the future. To improve the conditions for e.g. channelling studies, atomic collisions and molecular dissociation studies, the SME beam line should be equipped with an analysing magnet.

Experimental results need the support of theoretical models for their interpretation. Therefore, there is a clear need that theoretical work is developed and importantly supported, in parallel with advances in experimental techniques. A topic of particular concern in the physics of nuclei far from stability is the coherent treatment of nuclear reactions and nuclear structure.

As currently planned the GANIL/SPIRAL1+2 facility will, in 2015, be unique worldwide, both in terms of the broad variety of beams available and the energy domains (ISOL beams, post-accelerated beams, fragmentation beams). These energy domains are suitable for exploring almost all properties of and reactions with atomic nuclei, e.g. ISOL beams for radii, mass measurements, decay spectroscopy; post-accelerated beams for direct reactions, deep inelastic collisions, fusion; fragmentation beams for direct and knock-out reactions. An enhanced post-acceleration capability of the SPIRAL2 beams would provide for an even richer range of physics opportunities, including access to even more neutron-rich nuclei and to a vast program of research into the isospin dependence of the equation of state, symmetry energy and more. With
the broad spectrum of energies available at GANIL maintained, the physics of swift heavy ions will continue to play a major role and will remain competitive at world level.

The main conclusions of the study may be enumerated as follows:

• The broadening of the range of beams/species available from SPIRAL1 is considered essential to maintaining a vibrant physics programme.

• In terms of stable beams, higher intensities for the very heavy beams (Pb, U etc) are highly desirable.

• SPIRAL2 should bring about a step change in ISOL beams in the 0 - 15 MeV/nucleon range by increasing the spectrum of species available to the neutron-rich fission fragments and proton-rich medium-mass fusion-evaporation products.

• The current fragmentation beam facilities available at GANIL have, in general, significant difficulties in providing for a competitive physics programme compared to existing and future facilities. Given, however, the beam energy range (~30-80 MeV/u) and the unique instrumentation available, a case exists for maintaining, until at the very least 2015, the LISE3 installation. Small to medium scale upgrades of the separator, including a means to separate magnetically the beam and reaction products after secondary reactions in D6 should be considered if achievable in a relatively short timescale.

• Given the timescale for its implementation, its cost and that it will provide identical performances to SISSI, the SISSI2 device is considered to provide only limited benefits for the fragmentation beams programme.

• Modifications to the LISE spectrometer, the development of a gas filled mode of operation for VAMOS or the construction of a new zero-degree recoil separator should be considered for radioactive-beam fusion-evaporation reaction studies.

• In the longer term (beyond 2015), reacceleration beyond that which is possible with CIME, i.e. acceleration up to 100-150 MeV/u, is considered the most attractive option for future developments and would position GANIL well for hosting EURISOL.

• To maintain a world-leading programme in the interdisciplinary research field, the broad palette of beams and energies has to be maintained.

• Experiments with swift heavy ions could be markedly improved by the addition of an analysing magnet in the SME beam line.
• Appendix I

Comparison of low-energy stable-beam facilities

The following table compares beam energies and intensities of the most important low-energy stable-beam facilities. This table is meant to be a guide for comparison, keeping in mind that beam intensity and energy are not the only factors to be taken into account when comparing different facilities. Although much more difficult to quantify factors like access to beam time, available instrumentation, local support and many other factors should enter the comparison.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Ion</th>
<th>$^{9}_{Al}$</th>
<th>$^{12}_{C}$</th>
<th>$^{16}_{O}$</th>
<th>$^{56}_{Fe}$</th>
<th>$^{90}_{Zr}$</th>
<th>$^{208}_{Pb}$</th>
<th>$^{235}_{U}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GANIL-CSSS</td>
<td>Energy [MeV]</td>
<td>11.4</td>
<td>9.1</td>
<td>8.1</td>
<td>5.0</td>
<td>5.3</td>
<td>4.1</td>
<td>1.6 - 7.2</td>
</tr>
<tr>
<td>Max. Intensity [pA]</td>
<td>1500</td>
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<td>900</td>
<td>700</td>
<td>550</td>
<td>50 - 20</td>
<td>7</td>
</tr>
<tr>
<td>ANL</td>
<td>Ion</td>
<td>$^{9}_{Al}$</td>
<td>$^{12}_{C}$</td>
<td>$^{16}_{O}$</td>
<td>$^{56}_{Fe}$</td>
<td>$^{90}_{Zr}$</td>
<td>$^{208}_{Pb}$</td>
<td>$^{235}_{U}$</td>
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<tr>
<td>Energy [MeV]</td>
<td>13.5</td>
<td>11.25</td>
<td>11.7</td>
<td>10.3</td>
<td>10.4</td>
<td>9.5</td>
<td>8.6</td>
<td>8.0</td>
</tr>
<tr>
<td>Max. Intensity [pA]</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
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<td>1200</td>
</tr>
<tr>
<td>GSI</td>
<td>Ion</td>
<td>$^{9}_{Al}$</td>
<td>$^{12}_{C}$</td>
<td>$^{16}_{O}$</td>
<td>$^{56}_{Fe}$</td>
<td>$^{90}_{Zr}$</td>
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<tr>
<td>FLNR</td>
<td>Ion</td>
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<td>$^{56}_{Fe}$</td>
<td>$^{90}_{Zr}$</td>
<td>$^{208}_{Pb}$</td>
<td>$^{235}_{U}$</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>5.3</td>
<td>5.3</td>
<td>5.3</td>
<td>5.3</td>
<td>5.3</td>
<td>5.3</td>
<td>5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Max. Intensity [pA]</td>
<td>1200</td>
<td>3200</td>
<td>3200</td>
<td>3200</td>
<td>3200</td>
<td>3200</td>
<td>3200</td>
<td>3200</td>
</tr>
<tr>
<td>JYFL</td>
<td>Ion</td>
<td>$^{9}_{Al}$</td>
<td>$^{12}_{C}$</td>
<td>$^{16}_{O}$</td>
<td>$^{56}_{Fe}$</td>
<td>$^{90}_{Zr}$</td>
<td>$^{208}_{Pb}$</td>
<td>$^{235}_{U}$</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>6.0</td>
<td>5.7</td>
<td>5.7</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
</tr>
<tr>
<td>Max. Intensity [pA]</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>UNIL-Tandem or Piave</td>
<td>Ion</td>
<td>$^{9}_{Al}$</td>
<td>$^{12}_{C}$</td>
<td>$^{16}_{O}$</td>
<td>$^{56}_{Fe}$</td>
<td>$^{90}_{Zr}$</td>
<td>$^{208}_{Pb}$</td>
<td>$^{235}_{U}$</td>
</tr>
<tr>
<td>Intensity [pA]</td>
<td>40</td>
<td>25</td>
<td>3</td>
<td>3</td>
<td>15</td>
<td>5</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>RIKEN</td>
<td>Ion</td>
<td>$^{9}_{Al}$</td>
<td>$^{12}_{C}$</td>
<td>$^{16}_{O}$</td>
<td>$^{56}_{Fe}$</td>
<td>$^{90}_{Zr}$</td>
<td>$^{208}_{Pb}$</td>
<td>$^{235}_{U}$</td>
</tr>
<tr>
<td>Energy [MeV]</td>
<td>5.46</td>
<td>5.55</td>
<td>5.62</td>
<td>5.90</td>
<td>2.28</td>
<td>4.96</td>
<td>5.84</td>
<td>0.679</td>
</tr>
<tr>
<td>Max. Intensity [pA]</td>
<td>7400</td>
<td>5400</td>
<td>1400</td>
<td>5400</td>
<td>450</td>
<td>900</td>
<td>1600</td>
<td>1000</td>
</tr>
</tbody>
</table>
Comparison of high-energy fragmentation facilities

The following table compares fragmentation facilities. The available energy and the maximum intensity for this energy are given. This table alone allows not to compare the potential of different facilities. The higher energy of a facility and a better fragment separator often compensate largely the primary beam intensities. Therefore, the second table in this appendix compares production rates of some exotic nuclei ranging from $^{11}$Li to $^{64}$As. These production rates which are calculations with the LISE(++) code using the characteristics of the beams available as well as the fragment separators give a more realistic comparison of the different sites. However, here again a much more detailed comparison on a case by case basis would be needed. Nonetheless it is probably difficult to catch up with a factor of 100, which is often the difference between a possible combination SISSI2/LISE and BigRIPS or the SuperFRS.

<table>
<thead>
<tr>
<th>GANIL</th>
<th>$^{28}$Ne</th>
<th>$^{36}$Ar</th>
<th>$^{76}$Kr</th>
<th>$^{86}$Kr</th>
<th>$^{124}$Xe</th>
<th>$^{136}$Xe</th>
<th>$^{238}$U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion</td>
<td>95</td>
<td>95</td>
<td>73</td>
<td>60</td>
<td>45</td>
<td>45</td>
<td>24</td>
</tr>
<tr>
<td>Energy [MeV/u]</td>
<td>5*10$^{12}$</td>
<td>5*10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
</tr>
<tr>
<td>Max. intensity [pps]</td>
<td>2*10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GSI</th>
<th>$^{28}$Ne</th>
<th>$^{36}$Ar</th>
<th>$^{76}$Kr</th>
<th>$^{86}$Kr</th>
<th>$^{124}$Xe</th>
<th>$^{136}$Xe</th>
<th>$^{238}$U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [MeV/u]</td>
<td>2*10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
<td>10$^{12}$</td>
</tr>
<tr>
<td>Max. intensity [pps]</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RIKEN</th>
<th>$^{28}$Ne</th>
<th>$^{36}$Ar</th>
<th>$^{76}$Kr</th>
<th>$^{86}$Kr</th>
<th>$^{124}$Xe</th>
<th>$^{136}$Xe</th>
<th>$^{238}$U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Energy [MeV/u]</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
<td>6*10$^{12}$</td>
</tr>
<tr>
<td>Max. intensity [pps]</td>
<td>5*10$^{11}$</td>
<td>3*10$^{11}$</td>
<td>1.5*10$^{11}$</td>
<td>1.3*10$^{11}$</td>
<td>6*10$^{10}$</td>
<td>1.2*10$^{10}$</td>
<td>1.3*10$^{9}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NSCL</th>
<th>$^{38}$Ne</th>
<th>$^{36}$Ar</th>
<th>$^{76}$Kr</th>
<th>$^{86}$Kr</th>
<th>$^{124}$Xe</th>
<th>$^{136}$Xe</th>
<th>$^{238}$U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>140</td>
<td>120</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>Energy [MeV/u]</td>
<td>5*10$^{11}$</td>
<td>3*10$^{11}$</td>
<td>1.5*10$^{11}$</td>
<td>1.3*10$^{11}$</td>
<td>6*10$^{10}$</td>
<td>1.2*10$^{10}$</td>
<td>1.3*10$^{9}$</td>
</tr>
<tr>
<td>Max. intensity [pps]</td>
<td>5*10$^{11}$</td>
<td>3*10$^{11}$</td>
<td>1.5*10$^{11}$</td>
<td>1.3*10$^{11}$</td>
<td>6*10$^{10}$</td>
<td>1.2*10$^{10}$</td>
<td>1.3*10$^{9}$</td>
</tr>
</tbody>
</table>

Comparison of the production rates of exotic nuclei at SISSI2+LISE with facilities producing radioactive exotic nuclei since many years. The primary beam and its energy used for production for each installation are given. For the separators, their standard characteristics were taken.
Comparison with the RIBF facility at RIKEN presently being commissioned and the Super-FRS facility at FAIR:

<table>
<thead>
<tr>
<th>Isotope / Facility</th>
<th>SISSI-LISE</th>
<th>BIGRIPS</th>
<th>Super-FRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{11}$Li</td>
<td>$^{18}$O, 3μA</td>
<td>$2 \times 10^3$</td>
<td>$^{22}$Ne, $2 \times 10^{12}$ pps</td>
</tr>
<tr>
<td>$^{22}$O</td>
<td>$^{38}$Si, 10μA</td>
<td>$4.4 \times 10^3$</td>
<td>$^{48}$Ca, 200 pna</td>
</tr>
<tr>
<td>$^{38}$Si</td>
<td>$^{24}$Ar, 10μA</td>
<td>$35$</td>
<td>$^{38}$Ar, 300 pna</td>
</tr>
<tr>
<td>$^{36}$Si</td>
<td>$^{24}$Ar, 10μA</td>
<td>$5 \times 10^5$</td>
<td>$^{48}$Ca, 200 pna</td>
</tr>
<tr>
<td>$^{44}$S</td>
<td>$^{60}$Ni, 4μA</td>
<td>$10^3$</td>
<td>$^{38}$Ar, 300 pna</td>
</tr>
<tr>
<td>$^{48}$Ni</td>
<td>$^{60}$Ni, 8.5μA</td>
<td>$3 \times 10^5$</td>
<td>$^{38}$Kr, 30 pna</td>
</tr>
<tr>
<td>$^{68}$As</td>
<td>$^{74}$Kr, 7μA</td>
<td>$50$</td>
<td>$^{78}$Kr, 10 pna</td>
</tr>
</tbody>
</table>

- **Appendix 3**

List of re-accelerated radioactive beams and their characteristics at different facilities:

<table>
<thead>
<tr>
<th>FACILITY</th>
<th>DRIVER</th>
<th>POWER</th>
<th>USER BEAMS ACCELERATED</th>
<th>ENERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOUVAIN-LA-NEUVE</td>
<td>30 MeV protons</td>
<td>6 kW</td>
<td>$^6$He, $^7$Be, $^{10}$Na, $^{13}$C, $^{15}$O, $^{18}$F, $^{26}$Ne, $^{28}$Ar, $^{35}$Cl</td>
<td>10 MeV/u cyclotron</td>
</tr>
<tr>
<td>(BELGIUM) 1989-2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRIBF</td>
<td>100 MeV p, d, α</td>
<td>1 kW</td>
<td>$^7$Be, $^{17}$F, $^{60}$As, $^{78}$Ni, $^{84}$Ge, $^{86}$Ga, $^{90}$Zr, $^{117}$Sn, $^{128}$Xe</td>
<td>2 - 10 MeV/u tandem</td>
</tr>
<tr>
<td>Oak Ridge (USA) 1997</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISAC TRIUMF</td>
<td>500 MeV protons</td>
<td>50 kW</td>
<td>$^8$Li, $^{11}$Be, $^{19}$F, $^{20}$Na, $^{23}$Mg, $^{25}$Al</td>
<td>1.5 - 6 MeV/u linac</td>
</tr>
<tr>
<td>(CANADA) 2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPIRAL GANIL</td>
<td>100 MeV/u heavy ions</td>
<td>6 kW</td>
<td>$^{8}$Li, $^{14}$O, $^{19}$F, $^{24}$Na, $^{29}$Mg, $^{33}$S, $^{44}$Ar, $^{74}$Kr</td>
<td>2 - 25 MeV/u cyclotron</td>
</tr>
<tr>
<td>(FRANCE) 2001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REX ISOLDE</td>
<td>1.4 GeV protons</td>
<td>3 kW</td>
<td>$^{8}$Li, $^{15}$Be, $^{17}$F, $^{23}$Na, $^{29}$Mg, $^{34}$Ni, $^{67}$Cu, $^{74}$Se, $^{82}$Kr, $^{86}$Sr, $^{100}$In, $^{106}$Sn, $^{124}$Xe, $^{153}$Sm, $^{155}$Eu, $^{184}$Hg, $^{202}$Rn</td>
<td>0.3 - 3 MeV/u linac</td>
</tr>
<tr>
<td>(CERN) 2001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXCYT</td>
<td>45 MeV/u heavy ions</td>
<td>0.01 kW</td>
<td>$^8$Li</td>
<td>1 - 6 MeV/u tandem</td>
</tr>
<tr>
<td>(LNS Catania) 2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 4

Different research areas in nuclear physics and possible beams (stable and radioactive) identified for key experiments, with energy and minimum beam intensities in order to carry out experiments. Note that the numbers given are considered estimates and that many experiments will require new instrumentation (ACTAR, AGATA, FAZIA, GASPARD, PARIS, etc.) that are out of the scope of this study.

<table>
<thead>
<tr>
<th>PHYSICS</th>
<th>Energy (MeV/u)</th>
<th>Min. Intensity</th>
<th>Typical Beams</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collective modes</td>
<td>50</td>
<td>10^6</td>
<td>Ca,^56,^90, Ni,^56,^90, Zr,^90,^100</td>
<td>LISE, EXOGAM, ...</td>
</tr>
<tr>
<td>Deformation properties</td>
<td>3-6</td>
<td>10^6</td>
<td>RIB + stable</td>
<td>EXOGAM, LISE, VAMOS, ...</td>
</tr>
<tr>
<td>Super-heavy elements</td>
<td>5</td>
<td>10^10</td>
<td>Kr, also stable Si, Ar, Ca</td>
<td>LISE, VAMOS, EXOGAM, (S3)</td>
</tr>
<tr>
<td>High spin state</td>
<td>5</td>
<td>10^6</td>
<td>Kr,^124,^136, Sn,^136,^90, Xe,^136,^90, Nd</td>
<td>EXOGAM, VAMOS,...</td>
</tr>
<tr>
<td>Astrophysical reactions</td>
<td>1-3.5</td>
<td>10^6</td>
<td>stable and neutron-rich beams, e.g. Kr,^74,^76, Sn,^90,^110, Xe,^90,^110, Nd</td>
<td>LISE, EXOGAM</td>
</tr>
<tr>
<td>Ground state properties and astrophysics</td>
<td>low energy</td>
<td>low intensity</td>
<td>n-rich Be, n-rich nuclei close to N=50, N=82, close to p drip-line</td>
<td>SIRa, LIRAT, (DESIR)</td>
</tr>
<tr>
<td>Alpha clustering</td>
<td>10 - 40</td>
<td>10^4</td>
<td>Ar or radioactive nuclei N=Z</td>
<td>EXOGAM, VAMOS, SPEG, ...</td>
</tr>
<tr>
<td>Quasi-molecular nuclei</td>
<td>4 - 30</td>
<td>10^5</td>
<td>n-rich Be, C, O, Ne, Mg, Si</td>
<td>LISE, ...</td>
</tr>
<tr>
<td>Neutron pairing</td>
<td>6-10</td>
<td>10^4</td>
<td>Sn,^124,^136, Xe,^136,^90, He,^136,^90</td>
<td>VAMOS, SPEG, ...</td>
</tr>
<tr>
<td>p-n pairing</td>
<td>4-30</td>
<td>10^4</td>
<td>Cr,^56,^76, Ni,^76,^90, Zr,^90,^110,^76,^90</td>
<td>LISE, VAMOS, SPEG, ...</td>
</tr>
<tr>
<td>Shell evolution</td>
<td>8-30</td>
<td>10^6</td>
<td>Neutron-rich C isotopes,^56,^70,^80,^90, Ni,^80,^90, Zn,^90,^110, Cd,^132,^Sn</td>
<td>VAMOS, SPEG, EXOGAM, ...</td>
</tr>
<tr>
<td>Weakly-bound systems</td>
<td>5-20</td>
<td>10^4</td>
<td>Sn,^14,^30, Te,^14,^30, Li,^14,^30, Be,^14,^30, C,^14,^30, O,^14,^30, Ne,^14,^30, Na,^14,^30, Ar,^14,^30, Mg,^14,^30, S,^14,^30, Se,^14,^30, Kr</td>
<td>VAMOS, SPEG, EXOGAM, ...</td>
</tr>
<tr>
<td>Fission, fusion</td>
<td>5</td>
<td>10^6</td>
<td>C,^14,^16, O,^14,^16, Sn,^14,^30, U,^14,^30, Ni,^14,^30, Ar,^14,^30, O</td>
<td>VAMOS, EXOGAM, (S3)</td>
</tr>
<tr>
<td>Nuclear dynamics and thermodynamics</td>
<td>10-50</td>
<td>10^6</td>
<td>Sn,^56,^64,^74, Ni,^56,^74, Zn,^64,^80, Ni,^44,^80, Zn,^80,^94, Kr,^80,^94, Sr,^94,^145, Kr,^94,^145, Xe,^94,^145, Ca,^94,^145, Ni</td>
<td>VAMOS, INDRA, ...</td>
</tr>
<tr>
<td>Fundamental interactions</td>
<td>low energy</td>
<td>10^4 - 10^6</td>
<td>He,^16,^18, Ne,^16,^18, Ar,^16,^18, Mo</td>
<td>SIRa, LIRAT, EXOGAM, (DESIR),...</td>
</tr>
</tbody>
</table>

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4. APPENDIX n°4 : Report of Technical Advisory Board  
March 3rd 2009

Sytze Brandenburg (KVI, Nederland), Frédéric Chautard (chair, GANIL), Bernard Launé (IPNO, France), Olivier Laurent (GANIL), Jerry Nolen (ANL, USA), Eric Petit (SP2/GANIL), Josiane Sauret (GANIL), Thierry Stora (CERN, Switzerland), Maurizio Vretenar (CERN, Switzerland), Bertrand Rannou (GANIL)

1. INTRODUCTION

The Technical Advisory Board (TAB) will provide advice on the technical implications, including radio-protection and safety, of the requirement for the future physics experiments and the possible large-scale maintenance needed.

The committee had three meetings:
• October 7th
• October 22nd
• December 19th

The evaluation of the proposals by the TAB is based on the following documents:
• Cluster reports (all versions)
• Core group summaries

Additionally, members of the TAB participated in the “fragmentation meeting” held on December 4th. A summary of this meeting has been added to the Core group summary.

From those documents, the TAB has extracted the technical aspects of the proposals and summarized in tables in order to identify the common subjects (beam demands, ion source, experimental equipments…).

Each item (>60 in total) was evaluated from both technical and safety/radioprotection point of view.

From the analysis by the TAB four major items emerged that require a more detailed investigation:
• Source developments (Stable and exotic)
• Second station of irradiation for SPIRAL2
• Fragmentation
  o Modification of LISE spectrometer
  o SISSI2
• Experimental room adaptation to SPIRAL2 beams reception

Remarks:
• We have, after consultation of the Core group, excluded all the issues related to the post-acceleration of fission fragments up to 100 MeV/A, which is more in the scope of the EURISOL project, from the final discussions.
• It has been identified that the rooms G1, G2, G3, D4 and D6 might receive the SPIRAL2 beams. For each room, a preliminary study was performed in collaboration with the cluster group toward realistic technical solutions.
• The safety issues were considered of great importance by the Board. New beams, new target material, new room configurations might imply a new safety report. GANIL in its “10 years safety re-evaluation” must include most of those informations to be treated at once by the French nuclear safety authority. In annexe, the tables by room gather the relevant safety/radioprotection information.
Figure 1: Layout of the GANIL rooms concerned by the studies
## 2. LISE

<table>
<thead>
<tr>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Alpha separator with higher rigidity and acceptance</td>
<td>Linked to new SISSI. Very expensive and studies required (2 months).</td>
<td></td>
</tr>
<tr>
<td>Increasing the angular acceptance of the existing spectrometer would be possible by having one-meter distance more between the production target and the first dipole of LISE and by adding one quadripole.</td>
<td>Good idea but a proposed layout is needed to comment on feasibility for the overall LISE acceptance and resolution</td>
<td>Large safety report ASN Authorisation</td>
</tr>
<tr>
<td>A mass spectrometer would be useful behind LISE3 or LISE2000. see Table below</td>
<td>If it is a real mass spectrometer then it is very hard at these energies. [This option is only relevant when the new SISSI is not realized]</td>
<td>Large building modifications ASN Authorisation Access control system must be taken into account</td>
</tr>
</tbody>
</table>

In the LISE cluster group report the following table was presented. It has been completed by the Board in meeting:

<table>
<thead>
<tr>
<th>SISSI2 + ALPHA</th>
<th>LISE2000 extension with BBS (Figure 3)</th>
<th>SUPER-LISE (Figure 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Advantages</strong></td>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>• 2 target stations</td>
<td>• Two beam lines</td>
<td>• Advantages for production of p- and n-rich isotopes</td>
</tr>
<tr>
<td>• Several beamlines concerned (G3, LISE…)</td>
<td>• Advantages for n-rich nuclei due to higher magnetic rigidity</td>
<td>• Possibility to use velocity filter and spectrometer in “FULIS” mode (to be investigated)</td>
</tr>
<tr>
<td>• Advantages for heavier and in particular for p-rich isotopes</td>
<td>• Improvement of LISE2000 which is rarely used today</td>
<td>• Large acceptance of BBS</td>
</tr>
<tr>
<td>• Increased purity of beams due to distance between production and detection</td>
<td>• Possibility to use velocity filter and spectrometer in “FULIS” mode (to be investigated)</td>
<td></td>
</tr>
<tr>
<td>• Project already started</td>
<td>• Large acceptance of BBS</td>
<td></td>
</tr>
<tr>
<td>• Limited manpower involved</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Drawbacks</strong></th>
<th><strong>Drawbacks</strong></th>
<th><strong>Drawbacks</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Maintenance of 2 target stations</td>
<td>• Only one target station</td>
<td>• No 0° experiments possible any-more (e.g. DEMON)</td>
</tr>
<tr>
<td>maximal $B_p$ of 2.88 Tm</td>
<td>• Safety report</td>
<td>• Only one target station</td>
</tr>
<tr>
<td></td>
<td>• Manpower</td>
<td>• Only one beam line</td>
</tr>
</tbody>
</table>
Remarks:

A survey has been launched by the fragmentation community to converge toward a common agreement concerning the choice of the equipment (SISSI2, LISE2000 extension or SUPER-LISE). It should be realised, however, that the SISSI2 project consists of building a copy of the original system because of the lack of the manpower available at GANIL for development and safety, so that their involvement in the project could be minimised. A SISSI2 ready at the end of 2011 seems achievable.

If the spectrometer BBS from KVI is available:

• An integration study should be performed. Realistic data can be given only after several man-months of work.
• The safety considerations, caused by the relocation of a concrete wall should be included in the global GANIL safety re-evaluation report.

It is obvious that studies of any new spectrometer require significant full time human resources that were already impossible to find for the SISSI2 project.

Concerning the increase of the alpha magnetic rigidity, it worth it only in the frame of a new improved SISSI. A study of a large acceptance hot quadripole solution has been performed allowing reaching 3.2 T.m instead of 2.88 T.m. This study showed that the performances were slightly degraded but most importantly, the installation of such a large-scale magnets necessitates the rearrangement of the transport line downstream of the target, which has a too large implication on the safety. Therefore, in the actual SISSI2 studies the magnetic rigidity is expected to remain at 2.88 T.m.

![Figure 2: Actual right experimental rooms. LISE represent the D3+D4+D6](image)

![Figure 3: Extension of the LISE2000 beam by a velocity filter and the addition of a spectrometer.](image)
3. SPEG

---

<table>
<thead>
<tr>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>For experiments to be performed with SPEG the most relevant improvement for GANIL (fragmented) beams, is the increase of the intensity, which is main factor limiting the accuracy of the experiments (counting statistics).</td>
<td>Higher intensity primary beams to SPEG are related to the beam power limits of GANIL. Higher intensity heavy ions at SPEG seem feasible with ion source development or upgrade (see GTS table below).</td>
<td>Max intensities?</td>
</tr>
<tr>
<td>To have fragmented beams in SPEG, the most viable solution is to repair SISSI.</td>
<td>Repair of SISSI is high priority for this and other programs such as LISE.</td>
<td></td>
</tr>
<tr>
<td>To avoid problems related to radioactivity it is essential that the beams be as isotopically pure as possible, in principle already before injection in the CIME cyclotron.</td>
<td>In general a good idea – needs selective ion sources (e.g. laser plus n+ or surface source plus n+) for SPIRAL and/or better selection in CIME (such as the vertical deflection)</td>
<td></td>
</tr>
<tr>
<td>A larger Brho of the SISSI-ALPHA</td>
<td>Irrelevant because Brho SISSI = 2.88 T.m</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- SPIRAL2 beams of interest at intensity of $10^6$ pps
- At this level of intensity, no major modification of the cave seems required. However, evaluation for each specific beam required.
Remarks:

SPEG requires higher intensity beams to be fragmented into SISSI target. This is under development at GANIL within the project GTS. The table below recalls the expected gains for each energy range.

<table>
<thead>
<tr>
<th>Gains</th>
<th>IRRSUD</th>
<th>Middle energies (Up to 13 MeV/A)</th>
<th>High energies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intensities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Ions</td>
<td>1 à 2</td>
<td>1 à 2</td>
<td>1 à 2</td>
</tr>
<tr>
<td>Heavy Ions</td>
<td>2 à 4</td>
<td>2 à 4</td>
<td>2 à 4</td>
</tr>
<tr>
<td>Very heavy Ions</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Max Energies</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Ions</td>
<td>1 MeV/A</td>
<td>13.6 MeV/A</td>
<td>No gain</td>
</tr>
<tr>
<td>Heavy Ions</td>
<td>For all ions</td>
<td>For all ions</td>
<td>Possible Gain</td>
</tr>
<tr>
<td>Very heavy Ions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concerning the increase of the magnetic rigidity of the alpha spectrometer the remarks made for LISE on this issue also apply here.
4. **VAMOS**

<table>
<thead>
<tr>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change of the gap of the Wien filter for studies of fusion reaction with a high intensity stable beams</td>
<td>Need to see some optics layout or feasibility study.</td>
<td></td>
</tr>
<tr>
<td>To exploit multinucleon reactions with the high intensity beams of SPIRAL2 it is required to place a spectrometer near the grazing angle. The rotation of the spectrometer up to 90 degrees is required and not presently possible due to the size of the experimental hall.</td>
<td>This proposal is not clear. Is it a new spectrometer? Large building modifications ASN Authorisation</td>
<td></td>
</tr>
<tr>
<td>Beam dumping required for SPIRAL2 beams</td>
<td></td>
<td>Building modifications ASN Authorisation</td>
</tr>
<tr>
<td>Increase of the intensity of the heavy beams Pb, U up to 20 pnA at 8 MeV/A.</td>
<td>CSS1 could deliver such beams with the GTS source upgrade.</td>
<td></td>
</tr>
<tr>
<td>An improvement of time resolution of the beam pulses to about 500 ps. The time resolution should be improved to less than 1 ns without decrease of the beam intensity.</td>
<td>Requires machine studies of CSS2 and/or CIME. (Alpha tuning, buncher cyclotron tuning) with no guarantee for success</td>
<td></td>
</tr>
<tr>
<td>The priority of beam development would be to first develop a neutron rich Xe, Kr, Ga and Sn and then subsequently increase the intensity of the most neutron rich isotopes of these beams.</td>
<td>Probably a SPIRAL2 development. This is a fundamental goal of SPIRAL2. For $10^7$ – $10^9$ pps beams probable cave modifications required.</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**
VAMOS, as SPEG, is also interested by **high intensity** stable heavy ion beams from GANIL. The new GTS-source might provide the solution.

Additionally, a proposal of the G1 room adaptation to SPIRAL2 beams is given Figure 5. It has been identified the following requirements for Spiral2 operation:

- A beam dump to stop the intense radioactive beam,
- A rotation of the spectrometer up to 90° is needed for the physics with heavy radioactivity particles (the rotation is now limited to 45°)
- The operation at 0° has to be conserved.

It can be argued that an enlargement of the G1 room could be motivated by the following reasons:

- Spiral2 beams are likely to need remote handling
- Due to the future activated environment, intervention should be as short as possible; in consequence circulation around the experimental device should be eased.
- High intensity SPIRAL2 beams should be dumped in a new beamstop

**Preliminary technical proposal**

In Figure 5, a new beam line inclined at 45 degrees relative to the present beam line could be installed driving the beam to the shielded beam dump. With this line, VAMOS can be operated between 35 and 95 degrees with respect to the incident beam trajectory. Moreover, the 0-degree operation with the actual beam line is kept. This solution allows having all working modes.
Figure 5: Possible G1 new line design for SPIRAL2 beams.
5. INDRA

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>INDRA</td>
<td>Post-accelerated beams at higher energies</td>
<td>Within the CIME limit?</td>
<td>Max energies to evaluate the constraints</td>
</tr>
</tbody>
</table>

Remarks:
No major demands

Looks adaptative to any new beamline configuration on stand-alone or coupled to a spectrometer.

The requirements on ion beams are too general.
6. SPIRAL1 & SIRa

<table>
<thead>
<tr>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>The development of Alkali beams 1+N compact ion source</td>
<td>On-going and very useful development; high priority.</td>
<td>ASN Authorisation if new ECS in cave 1</td>
</tr>
<tr>
<td>Improvement of beam purity</td>
<td>CIME beam development; high priority also. Selective sources New scheme proposal for SPIRAL1</td>
<td></td>
</tr>
<tr>
<td>Study of high power target 3kW for other beams ((^{36})S, (^{40})Ar, (^{20})Ne)</td>
<td>For neutron rich a 2-step geometry is good. Use aerogel catcher? In the frame of ISOL and SDA/Physique/SPIRAL2 committee</td>
<td>Actual criteria: (2 \times 10^{13}) pps or 6 kW</td>
</tr>
<tr>
<td>Replace the existing C01 ion source.</td>
<td>With GTS. In the frame of SDA/Physique/SPIRAL2 committee</td>
<td></td>
</tr>
<tr>
<td>Reduce beam emittance out of CIME from 15-20 pj.mm mrad</td>
<td>Hard or impossible to do without large loss of intensity.</td>
<td></td>
</tr>
<tr>
<td>A requirement of another cave for the study of new beams will be very important (not SIRa) requirements</td>
<td>What are the issues relative to SIRa</td>
<td>ASN Authorisation</td>
</tr>
<tr>
<td>Using the intense (^{12})C beam from GANIL, the fragmentation of various target materials would considerably extend the scope of SPIRAL1 and in some cases also boost intensities.</td>
<td>Cave 1: Need permission for other target materials. Application of standard ISOL methods. Look at the old ISOLDE carbon beam data – could be very interesting. Or cave 2 SP1?</td>
<td>ASN Authorisation. Important report</td>
</tr>
<tr>
<td>(^{16})Xe RIB, post-accelerated at 4-5 MeV/u, can be produced at the SPIRAL 1 facility by fusion-evaporation with an intensity &gt; (10^4) pps. Using the intense (^{18})O beam impinging on a thin Pd foil in the SPIRAL 1 ECS and the usual thick (^{12})C target as catcher of the direct beam.</td>
<td>In progress</td>
<td>Internal Authorisation</td>
</tr>
<tr>
<td>The experimental program will require SPIRAL beams of (^{27-29})Ne, (^{40})Ar, (^{44-48})Se, (^{84-86})Kr</td>
<td>Energies and intensities missing</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**

The statement made in the cluster report: “In my opinion the continuation of SPIRAL1 does not make much sense unless effort is devoted to the development of new beam species”, makes clearly the need of new beam developments. GANIL already understood the importance of this task and a first step toward this goal is the creation of a committee ISOL gathering physicists and engineers. Beginning of 2009, a first meeting will be held.

In the last cluster report, no specific beam demand but new source demands.

The insertion of new source looks complicated due to the geometrical and safety constraints (see alkali source), therefore new beam developments go probably with the insertion of a charge breeder out of the cave 1 of SPIRAL1. This solution might be easing the safety aspect.
Nevertheless, the large beam losses around the charge breeder should be investigate and taken into account.

The use of the production cave 2 of SPIRAL1 (CS2) is proposed and strongly supported. It can be an answer to radioactive source developments. One can compare this development to the use of SIRa. In addition, it is not clear why SIRa cannot be the bench test of the future target-source development while the cave 1 of SPIRAL 1 is upgraded?

A new production cave is a major modification of the SPIRAL1 facility. It depends on the couple of target and ions needed, it could induce new types of radioactive releases and if not taken into account in the authorisation of releases (public inquiry) it will not be possible to realise.

Figure 6: Layout of the cave 2.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Upgrade CS1</th>
<th>New cave (CS2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Existing bench test</td>
<td>• Tests done in SIRa while safety report upgraded</td>
<td>Above 400W primary beam</td>
</tr>
<tr>
<td>• No nuclear ventilation</td>
<td>• Better flexibility on target source</td>
<td>• All to be design</td>
</tr>
<tr>
<td>• No remote handling</td>
<td>• Uses by for SPIRAL2 source developments</td>
<td>• New transport line</td>
</tr>
<tr>
<td>• Safety report for</td>
<td></td>
<td>• Cave occupied for SPIRAL1 gas bottles</td>
</tr>
<tr>
<td>modifications</td>
<td></td>
<td>• Cost</td>
</tr>
<tr>
<td>• Up to 400 W primary beam</td>
<td></td>
<td>• Manpower</td>
</tr>
<tr>
<td></td>
<td>• Impact study in progress to obtain gaseous release authorization does not</td>
<td>• New safety report (same than CS1)</td>
</tr>
<tr>
<td></td>
<td>include these upgrade</td>
<td>• Idem : incidence on impact study in progress</td>
</tr>
</tbody>
</table>

• Idem : incidence on impact study in progress
## 7. EXOGAM

<table>
<thead>
<tr>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXOGAM2</td>
<td>In progress. 2012 @ GANIL</td>
<td></td>
</tr>
<tr>
<td>More detectors available. Actions have been undertaken to improve the maintenance of the existing detector maintenance.</td>
<td>In progress (STP/GANIL)</td>
<td></td>
</tr>
<tr>
<td>Direct line to G1/G2.</td>
<td>Motivation? Why VAMOS not interested?</td>
<td>Large modification of GANIL. ASN Authorisation</td>
</tr>
<tr>
<td>Coupling to S3 (at intermediate as well as at the final focal plane) and Ge array in the DESIR cave</td>
<td>Is part of the SPIRAL2 plan</td>
<td></td>
</tr>
<tr>
<td>Improve beam quality from CIME (emittance, time structure too poor)</td>
<td>Hard to do while keeping intensity. See SPIRAL1</td>
<td></td>
</tr>
<tr>
<td>SPIRAL 2: Ar, Kr, Xe, Sn, Nd, p-rich nuclei, n-rich metallic beams, 81Ga, 82Ge, 80Zn, Ar to Zn up to 10^8-9 pps</td>
<td>Will require probably the same beamstop for VAMOS.</td>
<td>Probable room adaptation</td>
</tr>
</tbody>
</table>

### Remarks:

None
8. LIRAT

<table>
<thead>
<tr>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIRAT</td>
<td>The so-called LIRAT2 project proposed the extension of the existing LIRAT facility as a possible development strategy for SPIRAL, given the following arguments:</td>
<td>Large modification of the building. ASN Authorisation</td>
</tr>
<tr>
<td></td>
<td>More species (or even the whole production of SPIRAL I) should be authorized to be driven in the LIRAT line (Presently only 4 beams are authorized ( ^6\text{He}, ^{19}\text{Ne}, ^{32}\text{Ar} ) and ( ^{35}\text{Ar} ))</td>
<td>ASN Authorisation</td>
</tr>
<tr>
<td></td>
<td>Within the SPIRAL2 project, the LIRAT beam line should transport SPIRAL beams to the DESIR facility. It would not allow the running of experiments in parallel.</td>
<td>Taken into account in SP2 plan</td>
</tr>
</tbody>
</table>

Remarks:

For the short term, the authorisation of delivering other SPIRAL beams to LIRAT should be obtained.
### 9. INDUSTRIAL APPLICATIONS

<table>
<thead>
<tr>
<th>Industrial Applications</th>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>More beam time, on the same devices in the cave G4.</td>
<td>Direct Line CIME G1/G2 (project LCG) could help</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The ability to change ion in a short time (i.e. ion cocktails available in some other test sites), during a test run.</td>
<td>With CIME ok Not CSS1 or 2</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**

None
### 10. CIRIL, ARIBE

<table>
<thead>
<tr>
<th>Description</th>
<th>TAB comment</th>
<th>Safety TAB comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our community is well aware that, on the long term, hopefully well beyond 2015, the operation of the GANIL cyclotrons might not be guaranteed. We are also convinced that the use of the SPIRAL2 beams cannot be the appropriate answer to this situation.</td>
<td>Why not interested in SP2 driver?</td>
<td></td>
</tr>
<tr>
<td>Deporting the chopper after the SME entrance and/or modifying the intensity modulation by introducing for instance pepperpots or other devices.</td>
<td>To introduce to SDA/PHYSIQUE/SPIRAL2 committee</td>
<td></td>
</tr>
<tr>
<td>A concrete wall, inside D1, separating the stripping + slits area from the experimental area will help.</td>
<td>Charge load?</td>
<td>Explicit the need</td>
</tr>
<tr>
<td>Instabilities of beam position the intensity fluctuations are huge. Any solution to that problem will be welcome</td>
<td>In progress with operation staff</td>
<td></td>
</tr>
<tr>
<td>A reliable operation of the pulse suppressor is compulsory. Same specs as before?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTS type sources on the C0 platforms will be interesting, for a small part of the users, to have higher energies and current for heavy ions in the CSS1 energy range.</td>
<td>It is compatible with other demands for this new source.</td>
<td></td>
</tr>
</tbody>
</table>

**Remarks:**

None
11. CONCLUSIONS

From the analysis of the cluster group documents by the TAB four major items emerged which are:

- sources developments,
- second irradiation station for SPIRAL1 / 2,
- the fragmentation programme,
- SPIRAL2 adaptation of the experimental areas

For each topic, the TAB has kept only the most demanding issues. Only the technical aspects that the TAB considers most important will be emphasized.

Source developments (stable and exotic).

This item appeared to be common to several cluster groups and seems of utmost importance for the future of GANIL. Technical proposals were discussed with the source experts of the committee. It appeared that various source designs could be available at GANIL after at most four years of development and construction. The TAB considers that it cannot make a reasoned recommendation within the tight schedule of the present discussions. Meanwhile, a committee SDA/PHYSIQUE/SPIRAL2 was created at GANIL in which an expert group in the source domain, GANISOL, should investigate and realise the future sources at GANIL. Therefore, all demands regarding sources from the clusters have been transmitted to this committee.

Second station of irradiation for SPIRAL2/SPIRAL1

From the needs expressed, a second irradiation station seems the most important for the development of sources and targets not only for SPIRAL1 but also for SPIRAL2. An obvious solution is to equip the remaining cave 2 of SPIRAL1. This solution requires the installation of a large amount of new equipment:

- Beamline for primary beams
- Beamline for the secondary beams
- Cave infrastructure (remote handling, nuclear ventilation, gas storage …)
- …

The cost in terms of manpower and money of this project is very significant; a realistic estimate requires a study at an APS-level.

An alternative is to use the existing target stations: D2 (SIRa) and SPIRAL1 Cave. It seems reasonable to upgrade both caves. This configuration was used for SPIRAL1 beam developments where low power beam (<400W) production/source tests were performed on SIRa/D2. New sources/ new targets could still be tested in SIRa (upgrades needed but known by the users of the room). Meanwhile, cave1 safety report upgrade can be started to extend the high power (>400W) beam production.

Fragmentation

Modification of LISE spectrometer with BBS installation

A preliminary study to modify the D4, D5 and D6 rooms and to propose new beamlines adapted to the fragmentation community demand and an attempt to dedicate part of the LISE spectrometer to the SPIRAL2 beams (Figure 7) has been made. The report written in collaboration with IPNO defines the main building modifications and the area where SPIRAL2 beams might be transported. A first order evaluation of the cost and human resources has also been made.
The report should contain enough information to evaluate the safety issues. The estimated cost, resources and schedule are presented in the report [GANIL R 09 01] – See P82. The incidence on access control system (EIS) remains to be taken into account.

The precise beam optics and performance calculations of such a spectrometer will be done at a later stage.

![Figure 7: Proposal of the new LISE room layout.](image)

From a technical and GANIL human resources points of view, the replacement of SISSI with identical functionality and in collaboration with cryogenic experts from IRFU/SACM laboratory seems the optimum solution. This solution should not require a new safety report.

Already about 10 engineers and technicians are participating in the project since November 2008. GANIL has prepared a report containing the functional needs of the device and IRFU/SACM will submit to GANIL a technical solution. The next milestones identified are:

- April 2009: technical report on the chosen solution of replacement
- June 2009: submission for competitive tendering
- September 2009: return of the tendering.

Detailed documentation of the project is available via the committee SDA/PHYSIQUE/SPIRAL2.
SPIRAL2 room adaptation

The rooms G1, G2, G3 and D6 are likely to receive SPIRAL2 beams and probably need to be modified. The beam dump for SPIRAL2 beams requires the development of a new concept that has not yet started. It should also be pointed out that this new type of beamstop should probably also be implemented in other experimental setups where high intensity SPIRAL2 beams are to be used in the future (G2, SPEG, LISE3).

Safety issues

In the annexe (§12) information about the ion beams and experimental setups is summarized in a table per room and will be used as input for the GANIL safety report.

We notice also that the intensity limitation for stable beams out of CSS2 is \(<2\times10^{13}\) pps or \(<6\) kW beam. Essentially, for light ions the \(2\times10^{13}\) pps limitation in CSS2 is reached before the beam power limitation. It can be of interest to modify this limit.

Many smaller issues exist and are identified but can be treated by the experimental groups.

Therefore, the major items identified for safety/radioprotection are:
- the rooms that might receive SPIRAL2 beams: G1, G2, G3, D3, D4 and D6,
- two main modifications of rooms: LISE + new spectrometer (large building modifications) and a new production cave CS2 for SPIRAL1 (safety aspects + gas release authorization).

12. ANNEXES:

Safety inputs

The cluster groups have been requested to fill in a generic table defined by the persons in charge of the safety at GANIL and SPIRAL2. These tables give an overview of the expected beams and experimental setups in each room. Consequently, those tables will be used to evaluate the consequences on the safety requirements in the framework of the re-evaluation of the GANIL safety report.

Tables delivered:
- LISE
- SPEG
- VAMOS/SPRAL1
- INDRA
- CIRIL, ARIBE
- Industrial Applications

Tables not delivered:
- LIRAT
- SIRa
- EXOGAM
Table 1: LISE

<table>
<thead>
<tr>
<th>Beams characteristics</th>
<th>Stable beams GANIL</th>
<th>Exotic beams GANIL + SPIRAL1</th>
<th>Exotic beams SPIRAL 2</th>
<th>Exotic beams SPIRAL2 post accelerated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams of interest for physicists</td>
<td>GANIL range</td>
<td>No restrictions</td>
<td>Produced in LISE by fragmentation. No restrictions</td>
<td>Used only after CIME postacceleration</td>
</tr>
<tr>
<td>Energy range [MeV/A]</td>
<td>Maximum available</td>
<td>No restrictions</td>
<td>From few MeV/u up to 100 MeV/u</td>
<td>For calibration of the detectors and alignment of the beam, the same energy and characteristics as the radioactive beams.</td>
</tr>
<tr>
<td>Beam intensity [pps]</td>
<td>Maximum stable beams available and authorized in D3 (6 kW?). Very low beams (1 nAe) in D4 and D6 for alignment and calibration. Possibility to use intense beams (&gt; 1000 nA) en up to the FW in some experiments (FULIS with low energy beams), and atomic physics?</td>
<td>Maximum available</td>
<td>Beams produced from fragmentation in D4 and D6, maximum available (usually lower than 10^6 pps)</td>
<td>Few nAe (10^10 pps), for calibration of the detectors and alignment of the beam.</td>
</tr>
<tr>
<td>Targets used (type, form, activity...)</td>
<td>Solid targets. Be, Ni, Ta, W... Thickness: from few tens of microns to few millimetres. Use of Be degrader (same thicknesses), used in D3 for the fragmentation.</td>
<td>Solid, gaseous, cryogenic targets, usually thin targets (up to 1 mm).</td>
<td>Solid, gaseous, cryogenic targets, usually thin targets (up to 1 mm).</td>
<td>Solid, gaseous, cryogenic targets, usually thin targets (up to 1 mm) – used to calibrate detectors.</td>
</tr>
<tr>
<td>Radioactive waste produced (solid, liquid, gas)</td>
<td>YES - Solid</td>
<td>Not really – mainly from the decay of the radioactive nuclei</td>
<td>Not really – mainly from the decay of the radioactive nuclei</td>
<td>Not really</td>
</tr>
<tr>
<td>Beam losses (localization)</td>
<td>Mainly in the beam dump in the first dipole D3P1. A little in the selection slits along the spectrometer. In the Wien Filter.</td>
<td>In the selection slits</td>
<td>In the selection slits</td>
<td>In the selection slits + beam dump in D4 or D6</td>
</tr>
<tr>
<td>Detectors: toxic matter used (fire, explosion ...)</td>
<td>CAVIAR -&gt; gas</td>
<td>As it is in the present installation.</td>
<td>As it is in the present installation.</td>
<td>As it is in the present installation.</td>
</tr>
</tbody>
</table>
Table 2: SPEG

<table>
<thead>
<tr>
<th>Beams characteristics</th>
<th>Stable beams GANIL</th>
<th>Exotic beams GANIL + SPIRAL1</th>
<th>Exotic beams</th>
<th>Stable beams SPIRAL 2</th>
<th>Exotic beams SPIRAL2 post accelerated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams of interest for physicists</td>
<td>GANIL range</td>
<td>Depends on developments of SPIRAL1 beams. Possible interest in exotic species that will be produced.</td>
<td>GANIL range Fragmentation (SISSI) beams</td>
<td>SP2 range Stable beams to be used for calibrations Mass and charges similar to the exotic ones</td>
<td>SP2 range</td>
</tr>
<tr>
<td>Energy range [MeV/A]</td>
<td>GTS : max energies : see table</td>
<td>All energies available from CIME</td>
<td>Up to max available energy</td>
<td>Up to max energy available (6 MeV/A for heavy))</td>
<td></td>
</tr>
<tr>
<td>Beam intensity [pps]</td>
<td>Higher intensity GTS project ; gain expected : 1 to 2 for light ions 2 to 4 for heavy ions 10 for very heavy ions</td>
<td>Interest in most exotic species for elastic scattering and direct reactions -&gt; intensities $10^6$ pps max</td>
<td>Most exotic species are investigated -&gt; global intensities are never beyond $10^6$</td>
<td>Max $10^7$</td>
<td>Most exotic species are investigated -&gt; intensities of PURE beams $&lt;10^6$ (need to purify beams BEFORE coming to G3)</td>
</tr>
<tr>
<td>Targets used (type, form, activity…)</td>
<td>Thin foils, gas targets (isobutene, He).</td>
<td>Foils (CD2, CH2, heavy: Pb, Au…). Active target Maya/ACTAR filled with gas: isobutane, deuterium, helium.</td>
<td>Thin foils, active target</td>
<td>Thin foils, active target</td>
<td></td>
</tr>
<tr>
<td>Radioactive waste produced (solid, liquid, gas)</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Beam losses (localization)</td>
<td>CIME injection and ejection</td>
<td>Worst cases: incoming beam stopped in SPEG (fragmented beam $10^5$ pps)</td>
<td>Before CIME and in CIME</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detectors : toxic matter used (fire, explosion …)</td>
<td>Maya/ACTAR gas-filled target/detector. Max pressure ~2 bars (Already used)</td>
<td>Maya/ACTAR</td>
<td>Maya/ACTAR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 3: VAMOS/SPIRAL1

<table>
<thead>
<tr>
<th>Beams characteristics</th>
<th>Stable beams GANIL</th>
<th>Exotic beams GANIL + SPIRAL1</th>
<th>Exotic beams</th>
<th>Stable beams SPIRAL 2</th>
<th>Exotic beams SPIRAL2 post accelerated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams of interest for physicists</td>
<td>GANIL range In particular Heavy ion beams (Pb, U) of high intensity</td>
<td>ALL</td>
<td>NOT REQUIRED</td>
<td>NO</td>
<td>ALL ISOTOPES</td>
</tr>
<tr>
<td>Energy range [MeV/A]</td>
<td>Mainly CSS1 (CIME) range And &lt;=10 MeV/u</td>
<td>CIME range</td>
<td></td>
<td></td>
<td>CIME range</td>
</tr>
<tr>
<td>Beam intensity [pps]</td>
<td>High intensity 20 pnA Heavy ions (Pb, U)</td>
<td>MAX AVAILABLE</td>
<td></td>
<td></td>
<td>MAX</td>
</tr>
<tr>
<td>Targets used (type, form, activity…)</td>
<td>Stable isotopes Thickness &lt;= 50mg/cm2</td>
<td>Stable isotopes Thickness &lt;= 50mg/cm2</td>
<td></td>
<td>Stable isotopes Thickness &lt;= 50mg/cm2</td>
<td></td>
</tr>
<tr>
<td>Radioactive waste produced (solid, liquid, gas)</td>
<td>NO</td>
<td>NO</td>
<td></td>
<td></td>
<td>See below 2)</td>
</tr>
<tr>
<td>Beam losses (localization)</td>
<td>NO</td>
<td>Low intensity in VAMOS</td>
<td></td>
<td></td>
<td>See below 1) a and b</td>
</tr>
<tr>
<td>Detectors : toxic matter used (fire, explosion …)</td>
<td>IsoButane (gas detectors) and He (VAMOS)</td>
<td>IsoButane (gas detectors) and He (VAMOS)</td>
<td></td>
<td>IsoButane (gas detectors) and He (VAMOS)</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4: CIRIL, ARIBE

<table>
<thead>
<tr>
<th>Beams characteristics</th>
<th>Stable beams GANIL</th>
<th>Exotic beams GANIL + SPIRAL1</th>
<th>Exotic beams</th>
<th>Stable beams SPIRAL 2</th>
<th>Exotic beams SPIRAL2 post accelerated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams of interest for physicists</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy range [MeV/A]</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam intensity [pps]</td>
<td>Upgrade equivalent 13C up to 500W</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Targets used (type, form, activity…)</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radioactive waste produced (solid, liquid, gas)</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam losses (localization)</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detectors : toxic matter used (fire, explosion …)</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Table 5: EXOGAM**

<table>
<thead>
<tr>
<th>Beams characteristics</th>
<th>Stable beams GANIL</th>
<th>Exotic beams GANIL + SPIRAL1</th>
<th>Exotic beams SPIRAL 2</th>
<th>Stable beams SPIRAL 2 post accelerated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beams of interest for physicists</strong></td>
<td>Ganil range</td>
<td>New beam developments (Alkali, n-rich Xe, n-rich C)</td>
<td>Spiral 2 range</td>
<td>Spiral 2 range</td>
</tr>
<tr>
<td></td>
<td>Intense beam $^{12}$C</td>
<td>$^{26}$, Ar$^{19}$, Ne$^{20}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intense beam $^{16}$O</td>
<td>Xe$^{116,120}$ RIB at 4-5 MeV/A and $I &gt; 10^4$ pps</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ne$^{27,29}$, Ar$^{40,44}$, Se$^{84,86}$, Kr$^{88,92}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase Intensity He$^+$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low energy C$^{16}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Energy range [MeV/A]</strong></td>
<td>Ganil range</td>
<td>Cime range</td>
<td>Spiral 2 range</td>
<td>CIME range</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase beam intensity: level expected ?</td>
<td></td>
<td>Up to few keV/A for light ions</td>
</tr>
<tr>
<td><strong>Beam intensity [pps]</strong></td>
<td></td>
<td></td>
<td>Spiral 2 range</td>
<td>Spiral 2 range</td>
</tr>
<tr>
<td><strong>Targets used (type, form, activity…)</strong></td>
<td>Various targets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High power target 3 kW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thin Pd foil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Usual thick target</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Radioactive waste produced (solid, liquid, gas)</strong></td>
<td>Solid (new target material)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Beam losses (localization)</strong></td>
<td>CIME injection, ejection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduce beam emittance out of CIME</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Detectors : toxic matter used (fire, explosion …)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 6: INDRA

<table>
<thead>
<tr>
<th>Beams characteristics</th>
<th>Stable beams GANIL</th>
<th>Exotic beams GANIL + SPIRAL1</th>
<th>Exotic beams SPIRAL 2</th>
<th>Exotic beams SPIRAL2 post accelerated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams of interest for physicists</td>
<td>Medium mass (Zr, Mo, Ru, Pd, Te; Xe…) and heavy ions (Pd, U)</td>
<td>Post accelerated beams at higher energies</td>
<td></td>
<td>Post accelerated beams at higher energies Ar, Kr, Xe, Sn, Xe, Sn, Nd, p-rich nuclei, n-rich metallic, Ga, Ge, Zn, Ar</td>
</tr>
<tr>
<td>Energy range [MeV/A]</td>
<td>100 MeV/u medium mass 30 MeV/u (heavy ions Pd, U)</td>
<td>Higher energies 25</td>
<td>Higher energies 25 /100</td>
<td></td>
</tr>
<tr>
<td>Beam intensity [pps]</td>
<td></td>
<td>10⁸</td>
<td>10⁸</td>
<td></td>
</tr>
<tr>
<td>Targets used (type, form, activity….)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radioactive waste produced (solid, liquid, gas)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam losses (localization)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detectors : toxic matter used (fire, explosion …)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 7: INDUSTRIAL APPLICATIONS

<table>
<thead>
<tr>
<th>Beams characteristics</th>
<th>Stable beams GANIL</th>
<th>Exotic beams GANIL + SPIRAL1</th>
<th>Exotic beams SPIRAL 2</th>
<th>Stable beams SPIRAL2 post accelerated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams of interest for physicists</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy range [MeV/A]</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam intensity [pps]</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Targets used (type, form, activity…)</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radioactive waste produced (solid, liquid, gas)</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam losses (localization)</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detectors : toxic matter used (fire, explosion …)</td>
<td>Same as today</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dans le cadre des prospectives GANIL2015, nous présentons dans ce document nos réflexions concernant l'extension de la ligne d'ions super épluchés (LISE) dite LISE2000. Nous ne traiterons pas ici des motivations scientifiques de ce projet, ceci ayant fait l'objet de discussions dont les résultats sont accessibles [1,2].

I - Contexte

Dans ce contexte, nous proposons la modification de LISE2000 avec l'ajout d'une section de sélection en vitesse (Filtre de Wien) et d'un dipôle de sélection en moment. Ce couplage a été suggéré du résumé lors du meeting sur la fragmentation du 4 décembre 2008 [2] (voir la figure 1 de cette référence). La section de sélection en vitesse pourrait s'inspirer de celle existante sur LISE3. La section de sélection en moment pourrait provenir pour toute ou partie du spectromètre BBS (Big-Bite Spectrometer [3]) dont le programme scientifique auprès du cyclotron AGOR à KVI (Pays-Bas) pourrait s'arrêter à brève échéance. Des contacts ont été pris avec des physiciens locaux à ce sujet. Nous ne traiterons pas en détail dans cette note des aspects de dynamique des faisceaux ni des performances accessibles avec un tel système. Ces points ne pourraient être étudiés que dans un deuxième temps. Nous nous attacherons ici à une évaluation au premier ordre des coûts financier et humain, avec une indication des échéances temporelles possible.

La Figure 8 présente le schéma des aires expérimentales actuelles autour des salles D4, D6 (LISE2000 et LISE3) et D5 (INDRA).

Figure 8 : Schéma de principe de la zone sud-est des aires expérimentales du GANIL incluant les salles D4, D5 et D6. Les limites sud et est du bâtiment sont également précisées.
Toute extension de la ligne LISE2000 et la pérennité de la ligne LISE3 rend caduque la ligne de faisceau entrant dans la salle D5 (accès direct au multidétecteur INDRA). Cependant, il sera pertinent de conserver la séparation des salles D4, D5 et D6 afin de permettre, notamment, l’installation d’une expérience dans la salle D6 avec présence de faisceau dans la salle D5 ou inversement. De même, le cadre de l’adaptation de la salle D5 ayant pour but l’accueil du spectromètre BBS, la conservation de l’entité D5 permettra de ne pas stopper les expériences dans les salles D4 ou D6 durant l’installation. L’extension de la salle imposera le déplacement de certains murs et l’allongement vers l’est du mur de la salle D5, l’accès à cette salle étant alors déplacé (cf. Figure 9). La salle d’acquisition avancée (peu utilisée) attenante sera supprimée. Le mur sud des salles d’expériences n’est pas déplaçable plus au sud en raison d’une part de l’existence d’une galerie souterraine à la verticale du couloir de circulation ouest-est et d’autre part de la limite sud du bâtiment des aires (circulation du pont roulant). En termes de sureté et de radioprotection, il ne semble à priori pas nécessaire de faire d’évaluation spécifique, les niveaux radiologiques attendus devant être du même ordre de grandeur au maximum que ceux existant actuellement dans la salle D4. Une étude dédiée devra bien évidemment être menée en lien avec les services compétents en sureté et radioprotection du GANIL.

II – Extension de LISE2000

A partir de ces considérations générales, nous proposons une esquisse de l’extension envisagée (cf. Figure 9). Ce design doit avant tout être validé par la dynamique faisceau.

Figure 9 : Schéma de principe des aires expérimentales (salle D5) modifiées afin de prendre en compte l’extension de la ligne LISE2000.

A - Section filtre de Wien :

La section du filtre de Wien de LISE3 a été dupliquée. La distance entre l’entrée de cette section et le premier quadripôle est d’environ 1.2 m. C’est en ce point que pourrait se raccorder la ligne LISE2000 actuelle avec la section filtre de WIEN au point de fentes communes. La distance inter-quadripôle entre le dernier de LISE2000 (Q74) et le 1er du filtre (équivalent Q63) serait de l’ordre de 2.8 m. Cette distance devra être suffisante pour permettre des expériences nécessitant un temps de vol limité au bout de l’actuelle LISE2000. Dans cette hypothèse, on gagnerait très fortement à positionner les trois quadripôles d’entrée du filtre sur un banc déplaçable. Après études de dynamique faisceau, il pourrait être envisagé que ce banc puisse
également servir pour le filtre de LISE3 (petit intérêt en terme de coût d’éléments magnétique – 3 quadripôles : ~50k€). En considérant des propriétés optiques équivalentes en termes de focalisation après le filtre de WIEN, il pourrait être choisi une distance de focalisation de 2 m après le centre du dernier quadripôle du filtre (équivalent Q68). C’est en ce point que seront positionnées les fentes de sélection verticale du Filtre de Wien. Il faut ensuite construire une section de transport point-point (maille à trois quadripôles) de longueur environ 3.5 m. C’est au point image de cette section que sera localisé le point cible du spectromètre. Dans le design des deux sections d’adaptation du filtre et de la maille de transport, il sera essentiel de prévoir autour de ce point cible la possible installation de système de détection de grandes tailles comme MUST2, GASPARD, PARIS, EXOGAM, FAZIA, INDRA. Dans l’actuelle proposition, la distance entre le dernier quadripôle de la maille de transport et le premier de BBS est d’environ 1.9 m.

B - Section spectromètre:

BBS est un spectromètre disposé sur un banc tournant autour de l’axe de la cible (comme SPEG et VAMOS). Néanmoins, dans la configuration proposée, l’angle de rotation est limitée par la présence du mur sud de la salle D5 (rotation ~20°). A noter que ces considérations ne prennent pas en compte l’éventuelle modification de la structure du filtre de Wien compte-tenu des exigences scientifiques et des caractéristiques des noyaux mis en jeu (masses, rigidité…).

C - Ligne Arête-D5 :

Comme illustré sur la Figure 9, la ligne de faisceau entre l’arête et la salle D5 est supprimée, ceci n’impliquant aucune modification de structure particulière sur l’arête. Outre 2 dipôles, 7 quadripôles et 2 steerers, systèmes de pompage et détecteurs de profils de faisceau sont récupérés lors de cette opération. En particulier, la récupération des alimentations en courant de cette structure est intéressante. Cependant, certains de ces éléments étant connectés sur la grille de commutation du GANIL, il n’y a donc pas autant d’alimentations en courant rendues réellement disponibles.

D - Modification salle D5 :

L’insertion du spectromètre BBS implique une modification de la salle D5. Elle permettra en outre de disposer les baies d’électroniques associées à BBS et aux systèmes de détection. L’extension de cette salle impose l’augmentation de la surface au sol. Les modifications suivantes de la structure des murs sont à envisagées :

- Le mur Ouest de la salle D5 (séparation avec D4) est identique, seul est envisagé son déplacement vers l’est sur une distance de 2.2 m environ. Ce déplacement s’impose dans l’option d’un filtre identique à celui de LISE3 et le maintien de la salle D5 séparée de D4. La localisation de ce mur ne pourrait être faite qu’autour des quadripôles finaux de la section du filtre de Wien. Il sera néanmoins nécessaire de prendre en compte l’encastrément d’un ou de deux de ces quadripôles dans le mur. La contribution radiologique de ce point devrait être étudiée afin de s’assurer que le débit de dose dans D5 est limité quand il y a présence du faisceau dans D4 (avec une cage de Faraday ou bloc d’arrêt sur LISE2000 et/ou faisceau transmis en D6).

- Le mur Nord séparant D5 et D6 est concerné à deux titres. La petite chicane (dans laquelle le tube à vide du faisceau primaire vers D5 passait) pourra être supprimée (déplacement de ce tronçon de mur vers le sud). Le mur Nord délimitant D5/D6 et la salle d’acquisition avancé pourra être déplacé partiellement vers le nord sur environ 5 mètres de long et 1 mètre vers le nord. Le mur Sud est rallongé vers l’est d’environ 6 mètres.

- Le mur Est de la salle D5 étant déplacé vers l’est pour s’ajuster avec celui de la salle
D6, il y a un gain d’une longueur de l’ordre de 4 mètres sur ce mur. Cette longueur disponible sera employée pour le rallongement du mur Sud de la salle. Il restera à récupérer des 2 mètres manquant.

III - Investissements

A - Investissements financier

Les investissements à faire sur ce projet sont estimés en découplant les fonctions de sélection en vitesse (Filtre de Wien+maille point-point) de celle sélection en moment (BBS). La réalisation de la section filtre de Wien incomberait naturellement à GANIL qui dispose déjà d’une partie des éléments magnétiques et des alimentations en courant. Le spectromètre BBS provenant de KVI, il serait judicieux d’associer ce laboratoire pour la fourniture de toute ou partie des éléments de ce spectromètre : alimentations en courant, éléments magnétiques (quadripôles et dipôle), châssis, baies et électronique associées. Actuellement, un groupe de physique est intéressé par une utilisation de BBS à KVI pour des études sur les hyper-noyaux mais ce programme est en attente d’un financement européen. Il existe aussi un groupe de physiciens réfléchissant à la possibilité de se rapprocher de SPIRAL2 afin de monter un programme de recherche sur les noyaux exotiques. Des discussions sont en cours pour étudier leur intérêt dans le déménagement de BBS au GANIL.

Le coût du transport du spectromètre BBS est évalué autour de 50keuros (à préciser).

Pour la section du filtre de Wien, il faut potentiellement disposer de 6 quadripôles (2 de rayon de gorge 100mm, 4 à 140mm) et de deux filtres de Wien de 2.5 mètres de long. Nous rappelons que pour n filtres de Wien identiques, la dispersion en vitesse D varie comme n²D après le nème filtre à champ magnétique constant dans chaque filtre. Sachant qu’il est impossible d’avoir deux expériences simultanées sur LISE3 et LISE2000, les alimentations des quadripôles et des 2 dipôles du filtre ainsi que la plateforme haute tension du filtre de Wien seront utilisables par commutation de LISE3 à LISE2000. Ceci est à titre déjà le cas par exemple pour les quadripôles d’adaptation de LISE2000 (Q71 à Q74) avec ceux de l’adaptation en D4 (Q41 à Q44).

Une estimation du prix d’un quadripôle du type de ceux décrits plus haut est de l’ordre de 15k€. Le coût d’un Filtre de Wien, en tenant compte des éléments déjà existant au GANIL, a été estimé à 200 k€. Il peut être noté que le coût total de l’extension de LISE3 dans les années 1990 fut d’environ 200k€. Une re-normalisation au coût d’aujourd’hui devrait être logiquement appliquée. Une inflation de 3% sur 15 ans correspond à un accroissement de 50%, soit un total de 300k€. C’est l’option de base du projet. Une option consistent à mutualiser entre LISE3 et LISE2000 les sections d’adaptation (quadripôles) a aussi été envisagée.

Pour la section de transport entre le filtre et le spectromètre (maille point-point), il faut disposer de 3 quadripôles et du pompage (les alimentations provenant de la grille de commutation).

Pour le système de pompage de la section filtre de Wien, une réutilisation du système de pompage existant sur la section d’adaptation du faisceau de D5 est envisagée. Pour information, le coût d’une pompe type cryogénique est de l’ordre de 40k€.

Le coût de la section maille de transport entre le filtre et BBS est de 50k€. Elle prend en compte les éléments magnétiques et le pompage.

A ces investissements doit s’ajouter les câbles de l’ensemble des éléments : alimentations en tension et en courant, automate de LISE.
Le coût de la section "Filtre de Wien" est détaillé dans le tableau 1 :

<table>
<thead>
<tr>
<th>Filtre de Wien</th>
<th>Solution de base</th>
<th>Option 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 sections nouvelles et totalement indépendantes</td>
<td>coût</td>
<td>Nouveau filtre pour LISE2000 et Quadripôles partagés sur banc coût</td>
</tr>
<tr>
<td>2 Filtres</td>
<td>200</td>
<td>Nouveau Filtre pour L2000: 2 Filtres 200</td>
</tr>
<tr>
<td>6 quadripôles</td>
<td>90</td>
<td>Bancs transportables 50</td>
</tr>
<tr>
<td>Structure, chambre à vide…</td>
<td>50</td>
<td>Structure, chambre à vide… 40</td>
</tr>
<tr>
<td>Maille point-point</td>
<td>50</td>
<td>Maille point-point 50</td>
</tr>
<tr>
<td>câblage</td>
<td>50</td>
<td>câblage 50</td>
</tr>
<tr>
<td>Aléas (20%)</td>
<td>88</td>
<td>Aléas (20%) 78</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>528</strong></td>
<td><strong>468</strong></td>
</tr>
</tbody>
</table>

Tableau 1 : Évaluation du coût d'installation d'une section Filtre de Wien pour LISE2000

Pour la section spectromètre, nous avons aussi dégagé deux options. La première suppose la mise à disposition des seuls éléments magnétiques et de la structure. La deuxième suppose aussi la mise à disposition des alimentations en courant et du pompage.

Le coût de la section "Spectromètre" est détaillé dans le Tableau 2.

<table>
<thead>
<tr>
<th>Section spectromètre</th>
<th>Solution de base : Dispo spectromètre</th>
<th>Option 1 : Dispo Spectro+Alim+pompage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>50</td>
<td>Transport</td>
</tr>
<tr>
<td>Modification salle D5 (murs, sol)</td>
<td>30</td>
<td>Modification salle D5 (murs, sol)</td>
</tr>
<tr>
<td>câblage</td>
<td>50</td>
<td>câblage</td>
</tr>
<tr>
<td>détection</td>
<td>50</td>
<td>détection</td>
</tr>
<tr>
<td>pompage</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Alimentation</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Aléas (20%)</td>
<td>64</td>
<td>Aléas (20%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>384</strong></td>
<td><strong>216</strong></td>
</tr>
</tbody>
</table>

Tableau 2 : Évaluation du coût d'installation du spectromètre BBS pour LISE2000

Un coût total du projet compris entre 600 k€ (lignes d'adaptation communes entre LISE3/LISE2000 et récupération maximum de BBS) et 900 k€ (2 lignes totalement indépendantes et récupération minimum de BBS) peut être estimé.

B - Investissement humain

Concernant les besoins en personnel, l'évaluation a montré les besoins suivants (en hommes-mois) pour l'installation :

Étude : 3
Génie civil : 2
Électricité : 4
Installation : 8

Il pourrait être tiré profit de conserver l’existence de la salle D5 pour ne pas imposer l’arrêt durant une période trop importante des expériences sur LISE.
C - Planning

La première étape du projet sera l’étude approfondie de l’optique de ce dispositif afin de proposer un design complet de l’extension de la ligne. Les propriétés optiques seront confrontées avec les besoins scientifiques. C’est seulement après cette étude que pourra réellement être donné la pertinence du projet. 6 mois temps plein pour une personne sur la dynamique faisceau permettra d’obtenir des résultats satisfaisants.

Avant réception du spectromètre de KVI, les actions pourraient porter d’une part sur la réalisation du filtre de Wien et d’autre part sur la préparation de la salle D5 et ses afférents. Le temps de ces actions doit être de l’ordre de 5 mois. L’installation complète de BBS devrait prendre moins de 6 mois en espérant bénéficier du soutien d’experts techniques du KVI pour une petite partie de ce temps. En mettant ces temps bout à bout, le projet devrait pouvoir s’étendre sur 18 mois (cf. Figure 10) sachant que tout dépend du feu vert aux études de dynamique, des modes de financements, des engagements d’achats et de la collaboration avec KVI. L’arrivée du spectromètre doit pouvoir se faire quand la salle est prête et que les forces du GANIL sont disponibles durant cette période. Un démarrage théorique est possible pour octobre 2010. En incluant d’éventuels glissements jusqu’à 6 mois, pour un démarrage des études au second semestre 2009, il est plus raisonnablement envisageable un premier faisceau mi 2011.

<table>
<thead>
<tr>
<th>2009</th>
<th>2e trimestre</th>
<th>3e trimestre</th>
<th>4e trimestre</th>
<th>2010</th>
<th>1er trimestre</th>
<th>2e trimestre</th>
<th>3e trimestre</th>
<th>4e trimestre</th>
<th>1er trimestre</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>études</td>
<td>RÉALISATION FILTRE + PRÉPARATION SALLE + ACHATS</td>
<td></td>
<td></td>
<td>RECEPTION BBS + INSTALLATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 10: Planning du projet de la réalisation de l’extension de LISE2000

Annexe : Utilisation du Filtre de Wien D6 avec les faisceaux de SPIRAL2

Dans le cadre du réexamen du dossier de sureté du GANIL, il est nécessaire de définir les salles susceptibles de recevoir des faisceaux post accélérés de haute intensité. Dans cette optique, l’utilisation du filtre de Wien de la salle D6 est envisagée dans un mode FULIS par plusieurs Loi Spiral2. Afin d’une part d’éviter le transport des faisceaux radioactifs le long de l’ensemble du spectromètre LISE (et ainsi limiter les zones à “nucléariser”) et d’autre part de faciliter les procédures de réglage du filtre pour les réactions de fusion-évaporation, un accès direct au filtre de Wien de la salle D6 depuis l’arête de poisson est une option séduisante. Une illustration est proposée sur la Figure 11 ci-dessous. Il est important de noter que cette ligne directe arête-D6 implique une redéfinition des salles D4 et D6.

Figure 11 : Schéma de principe des aires expérimentales modifiées pour prendre en compte les faisceaux SPIRAL2 sur LISE.

La solution que nous proposons n'a pas fait l'objet d'étude plus poussée. La ligne de faisceau SPIRAL2 nécessite l'emploi de deux dipôles à 45° raccordée derrière un triplet de la maille de transport de l'arête de poisson du GANIL. La grosse difficulté est sans doute l'adaptation du faisceau après la déviation. Il est nécessaire de disposer de 4 quadripôles. D'après le schéma, la localisation du premier doublet ne peut se faire que directement après le 2ème dipôle à 45°. Le deuxième doublet est commun avec la déviation achromatique. Deux contraintes se dégagent dans cette adaptation, d'une part la grande distance entre les deux doublets et d'autres part la taille de la chambre à vide dans le 2ème dipôle de la déviation achromatique. Des études de dynamiques faisceaux doivent impérativement être menée afin d'envisager la coexistence des deux lignes de faisceaux.

Possible suggestions for a short and long term future at GANIL

Participants:
A. Navin, S. Grevy, M. Rejmund, A. Chbihi, R. Raabe, G. de France, J.C. Thomas and Olivier Sorlin

The two main conclusions of the GANIL2015 workshop held on October 23-24, 2008 to discuss the future of GANIL appeared to be as follows:

- The optimal use of high intensity SPIRAL2 beams with fusion or transfer reactions and to exploit the uniqueness of these facilities along with new detector development.

Figure 12: The possible scenario for the evolution of facilities at GANIL. The new facilities shown require proper planning and design based on the physics case to be defined by an interested and dedicated community at GANIL. The possibilities shown here are one representation for the future based on various discussions held.
• The need to plan a long-term future at GANIL based on its traditional domains of expertise coupled with unique beams from SPIRAL2. The utilization of the intense beams of fission fragments from SPIRAL2 to be accelerated and used for projectile fragmentation, compatible with the planned direction of EURISOL. The physics goals obtained by such a plan at GANIL visa viz. other facilities in the world should be studied in detail.

The figure represents the GANIL facilities as seen by this working group, addressing the above described goals. The road map presents the evolution of GANIL facilities and the necessary developments to assure its worldwide leadership and its compatible with the roadmap for European facilities like the future EURISOL facility.

**Fragmentation:**
- GANIL continues to deliver high energy stable beams suitable for fragmentation. A spectrometer behind LISE/CLIM should be installed at the highest priority by 2011, both for an immediate and varied exploitation of the fragmentation at GANIL. This in the long run could be a more optimum solution than the replacement of SISSI by an identical device or a technically difficult solution of an upgraded version of SISSI. The presented scenario does not require the fragmented beams in all experimental halls at GANIL.
- SPIRAL2 beams should be post accelerated by a new accelerator to energies greater than 100 MeV/u. Such a project can commence after the successful completion of SPIRAL2 in 2015.
- This new accelerator could also replace CSS1/CSS2 for the acceleration of stable beams.
- LISE separator should be upgraded to accept optimally the fragmentation of fission fragment beams.

**SPIRAL1:**
- GANIL continues to deliver low energy radioactive beams from SPIRAL1; ion source and beam development should have a high priority and independent of the priorities for SPIRAL2.

**SPIRAL2 (low energy radioactive beams):**
- VAMOS spectrometer should be used for low intensity beams, while for the high intensity beams radioactive ion beams requires the construction of a new beam line at 45 degrees (fusion, transfer …).
- As high intensity beams 0 degree operation for high intensity radioactive beams is not possible a new spectrometer/separator for 0 degree operation should be installed (in operation 4 years after SPIRAL2 startup, i.e. ~2017)

**Portable multi-detector systems (EXOGAM, AGATA, MUST2, INDRA, FAZIA, PARIS, GARFIELD, …)**
- Special care should be taken during the design studies to include the capability of coupling (space, infrastructures …) with the existing and new spectrometers to be able to achieve the planned physics cases in an optimum manner.
- In case of absence of the specific area for a stand alone operation the space in front of the spectrometer should be used. (with spectrometer unused)

The present plans try to make a judicial choice of using existing facilities with the building of the next generation facilities. As we are also talking about a long-term future piecemeal improvements may not be the optimum choice.
### 6. APPENDIX N°6 : List of the meeting

<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Group(s)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 16</td>
<td>Core Group</td>
<td></td>
<td>University Paris VI, VII</td>
</tr>
<tr>
<td>June 10</td>
<td>Open Meeting</td>
<td></td>
<td>Giens</td>
</tr>
<tr>
<td>June 23</td>
<td>Core Group</td>
<td></td>
<td>IN2P3</td>
</tr>
<tr>
<td>August 29</td>
<td>Core Group</td>
<td></td>
<td>IN2P3, by telephone</td>
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<tr>
<td>October 23-24</td>
<td>Open Meeting</td>
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<td>GANIL</td>
</tr>
<tr>
<td>Nov 21</td>
<td>Core Group</td>
<td></td>
<td>IN2P3</td>
</tr>
<tr>
<td>Dec 4</td>
<td>meeting on fragmentation beams</td>
<td></td>
<td>GANIL</td>
</tr>
<tr>
<td>Jan 29</td>
<td>meeting on separator/spectrometer</td>
<td></td>
<td>Caen</td>
</tr>
<tr>
<td>Feb 16</td>
<td>Core Group + cluster coordinators</td>
<td></td>
<td>IN2P3</td>
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<tr>
<td>March 2</td>
<td>Core Group + SC + SP2-SAC</td>
<td></td>
<td>GANIL, by telephone</td>
</tr>
<tr>
<td>March 9</td>
<td>Open Meeting</td>
<td></td>
<td>GANIL</td>
</tr>
<tr>
<td>March 23</td>
<td>Core Group</td>
<td></td>
<td>GANIL, by telephone</td>
</tr>
</tbody>
</table>
ORGANISATION OF GANIL 2015 PROSPECTIVE

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