Minutes of the
Meeting of the Executive Committee of the EURISOL Users Group (UEC)

Valencia, March 11th, 2019

Present: Didier Beaumel, Angela Bonaccorso (NUSPRASEN observer), Giacomo De Angelis, Lidia Ferreira, Adam Maj, Riccardo Raabe (vice-chair), Berta Rubio (chair), Haik Simon
Part-time via video: Ian Moore
Excused: Maria Borge

Agenda

1. Approval Minutes of the Pisa Meeting
2. Update of Eurisol DF progress (Berta or Marek via Skype)
3. Short Summary on the Pisa Town Meeting and proceedings (Angela/Berta)
4. Lisbon Proceedings (Lidia)
5. FAIR-EURISOL meeting in Autumn (Berta)
6. NUSPRASEN (Angela)
7. Progress with the new database (Riccardo)
8. How to proceed with the elections (all of us)
9. AOB

1. Approval Minutes of the Pisa Meeting

The minutes are approved without changes.

2. Update of EURISOL DF progress (Berta or Marek via Skype)

BR presents a few slides (most of them from Marek Lewitowicz).
EURISOL DF has originated from and is promoted by the EURISOL Steering Committee (SC). The general structure/idea of the initiative and its timeline are briefly recalled. The submission to ESFRI should be some time in 2019 (possibly August if the next ESFRI Roadmap will be in 2020 as announced; but the exact deadline is not known yet). The ESFRI review and decision should take an additional year after the submission.
The Executive Summary of the "EURISOL Distributed Facility Project" in our hands is from Feb 21, 2019 (in the attachment); some details (for example the foreseen budget for upgrades per partner) has changed in a later version. However, the whole document is still being revised and discussed. Gerda Neyens had a meeting with Eckhard Elsen, Director for Research and Computing of CERN, as a consequence of this meeting Elsen wrote a series of comments, questions. The SC already answered to some remarks made by him, with whom a meeting will be organised to discuss the document further (BR will try to be present).

A discussion followed in the UEC, touching several important points:

- The nature of EURISOL DF: legal entity, or not?
  Application to ESFRI requires a legal entity.

- The foreseen structure for the submission of proposals for experiments at EURISOL DF (i.e. at more than one facility), with one “SuperPAC” and the local PACs.
  One-stage or two-stage procedure? What is the added value of the SuperPAC? The details are not clear and probably we will need a testing period (for example in a preparatory phase). The procedure should help users and not be an additional administrative burden. The management of detection setups is given as an example of something that could benefit from the coordination by a DF “super-structure”.
- Support from funding agencies of at least three countries.
  This is a point of concern as it does not seem to be secured yet.
- Role of the UEC.
  As representatives of the users, we have helped defining the scientific objects of the project through the Lisbon and Pisa meetings. We will continue doing this with similar initiatives in the future. In addition, we will monitor the developments of the project with respect to the interests of the users.

ACTIONS:

- **We will suggest to the SC to promote EURISOL DF with a publication in Nuclear Physics News and offer our help/support for the realisation of the article.**
  Timing: after the full definition of the project (after the summer?).
- **Organise a meeting with the NUSTAR community (see below).**

3. Short Summary on the Pisa Town Meeting and proceedings (Angela/Berta)

AB: The Pisa Town Meeting (2-4 July 2018) was about the progress of the EURISOL JRA, plus a couple of physics topics for EURISOL DF (The r-process and related neutron rich nuclei, Reactions with Radioactive Beams).
The document is ready, with the contribution of the speakers. It can be printed with the NUSPRASEN funds.

6. NUSPRASEN (Angela)

Within ENSAR2, money for EURISOL networking was diverted from the JRA to the NUSPRASEN Network Activity. There are still enough funds available to print the Lisbon and Pisa proceedings, and probably to organise another meeting.
An interesting possibility is a joint meeting with NUSTAR. The NUSTAR week is in September 23-27, in Gif-sur-Yvette, France. Contacted, Marek Lewitowicz (EURISOL SC) and Yorick Blumenfeld (EURISOL JRA) are positive about the idea. After further discussion, it was decided to wait with this initiative until the status of EURISOL DF as ESFRI proposal is clarified (see further, point 5).
What about ERINS (the follow-up of ENSAR2)? As Ian Moore confirms, there is no networking activity supporting EURISOL in ERINS. This is a point of concern for the future.

4. Lisbon Proceedings (Lidia)

The proceedings are ready. Lidia presents the foreword; details of the front matter and editing are discussed.
We will print these proceedings and the ones from Pisa with the NUSPRASEN money. For the distribution we will try to use meetings to contain costs.

5. FAIR-EURISOL meeting in Autumn (Berta)

The opportunity of a joint meeting is summarised in a slide from Marek. The motivation is strategical in view of the support for EURISOL DF. As UEC we are mostly interested in the physics motivations. We agree that a two-side approach should be carried out: the UEC towards the NUSTAR community and users, the SC towards the FAIR/NUSTAR management. However, in view of the uncertainties regarding the three countries signatories of the ESFRI application in summer, the committee felt that that it was too early to start organising the meeting in Fall. So, no action will be taken for the moment.

8. How to proceed with the elections (all of us)

Charter rule: every 2nd year half of the committee members should be changed: 4 or 5 members, alternatively. However, 7 of the present members are new.
Thus: the two members who have served for a longer term (LF and AM) will step down. Of the other seven members, 5 will be confirmed (by vote of the users). Four new members will be elected among a list of new nominees. There is also a rule stating that each country should not have more than two representatives. After the elections, a new chair and vice chair will be elected by the EC.

We will proceed as follows:

- Launch a call for nominations through the EURISOL user email list. The email should clearly explain the rules (see AB's email from 2016 as an excellent model). Timing: a week after this meeting; collect nominations for about a month.
- Check with nominees, if they confirm their availability.
- Launch the voting procedure. There will be two lists:
    - The seven members who could continue in the UEC (DB, MB, GDA, IM, RR, BR, HS). Voters can select up to 5 names.
    - The lists of new nominees. Voters can select up to 4 names.
- Count the votes:
    - The five persons with the most votes from the first list will be elected.
    - The candidates from the second list will be ranked according to the number of votes, from largest to smallest. Starting from the top of the list, a candidate will be elected unless he/she is from a country which already has two representatives, until four candidates are elected.

The Election Committee is: Adam Maj and Lidia Ferreira.

ACTIONS:

- **Actualise the email address lists (DB, and all others who did not do it yet).**
- **Contact INFN Legnaro to check the availability of the voting platform (BR, GDA).**
- **Send the call for nominees next week (BR)**

7. Progress with the new database (Riccardo)

The current website appears under the eurisol domain (www.eurisol.org/usergroup) but it is not clear where it is hosted exactly. AB manages the website. Because there is no possibility to upload documents on the website, al important documents are stored on computers at the University of Pisa and linked on the website.
We want to transfer this responsibility to members of the present UEC and create a central repository of all the documents.
As a start, a similar news/blog platform has been prepared in Leuven. It has essentially the same functionalities as the previous one. However, the upload of files is also allowed.
All the files (entries/documents) from the previous website need to be transferred. The new website should still appear under the eurisol domain.

ACTION: RR contacts the technical personnel at Legnaro (current host of the eurisol domain) and Leuven to arrange the move.

9. AOB

We notice that the EURISOL MoU may be not in force anymore. The MoU is important also because its parties "are expected to share the cost of the organization of the Town meetings and to support the EURISOL User Group" through an annual fee. This could become important for the support of the future activities of the UEC, especially if ERINS does not provide that.

The EURISOL Distributed Facility Project

Draft 21/02/2019
YB, AB, ML, BR, IM, SP, GN

Additional contributions: M. Borge, U. Koester, P. Van Duppen, J. Pakarinen,

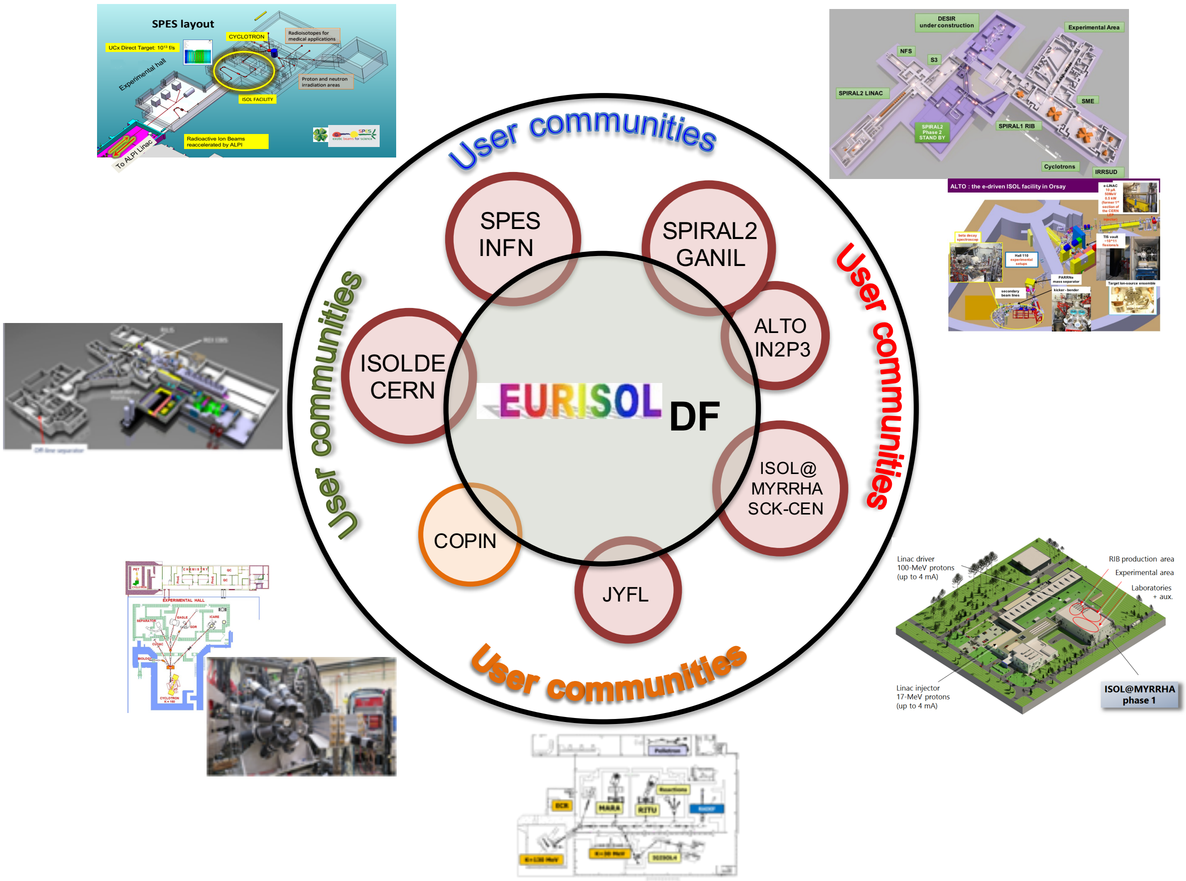
Executive summary

Abstract

Main goals, physics case and organisation of a new EURISOL Distributed Facility are presented. The project is aiming in a high-level integration of the European ISOL-based radioactive ion-beam (RIB) facilities seen as an ambitious and necessary intermediate step towards a construction of the EURISOL project. The members of the initiative, ISOLDE/CERN, SPES/INFN, GANIL-SPIRAL2 – ALTO, ISOL@MYRRHA, JYFL and COPIN consortium are proposing to join their efforts to implement a new scientific policy tackling major questions in nuclear physics and its applications, reinforce complementarities of the facilities in terms of scientific programs, available beams and equipment, have EURISOL-DF included on the ESFRI list by 2020, attract additional member states and EU funds, establish a joint strategy in education and training in nuclear science and develop EURISOL as a single site facility as a long-term goal.

1. Goals of the EURISOL Distributed Facility

A construction of the EURISOL facility is, together with FAIR, one of the major aims of the Nuclear Physics community in Europe. In order to reach the long-term goal of EURISOL (EURISOL Web site) a new European strategy is proposed with an intermediate and ambitious step: EURISOL Distributed Facility (EURISOL-DF), http://www.eurisol.org/eurisol_df/). The strategy was endorsed and strongly supported by NuPECC in the recently published NuPECC 2017 Long Range Plan http://www.nupecc.org/lrp2016/Documents/lrp2017.pdf .



Principle of the EURISOL-DF initiative emphasizing participating laboratories and a strong interaction between members of EURISOL-DF and user communities. Members of the consortium are marked in brown and an associated member in orange.

Science Objectives

EURISOL-DF aims in making a major step toward answers of the following fundamental questions in nuclear physics, astrophysics and fundamental interaction studies:

- *How does the complexity of nuclear structure arise from the interaction between nucleons?*
- *What are the limits of nuclear stability?*
- *How and where in the universe are the chemical elements produced?*
- *How does nuclear structure evolve across the nuclear landscape and what shapes can nuclei adopt?*
- *How does the structure change with temperature and angular momentum?*
- *How to unify nuclear structure and reaction approaches?*
- *How complex are nuclear excitations?*

- *How do correlations appear in dilute neutron matter, both in structure and reactions?*
- *What is the density and isospin dependence of the nuclear equation of state?*
- *What are the laws which govern the physics at the most fundamental level and how they can be tested in nuclear physics experiments?*
- *What are the most innovative and efficient applications derived from basic Nuclear Physics Research and having the largest impact and societal benefit in areas as diverse as nuclear medicine, energy, nuclear stewardship and security?*

In Europe, both EURISOL-DF and FAIR facility in Darmstadt, using complementary experimental approaches and different energy ranges will strongly contribute to answers to the above questions.

The goals of EURISOL-DF are:

- reinforce complementarities and synergies of the facilities in terms of scientific programs, beams and equipment;
- facilitate, promote and coordinate JOINT development, construction, upgrades and operation of the individual ISOL RIB facilities in Europe;
- optimize the scientific program at the ISOL facilities in order to avoid duplications and enhance smart specialisation of each facility;
- implement a new scientific policy tackling major questions in nuclear physics at ISOL-based Radioactive Ion Beam (RIB) European facilities and in particular:
    - organise experimental campaigns using all available observables, techniques, facilities and theoretical approaches to answer key questions in nuclear structure (eg. modifications of magic numbers in nuclei far from stability) and astrophysics (eg. genesis of medium to heavy mass elements in the Universe);
    - have a single-entry point for physics programmes that require beam from at least two EURISOL-DF facilities;
    - The EURISOL-DF facilities agree to provide a significant fraction of the Radioactive Ion beam time dedicated for such physics programmes, for which beam time will be distributed via the EURISOL-DF Program Advisory Committee;
- develop R&D on RIB production and instrumentation towards EURISOL and in particular:
    - organise and open to all EURISOL-DF members the R&D platforms to develop RIB (e.g. ion source test benches, target developments, separation techniques) and detector systems;
- promote user driven policy with an important role played by the EURISOL User Group and the EURISOL Instrumentation Coordination Committee in order to organise and optimize the campaigns of travelling detectors and arrays;
- have EURISOL-DF included on the ESFRI list by 2020 and attract additional member states and EU funds, in particular:
    - in-kind and/or cash contributions of the members for joint developments for EURISOL in the domains of accelerators, RIB production and instrumentation for experiments;
- establish a joint strategy in education and training in nuclear science (e.g. organising joint summer schools, hands on training, topical workshops and conferences);
- develop EURISOL as a single site facility as a long-term goal.

In general, EURISOL-DF will enhance complementarities and avoid duplication of efforts in the RIB developments at ISOL facilities in Europe. It will also largely enhance competitiveness of the European nuclear science and its applications at the global level.

EURISOL-DF has a clear Pan-European added value:

- optimal approach to study major questions in modern nuclear structure physics, nuclear astrophysics and related applications;
- European coordination of EURISOL related physics and technical R&D;
- sustainable resources for operation of the ISOL facilities and additional resources for R&D and detectors;
- clear strategy for upgrades of the complementary EURISOL-DF facilities towards EURISOL
- EURISOL-DF will act as a singly entry point for the close collaboration and synergy of European ISOL facilities with the ESFRI landmark facility FAIR/NUSTAR.

The map indicating: core members CERN-ISOLDE, INFN-SPES, GANIL-SPIRAL2 with ALTO, ISOL@MYRRHA (in the future), JYFL as well as associated member COPIN consortium participating in the EURISOL-DF project

The EURISOL-DF membership will be open to all European RIB ISOL facilities. The core facilities of the new distributed infrastructure are GANIL-SPIRAL1 and its upcoming SPIRAL2 facility with ALTO as its partner, CERN-ISOLDE, JYFL, the new INFN-SPES facility, and the planned ISOL@MYRRHA. The consortium of Polish research institutions COPIN will be an associated member of EURISOL-DF.

EURISOL-DF will closely collaborate with the FAIR facility and other ISOL facilities worldwide and it will strongly interact with the EURISOL Joint Research Activity in the Horizon 2020 ENSAR 2 and following European initiatives.

The EURISOL-DF project is coordinated by the EURISOL Steering Committee representing partners who signed the EURISOL Memorandum of Understanding, namely GANIL (France), CERN/ISOLDE, COPIN (Poland), Belgian EURISOL Consortium (BEC), INFN (Italy) and JYFL (Finland).

The EURISOL-DF project is aiming to develop following the timeline shown below:

2. Science of EURISOL-DF

Nuclear structure and reactions

An atomic nucleus consists of a set of protons and neutrons. Its properties are governed by the Strong and Electroweak forces. Recently *Ab initio* calculations based on fundamental theories have made a tremendous progress to find an adequate approach describing properties and structure of atomic nuclei. However, despite the success of the ab-initio approaches their precision do not allow their extension to heavy systems. Instead we must still rely on nuclear models where the interactions are based on effective forces between the nucleons that can describe some aspects or regions of nuclei. Here also great strides have been made in recent decades. This progress is due, at least in part, to the fact that these effective forces have been continually refined by comparison of model predictions with measurements.

Our models should be able to answer fundamental questions such as how nuclear properties change with the balance of neutrons and protons or where are the limits of bound nuclear matter for very neutron-rich or proton-rich (neutron-deficient) nuclei. They should reproduce, and predict, the persistence or disappearance of nuclear magic numbers. They should also describe exotic phenomena such as neutron haloes, or proton skins. They should tell us for example where alpha or heavier particle clustering should appear, whether extreme deformations are expected.

It is in this context that there is a particular interest in how the properties of nuclei change as we move away from the line of nuclear stability towards extreme ratios of neutrons to protons. Such nuclei are difficult to create and, as a consequence, their properties are generally not well known as current nuclear models do not yet have required level of predictive power.

In order to develop test recent models, we should look at the observables that are the most relevant as electromagnetic de-excitations, transition probabilities in beta-decay or spectroscopic factors measured in reactions. Similarly, ground state properties, such as masses, charge radii, magnetic moments, quadrupole moments and spins provide a critical testing ground for our models.

One can also try to isolate particular terms in the effective forces by looking at the appropriate observables. For instance, testing isospin symmetry in nuclei provides very valuable information on the isospin non-conserving terms in the nuclear interaction. This in turn can be tested by measuring mirror energy differences; (meaning here differences in excitation energy when one compares members of the same isospin multiplet occurring in different nuclei).

Slow or post accelerated Radioactive Ion Beams (RIB) at the various EURISOL-DF facilities are well suited to making essential contributions to study above mentioned topics. At each of the ISOL facilities in the consortium, different types of elements and isotopes are available in different quantities, and complementary experimental set-ups are available at the different facilities to study them. We can mention here a few examples. Nuclei with N ~Z can be studied at ISOLDE and HIE-ISOLDE at CERN and at Jyvaskyla, and will be available at the GANIL SPIRAL 2, S3 facility with unprecedented intensities. Different types of elements are available at these facilities (e.g, refractrory elements can only be produced using the thin target ISOL systems of Jyvaskyla and at the S3 at SPIRAL2).

On the neutron-rich side we see other effects such as the disappearance of well-established magic numbers when we move outside of the valley of stability. The first observation of this phenomena came as a major surprise in the field of nuclear structure. It has been followed by other evidences of shell evolution that eventually led to the appearance of new magic numbers. This evolution is now understood to have its roots in the properties of the nuclear force whose components (central, spin-orbit, tensor, and the role of coupling to the continuum) can be tested uniquely by exploring regions of the nuclear chart far from the valley of stability. The regions around N=50 and 82 magic numbersare of great importance for nuclear structure physics and astrophysics. The robustness of these magic numbers can be tested through detailed spectroscopic information obtained using modern state-of-the-art techniques.

Nucleon transfer reactions at energies typical of post-accelerated ISOL facilities (10A MeV) yield precise information on the energies and spectroscopic factors of states, and thus on the location and occupancy of the nuclear shells. Such studies just started at HIE-ISOLDE and GANIL-SPIRAL1 and will strongly develop in the near future. At SPES, in the framework of EURISOL-DF, an increase in intensity by more than one order of magnitude is expected for isotopes produced by the fission process, allowing investigations of neutron-rich isotopes further towards the dripline. These developments play also a key role for studies of pairing correlation employing two-nucleon transfer reactions.

EXAMPLE: Search for shape isomers by using sub-barrier transfer reactions with radioactive beams

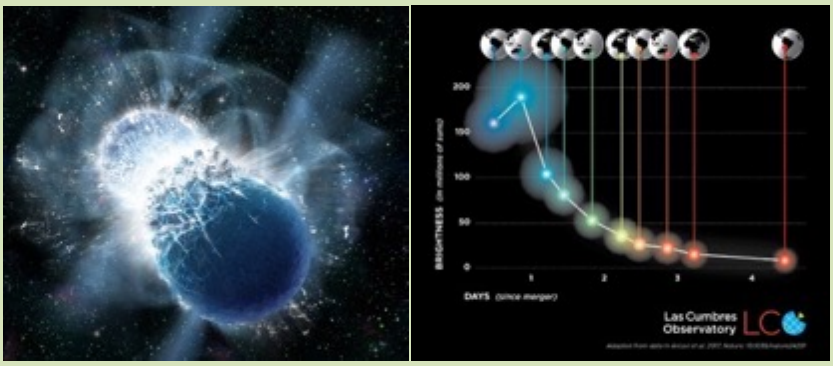
A possible research program at EURISOL-DF involving here facilities, HIE-ISOLDE and SPES, could aim at searching for shape-isomer like structures – the most extreme case of shape coexistence. Shape isomers are states at high deformation, separated from the main spherical configuration by a very high potential barrier. In the case a shape isomer decays toward the main minimum via photon emission, the transition is hindered by a nuclear shape change. Few examples have been found so far, in the actinides and in the nickel regions, although candidates for the occurrence of such phenomenon are 0+ states in exotic nuclei of $^{112-118}$Cd, $^{188-192}$Pt and $^{190-194}$Hg. To reach these states, sub-barrier transfer reactions could be employed, induced by radioactive Ag beams from the SPES facility, and radioactive Hg and Pb beams from the HIE-ISOLDE facility, respectively. For example, by choosing, a ^{117}Ag beam, the low-spin states in ^{118}Cd nucleus can effectively be accessed by the one-proton transfer on a ^{10}B target. In turn, by using an intense ^{190}Hg beam from the HIE-ISOLDE facility, and by employing sub-barrier two-proton transfer reaction on a ^{11}B target, a prolate 0+ state predicted to lie in the deep, secondary minimum in ^{188}Pt, could possibly be accessed.

Light nuclei exhibit a number of peculiar structures ranging from the neutron skin and halo at the neutron drip-line to the proton halo at the proton drip-line, showing also a variety of cluster structures. The theoretical understanding of these structures is particularly challenging. Reaction dynamics with light RIBs, in particular *halo nuclei*, are currently being extensively investigated. Up to now, due to low intensities, experiments have been limited mainly to elastic scattering and break-up measurements. Elastic scattering measurements of neutron halo nuclei have shown evidence of long-range absorption (both of nuclear and Coulomb origin) and core excitation effects. The proton halo dynamics have scarcely been investigated because of the unavailability, so far, of post-accelerated proton halo beams. In the framework of EURISOL-DF, new light proton-rich beams will be available at HIE-ISOLDE and SPIRAL1 and new experiments to investigate the reaction dynamics of proton halo nuclei are planned. New measurements of fusion cross-sections for a range of weakly bound nuclei will become possible with EURISOL-DF, in particular at HIE-ISOLDE, SPIRAL1 and SPES. Besides the interest of investigating sub-barrier fusion of weakly bound nuclei, the sub-barrier fusion dynamics of these systems is important for nuclear astrophysics.

Nucleosynthesis studied with radioactive ion beams and indirect methods

Understanding the chemical history of the Universe requires a clear and quantitative picture of nucleosynthesis in the different stages of stellar evolution. The slow neutron capture process (s-process), prevailing in asymptotic giant branch stars, is supposed to be one of the sources of elements above iron. Neutron star mergers, recently identified through gravitational wave and electromagnetic observations, are considered nucleosynthesis sites of the rapid neutron-capture process (r-process), responsible for creating about half of all heavy elements and all elements above Pb and Bi. Neutron capture cross sections are a crucial information for theories which describe the s- and r-process nucleosynthesis. Since s- and r-process nuclei are unstable, direct neutron capture measurements are generally impossible and one has to rely on indirect methods (like surrogate or Trojan horse), nuclear reactions that in specific kinematical conditions can be seen as a surrogate of the original ones. High resolution particle and gamma spectroscopy, together with well-defined nuclear reaction conditions specific of ISOL facilities, are essentials elements. EURISOL DF, providing access to different European ISOL facilities covering all range of energies and offering dedicated instrumentation is a perfect infrastructure for those investigations.

Rapid neutron-capture process



Artistic view n-star mergers (left) and the light curve determined by the radioactive decay of r-process nuclei (right)

According to the current understanding, the astrophysical rapid neutron capture process (r process) has produced around half of the elements heavier than iron. It proceeds mainly through a series of neutron captures and their counterpart (gamma, n) reactions and the ensuing beta-decay processes. While the (n, gamma) reactions drive the process further and further from stability line producing heavier and heavier nuclei, the beta-decay brings them back towards stability. Astrophysicists and nuclear physicists have worked for decades to model this process trying to decide where in our Universe the conditions (neutron density, temperature etc) are such that the process can occur. The recent discovery of a binary neutron star merger (NSM) and the observation of the subsequent electromagnetic radiation with an optical light curve that matches to a large extend the theoretical predictions provided the first direct evidence of the r-process nucleosynthesis in the Universe and its particular site. This exciting finding has motivated even further the efforts to reproduce as accurately as possible the abundance of the heavy elements and to investigate the different conditions in which the r process can occur in its different modalities (hot, weak r process…) with the hope that future observations will tell us whether neutron star mergers are the only possible source of r process elements or not. It is, however, currently understood that NSM occur too rarely to explain the production of all heavy elements. For instance, neutrino-driven winds from proton-neutron stars resulting from core-collapse supernovae could also contribute via the weak r-process to the production of lighter nuclei with A<120.

A considerable amount of nuclear data is needed to model the r process; binding energies, half-lives, level densities, (n, gamma) reaction rates, gamma strengths, beta-delayed-neutron and fission branching ratios, neutron capture rates, fission barriers etc. Some of the nuclei involved in the process will be accessible to experiment in the framework of EURISOL-DF, some of them will still remain out of reach. Theoretical nuclear structure models as well as sophisticated extrapolation models have to be used for the predictions. To measure the quantities mentioned above will be essential either as direct input to the nucleosynthesis calculations or to validate our models.

High-quality beams at ISOL facilities make precision mass measurements and detailed decay studies possible. For instance, at ISOLDE, Penning-trap mass spectrometry has provided a wealth of precision data on the masses of neutron-rich nuclei and multi-reflection time-of-flight spectrometers have been demonstrated to be very powerful in the investigation of the shortest-lived isotopes. On the other hand, most of the r-process models have not taken into account the contribution from long-lived isomers. In particular, low-lying isomers are thermally populated in astrophysical environments. As their masses, beta-decays and neutron-capture rate may significantly differ from the ground states, their properties should be included in the calculations. This kind of studies can only be carried out at ISOL facilities, as good-quality purified low-energy beams are needed for such precision studies. This has been demonstrated e.g. at Jyväskylä, where trap assisted mass separation has been used to isolate isomeric states from the ground state in order to measure their properties.

In general (n, gamma) reaction rates are calculated within global statistical models. Whereas this statistical approach appears to be applicable for nuclides in between neutron shells exhibiting sufficiently high-level densities, it fails for isotopes close to magic numbers with only a few widely spaced resonances. For such cases apart from compound-nucleus resonant capture, direct reactions are also important and may even dominate. In such cases the measurement of (d, p) reactions at incident energies around 10A MeV is the tool of choice to simulate (n, gamma) capture rates. Such experiments have already been performed around N=28 at GANIL/SPIRAL. Similar experiments around magic numbers N=50 and 82 could be carried out and results in the region around ^{132}Sn would strongly influence our understanding of the r-process. Post accelerated beams of ^{130}Cd and ^{131}In in its ground and isomeric states would be of particular interest. These will be available at HIE-ISOLDE and SPES and in a more distant future with higher intensity at SPIRAL2 phase2.

Fundamental Interactions

Precision measurements of beta decay play an essential role in the determination of the fundamental laws of physics and the construction of the standard model of elementary particle physics. These experiments are complementary to those performed at colliders such as the LHC and in case of V_{ud}, the most precise value of it originates from nuclear superallowed beta decays. Three main avenues of research are:

- Are there exotic scalar or tensor currents in the weak interaction?
- What is the precise value of V_{ud} and is the CKM matrix unitary?
- Is there time reversal symmetry breaking in beta decay?

Fundamental interaction experiments are generally based on highly optimized and characterized measurement setups and require long experimental campaigns spread over several years because a precise understanding of all details of the apparatus is crucial. Several projects at GANIL/SPIRAL, SPES, JYFL and ISOLDE are being realized and will benefit from upgrades in beam intensity and purity planned in the framework of EURISOL-DF. The ISOL@MYRRHA facility, with its high intensities and the possibility of lengthy beam times, offers ideal characteristics for the pursuit of such studies. Since the theoretical corrections are starting to dominate the error budget in many of the transitions, complementary nuclear structure studies should be performed in the vicinity of these nuclei in order to help to improve the correction terms.

Electric dipole moment search in exotic octupole deformed systems

Matter-Antimatter asymmetry in the Universe cannot be explained based on the Standard Model expectations requiring additional CP violation. Parity (P), Time Reversal (T) and Charge Conjugations (C) are discrete symmetry transformations. CP violation and CPT invariance imply T-violation, which is expected to occur at some level in atomic and nuclear phenomena. If both P and T are violated, an elementary particle, nucleus, atom, or molecule can possess a permanent electric dipole moment (EDM). This happens because CP violation and the weak interaction must induce EDM's at some level by means of radiative corrections to the P, C, T conserving electromagnetic interaction. At present the most sensitive EDM search is performed on ^{199}Hg and the upper limits already constrain various extension of the Standard Model. Exotic nuclei can be used to amplify the sensitivity to such symmetry violations, the occurrence of octupole deformation inducing a contribution to an atomic EDM. Being the expected EDM proportional to the square of the octupole deformation, very promising cases are octupole deformed nuclei in the actinide region like ^{223}Rh, ^{225}Ra or ^{229}Pa nuclei with enhancement factors calculated up to the order of 10^4 respect to Hg nuclei. EURISOL-DF offers a unique possibility to study in a coherent and complementary way such systems through high energy reaction (HIE-ISOLDE), performing nuclear structure characterization (SPES) and production (SPIRAL2 and ISOL@MYRRHA).

Instrumentation

Scientific advances often stem from progress in instrumentation. Nuclear physics instruments are becoming ever more diverse and more extensive. Coordination between laboratories is essential in the R&D phase in order to avoid replication of efforts. Many of today's detector arrays are too costly to duplicate and their optimal exploitation requires their travel between the different facilities. The Instrumentation Coordination Committee of EURISOL DF will coordinate instrumentation R&D and oversee the harmonious utilization of the traveling detector arrays.

The study of ground-state nuclear structure probes observables such as atomic masses, nuclear charge radii, spins and electromagnetic moments using state-of-the-art techniques in atomic physics including ion- and atom traps, and a variety of laser spectroscopic methodologies. To date almost all current and planned ISOL facilities host instrumentation with which to address ground-state properties. Laser spectroscopy and mass spectrometry inherently benefits from the use of radiofrequency quadrupole cooler-buncher devices which convert the continuous beams delivered from the target-ion source station into bunched beams with a time structure and beam quality optimized for low-energy measurements. These devices, along with the required Penning traps and laser systems used in such measurements are located on-site and are not easy to move between facilities.

Having duplicate instrumentation at each facility is however particularly useful in this instance. Complementary between facilities exists in the different target-ion sources and primary beams used. For example, ISOLDE with the availability of high beam intensities and fragmentation/fission/spallation production of radioisotopes affords exceptional access to much of the nuclear landscape. The IGISOL facility at Jyväskylä is unique in its access to refractory elements on both sides of stability. In the future, the S3 spectrometer Low Energy Branch as well as the MARA spectrometer Low Energy Branch at GANIL and JYFL, respectively, will provide access to nuclei near or at the N=Z line, thus far inaccessible to any facility for ground-state measurements.

The low-energy community maintains a strong tradition in developing new techniques which drive improvements in efficiency and selectivity as well as an exchange of know-how, in order to push towards ever more exotic nuclei while handling the increase in unwanted species inherently produced as the primary beam intensities are increased. Such innovations include Multi-Reflection Time-of-Flight devices, high-resolution ion-beam cleaning methods with Penning traps, Phase-Image Ion Cyclotron Resonance (PI-ICR) techniques, optical manipulation in rf cooler-bunchers, collinear resonance ionization and so forth. These methods are developed within long-standing collaborations and are then implemented across many facilities. For example, the PI-ICR method is now implemented at both JYFL and ISOLDE and has demonstrated a precision at the 10^{-10} level on stable Rb isotopes. At ISOLDE, collinear resonance ionization spectroscopy was successfully used to measure magnetic dipole and electric quadrupole moments up to ^{78}Cu, the latter produced at a rate of only 20 particles per second. Efforts continue to push the technique to even lower yields.

The EURISOL-DF, involving all major ISOL-based facilities as well as medium-sized facilities, is well positioned to further strengthen such collaborations. Notably, the connection to R&D developments within the Horizon 2020 framework program ENSAR2 (and future programs) includes laser-based activities which directly benefit ISOL facilities and will thus continue to benefit EURISOL-DF in the future.

Decay studies far from the line of nuclear stability require advanced and sophisticated instrumentation. Not far from stability, where the Q-beta values are small the decay schemes are relatively simple and most of the excited states decay by only a few gamma cascades. As a consequence, high efficiency, high resolution gamma arrays are important. On the other hand, farther from stability, excited states in the daughter nucleus may lie in regions of high-level density and de-excite by many separate fragmented gamma cascades at energies where the efficiency of the Ge arrays is modest. In these cases, complementary Total Absorption Gamma-ray spectrometers will be essential. It should be noted that the measurements with high resolution Ge detectors are still necessary for a full understanding of the decay scheme. On the other hand, information on electromagnetic transition probabilities can be extracted from half-life measurements of states populated in the decay using the "Fast Timing technique" based on fast scintillators in combination with Ge detectors. Furthermore, the characterisation of the absolute efficiency of Ge detectors with high precision is necessary for more precise determination of the unitarity of the CKM matrix by measuring super-allowed Fermi transitions. In addition, while moving farther away from the stability line some of the levels populated in the decay will lie above the proton (protons) or neutron (neutrons) binding energy rendering charged-particle and neutron detectors essential. In light proton-rich nuclei, decay schemes can be very complex with the emission of several protons and alpha particles as well as the unavoidable positrons. Current decay experiments at ISOL facilities allow for the measurement of simultaneous or sequential charged-particle emission because the charged particles can be measured separately using sophisticated and pixelated Si arrays surrounding the radioactive source. Beta-delayed neutron detection is also essential, not only to obtain information about nuclear structure but also because these processes make an important contribution to the astrophysical r-process and are needed for related calculations. Two kinds of neutron detection setup are currently used at ISOL facilities, ^{3}He based gas neutron counters for absolute beta-decay neutron branching ratios and Time-of-Flight scintillator arrays for neutron spectroscopy. Together they provide information on absolute beta-decay neutron (or neutrons) emission rates as well as the neutron spectra.

There is an intense effort to develop and further refine all of this instrumentation, which can be constructed and tested by small groups at Universities and small laboratories and brought to EURISOL-DF facilities such as ISOLDE, ALTO, SPES, GANIL and Jyväskylä. These groups specialise in the use and analysis of specific techniques. Moreover, most of this instrumentation is portable and one of the purposes and benefits of EURISOL-DF is the sharing of the know-how as well as the optimum use of these devices in organised, dedicated campaigns of experiments.

Nuclear reactions have historically been a major tool to investigate the structure of atomic nuclei. ISOL post accelerated radioactive beam facilities provide beams with excellent optical quality, matching that of stable beams. Intensities, however, are orders-of-magnitude lower. Upgraded EURISOL-DF facilities, in particular HIE-ISOLDE, SPES and SPIRAL1 will provide much increased intensities opening new regions of exotic nuclei for study using a large variety of direct and compound reactions. The measurement of reactions induced by radioactive beams requires innovative instrumentation exhibiting large efficiency. One can cite charged particle Silicon arrays such as GRIT and T-REX coupled to state-of-the-art gamma detectors such as AGATA, EXOGAM and MINIBALL or active target TPCs such as ACTAR-TPC and ATS (Active target for SPES). These detectors will travel between experimental sites and their scheduling will be coordinated by the EURISOL-DF. They will be complemented by fixed magnetic spectrometers such as VAMOS at GANIL, PRISMA at SPES or the ISOLDE Solenoid Spectrometer. In the framework of EURISOL-DF the users will have the opportunity to choose the spectrometer best matching their experimental requirements.

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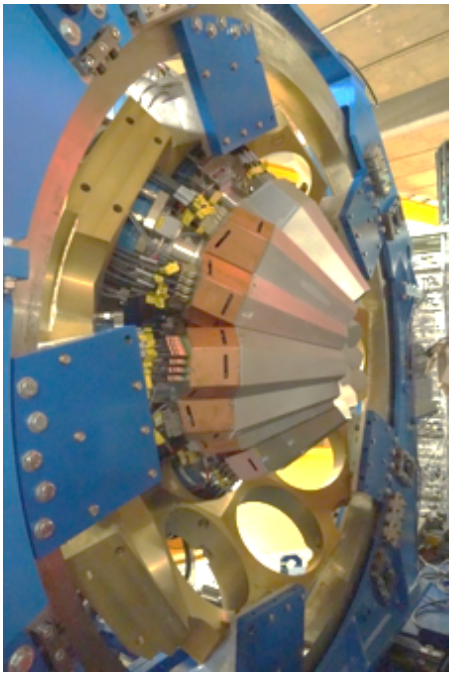
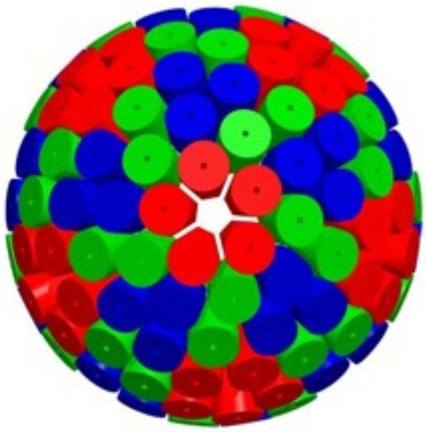
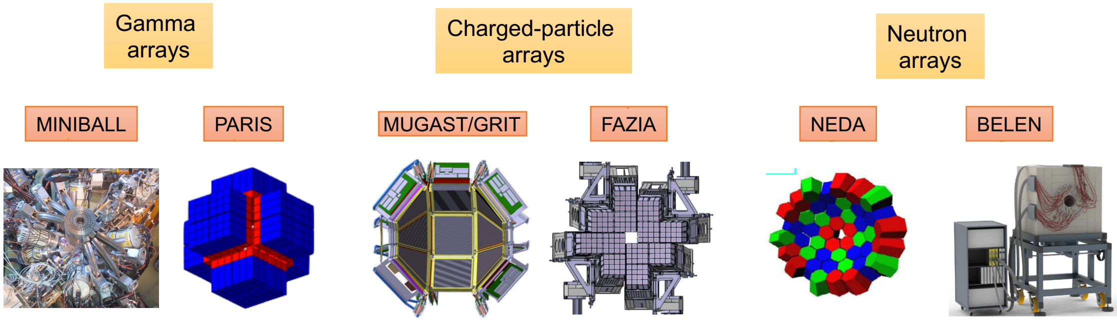




AGATA array in its current configuration at the GANIL-SPIRAL2 facility (left) and in its future 4Π full geometry (right).



Examples of travelling detectors developed, constructed and used at the RIB facilities by European collaborations

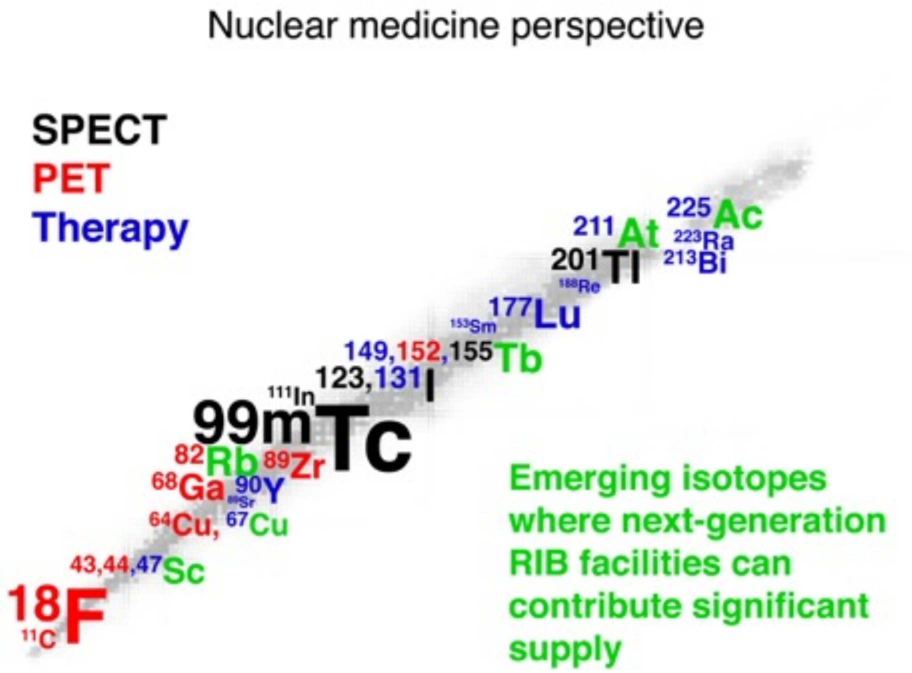
Storing radioactive ions produced by an ISOL facility in a ring would open a large domain of multi-disciplinary physics spanning from investigations of nuclear ground state properties and reaction studies of astrophysical relevance to investigations with pure isomeric beams and atomic physics experiments with highly charged ions. In addition, cooled beams could also be extracted and exploited by external spectrometers for high precision measurements. The construction of such a ring at the ISOLDE facility is foreseen within the EURISOL-DF framework. One should stress here that this experimental approach is complementary in terms of energy domain and range of isotopes to the storage-ring physics with RIB at the FAIR-NUSTAR facility.

Applications

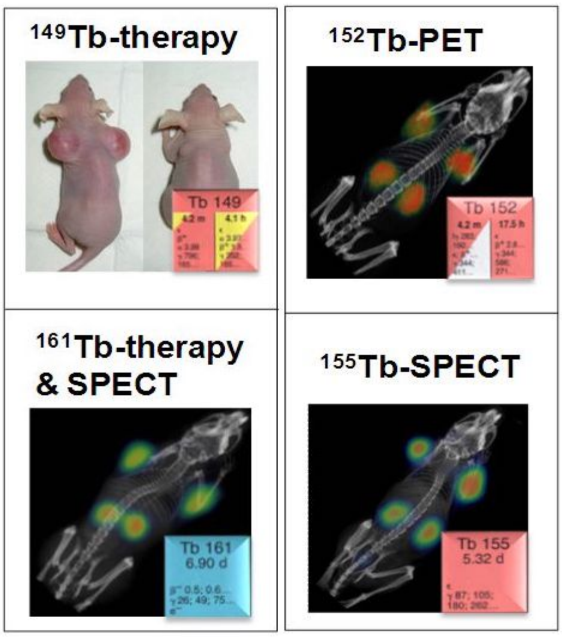
EURISOL-DF will largely contribute answering fundamental needs and questions addressed by the society specifically on energy, health and security. Improvements in nuclear applications are obtained thanks to an increase of the basic knowledge on nuclear structure and decay, nuclear reactions and properties of nuclei but also thanks to the developments performed in the related technologies: accelerator, instrumentation and high-performance computing.

The society will largely benefit from the important investments already done and foreseen in the future at EURISOL-DF. Recent achievements in particle- and radio-therapy within the new paradigm of theranostic approach and up-to-date, well-structured nuclear data libraries indispensable for a whole range of nuclear science applications are some of the most striking examples of the benefits from research at ISOL RIB facilities.

Radioisotopes play a vital role in medical imaging and cancer treatment. Their combination is named Theranostics, which means using diagnostic tests to guide therapy. One uses a given biomolecule (called vector) first carrying a diagnostic isotope (positron emitter for PET or gamma emitter for SPECT) to measure the biodistribution of the biomolecule and validate that it addresses correctly the disease sites. Today it is most used for cancer, so the imaging will highlight the primary tumour and metastases. The biomolecule is then equipped with a therapeutic isotope and administered for the therapy. Historically one used for example ^{123}I for the imaging of metastasized thyroid cancer and then ^{131}I for the therapy. Today this concept is used more generally with different biomolecules such as peptides, antibodies, etc. for neuroendocrine tumours, prostate cancer, lymphomas, etc. To avoid any biochemical uncertainty and assure perfect representativeness of diagnostic and therapeutic radiopharmaceutical it is best to choose so-called "matched pairs", i.e. pairs of diagnostic and therapeutic radionuclides belonging to the same chemical element. Metallic isotopes internalize in cells, i.e. tend to remain there until they decay. Thus, there is particularly high interest in the matched pairs ^{43}Sc/^{47}Sc, ^{44}Sc/^{47}Sc, ^{64}Cu/^{67}Cu and the matched quadruplet of terbium isotopes: ^{152}Tb for PET imaging, ^{155}Tb for SPECT imaging, ^{161}Tb for beta- and Auger-electron-therapy and ^{149}Tb for alpha therapy. ISOL facilities can provide large amounts of a great variety of radioisotopes. At CERN-ISOLDE the MEDICIS project is devoted to the production of “new” isotopes holding promise for medical use, which were not possible to produce with traditional techniques. At SPES the LARAMED project aims in a first stage at the industrial production of radio-nuclides which are already used or planned to be implemented in nuclear medicine. In parallel innovative production methods will be investigated in the framework of the ISOLPHARM project. These endeavours are generally administrated as spin-offs but benefit greatly from nuclear physics expertise and from target and ion source R&D carried out within the facilities.



Radioisotopes in medicine. For simplicity, the clinically used isotope is shown, while in some cases a precursor isotope will be produced to load a so-called generator: $^{99Mo/99m}$Tc, $^{82Sr/82}$Rb, ^{68}Ge/^{68}Ga, ^{225}Ac/^{213}Bi. ^{225}Ac can be used as generator of ^{213}Bi or directly as in-vivo generator. Some of these radioisotopes (e.g. Tb isotopes) require mass separation and would use the whole facility. Others (e.g. ^{82}Sr) can be produced by diverting part of the primary beam onto a dedicated production target. The size of symbols represents the number of exams per year.



Example of theranostics with Tb isotopes

EURISOL-DF facilities produce exotic radioactive isotopes on-line with high yields, high elemental selectivity and isotopic purity. These characteristics allow the use of a panoply of state-of-the- art nuclear techniques which apply nuclear methods to research on materials science, life sciences and biochemical physics. One can cite techniques such as Mossbauer spectroscopy, perturbed angular correlations, radiotracer diffusion, photoluminescence spectroscopy, and emission channelling. A special mention can be given to the development of the beta-NMR technique in soft matter studies in biology and chemistry which is carried out within the ERC grant BetaDropNMR. It will result in ten orders of magnitude more sensitivity compared to conventional NMR and make it applicable to elements which are otherwise difficult to investigate spectroscopically.

All above techniques are implemented today at ISOLDE and could be transferred to other ISOL facilities in the framework of EURISOL-DF. Increased intensities available from upgrades performed in EURISOL-DF would reduce the duration of the experiments and allow the use of new radio-nuclides that cannot be produced in sufficient amount today.

Amongst the many applications of nuclear physics, the fission reactor for energy generation is one of the most prominent. Although most of the energy generated comes from the fission of heavy elements in the reactor fuel, approximately 7% of the energy released in a reactor is due to the beta decay of fission products in the form of gamma and beta radiation. Following a shutdown of the reactor this source of energy, normally called the "decay heat", is the main source of heating. This is, of course, why the coolant must be maintained after the termination of the neutron-induced fission process as demonstrated by the incident at the Fukushima Daiichi power plant. Thus, it is very important that we have a full understanding and proper handling of the decay heat in reactors both for design, shielding and nuclear safety purposes. The decay heat varies as a function of time after shutdown. In principle this can be determined from known nuclear decay data using the summation calculation method. The essential ingredient in such calculations is a correct and proper knowledge of the gamma and beta energies released by the many nuclei produced, directly and indirectly, in the fission process together with their half-lives and yields. Many of the relevant radioactive species are difficult to produce or separate from other species, they involve the decay of a number of isomers or the measured values available are affected by systematic errors. The nuclear physics community is putting a considerable effort into this area in order to provide more reliable information for the international nuclear databases and, of course, supplying valuable information on nuclear structure at the same time. ISOL facilities such as Jyväskylä, where refractory elements can be extracted or ISOLDE where the yields are very high can make significant contributions that are essential to this effort.

Particle accelerators for RIB production

Particle accelerators play a central role in RIB facilities, both as Drivers and Post-Accelerators. These two functions require different and specific accelerator characteristics.

Since RIB production rate is increasing with the primary beam power, are usually of the high-power type Driver accelerators. In some practical cases (ISOLDE, ISOL@MYRRHA) the primary beam is spilled in a "parasitic" way from accelerators in use for other purposes, and only a fraction of the driver accelerator beam is used for RIB production. However, the new frontier of physics with RIBs is aiming at the development of high power targets with very high RIB production rates: this requires high beam currents and dedicated drivers. Suitable nuclear reactions in the target, with different kinds of mechanisms and final products, can be obtained with different types of primary beam, provided that their energy is sufficiently high. Thus, a typical driver accelerator must provide essentially a powerful beam, sometimes of a unique type and energy and preferably CW or pulsed at high frequency, to avoid mechanical shock waves in the targets.

Conversely, secondary radioactive beams are usually of very low intensity. Post-accelerators must be characterized by very sensitive beam diagnostics devices and by very good operational stability in the absence of feedback from the accelerated beam. Their operational parameters must be set by means of a stable pilot beam of sufficient intensity, and then precisely adjusted to values required by the low intensity radioactive beam to be injected afterwards in place of the pilot beam (sometimes "blindly" in terms of beam diagnostics). In addition, since a large fraction of nuclear physics experiments with RIBs require precision measurements around the Coulomb barrier energy, post accelerators able to provide RIBs covering the range 5 to 20 MeV/u, with very good energy resolution, stability, reproducibility and beam purity, are very valuable. Post-accelerators, differently from driver ones, must be able to accelerate a large variety of different A/q beams of extremely low intensity, to final parameters which must be adjustable with excellent precision in a wide range of energy and time configurations.

In Europe, the EURISOL-DF affiliated and collaborating laboratories can count on accelerators where ISOL-produced radioactive beams are either available or under development. They are among the world leading ones in development of specific cutting-edge accelerator technology, contributing not only in-house but also in several international projects with the design and construction of accelerator components.

Some of the technological highlights of the EURISOL-DF laboratories in RIB-related particle accelerators are:

- CERN/ISOLDE, part of the largest accelerator laboratory worldwide and pioneer of physics with RIBs, runs a RIB superconducting post-accelerator and has access to world-class infrastructures for accelerator development and construction. It is one of the only two laboratories able to produce Nb sputtered superconducting Quarter-Wave resonators.
- INFN/LNL is running heavy ion accelerators including a superconducting low-β linac. Within the SPES project it is implementing the superconducting RIB post-accelerator with highest energy in that category. It is specialized in RF Linac technologies - RFQs, DTLs and superconducting resonators (both with bulk and sputtered superconducting material) - which are being exported worldwide.
- GANIL is running a large RIB facility, called SPIRAL1, and with the SPIRAL2 project is implementing the superconducting low-beta linac for heavy ions with highest current worldwide. It is specialized in RFQs, superconducting resonators and cyclotrons.
- IPNO is running an electron linac within the ALTO facility, where RIBs are produced by photo-fission. The laboratory is a renowned center for super-conducting resonators and cryomodules development and has a long tradition of participation in linear accelerators studies (SPL, EURISOL- DS and MYRRHA) and constructions (SPIRAL2, ESS).

The capital of experience and know how in heavy ion accelerators technologies that can be found in the EURISOL-DF laboratories is a precious resource that could play a fundamental role in filling the gap towards the construction of the next-generation, dedicated European ISOL facility EURISOL, which would become a world leading center in nuclear physics with rare isotope beams. To reach this goal, a coordinated effort of all these competences is required.

3. Radioactive-ion-beam handling and development

The proposed activities are dedicated to develop new targets for n-rich nuclei and high-power beams together with improvements in beam purity and quality. Most of the proposed activities are promoted by the JRA's of ENSAR2. This means that there is already a certain degree of collaboration that EURISOL-DF will definitively consolidate. In addition, we address other aspects related to high power radioactive ion beams (RIBs) such as beam dumps and safety.

Target developments are facilitated by sharing know-how among the different facilities and organizing experiments together within the EURISOL-DF framework. Actinide targets offer attractive perspectives for the production of the most neutron-rich isotopes. A new way to facilitate diffusion and keep the production of RIB using less material is the implementation of nanostructured uranium targets. The study of optimised neutron converters is planned for the production of pure n-rich nuclei. Liquid metal targets to withstand high power beams toward the EURISOL Facility are a pending subject that require collaborative efforts of all facilities to test prototypes and most probably to develop new approaches.

The purity of the beams is crucial specially when going to the very exotic species of very low production. The production of pure RIB requires the use of selective and efficient laser ionization techniques. New laser-atom interaction regions will be studied to better suppress unwanted non-laser ionization mechanisms. Extensive spectroscopic studies are planned to improve the efficiency of the ionization process throughout the periodic table. This is a typical distributed activity where the collaborative effort is a must to facilitate fast progress.

In order to increase the charge of the RIB two different approaches are used within the EURISOL-DF Facilities the Electron Beam Ion Source (EBIS) and the Electron Cyclotron Resonance (ECR) source. The combined used of Penning trap with EBIS, pioneer by ISOLDE, has proven to be very versatile and provides low-contamination beams. The future challenges for the charge breeding process towards EURISOL lie in the higher beam intensities delivered by the primary target, the request for reduced breeding times and the demand for fully stripped heavy ions. The first step is to have a high current-density electron gun to reduce charge breeding times and produce higher charge states. This is a very ambitious long-term EBIS development and prototyping is absolutely needed. An alternative method is the ECR sources developed in

Grenoble and used in GANIL and SPES. Investigation to improve purity and charge breeding are critical for the latter device. New techniques to address breeding efficiency, especially for non-volatile ions, are under development.

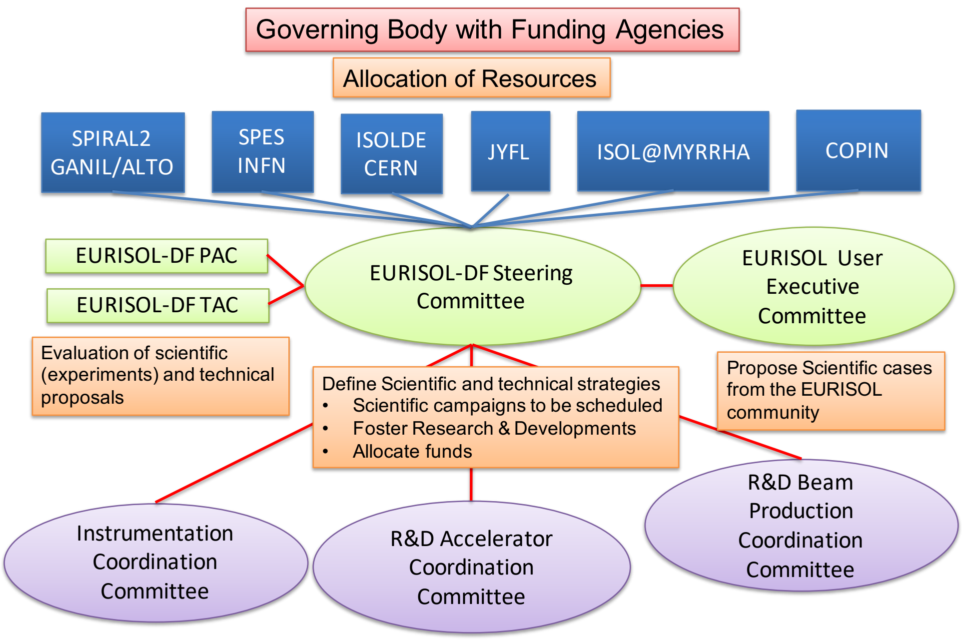
Improvements to RIB quality, i.e. emittance and purity are linked to the capabilities of a high-resolution mass separator (HRS). The development of beam cooling systems capable of accepting high intensity beams and reducing their emittance so that they can be effectively separated in a HRS is a crucial point. This subject is addressed jointly between SPES and GANIL aiming to a never previously observed mass resolution key point for the study of heavy masses.

The radiation safety of the MW production target (together with post acceleration) is again one of the most important aspects to be assessed towards the construction of EURISOL. Not only it is important to take into account safety issues related to the facility operations, but also the decommissioning procedures and costs must be considered. Again, the experience gained (and to be gained) in the different ISOL facilities must be taken into account for the design of high power facilities such as EURISOL.

4. Organization of EURISOL-DF

The legal and organizational/Governance framework for the EURISOL-DF project is being conceived to sustain and facilitate the scientific and technical activities of the community involved in the science based on ISOL radioactive beams. The general underlying features are the exploitation of synergies among the participating facilities and the flexibility to adapt to possible scenario changes in order to realize programs always at the frontier. The legal framework is to comply with the needs of the users and of the operation of the participating infrastructures and moreover to easily obtain formalization for actions that are beneficial to common or overlapping activities. An important point is that the legal framework is tailored to these goals and will go far beyond the ongoing collaborations, MoU and international agreements.

The organisation diagram of the EURISOL-DF project is shown in figure below.



The participating infrastructures are planned to provide budget, resources and beam time allocation. A steering committee having as core members representatives of the participating facilities will be put in place with the mandate of:

- defining scientific and technical strategies;
- promote and organize scientific campaign for physics and technical developments;
- to allocate funds which include in-kind contributions. The steering committee will use the advices

from the Programme Advisory Committee (PAC) and Technical Advisory Committee (TAC). These committees will analyse the scientific and technical proposals that are submitted by users. The PAC will propose how to share the work and experiments between the different facilities keeping in mind optimization and efficiency to reach the goal.

The proposed PAC of EURISOL-DF will will recommend experimental campaigns to be performed at two or more ISOL facilities. This PAC might be composed of chairs of individual PACs of facilities providing beam time plus one additional member and have typically one meeting per year. This should ensure a coherent and coordinated evaluation of scientific programs and at the same time will minimize a risk of rejection of the same proposals by PACs of individual facilities.

The TAC will organize technical developments and detector utilization and for that the TAC will present the need for resources to EURISOL-DF Steering Committee.

The uniqueness of each infrastructures will be considered in the realization of common programs.

The EURISOL-DF Steering Committee will prepare a general plan including a list of milestones in conjunction with timeline. Risk analyses are planned to be made for each program, possibly with backup solutions to mitigate risks.

For independent evaluation of the distributed facility will be done by ESFRI.

The EC funded preparatory phase will to be used to define of the organisation of EURISOL-DF and its operation mode. It is expected that one year will be necessary for the full definition of the above-mentioned structures and three following years will be dedicated to implement and improve them progressively.

5. Budget of the EURISOL-DF

The preliminary budget of the EURISOL-DF over different stages of the project is summarized in the table below.

It is anticipated that during the EURISOL-DF preparatory phase the facility and its operation will be covered by the EU contribution and in-kind contributions from the participating institutions.

During the operation of the facility from beginning in 2021 the costs of consortium will be covered by in-kind contributions of the EURISOL-DF partners.

Facility or Partner	Preparatory Phase (in k€) EC request 4,5M€ in for 4 years total including 2M€ for R&D total for all facilities together	Operation of the facilities for the EURISOL-DF experiments from 2021 offered by facilities (in-kind contributions of individual facilities)*				Cost of expected future upgrades of individual facilities 2021-2023 in k€
	Request from EC k€	in months of RIB/year	Cost of months of beam time or management k€/year	in months of other beams/year	in k€/year	
CERN-ISOLDE	350	2,0	4500			20000
GANIL-SPIRAL2	300	3,0	12000	0,25	1000	23000
ALTO	100	1,0	400	0,33	260	400
ISOL@MYRRHA	350	1,5	3500	2,00	200	3500
JYFL	350	2,0	1600			1000
SPES	350	4,0	2300			5000
COPIN Consortium	350			1,00	350	
EURISOL-DF consortium management, organisation, legal structure, User Group etc.	2000		200			
Total	**4150**	**14**	**24500**	**4**	**1810**	**52900**

*All numbers are preliminary. The beam time at which facility will be allocated by the given facility management following recommendations of the EURISOL-DF PAC and the PACs of individual facilities

Estimated cost of different phases of EURISOL-DF

It is anticipated that the additional cost related to the management, organization and operation of the internal bodies of EURISOL-DF will be fully covered during the first 4 years of its existence by the EC funded Preparatory Phase project.

APPENDIX: Description of the facilities and their contributions to EURISOL-DF

1. The ISOLDE Facility

The ISOLDE Radioactive Beam Facility is the dedicated CERN installation for the production and acceleration of radioactive nuclei. More than 1300 isotopes of 75 elements are available for a wide variety of pioneering physics experiments (mass measurements and fundamental interaction studies using a variety of traps, laser spectroscopy experiments, decay spectroscopy and reaction experiments, solid state physics and biochemistry experiments, …). It delivers radioactive beams at low energy (40-60 keV) since 1967 and these beams can be reaccelerated since 2001 to 2.8 MeV/u thanks to the installation of the REX normal conduction RFQ linear post-accelerator. For this, the singly-charged ions from ISOLDE are captured and bunched in a large acceptance Penning trap (REXTRAP) and charge bred in the REXEBIS ion source to an A/q ratio between 3 and 4.5. The higher charge of the beam allows it to be efficiently accelerated in a compact linear accelerator. An upgrade of the post-accelerator, with additional superconducting cavities gradually added between 2014 and 2018, now allow RIBs up to 10 MeV/u.

The ISOLDE facility uses a high-energy (1.4 GeV) proton beam (average current 2μA) from the Proton-Synchrotron Booster (PSB) on a thick target for the production of radioactive nuclei via spallation, fission and fragmentation reactions. The reaction products are stopped in the bulk of the target material, thereafter diffuse out into an ion source, and are then accelerated to 30-60 kV for transport to the magnetic mass separators. ISOLDE uses two target stations and related mass separators: GPS with a mass resolving power, M/ΔM=600, and the HRS which resolution exceeds 4000. Behind the HRS mass separator an ion cooler-buncher (ISCOOL) has been operational since 2008, providing the users with bunched beams with a typical time length of a few microseconds and user-defined repetition rates.

More than 20 different target materials, typically kept at about 1500 to 2000 °C, are in use. The radioactive atoms diffuse out of the target into different dedicated ion sources. Ionization can take place in a hot plasma, on a hot surface or by laser excitation. Resonance laser ionization is a very selective method of ionization, which guarantees the production of pure radioactive beams since more than 20 years now, and it is chosen as the preferred ion source by more than 70% of the experiments.

ISOLDE towards EURISOL Distributed Facility.

The use of high-energy protons has been recognized to be optimum for the production of radioactive nuclei via spallation, fission and fragmentation reactions on thick targets. More than 50 years of radioactive beam production at ISOLDE, has given us experience with the behaviour of targets using continuous and pulsed beams as well as in a large range of proton energies from 500 MeV to 1.4 GeV.

In the near future, ISOLDE wants to take advantage of CERN's LHC-injector (LIU) upgrade programme, which foresees an energy increase to 2 GeV in the Booster and an increase in the proton beam intensity by the connection of the new LINAC4. This could lead to an increase in the proton beam intensity for ISOLDE of a factor of 2-3, yielding immediately an increase in the RIB intensities by a similar amount. The 2 GeV energy upgrade would lead to a further increase in RIB intensities, which varies from a factor of 1.4 for the fission products to up to a factor of 5 in fragmentation and beyond 6-10 in spallation.

The ISOLDE Facility is the only one exploring the high energy dimension of the proton injector, which allows to use a multitude of nuclear reactions to produce isotopes over the full nuclear chart, with the exception of most of the refractory elements (as these do not leave the target/ion source). Such a high-intensity proton driver has been chosen as the preferred driver for the ultimate EURISOL facility.

In order to take full advantage of the higher available proton beam powers from the CERN Booster, the ISOLDE facility aims at the following upgrades and new installations, within the framework of the EURISOL-DF:

1. Primary beam dumps for high power beams

The current ISOLDE beam dumps were designed to withstand an energy deposit of 2kW from a 1GeV, 2μA proton-beam from the PS Booster at CERN. However, ISOLDE is now operating constantly at 1.4GeV with the same intensity and recent analysis of the ISOLDE beam dumps have revealed that in terms of compressive forces and energy deposit, the current dumps are operating at their limit. With the commissioning of Linac 4 providing more intense proton beams and a future upgrade of the PS-Booster to 2GeV, ISOLDE will be in a position to receive up to 13kW of proton beam power. Therefore, new beam dumps have to be designed and installed. Beam dumps and their shielding are important elements in the design of any high-power facility at high proton energies. The beam dump upgrade program of ISOLDE-CERN can be seen as a precursor for other such upcoming facilities. Specific areas of development include design, material studies and integration.

2. Consolidation and upgrade of the REX- and HIE-ISOLDE post-accelerators.

The final phase of the HIE-ISOLDE project includes the upgrade of the normal-conduction RF-cavities of the now almost 20 years old REX-injector for the HIE-ISOLDE accelerator. By replacing the normal conducting cavities by superconducting ones, the full range of energies from 0.5 MeV/u up to 2.8 MeV/u will become available (now some energies in this range are not accessible). During this upgrade, it is also planned to install an ion-chopper and buncher, which should provide users with intense pulsed beams. Both the energy range upgrade and the bunching are crucial e.g. for astrophysical reaction studies. Adding more cryomodules and cavities to the accelerator will also require the installation of a new (or upgrade of the existing) cryoplant, as it is currently running at its maximum capacity with the 4 cryomodules of the HIE-ISOLDE accelerator.

3. A storage ring for RIB

A storage ring receiving beams from HIE-ISOLDE will allow the realization of experiments with stored post-accelerated radioactive beams, which will be unique in the world. Indeed, such rings currently exist only at fragmentation facilities (e.g. at GSI-FAIR), where the stored RIB's have much higher energies and thus are used for different types of experiments. Using post-accelerated radioactive beams for injection into a storage ring has the advantage of a good beam quality and a higher beam intensity for many exotic isotopes, as compared to the two current storage rings coupled to a fragmentation facility. The physics programme with the storage ring is rich and large in scope expanding from reaction studies of astrophysical relevance to unique investigations with highly charged ions and pure isomeric beams. Innovative instrumentation to exploit the features of this storage ring will be developed by the ISOLDE collaboration. E.g. the Isolde Solenoid Spectrometer (ISS) which is currently connected directly to HIE-ISOLDE for transfer reaction studies, would benefit largely from the much-cooled beams extracted from the storage ring. Further, the ISOLDE Storage Ring can be used for removal of isobaric contaminants in the beams, a great advantage for reaction studies with exotic beams.

4. Two new target stations for ISOLDE

Since the installation of the REX- and HIE-ISOLDE post-accelerators, the ISOLDE collaboration has grown from 6 members at the end of previous century to 16 member countries today. This has increased the ISOLDE user community from a few hundred to more than 600 active users (and close to 1000 occasional users). That has enormously increased the amount of experiments approved by the CERN research board, As a consequence, In order to provide more beams to the many users ISOLDE would largely benefit from having 2 additional target stations. Thanks to the higher available beam intensities, it would be possible then to schedule low energy- and accelerated beams in parallel, and thus to double the amount of available beam time. That will be even more important if a storage ring is added to HIE-ISOLDE, as this new device would attract certainly another new user community, thus further posing pressure on the available beam time.

5. Improvements of RIB quality

Improvements to RIB quality fall into three categories: intensity, purity, and emittance (transverse and longitudinal). Emittance and purity are linked in that a high-resolution isotope separator (HRS) can deliver better beam purity from a lower emittance beam due to its increased mass resolving power.

ISOLDE is constructing a new offline test facility whose main function will be to serve as a development platform. A laser laboratory is coupled to the offline test facility allowing the RILIS team todevelop a wide range of ideas related to the laser ion-source. Specific areas of interest for EURISOL-DF and future EURISOL at this off-line laboratory, include the development of a 30 keV MR-TOF-MS that will allow a fast characterization of radioactive beam composition with the option to provide very pure beams in case a mass resolving power of 1E5 is required. The offline mass separator studies include construction, test and development of an ambitious and innovative separator magnet design with built-in alignment and aberration correction. Furthermore, an RFQ cooler (a copy of the on-line one) will be fully characterized, with focus on improved transmission across the full range of isotope masses, better control of bunched beams, optimised and quantified beam emittances for various masses and tunes, improved RF power supplies, improved buffer-gas control. The combination of these developments would lead to a design for a whole new HRS for ISOLDE that could be coupled to the new target stations, with a resolving power in the range 10000 - 20000 for all ion-source types.

2. The SPES Facility

SPES is a national facility of INFN, sited at LNL (Laboratori Nazionali di Legnaro, Italy), aimed at the production and acceleration of exotic beams, the design and construction of which involve LNS (Laboratori Nazionali del Sud, Catania, Italy) and some of the INFN units.

The main goal of the SPES project is the realization of a second generation ISOL system able to deliver neutron rich beams for the study of nuclei far from stability. The research on these nuclei, both from the point of view of structure and of reaction mechanisms, represents a current frontier for nuclear physics and astrophysics.

SPES integrates the existing superconducting linear accelerator ALPI, used as post-accelerator of exotic nuclei, with a proton cyclotron as driver, an ISOL target-ion-source assembly and a system for the selection and injection of the exotic ions into ALPI.

The SPES cyclotron is an H+ accelerator designed to extract two simultaneous beams, sharing the total current on two exits. This feature allows the simultaneous operation of two targets. In addition to the ISOL facility, the LARAMED medical radioisotope facility and a fast neutron facility will be supplied.

The cyclotron accelerates protons up to 70 MeV with a total maximum current of 750μA shared between the two exits.

SPES uses a direct target composed of UC_x disks, reaching 10^{13} fissions per second. The whole target ion-source system was properly optimised from the thermal point of view to be operated up to 10kW of incident proton beam.

The ion beam is then delivered for reacceleration to ALPI, through different elements sited along the transport line (Wien filter, Charge Breeder, mass separator, pre-acceleration RFQ) to select the radioactive beam of interest. The use of a laser source allows the selection of several beams with high purity.

The use of the superconducting ALPI Linac results in reacceleration energies above 10A MeV for ions with mass 130.

Intensities of 10^7–10^9 particles per second are expected to be achieved over a wide range of nuclear masses, namely $60 < A < 160$.

SPES towards EURISOL Distributed Facility.

The main features of the SPES facility to be exploited as a contribution to the EURISOL-Distributed Facility are presented and here briefly summarized.

The possible upgrading and/or extension of the SPES facility towards EURISOL-DF mainly concerns the developments of specific parts to improve the radioactive beam intensity and purity and to the increase the energy of the post accelerated beam. Altogether the aim is to enrich the physics program for EURISOL-DF and to develop the technology for a further step towards the EURISOLfacility.

1. Instrumentation –upgrade

For SPES, several European (Italy, France, England, Spain, Poland, Romania, Bulgaria, Turkey, Germany, Croatia, Sweden, Finland, Denmark) and extra-European (RIKEN, MSU-FRIB, ORNL, iThemba, BARC, New Delhi, Dubna, Moscow) collaborations are active on innovative itinerant detectors and related experimental proposals. The successful examples of AGATA, FAZIA, PARIS, NEDA, GASPARD, will possibly common activities towards the instrumentation for EURISOL-DF. For SPES the physics cases to be addressed were presented in about 50 Letters of Intent (LOIs) and were discussed at the Third SPES International Workshop (LNL, October 2016).

2. Low energy area for experiments with non-reaccelerated exotic beams - upgrade

*LOI*s for experiments to be performed with non-post accelerated beams at SPES have been presented at the "3rd SPES International Workshop". They mainly refer to the employment of the foreseen resident beta-Decay Station, but also propose the installation of additional set-ups.The LOIs cover all the ranges of applicability of decay studies, being focused both on nuclear structure and stellar nucleosynthesis. Nuclear structure evolution studies are expected to benefit from the measurement of E0 transitions and conversion electrons, to better define spin and parity of the nuclear levels. A rich program involving the use of TAS techniques is also envisaged, complementing high-resolution studies.

According to these proposals an area will be dedicated and instrumented to host experiments with non – reaccelerated beams.

3. High resolution mass separation at 1/20.000 –upgrade

The SPES upgrade for beam purity is based on the construction of a High-Resolution Mass Separator (HRMS) with a selectivity of 1/20.000. To overcome this goal a Beam Cooler must be coupled to the HRMS to match the beam quality necessary at the input of the HRMS. The experience at EXCYT, Argonne National Laboratory, SPIRAL2 and TRIUMF will be used to develop the full system.

With this expected mass separation all the LoIs presented up-to now will be performed with a high purity beam.

4. Second ISOL bunker and high intensity direct target –upgrade

The possibility to construct and operate a second ISOL target system, for which the civil construction project includes already a dedicated space, will increase the beam time for users and to perform the R&D for species that are more difficult to extract from the ISOL target. A very useful development is the design and construction of a direct UC_x target with the ambitious goal (using additional and larger disks) to sustain more power from the proton beam to exploit the full proton beam energy range (from 40 to 70 MeV at 0.3 mA). This development is expected to increase the number of fissions by a factor of four (from 10^{13} to $4x10^{13}$ f/sec).

5. Reaccelerated beam energy upgrade

a. New cavities for ALPI
b. New EBIS Charge Breeder with up to date performances

The increase of bombarding energy of the accelerated radioactive ions needs improvements in the charge breeder and an upgrade in the ALPI accelerator. For this, a possible scheme is to go from an ECRIS breeder to an EBIS type.

For the superconductive ALPI linear accelerator, the addition of new cavities in the available space is being investigated. This will lead for the ^{132}Sn beam an increase from 10A MeV (^{132}Sn (21+)), of the current project, to 16A MeV (^{132}Sn (27+)) without sizable decrease in beam current.

6. Upgrade of SPES application

The SPES strategy is to develop a facility for Nuclear Physics research together with a facility for applied Physics based on the same technology and infrastructure. The expected upgrades are:

1) the use of the ISOL technique to produce well selected radioisotopes for medical applications,

2) the installation of a fast neutron irradiation facility to have an intense quasi mono-energetic neutron (QMN) beam with a controllable energy peak in the 35-70 MeV energy range and an intense beam of fast neutrons (E > 1 MeV) with a continuous energy distribution similar to that of atmospheric neutrons found at flight-altitudes and at sea-level

3) the installation of a small accelerator (2-3 MV) dedicated to material science studies and coupled to the SPES exotic beam.

3. The GANIL-SPIRAL2 and ALTO facilities

GANIL SPIRAL2 Facility

The GANIL-SPIRAL2 facility is one of the major European stable-ion and radioactive ion beam facilities in Europe. The SPIRAL2 facility was selected by the European Strategy Forum on Research Infrastructures (ESFRI) as one of the 45 most important EU research infrastructure projects.

A first phase of the SPIRAL 2 facility, (see figure) an ambitious extension of the GANIL accelerator complex, will be accomplished in 2019. The future SPIRAL2 Phase 2, is expected to provide high-intensity ISOL radioactive ion beams using, in particular, a neutron-induced fission of uranium. The physics case of SPIRAL 2 is based on the use of high intensity RIB and stable light- and heavy-ion beams as well as on possibilities to perform several experiments simultaneously. In particular, a use of these beams at the low-energy ISOL facility and their acceleration to several MeV/nucleon as well as of high neutron flux at the n-tof-like facility will open new possibilities in nuclear structure physics, nuclear astrophysics, reaction dynamics studies.

The developments of high intensity stable and radioactive ion beams at the GANIL cyclotrons, SPIRAL1 and new SPIRAL2 facility as well as important upgrade of existing detection systems will offer new opportunities in experimental nuclear physics and its applications.

Stable-Ion and Radioactive-Ion Beams at GANIL/SPIRAL2

Since the first beams delivered 25 years ago, the performances of the GANIL accelerator complex, were constantly improved with respect to the beam intensity, energy and available detection systems.

Stable-Ion beams

The GANIL facility offers today a wide range of stable-ion beams from ^{12}C to ^{238}U with energies from 1 to 95 AMeV. In particular, the use of high-intensity beams of rare-stable isotopes including ^{36}S, ^{50}Ti, ^{48}Ca and ^{64}Ni offers unique experimental possibilities. A high intensity CW beam of ^{238}U, with energies from a few to 25 AMeV is unique in Europe and very well suited to studies of nuclear fusion and/or fission in inverse kinematics. The beam power currently provided to users reaches 3kW for beams from ^{12}C to ^{40}Ar.

The large part of the next paragraph is on radioactive beams!!

Much higher light- and heavy-ion beam intensities will be available soon at the new SPIRAL2 facility. SPIRAL 2, schematically shown in figure 1 consists of the superconducting linear accelerator (LINAC) and the associated experimental area (AEL) which include Neutrons For Science (NFS) and the Super Separator Spectrometer (S3) halls, the RIB production building with production cave, a RFQ Cooler and a High Resolution mass Separator (HRS) and the low-energy RIB experimental hall (DESIR). The high-power LINAC will deliver a high-intensity, light-ion beams (up to 40 MeV deuteron beam) as well as a variety of heavy-ion beams with mass-to-charge ratio of 3 and energy up to 14.5 MeV/nucleon. The SPIRAL 2 driver accelerator was designed, considering a wide variety of beams needed for physics experiments. The biggest challenge is to manage this choice of beams, the high power (200kW, CW) and the safety issues related to deuteron beam losses.

In the initial phase, two separate injectors are planned:

- the heavy ion injector (q/A=1/3): ECR source with its mass analyser, focusing systems and beam diagnostics,
- the light ions injector: ECR source (protons and deuterons) with its beam transfer line and diagnostics.

At the later stage a new heavy ions injector (q/A=1/7) will be constructed allowing for acceleration of heavier beams up to uranium.

Beams from both injector lines are pre-accelerated with a common RFQ cavity: a 4-vanes copper cavity (88 MHz) composed of 5 sections, 1 meter long each, dissipating 240 KW, with an electrode voltage of 110 KV and output energy of 0.75 AMeV. The Medium Energy Beam line will integrate 3 copper cavities bunchers, focusing and beam diagnostic systems, and a fast chopper for single bunch experiments at NFS.

The SPIRAL 2 LINAC will provide light-ion beams with intensities reaching 5 mA for protons, deuterons and ^{4}He and 1 mA (≤ 10¨15 pps) for heavy ions.

Radioactive-Ion Beams

Since the beginning of the experimental program of GANIL about thirty years ago, the facility delivered RIB produced in-flight at LISE and SISSI/Alpha fragment separators.

More recently, in autumn 2001, the SPIRAL facility allowing for the production and post-acceleration of the ISOL-type RIB entered into operation. The facility, specialized in RIB of rare gases (He, Ne, Ar, Kr but also N, O and F), importantly expanded the range of experimental possibilities dedicated to study of nuclei far from stability at GANIL. These beams are produced using high-intensity (up to 3kW) 70-95 MeV/nucleon heavy-ion beams impinging on a universal graphite target. The radioactive atoms diffused from the target are ionized in the ECR ion source and injected to the CIME cyclotron for the post-acceleration to energies ranging from 1 to 25 MeV/nucleon.

Today SPIRAL1 delivers in a routine way high-quality low-energy (keV) and post-accelerated beams of 40 isotopes of 6 elements. An upgrade of the SPIRAL1 facility, thanks to use of a new FEBIAD ion-source, new target materials and an ECR charge breeder, will enlarge the range of light ISOL beams up to 20 new elements and hundreds of isotopes. First experiments with these new RIB from SPIRAL1 should start by 2018.

The main RIB production scheme of SPIRAL2 is based on the fast-neutron induced fission of uranium. Using a carbon converter, a 5mA deuteron beam and a high-density (up to 11g/cm^3) 2.3kg uranium carbide target, the fission is expected to reach a rate of up to 10^{14}/s. The intensities of the post-accelerated RIB in the mass range from A=60 to A=140 will be of the order of 10^6 to 10^{10} particles/s (pps). For example, the intensities should reach 10^9 pps for ^{132}Sn and 10^{10} pps for ^{92}Kr. A direct irradiation of the UC_2 target with beams of protons or ^{3,4}He can be used if higher excitation energy leads to higher production rate for a specific nucleus of interest or if much smaller targets with fast release properties are required. The radioactive ions created using a variety of target and 1+ ion sources after a charge breeding in the ECR source will be post-accelerated in the existing CIME cyclotron and used in the GANIL experimental halls. Thanks to the high intensity heavy-ion beams provided by the driver the neutron-rich fission RIB will be complemented by beams of nuclei near the proton drip-line, provided by fusion-evaporation or transfer reactions. For example, an in-flight production of up to 1 atom of ^{100}Sn per second using a 1 pμA ^{58}Ni beam should be possible. Similarly, the heavy- and light-ion beams from LINAC can be used directly on different production targets to produce high-intensity light RIB with the ISOL technique.

One of the important features of the future GANIL/SPIRAL1/SPIRAL2 facility will be the possibility to deliver up to five stable or/and radioactive beams to different users simultaneously in the energy range from keV to several tens of MeV/nucleon. An example of this kind of parallel operation is the following: a high-intensity beam from SPIRAL2 LINAC is used to produce a RIB in the SPIRAL2 RIB Production Building. This beam is post-accelerated in the CIME cyclotron and then used in an experiment in the one of the experimental halls of the current GANIL facility. Simultaneously a high-energy (for example 95 MeV/nucleon $^{36}Ar^{+18}$) beam accelerated by the GANIL sector-separated CSS1 and CSS2 cyclotrons is used in the SPIRAL 1 production cave to produce a second RIB subsequently injected to the low-energy DESIR experimental hall. At the same time, 3 other simultaneous stable-ion beams can be provided for other users at GANIL: first at keV energies at the ARIBE facility (not shown in fig. 1), second at the IRRSUD facility using second GANIL injector cyclotron (typically at 1 MeV/nucleon) and third at the SME facility using another charge state of the beam accelerated by the CSS1 cyclotron after the stripping foil placed between CSS1 and CSS2 (for example 12 MeV/nucleon $^{36}Ar^{+17}$). All in all 5 different energy and/or nature (2 RIB and 3 stable-ion beams) are used by different users. Many other configurations of this type of operation are possible. After the construction of SPIRAL2 Phase 1 the LINAC beams will be delivered for experiments at the NFS and S3 facilities only but fully in parallel to all existing experimental possibilities at GANIL.

(too many logos)

GANIL-SPIRAL2 towards EURISOL-DF

The following upgrades and topics of the GANIL-SPIRAL2 facility are proposed in the framework of EURISOL-DF:

- RIB produced at SPIRAL1 and S3 facilities
- High intensity accelerator (SPIRAL2 LINAC) which can be seen as a prototype of the EURISOL driver accelerator
  - Operation with very high intensity stable-ion beams
  - Accelerator Protection System
- Handling of the high radioactivity and maintenance
  - Very high intensity RIB (SPIRAL2 Phase 2)
- Innovative Instrumentation (ACTAR-TPC, PARIS, MUGAST, spectrometers, …)

On a longer perspective:

- High-power 200kW converter and big volume UC_x target
  (SPIRAL2 Phase 2)

ALTO facility

The ALTO electron linear accelerator (50 MeV 10μA) is used as a driver to induce fission in a thick uranium carbide target (up to 1011 fissions/s). The fission products are extracted from the target using surface ionization, plasma or resonant ionization laser ion source (RIALTO) and mass separated before being sent to different experimental setups. These beams are of great interest for study in nuclear structure, decay heat in reactors and solid-state physics. Six experimental beam lines are available to accommodate various experimental systems, from β-delayed γ-spectroscopy and neutron emission probability to laser spectroscopy and mass measurements.

Research and development on target and ion sources for the next generation radioactive ion beam facilities (SPIRAL2, EURISOL …) are among the key activities at ALTO.

The laboratory has a rich palette of research instrumentation and several services (HPGe Detector maintenance, target, laser laboratory and experimental hall services).

ALTO toward EURISOL Distributed Facility

The Institute of Nuclear Physics has a tradition of over 45 years of radioactive beam production and R&D around target ion-sources. These studies began in 1973 with the ISOCELE installation at the synchrocyclotron and are currently continuing with the ALTO facility.

The main upgrades of the installation are made as part of the ALTO 2.0 project. ALTO 2.0 is the project of reliability and sustainability & physics program of ALTO within the framework of a national and European strategy. The reliability of ALTO is envisaged according to 5 main axes: stable beams, radioactive beams, safety and nuclear safety files, target and ion sources R&D and finally electronics, acquisition and networks.

The main topics for the proposed **upgrading** of the facility for EURISOL-DF are:

Development of new beams:

The use of molecular beams presents a two-fold interest. Firstly, at the production stage, when the predominant release process is desorption, the release can be highly improved by forming molecular compounds that are more volatile than the elements and therefore will escape the target more easily. Secondly, after the production stage, forming selectively a chemical compound with one of the elements produced can improve greatly the purification of radioactive beams which contain several isobars. The isobaric component of interest can be isolated by mass-separation since the (heavier) mass of the compound differs from the mass of the initial beam. Both methods are or will be implemented at ALTO.

A GANIL-IPN collaborative effort will explore the use of fusion-evaporation nuclear reactions within a series of new Target-Ion Source Systems, associated with innovative nano-structured materials, and applied for the first time to nuclear physics research. Initial in-beam tests and R&D will be carried out using the accelerated tandem beams at ALTO.

Increase of the RIB time at ALTO:

In view of the demand in beam time it seems important to increase the number of hours available at ALTO for radioactive beams. ALTO has decided to equip itself with a homemade robot system that will considerably reduce the time required before changing a target ion source system. We expect to be able to double the time reserved for radioactive beams, time which will be available within the framework of EURISOL-DF.

Upgrade to 60kV RIB extraction:

Several new experimental devices (laser spectroscopy, low temperature nuclear orientation) require a 60kV beam. A new front end will be put in place that will reach this beam energy. In addition, the new front end installed will be compatible with the operation of the robot manipulating the targets (which was not the case of the previous one)

Second experimental hall: PALTO

ALTO is partly limited in the number of experimental devices it can accommodate by the very limited space available. A new extension to the existing hall is under study. The main idea is to create a hall with low radioactivity hosting beams already purified by a trap which will be extremely useful for experiments of total absorption spectrometer type. Laser spectroscopy experiments can also be installed in this new hall in order to develop towards β-NMR detection.

New beamline for industry: SOURI

We propose the creation of a new experimental zone within the ALTO installation, the name of the project is SOURI (Stations OUvertes à la Recherche et à l'Industrie). The objective of this project is to offer to physicists, engineers and industry an experimental area completely equipped for R&D and irradiations. We already have requests for: diagnostic tests for future accelerators, hardening studies for aerospace components, studies and characterization of materials.

The construction of such a dedicated line will give a unique opportunity where, on the same line, researchers and engineers can have use of stable beams, monoenergetic MeV neutron beams and cluster beams.

4. The ISOL@MYRRHA facility

ISOL@MYRRHA is the envisaged Isotope Separation On-Line (ISOL) facility at SCK•CEN, in Mol, that will use a fraction of the proton beam of the MYRRHA accelerator to produce radioactive nuclei for fundamental and applied research. In the current conceptual design, a proton beam of 600 MeV and up to 200µA with a repetition rate of 250 Hz will be used in combination with a ruggedized target-ion source system that allows implementation of a range of materials (including actinides) dissipating the high power deposited by the beam. A two-stage mass separator incorporating a radio-frequency cooler and buncher would deliver high-quality and -purity radioactive ion beams (RIBs) at an energy around 60 keV. The projected RIB yields at ISOL@MYRRHA were extrapolated from data collected at ISOLDE-CERN (Switzerland) and ISAC-TRIUMF (Canada). An increase of up to two orders of magnitude may be reachable.

Following the phased-implementation strategy of the MYRRHA-ADS, the ISOL@MYRRHA facility will also be implemented in phases. The construction starts with the 100-MeV high-intensity (4 mA) proton linac built in MYRRHA phase 1 (2016-2024). The aim is to finalize the commissioning of the ISOL facility in 2025, in order to deliver the first RIBs for experiments in fundamental science and medical-isotope R&D. The second phase of the project (2025-2030) implies the extension of the proton linac to 600 MeV and consequently upgrade of the ISOL facility to operate at this high-energy level. Also, the experimental area will be extended in this phase, to enlarge the set of experiments that can be addressed. On the longer term, one can envisage the phase 3 of the ISOL@MYRRHA project, when the proton beam extracted for the ISOL facility is post-accelerated even further, up to 1 GeV, and the RIB-production area upgraded accordingly.

Potential contribution of ISOL@MYRRHA to EURISOL-DF

Given the high intensity and high energy of the proton beam considered for ISOL@MYRRHA, this facility will present the closest target-operation parameters to EURISOL. Basically, there is a full overlap between ISOL@MYRRHA and the RIB production with the 100-kW direct targets defined in the EURISOL Design Study. To this we have to add the high-power proton accelerators of the two envisaged facilities, which have a common starting design. Moreover, an important requirement of the MYRRHA linear accelerator is reliability over long periods of time: the goal is to limit beam trips (i.e. beam missing for more than 3 seconds) to less than one every ten days, on typical cycles of three months of continuous operation followed by one-month maintenance.

- *High-power targets*

While relying on existing technology and R&D for mass-separation systems at the other facilities of EURISOL-DF, ISOL@MYRRHA develops a new generation of production targets and target stations, which is required by the unprecedented-high proton-beam power at which the facility will be operating. These technical developments, as well as the envisaged operation procedures (target exchange, waste handling and disposal, etc.) and licensing-related studies, are extremely relevant especially for the EURISOL 100-kW direct target facility.

Beyond the high power targetry activities relevant for ISOL@MYRRHA in its final phase, a new set of target R&D has been initiated, focusing on target designs for use in phase 1, with 100-MeV protons and at highest possible beam powers. These targets will suffer from an even higher heat deposition per primary proton, which requires design adaptation in order to allow sufficient cooling. Also, high-power target material development is currently underway at ISOL@MYRRHA, with the emphasis on an enhanced isotope release and resistance to high thermal load and radiation damage. For the sake of conducting some of the material testing required in this framework, a thermal test stand is currently under construction at SCK•CEN.

- *Beam dumps adapted for high-power beams*

In the first phase of the MYRRHA project, a 100-MeV proton beam of up to 0.5 mA intensity will be delivered to the ISOL facility. Together with a beam spot of a few mm in radius, this would result in heat-deposition-density values exceeding capabilities of typical beam-dump materials at current ISOL facilities. In addition, as radiation-induced damage increases with the linear energy transfer of the beam, the lower p-beam energy in the first phase requires that the degradation of candidate materials should be thoroughly studied. Also, the even lower energy of the protons after their interaction with the ISOL target requires R&D on possible windows or integrated connections between the target and the beam dump. These issues are analysed in a beam dump design study for ISOL@MYRRHA phase 1, in order to better understand the behaviour of candidate materials under low energy and high-power proton irradiation conditions. Note that, as some candidate materials like graphite are also of use in ISOL targets, the gathered knowledge will also be relevant for high power targets. Furthermore, the first phase of ISOL@MYRRHA actually implies the realization of two different beam dumps: (1) a 400-kW power beam dump used for beam-tuning and testing of the 100-MeV proton accelerator at full power and (2) the 50-kW beam dump behind the ISOL target.

- *High-intensity ion sources*

With isotope-production rates up to two orders of magnitude higher and long irradiation periods, it is clear that any ion source at ISOL@MYRRHA will deal with a higher flux of neutrals (i.e. due to the large number of thermalized alpha-particles) and higher amounts of undesired ions constantly produced in the ion source than currently operating ion sources. Both phenomena will distinctly affect efficiencies, selectivity and possibly also emittance.

Anticipating these effects, a computational campaign started at SCK•CEN using a Particle-In-Cell code and, at the same time, an offline station, including a laser laboratory is under construction. The aim is to combine both theory and experiments in order to adapt the ion source of today towards the high-intensity ion source of tomorrow.

- *Physics programme*

The high reliability of the proton accelerator is expected to enhance a stable operation of the ISOL@MYRRHA target-ion source for extended periods of time. The physics programme of the facility will take advantage of this feature prioritizing experiments which require extended beam times and operation in very stable conditions. Thus, experiments that need very high statistics, need many time-consuming systematic measurements, for example searching for very rare events, or have an inherently limited detection efficiency will be addressed. With this, the scientific programme is complementary to the programmes of the other ISOL facilities in EURISOL-DF.

The ISOL@MYRRHA experimental hall will include on the one hand (semi-)permanent large-scale setups and will reserve sufficient space to host travelling setups of various sizes.

Since the ISOL@MYRRHA physics case focuses on high-precision and high-sensitivity experiments, the use of RIB's with very high purity is of paramount importance. This requirement will be enabled by installing a high-resolution mass separator including a RF cooler.

5. The JYFL facility

The Jyväskylä Accelerator Laboratory is a national centre for nuclear and accelerator-based research and education. It is an integral part of the Department of Physics, University of Jyväskylä. In addition to basic research in nuclear and accelerator-based materials physics, beam time is reserved for commercial services.

The present infrastructure consists of the four accelerators providing high-intensity light- and heavy-ion beams, starting from protons and reaching at the moment to Au:

1. K130 heavy ion cyclotron served by three ECR ion sources and light ion source. In operation since 1992.
2. A 1.7 MV Pelletron for ion beam analysis and modification of materials has been in operation since 2007.
3. MCC30 light ion cyclotron for proton (18-30 MeV) and deuteron (9-15 MeV) beams with maximum intensities of 200 microA and 62 microA, respectively. Commissioned 2012.
4. Electron LINAC. Commissioned in 2015.

The IGISOL facility allows an extraction of wide elemental range of low-energy exotic beams using light- and heavy-ion fusion evaporation reactions on thin targets, as well as charged-particle induced fission of actinide targets.

Potential contribution of JYFL-ACCLAB to EURISOL-DF

The present R&D program at JYFL can contribute to three topics of interest for EURISOL-DF: Target development, ECR development and ion beam manipulation techniques. Those are described in more detailed below.

EURISOL related target development :

- Neutron converter development at IGISOL-facility relying on intense proton and deuteron beams impinging on various converter materials. Presently such a development is concentrating on a combination of proton beam with Be converter, but other combinations may be tested as well.
- In connection to medical isotope production the JYFL accelerator laboratory has gathered experience with gas-targets. Similar developments are foreseen in the future for new radioisotopes.

EURISOL related ECR development.:

- MIVOC method for metal beams has been invented at JYFL and its further development will continue to solve problems related to metallic beams.
- ARC-ECRIS is an innovation from JYFL and the first down scaled prototype has already been built at JYFL. EURISOL project has shown interest for further development of ARC-ECRIS development, which would fit naturally for the R&D palette of the ion source group at JYFL.
- An innovative room temperature ECR with 18 GHz microwave frequency has been developed at JYFL.
- JYFL is leading ENSAR2 ECR network MIDAS and thus JYFL had a leading role in following and directing ECR related R&D in Europe over the past four years (2016-2019)

EURISOL related ion beam and optical manipulation topics

- Further development of optical manipulation in RFQ cooler and buncher. This technique was developed and first time demonstrated at JYFL IGISOL and since then copied to other laboratories.
- JYFL scientists are actively participating in the development of various ion trapping techniques, which is of interest for EURISOL project. Those include, for example, MR-TOF devices and various ion manipulation schemes in the Penning trap. So called Ramsey cleaning and interleaving scanning techniques are developed and routinely used at JYFL.
- A variety of laser ion source and developments and related improvements to laser technologies is a key part of the JYFL R&D program which will directly benefit other ISOL facilities within the EURISOL-DF framework.

6. The COPIN consortium

The COPIN consortium offers a unique cyclotron facility in Poland operating a double site infrastructure: at the Heavy Ion Laboratory (HIL) of the University of Warsaw and at the Cyclotron Centre Bronowice (CCB), the proton therapy and basic research facility of the Institute of Nuclear Physics Polish Academy of Sciences in Kraków.

Potential contribution of COPIN to EURISOL-DF

Main Accelerator Facilities to be offered for detector tests and technical developments for EURISOL DF by COPIN are:

1) Isochronous heavy-ion cyclotron (K=160) at HIL Warsaw, equipped with two ECR sources, accelerating beams from He up to Ar (soon up to Xe) up to energy of 10 MeV/u. One of the ECR ion source is coupled to the p/d cyclotron used for a commercial production of the PET radiopharmaceuticals. This will allow for accelerating of light, radioactive ions (^{18}F, ^{15}O, ^{11}C) in the future.

2) The IBA Proteus C-235 proton cyclotron at CCB Krakow, where the energy of the proton beam can be varied continuously over the energy range 70-230 MeV with proton beam current up to 500 nA. The facility, as it possess two scanning gantries and ocular line, beam is now intensively used for proton-therapy of eye and whole-body cancer. The basic nuclear physics research including detector testing can be conducted in the dedicated experimental hall during night and weekend shifts.

The contribution of the COPIN consortium to the EURISOL DF projects can be the following:

a) from the Heavy Ion Laboratory of University of Warsaw:

- *ECR source development*.
  HIL offers a the ECRIS test stand at HIL developed within the framework of ENSAR2 project. It allows performing experiments aiming at the improvement of the performance of ECR ion sources for high charge state production. HIL provides also a test bench designed for non-axial injection of 1+ ions.
- *Detector development and tests with heavy ion beams*

Research groups at the Heavy Ion Laboratory demonstrate an expertise in the development of the charge particle semiconductor detectors. HIL is producing and testing innovative detectors for future systems like FAZIA. The test of various diamond detectors was performed with the framework of ENSAR project and can be continued in the future. HIL offers a possibility to test novel gamma-detectors on a heavy ion beam.

b) from the Cyclotron Centre Bronowice at Institute of Nuclear Physics in Krakow:

- *Detector characterization with the high-energy proton beam:*

  The unique feature of the Proteus C-235 enables fast change of the energy of proton beam in the range of 70 to 230 MeV allows efficient characterization of detector responses. Detectors can be tested either in air or in the large vacuum chamber. So far, such studies were performed for the CALIFA@NUSTAR array, the PARIS gamma calorimeter and FAZIA modules, that will be used at SPIRAL2, SPES and HIE-ISOLDE.