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Physics and Technology for the Next Generation of Radioactive Ion Beam Facilities: EURISOL

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Summary

Since the discovery of artificial radioactivity in 1935, nuclear scientists have developed tools to study nuclei far from stability. A major breakthrough came in the eighties when the first high energy radioactive beams were produced at Berkeley, leading to the discovery of neutron halos. The field of nuclear structure received a new impetus, and the major accelerator facilities worldwide rivalled in ingenuity to produce more intense, purer and higher resolution rare isotope beams, leading to our much improved knowledge and understanding of the general evolution of nuclear properties throughout the nuclear chart. However, today, further progress is hampered by the weak beam intensities of current installations which correlate with the difficulty to reach the confines of nuclear binding where new phenomena are predicted, and where the r-process path for nuclear synthesis is expected to be located. The advancement of Radioactive Ion Beam (RIB) science calls for the development of so-called next-generation facilities, which will provide beam intensities several (2-4) orders of magnitude higher than presently available, and provide us with many isotopes currently inaccessible. In particular in Europe NuPECC, the European Coordination Committee for Nuclear Physics, recommends building the next generation ISOL installation EURISOL as the highest long term priority for low energy nuclear physics. The physics case and technological solutions for EURISOL were laid out during the EURISOL Design Study, which brought together 20 laboratories representing 14 European countries and was partially funded by the European Commission during the 6th framework program. CERN was a major participant in this study and was recognized as one of the possible sites for the future facility.

1. Introduction

Since the discovery of artificial radioactivity in 1935, nuclear scientists have developed tools to study nuclei far from stability. A major breakthrough came in the eighties when the first high energy radioactive beams were produced at Berkeley, leading to the discovery of neutron halos. The field of nuclear structure received a new impetus, and the major accelerator facilities worldwide rivalled in ingenuity to produce more intense, purer and higher resolution rare isotope beams, leading to our much improved knowledge and understanding of the general evolution of nuclear properties throughout the nuclear chart. However, today, further progress is hampered by the weak beam intensities of current installations which correlate with the difficulty to reach the confines of nuclear binding where new phenomena are predicted, and where the r-process path for nuclear synthesis is expected to be located. The advancement of Radioactive Ion Beam (RIB) science calls for the development of so-called next-generation facilities, which will provide beam intensities several (2-4) orders of magnitude higher than presently available, and provide us with many isotopes currently inaccessible. In particular in Europe NuPECC, the European Coordination Committee for Nuclear Physics, recommends building the next generation ISOL installation EURISOL as the highest long term priority for low energy nuclear physics. The physics case and technological solutions for EURISOL were laid out during the EURISOL Design Study, which brought together 20 laboratories representing 14 European countries and was partially funded by the European Commission during the 6th framework program. CERN was a major participant in this study and was recognized as one of the possible sites for the future facility.

2. Physics case

a. Nuclear Structure

The first major result stemming from the inception of radioactive ion beams was the discovery of neutron-halo nuclei, characterized by dilute neutron matter surrounding a tightly bound core. The large extension of the neutron wave function makes the ^{11}Li nucleus appear the size of ^{208}Pb. Heavier halo nuclei are also predicted by theory, such as ^{14}Be, ^{19}C, ^{23}O but have been scantly studied up to now due to low beam intensities. For heavier neutron rich nuclei the halo structure is expected to give way to a more compact neutron skin. These extended neutron distributions have major consequences for nuclear structure and excited states,. It has been observed that magic numbers, once thought to be immutable, are in fact quite fragile when large neutron to proton ratios are reached. For example, detailed studies of Oxygen and Magnesium isotopes have shown that the magic neutron number 20 is replaced far from stability by N=16. Reducing the number of protons for a given neutron number will modify the n-p interaction and hence the relative position of the single particle levels. The more diffuse density distribution due to a neutron skin should reduce the intensity of the surface peaked spin orbit interaction and therefore the shell gaps in the heavier nuclei which are known to be spin orbit driven. New types of excitations also appear, in particular oscillations of weakly bound neutrons against the tightly bound core called pygmy resonances due to their low energy and cross sections in contrast to the well-known giant resonances.

The understanding of the structure in a region of the nuclear chart requires a multifaceted approach over long isotopic chains including the measurement of ground state and excited state properties. The experimental approaches can be roughly classified in two categories: stopped beam experiments for the measurement of ground and isomeric state properties and radioactive decay and reaction experiments where states are excited through Coulomb or nuclear interactions. EURISOL will bring extraordinary advances to both types of experiments through unmatched intensities and a uniquely broad energy range spanning from keV/nucleon up to above 100 MeV/nucleon. One can expect for example to measure the mass and charge radius of ^{78}Ni as well as magnetic moments in this region. Combined with single particle energies obtained through the analysis of transfer reactions, these data will allow the magic character of Z = 28 and N=50 to be probed far from stability along the r-process path. In the lighter region the relics of doubly magic nuclei under the form of resonances such as ^{28}O will become accessible. Figure 1 shows the chart of the nuclides along with the main physics subjects for EURISOL.

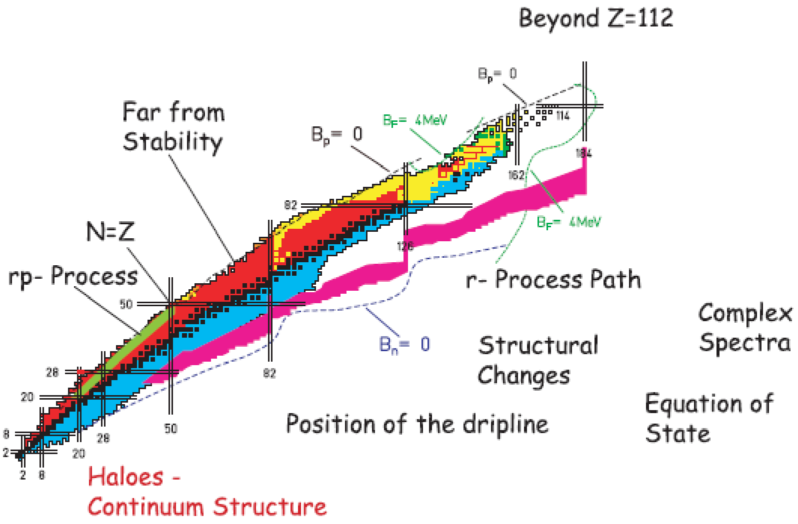


Figure 1 : Chart of the nuclides and main physics reach for EURISOL

EURISOL will also provide new insight into the existence and the structure of the heaviest of elements. The decay properties of their very neutron-rich isotopes will be investigated. The major goals of the experimental programme will be to push towards the predicted closed neutron shell gap at N=184 and to obtain systematic data on nuclear decay modes, half-lives and masses at the upper extreme of the Segré chart. Isotope shift measurements and hyperfine spectroscopy will be performed on various isotopic chains. The experiments will reveal the location of atomic levels and allow the determination of nuclear ground-state properties such as deformation and spin.

These new manifestations of nuclear structure are a challenge to theory. The results from EURISOL experiments will furnish major constraints for modern nuclear theories and enhance their predictive power for the properties of nuclei at the confines of the nuclear chart which may never be reached experimentally.

b. Nuclear Astrophysics

The bulk of the nuclear species heavier than iron are produced in rapid capture processes of neutrons or protons followed by radioactive decay, the so-called r-process, which is thought to take place during explosive supernova events. EURISOL will produce copious amounts of the radioactive nuclei involved in the r-process, providing the necessary values of nuclear masses, lifetimes and capture cross sections for input into the astrophysical models. The magic numbers far from stability greatly influence the r-process path and the final isotopic abundances – our expanded knowledge of exotic nuclei will produce the missing links for astrophysicists to fully understand the nucleo-synthesis of heavy nuclei.

Neutron stars are the remnants of core-collapse supernovae and are the most compact stellar objects after black holes. Many of their properties such as internal composition or temperature cannot be directly linked to observations but much of the missing information can be obtained from the study of unstable atomic nuclei which will be available at EURISOL. Of particular importance for the modelling of these stellar objects is the knowledge of collective excitations such as pygmy resonances, the understanding of nucleon pairing in exotic nuclei and a foray into nuclear thermodynamics through the evolution of the nuclear equation of state with increasing neutron to proton ratio. The latter exploration requires high energy exotic nuclei in order to excite their stiff giant monopole resonance and to induce their multi-fragmentation through violent nuclear collisions.

c. Fundamental Interactions

The study of nuclear decay modes has played a crucial role in determining the basic structure of fundamental interactions. For example, precision measurements of beta-decay have provided many experimental foundations for the standard model. The measurement of super-allowed $0^+ > 0^+$ transitions leads to the determination of the semi-leptonic weak coupling constant G_V and consequently of the V_{ud} element of the Cabbibo, Kobayashi, Maskawa (CKM) quark mixing matrix. EURISOL will allow such studies for N=Z nuclei up to ^{98}In much heavier than accessible today. These measurements will also lead to new insight into isospin mixing in nuclear states.

Correlation measurements in nuclear beta decay are a very sensitive tool to investigate the presence of exotic (i.e. scalar or tensor type) weak interaction components, search for right-handed charged weak currents and search for new sources of time reversal violation. This type of precision physics can lead us beyond the standard model. Such measurements will greatly benefit from the large intensities delivered by EURISOL, but will also necessitate the development of new types of ion and atom traps.

The beta-beam concept for the production of high intensity electron (anti-)neutrino beams for oscillation physics was first proposed by Piero Zucchelli at CERN in 2002. The EURISOL beta-beam facility is adapted for a base-line of some 130 km corresponding to the distance between CERN and the laboratory installed in the Frejus tunnel. The beta-beam facility is designed to use the existing CERN injector chain.. The chosen energy and baseline makes the facility an excellent tool for the study of CP violation for a large value of θ_{13} (>0.001), which seems now to be observed in the most recent reactor experiments.

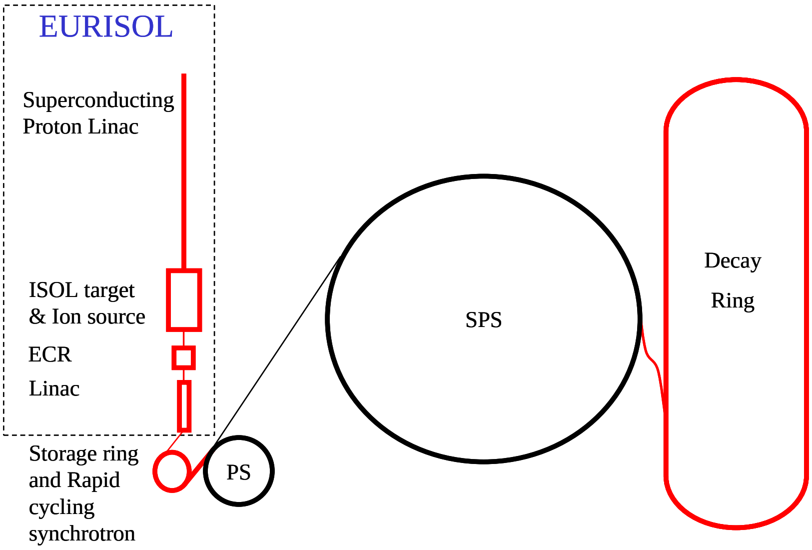


Figure 2: Schematic view of the beta-beam facility

3. Technical solutions

The planned EURISOL facility will use a large Continuous Wave (CW) superconducting linear accelerator (the “driver” accelerator) to accelerate H^- ions to energies of 1 GeV. The option of using a pulsed beam at 50 Hz with a minimum pulse length of 1 ms has been kept open to enable possible sharing of the driver with other physics users. This beam of particles will deliver a power of up to 4 megawatts to one target station, and through a newly developed magnetic beam splitting system some 100 kilowatts to three smaller target stations in parallel. To achieve these ambitious goals the low energy section of the linac will use a RFQ and Half Wave Resonator linac. The medium-low energy section is presently designed using the newly developed triple spoke cavities from IPNO in Paris while the medium energy section uses five cell elliptical cavities developed at CEA in Paris. Finally, the high-energy section will also use the five gap elliptical cavities adapted for the higher energy. The design has been optimized for beam quality and cost.

In an ISOL converter system, the neutrons are generated by high-energy protons impacting on a high Z material (so called spallation n-source). The radioisotopes are the fission products of fissile target material positioned close to the neutron source. In order to cope with the 2.3 MW power deposited in the spallation target, out of the 4 MW EURISOL proton beam, the converter has to be made of liquid metal. Two options based on axial or radial molten metal flow directions were investigated. Conceptually, several targets filled with ^{235}U or other actinides are inserted, through a channel created in the shielding, close to the neutron source at the position of maximum neutron flux. The neutron flux is thermalized in order to optimize ^{235}U fission while for other fissionable target materials, like ^{238}U or ^{232}Th, a hard neutron spectrum is required. Up to six targets can be positioned simultaneously, linked to single ionization ion sources (laser, plasma, ECR).

Up to three direct targets, in which the target material is directly exposed to the proton beam will also be available simultaneously. The main challenge set by the EURISOL beam power, is that the evacuation of the energy deposited by the 1 GeV protons through ionization in the target material, while the target materials (some of which are low density and open structure materials or are in the form of oxides with thermal insulating properties) are kept at the highest possible temperature to minimize the diffusion time of the radioisotopes.

The beam from the target stations has to be prepared for experiments with the merging, cooling, mass-separation and charge state multiplication of the six beams from the multi MW fission targets representing the biggest challenge. Preliminary studies have been performed of merging using a so-called arc ECRIS source which has geometry suitable for injection of several beams into an ECR plasma from which a single beam later can be extracted. The transverse cooling will be done in a newly developed high intensity RFQ cooler which also permits pulsing of the beam for experiments needing a specific time structure. The mass separation will be done with a classical dipole systems consisting of up-to four independents dipoles which should be capable of isobaric mass separation providing that the radioactive beam can be transversely cooled to a sufficiently small beam emittance. The exotic ion species from this area will then be directed towards low-energy experimental areas, where they can be captured in magnetic “traps” so that their properties can be studied, or led into the post-accelerators. Prior to post acceleration, the necessary charge breeding will be done in either an ECR source or in a new high intensity CW EBIS source.

There will be at least one superconducting linear accelerator, up to 200 meters long, in which exotic ions will reach energies up to 150 MeV (million electron-volts) per nucleon. The high-energy linac has been optimized for ions with mass-to-charge ratio (A/Q) up to eight with a final top-energy of 150 MeV/u for ^{132}Sn^{25+} which has been selected as the reference beam. The linac consists of only three different cavity types: independently phased quarter wave resonators, half-wave Resonators, and spoke cavities. The post-accelerated beams will have sufficient energy to undergo secondary fragmentation, leading to neutron-rich nuclei further from stability than those produced by any facility existing or under construction today.

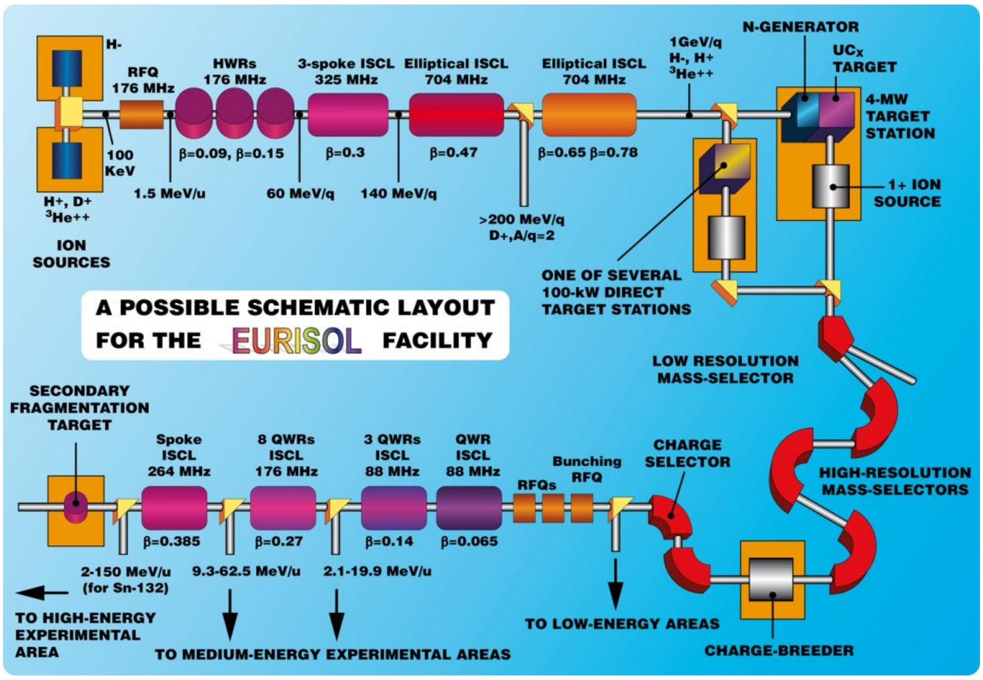


Figure 3: Schematic view of the EURISOL facility

4. Technological developments

Since the end of EURISOL-Design Study in 2009, a number of new large infrastructures that share common technical challenges in Europe and elsewhere are under design or have started their construction phase. The most relevant ones are Myrrha in SCK-CEN Mol, Belgium, ESS in Lund, Sweden, and ARIEL in TRIUMF, Canada. Myrrha is an ADS demonstrator. It will operate a 600 MeV, CW, 4 MW proton linac which will impact onto a liquid Pb/Bi eutectic target, part of the cooling system of the sub-critical core of a nuclear reactor. ESS in Lund is the European spallation neutron source that will operate a "long" pulsed proton Linac of 2.5 GeV, 14 Hz, 2.8 ms, 5 MW on average, intercepting a rotating tungsten target cooled with helium gas. Finally, ARIEL will be operating a 50 MeV, CW, 0.5 MW electron linac, aiming at producing 10^{14} fissions/s in a refractory actinide target to deliver neutron rich radioisotope beams, and will be complemented with a more traditional 500 MeV, CW, 100 kW, proton beam sent onto an ISOL target alike ISAC II presently in operation. This rapid overview should furthermore be completed with operational feedback obtained from SNS in Oakridge, the American neutron spallation source operating a pulsed 1 GeV, 1 MW proton linac onto a liquid mercury loop target.

In view of the elements obtained from these different high power facilities, and integrating recent evolutions in the way beams are delivered at ISOLDE at CERN, different key elements of the EURISOL facility needs to be specifically addressed in the coming 5 to 10 years.

a. Superconducting Linear Accelerator Technology

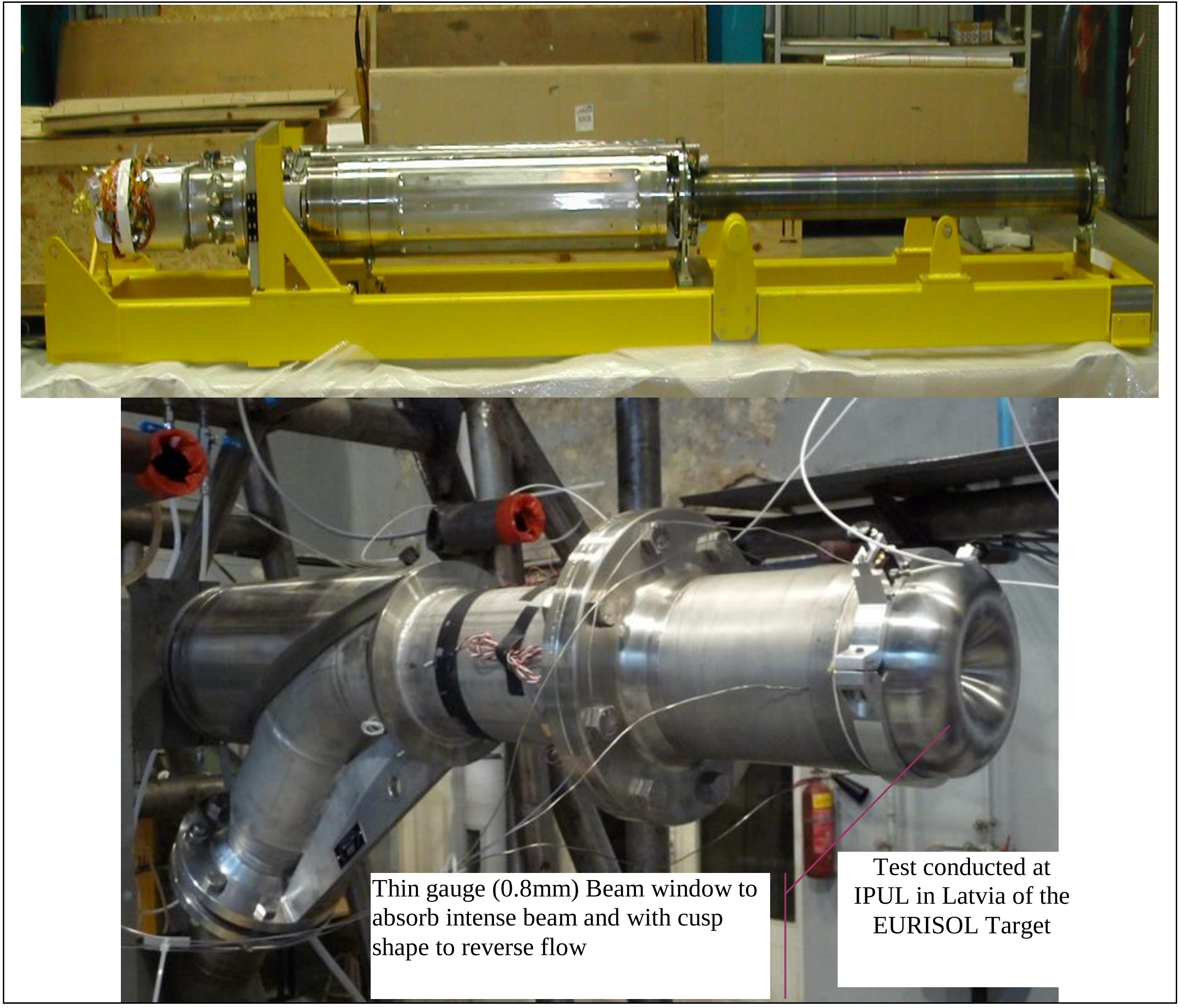
Advances in RFQ systems and superconducting accelerator cavities are necessary for the realization of the HIE-ISOLDE and SPIRAL2 projects and later for EURISOL, for both proton driver and heavy ion post-accelerator. At CERN activity driven by R&D towards HP-SPL for proton driver and HIE-ISOLDE for the post-accelerator and the low and intermediate energy of the driver. Strong synergy with ESS at Lund and ISOL@MYRRHA at CEN-SCK, Mol, Belgium.

b. Neutron converters

Converters which produce neutrons from initial charged particle beams are an essential component of high power ISOL facilities. Solid converters are in use at ISOLDE and being developed at GANIL for SPIRAL2.

Within the EURISOL Design study, the target complex was one of the key elements of the EURISOL facility, which was the subject of intense design work and preliminary prototyping. The 4 MW mercury converter was to be set up in a target station where it would be utilised in conjunction with a uranium target to create exotic isotopes by rapid fission. The converter was based on a circulating metal loop exposed to direct proton beam irradiation. First prototypes were developed and tested off-line, from which relevant experience was gained. At the present stage, several issues are yet to be addressed, such as the impact of beam irradiation parameters on the liquid metal loop operation. Likewise, the target development will necessitate further research in the field of heat exchange with liquid metal, irradiation, corrosion and fatigue testing of materials.

Achieving the design of the full-scale target for EURISOL will require several partial tests: first of sub-components, irradiation at lower power, through to instrumentation tests, and finally full-scale tests. In order to better ascertain the needs for testing a high-power target, various existing and projected facilities have to be examined and their characteristics evaluated. These issues will be partly addressed in the WP9 task of the TIARA project lead by CERN.



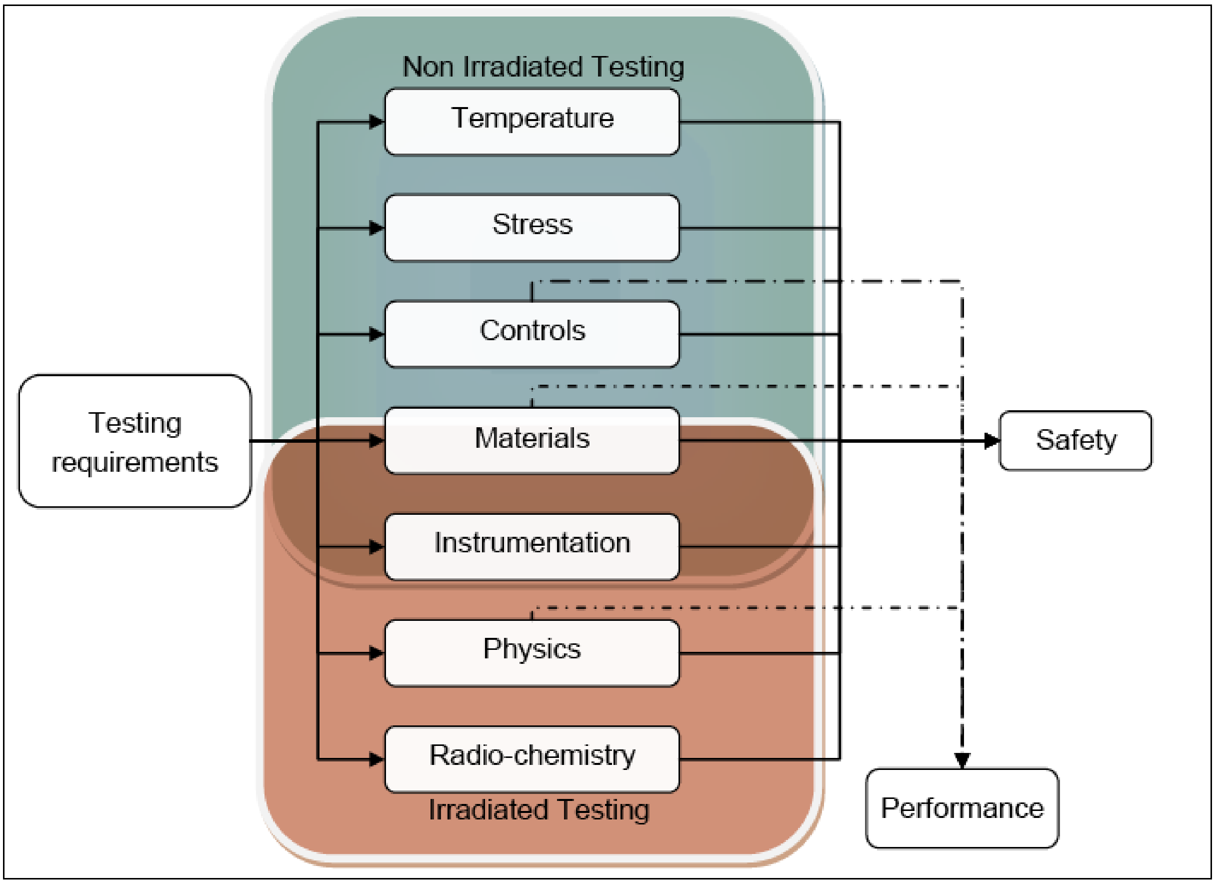
Thin gauge (0.8mm) Beam window to absorb intense beam and with cusp shape to reverse flow

Test conducted at IPUL in Latvia of the EURISOL Target

Figure 4: Liquid metal neutron source Megapie (top), Eurisol on test stand (bottom)

Testing liquid metal sources require setting up a liquid metal loop with all measurement devices required for measuring pressure, temperature flow and local velocities where needs. Prior experience gained in this respect indicates that selecting specific components for dedicated tests such as the beam window is a proven way forward. In a graded approach aimed at minimising risk, integral testing is required only once the component testing is successful.

In order to proceed in a cost-efficient manner, the different aspects of target testing have been broken down into separate testing requirements to avoid replicating large facilities or placing such high demands on the proposed facilities, that they would make the project unaffordable. Each requirement can thus be assigned to a specific facility. Where compatibilities exist, adaptations are to be made; otherwise a dedicated facility would have to be built. By focusing on a particular testing requirement, it is however far more likely that an existing facility may accommodate the specific testing needs, failing which the purpose-built facility which would have to be built would focus on a narrower set of objectives and thus be cheaper.



Ideally both solid and liquid metal targets should be developed in parallel so as to promote dissemination of knowledge. Some of the facilities may then be shared between a solid target testing station and a liquid metal target testing station if both options are pursued.

c. Development of fission and other target materials

The improvement of radiation hardness and release properties of ISOL targets are essential to increase the beam intensities and scientific output of ISOL facilities. Vigorous related R&D, particularly concerning sub-micron structured target materials, are performed at ISOLDE. This has already been witnessed using solid targets with nanostructures, and should be translated to the most important class of Uranium carbide targets within the WP8 in FP7-ENSAR. If the gain of at least one order of magnitude is confirmed for the most exotic isotopes, this would pose the question as whether a MW-class primary beam power is still required to meet the EURISOL physics goals, with implications on cost, site selection decision and safety aspects.

In line with the precedent results, an important prototype tests is foreseen in 2014 on a liquid metal target loop equipped with a diffusion chamber. This should indicate if isotope release properties can be improved by fragmentation of the molten metal into thin droplets.

A final axis of development consists in the production of beams of refractory elements that were until then not accessible by the ISOL method. Such beams are available by fragmentation of the post-accelerated (non-refractory) secondary radioisotope beams within EURISOL-DS. The method consists in the release of the refractory elements through volatile molecule formation and subsequent break-up in the ion source cavity, either by laser light or by electron impact.

d. Improvement of Ion Source performances

Extracted as singly charged ions from the target-ion source units, the radioactive isotopes have to undergo a charge breeding process to an n+ state to match the limit in mass-to-charge-ratio of the post-accelerator. The study and development of charge breeding techniques plays a prominent role for optimizing the post-acceleration of intense and exotic beams that will be produced in EURISOL. High charge states, i.e. relatively low A/q-ratios, allow for compact ion accelerators and higher final beam energies, in particular in combination with superconducting LINAC structures. This post-acceleration scheme, also known as 1+ n+ scenario, presents several technical challenges because of the diversity of the produced isotopes in terms of mass (spanning the complete nuclear chart), lifetime (short lived, 1ms to stable), produced intensities (from a few up to 1E13 ions/s) and because of the combined rareness and short lifetimes of the most exotic isotopes.

Because of the challenges listed above, the charge breeding technique used has to be universal, rapid, efficient and needs to deliver sufficiently high charge states to allow the post-acceleration of ISOL-type ion beams produced by a EURISOL-like facility. Other parameters may additionally influence the choice of technique. The time between system failures, the time to repair and the maintenance requirements may also have to be considered in view of radioprotection issues, while different aspects of flexibility includes ease of charge state selection and continuous wave (CW) contra pulsed operation capabilities.

Up to now, mainly three charge-multiplication techniques are in use for the post-acceleration of radioactive beams. The first one is the stripping technique based on acceleration of low charged ions followed by subsequent stripping in a gas jet or thin foil. Although it is a very efficient method for the production of bare light ions, a lower efficiency is experienced for heavy ions for which the post-stripping charge-state distribution is wide, and multiple stripping stages have to be used. It also requires a costly pre-stripper section, with low frequency RF-structures for the extreme A/q-range, which accelerates the radioactive ions to the minimum energy needed for the stripping process. Multi-charge state acceleration is an attempt to improve the overall efficiency, at the cost of worsened longitudinal and transverse emittance properties. The stripping method, although the most rapid and robust one, might not be the best choice for EURISOL due to the drawbacks given above. The two other charge breeding techniques make use of either an Electron Beam Ion Source (EBIS) or an Electron Cyclotron Resonance Ion Source (ECRIS) as charge breeders. Apart from EURISOL, many facilities are presently investigating or developing EBIS/T and ECRIS charge breeders. Among them, SPIRAL2, SPES, the CARIBU project at ANL and TRIUMF/ISAC will use ECRIS charge breeders. On the other hand MSU is developing an EBIT charge breeder for FRIB based. In this context the two techniques of charge breeding are expected to evolve rapidly, and second generation EBIS and ECRIS charge breeders are already being built or tested. This section will therefore focus on EBIS and ECRIS charge breeding methods.

The EBIS charge breeding concept combines an EBIS with a preceding Penning trap or RFQ cooler for accumulation, bunching and cooling of the beam. It has been pioneered at REX-ISOLDE and there provided beams with masses ranging from 8Li to 224Ra, and with very different half-lives and chemical properties (alkali, metallic and noble gas ions), including fragments of molecular beams coming from ISOLDE [1]. The inherent properties of an EBIS facilitate breeding of ions to high charge states combined with low residual gas content in the extracted beam, however, space charge limitations, primarily set by the Penning trap, limits the injected current to around 1 nA. The machine is best operated in pulsed extraction mode, favouring the injection into pulsed LINACs.

In the ECRIS charge breeder, the ions are injected directly without prior preparation. The device has a very high current capability, exceeding 1 uA injected current. It is a less complex system which demonstrates a high reliability. The extracted CW beam is well adapted to cyclotrons and superconducting LINACs, although the device can be operated in pulsed extraction mode with some ms extraction time. Presently the performance is hampered by the large current of residual gas ions produced on top of the charge bred radioactive ions.

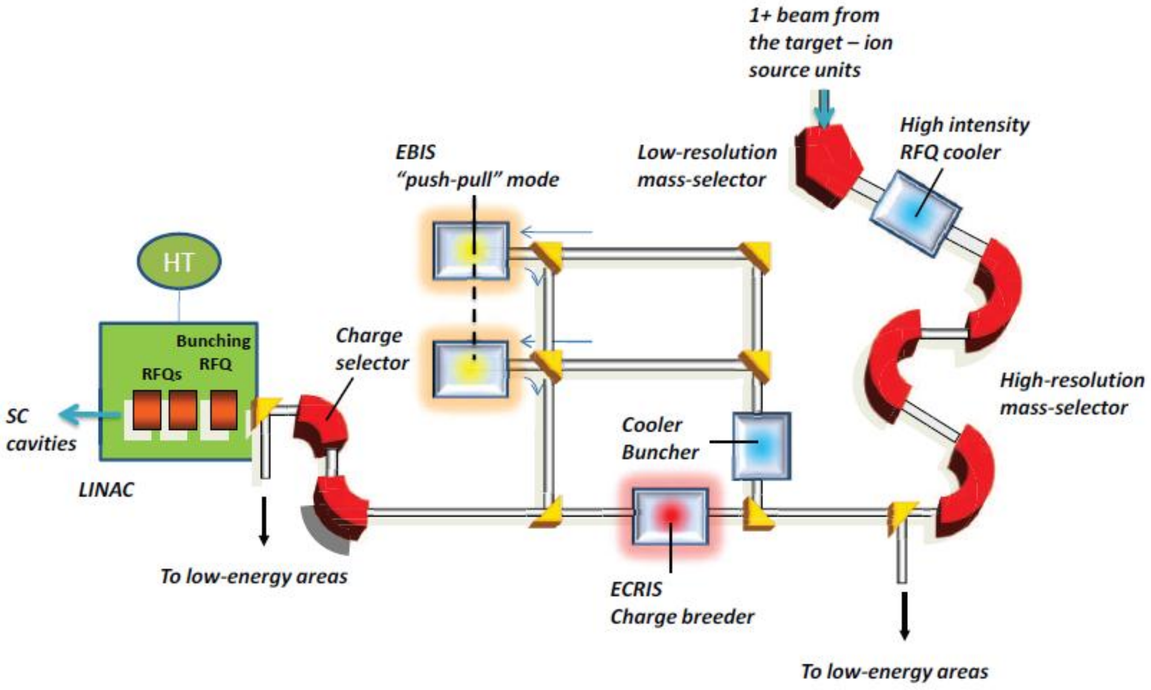


Figure 5: Detail of the EURISOL layout accommodating both charge breeders. Optionally the two EBIS will be run in "push-pull" mode for a pseudo-CW operation. Taken from [2].

Based on an evaluation of the two charge breeding methods performed within the EURISOL framework, a solution can be proposed that should satisfy the needs of a future facility by using both charge breeders types in parallel and their complementary features (see Fig. 5). In summary the abilities of both breeder systems are:

- Charge states yielding mass-to-charge ratios between A/q=2-3 and A/q=7 can be obtained for all elements in the chart of nuclides, with lowest A/q for EBIS.
- Efficiencies well above the per cent range for any A, Z range can be obtained, with a wide range of isotopes for which the efficiencies are around or higher than 5%. ECRIS breeders cover masses above 20 while EBIS systems cover the whole chart of isotopes.
- The charge breeding times are well below one second (whatever choice of charge breeder), which is shorter than or similar to the typical diffusion-

effusion times from ISOL targets. Very short breeding times for short lived isotopes, down to the ms region with an EBIS breeder, are a priori possible.

- Intense radioactive beams - up to 1E13 ions/s - can be charge bred without loss of efficiency by ECRIS charge breeders.
- Exotic beams of medium to low intensity – as low as 1E2-1E3/s – can be charge bred by the EBIS keeping very good beam purity.
- CW operation of the superconducting LINAC will be possible using the natural mode of operation of the ECRIS charge breeder, and two EBIS charge breeders in “push-pull” mode.

In the future, the performances of ECRIS and EBIS may overlap more and more. For instance, one should expect purified beams from ECR charge breeders and true CW operation from EBIS charge breeders. It is not yet clear where the exact frontier between the two techniques and their domain of application will be. The numbers given above are only indicative, and both techniques are expected to exhibit improved performances with time as experience is gained and numerous developing goals are achieved.

e. Beam manipulation and purification

Progress in this very challenging subject is essential for providing high quality beams to the users. Major progress is expected in Coolers and mass separators and Gas cells and traps within the HIE-ISOLDE design study phase.

The Isolde ion sources are heavily optimised for efficiency, the principal concern when studying exotic isotopes. It would be difficult to make any substantial reduction of the ion-source's emittance without having some significant effect on its efficiency. The solution is to employ a separate beam-cooler, downstream of the ion-source and upstream of the separator's dispersive sections. Isolde already possesses a beam-cooler based on a continuous-injection RFQ ion-trap. A low-pressure buffer gas inside the RFQ cools the beam and achieves an extracted beam emittance of $\leq 3\pi$ mm.mrad. However the existing cooler is situated downstream of the HRS, and therefore has no effect on the HRS performance. We propose to design a new cooler, based on the existing design, but adapted for operation as part of the HRS.

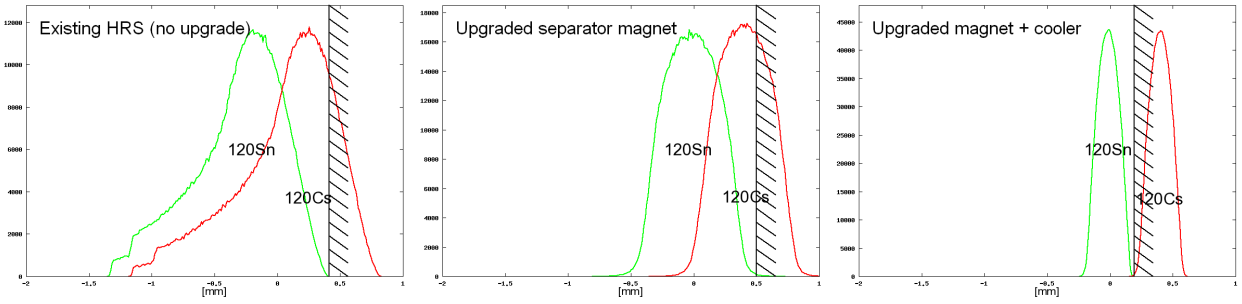


Figure 6: Example calculated beam profiles of the HRS

A calculation of the beam-profiles for A=120 beams is shown in figure 6. This example represents a typical case in which a upgraded HRS could deliver improved ^{120}Ag beam quality by drastically reducing the transmission of the unwanted background beam (in this case ^{120}Cs). The black vertical line represents a movable slit, positioned to optimise the statistical significance of the signal beam delivered to the experiment. The leftmost graph shows the situation for the un-upgraded HRS: in this case there is little the separator can do to suppress the unwanted isotope. The centre graph shows the effect of upgrading the separator magnet. The rightmost graph shows the effect of combining an upgraded magnet with a beam cooler: here the resolving power of the HRS is dramatically improved.

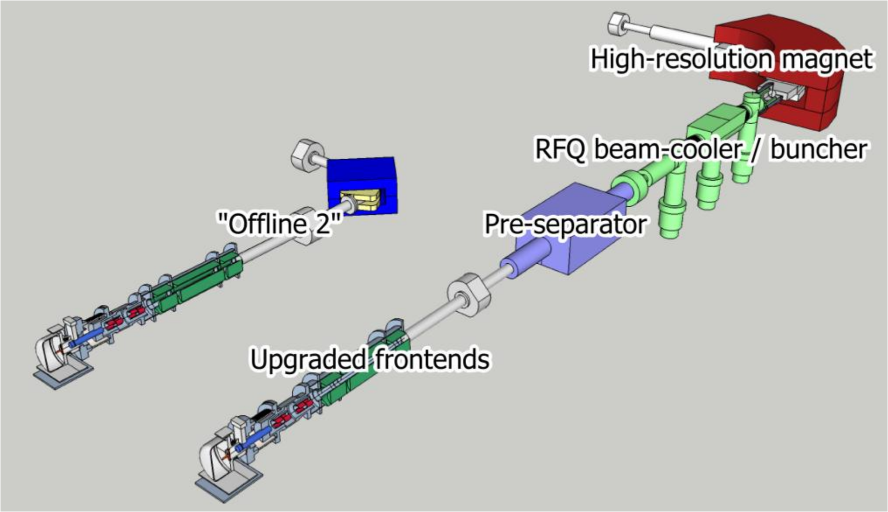


Figure 7: Layout of a Mark-II HRS offline test stand

To study the design and performance of a mark-II HRS we intend to construct an offline test stand, as illustrated in figure 6. Initially it will be a simple conventional low-resolution separator, to which prototypes of the cooler and corrected-magnet will be added as they become available. As shown in the diagram the cooler will also require a new pre-separator stage which must be designed and tested. The test stand will permit us to optimise the performance of each component and study its real-world performance with beam. It will also be used to verify the compatibility of each component and make adaptations where necessary. For example, the extraction stage of the cooler must produce a beam suitable for injection into the magnetic sections. There is limited space for dedicated matching sections, so it is desirable to design the cooler extraction optics to avoid the need for extra quadrupole lenses. The goal is to build a simplified but working version of the upgraded HRS, before any installation work begins on the Isolde facility.

5. Collaborations / Resources

The concentration of ISOL facilities in Europe is unique in the world, and coordination of their development work will strengthen Europe’s technological excellence. All major European ISOL installations that are research infrastructures (ALTO, EXCYT (LNL-LNS), SPIRAL (GANIL), ISOLDE and IGISOL (JYFL)) are helping to lay the groundwork for the future “ultimate” ISOL facility EURISOL which aims to integrate all European ISOL activities at the horizon of the 2020 decade. EURISOL will encompass the progress being achieved today in many areas at the existing facilities, R&D which will be performed at the intermediate generation facilities (HIE-ISOLDE, SPES and SPIRAL2).

EURISOL related activities are overseen by the EURISOL Project Office (PO) which has four members: Yorick Blumenfeld (CERN, chair), Albeto Facco (INFN- Legnaro), Marek Lewitowicz (GANIL) and Piet Van Duppen (UC Leuven). The PO meets at least 4 times a year by telephone. Currently a EURISOL collaboration is being put in place which will have a steering committee representing the stakeholders.

Future EURISOL users are members of the EURISOL USER Group, which has over 1000 members. This group elects an executive committee of 9 members, renewed by half every two years. The current chair is Angela Bonaccorso (INFN-Pisa).

There is a work package called EURISOL-NET within the ENSAR (European Nuclear Structure and Application Research, FP7) initiative funded by the European Commission. EURISOL-NET is led by Yorick Blumenfeld (CERN) and comprises two tasks:

- Coordinating EURISOL R&D at current European ISOL facilities led by Yacine Kadi (CERN)

- Updating the EURISOL Physics case led by Angela Bonaccorso (INFN-Pisa)

EURISOL-NET will organize the next EURISOL town meeting in Lisbon (October 2012) in collaboration with the PO and the User Group. The total budget of EURISOL-NET is 283 KEuros over 4 years.

Within ENSAR two Joint Research Activities (JRA), ACTILAB (led by Thierry Stora – CERN) and PREMASS conduct R&D for actinide targets and beam preparation respectively, useful for EURISOL.

The objective of the work package TIPHAC of the TIARA preparatory phase (FP7) is to coordinate the design of test infrastructures for two major technical issues before launching the construction of EURISOL: the development of high power targets (led by Yacine Kadi – CERN) and low beta superconducting accelerating structures (led by Sebastien Bousson – IPN Orsay). The total budget of TIPHAC is 690 KEuros over 3 years.

The EMILIE project, led by Pierre Delahaye (GANIL) and promoted by the FP6 network NuPNET, is a consortium of 9 European laboratories including CERN as associate partner which conducts R&D on improving performances of Charge Breeders which is a critical issue for post accelerating EURISOL beams. The total budget of EMILIE is 513 KEuros over 3 years.

Thierry Stora (CERN) is leading an effort to build and irradiate a Pb-Bi loop at ISOLDE, which can be considered a prototype for the EURISOL converter target. This collaboration includes CERN/ISOLDE, CEA-Saclay (SPhN), ESS, MYRRHA, PSI, and Saha Institute Kolkata, India. CERN has committed 300 KCHF over 3 years and 2 FTE manpower to this R&D effort which exploits the synergies of the major European high power accelerator projects (ESS, EURISOL and MYRRHA).

6. Conclusions

An ultimate ISOL facility such as EURISOL holds broad scientific promise but represents a formidable technological challenge. Therefore a European roadmap has been established which includes building of 3 so-called “intermediate generation” ISOL facilities: HIE-ISOLDE which is a major upgrade of the current ISOLDE facility at CERN, SPES in Legnaro, Italy and the most ambitious which is SPIRAL2 at GANIL, Caen, France. These facilities, which are precursors to EURISOL will provide a ground for development and testing of many of the technological solutions outlined in the reports from the EURISOL Design Study.

7. References

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[2] P . Delahaye et al., *Evaluation of charge breeding options for EURISOL*, Eur. Phys. J A46 (2010) 421-43.