Project objectives, work progress and achievements, project management

Project objectives for the period

In order to carry out research at the forefront of fundamental nuclear science, our community of nuclear scientists profits from the diverse range of large research infrastructures existing in Europe. These infrastructures can supply different species of ion beams and energies but are complementary in their provision of beams and address different aspects of nuclear structure. In this way, we can learn how the nuclear forces arising from the interaction between the building blocks, *i.e.* neutrons and protons, manifest themselves in the rich structure of nuclei, and how different isotopes of elements are synthesised in primeval stellar processes.

These European nuclear physics facilities are world-class and excel in comparison with facilities elsewhere in the world. Furthermore, the vibrant European nuclear physics community has made great efforts in the past to make the most efficient use of these facilities by developing the most advanced and novel equipment needed to pursue the excellent scientific programmes proposed at them. Our community also has a long tradition of applying state-of-the-art developments in nuclear instrumentation to other research fields (*e.g.* archaeology) and to benefit humanity (*e.g.* medical imaging). Together with multi-disciplinary and application-oriented research at these facilities, these activities ensure a high-level of ***socioeconomic impact***. This work has been done under the auspices of NuPECC (Nuclear Physics European Collaboration Committee) and drawing support from previous EC framework programmes. Our community has delineated the steps needed to pursue coherent research programmes at these facilities. This was done within the framework of the recent Long-Range Plans (LRPs) of NuPECC published in 2004 and 2010. In these LRPs, NuPECC addressed future perspectives in six major subfields of research in nuclear physics and re-emphasised the role of the European Network of complementary large-scale facilities where past achievements and future perspectives for research in nuclear physics are excellent. **ENSAR** is the integrating activity for European nuclear scientists who are performing research in three of these major subfields: Nuclear Structure, Nuclear Astrophysics and Applications of Nuclear Science. Its core aim is to provide access to seven of the complementary world-class large-scale facilities: GANIL (F), GSI (D), joint LNL-LNS (I), JYFL (FI), KVI (NL), CERN-ISOLDE (CH) and ALTO (F). These facilities provide stable and radioactive ion beams of excellent qualities ranging in energies from tens of keV/u to a few GeV/u. The stable-ion beams range from protons to uranium. Radioactive ion beams are produced using the two complementary methods of in-flight fragmentation (IFF) and isotope separation on line (ISOL), so that several hundred isotopes are available for the user.

These facilities will be offering access to a very large, wide and diverse user community. The size of this community of physicists in nuclear structure, nuclear astrophysics, and applications of nuclear science in addition to the staff that is involved in accelerator and detector development and in running the facilities ranges between 2700-3000 scientists and highly qualified engineers according to a recent survey by NuPECC (http://www.nupecc.org/pub/). The facilities will provide an increased amount of beam time for applications of nuclear techniques.

To enhance the access to these facilities, the community has defined a number of Joint Research Activities (JRAs), using as main criterion scientific and technical promise. These activities deal with novel and innovative technologies to improve the operation of the facilities. They are in general relevant to more than one facility and rely on strong participation of the European university groups. These activities involve all facets of operation of an accelerator facility starting with the improvement of ECR ion sources to increase the intensity and the energy of stable and radioactive ion beams for physics experiments (**ARES**). This goes hand in hand with ISOL target technology for the development of new actinide targets, which aims at increasing the intensity and reliability of the delivered exotic radioactive ion beams (RIBs) for the operating European ISOL facilities (**ActILab**). These two activities are supplemented by an activity to improve the low-energy beam preparation and manipulation of RIBs and to go beyond the state of the art in spectroscopic tools used in studies with RIBs (**PREMAS**). Experimenting at such facilities requires development of new detection materials and detection systems (**INDESYS**), general platforms for simulations of both current and future detector set-ups (**SiNuRSE**) and the development of modern theoretical tools for describing and interpreting experimental results as well as pointing the way ahead for experimental projects (**THEXO**). In addition, a key activity aims at integrating the laboratories in ***Central and South-Eastern European countries*** with those elsewhere in Europe, by developing novel technologies and methodologies of universal benefit that could be used both at these laboratories and elsewhere (**EWIRA**). These developments will give a strong impetus to these emerging laboratories and their communities and enhance their external use. Particular importance is attributed to all RTD work, which might lead to multi-disciplinary or industrial applications.

The network activities of **ENSAR** have been set-up with specific actions to strengthen the communities' coherence around certain research topics (nuclear astrophysics **- ATHENA**), to pool resources and to provide instruction courses to users (**EGAN -** Gamma and Ancillary detectors Network). They foster future cooperation towards achieving high-intensity stable beams (**ECOS**) and radioactive ion beams (**EURISOL-NET**). They promote foresight studies for new instrumentation and methods and stimulate complementarity. They ensure a broad dissemination of results and stimulate multi-disciplinary and application-oriented research at the Research Infrastructures (**EFINION**). In addition to these five specific networks, the managing network **FISCO** will insure a smooth running of the integrating activity as a whole in all aspects of technical, scientific, financial, administrative, contractual and legal activities. It will also stimulate dissemination of knowledge and outreach activities.

All of the activities proposed by **ENSAR** have objectives which have all been achieved within the project lifetime as indicated by the milestones that have been marked for each of the activities. These milestones and the deliverables of the activities are well defined and measurable in timing and content. They have all been achieved by the end of the project except for a minor milestone on which work is still ongoing.

Work progress and achievements during the period

Work Package 2: NA02-ECOS

Participants: GANIL, GSI, INFN, JYU, CNRS, UWAR, IFJ PAN

The objectives of the ECOS Network are:

- Bring together and coordinate the expertise that is available in the European countries in order to pursue the research and developments activities needed in all aspects related to the production and use of high-intensity heavy-ion beams.
- Optimise resources and manpower for the upgrade and development of various stable ion beam facilities in Europe in order to optimise their scientific output. From this point of view, NA02-ECOS has a direct link to the TNA delivering stable ion beams to the users community in Europe. These are GSI, GANIL, LNL/LNS, JYFL, ALTO and KVI

The network has defined 4 Tasks, 4 milestones and 3 deliverables:
The tasks are:
1- 1 High-power thin-target technology
2- Synergies in Super-Heavy Element (SHE) Research
3- Organisation of biennial ECOS Workshops
4- Coordination of stable ion beam facilities in Europe

The milestones are:
1- Network setup (month 12)
2- Webpage available (month 12)
3- 1st ECOS joint workshop and coordination committee meeting (month 24)
4- 2nd ECOS joint workshop, coordination committee meeting and town meeting (month 44)

The Deliverables are:
1- D-NA02-1: Report on the development of high-power thin-target technology with special emphasis on new techniques and methods that will allow increasing the primary beam intensity usable with such targets. (month 40)
2- D-NA02-2: Report on the research activities related to SHEs and on the achievement made in this research field (month 40)
3- D-NA02-3: Report on the collaborations and synergies between facilities providing stable ion beams in Europe initiated and driven by ECOS network (month 40)

During the third period of the contract many activities have taken place regarding the preparation of the three deliverables that correspond to three reports. The ECOS town meeting that was organised at IPN Orsay from 28-29 October 2014, represents the last milestone where the three reports have been discussed and agreed on.

D-NA02-1: Report on the development of high-power thin-target technology

In the study of super-heavy nuclei, a major experimental concern is the behaviour of targets under high-intensity heavy-ion beam irradiation as well as the manufacturing of targets and the availability of target materials.

The material supply is particularly problematic for actinide targets because of the scarcity and the radioactive properties of the starting material. Indeed actinides are produced in nuclear reactors and often require sophisticated facilities and equipment for producing and separating the required isotopes in sufficient quantities. Some actinides can only be produced in national facilities situated in the U.S.A. or Russia, and the full cost of production and separation is very high. Assuming the actinide material is available the transformation into thin foils of appropriate thickness and quality is also challenging. Due to the high radio-activities involved, the development of actinide targets requires specific knowledge of radiochemistry and the material can only be handled, transformed and transported by laboratories with special licenses granted by governmental authorities.

The behaviour of the target foils under irradiation is related to the properties of the selected heavy-ion beams and the structure of the target foils. On one hand, the properties of the beam and the spectrometer (such as energy, intensity, spatial dimensions, acceptance and transmission) constrain the thickness of target foils to be only in the order of some few hundreds of $\mu g/cm^2$. On the other hand, thin backings are required for state-of-the-art fabrication techniques and the prevention of undesirable beam scattering. These prerequisites result in multiple risks for the targets upon irradiation:

• Heating of the foil due to the beam energy loss

• Atomic and chemical reactions due to the beam impact at the material interface between backings and targets

• Mechanical stress and radiation damage.

These phenomena of material transformation under irradiation conditions must be carefully controlled during the use of these targets in order to ensure safety and target survivability.

A review of present and future target stations used for super-heavy element studies, has been done with a focus on target technology including material supply, fabrication techniques, and target characteristics. Some perspectives for improved target technology are also identified.

D-NA02-2: Report on the research activities related to SHEs

Since the mid-20th century, the synthesis of new chemical elements by nuclear reactions has dramatically expanded the periodic table, from 92 elements in 1940 to 118 today. This increase in the number of observed nuclei has been enabled by a series of advances in nuclear reaction physics, beginning with neutron and light ion bombardment, followed by the cold fusion of heavy nuclei, and most recently by hot-fusion experiments using actinide targets. This progress was possible thanks to advances in accelerator technology, high-flux reactors, radiochemistry, particle detection, and nuclear theory. The result has been new understanding of the physics of the atomic nucleus and the chemistry of heavy elements, as well as the production of new elements.

Super-heavy nuclei, i.e. nuclei containing 104 or more protons, challenge our fundamental understanding of nuclear structure and stability. Their very existence provides evidence for the shell structure of the nucleus, which confers stability and increased lifetime to nuclei containing closed shells of neutrons and protons. Many of the neutron-rich super-heavy nuclei have lifetimes thousands of times longer than would be expected without this shell stabilisation. The evidence points to an increase in lifetime as these nuclei approach the next predicted closed shells, at neutron number N=184 and proton numbers between Z=114 and Z=126. Nuclei in the vicinity of this “island of stability” are likely to have unique nuclear and chemical properties combined with significantly extended lifetimes.

Over the past two decades, significant progress has been made in the journey to the island of stability. Nuclei have been observed with neutron numbers up to 176 and proton numbers up to 118. Experiments aiming at increasing these numbers to N=179 and Z=120, are underway or planned. The powerful accelerators, in operation or under development at JINR in Russia, GANIL-SPIRAL2 in France, RIKEN in Japan, GSI in Germany, and LBLN in the U.S.A., offer the potential to accelerate the discovery and exploration of these extreme nuclei. The ultimate goal is to map the island of stability and produce measurable quantities of new, long-lived super-heavy isotopes for fundamental nuclear and chemical studies. This is an exploration unlike any in history, for the prize is finding new nuclei that may not exist on earth or in our solar system, and perhaps not even in the known universe. The physics and chemistry of these new elements will challenge our understanding of extreme nuclear matter and heavy element chemistry, and will open the door to a new materials regime that is both illuminating and revolutionary.

There are many significant challenges that must be addressed to achieve this vision. While substantial progress has been made, the path to significantly higher neutron numbers closer to the centre of the island is not obvious. Furthermore, the observed cross sections for the synthesis of super-heavy nuclei are very small, and improved production methods and accelerator technology are needed. However, there is much that can be accomplished today with existing capabilities, and much more progress will be enabled by new facilities currently under development. This progress in super-heavy element research and discovery will help show the way to the island, providing insights and answers to some of the most fundamental questions in nuclear physics and chemistry with broad implications for both science and technology:

- How many protons and neutrons can a nucleus hold together? What is the heaviest element that we can synthesise today and in the future? Where is the end of the nuclear chart in atomic number and mass?
- Can we develop a comprehensive theory of nuclei from the lightest to the heaviest? Are super-heavy nuclei fundamentally different, and do they represent a new state of nuclear matter?
- What are the properties and boundaries of the predicted "island of stability" for super-heavy elements? Does the stabilisation emerge without large energy gaps?
- How can we produce super-heavy nuclei that are more neutron rich?
- What is the physical and chemical behaviour of elements with extreme numbers of neutrons, protons, and electrons?
- Can we understand the details of the fission process and competing decay modes?
- Can we understand and optimise the production mechanisms for super-heavy nuclei: hot and cold fusion, multi-nucleon transfer, etc.? Can we produce measurable quantities of super-heavy elements?
- Do super-heavy elements exist in the universe, and how are they produced? Are there remnants of long-lived super-heavy elements on earth?

The report has been made to focus on:

1. General SHE strategy - "Visions and challenges"
2. Production of SHE and reaction dynamics
3. Nuclear structure of SHE
4. Instrumentation with emphasis on the accelerator projects at GSI, FLNR and GANIL/SPIRAL2

D-NA02-3: Report on the collaboration and synergy between stable ion beam facilities in Europe.

A number of meetings and workshops were organised during the funding period with the main goal of identifying and enhancing synergies between stable ion beam facilities in Europe and possible collaborations both in scientific and technical issues.

Physics cases that are currently studied with stable ion beams have been confronted at various facilities with both the possible beam intensity increase and the enhanced efficiency and sensitivities of future detection systems. As a result, it appeared that facilities such as LNL, GANIL and JYFL are very complementary in the field of gamma and particle spectroscopy and that GANIL and LNS remain among other activities very adapted to the study of nuclear dynamics. Important collaborations have been encouraged to join forces in order to use in the most effective and complementary way various European detection systems at several facilities. This concerns among others the AGATA collaboration and the FAZIA collaboration.

The Steering Committee of ECOS-NA through many meetings (up to 6 during the ENSAR contract period) has initiated several actions aiming at creating stronger ties between the stable ion beam facilities in Europe. One of these initiatives was the creation of a European chart of stable beams. This chart gathers beam data from eight European infrastructures: ALTO and GANIL in France, GSI in Germany, IFJ and SLCJ in Poland, JYFL in Finland and LNL and LNS in Italy. The chart is interactive. So, the user can choose the isotope of interest as well as its energy and its intensity. It is then possible to see which infrastructure produces the chosen beam. This is now available online: http://u.ganil-spiral2.eu/chart-ecos/. The other initiative that turned out to be very successful was the organisation of a 'Facilities Meeting' that gathered technical staff from various European stable ion beam facilities in order to exchange information, ideas and experience in technical issues going from optimising resources to improving and upgrading accelerator components. This meeting gave birth to an internet Forum for engineers and technicians to continue interacting on the same subjects. This 'Facilities meeting' is supposed to continue in the future on the basis of a biennial cycle.

The other initiative that has been undertaken by the community within the ECOS-NA is related to defining a European strategy for the future of stable ion beam facilities. This was thought to proceed through two activities:

- The success of ENSAR2 as an application for Integrated Activities within H2020. This will allow the continuation of many of the initiatives and actions that have been started under the umbrella of ENSAR.
- The revision and update of the ECOS/NuPECC roadmap of stable ion beams in Europe that has been elaborated more than 7 years ago and that needs, in addition to LINAG at GANIL, the inclusion of new projects such as the CW-LINAC project at GSI or the LINCE initiative in Huelva.

Deviations from Annex I
None.

Use of resources
It follows the work plan of Annex I.

Corrective actions
None.

Work Package 3: NA03-EURISOL-NET

Participants: GANIL, INFN, JYU, CERN, CNRS

Milestone achieved during the third period:

MS40 2nd EURISOL Town Meeting: dissemination of results and identification of physics and technologies for the future.

The second EURISOL Town Meeting was held on 30-31 October 2014 in Orsay. It was jointly organised with the second ECOS workshop (MS 33). There were 69 registered participants. The EURISOL part ran from Thursday, 30 October at 9:00 to Friday, 31 October at 13:00. On Thursday, seven talks covered the advances in ISOL technology in Europe over the past 4 years with emphasis on the new technologies which could be applied to a future EURISOL facility. Seven other talks summarised the scientific advances expected from ISOL facilities in the coming years, based on the reports from the five topical meetings which were organised in the framework of the EURISOL NET network. The Friday morning session included a presentation on synergies between EURISOL and the ESS project. It was followed by presentations of the two deliverables (D3.2 and D3.3) which were being finalised at the time. The meeting ended with a discussion on the future of the EURISOL concept and the opportunity to implement a first phase of EURISOL as a distributed facility encompassing major upgrades to the main European ISOL facilities: HIE-ISOLDE, ISOL@MYRRHA, SPES and SPIRAL2.

Deliverables submitted during the third period:

D 3.1 Transfer of R&D accomplishments between ISOL facilities-Report.

This deliverable was planned for month 32 and was delayed until month 40. This deliverable was compiled from the proceedings of the meeting which was milestone M3.4. It is 63 pages long and includes discussions of the following topics:

1. The SPIRAL2 RFQ
2. Multi-reflection time-of-flight mass analyser for analysis, optimisation, mass separation and precision mass measurements of radioactive ion beams
3. TWIN – Thermal-hydraulic experiment of the heat transfer coefficient on a concave beam WINdow
4. Recent ISOLDE RILIS developments and outlook for laser ionisation at next generation ISOL facilities.
5. Status of Neutron Converter for SPIRAL2
6. The MYRRHA Project in Belgium
7. Next-EBCB very fast charge breeding, production of fully stripped ions and CW beams with next generation Electron Beam Charge Breeder (EBCB)
8. Low-energy beam preparation, manipulation and spectroscopy - Summarising the activities of PREMAS in ENSAR
9. R&D on radioactive ion sources at the TNA ALTO facility
10. Status of TIS R&D for SPES RIB facility
11. UCx developments at IPN-Orsay
12. μ-Mapping of Electronic and Structural Properties of Complex Uranium Compounds

D3.2 Updated Physics and Instrumentation case for ISOL facilities

Planned for_month 44, submitted in month 52. This deliverable is based on the conclusions drawn from a series of topical meetings initiated by the User Executive Committee of the EURISOL Users Group within the scheme of Task 2, "Physics and Instrumentation" of the EURISOL-NET. It contains 5 chapters, each one resulting from one topical meeting:

1. The formation and structure of r-process nuclei between N=50 and 82
2. Neutron-deficient nuclei and the physics of the proton-rich side of the nuclear chart
3. Physics of light exotic nuclei
4. Going to the limits of mass, temperature, spin and isospin with heavy radioactive ion beams
5. Innovative Instrumentation for EURISOL

D3.3 Identification of technologies developed at ISOL facilities applicable at future facilities-Report

Planned for month 48, submitted in month 52. This deliverable is based on the technical workshops held at CERN in June 2011 (MS 37) and at Jyväskylä in May 2013 (MS 39). It contains five chapters detailing the technologies recently developed in the participant laboratories and applicable to a future ultimate ISOL facility such as EURISOL:

1. Solid and liquid neutron converters
2. Target materials: Uranium Carbide, Molten salts, Pb-Bi eutectic
3. Ion sources: FEBIAD, Laser ion sources
4. Charge Breeders: ECR, EBIS
5. Superconducting cavities and cryo-modules for particle acceleration

Scientific activity

The aim of the network EURISOL-NET was to coordinate the research and development at the major European ISOL facilities in view of constructing the future EURISOL facility which was designed during the FP6 Design Study contract EURISOL DS 515768 RIDS and to continuously update the scientific case for ISOL facilities in general and the future EURISOL in particular. To attain these goals EURISOL-NET included two tasks:

- TASK 1: Coordination and dissemination of R&D for ISOL facilities led by CERN
- TASK 2: Physics and Instrumentation for ISOL Facilities led by INFN

Activity of Task 1

No further workshops were organised during the third reporting period. Members of Task 1 met informally at CERN in order to complete deliverables D3.1 and D3.3.

Activity of Task 2

In order to continuously update the physics case and investigate new technologies for instrumentation for ISOL facilities and EURISOL the EURISOL-NET organised topical workshops in collaboration with the EURISOL User Group. These meetings brought together the best European experts of a given subfield in order to exchange ideas for long-term research plans. Each meeting gave rise to a comprehensive document which can be found at http://www.ensarfp7.eu/projects/eurisol-net/documents.

During the third reporting period the fifth and final topical meeting on “Innovative instrumentation for EURISOL” was held in York on 15-17 July 2014. There were 42 participants and 26 talks were given. The programme focused on the following subjects:

- Instrumentation for beam handling: storage rings, separators, ion traps;
- Instrumentation for radiation detection: charged particles, gamma-rays, neutrons, electrons;
- Spectroscopic techniques: electron scattering, fast timing, recoil decay tagging, measurement of ground-state properties.

In addition, the current status of the main ISOL projects for upgrades and new facilities was reviewed in a series of dedicated presentations.

In month 52, representatives of the different participants met in Pisa for 3 days in order to finalise deliverable D 3.2.

Conclusion

All milestones and deliverables of the activity have been fulfilled. Task 1 has successfully federated the research and development work at the current ISOL facilities through the exchange of information on the technical advances achieved. It also identified and promoted the advances useful for the design of the future “ultimate” facility EURISOL, following the strategy defined in the NuPECC roadmap for European research infrastructures. Task 2 has updated the science case for

ISOL facilities and for the future EURISOL facility in coordination with the user groups of current facilities and the EURISOL User Group.

Deviations from Annex I
None.

Use of resources
It follows the work plan of Annex I.

Corrective actions
None.

Work Package 4: NA04-ATHENA

Participants: INFN, TUD, NCSRD, UNIBAS, GUF

Summary of progress

General activities

Webpage
The webpage was updated regularly with current and up-coming events (http://exp-astro.physik.uni-frankfurt.de/athena/). The list of contact persons for each task was also updated and enlarged. The work on the webpage is continuously in progress.

Mailing list
The mailing list (http://dlist.server.uni-frankfurt.de/mailman/listinfo/ATHENA for information, address: athena@physik.uni-frankfurt.de) was updated and includes all contact persons listed on the webpage and other persons interested in the aims of ATHENA.

Presentations
ATHENA and its aims were presented at several workshops and meetings to increase its visibility and encourage collaborations with the associated scientific communities:

1. International School of Nuclear Physics – 35th course: Neutrino physics – Present and Future, Erice Sicily, Italy, 16-19 September 2013
2. NUSTAR week, Collaboration meeting, Helsinki, Finland, 7-11 October 2013
3. Future Directions in the Physics of Nuclei at Low Energies, ECT*, Trento, Italy, 21-23 May 2014
4. XIII Symposium on Nuclei in the Cosmos (NIC XIII), Debrecen, Hungary, 7-11 July 2014
5. 15th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics (CGS), Dresden Germany, 25-29 August 2014
6. 9th International Conference on Nuclear Physics at Storage Rings (STORI), St. Goar, Germany, 28 September - 3 October 2014

Workshops, schools, meetings

ATHENA Brussels Workshop on Astrophysics, Brussels, Belgium (27-28 January 2014)
From 1984 to 2004, a series of annual workshops was held at Université Libre de Bruxelles, Belgium, with the aim to bring together astrophysicists and nuclear physicists from both theory and experiment to discuss about current problems and to exchange views.
ATHENA aimed at reviving this grand tradition with a two-day workshop. Three main topics were proposed –Explosive nucleosynthesis, Stellar burning phases, and Neutron-capture nucleosynthesis – each being closely related to one of the three tasks of ATHENA. Other topics like, *e.g.*, Primordial nucleosynthesis emerged during the registration and abstract submission process and were also included. Time for intense and detailed discussions was available during the sessions as well as during the joint coffee and lunch breaks.
The workshop took place at the Université Libre de Bruxelles, Brussels, Belgium, from 27-28 January 2014, with Pierre Descouvemont as local organiser. The 44 participants came from 13 European countries (including Russia) as well as Israel and Turkey. The programme consisted of six invited overview talks (40 minutes plus 10 minutes discussion) and 24 contributed talks (15 minutes plus 5 minutes discussion). The pdf-files of all contributions are provided password-protected at the workshop's webpage instead of publishing proceedings (see http://exp-astro.physik.uni-frankfurt.de/meetings/athena-brussels-meeting).

ATHENA Final Workshop, Villa Vigoni, Lake Como, Italy (13-16 May 2014)
The aim of this Final workshop was to summarise the activities of ATHENA within the past years, to discuss about the outcome in the different tasks, and develop schemes for further funding applications on a European scale.
The workshop took place at Villa Vigoni, the German-Italian Centre for European Excellence located at Lake Como, Italy. It was divided in a scientific part and a part focussing on future funding

possibilities and strategies. For the scientific part, six invited speakers presented overview talks (45 minutes plus 15 minutes discussion). Two overview talks took place for each task of ATHENA: one about the developments during the funding periods of ATHENA and one about the plans for the short-term and medium-term future, respectively. In addition, eight contributed talks (20 minutes plus 10 minutes discussion) were presented by the participants. The second part of the workshop started with a presentation of the activities within ATHENA during the past funding periods and an outlook on the remaining actions. Afterwards, different funding schemes on European level were presented and discussed for their potential regarding Nuclear Astrophysics. Finally, the possibilities for future applications were summarised in a Round table discussion. Some of the participants were selected to act as contact persons for short-term applications.

The pdf-files of all contributions as well as the minutes of the Round table discussion are provided password-protected at the workshop's webpage instead of publishing proceedings (compare http://exp-astro.physik.uni-frankfurt.de/meetings/athena-final-workshop).

Seventeen participants from seven European countries and Turkey were present during the workshop.

Carpathian Summer School of Physics 2014 on „Exotic Nuclei and Nuclear/Particle Astrophysics (V) – From nuclei to stars“, Sinaia, Romania (13-26 July 2014)

The Carpathian Summer School of Physics (CSSP) is part of ENNAS, the European Network of Nuclear Astrophysics Schools, which includes also the schools held at Santa Tecla, Sicily, Italy, and Russbach, Austria. The organisers of the three schools created a network of periodic events that responds to the need of preparing and educating the younger generations of physicists in the cross disciplinary fields of nuclear physics and astrophysics through lectures and meetings with some of the best active scientists.

The topics of CSSP have a strong focus on nuclear astrophysics and cover all tasks of ATHENA with topics like, *e.g.*, Nuclear physics for astrophysics, Neutron stars and EOS, Issues in nuclear astrophysics & nucleosynthesis, Stellar evolution, Compact stars & supernovae, Cosmochemistry, Neutrino physics, Astroparticle physics, and Stellar and laser-induced plasmas.

The ATHENA networking activity acted as a main sponsor and was presented at the webpage of the conference (http://cssp14.nipne.ro/) as well as on the conference poster. A major contribution of ATHENA was the financial support of young researchers who presented their work during the second week of the school. In addition, some of the lecturers could only be invited to the school because of the funding provided by ATHENA. The financial support for participants of the school included the conference fee, accommodation in a nearby bed and breakfast, and the transport from Bucharest airport to Sinai with organised shuttle busses. The lecturers received a subsidy for their accommodation costs.

The following lecturers (highlighted by italic style) and participants (alphabetical order) were financially supported:

- Nicusor Arsene („Horia Hulubei" National Institute for Physics and Nuclear Engineering, Bucharest-Magurele, Romania)
- *Carlos Bertulani (Texas A&M University, Texas, U.S.A.)*
- Anna Caruso (Universtà di Catania, Sicily, Italy)
- *Karl-Ludwig Kratz (Institut für Kernchemie, Johannes Gutenberg-Universität Mainz, Germany)*
- *James Lattimer (State University New York, New York, U.S.A.)*
- Ghina Mahmoud-Halabi (American University of Beirut, Lebanon)
- Iulia Harca (Joint Institute for Nuclear Research, Dubna, Russia)
- Cristina Oancea (University of Bucharest, Romania)
- Sara Palmerini (Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Italy)
- *Marek Pfutzner (University of Warsaw, Poland)*
- Sebastiana Puglia (Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Italy)
- Partha Roy Chowdhury (Saha Institute of Nuclear Physics, Kolkata, India)
- Simone Sanfilippo (Universtà di Catania, Sicily, Italy)
- Maria Letizia Sergi (Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Italy)
- Shota Shibagaki (University of Tokyo, Japan)
- *Octavian Sima (University of Bucharest, Romania)*
- Onofrios Skourous (University of Ioanina, Greece)

Use of resources

List of person-months per participants

Participant number	Participant short name	Person-months: total planned	Person-months: reporting period
3	INFN	6.00	0.00 of 1.50
15	TUD	2.00	0.00 of 0.00
16	NCSRD	4.00	1.00 of 1.00
28	UNIBAS	4.00	1.00 of 1.00
31	GUF	10.00	4.00 of 2.50
Total:		26.00	6.00 of 6.00

List of deliverables and milestones

The following deliverables were due in month 48 of the project:

- Deliverable D4.1 (Work Package 04, Task 1): Report on identified key reactions, on technical ideas, on the coordination, and on experimental and/or theoretical verification of the key features
- Deliverable D4.2 (Work Package 04, Task 2): Report on increase of synergy, on the major upgrades, and on improved theoretical determination and experimental evaluation of input parameters
- Deliverable D4.3 (Work Package 04, Task 3): Report on the work of the measurement and data-analysis teams and on the current status of the preparation of experiments at future neutron sources
- Deliverable D4.4 (Work Package 04): Report on the meetings and workshops held within the work package

These deliverables were all fulfilled.

Deviations from Annex I and corrective actions

Contribution of person-months per participant

INFN was supposed to lead Task 3 of ATHENA and act as deputy coordinator of the activity. Unfortunately, the foreseen contact person quit so that a replacement had to be found. The deputy coordinator of the activity is Michael Hass from the associate partner TWI. In case of Task 3, the contribution was performed by GUF so that – added up – the number of person-months was delivered.

Actions within Task 3 – Nucleosynthesis in Neutron Capture Processes

Task 3 deals with the nucleosynthesis in neutron-capture processes and focuses on the measurements of neutron-induced reactions. The original plan was to support the experimental campaigns at the n_TOF facility at CERN, Switzerland, and the analysis of the obtained data by funding the travel costs of young researchers.

However, it turned out that the community would benefit more from a workshop or conference organised in collaboration with LANSCE, Los Alamos National Laboratory, U.S.A., where complementary experiments are performed. This workshop took place in March 2013 at Darmstadt (see http://exp-astro.physik.uni-frankfurt.de/meetings/athena-neutron-time-of-flight/).

Work Package 5: NA05-EGAN

Participants: GSI, INFN, CNRS, UNIMAN

During the 3rd period, the EGAN network has been working successfully and all the milestones and deliverables have been reached.

Task 1: Co-ordination of Scientific Activities and Dissemination.

• **Subtask 3**: Co-ordination and organisation of experimental campaigns

The setup of the Scientific Committee and the Working Groups has been accomplished (MS52) on occasion of the fourth workshop (June 2014) at GSI as scheduled. The presentation of new activities at different laboratories was done. A fruitful discussion on the development and maintenance of the germanium detectors took place. The minutes of the different meetings can be downloaded from the document server on the website.

• **Subtask 4**: Co-ordination with hosting infrastructures:

A fourth meeting took place at GANIL on 19 May 2014 (MS54+), between the AGATA management and the Directors of the three hosting laboratories (LNL, GSI and GANIL). The minutes of the different meetings can be downloaded from the document server on the website.

Task 2: Co-ordination on Ancillary Instrumentation

The minutes of the meetings can be downloaded from the document server on the website.

• **Subtask 1**: Activity of WG1: Co-operation on the use, design and construction of ancillary detectors to improve the performance and compatibility of the devices.

The fourth meeting took place on 26 June 2014 (MS58) at GSI.

• **Subtask 2**: Activity of WG2: Co-operation on designing and building the electronics and data acquisition and on the mechanical integration.

The fourth meeting took place on 26 June 2014 (MS62) at GSI.

• **Subtask 3**: Activity of WG3: Exchange of information on the development of simulation tools

The fourth meeting took place on 26 June 2014 (MS66) at GSI.

Task 3: Collaboration Workshops

The fourth EGAN workshop was organised at GSI on 23-26 June 2014 (MS70). With more than 100 participants, the workshop was very successful. In particular, almost half of the presentations were given by young researchers. There was time for informal discussions and new collaborations were born. The slides/presentations of the different speakers can be downloaded from the EGAN website or from the EGAN 2014 website: https://indico.gsi.de/conferenceDisplay.py?ovw=True&confId=2558.

Task 4: Transfer of knowledge

The third training course was organised in Padova on 1-3 October 2014 (MS72+). This course was organised in addition to those foreseen in the milestones following the request by the users. More than 30 young physicists participated to this course on the use of highly segmented germanium detector systems, digital pulse-shape analysis and AGATA data analysis. The presentations can be seen and downloaded from the EGAN website. Almost all the participants and the lecturers were supported by EGAN.

The corresponding deliverables have been fulfilled:

- D5.2: Final Report on the activity of the Scientific Committee
- D5.3: Final Report of the Working Groups
- D5.4: Final Report on the Collaboration Workshops
- D5.5: Final Report on Training courses for young researchers and engineers
- D5.6: Final Report on Exchange of key technical personnel

Deviations from Annex I

None.

Use of resources
It follows the work plan of Annex I.

Corrective actions
None.

Work Package 6: NA05-EFINION

Participants: GANIL, GSI, INFN, JYU, RUG, CERN, CNRS, CEA, NCSRD, USC, CIEMAT

EFINION is the 6th Networking Activity of ENSAR (WP6) aiming at a) compiling and coordinating existing and future applications of socio-economic impact stemming from ENSAR, b) identifying application-oriented synergies within ENSAR groups as well as between ENSAR and interested companies, and c) disseminating multi-disciplinary application-oriented research to the scientific community, the public and, especially, the policy makers.
In the third reporting period (months 37-52), EFINION objectives comprised milestones with the corresponding deliverables, as follows:

Milestones

- MS77 Workshop held
- MS78 "Catalogue of multi-disciplinary applications-oriented research activities of ENSAR"
- MS79 "Synergies and collaboration opportunities in applications-oriented research with and within ENSAR"
- MS80 Communication Day "Nuclear scientists and policy makers communicate"

Deliverables

- D6.2 Report on the Workshop on "ENSAR applications - oriented research"
- D6.3 "Catalogue of multi-disciplinary applications-oriented research activities of ENSAR"
- D6.4 "Synergies and collaboration opportunities in applications-oriented research with and within ENSAR"
- D6.6 "Nuclear scientists and policy makers communicate"

All milestones and deliverables are fulfilled. Due to the specific agenda of the Member of European Parliament who accepted to invite EFINION & ENSAR teams to the European Parliament, the Communication Day occurred on 27 January 2015, after the official end of the ENSAR project.

During this last period of the ENSAR project, the EFINION team finalised the actions to identify the activities in applications-oriented research within the ENSAR consortium and to communicate about them.

An important event was the EFINION workshop (deliverable D6.2) in July 2014 where most ENSAR infrastructures presented and discussed their applications-oriented research work.
In addition, the work on the Catalogue of multidisciplinary applications-oriented research activities of ENSAR (deliverable 6.4) allowed further highlighting of the similarities between infrastructures in this domain.
Last but not least was the Communication Day (deliverable 6.6) at the European Parliament with an exhibition and a presentation on applications within the ENSAR consortium.

The impact of nuclear physics research goes far beyond the purely scientific and reaches out to applications of great benefit to society and other disciplines. The EFINION work shows that many successful activities are currently performed in Europe in order to develop applications with heavy-ion beams. Possible collaborations were identified (deliverable 6.4) and ideas about possible common organisation to enhance nuclear-physics applications-oriented research in Europe are emerging.

Deviations from Annex 1
None.

Use of Resources

The use of EFINION budget was limited due to the careful budget management and the delay of the Communication Day (deliverable 6.6) beyond the end date of the ENSAR project.

All milestones and deliverables were fulfilled.

Corrections

None.

Work Package 7: JRA01-ARES

Participants: GANIL, GSI, INFN, JYU, RUG, ATOMKI-HAS, UWAR, IFIN-HH

Task 1: Plasma heating, wave-plasma interactions

1.1 Correlation between X-rays emission measurements, heating and CSD

The ARES team continued the exploration of plasma X-ray emission properties started in the previous period and followed the correlation with the distribution of the produced charge states.

The outputs of the GSI experiment showed that the frequency impact on the plasma heating can be relevant (especially in the build-up of the warm electrons population) as a consequence of the wave-to-plasma coupling mediated by the resonator nature of the plasma chamber. This suggested that space-resolved X-ray measurements would be necessary to investigate how the plasma structure in the "warm electrons" domain was eventually affected by resonant modes.

The new setup based on a CCD camera coupled to a small pin-hole for X-ray imaging and space-resolved spectroscopy has been designed, assembled and tested in November 2014 at ATOMKI, Debrecen (Hungary). As propaedeutic stage to CCD set-up, a silicon drift detector (SDD) and a HpGe detector were used to characterise the volumetric plasma emission. The SDD detector was placed on the injection side of the ATOMKI ECRIS in order to allow X-ray measurements and beam extraction (including CSD determination) at the same time, thus providing a direct relationship between the CSD and the plasma spectrum.

The overall setups used during the experimental campaign and the simplified sketches of the experimental apparatus are shown Figs. 1 and 2, respectively. Figure 2 shows the two different setups used for the measurements of the emission at intermediate energies (2-30 keV). The short-collimator configuration - estimating the total flux coming from the plasma plus chamber system - was useful for making possible CCD camera measurements ensuring safe operations below the critical photon flux. For the same reason a HpGe detector was also used for monitoring the high energy part of the plasma spectrum. These two detector setups were useful for the definition of the operative conditions, including set of frequencies for exploring the frequency tuning effect. The "long-collimator" configuration was instead very useful for evaluating plasma density and temperature. The collimator length, in fact, was calculated in order to avoid any interception of the cone of view with the extraction endplate (the cone lies exactly within the extraction hole). In this way, the detected X-rays can be considered as solely emitted by the plasma bulk itself, allowing plasma density and temperature calculation along the line of sight.

After the SDD measurements, the CCD (made by 256x1024 pixels and with a sensitivity range of about 400 eV – 10 keV) was coupled to a lead pin-hole and placed along the axis, facing the chamber from the injection flange. The plasma chamber inspection was performed with a mesh covering about 60% of the injection endplate.

Results collected during the experimental campaign are illustrated in Figs. 3 and 4. Figure 3 shows the trend of <q> as a function of plasma energy content. Each point corresponds to a different frequency, in the range 12.8-13.5 GHz, with steps of 40 MHz each. <q> clearly grows with the energy content, but the scattered points demonstrate that it is not strictly a matter of density or temperature (or the product between them) as each <q> is obtainable by different combinations of energy contents, depending on the pumping wave frequency. We expect it is the shape of the plasma density that can explain these data, and not only the global energy as detectable by the SDD. This motivated the X-ray imaging and space-resolved spectroscopy (XSRS). Imaging for a single excitation frequency is shown in Fig. 4. Colour scale refers to the number of photoelectrons produced in each pixel, which is proportional to the X-ray flux impinging on it. The general structure of the plasma is clearly visible: the hole in the near-axis region, the branches due to the electrons escaping from the confinement and the hot spots due to lost electrons producing bremsstrahlung radiation when impinging on the chamber walls. Several features of the plasma structure are already clear from this picture, providing an important feedback to the modelling efforts that will be presented later on.

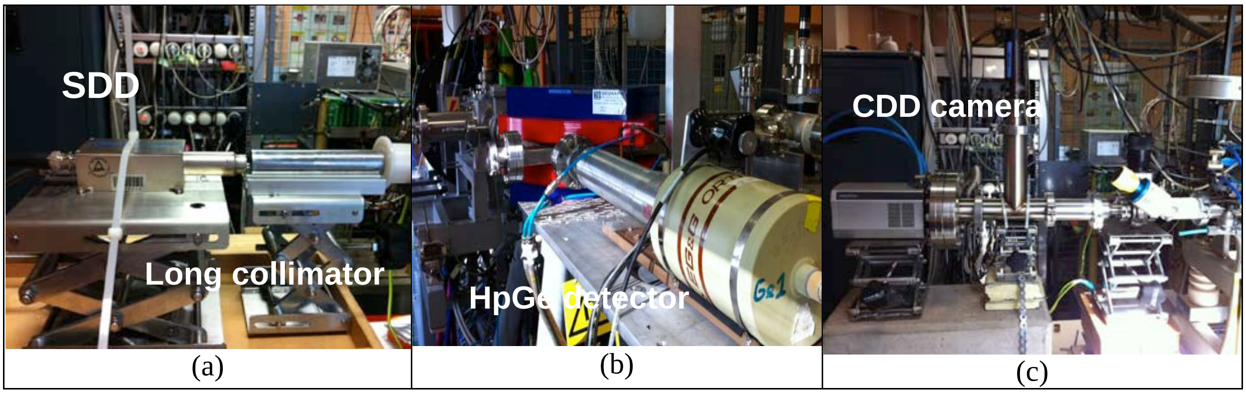

Figure 1: a) long-collimator setup for SSD; b) HpGe detector to characterise the X-ray emission at high energy (E>40 keV); c) CCD coupled to a lead pin-hole for X-ray imaging.

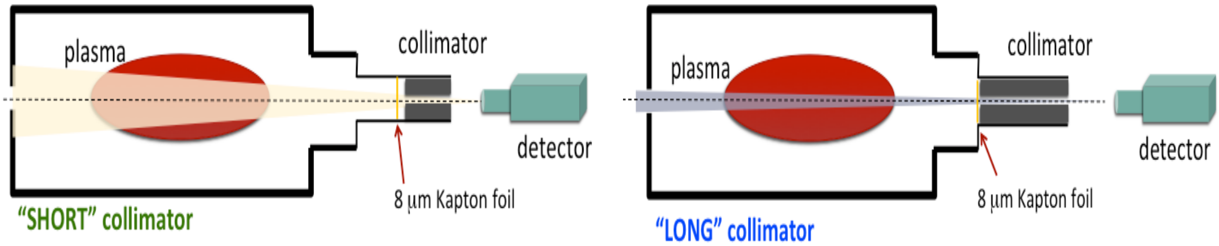

Figure 2: (left) short-collimator setup for SDD; (right) long-collimator setup for the SDD: the collimator was calculated in order to fit the cone of view inside the extraction hole.

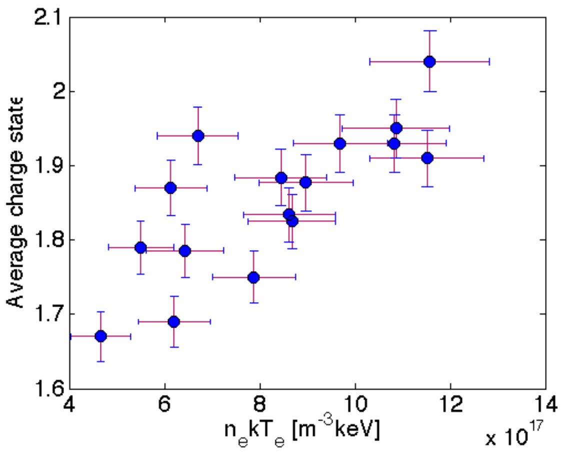

Figure 3: Average charge state as a function of the plasma energy content as measured by SDD. Points refer to different RF frequencies.

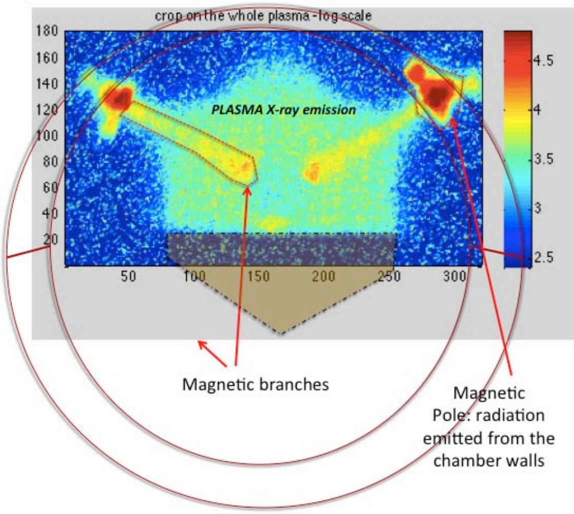

Figure 4: Image of the plasma obtained by the CCD camera pin-hole method.

1. 2 Plasma modelling via self-consistent simulations

Efforts on plasma modelling via numerical simulations still continued at INFN-LNS even during the last period of ARES activities. Numerical solution of Vlasov equation via kinetic codes coupled to FEM solvers is ongoing, based on a PIC strategy. Preliminary results of the modelling will be shown for wave-plasma interaction and electron-ion confinement as the obtained results are very helpful to better understand the influence of the different parameters (especially RF frequency and power) on the ion-beam formation mechanism.

The method is based on a strict interplay between COMSOL solver for Maxwell equations and the particle mover implemented in MATLAB. Due to huge time-consuming calculations needed at each loop-step **k**, we show here results up to step 2, i.e. after evaluation of RF action on electrons and vice-versa, for two times.

The most important result of the simulations is that although vacuum RF field distribution (i.e. a cavity, modal field distribution) is perturbed by the plasma medium, the non-uniformity in the electric-

field amplitude still persists in the plasma filled cavity. This non-uniformity can be correlated with non-uniform plasma distribution.
Some plasma features are now clear according to pictures of Fig. 5: i) the plasma concentrates mostly in near-resonance region; a dense plasmoid is surrounded by a rarefied halo; ii) at different energies, electrons distribute differently in space: cold electrons in the core, hot ones in near ECR regions; iii) ions are formed where hot electrons are located; iv) the ion-beam shape depends on the electron/ion distribution on the plasmoid surface. Therefore, optimisation of the ion-beam formation must begin well inside the plasma.

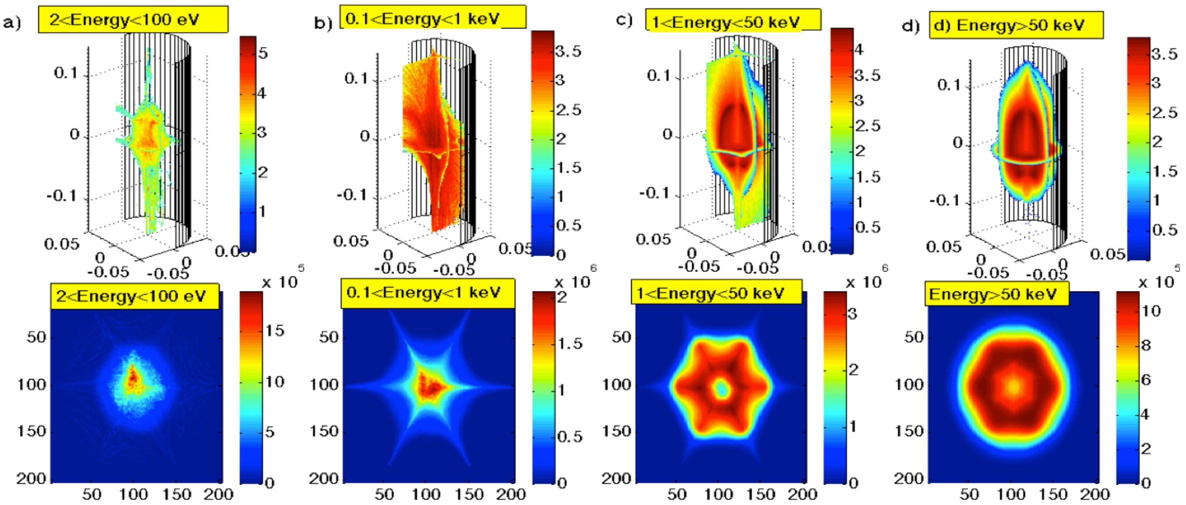

Figure 5: Top row: 3D density distributions at different energy ranges (arb. units in log scale); Bottom row: integrated density distribution in 2D transversal view (arb. units in linear scale).

1. 3 Beam pulse rise-time comparison and relationship with space-charge effects

The BETSI test bench was used delivering a proton beam of 4 to 40 mA, with pulse repetition rate of 14 Hz, by just changing the microwave power. The results obtained for the pulse rise-time are shown in Fig. 6(right) (Fig. 6(left) shows experimental setup): the current is normalised to the maximum value, in order to superpose the plots taken at about 4, 10, 20, 30, and 40 mA. It can be observed that the beam build-up is sudden for the lower currents (curves in blue, green, cyan) and become larger for the higher intensities (orange and red). In the last case, the time needed to reach the saturation level is about 100 ns, while it is only 30 ns for the lowest intensity. According to the simulations we may conclude that the fraction of build-up time of the pulse coming from the time necessary to transfer the microwave energy to the plasma electrons is not significant with respect to the space-charge compensation build-up time.

1. 4 MD method in the ECR plasma

The metal dielectric (MD) method as a tool of investigation of the physical properties and processes of the ECR plasma has been continued and the influence of the extraction voltage on the high-energy slope of bremsstrahlung radiation spectra has been reported. This was the subject of a dedicated study at the IKF ECRIS. Most of the new generation ECRIS installations use Double Frequency Heating (DFH) and Frequency Tuning (FT) to increase the very high-charge state intensities.
We carried out a series of dedicated experiments to study the influence of an enhanced EEDF, created by using the MD method, on the performance of DFH. A MD liner turns the ECRIS into a higher performing source. Additionally, it was observed that the efficiency of the gas-mixing method, when plasma-wall interaction is significant, is reduced in our experiment to 35% versus the standard ECRIS gas-mixing efficiency [RSI 83, 02A348 (2012)].

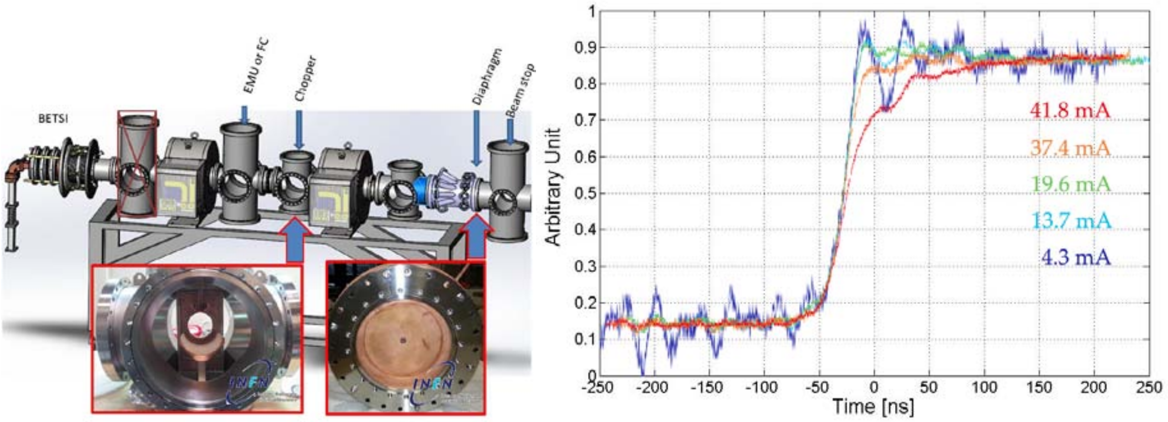

Figure 6: (left) -Experimental apparatus; (right) beam rise-time with the beam current.

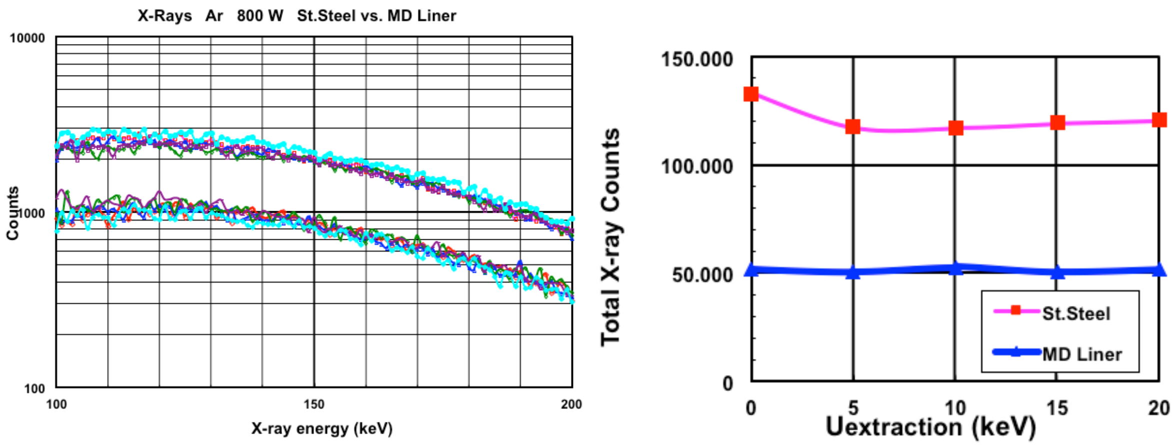

Figure 7: Influence of extraction voltage on Bremsstrahlung radiation spectra with and without MD liner.

We have measured bremsstrahlung radiation spectra by monitoring the Ar^{14+} charge state as the extraction voltage is varied from zero to 20 kV. In order to provide supplementary information, a 90 mm length MD liner was introduced in the plasma chamber covering the inner walls. The results are shown in Fig. 7.

The shape of the spectra are identical, however, the total yields for the MD configuration are on average three times lower. The total X-ray yields (detected in the range 140-200 keV), monitored as a function of the extracted voltage, confirm that the extraction voltage does not change the rate of X-rays. We can conclude that the bremsstrahlung measurements did not yield evidence for a change in the plasma energetic electron population. [RSI 83, 02A331 (2012)]. In order to gain information on the DFH-mechanism and on the role of the lower injected frequency we have put emphasis on the creation of a discrete resonance surface also for this lower frequency. Our established method of inserting an emissive MD liner into the plasma chamber of the source is used in these experiments as a tool of investigation. In this way the electron temperature and density for both ECR zones are increased in a controlled manner, allowing conclusions on the role of the change of the EEDF with and without DFH.

Task 2: Ion-beam formation and transport

2. 1 Ion-beam extraction and ion-beam transport

The theoretical model to describe the ion-beam extraction from an ECRIS and the following beam transport is improved. A joint effort of the groups of ATOMKI and GSI was established in using the results of the TrapCAD code for the electron density distribution as initial ion density distribution for different charge states to be used for the KOBRA3-INP code. For a realistic ion extraction simulation it is necessary to start the ions from inside the plasma chamber where they collect different $\int \mathbf{B}ds$,

depending on the path. The first attempts to simulate ray-tracing and emittance diagrams are very promising since the known structure of an ECRIS beam could be reproduced. This work will be continued in the future taking into consideration space charge, energy filtering of the electrons, concentration on specific charge states, improvement of diagnostic properties in the simulation (pepper-pot diagnostic), and further comparison with experiments.
The diagnostic tools for the simulation will generate 4D, respectively 6D data arrays, which need to be visualised. Because of the coupling between the different planes, it is necessary to reconsider the technique of emittance measurement and its representation.
The ion-beam structure observed in experiment has been reproduced with the applied model. The emittance is a useful quality measure for an ion beam; however, a simple projection of the 6D phase space onto a 2D plot is not sufficient to describe the complicated structure. Attempts were made to overcome this problem. Instead of using the definition $\mathcal{E}_{hor}=\iint f(x,y,x',y')dy'$, the integration should be avoided to obtain more information. Here, f denotes the ion density distribution. We started to investigate different display options of the 4D (or even the 6D) phase space. The present status of the work has been published [1].

2.2 Ion-beam formation and beam transport

The beam properties of the upgraded extraction of the JYFL 14 GHz ECRIS were carefully characterised by the simulations and the results were verified experimentally. The beam was ray-traced through the first section of the injection line using these experimentally defined beam properties. The beam diameter is 26 mm at the z=0 plane, which corresponds to the point where the ion beam leaves the extraction area of the JYFL ECRIS. A divergence value of 20 mrad was used in the simulation. The dipole magnetic field was constructed with COMSOL using the mechanical pole angle of 32° and by taking into account the dipole shimming. This resulted in the field angle of 30.8° while the correct angle for the optimum beam transport was found to be 28.3°. Fig. 8 (left-side) reveals three problems in the present beam optics of the JYFL ECRIS injection line: 1) the beam is too large inside the dipole resulting in beam losses, 2) the focal point is about 40 cm upstream the collimator in the y-plane resulting in beam losses by the collimator and 3) the beam is too large in the y-plane when it enters the Sol3. In addition to beam losses, Sol3 causes aberrations and emittance growth resulting in further beam losses downstream the injection line.
According to the simulations the afore-mentioned transport problems can be avoided by three different actions: 1) move the ion source closer to the dipole in order to avoid a focal point between the ion source and the dipole, 2) correct the entrance and exit angles of the dipole and 3) regroup the solenoids to minimise the losses and the aberrations caused by the solenoids. The new layout of the JYFL ECRIS is presented in Fig. 8 (right-side). The first solenoid is used to optimise the beam angle when it enters the dipole. In this new configuration, the simulation confirms that the beam is not cut by the dipole. The collimator is moved 38 cm closer to the dipole and as a result of corrected dipole angles the beam has the same focal point in the x- and y-planes. The regrouping of solenoids 1 and 2 allows efficient beam transport downstream the injection line. The upgrade of the injection line will be performed during the spring of 2015.

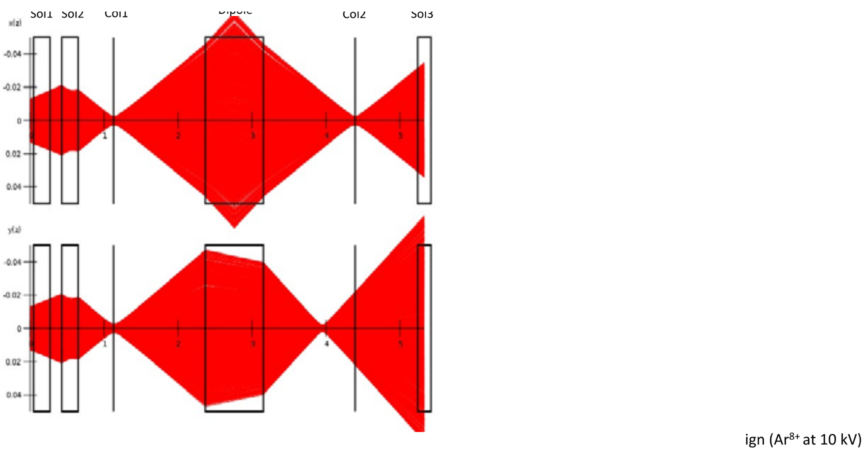

Figure 8: Beam transport through the present and proposed beam optics of the JYFL 14 GHz ECRIS injection line.

2.3 Extraction and transport of HCI beams from ECR ion sources

Previous work has shown that heavy-ion beams extracted from ECR ion sources are very sensitive for ion-optical aberrations in the bending and focusing elements of the low-energy beam transport (LEBT) line [2]. The main reason for this is the relatively large divergence of the ion beams, which are extracted in the decreasing magnetic field of the extraction solenoid of the ECRIS. A detailed study of beam transport in the first section of the LEBT line, which connects the ion source to the analysing magnet, was made by comparing calculated transverse phase-space distributions of ion beams behind the analysing magnet with measured ones using a pepper-pot emittance meter. The calculated phase-space distributions have been obtained using detailed particle tracking in the 3-dimensional (3D) electric and magnetic fields of the extraction elements and analysing magnet. The particle-tracking calculations start in the extraction plane of the ECRIS and the necessary initial conditions have been determined with a 3D particle-in-cell simulation of the ion dynamics in the ECR plasma of the ion source [3]. Comparison of calculated and measured phase-space distributions of the ion beam behind the analysing magnet shows: i) good agreement if one assumes that the ion beam is fully space-charge neutralised, ii) horizontal and vertical emittances behind the analysing magnet are increased fivefold to ~ 300 μm caused by large second-order aberrations of the analysing magnet and iii) calculated phase-space distributions behind the analysing magnet are not very sensitive to the details of the initial phase-space distribution in front of the magnet. Based on these results, it was shown that instead of particle tracking one can use higher-order transfer maps determined with COSY INFINITY to perform realistic beam-transport calculations [4].

The fivefold emittance blow-up can be mitigated by inserting a suitable focusing element between the ion source and analysing magnet. Using the transfer-map method we have investigated three different focusing elements, i.e. hexapoles in front and behind the analysing magnet, a solenoid or an einzel-lens in front of the analysing magnet. It turns out that hexapoles in front and behind the analysing magnet can partially compensate its second-order aberrations, but introduce additional higher-order aberrations and cannot minimise the emittance in both transverse planes simultaneously. A solenoid in front of the analysing magnet is clearly the best option; with enough focusing power the emittances behind the analysing magnet can be reduced to almost their original values before the analysing magnet. An einzel-lens is a reasonable alternative to a solenoid, although it does not completely recover the initial emittances.

To conclude, we have shown that low-energy heavy-ion beams produced by ECR ion sources are fully space-charge neutralised (at least for total beam currents up to 5 mA) and that their transport can be understood using second-order transfer maps. To optimise transport efficiency and minimise losses beams should be kept as paraxial as possible and fringe fields of the ion-optical elements of the beam line should be minimised. Particularly the design of the analysing magnet directly behind the ECR ion source is critical for efficient beam transport; its fringe fields should be minimised or compensated. Best results are obtained when a solenoid is used to couple the ion source to the analysing magnet.

References

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[2] S. Saminathan, J.P.M. Beijers, H.R. Kremers, V. Mironov, J. Mulder and S. Brandenburg, Rev. Sci. Instrum. **83**, 073305 (2012).
[3] J.P.M. Beijers and V. Mironov, Rev. Sci. Instrum. **81**, 02A307 (2010).
[4] K. Makino and M. Bertz, Nucl. Instrum. Methods A **558**, 346 (2006)

Task 3: Production of metal ion beams

3.1 Oven technique for medical and industrial applications

The 14 GHz ECR ion source of ATOMKI has recently been used as an implanter of low-charge, slow ions to irradiate metal or ceramic samples for industrial and medical applications. The oven was filled with pure calcium while helium was used as support gas. The ion beam intensities of 100 µA of the tuned charge state (Ca^{+} or Ca^{2+} or Ca^{3+}) were obtained. This high intensity allowed to irradiate large sample surfaces (15-20 cm^2) with the required dose (10^{15} – 10^{17} ions/cm^2) in reasonable time (10 min –

10 hours). Fig. 9 shows the calcium spectrum and the sample holder developed for the irradiation tests. A gold ion beam for the same applications was produced with the aid of axial sputter technique developed earlier.

3.2 Oven for the production of Mo beams

The evaporation of molybdenum requires a temperature which is too high for any resistive oven. Luckily, molybdenum forms a volatile oxide, MoO_3, reaching the vapour pressure value of 1 mbar at 800 °C. Due to the numerous isotopes of molybdenum the element was tested using enriched $^{92}MoO_3$ compound. During the Mo experiment the LEGIS source was operated with oxygen plasma. The tuning of the source and oven were difficult due to the fact that three oxygen atoms enter the plasma per each molybdenum atom changing continuously the equilibrium of the plasma and resulting in a less stable beam with respect to the other metal ion beams. Fig. 10 shows the ^{92}Mo (95 %) spectrum when a microwave power of 300 W was used.

3.3 Foil oven

The foil oven was further developed in order to improve its reliability. Special attention was paid to improve the mechanical connections in the high temperature region. After modifications the variation of the oven resistivity between the different oven assemblies decreased. *The oven was reliably tested up to 1500 ˚C*. Further experiments will be performed and the maximum operation temperature will be defined. The original plan was to perform movable oven experiments since the production efficiency could increase when the distance between the oven and plasma decreases. However, inside the plasma chamber the oven would be very close to the permanent magnets causing a local radiative heat load. This programme was stopped due to damage of the JYFL plasma chamber caused by the sputtering experiments.

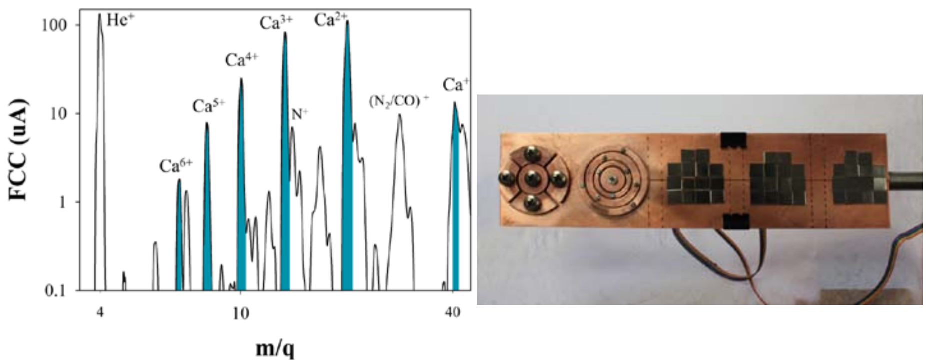


Figure 9: left: Calcium ion-beam spectrum. Right: The movable sample holder from left to right: 5-segment beam monitor, 4-ring beam monitor, group of samples to be irradiated 1-2-3.

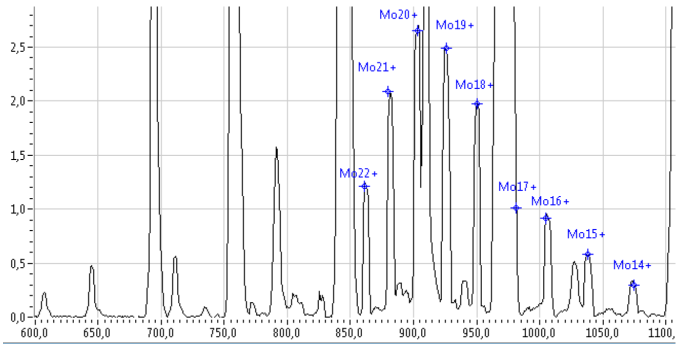


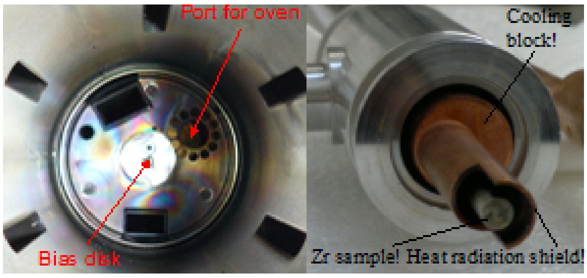
Figure 10: Charge state distribution of Molybdenum ions extracted from the LEGIS source.

3.4 Axial sputtering

The research and development work to produce metal ion beams by sputtering was continued by developing sputter configuration aiming at axial insertion of the sputter sample. The movable configuration allowed the sputter sample insertion of -40 mm into the plasma chamber. In this position, the distance between the sample and resonance zone (for cold electrons) is about 6 cm. The sample was situated between the radial magnetic poles, i.e. it was not directly exposed to the plasma flux. The intensities of Zr ion beams were lower than anticipated: at the position of -40 mm the intensity of Zr^{12+} beam was only 0.5 µA. The sputter sample and the effect of sputter sample position are presented in Fig. 11. Typical sputter current value in the case of radial sputtering is 1-2 mA while the sputter voltage of 1-2 kV is used (depending on the sputtered material and its sputter yield). These sputter voltage/current values typically produce an intensity of around 10 µA. The tendency shown in Fig. 11 indicates that the sputter sample was still too far from the plasma (1 mA sputter current vs 4 kV sputter voltage). As a next step, the device has to be modified to make deeper insertion of sample possible.

3.5 MIVOC beams

Several attempts to synthesise a compound using enriched titanium, especially ^{50}Ti, were carried out before the successful work performed by IPHC-Strasbourg group. As a result, the enriched compound has successfully been used to produce $^{50}Ti^{10+}$ and $^{50}Ti^{11+}$ ion beams for the nuclear physics experiments at JYFL and GANIL [1]. In both cases, the stable beam intensity of around 20 µA was maintained for the duration of at least two weeks.



Position [mm]	Sputter voltage [kV]	Sputter current [mA]
-10	3	0.21
-20	3	0.45
-20	4	0.52
-40	4	1.04

Figure 11: The axial sputter sample was inserted into the plasma chamber through the oven port (21 mm in diameter). The current measured from the sputter sample varies strongly as a function of position. Zero position corresponds to the level of the injection wall.

3.6 The production efficiency was indicated as a key factor regarding the metal ion-beam production

Different methods were compared and parameters studied to improve the production efficiency of different elements. Oxygen and nitrogen were found to be superior as a mixing gas compared to helium. The production method has a very strong impact on the production efficiency. This is demonstrated in Fig. 12. The Ti ion beams were produced with the aid of the MIVOC method while the Ca, Mn and Ni ion beams were produced using evaporation ovens.

The efficiencies of up to 7 % were obtained for the Kr ion beams. Surprisingly high production efficiency values have been reached with the MIVOC method (up to 4 %), while much lower efficiency is obtained with evaporation ovens (< 1 %). The plasma dynamics and ionisation processes regarding the Ca, Ti and Mn should be approximately identical, i.e. same ionisation efficiency could be achieved for them. In the case of the MIVOC method, the material is not heated and consequently no condensation of the molecules on the plasma chamber walls takes place before the dissociation. In the case of the evaporation ovens, the atoms, which are not captured by the plasma, will condense on the plasma chamber walls. The data presented here indicate that the production efficiencies with oven methods can be improved through further development work. The oven geometry should be designed in such a way that the evaporated metal atom has a very limited possibility to end up on the cold plasma chamber wall.

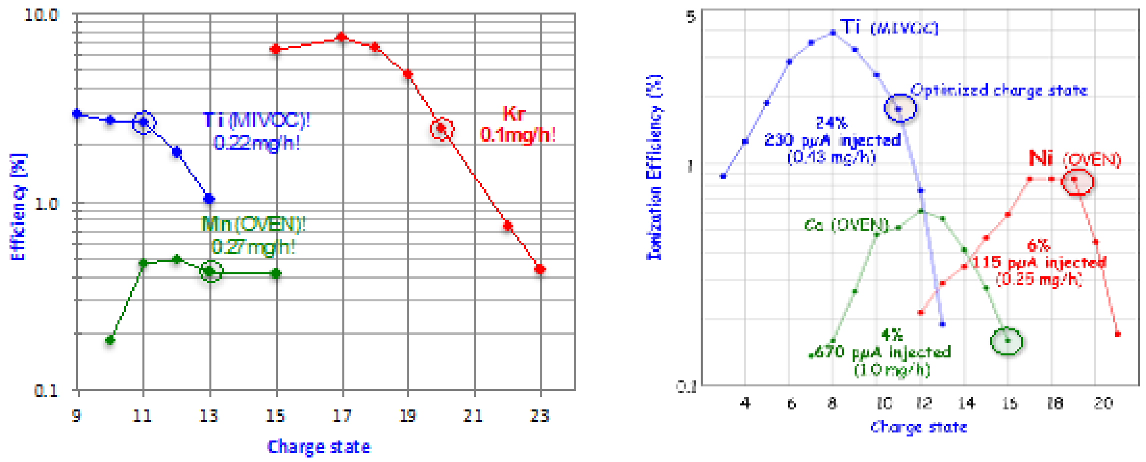


Figure 12: Production efficiencies of some elements when MIVOC or evaporation oven is used at JYFL and GANIL. Efficiency for krypton ion beams is presented for comparison.

In some cases, the production efficiency of solid elements can be improved by using a hot insulated liner at the plasma chamber wall. The hot liner decreases or even prevents the condensation of elements on the plasma chamber walls. Consequently, the recirculation of material becomes possible, thus improving the possibility to extract the element as an ion beam. This effect, earlier developed and tested in Joint Institute for Nuclear Research at Dubna, has been studied at GSI and LNL-INFN. At GSI, efficiencies comparable to gaseous elements were achieved for Ca ion beams. The temperature of the liner is a relevant parameter affecting the sticking probability of an element and consequently the temperature of the liner was simulated using the COMSOL-multiphysics code. The temperature distribution along the tantalum liner as a function of heating power is presented in Fig. 13. According to the graph, the liner temperature of around 950 K is reached using the heating power of 250 W [2]. Simulations were performed in collaboration with ITEP group (Moscow). The adequate plasma heating power and liner temperature that make sufficient recirculation of Ca possible need to be defined.

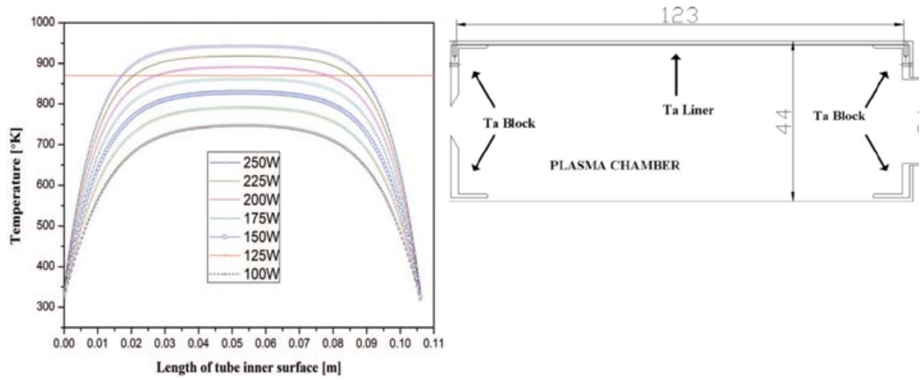


Figure 13: Temperature distribution of Ta liner as a function of heating power. Simulations were performed using the LNL-INFN ECRIS (LEGIS) geometry shown in the figure.

References

[1] J. Rubert et al., Nucl. Instrum. Meth. Phys. Res. B 276 (2012) 33.

[2] A. Galata et al., Rev. Sci. Instrum. 85 (2014) 02A929

Deviations from Annex 1

None.

Use of Resources

It follows the work plan of Annex I.

Corrections

None.

Work Package 8: JRA02-ActILab

Participants: GANIL, INFN, CERN, CNRS, PSI

This report covers the milestones and deliverables for the 3rd and last reporting period of ENSAR from 1 September 2013 to 31 December 2014. Four milestones were anticipated in the previous period: MS85 *Synthesis of actinide targets by sol-gel method - 'chimie douce'*, MS86 *Synthesis of nano-structured actinide targets,* MS87 *Characterisation of structures,* and MS90 *Analysis of online tests of new actinide targets*.
In this reporting period, the remaining three milestones and four deliverables were achieved and are now reported in the subsequent parts for each of the four tasks of ActILab.

TASK 1: SYNTHESIS OF NEW ACTINIDE TARGETS

D8.1 Novel synthesis of actinide targets

Various uranium carbide target materials have been synthesised following new synthetic routes. This includes different uranium precursors and graphite charges. The new uranium-carbide materials and their main characteristics are listed in Table 1.

Table 1: List of the different UC_x materials synthesised during ActILab.

Sample	Uranium	Carbon	ratio C/U	Milling of uranium powder	Carburisation
OXA	IPNO oxalate	Graphite	3	No	16 h at 1770°C
COMP30	IPNO oxalate	Graphite +30 wt % of microfibres	3	No	16 h at 1770°C
PARRNe 371	natural UO_2 depleted 0.3% - ref. MN371	Graphite	6	Mixer miller PM100 RETSCH	16 h at 1770°C
PARRNe 894	natural UO_2 depleted 0.25% - ref. MN894	Graphite	6	Mixer	16 h at 1770°C
PARRNe 894 BP	natural UO_2 depleted 0.25% - ref. MN894	Graphite	6	Planetary miller PM200 RETSCH	16 h at 1770°C
CNT	Westinghouse UO_2	Carbon nano-tubes	6	No	20 min at 1600°C

Table 2: Physicochemical characterisations by X-Ray Diffraction XRD (1) and He pycnometry (2).

Sample	Phase(1) and their relative proportion (wt %)	Effective density(2) ($g.cm^{-3}$, ± 0.2)	Open porosity(2) (%)	Closed porosity(2) (%)
OXA	UC / UC_2 and 70.5 / 29.5	12.2	26	7
COMP30	UC / UC_2 and 8.6 / 91.4	10.1	48	13
PARRNe 371	UC / UC_2 and 10.6 / 89.4	8.3	46	4
PARRNe 894	UC / UC_2 and 10.9 / 89.1	8.0	56	8
PARRNe 894 BP	UC / UC_2 and 5.8 / 94.2	8.2	44	6
CNT	UC / UC_2 and 14.7 / 85.3	8.5	77	5

Physicochemical characterisations were systematically performed to describe the structure and microstructure of the carburised pellets (Table 2).
A nano-structured uranium carbide target load was produced and tested with a proton beam from PSB at CERN-ISOLDE. The small sized UO_2 powder precursor and the produced pellets are shown on Figure 1.

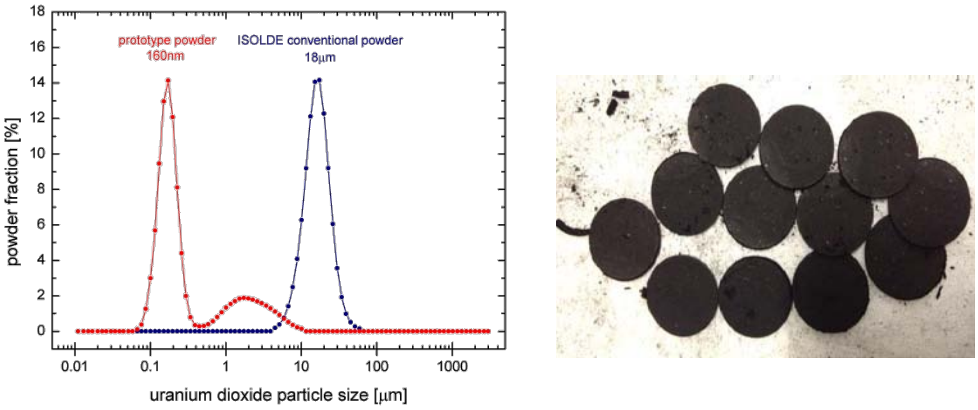


Figure 1: Left: reduced grain-size distribution of the nano-UO2 versus the standard powder used. Right: A set of pressed pellets used for a target nano-UC_x load before online tests (14 mm diameter).

References:
[1] B. Hy et al., *Nucl. Instrum. Meth. Phys. Res. B*288 (2012) 34
[2] S. Fernandes et al., *J. Nucl. Materials 416 (2011) 99*
[3] J.P. Ramos et al., *Nucl. Instrum. Meth. Phys. Res. B*320 (2014) 83-88

TASK 2: CHARACTERISATION OF NEW ACTINIDE TARGETS

MS88 Characterisation of thermal properties

Emissivity and thermal conductivity were measured with a new device and the feasibility tested with uranium carbide as seen in Fig. 2. The measured thermal gradient is used to determine the heat conductivity by an analytical fit, as seen on Fig. 3. The emissivity is also measured by optical pyrometry.

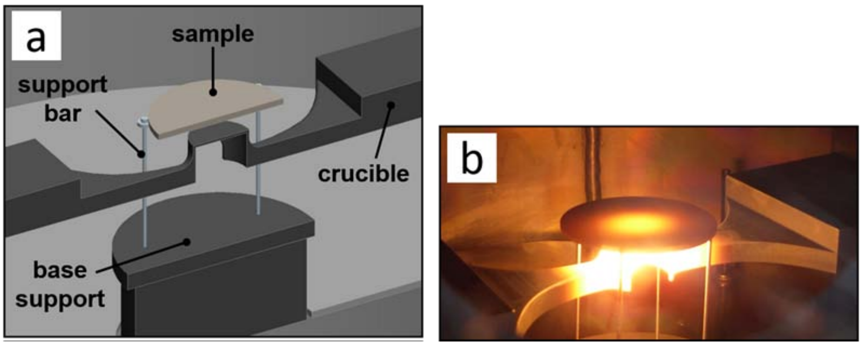


Figure 2: a) CAD view of the thermal conductivity estimation setup; b) sample heated by irradiation of the crucible, with the creation of a temperature gradient.

[4] M. Manzolaro et al., Rev. Sci. Instrum. 84 (2013) 05490

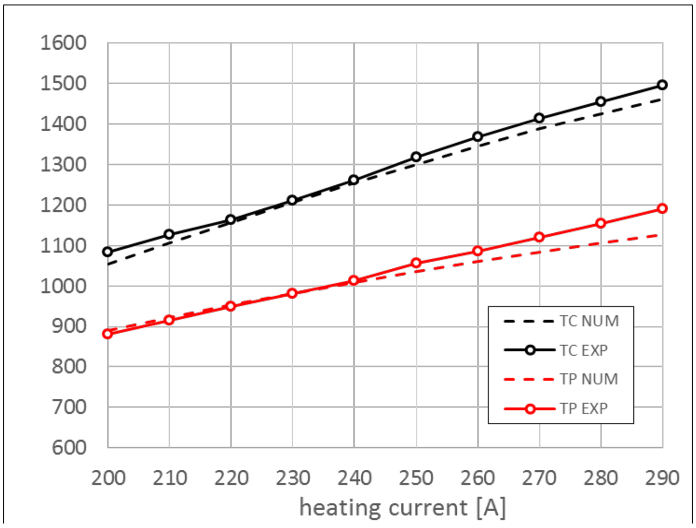


Figure 3: Experimental and numerical temperatures on centre and periphery of a UC_x disc.

D8.2 Characterisation of new actinide targets

Both thermal and structural properties were determined for a set of uranium-carbide prospective materials. The emissivity of the different materials is shown in Fig. 4. The crystalline phase, microstructures, and porosity were determined as shown in Fig. 5, 6 and 7.

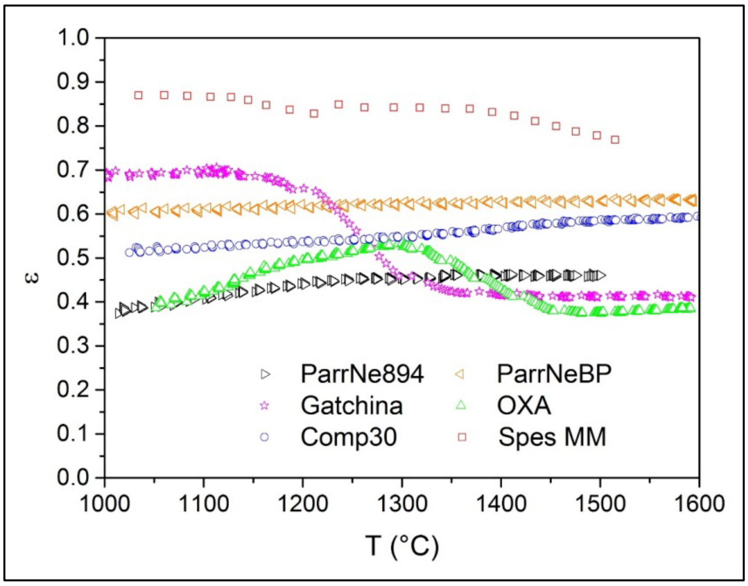


Figure 4: Thermal emissivity of different types of uranium carbide; Gatchina is a dense UC pellet, 12.9 g/cm^3, so-called "high density UC". The SPES MM sample is a large disk of UO_2 powder reacted with graphite powder of 29 mm diameter, 3.9 g/cm^3 density.

TASK 3: ACTINIDE TARGETS PROPERTIES AFTER IRRADIATION

D8.3 Characterisation of irradiated materials in hot cell

An irradiated target from ISOLDE was shipped to PSI and the unit was disassembled, the target container opened and three samples were extracted for further analysis as seen in Fig. 8. The material was analysed by Electron Probe MicroAnalyser (EPMA) and Scanning Electron Microscopy. It was compared with a reference non-irradiated sample. No significant differences could be observed between these different samples as can be seen in Fig. 9.

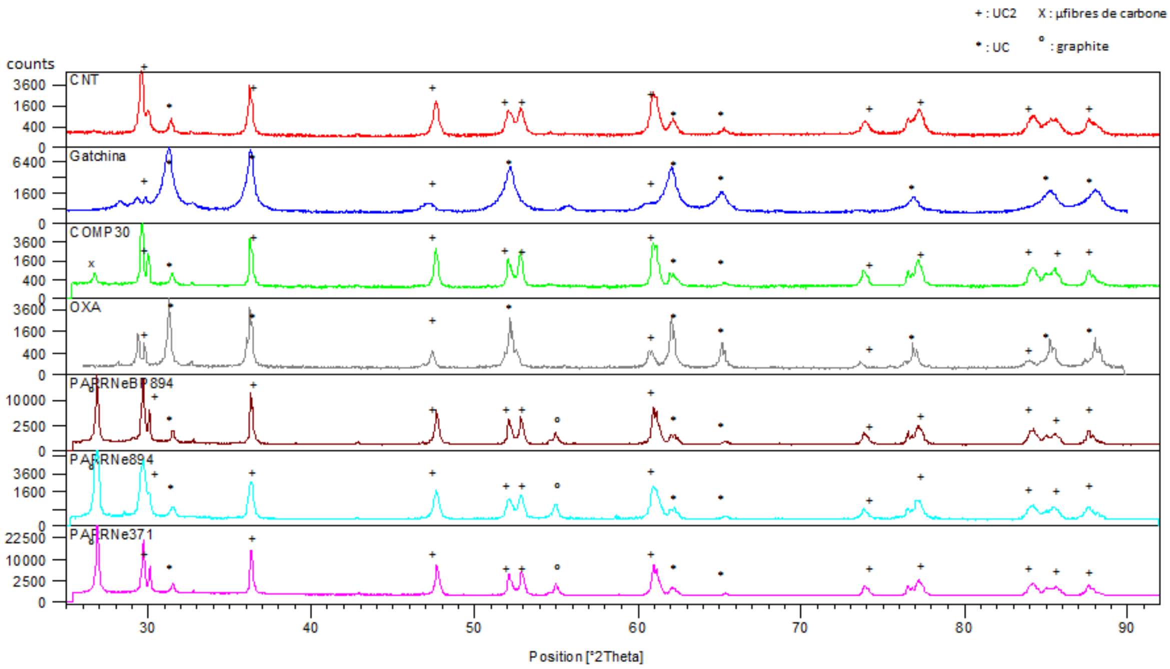


Figure5: XRD patterns of different samples, highlighting the presence of UC, UC_2, graphite and carbon microfibres.

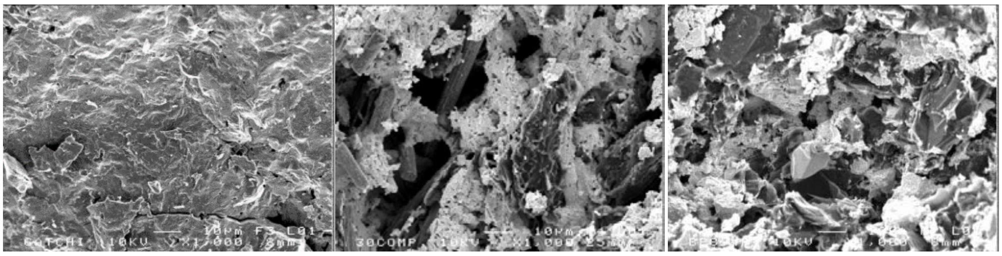


Figure 6: SEM images. From left to right: compact structure of high-density UC, open structure containing UC_2 grains and carbon fibres, open structure containing UC_2 grains and graphite residual clusters (black blocks).

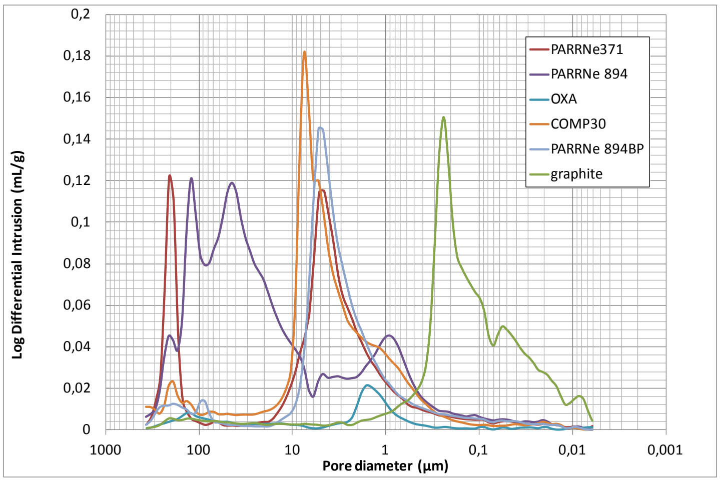


Figure 7: Pore-size distribution of different samples using mercury porosimetry.

Further to these investigations, the target materials have been prepared with a FIB milling and analysed with at the Swiss Light Source. There phase competition between UC and α-UC_2 at the grain level could be identified for the first time, as shown on Fig. 10.

Figure 8: Uranium-carbide target extracted from middle of the target container in the hot cell.

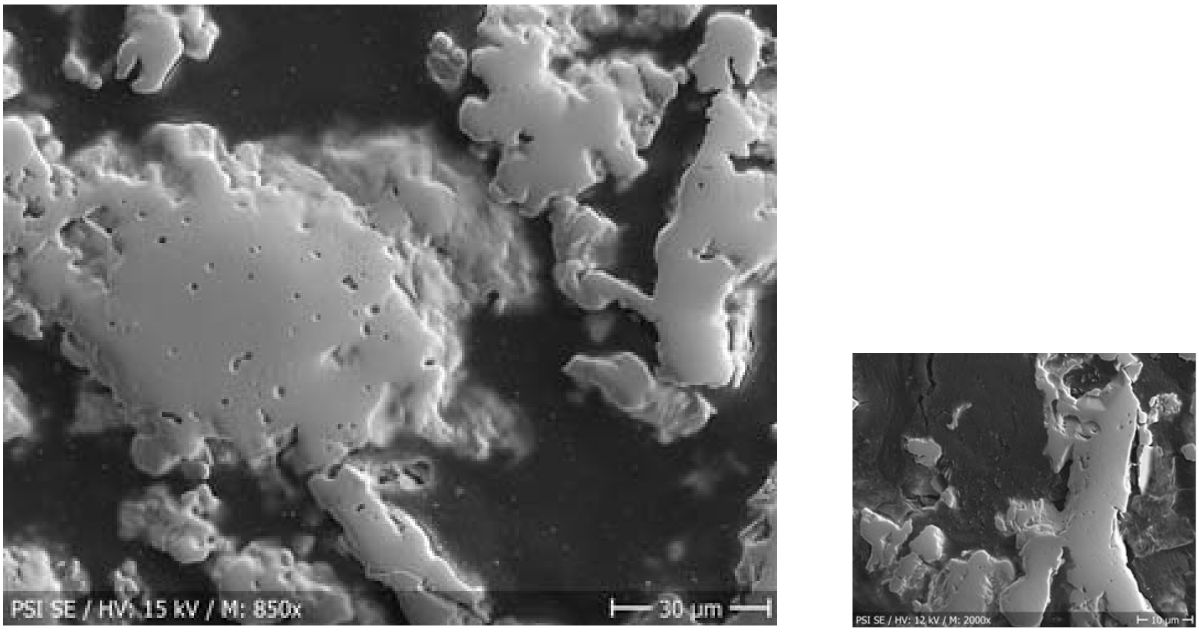


Figure 9: Left: standard UC_x target material before irradiation, right: UC_x target after irradiation. The size of the pictures have been adapted to represent the same scale.

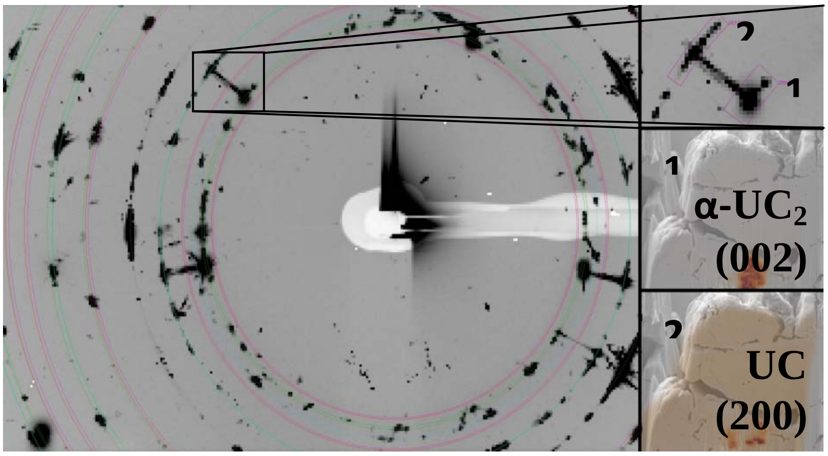


Figure 10: XRD pattern of the investigated UC_x; a zoom shows an inelastic scattering path between two co-existing UC and UC_2 submicron phase domains.

TASK 4: ONLINE TESTS OF ACTINIDE TARGETS

MS91 Effect of beam time structure on online tests

The impact of the time structure of the proton pulse at ISOLDE, CERN, has been investigated on a standard UC_x target and a newly developed nano-structured target. The yield of a representative isotope, ^{30}Na, has been followed in both cases. A decrease by two orders of magnitude is observed on the standard UC_x, while no or very little drop is seen with the nano-UC_x target, Fig. 11.

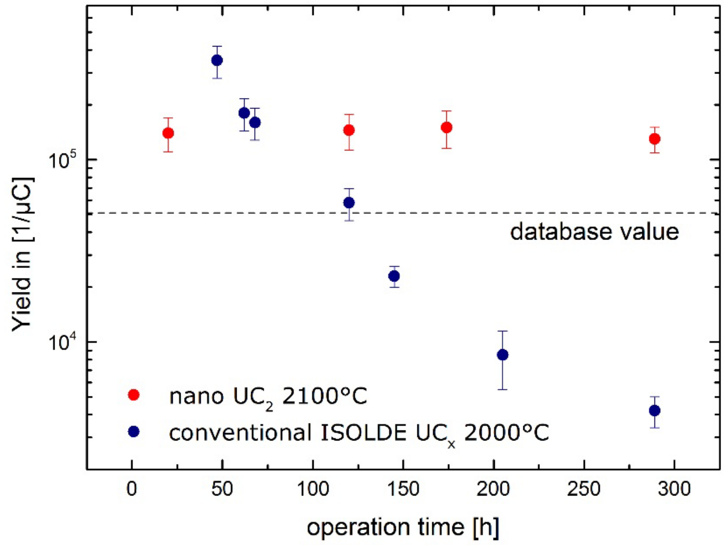


Figure 11: Comparison of impact of the proton beam pulsed tile structure on the evolution of the yield of ^{30}Na at ISOLDE.

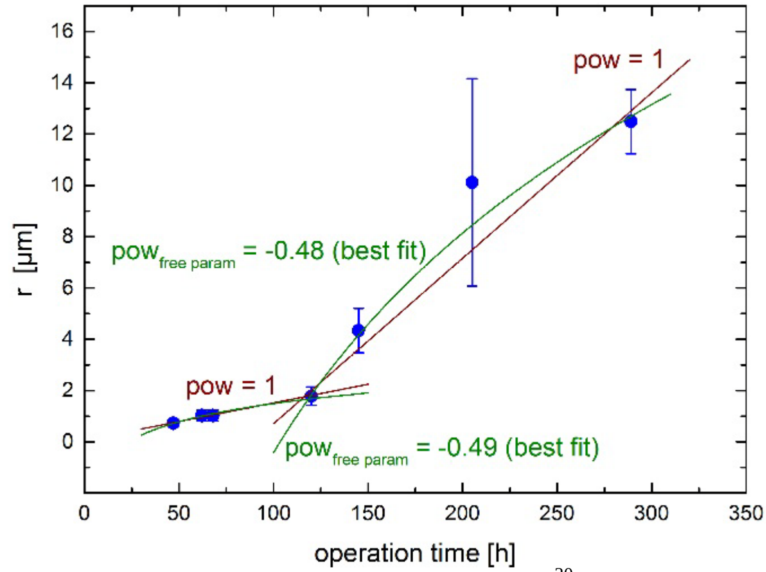


Figure 12: UC_x particle-size evolution assuming that losses of ^{30}Na occur uniquely due to nuclear decay during diffusion and assuming a diffusion constant $D=6\cdot10^{-11}$ $cm^{-2}s$. In the beginning sintering is kinematically hindered and accelerates once carbon diffusion causes a microscopically homogeneous carbon content.

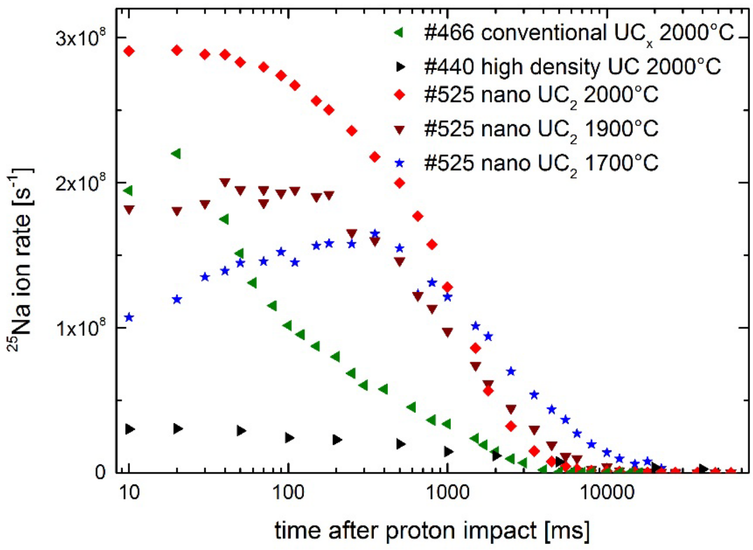


Figure 13: The release structure of ^{25}Na ions after a proton pulse at t=0 for different target materials and temperatures. The different release components are visible as function of time.

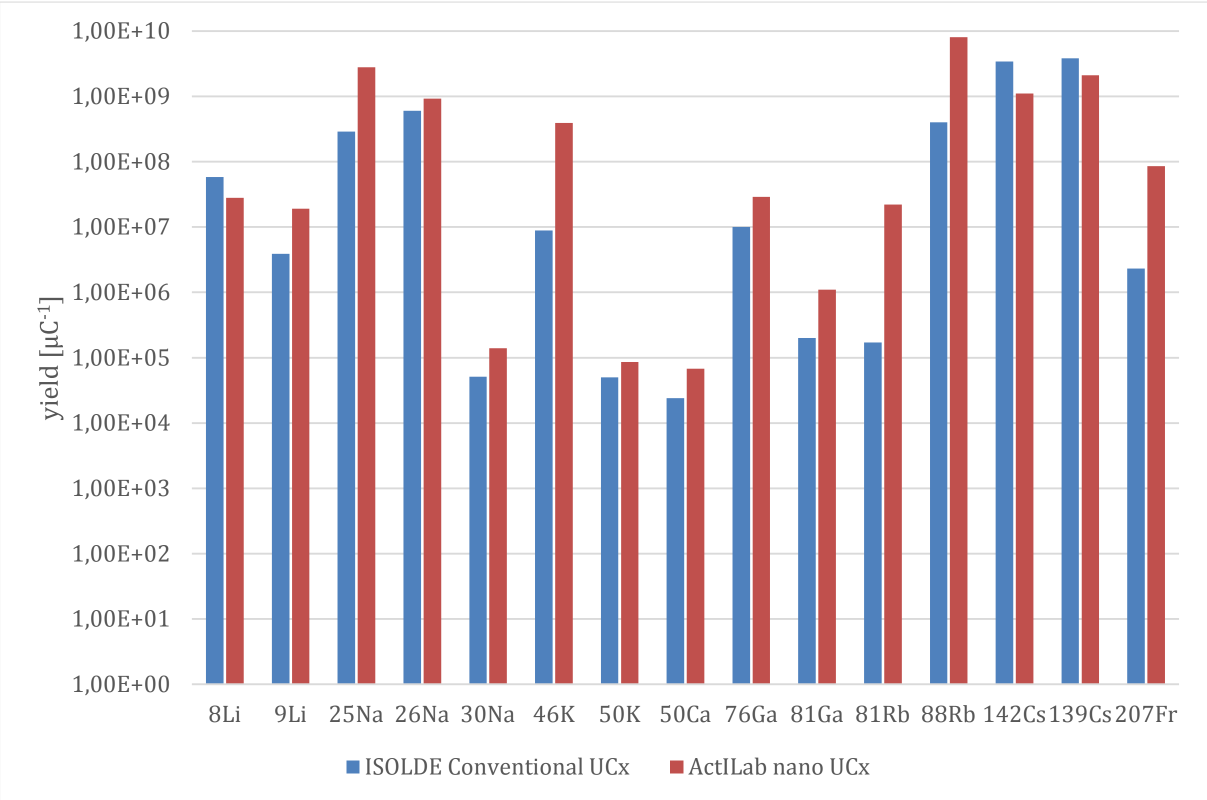


Figure 14: Preliminary results of the ActILab nano-structured UC_x (#525UC-Re) in comparison to conventional ISOLDE UC_x targets. The references are taken from the ISOLDE database; except for ^{26}Na and ^{88}Rb from measurements on targets #410 UC-W and #301UC-Ta.

In the case of many exotic radioisotopes, the beam intensity reduces over time more or less drastically, making the planning of an experimental campaign challenging. Fig. 11 shows this ageing effect as observed on conventional UC_x target materials (blue points) for short-lived ^{30}Na ($T_{1/2}$ = 48 ms) in comparison to the novel ActILab nano-UC_2 (red points). Over the time of a typical ISOLDE target life cycle (5-15 days) a drastic drop of isotope rates of two orders of magnitude has been observed for ^{30}Na from several conventional UC_x target units at ISOLDE. Assuming that losses are caused entirely by the growth of uranium carbide particles (sintering) and consequent decay of ^{30}Na during diffusion, a simple diffusion model (R. Kirchner, NIM **B70** (1992) 186) can be employed to relate every observed yield to a certain particle size. Since the temperature-dependent diffusion constants *D(T)* of Na in UC and UC_2 are not known, an assumption has to be made that can describe the initial crystallite size of both, the non-irradiated UC_x (see MS87) and the irradiated UC_x (see MS89) observed in synchrotron-based micro X-ray diffraction studies. The resulting particle-size evolution is shown in Fig. 12. Two domains of particle growth rate can be found in this way, indicating two competing mechanisms of sintering

D8.4 Isotope release properties and modelling

The isotope yields have been compared between a standard UC_x target and a nano-structured target operated at ISOLDE. The different release characteristics can be seen in Fig. 13. For many of the isotopes investigated, increased and steady yields have been observed; see Fig. 14.

Conclusion

The institutes involved in ActILab have used the allocated material resources and manpower as initially foreseen. All milestones and deliverables have been achieved, with significant findings and impact for the present and next-generation ISOL facilities.

Deviations from Annex I
None

Use of resources
It follows the work plan of Annex I.

Corrections
None

Work Package 9: JRA03-PREMAS

Participants: GANIL, JYU, CERN, CNRS, KU Leuven, UNIMAN, JOGU Mainz

Progress report of the third period (37-52 months)
The work package has three tasks (with the coordinating partner in parentheses):
1. Novel radioactive ion-beam production techniques (KU Leuven)
2. Advanced ion manipulation, spectroscopic techniques and instrumentation (JYU-JYFL)
3. Sources of pure and intense radioactive ion beams (GANIL)

Task 1: Novel radioactive ion-beam production techniques (KU Leuven)

Task 1 is further divided into three subtasks with responsible partner in parentheses:
Subtask 1.1 (KU Leuven): New LIS techniques (ion manipulation with DC electrical fields in gas cells, new resonance ionisation zones in RILIS) and novel methods for the collection of fusion-reaction products with half-lives beyond 100 ms.
Subtask 1.2 (Mainz): New LIS schemes (including atomic level searches in elements with unknown level schemes).
Subtask 1.3 (CERN-ISOLDE): Isomer selectivity using the combination of lasers and ion traps.

Progress report:

Reduction of beam contaminations in the gas-cell approach
The introduction of a new type of gas cell in which the stopping volume of the nuclear reaction products, including the primary beam path, are separated from the laser ionisation volume, has been a key development for the production and spectroscopy studies of pure radioactive beams at the Leuven Isotope Separator Online (LISOL) facility. In such a "Dual Chamber" gas cell the direct ionisation near the exit hole through hard X-rays is blocked, which enables the use of electrical potentials in a pair of collector electrodes within the gas cell. The use of these collector plates leads to a strong suppression of the isobaric contaminants surviving the neutralisation and therefore to an increase of the selectivity, i.e. of the ratio between the signal with lasers on and lasers off. In the first experiments using this approach, a laser selectivity of 2200 was achieved for rhodium isotopes produced in fusion evaporation reactions [1], opening up new possibilities for in-source laser spectroscopy studies in, e.g., the $N = Z$ nuclei [2] and the actinide regions of the chart of nuclides.
A recent experimental campaign at LISOL has been devoted to in-gas-cell laser spectroscopy studies of neutron deficient actinium isotopes. During this campaign we observed a very high production of these isotopes (~ 50 pps) in the absence of laser radiation that could be significantly reduced (to ~ 0.03 pps) by applying a 40V potential in the collector plates. The suppression of this off-resonance count-rate resulted in an ion selectivity of ~ 300 and allowed us to determine isotope shifts, magnetic moments, and tentative spin values for the $^{212-215}$Ac isotopes [3].
New ionisation schemes in the last 16 months
We highlight the recent development of the laser ionisation scheme of Ho (Z=67) at the University of Mainz over the final 16-month period of the ENSAR project. The primary motivation behind this work stems from the novel ECHo project, the Electron-Capture ^{163}Ho Experiment. ECHo aims to investigate the electron neutrino mass in the energy range below 1 eV via a high statistics calorimetric measurement of the ^{163}Ho electron capture (EC) spectrum. A number of challenges need to be overcome before such a high precision measurement can be attempted. One, of pertinence to this milestone, is due to contamination of the sample following the production of ^{163}Ho via high-flux neutron irradiation. Resonance ionisation is thus mandatory for initial isotope separation and purification of the sample.
An extensive search for the most efficient ionisation scheme was carried out according to Fig. 1. Detailed measurements of the overall efficiency and reproducibility were performed using the strongest excitation scheme with wavelengths of 405 nm, 818 nm and 837 nm, respectively. A remarkably high reproducible efficiency of 25(5) % has been obtained, which is of high importance for ECHo as well as for exotic isotope production.

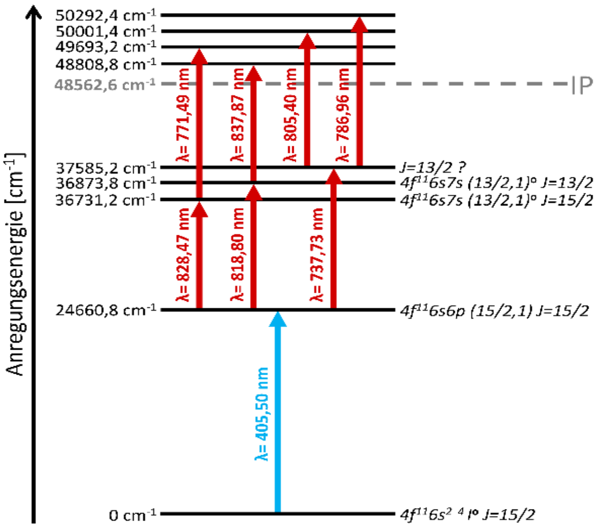


Fig. 1: Three-step excitation schemes tested in the study of Ho.

Based on this work on-going investigations concern level-scheme development in the neighbouring rare-earth elements of terbium (*Z*=65), dysprosium (*Z*=66) and erbium (*Z*=68) as well as the radioactive element praseodymium (*Z*=59), for which the ionisation potential is one of the last missing atomic physics quantities.

Task 2: Advanced ion manipulation, spectroscopic techniques and instrumentation (JYU-JYFL)

Task 2 is further divided into four subtasks with responsible partner in parentheses:

Subtask 2.1 (KU Leuven): Investigation of optimised open trap structures and development of related dedicated novel detection setups for decay spectroscopy with ion traps.

Subtask 2.2 (Manchester): Development and demonstration of collinear resonance ionisation spectroscopy coupled to a gas-filled RF cooler facility.

Subtask 2.3 (JYU-JYFL): In-source spectroscopy in a gas-cell environment and development of laser spectroscopy in a gas-jet environment

Subtask 2.4 (Manchester): Optical manipulation of radioactive ions in gas-filled RF coolers leading to population of specific ionic states and nuclear polarisations.

Progress report

Demonstration of on-line resonance ionisation spectroscopy in a gas-cell and gas-jet environment

In our earlier milestone (MS105), we reported at month 24 of the ENSAR project on the collaborative effort which led to an on-line comparison between the LISOL medium-repetition rate dye-laser system and the high-repetition rate laser system in use at JYFL, Mainz and GANIL for the laser ionisation of ^{59}Cu in-gas-cell as well as in-gas-jet. Compared to in-gas-cell laser ionisation, an improved resolution down to 2.6 GHz was achieved for in-gas-jet ionisation due to the more favourable environment (low temperature and pressure) of the gas jet [4]. This experiment thus motivated developments associated with narrowing of the tunable laser linewidths for higher-resolution studies, in particular targeting the gas jet.

In a first step towards the very-heavy elements, a recent campaign of measurements at LISOL has focused on spectroscopy of Ac. Preliminary in-gas-cell broadband laser spectroscopy was performed on ^{212}Ac, revealing a linewidth of almost 30 GHz for the excitation step [5]. Later, high-resolution RIS on long-lived ^{227}Ac (discussed in the second progress report) was performed in collaboration with JYFL and the University of Mainz to identify a more suitable transition for spectroscopy [6]. The most promising transition with the largest total splitting was subsequently used for isotope shift measurements of $^{212\text{-}215}$Ac at LISOL, the latter located at the *N*=126 shell closure [7].

In a very recent experiment, the same collaboration as reported in MS105 returned to LISOL to perform high-resolution in-gas-jet spectroscopy on ^{214,215}Ac. The JYFL contribution of the Ti:sapphire ring laser, injection-locked using the Mainz diode laser system, combined with the dual-chamber gas cell of Leuven with the GANIL-design de-Laval nozzle, resulted in a milestone for in-source spectroscopy and indeed the final experiment of LISOL. A spectral resolution as low as 300 MHz was achieved with a selectivity of ~200 and an efficiency of ~0.5% (the latter comparable to that measured in the gas cell). This resulted in isotope shifts as well as the hyperfine *A*- and *B*- parameters extracted from the data with a 25-fold higher precision than obtained via in-gas-cell spectroscopy. Both the earlier in-gas-cell measurements as well as the recent in-gas-jet measurements are currently under analysis and will be submitted for publication in 2015.

Task 3: Sources of Pure and Intense Radioactive Ion Beams (GANIL)

Task 3 is further divided into three subtasks with responsible partner in parentheses:
Subtask 3.1 (GANIL): Production and purification techniques for ECR-ionised RIBs.
Subtask 3.2 (LPSC): Compact and integrated target–ECR source systems.
Subtask 3.3 (JYFL): Development of radiation-hard ECR 1^+ or n^+ sources.

Progress report:

ECRIS performance report; projection from studies, results from off-line tests and possible on-line tests

Versatility of ECRIS for metallic ion-beam production

The use of ECRIS for producing pure radioactive ion beams of metallic elements has been studied with many different systems in this JRA:

- With the COMIC source at ISOLDE to produce 1+ beams of CO molecules (see MS111 report)
- With the Nanogan 3 source at GANIL and a combination of the COMIC source and Phoenix ECR charge breeder at LPSC (see Milestone report 112) to produce CO beams
- With the future ARC-ECRIS source used as a charge breeder (see Milestone report 113)
- With a combination of a FEBIAD source and of a Phoenix charge breeder which will be used at GANIL (see Milestone report 110)

While the first two studies concentrated on the tests of carbon beam production, the second two ones envisaged more universal methods of producing pure beams of metallic elements. The performances of COMIC were evaluated with a 2.45 GHz version [8]. It was shown that better results could be obtained with a 5.6 GHz version.

The comparison of the production of multicharged ion beams of carbon was done at LPSC with Phoenix and at GANIL with Nanogan 3 [9]. From this study, it appears that direct multi-ionisation in Nanogan is more efficient than a two-step ionisation.

The ARC ECRIS expected performances in terms of stability and versatility in term of beam injection were studied and discussed. Such performances are very attractive for a concept of 1+ beam merger and charge breeder at EURISOL. A cost estimate for such prototype was given.

The on-line production of radioactive ion beams at GANIL at the SPIRAL 1 facility should make use of an upgraded Phoenix charge breeder, which has been specifically designed for producing pure beams of light metallic elements [10]. The upgraded setup should become operational in the beginning of 2017.

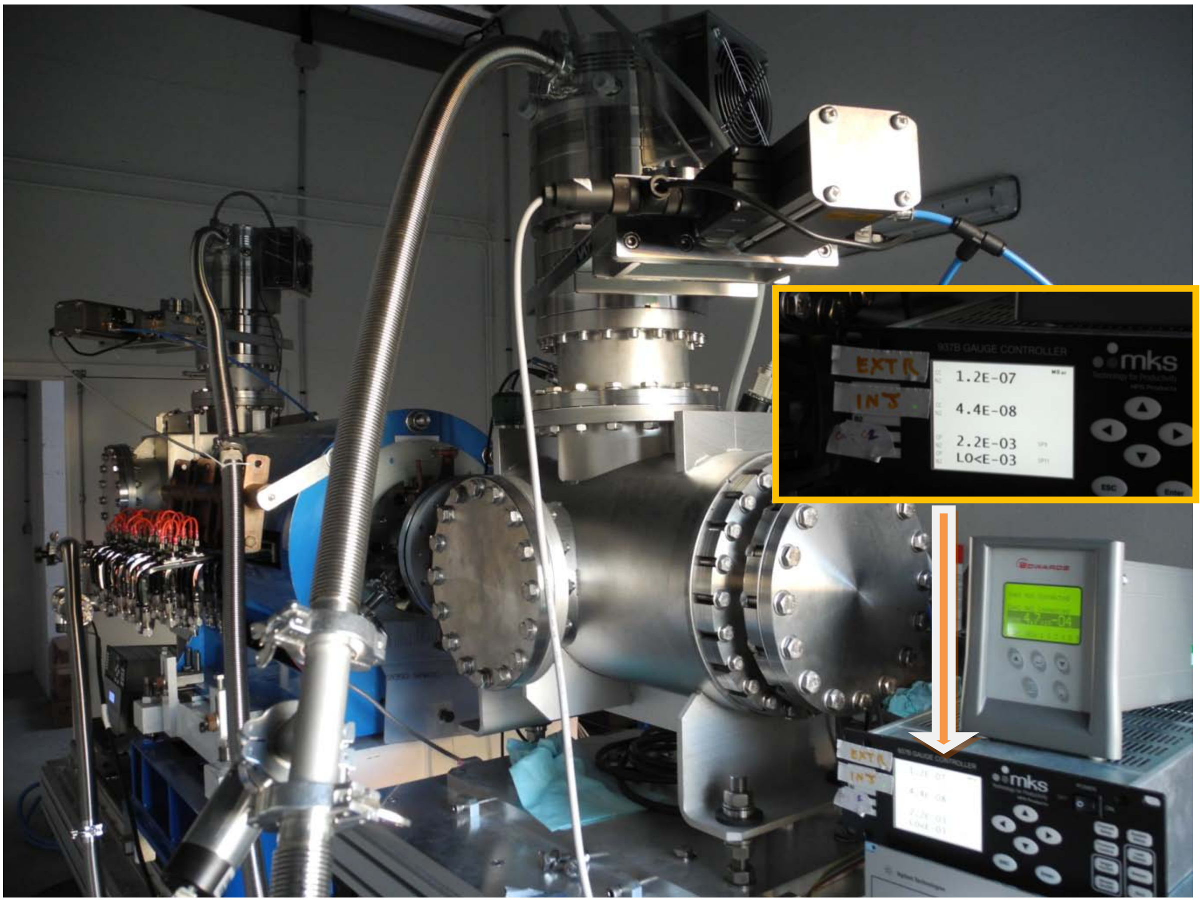


Figure 1: Photograph of the test bench. The inset is a zoom of the vacuum gauge display. Readings are in mbar. See text for more details.

Metallic ion-beam production and purification at GANIL

In the frame of PREMAS, the charge breeder and surrounding beam line has been assembled and first vacuum tests have been undertaken. Most of the charge-breeder components are of pure Al, including the plasma chamber, RF blocker, grounded tube and extraction electrode. All pieces have been chemically cleaned. Iron cones at injection and extraction have been coated with nickel to avoid oxidation. Such oxidation could be the source of an important residual partial pressure of O_2, as observed at LPSC. Most of the elastomeric O-rings used for these tests will eventually be replaced by metallic rings. Pressures of less than 5×10^{-8} mbar at injection and of about 10^{-7} mbar at extraction were obtained after a couple of days of pumping (see Fig. 1). At present only one turbo pump of 750 l/s was used at injection and only one at the extraction side. They should be completed soon with two sets of twin turbos. In such condition, the goal pressure of $\sim10^{-8}$ mbar should be obtained after a few weeks of pumping. With such low residual pressure, and with clean components mostly of pure Al, it is expected that the Phoenix charge breeder will provide the cyclotron CIME, which reaccelerates the beams of SPIRAL, with beams of a much better purity than standard ECR charge breeders. The cyclotron mass resolving power, up to about $R = m/\delta m = 10^4$, should then permit to purify further the beam before delivery to the GANIL experimental areas.

References:

[1] Yu. Kudryavtsev et al., Nucl. Instr. and Meth. B 267 (2009) 2908.
[2] R. Ferrer et al., Phys. Lett. B 728 (2014) 191.
[3] C. Granados et al., Phys. Lett. B. in preparation.
[4] R. Ferrer et al., Nucl. Instrum. Meth B 291 (2012) 29.
[5] R. Ferrer et al., Nucl. Instrum. Meth. B 317 (2013) 570.
[6] V. Sonnenschein, Ph.D. thesis, The University of Jyväskylä (2015).
[7] C. Granados et al., Phys. Lett. B. in preparation.

[8] P. Suominen et al., Proceedings of the ECRIS 2010 conference, MOPOT006, JACoW.
[9] L. Maunoury et al., Rev. Sci. Instrum. 85 (2014) 02A504.
[10] P. Delahaye, L. Maunoury, R. Vondrasek, Nucl. Instr. Meth. A 693 (2012) 104.

Deviations from Annex I
None.

Use of resources
It follows the work plan of Annex I.

Corrections
None.

Work Package 10: JRA04-INDESYS

Participants: GSI, INFN, JYU, TUD, IFJ-PAN, FFCUL, USC, CIEMAT

Task 1: R & D new and existing scintillation materials. Detectors coating and compacting

➢ **Subtask 1:** Study of new and existing inorganic scintillation materials with commercially available photo-sensors (LAAPD, SiPM, PM). Comparative study of the best commercial combination. Characterisation of organic scintillation materials to extend the neutron detection to lower energies. Investigate the use of LAAPD arrays and SiPM as photo-sensors of large-volume liquid scintillation cells. Comparative study of the best commercial combination. Test of new scintillation materials with neutrons, gammas and light charged particles with radioactive sources and dedicated irradiation at reference facilities (accelerators). Construction and test of detector prototypes.
Partners: USC, CIEMAT, INFN, JYU, IFJ-PAN

Progress

In 2014, two prototype detectors, each consisting of 64 CsI crystals with lengths of 170, 180 and 220 mm, were tested at the Bronowice Cyclotron Centre (CCB), Krakow and at GSI, Darmstadt, respectively. The crystals were wrapped with ESR, mounted to Hamamatsu LAAPDs and mounted with an alveoli carbon-fibre support structure. FEBEX FPGA were employed for the digital-electronics support.

The Bronowice Cyclotron Centre proved an excellent facility for the characterisation of the detectors, as nominally the accelerator is used for proton therapy, which demands an energy spread of lower that 0.7%. Protons ranging in energy from 70 to 230 MeV were elastically scattered onto the crystals, which gave excellent linearity across this energy range; a linear fit yielding proton residuals superior to 1 MeV across this range, with peak resolution superior to 2%. Gamma measurements up to 6 MeV were also made, the crystals yielding an excellent average resolution of 5.5% at 1 MeV.

Following characterisation, the prototypes were employed during a beam test at GSI, S348, where a number of different reactions and configurations were tested, including ^{48}Ca(p,2p) at beam energies around 400 MeV/u. Different targets (C and Pb) were used to explore the different working modes of the prototype as calorimeter, spectrometer and hybrid mode. The data analysis is still ongoing, but the detector proved to work very reliably both in stand-alone mode and also integrated with other detectors. The data are still undergoing analysis, but early results look very promising.

The activity related to the study of new scintillation inorganic materials concentrated in two branches. The first concerns the study of the properties of LaBr3:Ce scintillator crystal and the second concerns the study of the properties of novel types of very promising scintillators like CeBr3, SrI2, GYGAG and CLYC. In the study of LaBr3:Ce detector, we have studied basic properties such as the response of these detectors to gamma rays starting from very low energy (5 keV) up to very high energy (22 MeV). We have also studied the linearity of the response, and the non-homogeneity in the crystal light yield. For this purpose we have developed customised voltage dividers, analogue and digital unit (already adopted in working experimental arrays). We have additionally studied the response to high energy protons using the CCB.

In the studies of new scintillators we have characterised new scintillator in the energy windows 0.1-9 MeV and we have studied their response to collimated beams of photons. On CLYC scintillator, which can be used for spectroscopy of both gamma rays and neutrons, we have studied the response to fast and thermal neutrons using a crystal enriched with ^{7}Li or ^{6}Li. These detectors may identify neutrons better than ^{3}He and therefore could be possible alternatives. Measurements with monochromatic beams have been done in Frascati and Legnaro (in a parasitic mode) and one dedicated turn will be done in 2015.

The investigation of liquid organic scintillators for neutron detection in decay experiments has also been addressed. The design of an optimal neutron detector for beta-decay experiments has been completed. The optical design has been completed and a cell prototype has been characterised with monochromatic beams at PTB, Braunschweig and CEA/DAM, Bruyeres-Le-Chatel. The experimental data have been compared to Monte-Carlo simulations, thus validating the methodology used for the design and for determining the detector efficiency as a function of the energy threshold in a continuous way.

All these results are recorded in M115, M117 and D10.1

Major deviations: No deviations

➢ **Subtask 2**: Characterisation of light production, propagation and collection of new inorganic scintillation crystals to predict the response of these materials as stand-alone crystals or integrated in sophisticated devices. Implementation of a software tool able to define the best detector geometries. Characterisation of light production, propagation and collection of liquid scintillators. Determination of detector cell geometries in terms of light collection and compacting.
Partners: IFJ-PAN, CIEMAT, JYU, USC

Progress

During this last period we completed the studies on light response of inorganic scintillators for gamma rays based on simulations of light propagation in different detectors using GEANT4 code. The obtained light response was studied for cubic LaBr3″(2 ×2″×2″) and finger-like CsI(Tl) inorganic crystals. The response function to neutrons of energies in the range up to 14 MeV was also addressed for the case of liquid organic scintillators.
Extensive work has been performed in order to improve and verify GEANT4 packages concerning the optical transport processes inside scintillation assemblies, models for boundary processes like GLISUR and UNIFIED have been validated

All these results are recorded in M116 and D10.2

Major deviations: No deviations

➢ **Subtask 3:** Application to new and existing scintillation materials. Investigation of the performance of materials with both low photon and neutron interaction cross sections (i.e. carbon fibre) for detector housings. Application to germanium detectors. Development of minimal-interacting, passive cover for Ge detectors
Partners: GSI, INFN, USC

Progress

In order to capitalise on the CsI:Tl crystal properties it is essential that the light produced during scintillation is delivered without loss or degradation to the light sensor. In addition to the intrinsic crystal properties of the scintillator material, the wrapping surrounding the crystals is crucial.
A detailed evaluation on the best possible material and also on the adequate wrapping technique has been performed. Following this R&D campaign, the wrapping ESR (Enhanced Specular Reflector 3M) was selected. The improvement in the wrapping technique has also allow to achieve excellent results in extremely long CsI(Tl) crystals as the ones reported in Subtask 1.

The intrinsic surface placed in between the hyper-pure Germanium (HPGe) detector contacts has to be passivated and protected in order to minimise leakage currents that could affect the detector performance. Up to now, available passivation methods were fragile during the normal operation of the HPGe detectors and induced variations in the electric field inside the HPGe affecting the performance of the new generation of position-sensitive gamma detectors.

During these months we have developed different passivation methods for HPGe detectors. Two of these methods have shown extremely good properties that could be adapted for the production of high-resolution gamma detectors.

All these results are recorded in M118 and D10.3

Major deviations: No deviations

Task 2: Development of a detection concept and prototypes for high-energy neutrons

➢ **Subtask 1:** Simulation of response functions from fast-neutron detector prototypes and full detector optimisation with respect to efficiency, multi-hit capability, and converter implementation.
Partners: GSI, TUD, FFCUL

Progress

The simulation of a complete detector based on a highly modular, purely active scintillator for high-energy neutron detection was accomplished; as a result a prototype consisting of 150 modules was built.
This prototype has been tested using mono-energetic neutrons produced in $d(p,2p)n$ reactions using deuteron beams in the energy range from 200 to 1200 MeV. The data have been evaluated and compared in detail to the simulations. Very good agreement has been found validating the detector concept.
In 2014, different planes of the detector with a total thickness of 50 cm have been tested successfully at GSI under heavy-ion beam conditions. During the S438 experiment (April 2014) the first double-plane of the prototype detector was tested using neutrons from 700 MeV/u ^{58}Ni (Coulomb-)breakup on a Pb target. The preliminary analysis of the S438 data has resulted in a 100 ps time resolution for the gamma peak, confirming the design goals.
During 2-9 October an experiment took place testing various demonstrators and using ^{48}Ca beam from GSI synchrotron. Our prototype was exposed to neutrons primarily from nuclear breakup of Ca on C target, therefore dominantly one- and two-neutron events are expected. Of special interest are the multi-neutron events expected from fission studies during the SOFIA experiment performed during 17-25 October at R3B/GSI. The preliminary results for ^{236}U and other fissile isotopes already indicated the difference in the number of impinging neutrons compared to the ones stemming from nuclear breakup of ^{48}Ca. Important information on background handling was gained during the three GSI beam times in 2014. The measured data confirmed the time resolution obtained earlier and the active depth of the detector will allow for hit-pattern investigations.

See also MS119 and D 10.4.

Major deviations: No deviations

➢ **Subtask 2:** Development, tests and optimisation of RPCs for the detection of fast neutrons including test measurements using electrons and neutrons, and including a cost-effective electronic read-out scheme providing the excellent time resolution required (about 10.000 channels).
Partners: GSI, TUD, FFCUL

Progress

The simulation of a whole neutron Time-of-Flight spectrometer based on timing Resistive-Plate Chambers (tRPC) was successfully accomplished.
The detector concept was developed considering solely glass as a detector converter. Several aspects were considered during the study:

• Optimisation of glass thickness to reach the desired efficiency of ~ 100 % for one-neutron detection
• Optimisation of geometry (number of gas gaps) to reach the desired position resolution
• Simulation of full-size prototype to be exposed to relativistic neutrons

A prototype based on tRPCs was constructed and exposed to mono-energetic neutrons in the range from 200 to 1500 MeV produced in the reaction *d*(*p*,2*p*)*n* using deuteron beams at the GSI facility (same experiment as in Subtask 2) . The results are still under data analysis.

See M120 for a more detailed description**.**

Deviations from Annex I
None.

Use of resources
It follows the work plan of Annex I.

Corrections
None.

Work Package 11: JRA05-SiNuRSE

Participants: GSI, RUG, CEA, ATOMKI-HAS, IFJ-PAN, IFIN-HH, USC, CIEMAT, UCM

Objectives of the work-package

Performing simulations for nuclear structure and reaction studies has become a necessity in recent years as the experiments in the field of ENSAR sciences are getting more and more complex. This complexity reveals itself not only in the design of the detection systems, but also in the analysis of the experimental data obtained with these detectors. The particle and nuclear physics communities have developed a large number of simulation programmes for physics experiments. These programmes have generally been tailored to the specific needs and as such need serious modifications before they can be used for a different application. In the community of nuclear physics, the problem is even more enhanced due to the fact that the existing databases are generally not suited for nuclear structure studies and are even non-existent for heavy-ion induced reactions. The use of databases (contrary to event generators) is also not compatible with the accounting of correlations between particles, necessary in complex detector simulations. On the other hand, there are simulation codes developed for a wide range of applications such as reactor and neutron-source design, space or medical applications that are not suited to simulate complex detection setups, with for instance magnetic devices. In addition, there is a strong move in the physics community to make the simulation programmes as transparent as possible to the user. Several steps need to be taken in order to achieve the goal of a fully integrated suite of simulation programmes:

- *Event generators* based on realistic physics models must be developed, which are useful for the experimental activities pursued at the European facilities concerned by ENSAR.
- These models must be *benchmarked* against a wide set of available elementary experimental data and against each other.
- A platform for simulations should be created in which the user can easily switch between various modules. The ultimate goal is to be able to combine an event generator from a specific application with the definition of the geometry from another code and the tracking of a yet another programme.
- The results should be verified against several detector types which are currently being developed for the ENSAR facilities.
- The possibility of using large-scale grid-like simulations should be investigated.

In all these activities, the developers of various codes were consulted so that a uniform approach to solving problems is achieved.

The work-package is divided into three tasks:
Task 1: deals with the event generators and their benchmarking,
Task 2: deals with the development of virtual Monte-Carlo platform, and
Task 3: involves a few well-chosen test cases relevant for several activities of the community.

Performance of SiNuRSE

Aside from a somewhat late start for part of the work which was the result of delays in hiring the qualified personnel (which is very normal in our field), all the work was done within the timeframe of ENSAR and the deliverables were sent in time to the management. In order to guarantee the success of the work-package, a number of milestones were agreed which were used to guard the progress of the project. For almost all the deliverables, a milestone was also chosen which was, more or less, half way into the project. By reaching these milestones, the groups made an evaluation of their activity and made the right adjustment in order to reach the final destination which is the deliverables. These milestones are:

Milestone number	Milestone name	Delivery date	Means of validation
MS121	*Event generator for light-ion induced reaction ready for benchmarking and implementation*	*24*	Event generator vs. models
MS122	*Event generator for heavy-ion induced reaction ready for benchmarking and implementation*	*36*	Event generator vs. models
MS123	*Event generator for specific reactions ready for benchmarking and implementation*	*24*	Event generator vs. models
MS124	*Choice for codes to be implemented in the virtual Monte-Carlo simulations*	*24*	Software prototype for evaluation
MS125	*Implementation of neutron detector geometry and event generator*	*24*	Characteristic histograms of the detector
MS126	*Implementation of fast ejectile and heavy-ion detectors and event generator*	*24*	Characteristic histograms of the detector

Progress for Task 1

Task 1 was initiated to study various reactions, make the appropriate event generators for simulations and benchmark the models with experimental data or other predictions. This task was divided into 6 subtasks which are listed below along with the groups responsible for them:

Subtask 1: Development of an event generator for light-ion induced reactions (CEA, U-Liege)
Subtask 2: Development of an event generator for heavy-ion induced reactions (GSI)
Subtask 3: Development of an event generator for elastic proton-nucleus cross sections and *p*-*n* reactions with focus on exotic nuclei (UCM).
Subtask 4: Development of an event generator for beta-decay including delayed particle emission (*n*, *p*, alpha) (CSIC).
Subtask 5: Development of a gamma-ray event generator for neutron-capture electromagnetic cascades (CIEMAT).
Subtask 6: Development of a software tool which allows the use in GEANT4 of cross sections from correct (neutron and ions) reaction databases for low-energy reactions. (CIEMAT).

The event generators developed and benchmarked in this task are now available to the whole community of nuclear physicists, most of them being implemented into the GEANT4 transport code. The way the work was organised, these subtasks resulted in four specific deliverables:

D11.1*: Report on the benchmarking of the event generator for light-ion induced reactions (Month 36) (CEA)*
D11.2*: Report on the benchmarking of the event generator for heavy-ion induced reactions (Month 48) (GSI)*
D11.3*: Report on the benchmarking of the event generator for specific reactions (Month 48) (CIEMAT)*
D11.4*: Report on the benchmarking of the event generator for fusion-evaporation reactions (Month 48) (IFJ-PAN)*

The deliverables are now in possession of the management of ENSAR. Deliverable D11.1 had a few months delay to a late start of the project as mentioned in the introduction.

Progress for Task 2
The objective is the implementation of a virtual Monte-Carlo framework, so that various simulation programmes can be used by the whole community without dealing with the details of individual programmes.

This task was divided into three various subtasks:
Subtask 1: Basic framework structure, code management (USC);
Subtask 2: Parameters database management (RUG);
Subtask 3: Detector integration, quality assessment (IFIN-HH, ISS).

This subtask was also managed by having one milestone half way the project (MS124 as listed in the table above) and a deliverable:

D11.5: *The platform for Monte-Carlo simulations*

The deliverable of this task is also a website which can be visited by the community to download the appropriate files for running own simulations through the platform EnsarRoot (http://igfae.usc.es/~sinurse/index.php/downloadmenuitem).

Progress for Task 3
The main objective of this task was to perform simulations based on the work done in tasks 1 and 2. The goal was to improve the exploitation of the existing facilities and the accuracy of the experiments through the optimisation of the detection systems in use. However, the developments made in this JRA will also benefit future activities in the field. Three reference cases covering a wide range of experiments and applications have been chosen for this purpose. These are:

Subtask 1: The response of neutron detection systems (ATOMKI);
Subtask 2: The response of fast ejectile and heavy-ion detectors (RUG);
Subtask 3: The response of a calorimeter (USC).

Just like the other subtasks, milestones were set for the first two subtasks, MS125 and MS126. The last subtask already had a head start not requiring a milestone at the level of the other two. The milestones were reached in time and the projects progressed according to the original time plan. This task had three deliverables, namely:

D11.6: *Simulation results for various neutron detectors (Month 48) (ATOMKI)*
D11.7: *Simulation results for fast ejectile and heavy-ion detectors (Month 48) (RUG)*
D11.8: *Simulation results for a calorimeter (Month 48) (USC)*

The deliverables were either on time or ahead of schedule and were delivered to the management of ENSAR. The results of these simulations were also used for the design and development of detectors as well as for the running experiments.

Organisation
Aside from the written agreements in the form of milestones and deliverables, three collaboration meetings were organised for this work-package (namely a kick-off meeting in January 2011, a progress meeting in January 2012 and an advanced meeting in April 2013, all in Amsterdam). In the last meeting, resources were also examined carefully to make sure that all participants are on time regarding their budgets.

Resources
Due to the original cuts, almost all participants matched the resources with their own resources to a larger extent than originally planned, in order to achieve the objectives of the project. All the projects consumed their allocated resources.

Highlights

For this work-package, one can mention several highlights. Here, we enumerate a few of them.
Highlights from Task 1:

1. The fusion-evaporation reaction has been studied in detail and new classes were created for implementation into GEANT4. The starting point is the beam of a given energy, which passes through the target and produces the excited complex system – a compound nucleus. The fusion-evaporation reaction is characterised by the complete and incomplete fusion cross sections and the maximal spin of the compound nucleus. The fusion cross sections has been tested for more than hundred reactions. The evaporation of the particles and gammas takes into account various yrast lines and the Hauser-Feshbach approach. Three new GEANT4 classes are ready to implement in the GEANT4 platform. The results are tested for several reactions with a wide range of compound nuclei, various entrance-channel effects and compared with the state-of-the-art statistical code GEMINI++.

2. The C++ version of the Liège Intra-Nuclear Cascade code, INCL, has been extended to light-ion induced reactions and implemented into the GEANT4 transport code. Figure 1 shows an example of the good agreement between INCL++ and experimental results in the case of $^{12}C+^{12}C$ reaction at 290 MeV. Comparisons with other models available in GEANT4 are also displayed.

3. A new procedure to obtain *p-A* elastic cross sections valid in the range 20 to 800 MeV/u has been developed, with minimum previous knowledge, and is ready to use for exotic nuclei and inverse kinematics. Figure 2 shows the differential cross sections and analysing powers from the elastic scattering of 20 to 800 MeV protons from different nuclei using the formalism developed during the project.

4. A first version of an event generator for beta-decay processes has been assembled. The generator combines information from standard databases (RIPL-3) on level schemes, level densities and photon strengths to produce realistic decay events. The generator includes beta-delayed neutron emission from a simplified model.

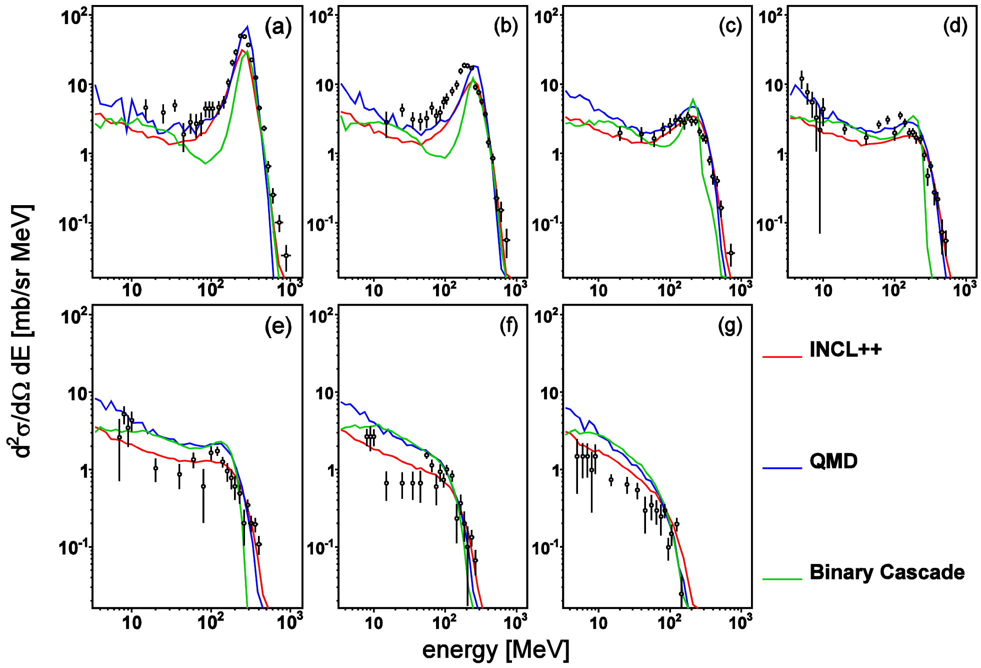


Figure 1

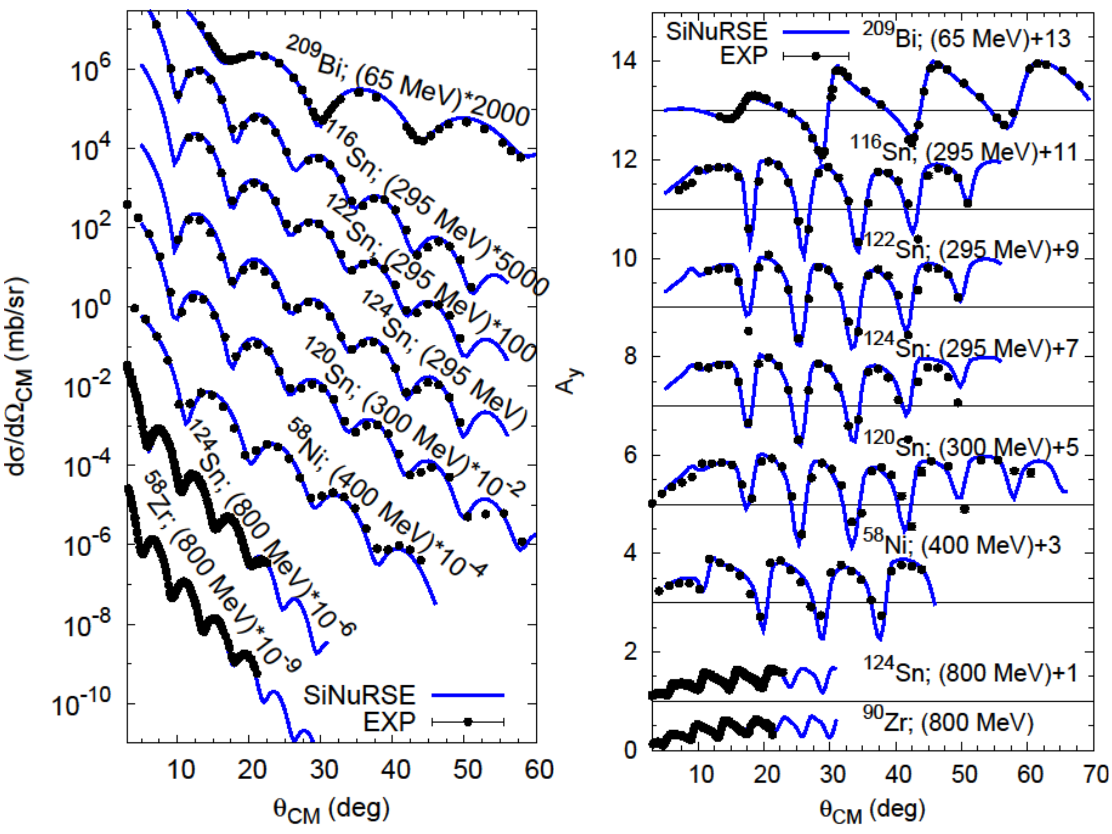


Figure 2

Highlights from Task 2:

5. Based on FAIRRoot, a complete analysis and simulation framework was set up to meet the demands of the community. The new framework called ENSARRoot contains several examples of working of typical detectors in a way that the user could easily access and duplicate them. The digitisation methods for two working detectors were implemented and a simple class structure for the Quality Monitoring framework was proposed.

Highlights from Task 3:

6. Complex calorimeter geometry and the full response of the crystals have been implemented for an archetypical calorimeter. The complete model is included in the ENSARRoot distribution. The main results are published (H. Alvarez-Pol *et al.*, Nucl. Instrum. Meth. Phys. Res. A 767 (2014) 453). Figure 3 demonstrates the event monitor for the CALIFA calorimeter: The top left pad shows the result of the simulation tracking, with energy-dependent track's width. The top right pad shows an isometric detector view where the hits are shown, with the length proportional to the deposited energy. The lower pads show azimuthal and transversal projections of the hit, again with the length proportional to the deposited energy.

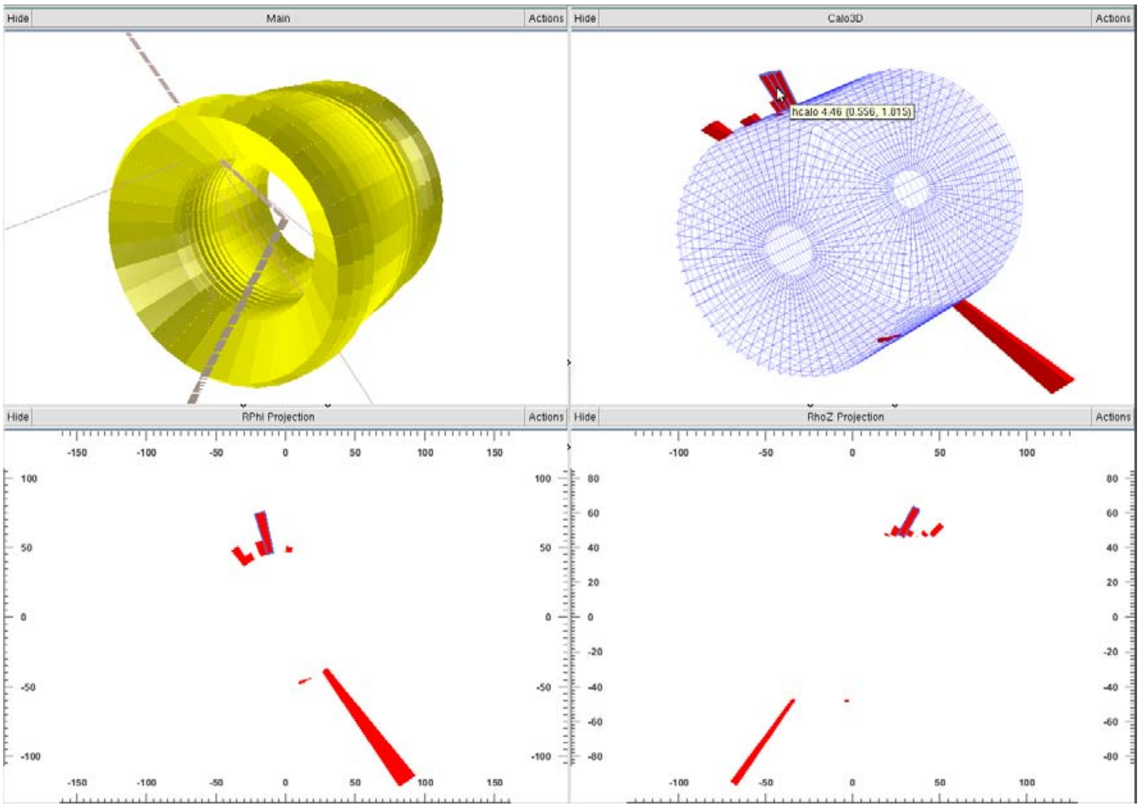


Figure 3

7. To perform simulations for the design of a detector in a storage ring, magnetic fields of two quadrupoles were implemented in a special way to increase the speed of the simulations. In Fig. 4, transversal distribution of ^{54}Fe decay fragment 8 meters away from the target position, after the doublet quadrupole, is plotted. The effect of the quadrupole magnets in an otherwise symmetric distribution is evident from the elliptical shape. The ^{54}Fe nucleus is the result of the decay of an excited ^{58}Ni nucleus into an alpha particle and an iron nucleus for this experiment. Total coincidence acceptance between the recoil detector upstream detecting the alpha particles and the pin-diodes shown in this picture as yellow squares is 1.47% (3.04%) when pins are placed 6 mm (115 mm) away from the beam orbit, top panel (bottom panel). The numbers on each pin shows the coincidence acceptance for that particular pin.

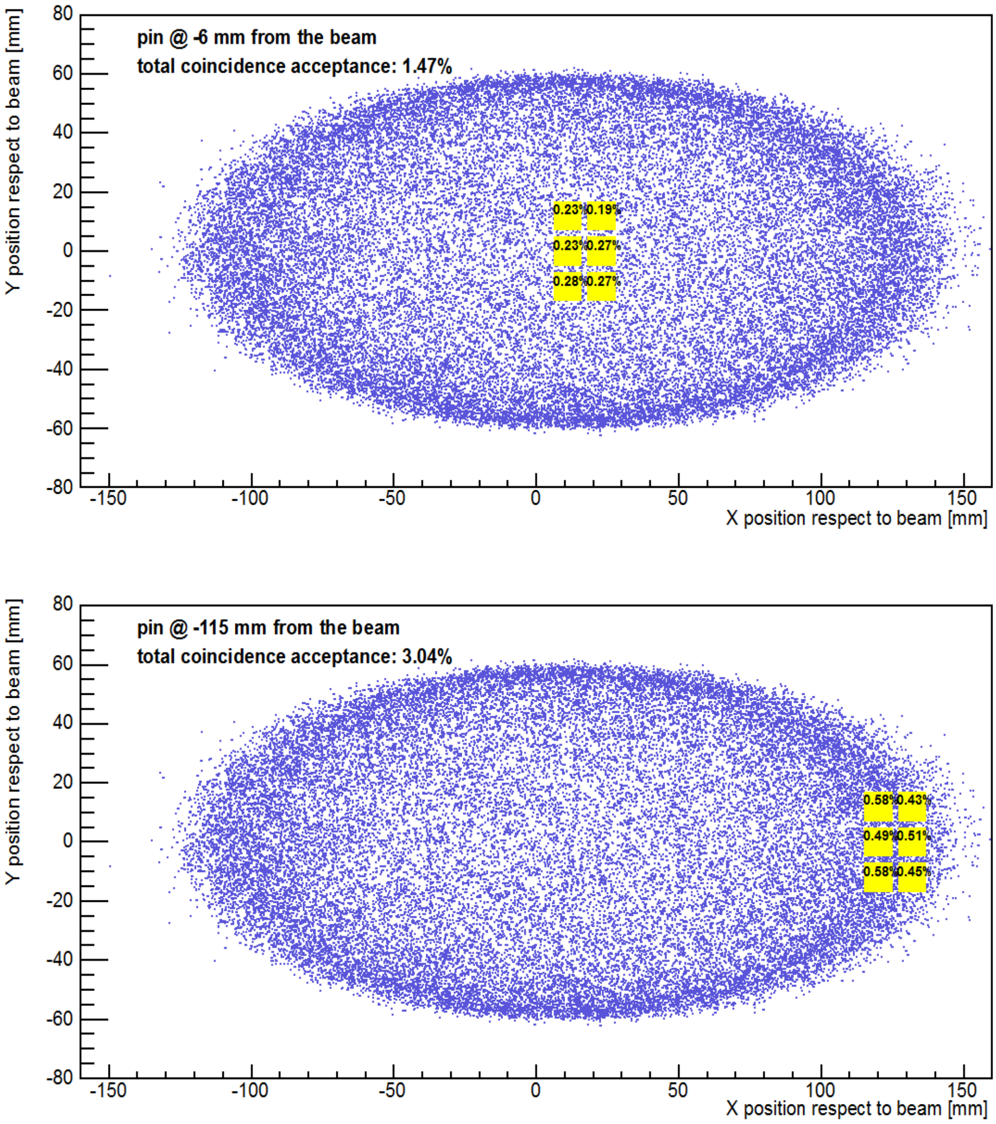


Figure 4

Deviations from Annex I
None.

Use of resources
It follows the work plan of Annex I.

Corrections
None.

Work Package 12: JRA06-EWIRA

Participants: CNRS, INRNE-BAS, RBI, NPI, CEA, NCSRD, ATOMKI-HAS, UWAR, IFJ-PAN, IFIN-HH

This Joint Research Activity combines the resources and enhances the performance of several ***accelerator laboratories from Central and South-Eastern Europe***:

- Tandem Laboratory, National Centre for Scientific Research (NCSRD) "Demokritos", Athens,
- Tandem Laboratory, National Institute for Physics and Nuclear Engineering (IFIN-HH), Bucharest,
- Cyclotron Laboratory, Institute of Nuclear Research (ATOMKI-HAS), Debrecen,
- Cyclotron Laboratory, Nuclear Physics Institute of the ASCR (NPI), Řež near Prague,
- Heavy-Ion Laboratory, University of Warsaw (UWAR),
- Tandem Accelerator Centre, Rudjer Boskovic Institute (RBI) Zagreb,

as well as nuclear physics institutes which have strong scientific communities:

- the Institute of Nuclear Research and Nuclear Energy (INRNE-BAS), Sofia, and
- the Henryk Niewodniczanski Institute of Nuclear Physics (IFJ-PAN), Krakow,

which form the core of this East-West Integrated Research Activities (EWIRA). The goal of the project is to create a niche for the small laboratories and bring them to a level comparable to that of the existing Western European laboratories, thus providing an opportunity for some of them to become part of the European Research Infrastructures (RI). This was achieved through joint activities and point-to-point interaction with the Western European laboratories.

Specific goals of EWIRA were:

- investigate the use of radioactive ion beams and alternative mechanisms for nuclear moment measurements,
- identify the necessary developments and build the necessary instrumentation, and
- establish data-analysis standards and make them available to researchers.

The goals of the EWIRA JRA were achieved by solving the identified specific tasks. The main most important achievements of this work package can be summarised as follows:

Task 1: Novel approach to static moments and lifetime measurement techniques and novel instrumentation for rare nuclear processes (IFIN-HH)

Subtask 1: New plunger devices for stable and radioactive beams in different energy regimes and Doppler-shift techniques for lifetime measurements: Lifetimes of excited nuclear states are critical experimental parameters in determining the reduced transition probabilities in a model-independent way. Within this task new plunger devices were designed and made operational at IFIN-HH in collaboration with the University of Köln, which is the world-class laboratory for plunger instruments.

A plunger device is a mechanical device widely used in γ-ray spectroscopy to measure lifetimes of excited nuclear states in the picosecond range by the Recoil-Distance Doppler-Shift (RDDS) method. A review describing the method and different designs was published [1]. The method compares the lifetime of a nuclear level emitting a γ-ray with the time taken by the recoiling nucleus to travel in vacuum between two foils separated by distances in the range 2 μm to 2 cm. The RDDS method relies on the plunger device to achieve the characteristic micrometric separation distances between the target and stopper foils and on HPGe detectors to separate between the Doppler-shifted in-flight component and the unshifted stopped component. The design of a **plunger device with tracking capabilities** is centred on the design of a new endcap that will allow the use of tracking detectors. The design solutions are to extend the reaction chamber in the direction of the beam, resulting in more cylindrical shape, or to extend the diameter of the chamber, keeping a spherical symmetry.

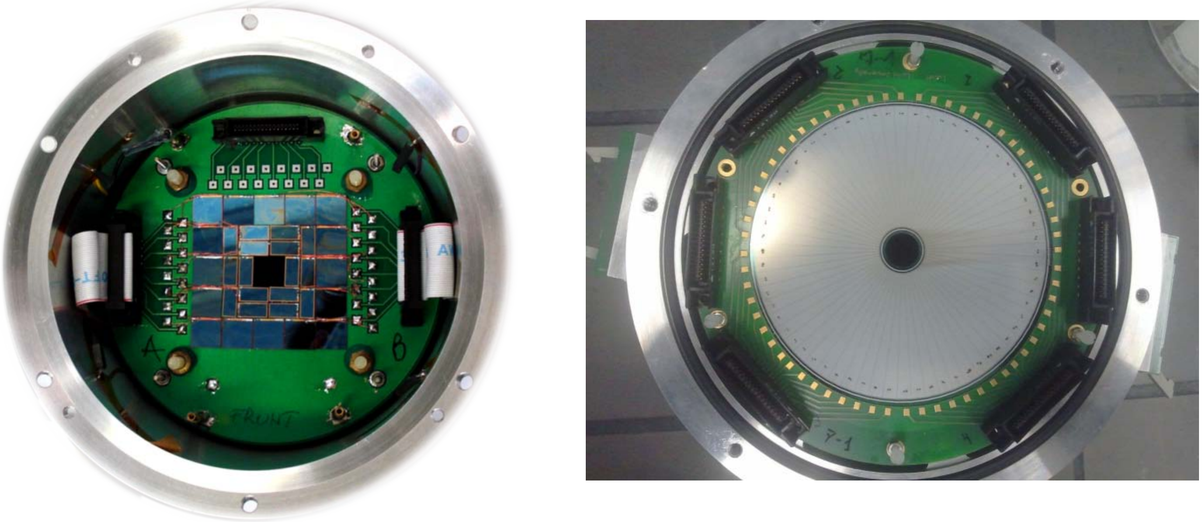


Figure 2: (Left) Photodiodes matrix and (right) annular DSSSD detector installed in the cylindrical plunger endcap.

Figure 3: The spherical plunger endcap during initial tests.

A cylindrical endcap was used both with a photodiode array and an annular double-sided Si-strip detector (DSSSD). As shown in Fig. 1, this array consists of 32 photodiodes with two different sizes arranged in matrix geometry to provide a high granularity at small scattering angles. The DSSSD detector was a custom design developed in Lund University, having an active outer diameter of 85 mm and an inner diameter of 14 mm, segmented in 32 rings and 64 sectors.

The spherical plunger endcap, pictured in Fig. 2 during tests in the RoSphere array at IFIN-HH, was designed to be used with annular DSSSD detectors. The hemisphere has a radius of 87.5 mm, allowing the use of S2 type DSSSD detectors, segmented in 48 rings and 16 sectors, constructed by Micron. Four such detectors are available at IFIN-HH. An analogue data-acquisition system was developed based on 16-channel charge-sensitive preamplifiers, 16-channel MSCF-16 shapers/discriminators, produced by Mesytec, and 32 channels VME peak-sensing ADC. The detectors were tested and characterised. The endcap diameter allows the use of larger area detectors in a single or telescope configuration.

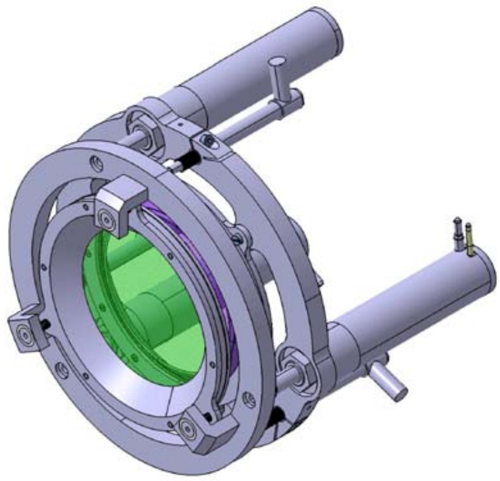


Figure 3: Schematic drawing of the HISPEC plunger device. Near to each of the three linear actuators an inductive sensor is mounted which is clearly visible close to the upper actuator to measure independently the movements induced by the actuator.

The **HISPEC plunger** for high- and medium-energy radioactive beams is a core device for the HISPEC-DESPEC programme, part of the NuSTAR collaboration within FAIR. This plunger (shown in Fig. 3) is meant to be used in experiments measuring level lifetimes in nuclei far from stability, produced in secondary reactions induced by radioactive ion beams separated by the Super-FRagment Separator (Super-FRS), having large beam diameters, typically in the range of several centimetres. The excited exotic nuclei produced at the secondary (plunger) target will recoil into vacuum with velocities up to $\beta = 60\%$ before being slowed down in a degrader and identified further downstream with the LYCCA array. The analysis of the intensities of Doppler-shifted γ rays emitted between the secondary target and the plunger degrader or after the degrader will provide lifetimes of low-lying excited states. The design of the plunger needs to be compact as to minimise the absorption of γ-rays and the beam-induced background. The technical solution is to use three synchronised linear actuators to move the target with respect to the degrader, while three TESA probes will be used to check for thermal drifts and deviations from parallelism.

Subtask 2: New instrumentation for ultra-high efficiency and precise off-beam γ-ray spectroscopy studies. In order to measure the lifetimes of high-lying non-yrast excited states populated in β^+ decay, a new instrument, based on the characteristics of the angular distribution of the reaction products was designed and built to separate the recoiling nuclei in fusion-evaporation reactions from beam particles. This was combined with very high efficiency γ-ray spectrometers and ultra-fast novel scintillators (FEST method). The β-decay parent nuclei are produced in a thin target, so that the reaction products are emerging from the downstream side of the target together with the unreacted incident beam. The incident particle beam is focused on the target by a doublet of magnetic quadrupole lenses to a spot dimension of 1-2 mm. After the target, one has to stop the beam due to its power density that is able to melt the tape material at beam currents of the order of tens of pnA. We are also using a beam collimator, placed before the target, for the same safety reasons regarding the tape. The unreacted incident beam which will mainly pass un-deflected through the target will be then stopped on a metal plug, shown in Fig. 4. In contrast to the beam, the fusion-evaporation product nuclei are emitted from the target in an angular distribution spread over several angles, thus bypassing the plug and stopping in the tape.

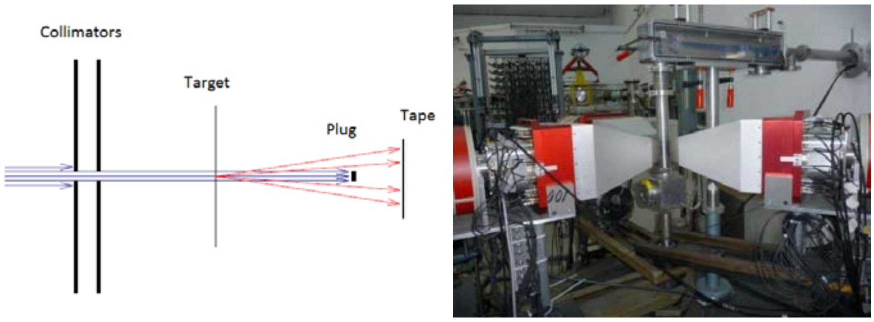


Figure 4: Tape station principle scheme (left) and (right) the γ-ray detectors (HPGe clovers) arranged in close geometry. The setup is split between two experimental halls at IFIN-HH, one hosting the reaction chamber and recirculation box and the other the detection area.

Subtask 3: Static moments of isomeric and short-lived excited states. The use of RIB at ENSAR facilities requires extension of the techniques for studies of static moments in nuclei not available in the past, in particular for neutron-rich nuclei. Such measurements require production of spin-oriented ensembles of excited short-lived or isomeric nuclear states.

The nuclear spin polarisation is an essential ingredient of most of the nuclear-moments study techniques. Obtaining a nuclear spin-polarised ensemble, especially for short-lived states, is not a trivial task and requires a rigorous control over the atomic and the nuclear spins and their interaction from the moment of the population of the state of interest up to its decay. The Tilted Foils technique is based on the possibility of obtaining an atomic spin-polarisation and on the transfer of this orientation to the nuclear spins. We have installed a combined Tilted Foils and β-NMR setup at REX-ISOLDE. During the commissioning tests in July 2012 we have used a ^{8}Li beam accelerated to 300 keV/u from the REX LINAC. The beam was further sent to the TF apparatus, positioned right in front of the beta-NMR setup that was used for determining the level of the nuclear polarisation. The results obtained demonstrate a nuclear polarisation on the level of 3.6±0.3 % (see Fig. 5), which should be considered rather as a lower limit for the present measurement [2].

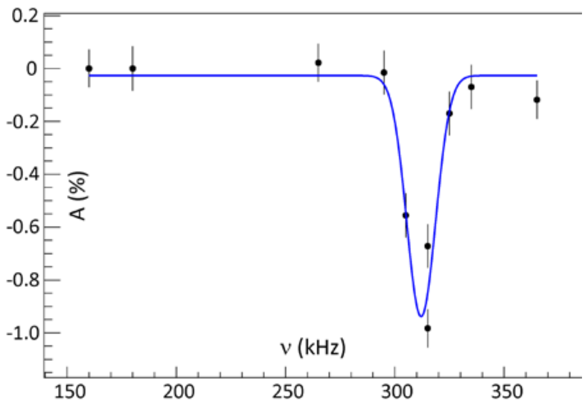


Figure 5: Observed nuclear asymmetry as a function of the applied RF field [2].

In order to perform a nuclear moment study it is necessary to provide a sufficiently strong perturbation to the state of interest so that a sizeable modification of the nuclear spin ensemble can occur within the lifetime of the state. If the lifetime of the studied state is of the order of picoseconds than the strength of the magnetic field needs to be of the order of thousands of Tesla – fields that are not achievable at present with macroscopic devices. Therefore, hyperfine fields are usually used in this type of measurements. We developed a new method, for such measurements by using H-like configuration and applying the Time Dependent Recoil in Vacuum Method (TDRIV) [3]. Results of these experiments are shown in Fig. 6.

Subtask 4: New e^+e^- spectrometer for rare nuclear processes. A Compact Orange-type Positron-Electron Spectrometer (COPE) for precise studies of the positron-electron pair creation in the energy range of about 10-20 MeV was constructed, which will be used for the measurement of dilepton yields (e^+e^- decays) occurring during nuclear interactions. A new-generation spectrometer was designed, having large solid angle (>2π), good energy (1%) and angular (2º) resolutions.

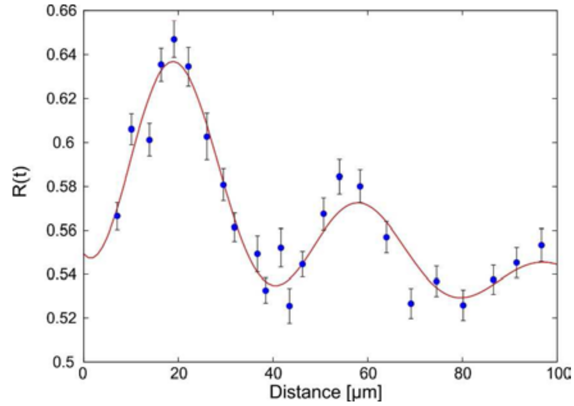


Figure 6: Experimental R(t) function for the 2^+ state in ^{24}Mg [3].

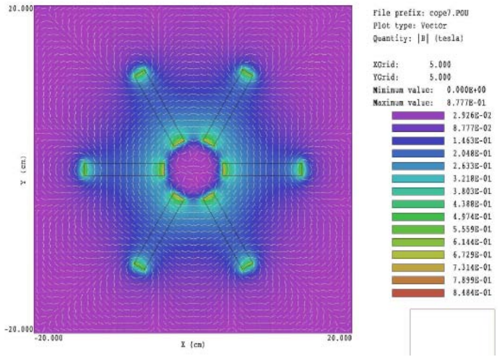


Figure 7: Magnetic-field calculations for the COPE spectrometer.

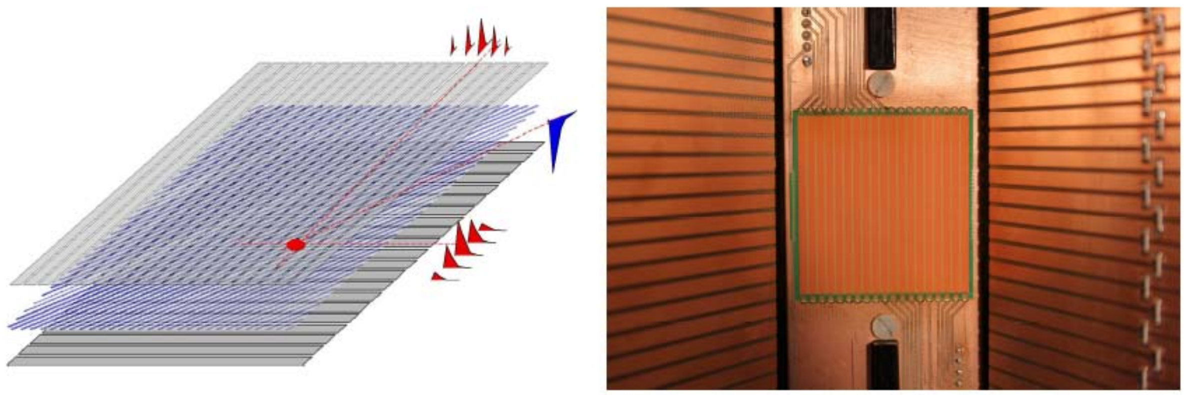


Figure 8: Principle of the MWPC and the construction of the central MWPC detectors and the electric field cages.

A toroidal magnetic field is maintained by permanent magnets. The magnetic field distribution was calculated by the PerMag 6.5 code (http://www. fieldp.com). Inside the gaps the magnetic field of 0.3±0.1 T is reasonably homogenous as shown in Fig. 7.

GEM detectors are the best choice for position-sensitive e^+e^- measurements. Triple GEM detectors were mounted and tested at MTA Atomki, and will be used in the final version of the COPE spectrometer, which will be ready in 1-2 months. Within the project, in a simplified first version of the spectrometer, multi-wire proportional chambers (MWPC) were used as detectors. The positions of the hits are measured by conventional MWPC detectors, which were constructed at ATOMKI as shown in Fig. 8. The anode of the MWPC is a set of parallel 10 μm thick gold-plated tungsten wires at a distance of 2 mm from each other. The two cathodes are composed of copper strips on thin (50 μm) PCB boards separated by 1.27 mm. The anode-cathode distance is 3.5 mm. The two cathodes are placed perpendicularly to each other giving the x and y coordinates of the hit. Delay-line read-out (10 ns/tap) is used for the cathode wires. The accuracy of the (x, y) coordinates implies an angular resolution of $\Delta\theta \leq 2^0$ (FWHM) in the 40^0-180^0 range. The design of the COPE spectrometer and the performance of its present version are submitted for publication [4].

Since some of the experiments which were planned to be done with such spectrometer were urgent, a simplified version spectrometer was assembled, using only the central MWPC detectors and their electronics together with plastic scintillator telescopes. We have already got some nice experimental data with this version of the spectrometer, which are prepared for publication.

Task 2: Novel highly-segmented detectors for Coulex measurements and ion-beam applications and novel target developments.

Subtask 1: Novel highly-segmented CVD scattered beam detector and novel techniques for data analysis for Coulomb-excitation measurements. Experiments with high-intensity beams require detectors resistive to radiation damage and experiments in inverse kinematics require precise reconstruction of the velocity vector of the scattered beam for achieving good Doppler correction of the detected gamma-rays. A solution is to use pixel detectors based on thin synthetic diamond foils produced by the CVD technique, which can detect charged particles at very high rates maintaining excellent timing properties.

Several tests of single-crystal CVD detectors with alpha radiation sources were performed at the Institute of Nuclear Physics of Polish Academy of Sciences in Kraków and at the Heavy-Ion Laboratory, University of Warsaw. Goals of these short measurements were to check properties of various detectors and the applicability of experimental electronic solutions.

Main experimental studies of the properties of diamond detectors employ a high-energy proton beam from Cyclotron Centre Bronowice (CCB) in Kraków and ^{32}S beam form cyclotron U200P in Warsaw. Response of single-crystal CVD (scCVD) detectors to protons was used to design and check the performance of a newly developed electronics. Heavy-ion beams from Warsaw cyclotron allow to test spectroscopic properties and time resolution of the diamond detectors.

In total ten different scCVD detectors were tested with the set-up of Fig. 9. The results of these experiments can be summarised as follows:

- The possibility to use high-speed digital readout for spectroscopic measurements with acceptable performance was demonstrated.
- The timing performance of the detectors is very promising. The measured width of a timing peak is determined by the energy loss in the target, but the result is much better than the resolution obtained with Si detectors.
- The polarisation effect observed with the heavy-ion beam shows that scCVD detector cannot be used at a high rate. Further studies of the effect are required.

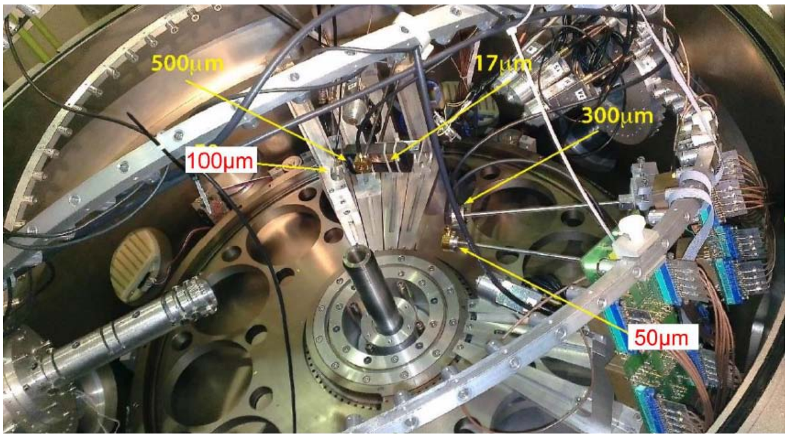


Figure 9: The experimental set-up used for scCVD detector test at the Heavy-Ion Laboratory, University of Warsaw. Detectors used for the coincidence measurement are labelled in white boxes.

The quality of scCVD detectors is unstable and spectroscopy of heavy ions with them is difficult at the present state of technology. Coulomb excitation is a well-developed method to determine electromagnetic properties of nuclei in the ground and excited states. This experimental technique is widely applied to the unstable-nuclei studies, which started to become possible with the availability of exotic-beam facilities. The analysis of Coulex data is a complex numerical process of minimisation in a multi-dimensional space. A basic analysis tool for Coulex measurements is the least-squares search computer code, GOSIA.

Advantages of GOSIA are:

- χ^2-fitting procedure (using a gradient method) to determine the best set of electromagnetic matrix elements,
- fast approximation method developed to speed up the analysis of the complex experiments, and
- extensive possibilities to take into account various geometries of the experimental setup.

Limitations of the gradient method implemented in the code are:

- a susceptibility to local minima, and
- a time-consuming process to search for alternative solutions.

The goal of the project was to propose and implement a new minimisation technique for the Coulomb-excitation data analysis. The Front Line Algorithm (FLA), the new geometric method for the objective-function-shape investigation in the neighbourhood of a minimum, was developed. It exploits samples non-uniformly generated and evaluated during the minimisation process, which are stored in a file called repository. The shape of the objective function cut at a specified threshold comes as a result. A comparison of the standard GOSIA and the new data flow, using the new JACOB and RepScan applications is shown in Fig. 10. The new approach for analysis of Coulex experiments has been applied to several experimental datasets [5,6]. The package is available on the webpage: http://www.slcj.uw.edu.pl/~pjn/Jacob/.

Subtask 2: Segmented detection systems for increased particle detection sensitivity and imaging of light elements using coincidence ion-beam analysis techniques. An important application of segmented position-sensitive detectors is related to ion-beam analytical techniques. The possibility to use diamond detectors in ion-beam analysis applications has been explored for coincident elastic-scattering technique. This technique is based on the concept of irradiation of transmission samples by ion microbeam and detection of both scattered and recoiled nuclei in coincidence. In this way a 3D analysis of elements similar in mass to the mass of the projectile ion could be performed.

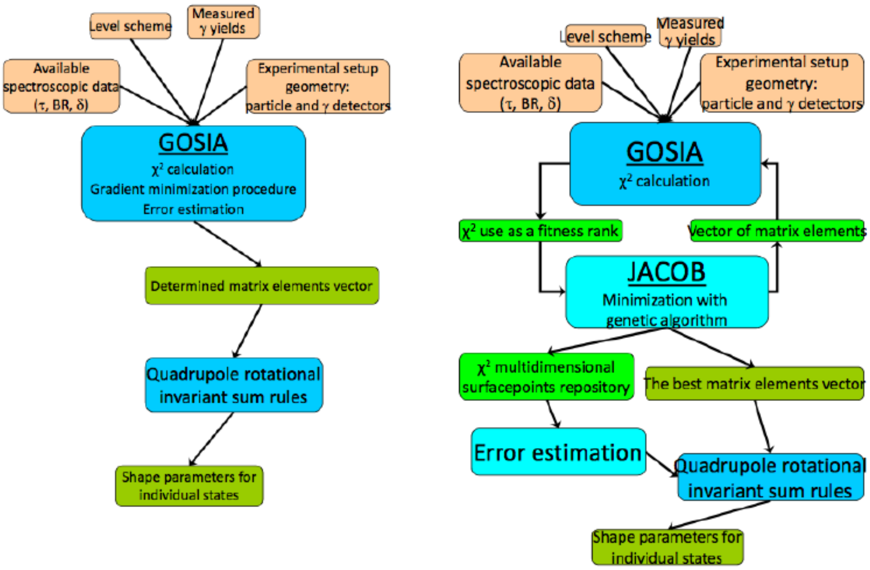


Figure 10: The data flow diagram for the standard Coulomb-excitation analysis (left) and for the JACOB/RepScan scheme (right).

In order to determine capabilities of CVD diamond detectors to replace silicon detectors for ion-beam analysis, and in particular in elastic-scattering coincidence setup that uses microbeams of C or O ions (which offer the widest range of elements for the analysis), the heavy-ion nuclear microprobe facility at the RBI has been used. Details of the experimental set-up are shown in Fig. 11. The performance tests consisted of:

- diamond-detector radiation hardness measurements,
- studies of their timing properties,
- possibility to obtain position sensitivity without using a stripdetector approach, and
- feasibility study for coincidence-measurements 3D-analysis applications using CVD diamond detectors.

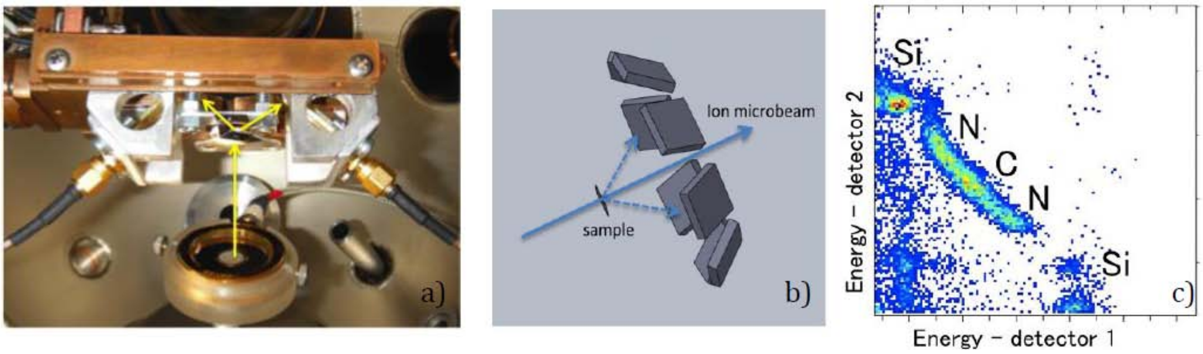


Figure 11: a) Coincident scattering module with two CVD diamond detectors, b) concept of array of eight detectors for energy and timing of coincident events, and c) 2-dimensional energy spectrum with elastic scattering peaks for SiN sample exposed to 6 MeV C ions.

Based on the performance tests within this task the following conclusions can be made:

- Radiation hardness of single-crystal CVD diamond detectors for detection of MeV energy ions (protons, C and O ions) is not better than silicon and therefore radiation hardness of diamond cannot justify the replacement of silicon by diamond.
- Timing properties of diamond detectors are surely better than silicon and moreover they have a negligible leakage current. However, in the case of coincident scattering, the timing properties could not be utilised for the low-energy range of C ions available at the RBI microprobe. Higher energy of detected particles (of the order of 10 MeV) would give better results, which is unfortunately too high for most of the analysis applications.
- Both the radiation hardness and superior timing properties are advantageous for very thin diamond detectors (e.g., 6-micrometres thick diamond membrane detector). Such detectors may be used as a trigger for transmitted ions that induce signals in other detectors using other processes (e.g., STIM - scanning transmission ion microscopy, IBIC - ion-beam induced charge, SIMS – secondary-ion emission spectroscopy, etc.). It is clear that in these cases diamond would be superior to silicon.

Results of these studies were published in Refs. [7,8].

Subtask 3: Development of novel targets for neutron production. Dedicated neutron-production targets were optimised providing both the white neutron energy spectra (from 0.1 MeV to 50 MeV) as well as quasi-monoenergetic neutrons. Usually, rotating solid converters (C, Be, Li) have been considered and only recently liquid target-converter option is examined as a possible replacement. The considered target design is presented in Fig. 12. We did thermal and radioprotection analysis for future neutron-generator targets of SPIRAL2/NFS - thick beryllium and carbon targets, quasi-monoenergetic lithium target with two possible cooling models. We have looked into the possibility to use thin Be targets for quasi-monoenergetic neutrons generators. We have performed two experiments on neutron generators at NPI ASCR to study the method of infra-red temperature measurement of lithium target and to clarify reported uncertainties on neutron spectra at relevant beam energies for the thin Be target.

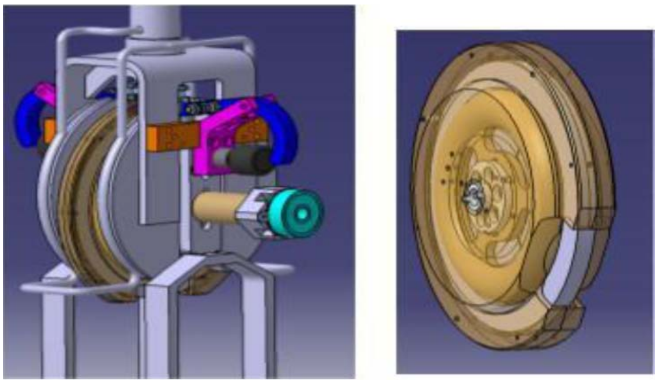


Figure 12: Preliminary design of rotating neutron target.

Task 3: Outreach activities.

A major goal of this project has been to bring the EWIRA laboratories to a level comparable to that of the existing European large-scale facilities. User communities were structured at the EWIRA laboratories. The complementarity of the laboratories at IFIN-HH, Bucharest and HIL, Warsaw for lifetime and Coulex measurements was demonstrated during the EWIRA workshop. The programme of the workshop is available at:

http://www.nipne.ro/indico/conferenceDisplay.py?confId=180

A foresight study of the strategic development of the different EWIRA laboratories was prepared. It summarises the information on the specialisation, funding situation, upgrade plans and infrastructure perspectives of each of the laboratories.
Two of the facilities in the EWIRA countries, namely the Heavy-Ion Laboratory of the University of Warsaw, the Cyclotron Laboratory of IFJ PAN, Krakow, the Tandem Laboratory of IFIN-HH and the ELI-NP facility in Bucharest, Romania, were identified as Research Infrastructures in the ENSAR2 project within Horizon 2020 EC programme. Note that all EWIRA laboratories take part in a variety of EC networks and projects. Each of the laboratories has developed its specific specialisation within the European Research Area. New basic equipment has been installed or is under construction in the different laboratories, which is reflected in the presented materials and a description of these is included in EWIRA Foresight Study. The EWIRA Foresight Study was submitted and reviewed by the SAC members.
All milestones of the EWIRA JRA were reached and deliverables of the work package were submitted according to the project deadlines. Some small delays in achieving a few milestones did not affect the overall work plan of the EWIRA work package.

References:

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[2] H. Tornqvist, C. Sotty et al., Nucl. Instr. and Meth. B 317 (2013) 685.
[3] A. Kusoglu et al., Phys. Rev. Lett. (2015) in print.
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[5] K. Wrzosek-Lipska et al., Phys. Rev. C 86 (2012) 064305.
[6] K. Hadyńska-Klęk, Ph.D. thesis, University of Warsaw, 2013; K. Hadyńska-Klęk et al., Acta Phys. Pol. B 44 (2013) 617
[7] N. Skukan, V. Grilj, M. Jakšić, Nucl. Instr. Meth. B306 (2013) 186.
[8] M Jakšić et al., J. Inst. 8 (2013) P09003.

Deviations from Annex I
None.
Use of resources
It follows the work plan of Annex I.
Corrections
None.

Work Package 13: JRA07-THEXO

Participants: TUW, ULB, ECT*, UWAR, UNIBAS

Three highlights demonstrate the evidence of outstanding results achieved by Task 1 of the THEXO Work Package (WP) that is dedicated to low-energy nuclear spectroscopy.

The first is the solution of the long-standing problem of coupling between single-particle and collective degrees of freedom in nuclei. For the first time we have obtained and analysed results of the polarisation corrections and particle-vibration coupling (PVC) in all doubly-magic and semi-magic nuclei, both with and without pairing correlations taken into account. Up to now, models based on using perturbative polarisation corrections and mean-field blocking approximation were giving conflicting results for masses of odd nuclei. We systematically investigated the polarisation and mean-field models, implemented within self-consistent approaches that use identical interactions and model spaces, to find reasons for the conflicts between them. We have identified and numerically evaluated self-interaction energies that are at the origin of different results obtained within the mean-field and polarisation-correction approaches. We also addressed the question of how to improve the agreement between theoretical nuclear single-particle energies (SPEs) and observations. We determined the PVC corrections in a fully self-consistent way. Then, we adjusted the SPEs, with PVC corrections included, to empirical data. We concluded that the main source of disagreement is still in the underlying mean fields, and not in including or neglecting the PVC corrections. This research has already been published in two publications, Phys. Rev. C89 (2014) 014307 and Phys. Rev. Lett. 113 (2014) 242502. Two other publications are in preparation; one of them will discuss novel effects of coupling the single-particle states to proton-neutron collective channels, which has never been considered up to now.

Another highlight of the work that we have performed within this WP concerns the introduction of correlations beyond a mean-field approach and systematic applications to a large set of nuclei. The correlations that we have considered are those related to symmetry restorations, particle number and angular momentum, and to configuration mixing. Applications have been done most often in collaboration with groups of experimentalists. We have studied in details the spectroscopic properties of nuclei in the region of the neutron-deficient lead isotopes. These nuclei have a complicated structure and show several low-lying states that are interpreted as arising from the coexistence of two or three different shapes. Our calculations confirm this interpretation and are in general in good agreement with the experimental data. Although the theoretical spectra are too spread, the main tendencies are well reproduced and the transition probabilities agree satisfactorily with the data. Note that no effective charges are introduced in the model. These calculations have generated a large set of results that are available to the community as supplementary material of a publication in Phys. Rev. C. This material has been used to support the publication of experimental data, especially of the determination of isotopic shifts. A similar extensive application has been performed for the Ni isotopes with a special focus on the determination of transition densities between low-lying states.

Lastly, thanks to new extensions of our model, as the inclusion of several quasi-particle excitations, it has been possible to study nuclei with an odd number of neutrons or protons. A first application to ^{25}Mg has demonstrated the potentialities of our model. Energies and electromagnetic transition probabilities obtained for this Mg isotope are in good agreement with the data. They are obtained without fine tuning of the interaction and without the introduction of effective charges. This generalisation of our model to odd nuclei but also to two quasi-particle states in even-even nuclei greatly extends the potentialities of beyond-mean-field methods

Task 2 of the THEXO WP was led by the group at Technische Universität Wien (TUW) on reaction techniques useful for studies at exotic ion-beam facilities. The main achievement of this WP is the development of a versatile code package, GECCCOS (General Coupled-Channel Code System), a modern tool for the calculation of nuclear reactions performed at radioactive ion-beam facilities. The code package written in Fortran95 is designed as an easy-to-use code for practitioners in a wide field of applications. The code makes use of up-to-date tools and is clearly structured with well-defined interfaces which allow straightforward extensions with new reaction modules. In addition, the code is self-contained, includes recent data libraries and provides default values for technical parameters which enable the user to perform blind calculations with a minimum of input information. The current version of GECCCOS provides a flexible environment and contains all essential modules (input, direct and coupling potentials, scattering equation solver, reaction modules providing the scattering amplitude, modules for various observables, data libraries and an auxiliary programme library) for reaction calculations. Although the implemented reaction mechanisms are limited it represents a well-defined basis for nuclear reaction calculations and is well suited for extensions with new reaction modules accounting for various reaction mechanisms and models. After completion of the breakup modules (see below) publication of the code package is envisaged together with a set of test examples.

Task 3 of the THEXO WP lead by UBAS consisted of two subtasks:
Subtask 3.1: Prediction of astrophysically important reactions across the nuclear chart with a library of a full set of cross-section predictions as deliverable, and
Subtask 3.2: The asymmetry energy of nuclear matter and the nuclear equation of state (EoS) with a Library/Depository of EoS tables as deliverable.
Both libraries have been established, leading in total to 37 and 15 publications, respectively. http://nucastro.org/thexo.html or http://phys-merger.physik.unibas.ch/~hempel/eos.html.

Subtask 3.1 included the determination of key input parameters, e.g., masses, fission barriers, level densities of excited states, giant electromagnetic resonances for capture reactions, direct capture, optical potentials and state properties (parallel and in synergy with work performed in tasks 1 and 2 of WP13): One of the highlights is the resolution of the long-standing "apparent" alpha potential problem for heavier nuclei which disappears if Coulomb excitations are included properly.

Subtask 3.2 included the evaluation of the asymmetry energy of nuclear matter via medium-energy heavy-ion collisions, its density dependence, and the analysis of the effect of pairing/finite temperatures (utilising constraints from astrophysical observations, as well as comparing to results obtained from the energy-density functionals studied and tested within subtask 1.4 of WP13). As a highlight we obtained density functionals based on constraints for the asymmetry energy S (29-31 MeV) and its density dependence L (40-60 MeV), which lead to realistic mass-radius relations and good estimates of maximum neutron-star masses slightly above 2 M_{Θ}, as discovered in recent observations.
Both projects were undertaken in close collaborations with ENSAR partners ATOMKI-HAS, GSI, GUF, JYU and TUD, including the Basel participants and Non-Basel ENSAR partners.

Use of ressources
The THEXO budget was mainly spent to fund postdoc positions in the four institutions that were leading the project. The UWAR THEXO budget was spent to fund 45 months of the postdoc contract, plus some travel expenses, offered to Dr. Dimitar Tarpanov, who was the main contributor to the project. The budget was overspent by about 2500 euro. The ULB budget was mainly spent on postdoc contracts, for K. Washyama, S. Barone and J. Yao. A small fraction was also devoted to travel expenses for collaboration meetings and workshops, in particular at the ECT*, Trento. The TUW THEXO budget was spent for travel to THEXO meetings and to fund 28 months of PhD students (M. Gal, Th. Srdinko, G. Schnabel, and B. Brumec) as well as staff costs (254h) for recovering work because of the unexpected leave of M. Gal which led to disruptions in the work plan. The UBAS THEXO budget was spent to fund the postdoc contract for T. Rauscher (for part of the duration), plus travel expenses related to work on Subtask 3.2 for M. Hempel, as well as travel for the above-mentioned collaborators to collaboration meetings at ECT*, Trento. The budget was not fully spent, about 2700 euro are remaining. This amount is available for ENSAR at the final budget redistribution.

As planned, the ECT* budget was devoted exclusively to organise collaboration meetings and workshops that gather the groups participating to the project together with experimentalists and theoreticians developing methods different from those of the THEXO partners.

Deviations from Annex I
None.

Corrections
None.

Work Package 14: TNA01-GANIL

Report on TransNational Activities at GANIL

Description of the publicity concerning the new opportunities for access

A dedicated Users Guide on the GANIL Web-site exists to publicise the opportunities for access: http://pro.ganil-spiral2.eu/users-guide.
This Web-site details the facilities available, the laboratory infrastructure and services, the selection process and a call for proposals.
In a subsidiary Web-site, http://pro.ganil-spiral2.eu/users-guide/ensar-tna, the application for financial assistance for Transnational Access is described, i.e.:

- Financial support available
- Who can apply
- How to apply
- The application form

Description of the selection procedure

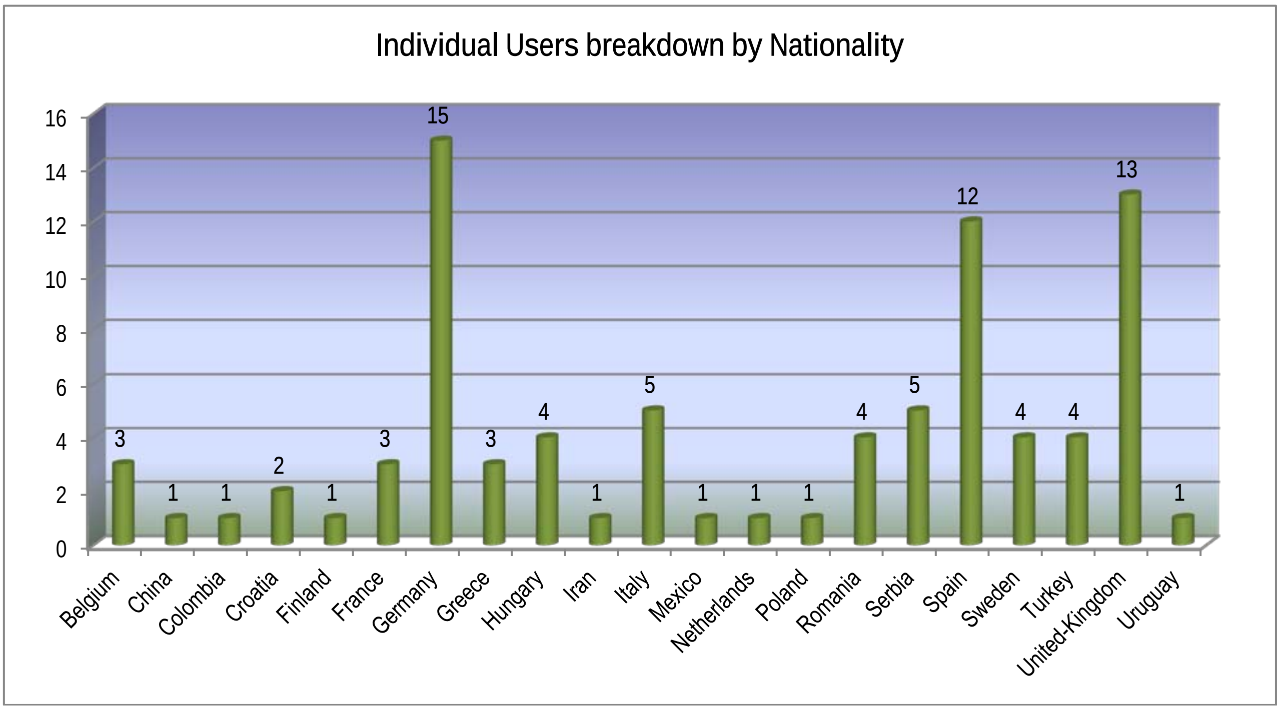
The selection of users by the PAC (Programme Advisory Committee) is made only on the scientific merit of the proposals submitted. The proposals are reviewed independently of their country of origin. Experiments are evaluated and awarded a number of 8-hour shifts of beam time, according to the number requested and the number deemed suitable by the PAC. Once the list of approved experiments has been determined by the PAC, the external (i.e. non-GANIL) members of the PAC are asked to choose, from the approved experiments, those which are entitled to financial support through the TA activity.
During the reporting period, one PAC for nuclear physics was held at GANIL, on 3-4 April 2014. 32 proposals were submitted of which 19 were eligible to financial support, but only 13 proposals were accepted of which 5 were eligible.
For interdisciplinary research, a PAC meeting was held in July 2014
In Annex 1, there is the list of the Selection Panel members for the reporting period as well as the number of eligible user-projects submitted to the panel during the reporting period and the number of the selected ones.

Transnational Access activity

During the reporting period

- 2 079.20 experimental hours were delivered
- 120 stays were financed
- 85 different individual users have visited the facility
- They spent 1101 person-days at GANIL
- 25% were women
- There were 37 experienced researchers, 13 Post-doc researchers, 33 Post-graduate,1 Undergraduate and 1 technician
- 59% were new users

The scientific areas of the experiments performed at GANIL are as follows: nuclear structure and spectroscopy of exotic nuclei; fusion, fission of heavy nuclei; and test of AGATA tracking array - in preparation of the forthcoming 4 year experimental campaign at GANIL. Among others, the goals are to understand the structure of the nuclei far from the stability line, their shapes and shell evolutions down to the drip lines. GANIL - together with European and/or international collaborations and several French partners - is engaged in all these fields of research, which are also the major scientific motivations justifying the SPIRAL2 project.


Individual Users breakdown by Nationality
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Finland
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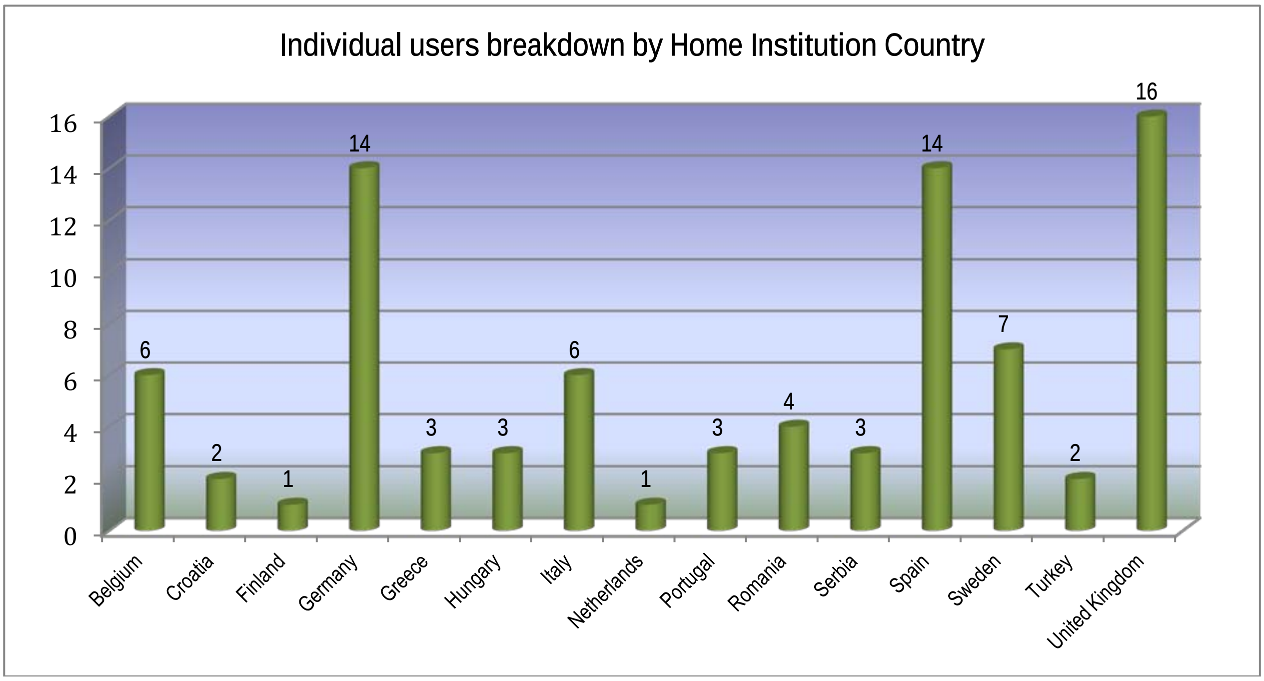
Individual users breakdown by Home Institution Country
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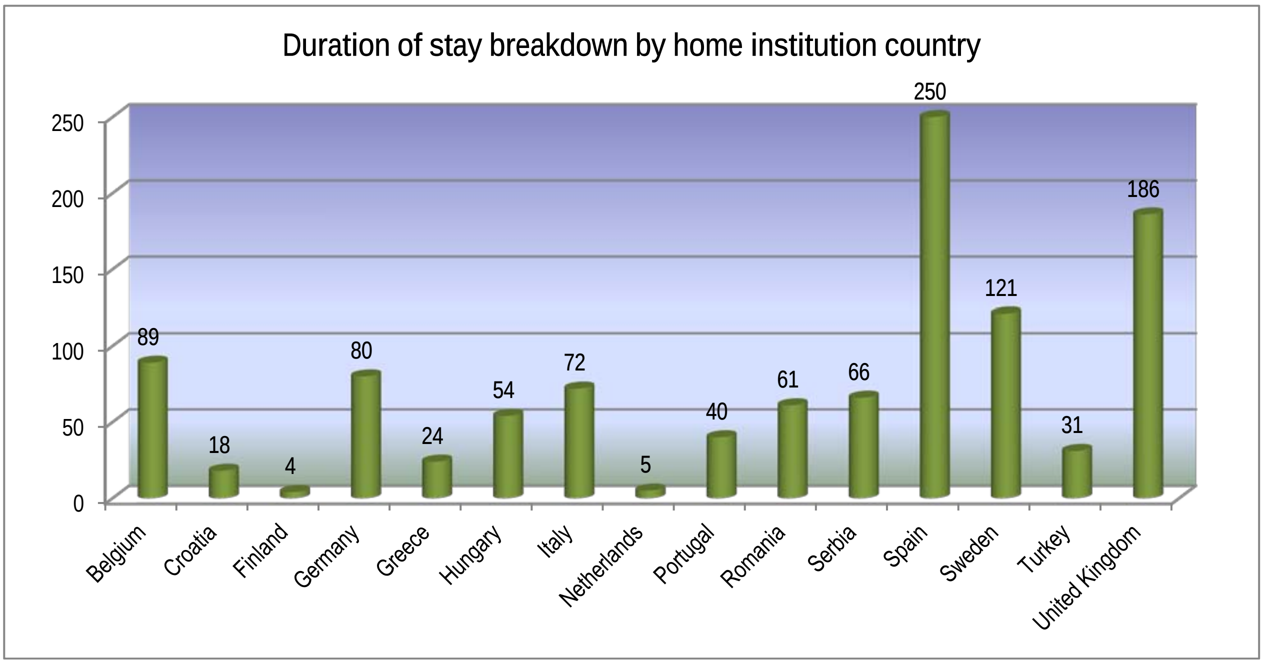

Scientific output of the users at the facilities

Obviously not many publications have yet been published from the complex experiments performed at GANIL during the reporting period (see Annex 4 of the Data Base). Please find in attachment to the ENSAR report the list of peer-reviewed publications based on experiments supported by the previous TNA (FP6-EURONS) at GANIL and not yet reported to EC. They are 22 in total.

During the reporting period, some unique results have been obtained and are being fully analysed. We mention below some highlights from the user-projects supported under the grant agreement.

- Evolution of nuclear structure far from stability studied in the reaction $^{16}C(d,p)^{17}C$,
- Study of the *p-n* T=0 and T=1 pairing in the reactions $^{48}Cr(p,^{3}He)$' (d,α) $^{56}Ni(p,^{3}He)$' (d,α),
- Measurement of the fission time of $^{238}U+^{76}Ge \Rightarrow Z=126$ nucleus using $\boldsymbol{X_K}$ fluorescence of atoms,
- Study of the spin-aligned neutron-proton paired phase in ^{96}Cd using EXOGAM+Nwall+Diamant detectors,
- Alpha clustering phenomena in the ^{40}Ca, ^{44}Ca, ^{48}Ca isotopes.

Several important instrumentation tests were also accomplished:

- test of AGATA tracking array and VAMOS spectrometer in preparation of the forthcoming 4-year experimental campaign at GANIL,
- test of the production and focal-plane detector system for studies of SHE and heavy nuclei at LISE spectrometer, and
- test of detection of fission events in inverse kinematics with ^{238}U beam using MAYA active-target detector.

The information on the results of previous experiments realised with the financial support of TNA can be found in Annexe 2.

User meetings

The GANIL/SPIRAL2 Week 2014 was held in Caen during 4 days, in October (350 participants). The main goal of the meeting was to present and discuss the current status of the GANIL/SPIRAL2 projects in front of a large community of scientists and engineers. The major part of the scientific programme of the GANIL/SPIRAL2 Week is dedicated to presentations of the main advances in physics, instrumentation for the GANIL/SPIRAL2 and construction of the SPIRAL2 accelerator and experimental halls.

Furthermore, in order to improve feedback between the users and GANIL staff, there is a short meeting (~30 min) every week during the running period of the facility, to discuss problems, which might appear during the previous, current and next week. Users with experiments during these weeks do participate or send a representative.

Annexes

Annex 1 – Composition of the Users Selection Panel
    See "Selection Panel" in MS Access Database
Annex 2 – List of User-Projects
    See "List of User-Projects" in MS Access Database
Annex 3 – List of Users
    See "List of Users" in MS Access Database
Annex 4 – List of Publications (from work carried out under the Transnational Access activity).
    See TNA GANIL list of publications in attachment

Work Package 15: TNA02-GSI

Report on TransNational Activities at GSI

Publicity concerning the opportunities for access to TA02

The measures taken to publicise the opportunities for access are:

A dedicated web site: www.**gsi**.de/user/**funding/ENSAR**.html

On this web site the following information is offered:

- General information on GSI
- Research capabilities
- Access procedure
- Beam-time scheduling
- Support offered to user
  - Technical and logistic support
  - Accommodation and Housing
  - Health and liability insurances
  - Nurse for immediate medical help
  - Access to laboratories of GSI
    - Target laboratory offering deposition techniques (sputtering, evaporation), mechanical treatment (milling, sawing) and quality control for solid targets
    - Detector laboratory with clean rooms, ageing test stand for gaseous detectors and CNC milling machine for prototyping
    - Electronic laboratory with automatic placement machine and soldering oven
- Financial support within ENSAR
    - How to get access funding
    - Who can apply for access funding
    - Open calls for proposals and deadlines
- Application form
- User registration
- Instructions for reimbursement of travel costs and statement of travel costs

* Mails distributed either via the Research Deputies of GSI or sent directly to the users with scheduled beam times
* Mails to the spokespersons of ENSAR-related collaborations having approved beam time at GSI

Selection procedure

Selection Panel

GSI is open to national and international user groups. To apply for access to the accelerator and experimental facilities, a written project proposal has to be submitted to the GSI scientific director. The proposals are reviewed by an international Programme Advisory Committee, the GSI General Programme Advisory Committee (G-PAC). If a user group in addition applies for EC support under one of the Integrated Infrastructure Initiatives of FP7, a separate funding application has to be submitted.

The G-PAC presently has 12 members (all external), with more than half of them coming from universities or research institutes outside Germany. There are specialised PACs for some research activities pursued at GSI (plasma physics P-PAC, biophysics BIO-PAC, and material science MAT-PAC). Regular All-PAC meetings have been introduced to improve the communication between the PACs, where the future beam-time contingents are discussed and decided.

GSI, together with national and international partner institutions, is planning the construction of a new large accelerator and research complex – the Facility for Antiproton and Ion Research (FAIR). FAIR enables a rich and multidisciplinary research programme covering a broad spectrum of research fields such as: QCD studies with cooled beams of antiprotons; QCD-Matter and QCD-Phase Diagram at highest baryon density; nuclear structure and nuclear astrophysics investigations with nuclei far off stability; precision studies on fundamental interactions and symmetries; high-density plasma physics; atomic and material-science studies; radio-biological investigations and other application-oriented studies.

During the construction phase GSI has taken over the responsibility not only for parts of the FAIR accelerator and storage rings but also for the link of the existing facilities to the FAIR complex. These tasks require major human and financial resources. Consequently, the GSI executive committee decided in April 2012 that GSI has to focus employees, infrastructure and financial resources on the building of FAIR. This had several consequences: Despite the fact that the beam time offered to users in 2012 was slightly larger than in 2011 (197instead of 174 days) there is still a substantial backlog of granted beam times (in the order of at least 100 days for each of the three main experimental accelerators at GSI). In addition, no beam time could be offered in 2013 due to major upgrade works on the accelerators of GSI.

As a consequence of the conditions enforced by the GSI executive committee beam time offered to the users had to be reduced severely, and the GSI directorate decided middle of 2012 to give up the Programme Advisory Committee Meetings (except for plasma physics) and the respective open calls for proposals. Instead of regular PAC Meetings the selection of new experimental proposals and scheduling of experiments already approved by a GSI PAC took place in close collaboration with the user groups, the head of the Wissenschaftliche Beirat WBR of GSI (Karlheinz Kampert, Univ. Wuppertal), the chairperson of the G-PAC (Paolo Giubellino, CERN) in close contact with the members of the G-PAC and the Board of FAIR Collaborations BFC (Chair Reinhold Schuch, Univ. Stockholm) and representatives of the four scientific pillars of FAIR. The chairperson of the G-PAC informed and/or contacted the G-PAC members in all issues relevant for the beam time scheduling.

Apart from evaluating a small number of new proposals this committee selected in essence projects which have been started already (e.g. the AGATA campaign) or proposals which have been granted beam time in former G-PAC meetings for being scheduled in 2014.

Selection-Panel meetings

Selection-panel meeting: Firenze, June 6, 2013
Discussion on procedure to select experiments for the beam time 2014 by representatives of G-PAC, WBR, BFC and scientific directorate of GSI

Selection-panel meeting: July/August 2014
Proposal evaluation and decision on beam-time scheduling via E-mail circulation

Selection-panel meeting: June 2014
Proposal evaluation of a sub-committee of the G-PAC via E-mail circulation

Selection criteria

The Selection Panel based its selection on scientific merit and relevance, but also on the importance for the future FAIR facility. For Transnational Access within ENSAR only user projects positively evaluated by the G-PAC were considered. Since the number of experiments which were finally scheduled was rather limited, every user group related to ENSAR and fulfilling the rules of the contract could be supported. The majority of the eligible user groups had active projects already and were allowed to continue or asked to write a new proposal if their scientific goals had to change because of the beam-time restrictions. This affected only experiments in the field of super-heavy elements, since all proposals with especially long beam time requirements had to be postponed to a later time.

Transnational access activity during the reporting period

Beam was available during this reporting period from March 2014 to November 2014. The accelerator operation was characterised by rapid changes of ion species and experiments to fulfil the demands of groups testing accelerator components and detectors for FAIR – such tests being the key aspect of this beam time – and scientific experiments. Already at the very beginning of the beam period it turned out that an aperture problem in the SIS18 prevented high beam intensities. This problem influenced scientific experiments with extremely neutron-rich radioactive beams relying on the maximum beam intensities available at GSI. The AGATA collaboration – being affected by this issue – decided to give up one experiment with particular high demands on the primary beam intensities to guarantee the success of others. As a consequence, the user project 70Kr/Sahin could not be finalised. Experiments at the UNILAC were not influenced and beam was delivered to various experiments without problems. The SIS focusing problem was fixed later during a maintenance break.
Achievements from the accelerator and instrument side during this reporting time period: The proton microscope PRIOR started operation, an EBIT source was integrated to the HITRAP facility, the installation of the CRYRING as a low energy storage ring for radioactive ions was started, Uranium 28+ beams at 1.4 MeV/u were produced with an intensity of 7.8 mA and an excellent beam quality. This intensity value is approximately 50 % higher than the highest intensities measured so far at GSI. This beam intensity is a major step towards the beam parameters which are required for FAIR and will offer new experimental possibilities at GSI before FAIR becomes operational once – after another two-year break of the accelerator – SIS18 will be available again in 2017.
Despite the long shutdown of the accelerator beam failures have been recorded only with 6% at UNILAC and 14% at SIS, which is comparable to previous years. In summary, the beam time 2014 was – apart from the focusing problems in the SIS18 described above – very successful for the experimentalist in the fields of nuclear, hadron and atomic physics as well as materials sciences and biophysics.

A total of 15 projects have been supported during the reporting period:

(1) **AGATA/Scheidenberger:** Special funds for AGATA campaign at GSI
(2) **115decay/Rudolph:** X-ray fingerprinting of element 115 decay chains by Dirk Rudolph et al.
(3) **70Kr/Sahin:** AGATA@GSI: Breaking isospin symmetry in the mass 70 region: Study of the T_z=1 nucleus ^{70}Kr by Eda Sahin et al.
(4) **Commiss/Korten:** AGATA@GSI: Scientific and technical commissioning proposal for the AGATA – PreSpec campaign by Wolfram Korten et al.
(5) **E039/Indelicato:** Precision X-ray spectroscopy in one- and two-electron heavy ions by Paul Indelicato et al.
(6) **ESR/FRS Trassinelli:** Measurement of bound-state beta decay of bare ^{205}Tl ions
(7) **Ice/Domaracka:** Ion induced sputtering and phase transitions in water ice
(8) **Isospin/Recchia:** AGATA@GSI: isospin symmetry-breaking transition rates and mirror energy differences in isobaric multiplets by Francesco Recchia et al.

(9) **Pyg-64Fe/Wieland:** AGATA@GSI: The Pygmy dipole resonance in ^{64}Fe and the properties of neutron skin (S430) by Oliver Wieland et al.
(10) **R3B/Gil:** R3B demonstrator test
(11) **S426/Rainovski:** AGATA@GSI: Relativistic Coulomb M1 excitation of neutron rich ^{85}Br by Georgi Rainovski et al.
(12) **U253/Kozul:** Study of shell effects and clustering in the giant nuclear system U+U
(13) **U259/Rudolph:** Chemical study of element 114 (follow up of E115/Rudolph)
(14) **U278/Antal:** Decay properties of ^{258}Db using the SHIP separator
(15) **U279/Zimmer:** Single-event transient measurements in asynchronous logic for the project FATAL.

Some former projects were included into the TNA database to add publications which arose from those experimental campaigns, for which data analysis has been completed.

(1) **BetaFiss/Andrey:** Identification and systematic studies of the beta-delayed fission in the lead region
(2) **b-neutron/Redondo:** Measurement of beta-delayed neutrons around the third r-process peak
(3) **E105/Kalantar:** Start-up of part of the EXL physics programme with ^{56}Ni
(4) **Interact/Patera:** High-precision carbon fragmentation cross sections for medical applications
(5) **Ionisat/Rothard:** Ionisation dynamics

1938 (+279 in parallel mode) hours of beam time were delivered; 97(111) individual users (users in projects) visited the facility and spent 924 person-days at GSI.

User project acronym	**Users**	**Scientific field**	**Number of days spent at the infrastructure**
115decay/Rudolph	1	Physics/Nuclear Physics	6
70Kr/Sahin	10	Physics/Nuclear Physics	30
AGATA/Scheidenberger	36	Physics/Nuclear Physics	280
Commiss/Korten	3	Physics/Nuclear Physics	40
E039/Indelicato	1	Physics/Nuclear Physics	4
ESR-FRS/Trass	10	Physics/Nuclear Physics	81
Ice/Domaracka	3	Physics/Material Sciences	24
Isospin/Recchia	10	Physics/Nuclear Physics	76
Pyg-64Fe/Wieland	6	Physics/Nuclear Physics	37
R3B/Gil	10	Physics/Atomic Physics	89
S426/Rainovski	1	Physics/Nuclear Physics	8
U253/Kozul	5	Physics/Nuclear Physics	77
U259/Rudolph	10	Physics/Nuclear Physics	108
U276/Antal	3	Physics/Nuclear Physics	44
U278/Zimmer	2	Physics/Nuclear Physics	20

In Annex 2 (Database) the User Projects for which costs have been incurred in 2014 are tabulated. The users are listed in Annex 3 (Database).

Significant achievements obtained by the users during the reporting period

A number of scientific results were obtained. Some of these results are of particular importance for future nuclear physics studies later at FAIR or were even mentioned in the international press.

(1) **AGATA/Scheidenberger:** With the establishment of FAIR, the European nuclear structure community is now heavily committed to a future programme of in-flight spectroscopy of highly exotic nuclei produced from the Super-FRS. Ground-breaking experiments are encompassed by the HISPEC project (Hi-resolution In-flight SPECtroscopy), which groups around AGATA (Advanced Gamma-Tracking Array), and which represents one of the first experiments of the entire FAIR facility to take beam at day one. To position the research community to take full advantage of this unique opportunity, and to build up the vital experience of the novel techniques and methodologies offered by both the HISPEC and the decay-spectroscopy (DESPEC) campaigns, the pre-cursor experiment PRESPEC has been established, which builds on the successful RISING project.
The scientific programme for the PRESPEC-AGATA in-flight campaign comprises exclusively topics of major significance in contemporary nuclear structure physics. These include the evolution (and modification) of shell structure with increasing neutron excess, the breakdown of isospin symmetry, the exploration of the limits of nuclear existence near the drip-lines, the onset of collectivity in yet unexplored mass regions and the study of electric and magnetic dipole strength in nuclei. Table 1 shows a list of all experiments performed in the campaign during 2012 and 2014.

Table 1: *Experimental programme of the PRESPEC-AGATA campaign.*

Title	No.	Spokespersons	Run
Performance Commissioning	S424	W. Korten / J. Gerl	^{86}Kr ^{54,56}Fe
Relativistic *M*1-Coulomb excitation of ^{85}Br	S426	G. Rainovski / N. Pietralla/ J. Gerl	^{85}Br
Shape evolution in neutron-rich Zr	S428	S. Pietri	$^{102\text{-}106}$Zr
Quadratic evolution of collectivity around ^{208}Pb	S429	D. Rudolph /Zs. Podolyák / J. Gerl	$^{196\text{-}206}$Pb ^{206}Hg ^{200}Pt $^{204\text{-}208}$Po ^{205,207}Po
Pygmy Dipole Resonance in ^{64}Fe and the properties of neutron skin	S431	O. Wieland / M. Gorska	^{64}Fe ^{62}Fe
Coulomb excitation of the band-terminating 12^+ yrast trap in ^{52}Fe	S433	A. Gadea / M. Gorska	^{52}Fe
Transition rates and mirror energy differences in isobaric multiplets	S434	F. Recchia / M. Bentley	^{46}Ti/Cr/V
Slow-down Beam test	S386	P. Boutachkov	^{46}Cr

All the experiments profited from the unique combination of (i) relativistic energy beams from the SIS synchrotron, (ii) high-intensity exotic beams produced and selected by the FRS, and (iii) high-efficiency and high-resolution gamma detection with the AGATA Ge detector array. The exotic beams were produced at relativistic energies (β~0.4-0.5) in fragmentation or fission reactions of relativistic projectiles delivered from the UNILAC-SIS accelerator complex. The GSI Fragment Separator (FRS) was employed to select the fragments of interest. A thick secondary target positioned at the final focal plane of the FRS (S4) was used for Coulomb excitation or (secondary) fragmentation of the separated nuclei. Gamma-rays emitted in these reactions were detected by the AGATA and HECTOR arrays.

The fragments produced at the secondary target were identified and tracked by the Lund-York-Cologne Calorimeter Array (LYCCA), a HISPEC development already available in its early implementation LYCCA-0.
A major step forward with respect to the RISING Cluster array is the tracking ability of AGATA which allowed placing the array much closer to the target, thus gaining in gamma-ray efficiency and peak-to-background performance, while at the same time also improving on the achievable energy resolution for in-flight gamma-ray emission. Along with the recently achieved upgrade of primary beam intensities at GSI and the improved capabilities of the FRS detectors the AGATA-PRESPEC setup provided a very significant improvement over RISING with a sensitivity gain of up to a factor of 10.
The analysis of the experiment data obtained in the PRESPEC-AGATA campaign will require several years. First physics results from the early runs are expected later in 2015. Already now it can be stated that all runs performed in 2012 and 2014 reveal new, interesting nuclear structure data. Moreover, experience gained in the campaign is very valuable and will be used to further improve the instrumentation, the analysis algorithms and the experiment methodology for later in-beam gamma-spectroscopy experiments with HISPEC at the FAIR facility.

(2) **115decay/Rudolph**: In November 2012, three weeks of beam time for experiment U261 were scheduled. Despite the limited beam time thirty correlated alpha-decay chains were observed following the reaction ^{48}Ca+^{243}Am. Decay schemes arising from high-resolution spectroscopic coincidence data, in conjunction with comprehensive Monte-Carlo simulations, open the door for direct nuclear structure insights of these heaviest man-made atomic nuclei. Previous assignments linking the majority of the decay chains to the decay of ^{287,288}115 are confirmed. This includes first candidates for Z fingerprinting of the Meitnerium-decay by means of characteristic K-X-ray detection. There is clear evidence for direct determination of the atomic number of the descendants of super-heavy elements. Spectroscopic means and results were detailed in a number of publications, and a second article has been submitted to Phys. Rev. C challenging the connection between isotopes of element 117 and element 115 based on improved and more precise data from U261 on recoil-alpha-(alpha)-fission decay chains. A comprehensive summary article (and PhD thesis) is due 2015. **U259/Rudolph** is the follow up project of this experiment.

(3) **Commiss/Korten:** The installation and commissioning of the AGATA array have been successfully accomplished. All detectors were verified in their performance and the analysis was tested. After restarting operation of the whole Setup after more than one year of standstill the second part of the experimental programme was started. During the shutdown period in 2013 detectors had to be replaced or repaired and several travels have been undertaken in this period.

(4) **E039/Indelicato:** For the accurate determination of the 1s Lamb shift of H-like gold via X-ray spectroscopy of the Lyman alpha transitions it is necessary to investigate the different systematic effects that are crucial for metrology of the experiment. The accurate determination of the position of the gas-jet target and the effect of the X-ray penetration in the position-sensitive detectors is indispensable. To measure the position, the diameter and the density distribution of the gas target of the ESR a new device has been designed and built. After a measurement campaign, we were able to determine the gas-jet position with an accuracy of few tenths of millimetre. This measure is crucial because a misalignment of it with respect to the X-ray spectrometers used in the experiment can generate a systematic shift on the recorded photon energy due to the Doppler Effect as a result of the fast motion of the ions during the collision with the target. An investigation of the effect of the X-ray penetration in the spectrometer detectors has been also performed. The X-rays have a small incidence angle with respect to the position-sensitive detector. Due to the penetration of the X-rays in the position-sensitive detector, this incidence angle induces a spatial asymmetry of the spectral line. This effect has been studied with the support of X-ray – matter interaction simulations and the implementation of adapted profile modelling for the 1D and 2D fits of the position-sensitive detector outputs. Asymmetries in the spectral line profiles (simulated and measured) are now completely understood.
The complete check of the systematic effects and uncertainty is still not completed.

(5) **ESR-FRS/Trass:** Initially planned for September 2014, the experiment on bound-state beta decay of fully ionised ^{205}Tl was suspended on recommendation of the G-PAC in favour of a similar experiment on two-body beta decay of hydrogen-like ^{142}Pm ions conducted in the ESR. Single-particle spectroscopy with a newly developed data-+acquisition system was applied resulting in about 10000 precisely measured orbital electron-capture decays. Furthermore, a novel in-ring position and charge-sensitive particle detector was taken into operation showing excellent mass and position resolution. The obtained data will be sufficient to answer the long-standing question on the existence of *modulated* two-body weak decays which might give rise to exciting new physics. The data analysis is presently performed by the user groups in Vienna and Paris. The groups met during the beam time and defined a common strategy for the data analysis and interpretation of the results. In particular, results from the groups will be compared to older data corroborating the robustness of the different analysis methods.
The second experiment suggested by this user group on proton-capture reactions in the ESR was commissioned in the ESR with Xe beam. Form the accelerator operation point of view this is a complex experiment, which requires injection, storage, slowing down and cooling at the maximum intensity of the beam in the storage ring in conjunction with an internal gas target at lowest beam energies. Specially built detector manipulator together with in-vacuum particle detectors were successfully taken into operation showing the feasibility of such experiments in future at the ESR as well as at CRYRING.

(6) **Ice/Domaracka:** In September 2014, we have performed two types of experiments with 4.8 MeV/u Xe^{q+} (q= 21, 38) ion beams. The first one was dedicated to study sputtering of CO, CO_2 and D_2O ices under UHV conditions by means of time of flight and quadrupole mass spectrometry. In the second one, CO_2 ice was irradiated, and the induced effects monitored as a function of projectile fluence via infrared absorption spectroscopy in order to obtain information about the destruction cross section and the sputtering yield of CO molecules and chemical modification of the ice. The analysis of the data is in progress. Preliminary results for CO_2 ice confirms that the sputtering yield (Y) shows indeed a quadratic increase with electronic stopping power (S_e).

(7) **R3B/Gil:** The R3B setup at FAIR will allow kinematically complete measurements of peripheral nuclear reactions with radioactive beams. Demonstrators of three major components of this setup have been tested successfully in this beam period: the neutron detector NeuLAND performs within the anticipated parameters necessary for detecting multiple neutron events with high precision and resolution, the operation of the CALIFA calorimeter demonstrator was verified in beam in different modes of operation, and the close to final version of the Silicon tracking station behind the secondary target war taken into operation.

(8) **U253/Kozul:** First observation of long-living (up to about $5 \cdot 10^{-20}$ s) nuclear molecules which rotate by angles of 180 degrees in systems with proton numbers up to Z=136 and detailed studies of their properties. This confirms a basic assumption of theoretical models which describe the fusion process in (super) heavy systems. Even in the giant system U+U (Z=184) the typical signatures from deep inelastic processes and noticeable time delays up to several times 10^{-21} s were observed. The observations demonstrate the still large nuclear stability of systems with proton numbers far beyond the ones of heaviest known elements and a rather slow fading of stability with increasing proton number.

(9) **U278/Antal:** In this measurement exceptionally high statistics for the ^{258}Db was collected, which allowed the first detailed gamma-spectroscopy study of this isotope and its daughter products. A unique result was the direct proof of an electron capture decay of ^{258}Db and experimental evidence for excited states populated via this decay mode of ^{258}Db.

(10) **U279/Zimmer:** In our experiments we have investigated the pulse shapes of single-event transients (SETs) arising from particle hits in 90 nm CMOS logic cells. These single-event transients are one of the major error sources in modern semiconductor technologies, especially in environments with increased radiation levels, as in space and aviation technologies. A better understanding of the generation and propagation of these SETs may help developing electronics that is less susceptible to radiation hits in future. Especially for asynchronous logic it is important to know the shape of the single-event

transients in order to estimate their impact on different circuits. It was revealed that there is a strong influence of the input state of a single inverter on the susceptibility of these devices to radiation hits. Former experiments with alpha particles showed that for input voltages close to half of the supply voltage the resulting SETs get larger and longer compared to the standard high and low state. However, with alpha particles, the resulting pulses are relatively small and are not very probable to cause any error. The experiments performed at the GSI resulted in much larger SETs that are definitely capable of causing errors in electronics. Including increased pulse heights and widths a tremendous increase of the sensitive area was found for an input voltage close to half of the digital supply voltage. This may at least partly explain why the susceptibility to radiation induced failures depends on the operating frequency for different circuits. During changing from one state to the other the inverter has to pass this very sensitive intermediate input state of half of the supply voltage. With increased operating frequency this state is passed more often per time period.

(11) **E105/Kalantar:** Determination of the matter radius of ^{56}Ni by proton elastic scattering in inverse kinematics and investigation of the isoscalar Giant Resonance in ^{58}Ni. The experiment is the first of its kind and represents an essential milestone towards the realisation of the EXL project at FAIR. By using DSSDs as active windows, it was possible to operate these detectors directly in the UHV without compromising a low energy threshold.

The current list of peer-reviewed publications of all user projects published in this reporting period is part of Annex 4.

Users meetings

One user meeting took place during the reporting period at GSI to discuss the beam time scheduling in 2014.

Annexes

Annex 1 – Composition of the Users Selection Panel
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Work Package 16: TNA03-INFN

Report on TransNational Activities at LNL-LNS of INFN

PUBLICITY CONCERNING THE OPPORTUNITIES FOR ACCESS TO TNA03

A website dedicated to the Transnational Access activity was built and published at http://www.lnl.infn.it/~ENSAR/ since 15 November 2010. It is continuously updated and contains all the useful information for the European research groups interested to apply in order to get the financial support foreseen by the grant agreement.

ENSAR opportunities were presented during the following event:

- meeting of the LNL User Board – LNL, 8 November 2013
  Status and news regarding the ENSAR TNA

SCIENTIFIC COMMITTEES

During the third reporting period no change occurred in the compositions of the local Programme Advisory Committees (PAC) of both INFN laboratories (LNL and LNS) and the User Selection Panel for Interdisciplinary Research (USIP) of LNL which are available at:
- http://www.lnl.infn.it/~lnldir/UE/PAC-USP.html (LNL) and
- http://www.lns.infn.it/index.php?option=com_content&view=article&id=477&Itemid=223 (LNS).
No change also occurred in the composition of the ENSAR User Selection Panel (ENSAR USP) available at http://www.lnl.infn.it/~ENSAR/. The list of the ENSAR USP members for the reporting period can be found in Annex 1.

Calls for Proposals, both for the beam-time request and for the EC support, during the third reporting period:

– ***LNL PAC*** for experiments at Nuclear Structure and Dynamics Based Facilities (NSDBF)
  Deadlines: 12 December 2013 – 4 June 2014 (extended to 9 June 2014);
– ***LNL USIP*** for experiments at Applied and Interdisciplinary Physics Facilities (AIPF).
  Deadlines: 12 December 2013 – 10 June 2014;
– ***ENSAR USP***
  Deadlines: 12 December 2013 – 4 June 2014 (extended to 9 June 2014) and 10 June 2014.

MEETINGS OF THE SCIENTIFIC COMMITTEES

The meetings of the Scientific Committees during the third reporting period were held on:

- **LNL PAC**: 23-24 January 2014 – 7-8 July 2014;
- **LNL USIP**: 24 January 2014 – 15 July 2014;
- **ENSAR USP**: 24 January 2014 at LNL – 9 July 2014 at LNL.

No meeting of the **LNS PAC** was held during the present reporting period because of the backlog of experiments due to stop in operation of Superconducting Cyclotron.

SELECTION CRITERIA

No change to the existing procedure, described in the previous reports, was done in the third reporting period.

TRANSNATIONAL ACCESS ACTIVITY DURING THE REPORTING PERIOD

A brief report on the status of the LNL and LNS accelerators is provided in Annex 5.

Please find below details about the experiments supported during the third reporting period.

NUCLEAR STRUCTURE AND DYNAMICS BASED FACILITIES (NSDBF) – Nuclear physics experiments at LNL have requested access to the large acceptance magnetic spectrometer **PRISMA** in its upgraded configuration with a **second arm** - composed of a Micro-Channel Plate (MCP) followed by a position-sensitive Parallel-Plate Avalanche Counter (PPAC) and a Bragg Chamber (BC) - for kinematic coincidence measurements, the in-flight facility for the production of light exotic nuclei **EXOTIC** equipped with the **EXPADES** multi-detector array, the **LNL electrostatic deflector**, the beam line **LIRAS** mainly devoted to measurements of astrophysical interest. Finally, one nuclear physics experiment was carried out at LNS by using the large solid angle magnetic spectrometer **MAGNEX** equipped with a **Si detector** for kinematical coincidence measurements.

In total during the reporting period:

- 20 proposals have been submitted to the LNL PAC Committee - 15 experiments were approved for a total of 107 days of beam time and 9 days of beam preparation (156 beam-on-target days and 21 days of beam preparation → average acceptance rate of about 69%);
- 9 projects at LNL asked for EU support - 9 were considered eligible and 6 of them were selected by the ENSAR USP.

Objectives and achievements of the funded experiments

Acronym	***Project Title***

LNL 13.18 – *Study of fusion hindrance for $^{24}Mg+^{30}Si$ at extreme low energies*

Objectives – To measure accurately the fusion cross-sections of the ^{24}Mg on ^{30}Si reaction at energies around and below the Coulomb barrier in order to search for a fusion hindrance effect at the lowest energies investigated.
Achievements – The evaporation residues were identified with the **LNL electrostatic deflector** in its upgraded configuration. The ^{24}Mg+^{30}Si fusion cross section was measured at seven ^{24}Mg bombarding energies between 52.0 and 37.2 MeV. An *S*-factor maximum has been observed for this large positive *Q*-value system, which is the best developed maximum observed thus far.

LNL 13.16 – *Fusion hindrance and quadrupole collectivity in collisions of A~50 nuclei*

Objectives – To measure the fusion excitation function of the system ^{48}Ti+^{58}Fe from above the barrier to very low energies, where the phenomenon known as “fusion hindrance” is expected to show up, and to put in evidence similarities and differences with respect to the behaviour of heavier systems like ^{60}Ni+^{100}Mo, and ^{64}Ni+^{100}Mo, recently studied at Argonne National Laboratory (USA).
Achievements – The fusion excitation function of the system ^{48}Ti+^{58}Fe has been measured from above the barrier to below by using the set-up based on the **LNL electrostatic deflector**. After five days of beam on target, a problem with the ion-source emerged, consequently the measurement could not be completed. The very low energy region, which is very important for the fusion hindrance phenomena, could not be measured.

LNL 13.03 – *Breakup process for the system $^{7}Be+^{208}Pb$ at Coulomb barrier energies*

Objectives – To investigate the reaction dynamics for the system ^{7}Be+^{208}Pb at two energies around the Coulomb barrier by detecting charged particles (^{3}He and ^{4}He breakup fragments as well as ^{7}Be elastically scattered secondary beam) with the detector array **EXPADES** (16 Double-Sided Silicon-Strip detectors arranged in 8 two-stage ΔE-E telescopes in a cylindrical configuration).
Achievements – A ^{7}Be secondary beam has been produced by using a primary ^{7}Li beam impinging on a H_2-filled gas target and the **EXOTIC** facility at LNL allowed to select the ^{7}Be ions and to focus them on a ^{208}Pb secondary target. The reaction ^{7}Be+^{208}Pb was studied at three different energies. One of these values was that obtained from the production reaction using a gas target cooled with liquid nitrogen; the second value was obtained by inserting a degrader after the production target while for the third one the production target at room temperature was used. The data analysis is still in progress.

LNL 13.04 – *Elastic scattering and reaction mechanisms of $^{7}Be+^{28}Si$ at near barrier energies*
Objectives – To probe the energy dependence of the optical potential at near barrier energies for ^{7}Be+^{28}Si and the reaction mechanisms (fusion versus direct) via an angular distribution of the emitted alpha particles.

Achievements – The ^{7}Be secondary beam has been produced by using the **EXOTIC** facility at LNL. An angular distribution measurement for the elastic scattered ^{7}Be nuclei in a silicon target and the emitted alpha particles was performed in a wide angular range with the **EXPADES** apparatus. The radioactive beam reconstruction was possible by using two PPAC detectors installed in the entrance of the target chamber. Measurements were completed only for two of the suggested near barrier energies of the proposal, due to a technical problem concerning the filling of the cryogenic primary gas target. The consequence of that was a very low secondary-beam flux (almost 1/3 of the expected one). The data analysis is in a very preliminary stage for the determination of the solid angle via a scattering measurement on a Au target and a GEANT simulation.

LNL 13.13 – *Revealing the structure of carbon nuclei A = 10-14 through measurements of the excited-state decay properties*

Objectives – To perform kinematically complete measurements of the $^{14}N+^{10}B$ reactions using a ^{14}N beam of energy 95 MeV from the XTU Tandem, with $^{14}C+^{10}C$, $^{11}C+^{13}C$ and $^{12}C+^{12}C$ in the exit reaction channels. Measurements of energy and momenta of all except one reaction product makes possible the clear identification of the many-body reaction exit channel and the full reconstruction of the decay pattern of the excited state. Comparison of detailed spectroscopic information for the beryllium and carbon nuclei can provide crucial information for understanding of the clustering and its evolution with increasing number of the clusters. Of particular interest are the ^{14}C and ^{10}C nuclei, both being related to the ^{10}Be, the only nucleus with experimentally confirmed molecular structure.

Achievements – Measurements of the $^{14}N+^{10}B$ reaction have been successfully performed on the beam line **LIRAS** at LNL. Experimental set-up worked very well and the beam intensity was adequate for the proposed measurement. All applied online checks show adequate quality of the data to achieve the experiment objectives. Recorded data are converted to data format required for the data analysis, which is still in progress.

LNL 13.15 – *Elastic scattering and breakup of $^{8}B+^{208}Pb$ below Coulomb barrier*

Objectives – To determine at one energy below the Coulomb barrier the elastic scattering and breakup for studying possible deviations from the Rutherford scattering and the coupling channel effects.

Achievements – As it was impossible to deliver a secondary beam of ^{8}B by using the **EXOTIC** facility at LNL with the appropriate flux for achieving our objective, a ^{8}Li beam was finally delivered and elastically scattered at two energies in a ^{90}Zr target. A preliminary analysis of the elastic scattering angular distribution of the first energy at 18.9 MeV has already been done. A more detailed analysis "pixel by pixel" will follow.

LNL 14.07 – *Study of fusion reactions for Ni+Sn at low energies*

Objectives – To study the fusion process for $^{64}Ni+^{124}Sn$ reaction in order to verify the effect of *Q*-value systematics on heavy-ion fusion below the Coulomb barrier and to clarify the conclusions drawn from recent studies involving the ^{132}Sn beam.

Achievements – The fusion excitation function has been successfully measured between E_{lab}= 220 MeV and E_{lab}= 246 MeV by the **LNL electrostatic deflector**. The data analysis is being completed and the results will be published soon.

LNL 14.01 – *Study of carbon-carbon burning by measuring excitation function of the $^{20}Ne+^{4}He$ resonant reactions*

Objectives – To search for resonances in the excitation functions of the $^{4}He+^{20}Ne$ reactions at relative energies between two ^{12}C from 1 to 3 MeV and their full characterisation.

Achievements – Measurements were planned at four beam energies on the beam line **LIRAS** at LNL. Due to technical problems, measurements were taken at three lower beam energies only, but these measurements still cover the most interesting range of ^{24}Mg excitations for the astrophysical purpose. Online spectra show good energy resolution and high statistics, both are requirements to improve current knowledge on the topic. Data analysis is still in progress.

LNL 14.05 – *Neutron-rich nuclei populated via multinucleon transfer reactions: the $^{197}Au+^{130}Te$ system as a benchmark*

Objectives – To determine the final yields of both, "light" and "heavy" reaction products in the reaction ^{197}Au+^{130}Te. In particular, via the 2-proton stripping and 4-neutron pick-up channel one should be able to populate ^{132}Sn, which represents a benchmark neutron-rich nucleus for different physics cases. The importance of secondary processes, which may significantly modify the final yields, will be investigated by measuring the yield distribution of heavy transfer products.
Achievements – Multi-neutron and multi-proton transfer channels were studied at E_{lab}=1070 MeV using a ^{197}Au beam delivered by the PIAVE+ALPI accelerator complex of LNL and detecting via kinematic coincidence with **PRISMA** + the **second arm** (MCP+PPAC+BC), for the first time, both projectile-like and target-like ions. Inverse kinematics was used in order to exploit the unique performance of PRISMA in terms of both resolution and efficiency. The complex data analysis (the tracking through the spectrometer "event-by-event") is in progress. The collected data look promising.

LNL 14.20 – *The influence of the 2-neutron elastic transfer on the fusion of ^{42}Ca+^{40}Ca*

Objectives – Measuring the near- and sub-barrier fusion excitation function of ^{42}Ca+^{40}Ca, so to extract the barrier distribution with good accuracy. This is the purpose of the experiment, because a striking distribution is predicted for strong coupling to a single channel with zero *Q*-value, as is the case of the transfer of a pair of neutrons in ^{42}Ca+^{40}Ca (elastic transfer): one should obtain a roughly symmetric distribution possessing two peaks, one on each side of the original uncoupled Coulomb barrier.

Achievements – The full excitation function of ^{42}Ca+^{40}Ca has been measured with good statistical accuracy by using the set-up based on the **LNL electrostatic deflector**. The angular distribution of the fusion-evaporation residues has been measured at two representative energies near the Coulomb barrier. A preliminary data analysis has been performed during the experiment, and the detailed analysis is presently in progress.

LNL 14.12 – *Study of ^{58}Ni+^{124}Sn fusion at low energies*

Objectives – The possible influence of transfer channels on sub-barrier fusion of heavy ions has become a matter of renewed interest; measurements of sub-barrier cross sections have been made possible by the developments of the set-ups, and some of them could be performed using heavy exotic beams. The measurement of the fusion excitation function has been performed for the system ^{58}Ni+^{124}Sn where the effects of couplings to positive *Q*-value transfer channels are expected to be strong, especially at low energies. The excitation function presently known is rather incomplete. The full comparison of the two cases ^{58,64}Ni+^{124}Sn will be crucial.

Achievements – The measurements have been successfully performed with the **LNL electrostatic deflector**, with high intensity and good quality of the ^{58}Ni beam. The excitation function has been fully measured, as well as the angular distribution of fusion-evaporation residues at an energy slightly below the barrier. After the on-line data analysis showing encouraging results, the off-line analysis is almost complete, and the results will be soon available.

LNL 14.15 – *Elastic scattering and reaction mechanisms of ^{7}Be+^{28}Si at near barrier energies*

Objectives – To measure the energy dependence of the optical potential via elastic scattering angular distributions and to study the reaction mechanisms via the measurement of alpha particles originating from various direct and compound reactions (completion and extension of the experiment LNL 13.04 approved in the second reporting period).

Achievements – A ^{7}Be secondary beam has been produced by using the **EXOTIC** facility at LNL. Elastic scattering angular distributions at 4 energies (13 MeV, 16 MeV, 20 MeV and 22 MeV) have been measured with the detector array **EXPADES**. The measurement was repeated for the lower energy with a lead target for the solid angle determination.

LNS LIP-MAGNEX – *Total reaction and breakup cross sections for ^{6}Li+p at near Coulomb energies*

Objectives – To measure the elastic scattering angular distributions by detecting the heavy ejectile by means of the large acceptance magnetic spectrometer **MAGNEX** at LNS, to study the inverse kinematic reaction ^{6}Li+p $\rightarrow$^{3}He+^{4}He, and finally to study the breakup process with coincidence measurements between MAGNEX close to 0° and a **silicon detector** at 5°.

Achievements – The experiment allowed to obtain in a very satisfactory measurement:

- angular distributions for ^{6}Li+p - elastic scattering - at 16 MeV, 20 MeV, 25 MeV and 28.8 MeV with MAGNEX;
- angular distributions for ^{6}Li+$p \rightarrow ^3$He+^{4}He at the same energies measured with DINEX;
- breakup coincidence measurements - direct and resonant - at 20 MeV, 25 MeV and 28.8 MeV with MAGNEX at 0° and a Si detector at 5°.

The data were “decoded” to be analysed with the PAW code and for some of the runs the reconstruction of the beam and ejectile trajectories in MAGNEX was achieved. The analysis is still in progress.

Details about the access for the selected user groups, performing experiments in the present reporting period at the Nuclear Structure and Dynamics Based Facilities, are provided in the following table. Seven of the performed experiments have been approved in PAC and ENSAR USP meetings held in previous reporting periods.

Project Acronym	*Access (beam-on-target hours)*	*Person-days*	*Visits*	*Users*
LNL 13.18	151	37	4	4
LNL 13.16	96	36	5	5
LNL 13.03	180	32	4	4
LNL 13.04	140	60	9	9
LNL 13.13	178	76	10	10
LNL 13.15	142	63	8	8
LNL 14.07	186	44	6	6
LNL 14.01	82	60	9	9
LNL 14.05	101	67	9	9
LNL 14.20	156	8	1	1
LNL 14.15	91	64	7	7
LNL 14.12	189	19	3	3
LNS LIP-MAGNEX	278	38	6	6
	1970	**604**	**81**	**81**

APPLIED AND INTERDISCIPLINARY PHYSICS FACILITIES (AIPF) – Applied and interdisciplinary physics experiments mainly concerned the elemental analysis of archaeological and geological samples by using nuclear techniques based on the Ion-Beam Analysis (IBA) with the **micro-beam** facility at the AN2000 accelerator of LNL, the study of the ionisation structure of the carbon ion track by using the **PTB ion counter** and radiobiological studies with the irradiation of cell cultures at the **0° beam line** and the **CATANA** facility at LNS.

In total during the third reporting period:

– 70 proposals were presented to the LNL USIP (67 experiments were approved for a total of 276 days of beam time – 400 requested days → average acceptance rate of 69%);
– 5 projects asked for EC support – 5 were considered eligible and were selected by the ENSAR USP.

Objectives and achievements of the funded experiments

Acronym	*Project Title*

LNL USIP13.40 – *Investigation of light-ion track structure (ILITS)*

Objectives – To contribute with the **PTB ion counter** to the investigations on the correlation between characteristics of track structure at different length scales. In fact, while the PTB Ion Counter measures at the DNA scale (2 nm), the StarTrack detector, also installed at LNL, is able to investigate the ionisation track structure in the range of 20-30 nm, which corresponds to the thickness of the chromatin fibre. In view of the upcoming radiation therapy with carbon ions, the ionisation structure of the carbon ion track is of particular interest.

Achievements – The ionisation cluster size distributions generated by $^{12}C^{6+}$ ions with kinetic energies of 48 MeV, 78 MeV, 96 MeV, 102 MeV and 156 MeV in a target gas consisting of 1.2 mbar C_3H_8 have been measured. The data analysis is still in progress.

LNL USIP13.52 – *Compositional investigations of Byzantine ceramics using LNL nuclear microprobe*

Objectives – To determine the chemical composition of 60 Byzantine ceramics shards excavated on Romanian territory from the site of Oltina (10th-11th centuries A.D.) using **micro-PIXE facility** at AN2000 accelerator of LNL. The measurements will also be used to estimate the thickness and composition of the green glaze superficial layers decorating some of these pottery fragments.
Achievements – During the first experimental run (November 2013) 30 samples coming from different types of ceramics were measured as pelletised powders. Due to some technical problems with the AN-2000 accelerator, during the second run (May 2014) only one day (out of the 3 days of assigned beam-time) has been used. As a consequence only half of the samples have been analysed. The interpretation of the obtained results is in an incipient stage, being made in close collaboration with the archaeologist who discovered the Byzantine ceramic shards, and took part in the PIXE experiments, assuring the adequate sample preparation.

LNL USP13.62 – *Micro-PIXE studies on archaeological samples (MicroArchaeoStudy)*

Objectives – To determine the (micro)composition – major, minor, traces elements and micro-inclusions – using the LNL **micro-PIXE facility** of:

- small samples from silver and bronze archaeological objects from Romanian museums - mainly micro-fragments of Thracian and Dacian adornments and coins;
- natural gold-silver alloy and native copper samples from geological deposits situated near archaeological sites where the artefacts were discovered

Achievements – Ten ancient silver and bronze coins were measured to identify minor and trace elements and to investigate the homogeneity of alloys composition. The different corrosion, especially of copper and silver in various areas of coins, have been put in evidence. In addition, six geological gold samples from Rosia Montana - the most important Romanian native gold deposit, exploited from Roman times (2nd Century A.D.) were also measured. Micro-inclusions of antimony and tellurium (fingerprints for Transylvanian natural gold) and, in one sample, few micro-inclusions of mercury, which can also be used as fingerprint, were identified.

LNL USIP14.16 – *Compositional investigations of Byzantine ceramics using LNL nuclear microprobe*

Objectives – To determine the chemical composition of 70 Byzantine ceramics shards discovered in two Romanian archaeological sites (Valu lui Traian and Pantelimonu de Sus), dated to the 10th-11th centuries A.D. To estimate the thickness and the composition of green glaze superficial layers decorating some of these pottery fragments.

Achievements – The measurements were made using **micro-PIXE facility** at the AN2000 accelerator of LNL. During the experimental campaign 111 samples belonging to several types of ceramic were successfully measured as pelletised powders. In this way, the user group could recuperate the beam-time lost in May 2014 due to the technical problems of the AN-2000 accelerator and also to analyse the remaining samples.

LNL USIP14.24 – *Micro-PIXE studies on archaeological samples (MicroArchaeoStudy)*

Objectives – To investigate the (micro)composition for archaic Greek pre-monetary signs (Copper and Bronze – VI Century BC) issued in Greek Black Sea colonies (Histria-Istros especially). These signs are practically arrow-heads and small dolphin figures, their alloys depending on the geological Copper sources – Caucasus, Ukrainian mountains, Carpathian Mountains, Balkans, Greece, Anatolia (Asia Minor), etc. Besides Copper provenance, the project intended to clarify the metallurgical procedure used to produce the Bronze alloy (Cu-Sn-Pb with small quantities of Fe, Mn, Zn, Sb, etc.) in order to obtain information concerning the commercial relationships between these cities and their Thracian and Scythian neighbours.

Achievements – Small samples (100-300 μm diameter) from 50 bronze pre-monetary signs were analysed using **micro-PIXE facility** at the AN2000 accelerator of LNL. Point spectra and elemental maps for Ag, Cu, Sn, Pb, Sb, Bi, Zn, Br, Cl, Mn, Fe, Ca were obtained.

LNS HADMAC 2013 – *Hadrons on malignant cells - Radiobiological studies of human malignant cells after irradiation with 62 MeV/u ^{1}H and ^{12}C ions*

Objectives – From the radiobiological point of view the most important lesions produced by ionising radiation are the DNA double-strand breaks (DSB). One of the first steps in the cellular response to DSB is phosphorylation of histone H2AX (γ-H2AX) at the damage sites that are DSB very soon after irradiation. The number of γ-H2AX foci is considered as one to one DNA DSB. They seem to have an important function in the activation of the DNA repair system of the cell. Therefore, kinetics of the appearance of the γ-H2AX foci after irradiation of the human malignant cell monolayers by different types of radiation was studied. The chosen time points cover the interval up to 24 h after irradiation. Detection and quantification of γ-H2AX foci is performed by Western blot and immunohistochemical analyses.
Achievements – The measurements were carried out on the **0° beam line** at LNS. One melanoma, a breast carcinoma and two non-small cell lung carcinomas were irradiated by γ-rays, protons and carbon ions at low doses. Immunofluorescent staining followed by laser scanning confocal microscopy was used for the detection and quantification of γ-H2AX. This allows quantification of radiation response in individual cells. γ-H2AX foci appeared in cells just a few minutes following irradiation. Their number reached maximum at ~ 60 min and then decreased, thus reflecting the kinetics of DNA DSB repair. The data analysis is currently in progress.

LNS DNA-BRAGG 2013 – *DNA damage and cellular response along and around the Bragg curve of heavy ions*

Objectives – To investigate the DNA repair, bystander signalling and out-of-field effects and to complete the preliminary senescence studies since the effectiveness with which this sub-lethal effect is induced does vary along the Bragg curve, and particularly along the SOBP. The experiment also planned to test a new irradiation set-up using solid water phantom and hypoxia chambers.
Achievements – Over 350 samples have been irradiated for senescence and chromosomal aberration studies by using the **CATANA** facility at LNS. A new set-up using solid water slabs was successfully implemented allowing investigation of the biological effectiveness at the end of the beam (scattered particles) and use of oxygen scavengers for mimicking hypoxia conditions. Data analysis is still in progress.

Details about the access for the selected user groups, performing experiments in the present reporting period at the Applied and Interdisciplinary Physics Facilities, are available in the following table. Five of the performed experiments have been approved in PAC and USP meetings held in previous reporting periods.

Project Acronym	***Access (beam-on-target hours)***	***Person-days***	***Visits***	***Users***
LNL USIP13.40	134,5	32	8	4
LNL USIP13.52	20	14	4	2
LNL USIP13.62	17	12	4	2
LNS USIP14.16	66	8	2	2
LNS USIP14.24	115	9	3	3
LNS HADMAC 2013	24	40	4	4
LNS DNA-BRAGG 2013	40	10	2	2
	416,5	**125**	**27**	**19**

During the third reporting period, in total 20 projects have been supported, 2386,5 beam-on-target hours were provided, 100 users – 47 individual users – had access to the INFN/LNL-LNS research infrastructures and 729 person-days and 108 visits were allocated.

The list of projects supported in the present reporting period and the list of users can be found in Annex 2 and Annex 3 (Database).

SCIENTIFIC OUTPUT OF THE USERS AT THE FACILITIES

Publications gathering results from financed projects are constantly monitored: e-mails are periodically sent to the user group leaders inviting them to send any scientific useful details concerning the funded projects (last e-mail 9 December 2014). Some results and news from the supported experiments are given below.

LNL 13.18

Measurements of the excitation function for the fusion reaction ^{24}Mg+^{30}Si (Q=17.89 MeV) have been extended toward lower energies with respect to previous experimental data. The observed fusion hindrance in this system is unique and leads to a maximum of the astrophysical S factor which would have important consequences in stellar burnings of light heavy-ions. The S-factor maximum observed in this large, positive Q-value system is the most pronounced among such systems studied thus far. This observation implies that the cross section falls off very steeply at even lower energies. By extension, one may expect that similar precipitous reduction in the cross sections occurs for other positive Q-value systems, such as those involved in the carbon phase of giant stars.
The results of this experiment have been published in Physical Review Letters in July 2014 (see Annex 4).

LNL 11.32 (*supported in the first reporting period*)

New data concerning the nature of the pygmy dipole states in ^{208}Pb were obtained using the ^{208}Pb(^{17}O,^{17}O$'\gamma$) reaction at 340 MeV and measuring the γ decay with high resolution with the AGATA Demonstrator array. In particular, cross sections and angular distributions of the emitted γ rays and of the scattered particles (two segmented ΔE-E silicon telescope prototypes for the TRACE project) were measured. The results were compared with (γ, γ') and (p, p') data. The E1 transitions cross sections for ^{208}Pb were analysed for the first time using a microscopic form factor and the isoscalar potential was found to depend on the presence of the neutron skin. A consistent description was obtained for elastic and inelastic excitations of E2 and E3 states.
The inelastic scattering of ^{17}O was also used to study the pygmy dipole resonance in ^{140}Ce nucleus. Gamma-rays were registered by AGATA Demonstrator and 9 large-volume scintillators ($LaBr_3$) of the HECTOR+ array. Very preliminary results of the study have shown a strong domination of E1 type transitions in the region of 'pygmy' energies. However, some indication of possible 'isovector' states is also visible. This will soon be confirmed as the analysis is still in progress (~20% of the data not analysed yet). The results of this project have been published in Physical Review Letters and Physica Scripta in 2014 (see Annex 4).

LNL 11.33 (*supported in the first reporting period*)

The excitation function of one- and two-neutron transfer channels for the ^{60}Ni+^{116}Sn system has been measured with the large acceptance magnetic spectrometer PRISMA in a wide energy range, from the Coulomb barrier to energies corresponding to very large distances of closest approach where the nuclear absorption is negligible. The experimental probabilities for one- and two-neutron transfer channels have been well reproduced, for the first time with heavy ions, in absolute values and in slope by microscopic calculations which incorporate nucleon-nucleon pairing correlations.
The results of this experiment have been published on Physical Review Letters in 2014 (see Annex 4).

LNL 12.10 (*supported in the second reporting period*)

Fusion excitation functions for ^{40}Ca+^{58}Ni and ^{40}Ca+^{64}Ni were measured at energies around and below the Coulomb barrier. The barrier distributions were also extracted for the two systems. Good agreement was found between the measured and calculated fusion cross sections for the ^{40}Ca+^{58}Ni system. The situation is different for the ^{40}Ca+^{64}Ni system where the coupled-channels calculations (CC) with no nucleon transfer clearly underestimate the fusion cross sections below the Coulomb barrier. The fusion excitation function for this system was, however, well reproduced at low and high energies by including the

coupling to the neutron pair-transfer channel in the calculations. Experiments to measure directly the transfer cross sections would also be of the highest interest to better understand the influence of nucleon-transfer channels on ^{40}Ca+^{58,64}Ni.
This work has been published in Physical Review C in 2014 (see Annex 4).

LNL 13.04
The elastic scattering data were analysed in a BDM3Y1 framework and the normalisation factors of the optical potential were deduced. These are compared with the normalisation factors of ^{6,7}Li+^{28}Si obtained previously in the same framework. The indication is that ^{7}Be resembles rather the behaviour of ^{6}Li and not that of ^{7}Li. More data at other energies are necessary to confirm this conclusion.
The results of this experiment were presented in the Carpathian Summer School of Physics 2014 Exotic Nuclei and Nuclear/Particle Astrophysics (V) "From nuclei to stars", 13-26 July 2014, Sinaia, Romania and the 2nd Workshop on New Aspects and Perspectives in Nuclear Physics, 12 April 2014, Thessaloniki (Greece).

LNL USIP13.62
Metallurgical aspects of silver adornments and coins give important information on provenance – mines, metal production workshops, jewellery makers, commercial relations. Results of the micro-scale analyses of archaeological and geological samples have been presented at the 14th ICNMTA Conference (International Conference on Nuclear Microprobe Technology and Applications), 7-11 July 2014, Padova (Italy) and SR2A-2014 (Synchrotron Radiation in Art and Archaeology) Conference, Paris, 10-12 September 2014 and included in the conference proceedings (both of them in press).

LNL USIP13.52

Two compositional groups (kaolinitic and non-kaolinitic clays) have been evidenced from the statistical analysis of micro-PIXE data of Byzantine (10th-11th centuries A.D.) ceramic shards discovered in several archaeological sites from Romania. The green decoration is composed of a Pb-rich glaze onto a non-calcareous glaze. The results have been presented at the 14th ICNMTA Conference, 7-11 July 2014, Padova (Italy) and included in the conference proceedings (accepted for publication in NIMB).

LNS DNA-BRAGG (*supported in the second reporting period*)
Glioblastoma (U87) and Fibroblasts (AG01522) have been exposed to different depth positions along a clinical proton beam with unprecedented ~50 µm accuracy. By comparison with X-ray, the Relative Biological Effectiveness (RBE) has been estimated as a function of dose, depth and intrinsic cellular sensitivity. Data have been used to evaluate shortfall of current clinical practice employing a fix RBE value of 1.1 and to develop a parameterised RBE model.
This work has been published in 2014 in International Journal of Radiation Oncology - Biology - Physics (see Annex 4).

LNL USP13.03 (*supported in the second reporting period*)
The ion-beam techniques Rutherford Backscattering Spectrometry (RBS) and micro-Particle Induced X-Ray Emission (µPIXE), available at the AN2000 accelerator of LNL, were selected to study radionuclide diffusion and surface retention within heterogeneous rocks. Diffusion coefficients and retention parameters at the micro-scale were determined for U and Se on granite selected minerals, both under oxic and anoxic conditions.
The Se data have been published in 2014 in Applied Geochemistry Journal (see Annex 4).

LNS PIXE (*supported in the second reporting period*)
Proton-induced X-ray emissions (PIXE) from gold and silver markers were detected at different penetration depths of a 59 MeV proton beam at the CATANA proton facility at INFN-LNS (Italy). This study establishes that proton induced X-ray emissions (PIXE) from implanted metal markers, could potentially be used to verify in real-time beam range overshoots during eye proton treatments. Preliminary results from silver are more promising. Further investigations are needed to demonstrate the feasibility of the technique in a clinical set-up.
Results of this work have been published in Physics in Medicine and Biology in 2014 (see Annex 4).

The list of publications that appeared in peer-reviewed journals (or peer-reviewed conference proceedings) resulting from the experiments carried out at LNL and LNS under the Transnational

Access activity and supported through the EC grant agreement ENSAR (no. 262010) can be found in Annex 4. These publications have never been reported in previous ENSAR activity reports.

USERS MEETINGS

A meeting of the LNL User Board was held on 8 November 2013 at LNL. Three meetings of the LNS User Committee were held on 6 December 2013, 1 October 2014 and 21 November 2014 at LNS.

Moreover, several meetings and workshops, related to the Transnational Access activity, were also held at LNL and LNS during the third reporting period (see table below).

Title of event	**Venue**	**Date**
Meeting of the Accelerator Division and spokespersons of experimental set-ups installed at the Tandem/PIAVE-ALPI	LNL	14 April 2014
Workshop on Accelerator-Based Neutron Production	LNL	14-15 April 2014
Second SPES International Workshop	LNL	26-28 May 2014
Joint Training Course on Ion-Beam Microscopy	LNL	3-4 July 2014
Third SPES One-Day Workshop	LNS	8-9 October 2013
LNS users meeting	LNS	6 December 2013
LNS users meeting	LNS	2 December 2014

Annexes

Annex 1 Composition of the Users Selection Panel
See "Selection Panel" in MS Access Database

Annex 2 List of User-Projects
See "List of User Projects" in MS Access Database

Annex 3 List of Users
See "List of Users" in MS Access Database

Annex 4 List of Publications (from work carried out under the Transnational Access activity)
See "List of Users' Publications" in MS Access Database

Annex 5: Report on the status of the LNL and LNS accelerators – in attachment to the periodic report

Work Package 17: TNA04-JYFL

Report on TransNational Activities at JYFL

Description of the publicity concerning the new opportunities for access

The measures taken to publicise the opportunities for access are:

A dedicated **website**:
https://www.jyu.fi/accelerator/ensar.html

In web site it is described:
- Who can apply
- How to apply
- Call for proposals
- Financial support
- Structure and services of the research infrastructure

Advertisement of calls for proposals (15 March and 15 September) and new developments at JYU-JYFL are published in **JYFL Accelerator News** biannually, which is posted to nuclear physicists all over the world and published at http://www.jyu.fi/accelerator/anews.

Description of the selection procedure

Access is based on approved proposals for the experiments (= projects) to be carried out at the JYU-JYFL Accelerator Laboratory by the user groups. They are evaluated by the Programme Advisory Committee (PAC) (= the Users Selection Panel), which meets in Jyväskylä around 2 weeks after the deadline for submitting proposals (March 15 and September 15).

Before the PAC meeting, every proposal is looked at in great detail by one PAC member, if possible by someone with particular experience in the relevant research topic. During the PAC meeting, each proposal is discussed in detail. The criteria used in judging a proposal are: the importance of the physics topic, the feasibility and the suitability for the JYFL facility. The PAC can propose to reduce the amount of beam time from that requested. After the discussion of all proposals, they are ranked according to the average mark they received. Since there are 2 calls for proposals per year, it makes no sense to award more than about 6 months worth of experiments during each PAC meeting. Going from the highest to lowest ranked proposals, the beam time is added until a total time of 120 to 150 days is reached, thus setting a cut-off mark. The PAC then recommends to approve the proposals with a mark higher than this cut-off value. All spokespersons of the proposals are notified of the result of the PAC discussion and of how much beam time (if any) was awarded.

The decision to award financial support under the ENSAR-TNA contract is taken by the board of the Accelerator Laboratory. During the PAC selection process, no priority is given to new and young users of the facility. However, this criterion is taken into account in awarding the financial support.

Please find in **Annex 1 (Database) the list of the Selection Panel members** for the reporting period.

Three Panel members of P2 were replaced by new members.

Three selection meetings: on 11 October 2013, 14 April 2014 and 24 October 2014.
A total of 23 proposals (projects) out of 26 proposals eligible for ENSAR support were approved for experiments at JYU-JYFL-ACCLAB.

Transnational Access activity

A total of 64 out of 88 approved eligible proposals have been selected for execution within the 1st, 2nd and 3rd ENSAR reporting periods (1 September 2010 – 31 December 2014).
A total of 17 projects have been executed during the 3rd reporting period. All of the projects belong to the field of nuclear physics and related applications, and are based on experiments performed at the JYU-JYFL Accelerator Laboratory by employing beams from the JYFL cyclotron and available instrumentation. The ENSAR supported experiments were performed by the visiting users in collaboration with the local expert research groups and technical staff.

During the third reporting period, a total of 1646 beam-time hours (share of the supported access) were delivered, 135 users (travel+sub. reimbursed) have visited the facility and spent 1486 person-days at JYFL.

Please find in **Annex 2 (Database) the list of user-projects** for which costs has been incurred in the reporting period.
Please find in **Annex 3 (Database) the list of users** in the reporting period.

The supported projects in chronological order are:

48. S12: 2-9/09/2013 (continuation of s12 from 5-12/8/2013)
Probing the E0 transitions in ^{186}Pb using the SAGE spectrometer

49. S13: 16-30/09/2013
Study of the structure of high-K states in ^{254}No using the SAGE spectrometer

50. S17: 21/10- 4/11/2013
Shape coexistence in odd-Au Isotopes: In-beam gamma-ray and conversion electron coincidence spectroscopy of the ^{179}Au

51. S15: 4-11/11/2013
Spectroscopy of the odd-proton nucleus ^{249}Md and feasibility study for ^{243}Es

52. I159 29/11.-912/2013
Branching ratio of ^{26}Si

53. I169 10-17/12/2013
Laser spectroscopy of Mo and Y using optical pumping in an ion-beam cooler-buncher

54. JR126 20/1-3/2/2014
Spectroscopic studies of excited states above and below 6^+ Isomer in ^{102}Sn

55. J19 11-17/2/2014
Defining the nature of the ultrahigh-spin region of ^{162}Hf

56. I154 17-22/2/2014
Total absorption measurement of the beta decay of ^{100}Tc

57. I153 23/2-3/3/2014
Study of nuclei relevant for precise predictions of reactor neutrino spectra

58. JR103 10-17/3/2014
Magnetic rotation and shape coexistence in ^{144}Dy

59. JR130 11-17/6/2014

Shape coexistence and quadrupole transition strengths in ^{174}Pt

60. JR122 26/6-8/7/2014
Shape coexistence in neutron deficient ^{178}Hg: First measurement of E2 transition strengths in the yrast band

61. JR129 4-19/8/2014
Lifetimes of Proton-Unbound States in deformed ^{113}Cs

62. JR132 19-30/9/2014
Identification of excited states in ^{70}Kr

63. JR135 30/9-7/10/2014
Search for breakdown of T=1/2 mirror symmetry: Recoil-$ß^+$ tagging and decay spectroscopy of ^{71}Kr

64. I187 27-31/10/2014
Measurement of nuclear charge radii of plutonium isotopes by collinear laser spectroscopy

Scientific output of the users at the facilities

Please find in Annex 5 the list of peer-reviewed articles published in the period 1/9/2013-31/12/2014 (ENSAR P3) based on EU-supported experiments (supported by the previous TNA-FP6-EURONS and the present TNA-FP7-ENSAR). The number of publications acknowledging EURONS and ENSAR within P3 is 19 and 11, respectively.
(Note that Annex 4 of the data base only allows to insert publications related to the projects executed within the same period).

A highlight (Project JR124, P2) was the first observation of yrast states in ^{74}Sr, a nucleus beyond the N=Z line, enabling extraction of triple-energy differences for the analysis of Coulomb-energy differences in A=74 nuclei at the N=Z line:

J. Henderson, D. G. Jenkins, K. Kaneko, P. Ruotsalainen, P. Sarriguren, K. Auranen, M. A. Bentley, P. J. Davies, A. Görgen, T. Grahn, P. T. Greenlees, A. Hay, T. W. Henry, A. Herzáň, U. Jakobsson, R. Julin, S. Juutinen, J. Konki, M. Leino, C. McPeake, S. Milne, A. J. Nichols, J. Pakarinen, P. Papadakis, J. Partanen, P. Peura, P. Rahkila, E. Sahin, M. Sandzelius, J. Sarén, C. Scholey, M. Siciliano, L. Sinclair, J. Sorri, S. Stolze, J. Uusitalo, R. Wadsworth, M. Zielińska
Spectroscopy on the proton drip-line: Probing the structure dependence of isospin non-conserving interactions
Phys. Rev. C 90, 050303(R) (2014)

Annexes

Annex 1 – Composition of the Users Selection Panel
See “Selection Panel” in MS Access Database

Annex 2 – List of User-Projects
See “List of User Projects” in MS Access Database

Annex 3 – List of Users
See “List of Users” in MS Access Database

Annex 4 – List of Publications (incomplete as only publications from P3-projects is allowed).
See “List of Publications” in MS Access Database

Annex 5 – List of Publications (during P3 from earlier EURONS and ENSAR supported) in attachment

Work Package 18: TNA05-KVI

Report on TransNational Activities at KVI

Description of the publicity concerning the new opportunities for access

As in the first reporting period, the opportunities for access were publicised by means of a dedicated website: http://www.rug.nl/kvi/ensar . For details, see the first periodic report.
Additionally, a request for beam access proposals was sent out to the RUG-KVI mailing list in November 2013 and to a selected list of potential users in May 2014.

Description of the selection procedure

No Selection Panel meetings were held in the reporting period. A recommendation for new beam access proposals was obtained from the Selection Panel via e-mail communication. In total, 2 new experiments (KVI-T36, KVI-T37) were given a positive recommendation while the continuation of a previously performed experiment (KVI-T29) was recommended (KVI-T29).

See Annex 1 (extracted from Database) for the list of the Selection Panel members.

Transnational Access activity

Three projects have been supported during the reporting period:
1. KVI-T29: Radiation damage and defect studies in PWO crystals, and hadron response of inorganic scintillating fibres (spokesperson: R. Novotny, Justus-Liebig University Giessen, Germany);
2. KVI-T36: Tests with a LaBr3-SiPM telescope in proton and Carbon ion beams (spokesperson: C. Lacasta, Instituto de Física Corpuscular, Valencia, Spain)
3. KVI-T37: Proton measurement with MAPS (spokesperson: D. Roehrich, University of Bergen, Norway)

All experiments mentioned above are in the field of physics. Experiments KVI-T29 is in the discipline of nuclear physics, experiments KVI-T36 and KVI-T37 are in the discipline of other physics (medical physics).

See Annexes 2 and 3 (extracted from Database) for the List of User-Projects and the List of Users, respectively.

Scientific output of the users at the facilities

Highlights of important research results from the supported user-projects:

i. KVI-T29 (Radiation damage and defect studies in PWO crystals, and hadron response of inorganic scintillating fibres):
Irradiated samples: Si films for MVD detector of PANDA experiment; LYSO fibres with lengths up to 23 cm and 1 and 2 mm diameters; full-size LYSO crystal (2x2x10 cm^3) and set of small (1-3 cubic centimetres) samples of BaF2, DSB and DSL glasses, YAG:Ce, YAG:Pr, LuAG:Ce, LiF. Samples were irradiated with 150 MeV proton beam with integral fluence on the level of $5\text{-}6\times10^{13}$ p/cm^2. The aim of the test was to investigate the radiation hardness of the samples after irradiation with comparatively low-energy (150 MeV) protons. Results of the beam test were presented at the IEEE2014 NSS/MIC Conference, 8-15 November 2014, Seattle, WA USA. It was found that crystalline and glass materials constructed from light atoms are subject to a strong damage. In contrast, both crystalline and amorphous compounds composed of middle heavy ions demonstrate good resistivity. A high level of phosphorescence was observed in Lu-garnet doped with Ce compared to the isostructural Y-based garnet. It

appears that high level phosphorescence is a genuine property of Lu-based oxide scintillation materials.

ii. KVI-T36 (Tests with a LaBr3-SiPM telescope in proton and Carbon ion beams):
During the 3-day measurement campaign performed at KVI-CART different proton beam intensities at a fixed energy of 150 MeV have been employed ranging between 1.5×10^6 and 5.0×10^8 p/s. Acquisitions have been performed in two modalities: single acquisition mode in order to recover the prompt-gammas energy spectrum in each layer of the device and coincidence mode employing different coincidence window (10, 20 and 40 ns). Different targets have been employed to study the emitted prompt-gamma spectra: a PMMA cylindrical target and a cubic Graphite target providing (p,^{12}C) and (p,^{16}O) emission lines from nuclear interactions. To preserve beam properties (lateral spread and longitudinal energy straggling) no degraders have been employed to modulate the beam energy but the target was moved with respect to the isocentre of MACACO to simulate Bragg peak shifts of +5, 0, -5 mm. Acquisition has been performed with two layers in coincidence and measured data will be analysed and reconstructed by means of a novel image reconstruction approach based on a Spectral ML-EM algorithm.

iii. KVI-T37 (Proton measurement with MAPS):
During the beam test we could measure the calorimeter response at different energies. In particular, we could check the expected behaviour of a proton at 120, 170 and 190 MeV. We measured the incoming track of the proton and at the end of its path an enhancement of the activated pixels was detected. We could take data at different sensor sensitivity. The analysis of the beam data is in progress. The main and the only difficulty encountered during the execution of the project was due to the tight schedule for the installation and the deinstallation of the equipment in experimental zone. To operate the detector, around 200 cables have to be connected and other cabling is required to get operational the front-end electronics, the acquisition and the trigger detector and system. Unfortunately, the total cabling requires 8 hours for the installation and the same for the deinstallation of the equipment. This time was only partially taken into account

The Database and Annex 4 list the publications on work carried out under the present contract and published during the third reporting period. The list is at the moment of reporting (January 2015) rather limited. Many more publications are expected to appear over the next few years, once the users have fully analysed the data obtained during the ENSAR-supported experiments at KVI.

<u>User meetings</u>

No user meetings have taken place in the reporting period.

<u>Annexes</u>

The following Annexes are in the MS Database:
Annex 1: List of Panel members
Annex 2: List of User-Projects
Annex 3: List of Users
Annex 4: List of User's Publications

List of FP6 EURONS publications in attachment.

Work Package 19: TNA06-ISOLDE

Report on TransNational Activities at ISOLDE

Publicity concerning the opportunities for access under the grant agreement

The measures taken to publicise the opportunities for access are:

- a dedicated website: https://isolde.web.cern.ch/
  On the website it is described:
  - Who can apply
  - How to apply
  - Call for proposals
  - Financial support
  - Application form
  - Structure and services of the research infrastructure
- group leaders of scheduled projects are informed via email
- the user community is informed at the annual user meeting
- international workshops/conferences are used to inform a wider scientific community

Selection procedure

Users Selection Panel

ISOLDE is open to international user groups. A written proposal has to be submitted to apply for access to the experimental facilities. Proposals are reviewed by an international Programme Advisory Committee (PAC): the ISOLDE Neutron Time-of-Flight Committee (INTC). After open-session oral presentations by the proponents the INTC evaluates the proposal and presents recommendations to the CERN Research Board which decides whether to approve or reject the proposal.

The INTC presently has 11 members from external institutes or universities. These members are experts in topics related to the physics activities of the facilities (nuclear structure physics, weak interactions, nuclear astrophysics, solid state physics, and life sciences). There are also 12 ex-officio members from CERN in the INTC. The CERN research board has 18 members.

After the approval of an experiment the user group can apply for funding from the transnational access programme. A specific users selection panel reviews the applications and decides on the subsistence person-days that can be allocated to the experiment in question. The decision is based on the beam-time allocated as well as the number of young researchers and new users planning to join the experiment.

All users have access to the decisions of the INTC via the CERN website. In case a proposal is rejected the proponents are informed about the scientific/technical or other reasons for not accepting the proposal (e.g. eligibility). Proponents may after considering the comments by the committee submit revised proposals.

Please find in Annex 1 (Database) the list of the Selection Panel members for the reporting period.

Selection Panel meetings

In 2014, there were two meetings held at CERN: 25/07/2014 and 29/10/2014

Selection criteria

The Users Selection Panel bases its selection on scientific merit, following the prescriptions of Annex III of the contract, Article III.3.6.

Transnational access activity during the reporting period

During the 3rd reporting period from September 2013 to December 2014 a total of 26 projects were supported. A total of 1532 beam hours were delivered; 66 individual users were paid a total of 237 subsistence days while at ISOLDE. While the majority of users come from the field of physics, the fields of chemistry and biology are also represented.

Three projects either did not receive the scheduled beam or the beam received was considered as test beam and will be rescheduled at a later date.

Please find in Annex 2 (Database) the list of user-projects for which costs has been incurred in the reporting period.

Please find in Annex 3 (Database) the list of users in the reporting period.

Scientific output of the users at the facility

Please find in Annex 4 the list of publications that have appeared in peer-reviewed journals during the reporting period (or peer-reviewed conference proceedings) and resulting from work carried out under the TNA activity. The current programme started in September 2010. Publications from experiments taking place during this reporting period are thus under preparation. Keeping in mind the time scale of experiments of the kind performed at the facility one may expect that data analysis and publication of the results require typically one to two years.

Below are highlights of important results from the user projects supported under the grant agreement. These results were obtained in the second part of 2014 during the running time of the facility corresponding to the 3rd reporting period.

In 2014, many successful experiments could be performed at ISOLDE, including rare-earth collections of medical isotopes for PSI, Denmark, and Lausanne; masses of neutron-rich Cd isotopes for r-process nucleosynthesis; solid-state studies with beams produced by molten lead and tin targets; hyperfine structure studies on astatine isotopes; and many target and ion source tests. There were also several new setups and even new groups that performed successful studies: the new ISOLDE Decay Station (IDS) was used for the study of three-proton emission in ^{31}Ar, high efficiency gamma spectroscopy of ^{207,208}Hg and and the unknown decay scheme of $^{149\text{-}150}$Cs. Lifetimes of excited states in the beta-decay daughters were measured using the fast-beta-gamma-gamma-time method. With the same technique the half-life of the first-excited state in ^{129}Sn was measured and it was found that the half-life was a factor of 100 faster than expected from theory with important impact on the nuclear structure in the region. A new group from Bratislava used their TATRA setup for decay studies of neutron-deficient Hg isotopes; and finally the LPC Caen and Madrid groups led two-neutron-correlation studies of ^{11}Li, using their large liquid-detector array. In addition, the Versatile Ion-polarised Techniques On-line (VITO) beam-line for solid-state and biological studies successfully completed its first experiment in December.

Users meetings

During the 3rd reporting period from September 2013 to December 2014 two users meetings took place at CERN. The first was held 25-27 November 2013 and was attended by 125 people of whom 96 were users (http://indico.cern.ch/event/263071/). The second took place 15-17 December 2014 and was attended by 146 people of whom 111 were users (https://indico.cern.ch/event/334117/). The users meeting in 2014 included a special session to celebrate the 50th anniversary of the facility which summarised the technical developments and physics achievements since 1964.

Young researchers were gathered at different training courses held at ISOLDE during the period from September 2013 to the end of 2014.

One dedicated to "Shell Model for non-Practitioners" was given by F. Nowacki, E. Caurier, G. Martinez-Pinedo, A. Poves and K. Sieja from 14-18 October 2013

(http://indico.cern.ch/event/248704/).

Another course on "Nuclear Reaction and Nuclear Structure" given by W. Catford, A. Di Pietro and A. Moro took place from 22-25 April 2014 (http://indico.cern.ch/event/298890/).

Annexes

Annex 1 Composition of the Users Selection Panel

See "Selection Panel" in MS Access Database

Annex 2 List of User-Projects

See "List of User Projects" in MS Access Database

Annex 3 List of Users

See "List of Users" in MS Access Database

Annex 4 List of Publications (from work carried out under the Transnational Access activity)

See "List of Users' Publications" in MS Access Database

See list of other ENSAR publications in attachment of the periodic report

Work Package 20: TNA07-ALTO

Report on TransNational Activities at ALTO

Description of the publicity concerning the new opportunities for access

A dedicated Users Guide on the ALTO Web-site exists to publicise the opportunities for access: http://ipnwww.in2p3.fr/Guide-des-utilisateurs,84
This renewed Website details the facilities available, the laboratory infrastructure and services, the selection process and a call for proposals.
In the ALTO page http://ipnwww.in2p3.fr/Utilisateurs-ENSAR-TNA the application for financial assistance for Transnational Access is described, i.e.:

- Financial support available
- Who can apply
- How to apply
- The application form

Description of the selection procedure

The selection of users by the PAC (Programme Advisory Committee) is made only on the scientific merit of the proposals submitted. The proposals are reviewed independently of their country of origin. Experiments are evaluated and awarded a number of 8-hour shifts of beam time, according to the number requested and the number deemed suitable by the PAC. Once the list of approved experiments has been determined by the PAC, two members of the PAC (the chairman and the scientific coordinator) together with the responsible of the TNA are asked to choose, from the approved experiments, those which are entitled to financial support through the TA activity.

During the reporting period, one PAC for nuclear physics was held at Orsay, on 23-24 January 2014. 25 Proposals were submitted of which 12 were eligible to financial support, but only 18 proposals were accepted of which 10 were eligible.

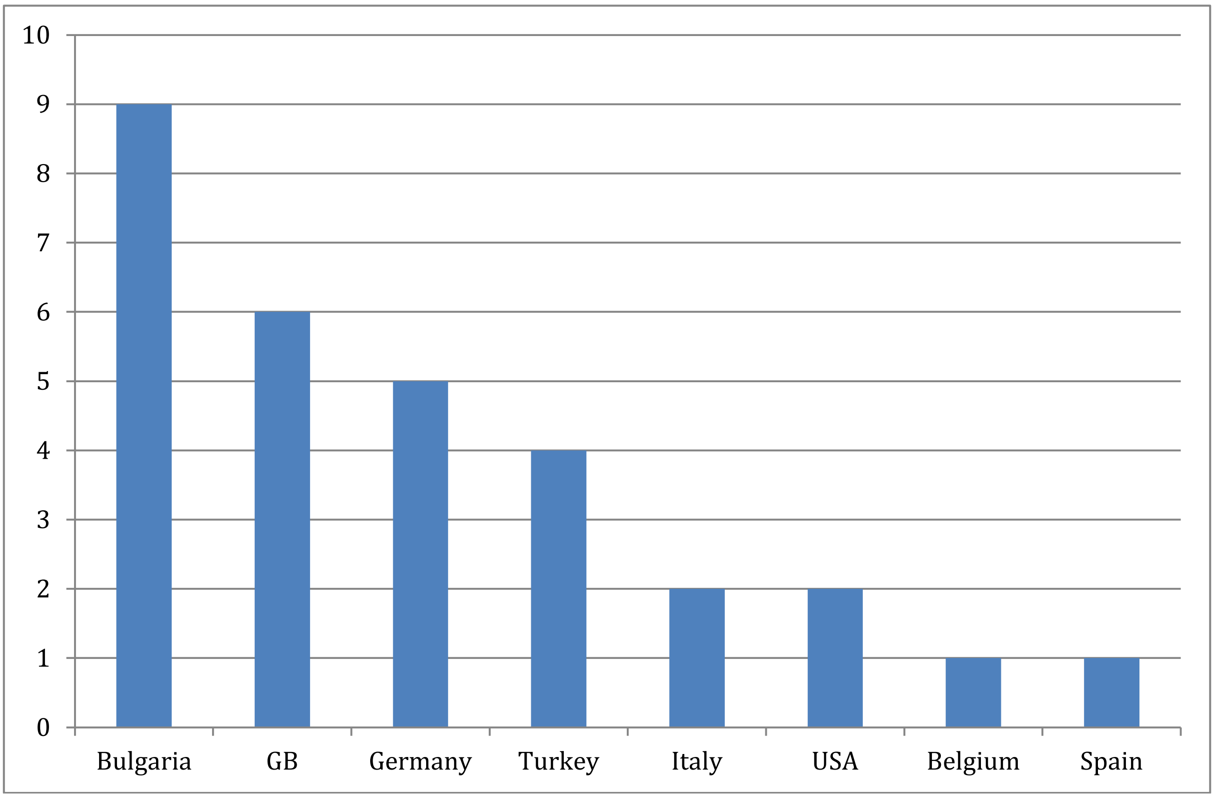
In Annex 1, the Selection Panel members for the reporting period as well as the number of eligible user-projects submitted to the panel during the reporting period and the number of the selected ones are listed.

Transnational Access activity

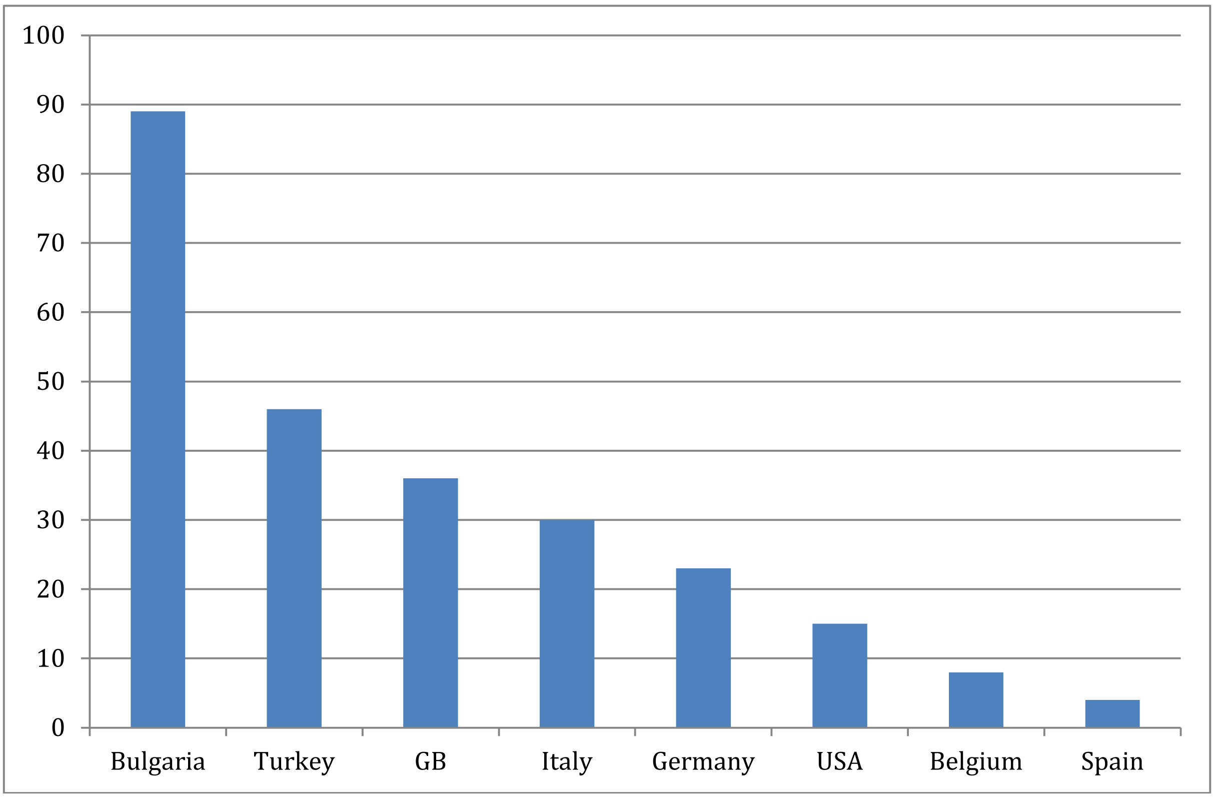
During the reporting period

- 4136 experimental hours were delivered in total
- 1080 experimental hours were offered under the proposal
- 31 users were supported by the TNA
- They spent 251 person-days at ALTO
- 52% were new users

The scientific areas of the experiments performed at ALTO are as follows: nuclear structure and spectroscopy of exotic nuclei; fusion, fission of heavy nuclei; nuclear astrophysics; and tests of fundamental interactions. Among others, the goals are to understand the structures of the nuclei, their shape and shell evolutions from stable to drip line nuclei, to measure the properties of nuclear matter and to evaluate the possible astrophysical implications.



Individual Users by Home Institution Country



Duration of stay by Home Institution country

Scientific output of the users at the facilities

8 publications have been published from the complex experiments performed at ALTO during the reporting period (see Annex 4 of the Database) and 4 have been submitted and accepted.

User meetings

The chairman of the User Group has been designated: Georgi Georgiev (CSNSM, Orsay, France)

An International workshop of the users – "Workshop ALTO"- was organised on May 14and 15, 2013. http://ipnweb.in2p3.fr/wsalto2013/

The purpose of the Workshop was to review and discuss the research carried out at ALTO and the related activities carried out at similar facilities around the world.

The Colloque/workshop covered the range of topics addressed at ALTO

- Nuclear structure
- Reaction mechanism
- Nuclear astrophysics
- Interaction of ions with matter
- Interdisciplinary research

Annexes

Annex 1 – Composition of the Users Selection Panel

PAC:

Chairman of the PAC:

Richard F. CASTEN – WNSL, Yale University, New Haven, USA: richard.casten@yale.edu

Tandem-ALTO Scientific coordinator:

David VERNEY – IPN Orsay-France: verney@ipno.in2p3.fr

Facility chief engineer:

Abdelhakim SAÏD - IPN Orsay-France: said@ipno.in2p3.fr

Member:

Emmanuel BALANZAT (CIMAP – Caen-France): balanzat@ganil.fr

Member:

Dimiter BALABANSKI (ELI-NP – Bucharest-Romania): dimiter.balabanski@eli-np.ro

Member:

Stéphane GREVY (CENBG-France): grevy@cenbg.in2p3.fr

Member:

Elias KHAN (IPNO-France): khan@ipno.in2p3.fr

Member:

Berta RUBIO (IFIC-Valencia-Spain): Berta.Rubio@ific.uv.es

Member:

Patrick REGAN (University of Surrey-UK): p.regan@surrey.ac.uk

Member:

Peter REITER (Universität zu Köln-Germany): preiter@ikp.uni-koeln.de
Member:
Jean-Charles THOMAS (GANIL-Caen-France): thomasjc@ganil.fr
Member:
Aurora TUMINO (LNS-INFN-Catania-Italy): tumino@lns.infn.it
Member:
Christina TRAUTMANN (GSI- Germany): C.Trautmann@gsi.de

Annex 2 – List of User-Projects

I-SI-21:
Pulse-shape analysis studies for Gaspard-Hyde-Trace
Spokesperson: Duenas (Huelva, Spain)

N-SI-48b
g-factor measurements of short-lived states in the Mg isotopes towards the Island of Inversion: ^{26}Mg and ^{28}Mg.
Spokesperson: Kosuglu (Istanbul, Turkey)

N-SI-56
Study of key resonances in ^{19}Ne relevant to the ^{18}F(p,α)^{15}O reaction in novae. Spokesperson: Laird, (York, UK)

N-SI-62
Nuclear moment and nuclear orientation from complete fusion and transfer reactions
Spokesperson: Marginean (Bucharest, Romania)

N-SI-63
Time dependent recoil in vacuum for Na like ^{56}Fe ions
Spokesperson: Balabanski (Bucharest, Romania)

N-SI-64
Investigation of shell effects in fusion-fission and quasifission processes in the reaction ^{16}O+^{204}Pb, ^{34}S+^{186}W
Spokesperson: Vardaci (Napoli, Italy)

N-SI-66
Single-particle structure in the second minimum. Search for high-K bands above fission isomers
Spokesperson: Balabanski (Bucharest, Romania)

N-SI-74
Search for X(5) symmetry in ^{78}Sr nucleus
Spokesperson: Gladnishki (Sofia, Bulgaria)

N-SI-79
Lifetime measurements in ^{113}Te: Determining Optimal effective charges approaching the N=Z=50 doubly-magic shell closure.
Spokesperson: Cullen (Manchester, UK)

Annex 3 – List of Users

UserProject_Acronym	**Family_Name**	**First_Name**	**Country**	**Institution**	**Duration_of_stay**
N-SI-48b	ATANASOVA	Lilya	BG	Medical University of Sofia	6
N-SI-48b	GOASDUFF	Alain	IT	University of Padova	7
N-SI-48b	KUSOGLU	Asli	TR	University of Istanbul	11
N-SI-56	BARTON	Charles	GB	University of York	3

N-SI-56	GARG	Ruchi	GB	University of York	7
N-SI-56	LONGLAND	Richard	OT	North Carolina State University	5
N-SI-56	PARIKH	Anuj	ES	University Politecnica de catalunya	4
N-SI-56	RILEY	Joscelin	GB	University of York	10
N-SI-56	TOMLINSON	Jessica	GB	University of York	7
N-SI-62	ATANASOVA	Liliya	BG	Faculty of Physics, University of Sofia	7
N-SI-62	BLAZHEV	Andrey	DE	Institute for Nuclear Physics	4
N-SI-62	DANCHEV	Miroslav	BG	University of Sofia St Kliment Ohridski	7
N-SI-62	DETISTOV	Pavel	BG	INRNE	7
N-SI-62	GLADNISHKI	Kalin	BG	University of Sofia St Kliment Ohridski	7
N-SI-62	KUSOGLU	Asli	TR	Istanbul university	14
N-SI-63	GLADNISHKI	Kalin	BG	University of Sofia	0
N-SI-63	KARAYONCHEV	Vasil	DE	Inst. for Nuclear Physics	6
N-SI-63	KUSOGLU	Asli	TR	Istanbul University	14
N-SI-63	WILMSEN	Dennis	DE	Institute for Nuclear Physics	6
N-SI-64	CHUBARYAN	Grigor	OT	Texas A&M University, Cyclotron Institute	10
N-SI-64	HANAPPE	Francis	BE	Univ. Libre Bruxelles	8
N-SI-64	VARDACI	Emanuele	IT	Universita Degli Di Napoli	16
N-SI-66	ATANASOVA	Lilya	BG	Medical University of Sofia	10
N-SI-66	DETISTOV	Pavel	BG	Institute for Nuclear	20

				Research and Nuclear Energy - BAS	
N-SI-66	KOCHEVA	Diana	BG	University of Sofia	20
N-SI-66	KUSOGLU	Asli	TR	University of Istanbul	7
N-SI-66	REITER	Peter	DE	University of Cologne	3
N-SI-74	ATANASOVA	Lilya	BG	Medical University of Sofia	5
N-SI-74	BLAZHEV	Andrey	DE	University of Cologne	4
N-SI-74	GOASDUFF	Alain	IT	University of Padova	7
N-SI-79	CULLEN	David	GB	University of Manchester	4
N-SI-79	TAYLOR	Michael	GB	University of Manchester	5

Annex 4 – List of Publications (from work carried out under the Transnational Access activity).

F. Hammache et al., Phys. Rev. C 88 (2013) 062802
B. Hy et al., Nucl. Instrum. and Meth. B288 (2012) 34
K. Kolos, Phys. Rev. C 88 (2013) 047301
S. Benamara et al., Phys. Rev. C 89 (2014) 065805
A. Etilé et al., submitted to Phys. Rev. C
D. Testov et al., submitted to Nucl. Instrum. and Meth.
M. Lebois et al., Nucl. Instrum. and Meth. A 735 (2014) 145
B. Genoloni et al., Nucl. Instrum. and Meth. A 732 (2013) 87 **I-SI-21**
J. Duenas et al., Nucl. Instrum. and Meth. A 743 (2014) 44 **I-SI-21**
S. Go et al., submitted Phys. Rev. C
A. Kusoglu et al., submitted to Phys. Rev. Lett. **N-SI-62**

Project management during the period

Consortium management tasks and achievements;

During the 3rd period of the Project, the management work package, WP01 NA01-FISCO, first collected the scientific and financial information for the reports of the 2nd period. These reports were validated on 11 July 2014.

The Facility Coordinating Group (FCG) reviewed the working procedures of various Programme Advisory Committees (PACs) of RIs and participated in the definition and improvement of the criteria for access as well as make recommendations on common policies. This could entail harmonisation of the access procedures to the 7 ENSAR RIs and harmonisation of the support offered to users by the RIs. In its third and fourth meetings on 16 October 2013 in Legnaro, Italy, and on 28 November 2014 at CERN, Switzerland, the functioning of PACs (and User Selection Panels) of the 7 infrastructures was presented, and a few issues were addressed, e.g.,

How to deal with new proposals (LoIs)? Referees - rankings – ENSAR support, etc.
How to deal with accepted proposals? Scheduling of beam time.
What is the policy with respect to backlogs?
What to do regarding shutdown periods at major infrastructures?
ISOLDE: December 2012 - June 2014
GANIL: short shutdowns each year from 2012 to 2014.
GSI: 6 months of beam time in 2013-2014.
Future infrastructures: ECOS & EURISOL DF

In particular, because of the shutdown periods planned at the major infrastructures of ENSAR as a consequence of upgrading the facilities or building new ones, special attention was given to ENSAR-supported experiments at the facilities. These were given higher priority, which meant that more experiments were supported by ENSAR. This is more on the average than would be expected from spreading beam-time allocation to ENSAR projects over four years. This special attention was also given to ENSAR-supported experiments after the shutdown periods.

Problems which have occurred and how they were solved or envisaged solutions;

No peculiar problem.

Changes in the consortium, if any;

No changes in the Consortium during this period.

List of project meetings, dates and venues;

Meeting	Date	Venue
General Assembly	February 13, 2015	Vienna, Austria
Project Coordination Committee	October 17, 2013	Padova, Italy
	April 11, 2014	Darmstadt, Germany
	November 28, 2014	Phone Meeting
	February 12, 2015	Vienna, Austria
Facility Coordination Group	October 16, 2013	Legnaro, Italy
	November 28, 2014	CERN, Switzerland

Project planning and status;
Adding the three instalments received since the start of the Project, ENSAR was financed at 84,94 % of the total EC request.

All deliverables and all milestones, except one, have been accomplished during this period.

The milestone that was not achieved is MS108 (Polarisation of ion beams achieved) of the work package 09 - PREMAS. This is mainly due to the construction and commissioning period of the new IGISOL-4 facility at JYU (partner n°4). This milestone remains a priority for the JYU team.

Impact of possible deviations from the planned milestones and deliverables, if any;
The unachieved milestone impacts only itself. It does not affect the other milestones and deliverables of the project.

No change to the legal status of any of the beneficiaries has occurred since the beginning of the ENSAR project.

Development of the Project website, if applicable;
The web site http://www.ensarfp7.eu/ presents information, articles, documents, etc., related to the ENSAR project. The site is hosted at GANIL (Beneficiary n°1).

Two types of material are displayed:

- material visible for general public (without user registration and authentication)
- material visible for participants of the project and representatives of the participating institutions (registration of users required and login procedure used).

An update of the Project web site has been performed in July 2012.