Report of the GSI NUSTAR PAC

The GSI NUSTAR PAC met on June 14-16, 2004 to consider 12 Letters of Intent (LOIs) for research in nuclear structure, astrophysics, and reactions at GSI when the new capabilities are in place. In this report, we summarize our findings.

They consist of a summary Table of ratings of the scientific, technical and collaborative aspects of each LOI, according to 4 categories, **A, B, C,** and **D**. These are defined below. In addition a short commentary on each LOI in included.

We stress that the Table gives **ratings, not rankings**. **We make no distinction between various LOIs given the same rating**. (Example: if two LOIs are given straight across A ratings, there is no implied priority to that one listed higher.) Moreover, we also stress that these are ratings of the LOIs **as presented** in writing and verbally to the PAC. Thus, a lower rating (say, a B) does not necessarily imply a lower scientific assessment or a significant technical issue. It may well be that such a rating simply reflects the fact that the PAC felt that the scientific case was not convincingly made in the existing LOI or that questions or uncertainty arose regarding some technical point. We view the point of the present assessments as giving guidance to the LOI collaborations in their further work towards more formal proposals. A lower rating should therefore be viewed in the context of the accompanying texts and may, in some cases, be a message that further justification of the proposed research is a priority.

We do not reject any of the 12 LOIs. (That would correspond to a rating of D, which does not appear in the assessments.) Ratings of C, though, imply considerable concern on the part of the PAC and suggest the need for serious evaluation by the LOI concerned as to how to proceed.

It is important also to note that all these LOIs are preliminary documents and none are complete. For example, all are in need of quantitative simulations and better estimates of count rates, backgrounds, contamination, needed beam intensities, and the like. It is natural that this should be the case at this stage. Since this need applies to essentially all of the LOIs we make this comment here and, generally, unless it is felt to be a particularly serious issue, we do not repeat it in each commentary. Largely the same comment applies to the need for firmer cost estimates.

Generally speaking, the category of Science refers of the physics goals and motivation for the research proposed. It takes into account the intrinsic interest of the science and its likely impact on the field, the link established in the LOI between the observables measured and the physics to be extracted, as well as the uniqueness of the science, its suitability to what will be the new research program at GSI, and the likelihood that it may be done elsewhere. The Technical category refers to all the experimental facets, including feasibility, quality of the data, ease or difficulty of analysis, compatibility with the GSI CDR, and so on. The category Collaboration refers to our perceived "quality" of the collaboration where this may refer to whether the collaboration is well defined, whether clear goals and responsibilities are established, whether leadership is in place, and/or whether there are gaps in the expertise needed to carry out the research. The overall rating gives our assessment of the LOI as a whole. It is not simply a product of ratings. Indeed, more weight is given to the scientific and technical aspects and, needless to say, a poor scientific rating cannot be saved by excellent technical feasibility.

It is difficult to define the ratings in a couple of words, and the reasons for equivalent ratings (say, Bs for the science) in two LOIs may be quite different. Broadly speaking, though, one may think of the ratings according to the following guidelines.

A Excellent. Note that this does not mean there were no issues of concern to the PAC, but that none were considered likely to impact the scientific quality or technical feasibility of the project. Again, even for those LOIs with A ratings, quantitative simulations, and more detailed design work, is obviously needed.

B This category is the most difficult to define. Clearly, it implies a lower assessment than A. Again, we stress that the motivation for this assessment may reside in the science or technical aspects themselves, or in the cases made for them in the LOI. Generally, a rating of B implies that the PAC felt that the scientific case, as presented, was not as compelling as for an A rating, or that technical aspects need to be resolved before a reliable assessment of feasibility can be made. A rating of B may well become an A rating following further work on the part of the collaboration involved.

C Scientific or technical issue of significant concern. This may be a substantive problem or simply reflect the need to make a more convincing scientific case or technical demonstration of feasibility. The collaborations receiving C ratings should carefully consider whether and how to go forward with their proposals.

D Scientifically flawed. Such a rating would be serious grounds for rejection of an LOI.

The table below contains other notations as well (briefly summarized in its footnotes). A rating of **A-B** means that part of the LOI was given an A rating and part a B rating. The respective parts are indicated in parentheses after the letter rating.

The notation **A/B** denotes that the PAC was divided in its opinion on the merits.

Finally, lower case footnotes **a, b,** and **c** link LOIs that the PAC felt should explore the possibility of joining together, or at least mutually defining their respective priorities and focus areas.

The Table is given below, followed by brief commentaries on each LOI.

NUSTAR PAC
June 14 – 16, 2004

Ratings of LOI’s: Not RANKINGS
LOI’s with equal ratings are not rank ordered

LOI	Science	Technical	Collaboration	Overall*
R^3B	A	A	A	A [a)]
EXL	A	A	A	A [a)]
ILIMA	A	A	A	A [b)]
LASPEC	A	A	A	A
HISPEC	A	B	A	A (Int. En.) – B (Low En.)
DESPEC	A	B	A	A/B
ELISE	A	B	A	A/B
MATS	A/B	B	A	B [b)]
Exo - $\bar{p}$	B	B	A	B [c)]
NCAP	B	B	A	B
$\bar{p}$ - A	B/C	C	C	C [c)]
PIONIC	C	B	B	C

***: Primary weight given to scientific and technical aspects**
A: Excellent
B: Very good, some problems need to be addressed
C: Technical problems or need to establish scientific case better
D: Scientifically or technically flawed
X-Y: Ratings apply to different parts of LOI
X/Y: PAC divided on merits
a, b, c: LOI’s should explore possibility of joining together

HISPEC

This LOI proposes to study the structure of exotic nuclei through high resolution gamma and particle spectroscopy of the isotopes produced at the super-FRS. This study would use multiple Coulomb excitation, direct reactions and compound reactions at barrier energies as well as single step Coulomb excitation and fragmentation reactions at intermediate beam energies. The physics goals are excellent. The collaboration is extensive and expert.

The two beam energy regimes need to be considered on different footings.

Near the barrier:

The proposal could indeed benefit from the short-lived nuclei and refractory nuclei that will not be available from typical RNB facilities based on the ISOL method. But at the Coulomb barrier these beams may not have the required qualities for high resolution in-beam studies and will need beam tracking and identification devices well adapted to low energies (down to few MeV/A) and to relatively high counting rates (as high as 10^7p/s). The collaboration should detail the planned R&D for the beam tracking and identification detectors. Developing such beam diagnostics is a strong recommendation for the future of this project. Using beams from the NESR will not suffer from this beam quality limitation but will lose the advantage (with respect to ISOL facilities) of access to the shorter lifetime nuclei.

At Intermediate energies:

This case is more straightforward and the collaboration should be encouraged to proceed with a detailed design study for the gamma and particle detector arrays, with the dipole magnet (ALADIN) and its focal plane detectors. Limitations (if any) due to different backgrounds, feeding, etc. should be investigated.

DESPEC

This LOI aims at decay measurements of fully stopped exotic nuclei. The main goal is to provide nuclear structure and decay information for r- and rp-process nucleosynthesis by nearly complete spectroscopy including lifetime measurements as well as β-delayed particle and gamma spectroscopy. Short lived (μs) proton, alpha, and gamma emitting isomers provide key benchmarks for shell evolution and residual interactions. The proposed studies will provide access to isotopes in the μs range and will therefore expand on the experimental possibilities of ISOL facilities.

The LOI is based on the development of a new detector system including a DSSD for p, α, and β detection, a Ge-detector array for γ spectroscopy, and a neutron detector array for high resolution neutron spectroscopy. These detectors will be supplemented by a BaF2 detector array for lifetime measurements in the 10 ps range. The DSSD design is pretty straightforward and is based on the design of similar systems at other RIB facilities. For the Ge-detector system an array of planar Ge has been proposed. However, simulations should be developed to show that the choice of planar Ge detectors provides optimal conditions. No design is available or has been proposed for the neutron detectors. A detailed design should be developed. Also not clarified is the geometrical positioning of the BaF2 detectors. The collaboration could investigate the option of beta decay measurements following mass separation of products stopped in the gas catcher.

The collaboration reflects considerable experience which is very promising for the successful implementation of the project. However, at the present time the role, responsibility, and contributions of the different collaborating groups is not clearly identified. There is no clear lead institution but in principle sufficient experience and expertise is available in the participating groups. It is felt that the cost estimates might be too optimistic.

MATS

Mass measurements of exotic nuclei are a sine qua non for probing the structure and binding of exotic nuclei. MATS is a LOI for high precision measurements, approaching 10-8 in accuracy. Such high accuracy is necessary for tests of the isobaric mass multiplet equation, for tests of unitarity of the CKM matrix and for the resolution of close-lying isomers. However, the LOI does not specify further where the high mass precision is needed for nuclear structure purposes. For fundamental studies, tests of CKM unitarity also require precise branching ratio and lifetime measurements and therefore are limited to cases where such data will be forthcoming. In further developing this LOI, the collaboration should therefore focus on defining better the physics case for nuclear structure, astrophysics and fundamental studies with MATS, in particular identifying where ultra high precision masses are needed. In this way, the uniqueness of this LOI and complementarities to the ILIMA LOI will be clarified.

The MATS trap technology is state-of-the-art, as known from transfer from ISOLTRAP at ISOLDE. There is competition with the new EBIT based program at ISAC but this latter is limited to isotopes available with the ISOL method.

The range of lifetimes accessible depends on the charge breeding time, the trapping time and the number of ions trapped. In general, the LOI shows that one can expect precise masses for nuclei with lifetimes in the tenths of seconds range and higher. In many cases where the highest mass precision is not essential for physics reasons, the efficiency and speed of ILIMA may be the preferred approach for such studies. The method of carbon cluster calibration in this LOI removes systematic uncertainties and is absolute standard for all mass measurements.

The technique requires reasonable efficiency (<1%) and speed of extraction for the gas catcher. Injection and trapping of highly charged ions is an issue for that will enhance efficiency and accuracy of mass measurements.

The collaboration is an excellent one from the ISOLDE flagship ISOLTRAP program and is supported by universities local to GSI (*e.g.*, Mainz).

LASPEC

Measured ground state properties yield valuable information on sub-shell structure and orbit occupation, deformation/shape and charge radii -- the latter also being an important complementary input for the evaluation of matter radii in terms of the neutron radius. Scientifically, the proposal addresses key topics of nuclear structure such as shell and shape evolution far off stability towards the driplines.

The RIS and CLS techniques are well established methods and there is abundant expertise accumulated within the collaboration. With the limitations in yield, nuclear half life, sensitivity and resolution as given in the LOI, it is recommended that both methods should be implemented. MOT, with a great potential of development in the years to come, will probably be restricted to a few high precision experiments addressing physics beyond the standard model. EBIT experiments will probably be performed at a later stage elsewhere. The method proposed in this LOI fit perfectly into the half-life gap of ms to hours between the perturbed angular distribution and atomic beam methods.

While at the Super-FRS LEB, full coverage of all elements is possible, the proper selection of specific cases such as the refractory elements is warranted by the fact that the groups involved are also working at ISOL facilities with identical setups that can be easily transferred to the LEB. As behind the LEB and after re-acceleration the experimental situation is completely analogous to ISOL facilities the need for further simulations and design studies are modest.

The cost estimate is given only for CLS. Implementation of MOT and EBIT at a later stage may increase costs by a factor of 2-3 if not shared with other projects. The re-acceleration including ionisation, mass separation, bunching, and cooling is not included or largely underestimated in the cost estimate. Likewise the space requested does not account for these devices. The interface between the Super-FRS LEB facility and experiment should be clearly defined. The time schedule for RIS and CLS is reasonable.

Generally, the synergy between the various laser systems, experimental setups/beamlines envisaged around FAIR/LEB, including a laser beam transport system, should be exploited where possible.

The collaboration is encouraged to present a fully developed proposal addressing the points mentioned above. A working schedule for implementation of EBIT and MOT should be given. As far as a high-precision MOT experiment is concerned, a separate proposal would be appropriate.

NCAP

The NCAP LOI is concerned with the measurement of neutron capture cross sections on long-lived radioactive nuclei near the line of stability. These reactions play an important role as s-process branching points. The measurement of the reaction rates will provide important information about temperature, density, and neutron flux condition in AGB stars for the s-process. The scientific question is of great relevance in particular in view of the recent progress in the Cosmochemistry of meteoritic inclusions resulting from AGB star (planetary nebulae) condensates and the theoretical progress in AGB star nucleosynthesis modeling. Reliable nuclear physics data are of great interest for testing or interpretation of the s-process site and nucleosynthesis.

The proposal addresses two modes of operation -- implantation of long-lived radioactive species with off-site neutron activation and implantation of isotopes with halflives of less than 1 day with on-site neutron activation. The second part requires the construction of a 3 MeV high-intensity proton generator.

The LOI proposes on-line implantation of radioactive isotopes in thin C foils with subsequent neutron capture measurements. After implantation the target is irradiated by low energy neutrons which are produced by the 7Li(p,n) reaction at 2-3 MeV proton energy. A 4π BaF2 detector array is used to measure the gamma summing signal with nearly 100% efficiency. The technique is state of the art for s-process measurements and has been developed and tested by the collaboration at existing facilities at FZK Karlsruhe, n-ToF CERN, and LANSCE, Los Alamos.

The group is doing similar work elsewhere and a number of long lived cases may, in fact, not require the use of GSI. However, this LOI can take excellent advantage of the new GSI capabilities, especially for short lived and/or refractory nuclei, provided that a 500 kHz pulsed high intensity 3 MeV proton accelerator with up to 20mA beam is installed on-site. However, documentation of which cases are unique to GSI capabilities would solidify the scientific justification. The facility requires a special location near the actual implantation site on account of the short transport times. One problem might be the proposed short 4 cm neutron flight path. Test experiments with stable targets at the FZK facility will be performed to confirm that the short flight path conditions are sufficient. Additional space is also necessary for the 4π BaF2 array. In view of the extremely short flight path and the possible limitations for the experiment, GEANT simulations for (n,γ) measurements with the proposed set-up are desirable. Another issue is the presence of contaminant beams. It will be necessary to demonstrate that sufficiently clean beams can be obtained.

The proposal is not very specific about the choice of accelerator. The plan is to purchase a small electrostatic machine. Since proton beam resolution is not an issue it might be interesting to explore the possibility of a small RFQ/LINAC proton accelerator. This could be developed in collaboration with the GSI/Frankfurt accelerator group.

The collaboration is well experienced and the group reflects the core members of the n-ToF collaboration. However the specific role of the various collaborators is not clearly identified. The lead institution is the FZK Karlsruhe. The group is a worldwide leader in s-process measurements. The local facilities are excellent to perform the necessary tests and measurements for optimizing the experimental conditions for the NCAP LOI.

The first test experiments with long-lived targets will not require any specific modifications for the facility since the actual neutron capture studies will be performed off-site using the FZK neutron beam. More detailed information should be provided about the beam intensity for the proposed isotopes. R&D will be performed at existing facilities.

Exo-pbar

The objectives of this LOI are the study of anti-protonic radioactive nuclides and the extraction of information on proton and neutron distributions. The idea is very interesting and challenging, and this should be a unique program in nuclear physics. However, the methodology how to use pbar as a probe for studying proton and neutron distributions (not only the radii) is not well developed and should be verified with stable nuclei. The definition of the surface region and the relation between the observables and the surface nucleon distribution needs to be better understood. Exclusive measurements could lead to such distributions, but need also detailed investigations of the annihilation process, which can be investigated at CERN at this moment. Since the trapping of both anti-protons and radioactive nuclei are already possible technologically by the group, it should be encouraged to refine the proposal and also to begin the experiment with examples that are currently possible.

There is also a need for an implementation of X-ray measurements. It might be better to set up the facility at the low-energy atomic physics line (pbar) for pbar trapping. A description of a realistic experimental setup, and the background estimate with it, is needed. For instance, it is not mentioned how to set x-ray detectors in the close geometry under strong backgrounds from the annihilation process. The π^0 particles have to be measured to deduce more information than just radii. The setup needs to implement this capability as well.

The collaboration is expert and most parts of the LOI can be done with the present members.

R3B

This LOI aims for a versatile reaction setup for optimized efficiency, acceptance and resolution for kinematically complete measurements of reactions with high energy radioactive beams from the super-FRS. It contains several proposals for nuclear structure studies at the drip lines using different approaches: Total absorption measurements, elastic scattering, knock-out reactions, quasi-free scattering, electromagnetic excitation, charge exchange reactions, fission and multifragmentation reactions.

This proposal is the most natural LOI for nuclear structure studies at the future GSI facility. It uses the in-flight nature of the produced radioactive beams and takes full advantage of their high energies. It is well adapted to explore nuclei very far from stability and sometimes at the border and beyond the drip lines. Most of the detectors and spectrometers of the HEB are new. This project is one of the most advanced LOIs presented to the NUSTAR PAC. The physics programs rely very much on the specifications and performances of the detectors and spectrometers set-up. An update and follow-up with a more detailed design study, especially for the total absorption gamma array and the high resolution spectrometer should be done. The collaboration is excellent and well organized. At the present stage, the cost estimates seem to be reliable.

ILIMA

Mass measurements of exotic nuclei are fundamental. ILIMA is an LOI for precision measurements, with accuracies around 10-6, that can be applied to many radionuclides simultaneously. The limit of applicable nuclear lifetimes is microseconds for the isochronous mode in the CR and seconds using Schottky pickup in the NESR. Complementary to this, the mass resolution and accuracy are higher in the NESR. The LOI also plans to measure lifetimes of exotic nuclei and to make isomeric beams by exploiting the mass differences from the ground state.

The ILIMA technique is state-of-the-art and highly efficient. The collaboration has a wealth of experience from present ESR measurements. The CR measurement requires technical development. Neutron-rich nuclei farthest from stability require reasonable efficiency for injection into NESR. The resolution should be adequate for many isomeric levels but not in the cases of close-lying isomers. Absolute calibrations from other sources, such as MATS, are important.

EXL

The key issues of EXL are: matter distribution, in order to obtain proton-to-neutron asymmetry, giant resonance strengths, which could be very different from those presently known, single particle structure, deformation, and other nuclear structure information of unstable nuclei. This information is obtained via nuclear reactions involving light targets (p,d,^{3}He, ^{4}He) in inverse kinematics. The reaction channels to be measured in this proposal are: elastic, inelastic, transfer, charge-exchange and quasi-free scattering. The experiments are performed in the storage ring NESR. The most interesting aspect is, no doubt, the fact that this would constitute the first experimental study involving nuclear reactions using heavy ion storage rings. The physics program is partly complementary to R3B when, in reactions involving low momentum transfer, the recoil energy obliges the use of thin targets. Some overlap exists when this condition is not fulfilled. This means that, in principle, the same reaction could be measured by R3B and EXL. Nevertheless, it is worthwhile obtaining the same information using such different techniques.

The experimental developments needed for the project are: i) Target recoil detector with mainly Si-strip and CsI, ii) Gamma-ray and neutron detectors around the target, iii) adaptation of some elements of NESR in order to work as a spectrometer for projectile-like fragments and iv) projectile recoil detectors for the spectrometer.

The collaboration has the needed expertise in the physics field. Concerning the storage ring aspect, GSI is the best place in the world for proposing such a scientific program and has the technical expertise. The cost seems to be reasonably estimated in this stage of the project.

This proposal implicitly uses parts of the NESR ring as a spectrometer. Thus, this issue should be considered in the design of this ring. No simulations, in particular concerning beam optics, have been presented.

It is strongly recommended that realistic tests of this method are performed with stable nuclei in the present ESR storage ring.

ELISe

This is a proposal with clever objectives, based on the very successful results of electron scattering experiments. The most important physics issues would be the measurements of nuclear charge radii, moments, charge density distributions and spectroscopic factors for unstable nuclei. Electro-fission data for unstable nuclei would also be obtained for the first time. The reaction channels, which would be studied, are elastic, inelastic and quasi-free scattering. Another interesting aspect of this technique is the possibility to obtain kinematically complete data, allowing a clean separation of all reaction channels for the first time. This is also interesting for stable nuclei experiments.

The experimental developments needed in this proposal are: i) the eA collider, ii) the electron spectrometer and focal plane detectors, iii) heavy ion spectrometer and focal plane detectors (same of EXL).

This proposal implicitly uses parts of the NESR ring as a spectrometer. Thus it is important to consider this in the design of this ring. The luminosity of the collider needed for this kind of experiment was estimated to be of the order of 10^{28} cm^{-2} s^{-1}. The committee was concerned that the technique may not be widely applicable due to luminosity limitations and would like to have a reliable estimation of the regions of nuclei where the required luminosity is achievable.

The collaboration has the needed expertise in the physics field. Concerning the storage ring aspect, GSI is the best place in the world for proposing such a scientific program and has the technical expertise, together with Novosibirsk colleagues. The cost seems to be reasonably estimated in this stage of the project and is basically given in the CDR.

PbarA

Although this proposal is intriguing, it is premature and minimally defined in many aspects. The authors are proposing to measure exclusively the absorption processes of pbar with short-lived nuclei. Momentum distributions of protons and neutrons in the nucleus would be deduced from the recoil momentum distributions following annihilation. It is not discussed how to deduce the physical observables from the measurements or what kind of accuracy is needed for each detector. Moreover, while the proton and neutron radii are of interest, their spatial distribution, as sought in the Exo-Pbar LOI, would provide more useful information. In the analysis of momentum distributions to infer spatial proton/neutron distributions, cascade reactions of, for example, pions created in the annihilation process could mask the information.

Detailed design and simulation studies are strongly advised to determine if this LOI should proceed further. The idea is interesting but no collaboration exists at present and this LOI should proceed only upon establishment of a strong collaboration group for all aspects of the project and upon a satisfactory answer to the technical and physics questions.

Technical Question: Can the e-storage ring be modified to use as a pbar storage ring?

PIONIC

This LOI aims to produce pionic atoms in inverse kinematics by the reaction d(RI,3He)RI*pi, taking advantage of the production of RI's of long isotopic, neutron rich, chains at FAIR. The goal is to determine the degree of chiral symmetry restoration in the nuclear medium. The measured quantity is the Q-beta value of the reaction, i.e. the binding energy of the pionic levels. It is not clear whether this information could, or not, be supplemented, at least in some cases, by the measurement of the pionic X-rays.

The topic is undoubtedly interesting. However, it would be important to know the opinion of the hadronic physics community on the validity of the conclusions that could eventually be extracted in these experiments. Along that line, the link between the Q value and the optical potential needs to be better explained. The difference between the neutron and proton densities as a function of r is needed as an input and does not come out as a result. In general, more theoretical input on the relation between the observables and the physics seems to be needed.

There are also some technical questions concerning the energy deposited in the target.

The collaboration is narrowly based. The proposal does not seem to demand special new equipment.

A more elaborate project, including benchmarks of the methods in simpler cases and improving the theoretical modeling of the process, would offer the possibility of a better scientific and technical justification of this LOI.