Executive Summary:

Experimental nuclear physics is one of the top research activities at the Ruder Boskovic Institute (RBI), the largest Croatian research centre in science and applications. The RBI nuclear physics group has strong link with the research group at the University of Zagreb (UoZ). RBI scientists perform experiments at the RBI Tandem accelerator facility and at the top EU experimental facilities in collaboration with the prominent EU research groups in the field, including partners from the Laboratori Nazionali del Sud INFN (INFN-LNS), Catania, Italy and the Nuclear Physics Group from the University of Birmingham (UoB), UK. With CLUNA we strengthened scientific relationships, the exchange of know-how and sharing of experience between RBI, UoZ, INFN-LNS and UoB partners in the research field of our common interest, focusing on the studies of nuclear molecules and other areas at the forefront of research for new phenomena in nuclear physics.

This was achieved by:

- reinforcement of RBI experimental capabilities through the upgrade of the local experimental facility;
- exchange of personnel between partner institutions, hiring and training of young staff at accelerator facilities;
- organization of workshops and short term training events, dissemination of project results to specialists and general public.

In particular, the existing nuclear physics experimental end station, including detector system, at RBI Tandem Van de Graaff accelerator was upgraded. New low-noise high-power electricity system and gas target system for use of the helium and hydrogen gas were designed and built. The upgraded silicon detector array for detection of charged particles was accompanied with the detection system for neutrons. Both detection systems were coupled together in the data acquisition system to enable simultaneous detection of neutron and charged particles. Data acquisition system was completed and commissioned. Procedures for production of new ion beams for nuclear physics experiments, including 3He, 4He, 9Be, 10,11B, and 18O, have been adopted and as a result those beams are now routinely available. Water and gas isotopically enriched in 18O required for production of the 18O beam, 4He and 3He gas for production of related isotopic ion beams were purchased to sustain future production of related ion beams. Upgraded research infrastructure for low energy measurements at RBI and complementary facility at LNS for intermediate energy measurements through this partnership contribute to the increase of research opportunities for even broader European experimental nuclear physics community.

Three outstanding graduated students were employed, now all being supported as PhD students by local funds. Extensive visits of junior and senior staff between the partners were organized to exchange know-how and to share experience. Workshop on "Inverse kinematics measurement technique for gas targets' was held in April 2010 at INFN-LNS. Two planned RBI workshops, on elastic and inelastic scattering as a toll in spectroscopic studies, and on nuclear molecules, were merged into one longer workshop, held in April 2011. Practical training at the SPIRAL facility of the GANIL laboratory was held in autumn 2010. This event provided excellent opportunity for the RBI/UoZ researchers to work in international environment at top class international laboratory, enlarging their research experience. The

new RBI detection system functioned well in complex experimental conditions applied in these trainings.

Project achievements were disseminated to international nuclear physics community through participation at conferences and seminars, and to general public by hosting high school and university students and participation at the RBI Open Days 2010. Brochure on nuclear physics/astrophysics research for general public was published, and the project web site was launched and continuously updated.

Project Context and Objectives:

The overall objective or goal of CLUNA project is to strengthen relationships, to exchange the knowhow and to share experience between Ruder Boskovic Institute (RBI), Laboratori Nazionali del Sud INFN (INFN-LNS), School of Physics and Astronomy, University of Birmingham (UoB) and Faculty of Science, University of Zagreb (UoZ) in the research of common interest. The focus is on studies of nuclear molecules and other related topics at the research forefront for new phenomena in nuclear physics.

The project particularly aims to boost scientific and technological research potential of the RBI experimental facility for common RBI-LNS-UoB-UoZ studies with low energy ion beams. This includes an upgrade and renewal of the existing nuclear physics experimental end station at RBI Tandem Van de Graaff accelerator to improve its capabilities for collaborative research in low energy nuclear physics. Important activities in realization of the objectives are the exchange of personnel between partner institutions, hiring and training of young staff at accelerator facilities and organization of workshops and short term training events.

In particular, specific objectives of CLUNA are:

Objective 1

To upgrade the existing nuclear physics experimental end station, including detector system, at the RBI Tandem Van de Graaff accelerator and production of new beams at the accelerator facility.

This includes:

a) Removal of the existing scattering chamber to the position more appropriate for new proposed experimental activities (including modelling of the ion beam optics, changes on the beam line, new collimating system, changes on vacuum system), and building of new vibration-free chamber stand.
b) Upgrade of the chamber in order to allow experiments with gas target for inverse kinematics measurements (including development and assembly of new flanges, new valves for pumping and venting operations, control of the gas flow, development and assembly of entrance window). Development of the helium gas target as well as production of new beams at the facility would enable measurements of resonant (in)elastic scattering in the inverse kinematics, a powerful method already applied worldwide and at the INFN-LNS facility. Collaboration with the INFN-LNS and UoB groups is essential, since they have large experimental experience in the field.
c) Renewal of the noise-free high power electricity system with proper grounding at the experimental end station, which will allow use of the recently acquired detector and electronics setup (with much larger number of detectors and electronic units than in the former setup) required for new experimental activities.
d) Acquisition, assembly and commissioning of several fast neutron detectors and associated electronics, including building of detector mounts, and coupling of the neutron detectors to the existing detection system for charged reaction products. This new detector system, via detection of neutrons from nuclear reactions, will make possible new research

activities for institutions involved in the proposal and will significantly increase research capabilities of the RBI facility, which are presently limited to the detection of charged reaction products. It also includes development of adequate fast neutron shielding for neutron detectors and chamber's Faraday cup.

e) Upgrade of the existing detection system for charged reaction products with new large area thin silicon detectors for detector telescopes (particle identification) and acquisition of adequate preamplifiers for these detectors. This upgrade will extend detectable energy range of charged reaction products. Upgraded detection system including neutron detectors will be compact and transportable for measurements at different experimental sites including INFN-LNS.

f) Continuous and increased usage of 3He and 4He beams, and production of new beam species of interest in nuclear cluster studies: 9Be, 10,11B and 18O. In addition to standard heavy ion beams from the EN Tandem accelerator, the 3He and 4He beams have been used in Zagreb since the commissioning of ion source for helium negative ions in 2004. Nevertheless, several improvements and upgrades of the experimental end station for nuclear reaction studies are needed to further explore usability of these beams.

g) Reinforcement of the RBI group human potential by hiring new young researcher(s) who will be involved in the upgrade and later use of experimental end station. Young researcher(s) will acquire knowledge and experience from senior researchers of all four partner institutions and will be involved in all activities of the RBI group. Strengthening of RBI group with young researcher(s) will allow more frequent and efficient use of the upgraded experimental end station. Hired young researcher(s) will start postgraduate studies during the first year of employment. Usual Croatian practice for hiring of young researchers imply that research group finds graduated student first and then apply for his/her position. It usually takes a year or even longer to employ new PhD student. Through this project we would require funds for covering young researcher expenses for period before official employment at RBI by Croatian Ministry of Science, Education and Sport (MSES). Once employed by MSES, young researcher will continue his/her employment at RBI until he/she obtains PhD degree, and possibly later as a research associate.

Objective 2

To strengthen the collaboration between RBI, UoZ, INFN-LNS and UoB through the exchange of knowledge and experience relevant to the field, leading to future common experiments and knowledge transfer at international level

This includes:

a) Exchange of knowledge and experience in the field of 'Data acquisition and front end electronics' between the UoB and RBI/UoZ staff, including training of young researcher(s) from RBI at UoB. Staff at UoB has valuable experience with electronics and data acquisition for nuclear reaction measurements, which is very important in upgrading of the RBI experimental capabilities.

b) Exchange of knowledge and experience in the field of 'Inverse kinematics measurement techniques' between the INFN-LNS, UoB, UoZ and RBI research personnel, including

knowledge transfer from the INFNLNS to RBI on production and maintaining of gas targets, and training of young researcher(s) from RBI at INFN-LNS experimental site.

c) Exchange of knowledge and experience in the field of 'Experimental techniques employed in cluster studies' between RBI, UoB, UoZ and INFN-LNS through specialized workshops and training events at RBI facility.
d) Short term specialized training of RBI researchers at one of the European top research laboratories for knowledge sharing in experimental techniques for nuclear structure studies and work of the RBI staff in an international environment with researchers from partner institutions.

Objective 3

Dissemination of knowledge and project results

This includes:

a) Participation of the RBI research staff at international conferences on nuclear structure and reactions. RBI researchers will present there their new results obtained in collaborative work with partners from INFN-LNS and UoB.
b) Some of our collaborators from other European institutions (Laboratori Nazionale di Legnaro Italy, University of Surrey UK, University of Caen France etc.) have also shown interest for experiments at RBI facility. Presentation of upgraded RBI facility and its capabilities for new experimental activities to broader European nuclear physics community through personal contacts would lead to new collaborative experiments at RBI, increasing the number of international users of the facility and will increase RBI international reputation.
c) RBI staff will work on popularization of science in general and specifically nuclear physics through presentations of upgraded nuclear physics end station to general public during the RBI 'Open Days' and lectures for general public, organization of seminars on nuclear physics at RBI. For educational purposes, the facility will be used in the nuclear physics undergraduate and graduate courses as well as for the experimental part of the BSc, MSc and PhD thesis. Staff of other partner institutions will work accordingly at their local environment.
d) Upgraded and renewed experimental end station at RBI will be presented at a new web site, as well as all other activities of RBI group and RBI-UoZ-LNS-UoB collaboration.

Ruder Boskovic Institute (RBI) is the largest Croatian research centre in science and applications. Experimental nuclear physics has been one of the top research activities at RBI from its very beginning in 1950s. Nuclear Physics group from RBI closely collaborates with the Nuclear Physics group of the Faculty of Science, University of Zagreb (UoZ). UoZ is the largest Croatian university and the oldest university in South Eastern Europe. Faculty of Science is its scientifically most productive subunit, with large Department of Physics.

INFN-LNS is one of the two accelerator laboratories for nuclear structure and reactions research in the Italian national network for Nuclear Physics research (INFN) and is one of the top Italian institutions for nuclear physics research.

Nuclear Physics Group from the University of Birmingham is one of the most active UK research groups in nuclear physics with high scientific impact.

Researchers from INFN-LNS and RBI have been working in strong collaboration for 30 years and performed many experiments at INFN-LNS, other EU experimental facilities and several experiments at the RBI accelerator facility. Collaboration between RBI and Birmingham group started in 2000 and resulted so far with more than 30 experiments at international facilities. Through this project we will strengthen partnership between these four institutions for benefits of all partners: RBI will improve its research capabilities in nuclear physics and will serve as a competitive research centre for low energy nuclear reaction studies at European level, INFN-LNS will increase number of users of its intermediate energy facilities and will increase its value as the research centre at European level, UoB will have two new sites for complementary types of nuclear reactions measurements and UoZ will have upgraded local facility for research and educational activities. Moreover, tighter partnership of these four already successful groups will form highly competitive collaboration at the international level which will propose and perform future experiments at INFN-LNS, RBI and other European accelerator facilities.

By reinforcing the existing research potential of the RBI nuclear physics end station through this project, the facility will be able to continue and extend its traditional light nuclei collisions studies and will provide services to the collaborators in a more efficient way. The realization of proposed project will also open the possibilities to offer new research activities to the WBC region and to the broader European nuclear physics community, as well as to strengthen RBI presence at the European Research Area in this specific research field.

Specific project objectives are accomplished through work packages. The first work package (WP1) groups together all project management activities, and the last one (WP7) deals with the project dissemination activities. WP2 to WP6 are technical work packages, i.e. they group together activities leading to implementation of the scientific and technical objectives.

Work package 1 (WP1):	Project Management
Work package 2 (WP2):	Improvements of experimental capabilities for nuclear structure research at RBI
Work package 3 (WP3):	Young researcher employment and education
Work package 4 (WP4):	Data acquisition system and front-end electronics
Work package 5 (WP5):	Measurement techniques for inverse kinematics reactions
Work package 6 (WP6):	Experimental techniques in nuclear cluster studies
Work package 7 (WP7):	Public awareness and dissemination of project results

Activities related to the specific objective 1, upgrading the research capacities of the RBI, are within work packages WP2 and WP3. Activities related to the specific objective 2, further development of partnership between RBI/UoZ, INFN LNS and UoB, are under work packages WP4, WP5 and WP6. Most activities related to realization of the specific objective 3, dissemination of knowledge and project results, and promotional activities against general public and European nuclear physics community, are within WP7 (with some activities in WP4, WP5 and WP6).

Project Results:

Main S&T project results/foreground are presented for each technical work package (WP2 to WP6).

Work package 2 (WP2): Improvements of experimental capabilities for nuclear structure research at RBI

The objectives of WP2 are:

1) to upgrade and renew the existing nuclear physics experimental end station at the RBI Tandem accelerator for nuclear physics measurements in order to increase its experimental capabilities;
2) to increase the performance of existing detection system at the RBI nuclear measurement end station in order to increase its usability for nuclear structure and reaction studies; and
3) to assure long term delivery of 3He and 4He beams and to make available new ion beams at the Tandem facility.

The old experimental end station had limited capabilities for nuclear structure and reactions studies, but was already in use for some simpler collaborative research activities, primarily in collaboration with the INFN-LNS research group. Part of work on its upgrade, including acquisition of new detector system for charged particle detection, started several years before the CLUNA beginning. Yearly available local funding was very limited, but during the years large part of required equipment was collected. The CLUNA funds were used to finalize and commission the experimental setup.

Implementation tasks started according to the Action Plan adopted at the beginning of the project. All the planned activities were implemented. As a result, the upgraded experimental end station is now available for regular use. Detailed explanation of results follows.

New vibration-free stand for the measurement chamber was designed. Sub-contractor for its building was found in concordance with national regulations and the stand was built. The existing scattering chamber was then moved to the new position on the stand. Ion beam optics was calculated and setup of new experimental beam line was optimized. This work was performed during the first project year. The other important step was to build new low-noise high-power electricity system.

New low-noise high-power electricity system

New low-noise high-power electricity system was designed and built at the new chamber position. The experimental end station requires electricity for normal operation: vacuum elements like mechanical and turbo-molecular pumps or mechanical elements of the scattering chamber like lid opener use electricity. Additionally, all kind of detectors, including different types of silicon detectors for charged particles, and all electronic units for signal processing from detectors, require electricity (as example for bias voltage) for their operation. Particular care should be paid to electricity source for detectors and associated electronics,

because electric signals from the detectors are very small (in the milivolt range) and could be disturbed by electronic noise from various sources. To reduce a noise and increase performance of the detectors and associated electronics chain (preamplifier, spectroscopic and timing amplifiers, logic units, analog-to-digital converter), their electricity source has to be well isolated from all other power systems and properly grounded. Initial power system used at the experimental end station was not properly separated from the rest of the building electricity system and its power was enough only for up to ten electronics chains. This is adequate for the old small silicon detector system used at the experimental end station before, but is not enough powerful for the new silicon detector array composed of large number of silicon strip detectors. For this reason, a new low-noise high-power electricity system was designed and built at the experimental end station. In the first year of the CLUNA project experimental end station was moved to the new, more appropriate position for the new experimental activities. So, the work on the new power system was performed during this movement of the end station. Actually, the work on this task started before the start of the CLUNA project due to its importance for our experimental program. Significant part of the equipment for this task (15 kW transformer, cables, small electrical equipment and materials) was acquired before the CLUNA start and these costs were covered by our national grant. The most of the work was performed in the first months of the CLUNA project and the work costs of the RBI employees were covered by the CLUNA project funds. The new system has enough power (15kW) for use of detector system with 250 signals and associated 250 electronic chains. Its noise level is reduced to the lowest possible. The setup was tested twice using our new detection system, and the system is now in full operation.

Gas target system at the experimental end station

Initially, the RBI experimental end station was suitable for experiments with thin foils as target only. Introduction of the gas target measurements, particularly suitable for low energy beams provided by the RBI Tandem Van de Graaff accelerator, presents a large increase of experimental capabilities of the facility and opens the new research topics on nuclear structure and nuclear astrophysics research at RBI. Of particular interest are hydrogen (proton and deuteron) and helium targets. Main experimental technique with gas targets is resonant scattering in inverse kinematics regime, when heavy beam particle is scattered off the light target particle detected in the measurement.

Originally, in the project proposal only helium gas target was considered. The work on the design, purchase of required hardware, and on building of the gas target system was finalized during the first year of the project. New valve was mounted on the scattering chamber for gas inflow. The scattering chamber was isolated from the vacuum in the beam lines with entrance window which was designed, manufactured and tested. Various designs of the window, the range of the window size and thickness as well as various materials for the window were tested before the final setup was accepted and commissioned. For low intensity ion beam measurements Mylar window is behaving well and it is preferred material due to very low cost. However, measurements with high intensity ion beam require much stronger, but also very expensive, HAVAR window. Introduction of the entrance window required replacement of the existing collimator system with the new one. Beam optics for the new collimator was calculated, and collimator was designed and manufactured.

During the work on this task, the RBI group developed new research program on nuclear astrophysics and started new research project managed by European Science Foundation under the EuroGENESIS program (part of the Eurocores program) funded by Croatian National Foundation for Science and High Education (Nacionalna Zaklada za znanost i visoko obrazovanje - NZZ). It came out that for nuclear astrophysics studies hydrogen gas target would be highly desirable. Also for nuclear structure studies, our main research topic, hydrogen gas target (in the first instance deuterium gas) would be very useful. The essential difference between helium and hydrogen target is that hydrogen is flammable, which requires additional security measures in handling gas. We found out that simple changes on the gas target system and small additional investment could enable the use of hydrogen gas in the target system. We therefore redesigned the gas target system. New pumping system for gas outflow was purchased and installed. All required work was performed by the end of July 2009, with a small delay compared to the original planning.

Unfortunately, during September 2009 the main vacuum pump in the target room of the Tandem accelerator facility broke. This pump was providing vacuum for all experimental lines of the facility. Spare pump was not available, as well as funds for the new large vacuum pump. That accident resulted with the tandem accelerator facility out of use for some time. The RBI Laboratory for Ion Beam Interactions (LIBI), the main user of the accelerator facility, managed to get funds for couple of small turbo-molecular pumps for the most critical experimental lines, but nuclear physics experimental end station remained out of use. The large cost for new vacuum system was not planned in the CLUNA project. In late November 2009 the Laboratory for Nuclear Physics got approved national funding for new turbo-molecular and mechanical pumps to be installed at the nuclear physics experimental end station. Installation of this new vacuum system also required replacement of the beam pipes in front of the scattering chamber. The pumps were purchased, beam pipes redesigned and replaced, and new vacuum system was installed and commissioned finally in March 2010. Clearly, additional funds, time and work were required to get nuclear physics experimental end station back in operation. Only small part of hardware costs, mainly on beam lines, was covered by the CLUNA project and some part of work costs of the RBI employees was covered by the project funds. This pump accident created some delays in realization of this task. However, the gas target system was finally tested in real experimental conditions in March and May 2010 and it is now in full operation.

Silicon detector array

Essential step in increasing research capabilities and capacities of the RBI facility in nuclear structure and reaction studies was completion and commissioning of the detection system for charged particles. Core of the detector system was acquired before the start of the CLUNA project: five large area thick (500 μm) position sensitive strip detectors and four large area thin (50 μm) quadrant detectors, as well as preamplifiers, amplifiers, analog-to-digital converters (ADC) and most of other electronics for 160 signal channels.

One of the CLUNA project goals was enlargement of the silicon detector pool with thinner and thicker large area strip detectors and increased number of electronics units required for full utilization of the detector array. The first step in this task was decision on type of the new silicon detector. After extensive discussion with partners from the University of Birmingham

and INFN-LNS, it was decided to purchase four 20 µm thin silicon strip detectors and two 1000 µm thick position sensitive strip detectors. Purchase procedure started in October 2008. Detector manufacturer, Micron Semiconductor Ltd. UK, had problems with production of the thin detectors and detectors were finally delivered in July 2009. Shortly after that, purchase of the preamplifiers adequate for the thin detectors as well as cabling from detectors to amplifiers was realized. Also, detector mounts were designed and manufactured by the autumn 2009.

Due to the pump accident in summer 2009 (as described above) we tested detectors using alpha source only by the end of 2009. At that time it was not possible to use ion beam in the RBI nuclear physics experimental end station. After the commissioning of the new pumping system, when the experimental end station returned back to normal operation, we tested upgraded detector systems with ion beams. The system was commissioned in April 2010 and it is in regular use.

Neutron detector array

For further enlargement of the RBI experimental facility capabilities and capacities for low energy nuclear physics research, commissioned large silicon detector array for detection of charged particles was accompanied with new detection system for neutrons. Neutrons, neutral particles building atomic nucleus, are reaction products in many processes important in nuclear physics and nuclear astrophysics. Availability of the neutron detection system makes possible a new sort of experiments designed to study these processes at the RBI accelerator facility and other facilities in Europe at which we regularly perform experiments.

Works on tasks related to neutron detector array were delayed regarding to original work plan due to delay on commissioning of the silicon detector array and the data acquisition system. The reason for this delay was the above mentioned hardware failure at the RBI Tandem Van de Graaff accelerator facility, which put our experimental end station out of use for six months. Work on acquisition of the neutron detectors started in the second half of 2009. Detailed study on available neutron detectors on the market was performed. Extensive discussions within the project partners and our collaborators from other institutions with experience on neutron detection (we appreciate great contribution from our collaborators from the GANIL and LPC Caen France) was taken for decision on the detection system properties most suitable for our research activities.

Our middle term research plan focus on the studies of structure of neutron-rich light nuclei and on nuclear reactions between proton-rich light-heavy nuclei important for understanding of nucleosynthesis and energy production in explosive stellar phenomena like novae, x-ray bursts, supernovae and super-bursts. This research plan includes measurements of the nuclear reactions in which neutrons with energy between 1 and 10 MeV are produced in relatively small solid angle in laboratory frame. Accordingly, it was concluded that smaller number of large volume detectors with liquid scintillator of one particular type developed for discrimination of fast neutrons from gamma-ray background has the best performance for requirements of our research.

We collected quotations from manufacturers of this type of the detectors and purchased six detectors based on the liquid scintillator EJ-309 manufactured by SCIONIX Holland BV,

which gave us the best offer. The detectors were assembled from liquid scintillator container filled up with the scintillator, photomultiplier and the base. The next step in setting up the neutron detection system was work on the design and manufacturing of detector mounts and passive neutron shielding around detectors and beam dump on the experimental end station. This shielding should suppress detection of neutrons from background, both from natural sources and induced by beam on the elements of the experimental end station. It came out that for the beam dump shielding the best choice are paraffin blocks already existing at RBI and used for shielding at the neutron generator facility run by our Laboratory. These blocks can be arranged around the experimental end station in a way which minimizes background for this particular experiment for every measurement when we use neutron detectors, and are removed away when we don't use neutron detector array. By doing so, we keep more available space around the end station, what gives us more freedom in designing detection setup for various experiments.

For the neutron detector shielding we decided to use plastics rich in hydrogen (it slows down neutrons in the most efficient way) and mixed with boron (isotope 10B has very large probability for slow neutron capture). The chosen material was polyethylene, and as boron material we used borax. Different proportions of polyethylene resin and grains were mixed with borax until we found recipe for material with good mechanical properties and satisfactory neutron absorption. In the production and testing of the material we had assistance from a Croatian SME which manufactured shielding and stands for the neutron detectors. Each detector has its own stand allowing flexibility in experimental setup.

Signals from the neutron detectors are processed by electronics chain which produces logic signals sent to QDC (Charge to Digital Converter) unit in Data Acquisition System (DAQ). The DAQ records all events for which trigger signal exist. Therefore logic signals from the neutron detector electronics have been coupled into the trigger of the existing DAQ for silicon detector array. In such a way simultaneous detection of neutron in neutron detector array and charged particle in silicon detector array is possible. These logic signals are used for later offline separation of neutron events from background gamma-radiation, and together with logic signal from the silicon detector array, for time-of-flight measurement, which determines the detected neutron energy. Tests of the neutron detector setup were performed using neutron source and neutrons from the RBI neutron generator facility. The neutron detector setup is now working properly and it is ready for use in experiments.

Work performed on DAQ setting and achieved results

Very important step in increasing research capabilities and capacities of the RBI facility for nuclear structure and reaction studies was completion and commissioning of the detection system for measurements of nuclear reaction products. In the measurements, analog electric signals from various detectors produced by detected reaction products are processed in electronics. The electronics role is double-fold:

1) to produce amplified and reshaped useful electric signals,
2) to produce logic signals related to detected particles which are required for selection of interesting events from background and other non-relevant events.

These logic signals are processed in various logic electronic units resulting in trigger signal which signalize detection of physically relevant events. Such selection mechanism has to be fast and efficient due to high counting rate of the detection system required to collect significant statistics of interesting events. Obviously, trigger cannot (or can in only very limited number of cases) provide clear online separation of all physically interesting events from background and non-relevant physics, so its main role is to significantly reduce all background/unwanted processes and enable further processing of reduced volume of data. Such accepted signals are then converted to digital values in Analog-to-Digital Converters (ADC) activated by trigger signal. These data are recorded on event by event basis for later offline analysis and extraction of results.

Part of electronics system performing reduction of events, conversion of data to digital form and recording of data is called Data Acquisition system (DAQ). As was the case with other parts of the detection system for measurements of nuclear reactions, core of the DAQ was acquired before start of the CLUNA project: many logic electronics units, VME crate, 6 analog-to-digital converter (ADC) units with 32 channels each, VME processor and ADC control unit. This core makes possible building of the DAQ for processing of 192 signals from the detectors using DAQ software MIDAS (http://npg.dl.ac.uk/MIDAS/) developed at the Daresbury Laboratory in UK.

One of the CLUNA project goals was finalizing and commissioning of the DAQ. The MIDAS software communicates with the VME processor, uploads the operating system into the VME processor, enables settings of the various units in the DAQ and receives and records data from the DAQ to the computer hard disc. Software was originally written for Sun operating system Solaris running on the Sun computers built on SPARC architecture. It was recently modified to work on Solaris operating system on computers with Intel and AMD architecture. There are also versions of MIDAS for other operating systems, like Linux and Microsoft Windows, but the most reliable and highest performance version is still built for Solaris operating system. The University of Birmingham group members have vast experience in running older versions of MIDAS on Solaris SPARC computers connected to VME DAQ systems and their experience and knowledge have been of the prime importance for setting up the DAQ system at RBI. Their support was realized through work package 4.

It was decided to build DAQ on Solaris operating system due to its favourable performance and experience of the Birmingham group. Detailed study of the available hardware options and requirements on computer set by our detection system showed that the best value for money provide Sun server computers built on AMD architecture. The server Sun Fire X4100 M2, computer in the middle class of Sun servers on the market in Croatia, running on the latest version of Solaris operating system, was purchased using national funding. Solaris was reconfigured for the use as DAQ server and the latest version of the MIDAS software for INTEL/AMD architecture was installed and configured.

Intensive testing of all DAQ electronics units, as well as the MIDAS, was performed using pulse generator in the first stage. Next step was testing of the DAQ system in real experimental conditions at our experimental end station at the RBI accelerator facility. The first test was performed with just one position sensitive strip detector giving 32 detector signals for the DAQ. Later test included two full detector telescopes (thin quadrant silicon detector and position sensitive strip detector in each telescope) providing 72 detector signals for analysis. The DAQ system was successfully running in both cases. Setting up of the DAQ

system and part of its testing were performed with the help of the experienced researchers from the University of Birmingham who visited Zagreb for this purpose.

The final and full test of complete detection system, including silicon detector array, electronics and DAQ, was performed during the workshop held at INFN-LNS Catania in April 2010. Test was done using large detector array with six detector telescopes giving 288 detector signals into the electronics and the DAQ system. The research equipment of our partners from INFN-LNS and University of Birmingham was used together with our equipment. Beam from the Tandem accelerator of the INFN-LNS was used in the test. In this test very complex experimental setup and conditions were applied. The all the components of the detection system were running smoothly, providing final evidence for successful commission of the detection system.

New detection system at RBI, which includes silicon detector array, electronics for detector signal processing and data acquisition system is compact and transportable, so it can be used for research not only at the local RBI experimental facility, but also at the INFN-LNS accelerator centre and other accelerator laboratories worldwide. Detection system is fully compatible with research equipment of our partners from University of Birmingham and INFN-LNS. This compatibility makes possible building and using very large and complex detection systems for our collaborative research activities using equipment of all the three partners. This detection system is also available for use at other workshops at RBI and training at major European accelerator laboratory.

Production of ion beams

Work on production of new ion beams at the RBI Tandem accelerator started according to the plan. The production procedure for the 18O beam was developed during the first project year. Commissioning of the first 18O ion beam was successfully performed in April 2009 and it is now available for regular use. We purchased more material (water and gas) isotopically enriched in 18O required for production of the 18O beam for future research at the RBI accelerator facility.

Head of the accelerator facility technical team Mr. Natko Skukan, who is responsible for the ion beam production, visited INFN-LNS in between 9th and 19th July 2008 for training to acquire knowledge on 9Be and 10,11B ion beam production methods.

Based on the knowledge acquired during that visit, technical staff of the RBI Tandem Accelerator Facility tested various materials containing 10,11B isotopes in search for the most efficient production procedure. As a result, 10,11B ion beams were successfully injected through the EN Tandem Accelerator during the second project year and are available for regular use. During the same year testing with 9Be ion beams was performed. Tests with various materials containing beryllium were performed. The best results were achieved using beryllium oxide, but also beryllium hydride provided good quality beam. As a result the 9Be ion beams are now routinely available for experiments.

In order to maintain possibilities for delivery of these ion beams for future research at the RBI accelerator facility, the necessary material was purchased. This includes water and gas

isotopically enriched in 18O required for production of the 18O beam, 4He and 3He gas for production of related isotopic ion beams.

The production of the 14C beam has been postponed for future. The reason for this decision is related to the possible future use of the EN Tandem Accelerator as Accelerator Mass Spectrometer (AMS). This is currently the most sensitive method for radiocarbon dating and there is at the moment an interest at the RBI to introduce this technique at the EN Tandem Accelerator. Since radiocarbon dating is based on the use of 14C ion beams, its parallel use for nuclear physics experiments could result with unreliable radiocarbon dating measurements.

To summarize, all the tasks associated with WP2 were successfully completed. As a result, the experimental end station is fully upgraded according to the project description of work, with some additional improvements which required small additional investment. Upgrade and renewal of the existing nuclear physics experimental end station increased its experimental capabilities. The RBI detection system is enlarged with the large silicon detector array for charged particles detection, neutron detector array, associate front-end electronics and data acquisition system. The system is fully operable and in usage for nuclear structure and reaction studies as well as for research in nuclear astrophysics. Availability of helium beams for future research have been secured and new ion beams of 9Be, 10,11B, 13C and 18O are available for experiments at the RBI Tandem accelerator facility.

The upgraded end station has been already used for two measurements performed in collaboration with researchers from University of Birmingham and INFN-LNS. The first publication from these measurements has been recently published in Physical Review C (M. Freer et al, Phys. Rev. C 84 (2011) 034317), one of the major journals in nuclear physics. New detection system at RBI is compact and transportable. It can be used for research not only at the local RBI experimental facility, but also at the INFN-LNS accelerator centre and other accelerator laboratories worldwide. The detection system is fully compatible with research equipment of our partners from University of Birmingham and INFN-LNS. This compatibility makes possible building and usage of very large and complex detection system for our collaborative research activities using equipment of all three partners. Successful realization of WP2 largely increased research potential not only of the RBI research group, but also for collaborative research performed by all four partners of the CLUNA project.

During the first project year the described work was performed by the RBI staff with the assistance of UoZ staff and staff efforts were approximately 7.25 person-months (RBI 7p/m, UoZ 0.25 p/m), which is in accordance with the activity plan for the first year. The costs of this workpackage included payment for the permanent staff work (EUR 7 563.05), travel costs of N. Skukan to INFN-LNS (EUR 1 166.51), subcontracting work for scattering chamber stand building (EUR 2 693.46), equipment costs (EUR 1 294.93) and costs of materials for experimental end station upgrade (EUR 1 434.90).

During the second year the work was performed by the RBI staff with the assistance of UoZ staff and staff efforts were approximately 9.75 person-months (RBI 9.5 p/m, UoZ 0.25 p/m). The costs of this workpackage included payment for the permanent staff work (EUR 15 565.69), equipment costs of EUR 46 258.36 (includes silicon strip detectors, preamplifiers, cabling system for silicon strip detectors, vacuum pump for gas target and digital oscilloscope required for setting of the detectors and electronics) and material costs of EUR 7 799.98

(includes hydrogen and 4He gas, various small mechanical parts for the experimental end station, valves and vacuum-meter for the gas target, foils for chamber entrance window for the gas target, adapters and connectors for signal cables between electronics units which process signals from the detectors). Total cost for RBI of this work package in the second project year was EUR 69 624.03.

The work performed during the last project period was realized by the RBI staff, with the assistance of the UoZ staff, and using the expertise of researchers from University of Birmingham, INFN-LNS, LPC Caen and GANIL Caen France. Staff efforts in total were 6.75 person-months (RBI 6.25 p-m, UoZ 0.5 p-m). Total staff efforts during the project in WP2 are larger than expected for some 30%. This additional effort, required for successful realization of the project, was taken by the RBI staff. Related costs of this work package included payment for work of permanent staff (EUR 21 490), equipment costs of EUR 60 050 (includes neutron detectors, multichannel amplifiers and logic electronics units required for DAQ) and material costs of EUR 31 252 (includes 18O enriched water and gas for the 18O ion beam production, thin HAVAR foils for gas target window (approx. EUR 11 000), 3He gas for the 3He ion beam production (5 litres at price of approx. EUR 12 400), various small mechanical parts for the experimental end station, aluminium box for detection system shipment, adapters, connectors and cables for signal cables between electronics units which process signals from the detectors, stands and passive shielding for the neutron detectors). The cost for work of the RBI permanent staff is somewhat larger than expected, due to required enlarged staff efforts for successful finalization of the project. Costs for materials are 2.5 times larger than expected due to large increase of 3He price on the world market in last 3 years and due to the need for very thin HAVAR foils for the gas target window, which costs much more than thin Mylar foils supposed for the window in the project proposal. These extra-costs are covered by funds saved in travelling, as it came out that project objectives can be achieved with smaller travel funding than planned at the beginning, and management (there was no need for audit as the project funding is less than EUR 375 000). Total cost for RBI of this work package in the last project period was EUR 112 783.

Total cost of this work package was EUR 196 560, 25% more than originally planned.

Work package 3 (WP3): Young researcher employment and education

The objective of WP3 was to strengthen the RBI group human potential for project activities and research. This objective was realized through employment of young researchers and their education for work on CLUNA project and on nuclear physics research.

Activities started in May 2008. The standard procedure for employment of research PhD student at the RBI was followed. Public call for open position was published in the Official Gazzette of the Republic of Croatia 'Narodne novine' (http://www.nn.hr/sluzbenilist/oglasni/index.asp) no. 71, daily newspapers 'Vjesnik' (http://www.vjesnik.hr) on June 20th 2008 and on the RBI official web page (http://www.irb.hr). Requirements for the position were: BSc degree in physics, preference for experimental work in nuclear physics, final average mark at graduated studies greater than 4.0 (out of maximal grade of 5.0), candidate should be fluent in English and have affinity for team work in international environment. Duties of the new employee included engagement in all activities of the CLUNA project,

particularly in work on renewal and update of the experimental end station at the RBI accelerator facility and associated detector setup, including acquiring of knowledge and experience required for experimental research work in nuclear physics.

We followed the idea to enrol young researcher in postgraduate studies in nuclear physics during the first year of employment. In addition, in order to sustain employment for a period after CLUNA, in parallel with the employment, a PhD student position at RBI would be asked for young researcher from Croatian Ministry of Science, Education and Sport (MSES). In case of MSES approval before the end of the project, another young researcher would be employed, with parallel support request from MSES. Strengthening of RBI group with young researcher would allow more frequent and efficient use of the upgraded experimental end station.

At the beginning of the project implementation we found two outstanding graduated students for this position. On 1st July 2008 Ms. Iva Bozicevic was employed. She graduated physics at University of Zagreb in spring 2008. She was employed on CLUNA project until 31st December 2008. From1st of January 2009 funding for her position was secured by MSES in the LIBI research group at the RBI accelerator facilities, also involved in the CLUNA project.

Therefore, another graduated student, Mr. Lovro Propolec, was employed on 2nd February 2009. In early 2010, coordinator of the CLUNA project re-applied to MSES for PhD student position for Lovro (the first application in 2009 was not approved due to very limited number of positions). Application was approved in late 2010 and Lovro has been employed by MSES on six years PhD student contract, starting from the December 9th 2010.

Lovro significantly contributed to the work on all the tasks of the experimental end station upgrade, work on setting up the data acquisition system and testing of acquired silicon detectors and associated electronics. He was educated and trained by senior RBI and UoZ researchers involved in the CLUNA project on experimental techniques and methods in nuclear structure research, settings and use of silicon detectors and electronics and data analysis. INFN-LNS and UoB researchers transferred their knowledge and experience to him during visits at RBI, during Lovro visits to INFN-LNS and UoB, and on CLUNA workshops and practical training event.

Lovro attended international conference 'Nuclear Structure and Dynamics 09' (conference web page is http://www.phy.hr/~dubrovnik09/) which CLUNA researchers from RBI/UoZ coorganized (Matko Milin from UoZ was Scientific Secretary, Suzana Szilner from RBI was cochair, Neven Soic of RBI was member of Local Organizing Committee) in Dubrovnik on May 3rd to 9th 2009. Conference was attended by large number of world class researchers who gave presentations of their contemplate research results. This was excellent opportunity for young researcher to learn about state-of-the-art research in nuclear physics from world experts.

Lovro also attended summer school on nuclear physics by European Summer University 'The secrets of the atomic nucleus' in Strasbourg France from June 28th to July 4th 2009 (the school web page is http://esc.u-strasbg.fr/2009/). Summer school was organized with 12 lectures given by world experts in the field, 2 round tables and 3 practical student workshops. Lovro attended practical training on detection of neutrons which was particularly useful in setting up neutron detector array at RBI (WP2).

He attended short training on beam and target production at INFN-LNS accelerator facility (March 15 - 18, 2009), practical training on the use and setting up of the silicon detector array and all associate electronics from preamplifiers to DAQ (April 7th - 12th), and another training on calibration of position sensitive silicon strip detectors and analysis of data collected with such detectors (April 24th - May 2nd). He also attended the workshop held at INFN-LNS from April 13 - 23 2010. More details about the workshop are given in section on WP5. The short practical trainings with equipment were particularly useful for Lovro to increase his level of knowledge and experience and enable higher level of knowledge transfer at the INFN-LNS workshop.

In autumn 2009 Lovro started PhD study of nuclear physics at the University of Zagreb. Duration of PhD study is three years.

Lovro visited University of Birmingham between 31st May - 5th June 2010, where he attended training on DAQ and front-end electronics for silicon detectors, given by Birmingham nuclear physics group researchers. This training largely improved his knowledge on DAQ system and its setup. This visit enabled him to take position of responsible person for DAQ system at RBI nuclear physics research group.

In summer 2010 (31st July - 8th August) he attended Ninth Summer School on Exotic Beam Physics held at Oak Ridge National Laboratory USA. Subject of the school was experimental work with radioactive ion beams and associated theoretical approaches. Apart from morning lectures given by world experts in the field, the school included afternoon sessions with the hands-on activities in the laboratory of a radioactive ion beam facility where students learnt about the techniques and instrumentation needed to carry out experiments with unstable ion beams. These activities took place at the Holified Radioactive Ion Beam Facility at ORNL. Subject of some lectures and practical activities were on nuclear astrophysics, research topic which our group started recently.

Lovro also attended intensive practical training on various aspects of experimental work with radioactive beams at the SPIRAL facility of GANIL in Caen France, organized and realized as part of the CLUNA project. This training event was organized at one of the world top research laboratories for nuclear physics research and one of very few facilities in the world providing re-accelerated unstable beams, and provided excellent opportunity to acquire experience and skills for work in international environment. The training included preparation of experimental end station for the measurements, setting up of very complex and large silicon detector array, associated electronics and DAQ. The training included measurements with the 6He beam, during which experienced senior researchers educated Lovro and other younger and inexperienced researchers on experimental methods and techniques needed for research work with unstable ion beams. Courses on analysis of the data collected in the measurements were given just before the end of the training event.

Lovro was involved in all activities on the CLUNA workshop organized at the RBI in April 2011. This workshop was another opportunity for knowledge and experience transfer on experimental methods and techniques for study of cluster structure in light nuclei. Workshop included hands-on experience on instrumentation for measurements with stable beams, on operation of accelerator facility and on data analysis.

Lovro has shown excellent progress and his skills and abilities are valuable for the RBI research group. Already after the first year of his employment, he was able to prepare and run simpler measurements independently and up to now he has collected enough knowledge and experience to contribute significantly in complex measurements using large detector arrays. He is excellent team worker in international collaborations.

The third employed PhD student was Ms. Tea Mijatovic, who graduated in July 2009 and was employed on CLUNA from 25th October 2010 until the project end (31st July 2011). Tea was involved in work on neutron detector array setup and testing as well as on all activities at the local accelerator facility, including workshop organized at the facility in April 2011. Tea attended school with practical training on measurements of gamma-radiation in coincidence with the charged particles in silicon detectors and magnetic spectrometers at the INFN - Laboratori Nazionali di Legnaro from 9th to 13th November 2010, given by senior researchers involved in experiments at the INFN-LNL facilities. Tea started her postgraduate studies of nuclear physics at University of Zagreb in academic year 2010/11. Tea is hardworking person showing a lot of enthusiasm for experimental research work. As her work performances were excellent, senior researcher from our research group applied for MSES PhD student position for her, which was approved just before the end of the CLUNA project.

Another young researcher in our group, Ms. D. Jelavic Malenica, employed on PhD student position funded by MSES from August 2007, also attended practical training event at INFN-LNS from 9th to 21st July 2008, workshop at INFN-LNS from 15th to 22nd April 2010 and workshop organized at RBI in April 2011.

In conclusion, the objectives of WP3, strengthening of the RBI research group human potential with young researchers and more efficient realization of other project objectives, were realized with great success. During the course of the CLUNA project three outstanding graduated students were employed. They were nicely incorporated into the RBI research groups involved in CLUNA. They are all now employed as PhD students on national research grants supported by the Ministry of Science, Education and Sport (MSES)) and will earn PhD degree before the end of their contracts.

During the first project year, CLUNA funding for young researcher position was exploited for 9 months. Funding was not used for two months at the beginning of the project during the settling of the project and due to time required for the standard employment procedure. One month was required for the second employment, causing gap between two employed young researchers. Cost of this position in the first year was EUR 11 755.52.

Young researcher position was filled during all the second project year (12 person-months). RBI senior staff efforts in training and knowledge transfer activities is estimated to 8 person-months (not included in the CLUNA staff efforts as is considered as regular work duty). Cost of the young researcher position (salary and other payments) in the second project year was EUR 14 289.99. Travel expenses for all training and knowledge transfer events were EUR 4 279.53. Total cost for RBI was EUR 18 569.52.

Staff efforts of the employed young researchers in the last project period were 20.5 person-months. This is more than planned due to the three months extension of the project and overlap in the employment time of Tea and Lovro. RBI senior staff efforts in training and knowledge transfer activities is estimated to 10 person-months (not included in the CLUNA

staff efforts as is considered as regular work duty). Costs of the young researcher position (salary and costs of postgraduate study at University of Zagreb) in the last project period were EUR 22 889. These costs are larger than expected due to larger costs for salary for extension period. Travel expenses for all training and knowledge transfer events were EUR 5 092. Total cost for RBI was EUR 27 981.

Total cost of WP3 in the project was EUR 58 306, 16% more than planned.

Work package 4 (WP4): Data acquisition system and front-end electronics

The objectives of WP4 were:

1) to strengthen the collaboration between UoB and RBI/UoZ research groups;
2) to exchange knowledge and experience on data acquisition and electronics for nuclear reaction measurements between UoB, RBI and UoZ researchers; and
3) to help realization of WP2 and WP3. In particular, for WP2 objectives, support is needed in assembly, testing and commissioning of VME data acquisition system and in coupling of the existing detection system for charged nuclear reaction products with a new one for the fast neutron detection and for WP3 is related to education of young researchers.

It was planned for the 1st year to realize 40 person-days of staff exchange between Zagreb and Birmingham, equally shared between UoB and RBI/UoZ researchers. These visits were not realized because researchers from these two groups met in months just before the CLUNA start and in the first project year in four occasions: for three experiments at international accelerator facilities and at the international conference on nuclear structure and reactions our group co-organized in Dubrovnik Croatia. During these occasions all aspects relevant to CLUNA were discussed, so there was no need for additional visits.

During the second year, three visits of UoB researchers to RBI were realized (17 person/days in total). Martin Freer, head of the UoB research group and WP4 work package leader, visited RBI between November 2nd and 4th 2009. Victor Ziman, DAQ and software expert of the UoB group, visited RBI twice: from September 29th to October 3rd 2009 and between October 27th - November 4th 2009. During these visits they helped RBI researchers in building local DAQ system by transferring their knowledge on hardware and software aspects of DAQ.

Exchange of knowledge and experience was realized by visits of Lovro Prepolec, Milivoj Uroic and Neven Soic to University of Birmingham, from May 31st to June 6th 2010 (21 person-days), and visit of Neven Soic from 24th to 28th January 2011 (5 p-d). Subject under discussion was setup of neutron detector array, development of neutron shielding material, realization of neutron detectors trigger signal and its implementation into DAQ.

RBI/UoZ and UoB researchers also met several times for experiments at European accelerator laboratories. At these occasions discussions were held and knowledge and experience transferred on topics crucial for realization of the CLUNA project. In helping to set up DAQ system at RBI, UoB staff also upgraded and tested their local DAQ system. They also tested

all RBI electronics units at their local DAQ, before RBI DAQ was commissioned. Details of the performed work are given in the section on setting DAQ (part of WP2).

All WP4 objectives were achieved. Collaboration between UoB and Zagreb group has been enhanced. RBI research staff acquired knowledge and experience required for setup of electronics and DAQ system. Coupling of neutron detector array and silicon detector array into common DAQ setup was successfully realized. It came out that for full realization of the project objectives we needed less exchange visits than planned, because RBI and UoB researchers met regularly for experiments and these occasions were used also for CLUNA activities. For this reason, realized staff efforts and accordingly expenses, were smaller than expected.

While during the first project year we did not have major activities under this WP, during the second year, staff efforts in realization of the WP4 were 1.9 person-month for UoB staff and 1.5 person-month for RBI staff. Cost of the WP4 was only for travelling from Birmingham to Zagreb for UoB in amount of EUR 2 340.25.

During the last project period staff efforts in realization of the WP4 were 0.75 person-month for UoB staff and 1.25 person-month for RBI researchers. Costs of the WP4 were for travelling from Zagreb to Birmingham in amount of EUR 4 371.

Total cost of WP4 during the project was EUR 6 711.25, some 30% of the planned funding.

Work package 5 (WP5): Measurement techniques for inverse kinematics reactions

Objectives of WP5 were:

1) to strengthen the collaboration between INFN-LNS and RBI/UoZ research groups;
2) to exchange knowledge and experience on measurement techniques for inverse kinematics reactions using gas target, and on design and assembly of gas targets between research staff from INFN-LNS and RBI/UoZ; and
3) to help realization of WP2 and WP3 (education of young researcher).

During the 1st project year it was planned to realize 40 person-days visits in total, equally shared between INFN-LNS and Croatian staff, as well as one short-term training of the RBI young researcher at the INFN-LNS experimental facility. Realization of the visits was a bit different: RBI staff spent 43 person-days at LNS-INFN and two trainings of young RBI researchers were performed (26 person-days in total). Reason for that is high level of occupation of INFN-LNS staff at their local accelerator facilities with research and development of new projects, causing their inability to travel.

Senior researchers from RBI travelling to Catania for knowledge and experience exchange were N. Soic (16-21 July 2008, 7-21 February 2009) and M. Uroic (11-21 July 2008, 7-21 February 2009). During these visits all relevant aspects of upgrade of the RBI experimental end station were discussed with INFN-LNS researchers. Also tests of INFN-LNS newly acquired research equipment were performed what helped RBI staff on decision which silicon strip detectors and electronics units will be purchased using CLUNA funding.

Concerning training and education of the young researchers, Mr. Lovro Prepolec spent 14 days (7-21 February 2009) at the INFN-LNS. Part of his training included practical work with nuclear instrumentation, silicon strip detectors and associated electronics. Another young researcher in our group, Ms. D. Jelavic, employed on position funded by MSES, participated on similar training at LNS-INFN from 9-21 July 2008.

During the second project year INFN-LNS staff visited RBI four times, 58 person-days in total. Pierpaolo Figuera, WP5 work package leader, visited RBI twice: from June 15th to 24th 2009 and between November 4th - 11th 2009. During these visits he helped RBI researchers with his knowledge and experience on building and use of gas target system, assembly and running of silicon detector array and front-end electronics for silicon detectors. Domenico Torresi, who possesses excellent computing and software skills, visited RBI also twice: between October 13th and November 1st 2009 and from 11th to 30th January 2010. His contribution to the realization of the work package activities was on performing measurements with the gas target system, analysis of the data collected using gas targets and silicon strip detectors, and on software tools for data analysis.

The main event in WP5 was a workshop with extensive practical training entitled 'Inverse kinematics measurement technique for gas targets' organized between 13th and 23rd of April 2010 at the INFN-LNS Catania using Tandem Van de Graaff accelerator facility, with participation of staff from all four CLUNA institutions. RBI staff participating to the workshop was: Neven Soic, CLUNA coordinator (13th - 23rd), Milivoj Uroic (13th - 23rd), Stjepko Fazinic, CLUNA project manager (13th - 17th), D. Jelavic Malenica (15th - 22nd) and Lovro Prepolec (13th - 23rd). Workshop also attended Matko Milin from UoZ (15th - 24th). UoB researchers participating at the workshop were Martin Freer (12th - 15th) and Victor Ziman (12th - 2st). Vulcan eruption at Iceland, which stopped air-traffic over most of Europe just at the beginning of the workshop, caused changes in travelling dates of some participants: Martin Freer and Stjepko Fazinic had to left Catania earlier than planned, while Nick Ashwood from UoB was not able to reach Catania and did not attend the workshop. INFN-LNS staff participating at the workshop was: Marcello Lattuada (director of the INFN-LNS), Pierpaolo Figuera (leader of the WP5 work package), Alessia Di Pietro, Maria Grazia Pellegriti, Domenico Torresi and Valentina Scuderi.

The workshop included practical training with research equipment. For the workshop all available RBI equipment was transported to INFN-LNS to be tested in complex experimental conditions. Equipment of INFN-LNS and UoB research groups were also used to build large and complex experimental setup similar to one which we will use in our future research activities.

The workshop organization was as follows: every working day started with lesson given by INFN-LNS or UoB senior researcher followed by extensive practical training of all participants using research equipment for measurements of nuclear reactions with the gas targets. All equipment required for running experiments, from various types of silicon detectors, preamplifers, amplifiers, discriminators, logic units to analog-to-digital converters and other front-end electronics and DAQ electronics, was studied in details, tested and set to various running conditions to analyze its effect on quality of collected data in the first half of the workshop (13th - 17th) using alpha-source and accelerator beam (from 15th). Particular consideration was put on silicon detector array (main topic of the first 2 days), preamplifiers (main topic on the 3rd day) and DAQ (main topic on the 4th and 5th day). On Sunday 18th

we did not have lectures and training course, but started collecting data with optimized experimental setup for the rest of the workshop. Second part of the workshop (19th - 23rd) was dedicated to course on the data analysis. Course also included lectures and practical work on the collected data. Data were continuously collected using ion beam from the Tandem accelerator and techniques for detector calibration as well as the data analysis techniques and tools adequate for inverse kinematics measurements with gas targets were studied.

The workshop was successfully performed even if its work plan had to be changed because some lecturers had to leave earlier (Martin Freer) or were not able to come (Nick Ashwood). Their lectures were shifted to earlier dates or replaced with lectures given by experienced INFN-LNS staff on similar topics. All RBI equipment was tested and worked properly in joint complex experimental setup with INFN-LNS and UoB equipment. The RBI staff has collected new knowledge and experience on setting and running complex measurements, running measurements with gas target and data analysis.

Neven Soic and Milivoj Uroic (as well as Lovro Prepolec, for more details see section on WP3) arrived to INFN-LNS couple of days before the workshop and extended stay for couple of days after the workshop for discussion and knowledge/experience exchange with INFN LNS researchers on silicon detector array setup and data analysis of measurements with gas target and silicon strip detectors.

During the last project period, the INFN-LNS researchers Pierpaolo Figuera, leader of WP5 (in June 2010 and February 2011, in total for 15 person-days) and Marcello Lattuada, director of the INFN-LNS (in June 2010 for 4 p-d), visited RBI for 19 p-d in total. Matko Milin from UoZ visited INFN-LNS for 6 p-d. Exchange of knowledge and experience during these visits was essential for successful accomplishment of WP2 work tasks on coupling of the silicon detector and neutron detector array into DAQ and for further improvement of the gas target system, as well as on analysis of the experimental data on resonant elastic experiments. Work on window stability shown that we need thin HAVAR foils if we run measurement with intensive ion beams.

All WP5 objectives were accomplished. Collaboration between research groups from all the four partner institution is strengthened compared to the situation before the CLUNA project. RBI researchers gained new knowledge and experience. New knowledge and skills were successfully used in realization of WP2 and WP3 tasks.

During the first project year the INFN-LNS staff spent 2.5 person-months, while RBI staff spent 3.5 person-months on the activities of this WP. Costs of this WP in the first year were EUR 7 699.57.

In total, during the second project year RBI staff visited INFN-LNS for 79 person-days which include participation of five researchers at the workshop, training of young researcher and visits for knowledge and experience exchange of senior researchers. INFN-LNS staff efforts for this work package in total were 5.5 person-months. UoB staff efforts for WP5 were 0.6 person-month. UoZ staff efforts were 0.5 person-month. Costs of the WP5 were: 12149.07 for RBI (includes all travelling expenses to Catania and transport of the equipment for the workshop from Zagreb to Catania and back), EUR 7 668 for INFN-LNS, EUR 1 653.16 for UoZ and 1 927.27 for UoB.

During the third project year, staff efforts of RBI were 0.75 p-m, INFN-LNS 0.75 p-m and UoZ 0.3 p-m. Costs of the WP5 were EUR 2 407 for INFN-LNS and EUR 1 199 for UoZ.

Total cost of this WP during the project was EUR 34 703, 17% less than originally planned.

Work package 6 (WP6): Experimental techniques in nuclear cluster studies

The objectives of this WP are:

1) to strengthen the collaboration between RBI/UoZ, INFN-LNS and UoB;
2) to exchange knowledge and experience on experimental techniques for nuclear structure studies between all partner institutions; and
3) to help in realization of WP2, WP3, WP4, WP5 and WP7.

Workshop at the RBI

Two workshops were planned at the RBI accelerator facility under WP6, the first one with the topic on elastic and inelastic scattering as a tool in spectroscopic studies, and the second one on nuclear molecules. The first workshop, on the use of scattering measurements for spectroscopic studies of nuclei, was planned to have strong practical component with extensive training of the Ruder Boskovic Institute and University of Zagreb staff at the RBI accelerator facility. It was planned that experienced staff of University of Birmingham and Laboratori Nazionali del Sud transfer their practical knowledge on the use of experimental equipment for measurements of scattering processes with light nuclei to RBI and UoZ researchers. It was planned to concentrate the second workshop, on exotic structure in light nuclei similar to atomic molecules, to analysis techniques of the experimental data resulting with information on nuclei structure and experimental evidence for nuclear molecules in light nuclei. These two workshops were complementary dealing with clustering phenomena in nuclear physics, scientific topic behind the CLUNA project. The Project Management Board proposed and the Project Officer approved to merge these two workshops in one, covering the planned topics of both workshops, including additionally interrelation between experimental technique (measurement of scattering processes, topic of the first workshop) and structural phenomena in nuclei (nuclear molecules, the topic of the second workshop). In this way one combined workshop provided additional added value to the project. Merging of the two workshops gave a chance to attendances to work on both subjects at the same time and easier follow a path from experimental work on measurements, which provide required data, to data analysis and interpretation of experimental results, which finally results with the new scientific information. Initially, the first workshop, one with the practical training requiring ion beams in the RBI experimental chamber, was planned to be performed during the 2nd project year, but due to the vacuum pump failure and six months (Sep 2009 - Mar 2010) unavailability of the beam, we were not able to realize it at that time. This workshop was rescheduled to Sep 2010. In summer 2010 GANIL management informed us that the two experiments in which were involved researchers from the CLUNA project, as well as our CLUNA practical training event (part of WP6) were scheduled for the period from middle September until the beginning of November the same year. For this reason the workshop at Zagreb was postponed to December 2010. Unfortunately, another hardware failure at the RBI

Tandem accelerator facility, malfunction of power supply of the switching magnet (one which delivers ion beams to the experimental end lines), hampered realization of the workshop. Power supply of the switching magnet was repaired in January 2011 and the Tandem accelerator facility was back to normal operation by the end of January 2011. Due to the quite short time left until the end of the CLUNA project, merging two workshops in one sounded as good option. Merging has also saved time and funds required for the full realization of the project.

This combined workshop finally took place from 14th to 22nd of April 2011 at the RBI Tandem accelerator facility, with participation of researchers from all the four partner institutions. The workshop was attended by following researchers from University of Birmingham: Martin Freer, leader of WP4, Neil Curtis, Nick Ashwood, Carl Wheldon and Tzany Kokalova, all of them from April 18th - 22nd. The INFN LNS participants were Alessia Di Pietro (20th - 22nd), Pierpaolo Figuera (14th - 22nd), leader of WP5, Valentina Scuderi (14th - 20th) and Domenico Torresi (14th - 21th). The participants from Zagreb were Matko Milin from University of Zagreb and PhD students Deša Jelavic Malenica, Tea Mijatovic, Lovro Prepolec and Vedrana Tokic, and researchers Neven Soic, project coordinator, Suzana Szilner and Stjepko Fazinic, project manager, from RBI. Technical head of the accelerator facility, Natko Skukan, also participated at the workshop.

This workshop was organized in the same way as the one at INFN-LNS. It was mainly dedicated, especially the first half of the workshop, to practical work with the research instrumentation, including intensive training on equipment usage in the measurements of the scattering processes. For this training, some research equipment from Birmingham and Catania was required to complete experimental setup based on the RBI equipment. Data acquired from the scattering measurements provide important results on spectroscopy of nuclei which obey the laws of quantum physics: characteristics of the nucleus excited states. Full characterization of the excited states makes possible understanding of structure of the studied nucleus. The second part of the workshop was dedicated mainly to offline analysis of the experimental data, interpretation of the results on nuclear spectroscopy and extraction of the results on nuclear structure from the knowledge of nuclear spectroscopy. Techniques and methods of the analysis were demonstrated on the experimental data collected during the workshop. Experienced researchers from UoB and INFN-LNS, having complementary expertise on various steps in this complex process of acquiring new results on nuclear cluster structure and nuclear molecules, were giving lectures and leading training sessions with the help of senior Croatian scientist with adequate expertise for the considered topic.

Occasion that all Project Management Board members were at the same place was used to organize PMB meeting on April 18th. Work package leaders reported on the situation related to their work packages and the review of all the project activities was made. Unfinished activities were examined. Required measures for successful realization of the all project activities, as well as changes in the financial plan, were discussed and agreed between the PMB members. The updated work plan for the period left until the project end was prepared and adopted.

This workshop was successfully realized. All RBI equipment was tested in experimental conditions different than the ones in the previous workshop at INFN-LNS and worked well in joint complex experimental setup with INFN-LNS and UoB equipment. RBI researchers, particularly PhD students, collected new knowledge and experience on setting up and running

complex measurements, running measurements for spectroscopic studies and the data analysis which results in the new knowledge on nuclear structure.

Practical training at GANIL

The next large event planned in the CLUNA project was practical training of the RBI/UoZ researchers at the radioactive ion beam facility SPIRAL located at GANIL laboratory in Caen, France (http://www.ganilspiral2.eu/). This facility is currently unique facility in the world considering wide spectrum of reaccelerated unstable ion beams of light nuclei and the beams intensity, purity and focusing properties. This event provided excellent opportunity for the RBI/UoZ researchers to work in international environment at the top class international laboratory, significantly enlarging their research experience.

Experimental work with unstable ion beams is largely complementary to the work with stable ion beams due to very different constraints on experimental techniques and methods, and in the same time it is prerequisite for experimental work in contemporary nuclear physics. New knowledge in the field of nuclear physics can be gained only from measurements performed using high quality stable and unstable beams as their results puzzled together provide complete picture of the atomic nucleus. For these reasons, this training event at unstable ion beam facility, unavailable at the RBI and INFN-LNS, was important step towards the full realization of the CLUNA project objectives.

In organization and implementation of this training event we had help and support from our collaborators from Laboratoire de Physique Corpusculaire de Caen (http://caeinfo.in2p3.fr/) and the GANIL laboratory, at no costs for the CLUNA project. We acknowledge their important contributions which made possible this event. The training event took place from October 17th to November 5th 2010. In this training event we had experienced researchers as lecturers and trainers from University of Birmingham (Martin Freer, Neil Curtis, Nick Ashwood, Carl Wheldon and Tzany Kokalova) and INFN-LNS (Valentina Scuderi, Domenico Toressi and Luis Armando Acosta Sanchez) as well as local research staff from LPC and GANIL. Participants from University of Zagreb were Matko Milin (24th Oct - 2nd Nov) and Marija Majer (24th Oct - 2nd Nov). RBI researchers participating at the training event were Saša Blagus (17th - 24th Oct), Lovro Prepolec (17th Oct - 5th Nov), Milivoj Uroic (17th Oct - 5th Nov), Neven Soic (17th Oct - 5th Nov) and Stjepko Fazinic (28th Oct - 5th Nov). In summary RBI staff efforts were 77 person-days, UoZ 20 p-d, INFN-LNS 33 p-d and UoB 63.5 p-d.

The reason that this training event took longer than the workshops organized at INFN-LNS and RBI is that training included full preparation of experimental end station for the measurements (including moving and mounting of the experimental end station to the experimental line) and setting up of the most complex and largest silicon detector array, associated electronics and DAQ in our collaboration ever. The preparation of the experimental end station is usually performed by local staff alone before arrival of other participants, but in this case even if we had support from local researchers from LPC and GANIL, our presence as the event organizer, at GANIL during the early preparation phase was required for successful implementation of the training event. For this on-the-job training the research equipment from UoB and INFN-LNS was used together with the RBI equipment

to build the experimental setup. The training included measurements with the 6He beam during which experienced senior researchers educated younger and inexperienced researchers on experimental methods and techniques needed for research work with unstable beams. Courses on offline analysis of the data collected in the measurements were given at the last days of the training event.

As already mentioned above, there are significant differences between running experiment with stable and unstable beams due to very different quality of available beams. In the lectures and training sessions special emphasis was on these differences and experimental techniques specially developed for radioactive beam experiments. Subjects of the lectures and the hands-on activities covered all required research instrumentation (from detectors, pre-amplifiers, amplifiers and other electronics to data acquisition system) and analysis techniques and methods (from calibration of the detector array, extraction of interesting events in noise and background environment, to extraction of new information on nuclear structure).

This training event was completed successfully. All components of the experimental setup were functioning properly. The new knowledge and experience were transferred to RBI/UoZ research staff giving them possibility for larger contribution and increased impact in future experiments with unstable beams. In modern nuclear physics, such experiments are crucial to acquire new knowledge on atomic nuclei and the largest part of current and planned future investments in nuclear physics is dedicated to building of new radioactive ion beam facilities and research instrumentation required for research with them. Facilities currently in building phase in Europe are SPIRAL 2 at GANIL France (http://www.ganil-spiral2.eu/), HIE-ISOLDE at CERN (http://hie-isolde.web.cern.ch/hie-isolde/) and FAIR at Darmstadt, Germany (http://www.fair-center.com/), in USA it is FRIB at Michigan State University (http://www.frib.msu.edu/) and in Japan it is RARF facility of RIBF at RIKEN (http://www.nishina.riken.jp/Eng/facilities/RIBF.html). Clearly, future of the experimental nuclear physics is at these facilities and research work with unstable beams is prerequisite to keep nuclear physics research group from Zagreb alive and active.

Participation at international conferences

WP6 activities also included participation of the RBI and UoZ research staff at international conferences and workshops on nuclear physics, where they presented results of the research work performed in collaborations with researchers involved in the CLUNA project, as well as on new possibilities for experiments at the RBI nuclear research end station upgraded through the CLUNA project. Attendance of RBI/UoZ researchers to six conferences was planned, but at the end travel expenses for three conferences were covered using CLUNA funds. However, the RBI/UoZ researchers attended some international meetings, schools, conferences and workshops using other funding sources, using these occasions to disseminate results of the CLUNA project and present enlarged research capability and capacity of the RBI nuclear physics research instrumentation.

During the 2nd project year Suzana Szilner attended XVIII International School on Nuclear Physics, Neutron Physics and Application held between 21st and 27th September 2009 at Varna Bulgaria (web page of the conference is http://old.inrne.bas.bg/Varna2009/). She had

invited oral presentation of her recent research results as well as our recent activities in improving research quality at the RBI, including the CLUNA project. Conference proceedings has been published, her reference is S. Szilner, Quasi-elastic reactions: a survey on recent results, Journal of physics Conference series. 205 (2010);012033-1-012033-6.

Suzana Szilner also attended International Symposium 'Quasi-fission Process in Heavy Ion Reactions' held from November 8th to 9th 2010 in Messina, Italy. The symposium was organized in collaboration of INFN-LNS Catania (partner in the CLUNA project) and University of Messina. Scientific Secretary of the symposium representing INFN-LNS was Alessia Di Pietro, researcher involved in the CLUNA project. The main topic of this symposium was the reaction mechanisms, with particular emphasis on reaction mechanisms leading to the formation of the exotic nuclei with large excess of neutrons or protons, i.e. nuclei very different from stable isotopes found at Earth. Suzana presented recent results of a collaboration in which our group and new knowledge and experience acquired through CLUNA project significantly contributed to results on structure of neutron-rich nuclei. The proceedings of the Symposium was published in Journal of physics Conference series, and relevant publication is S. SZILNER, L. Corradi, G. Pollarolo, S. Beghini, S. Courtin, E. Farnea, E. Fioretto, A. Gadea, F. Haas, D. JELAVIC MALENICA, D. Lebhertz, S. Lunardi, D. Mengoni, T. MIJATOVIC, G. Montagnoli, F. Scarlassara, N. SOIC, A.M. Stefanini, C.A. Ur, J.J. Valiente-Dobon, Quasi-elastic reactions: an interplay of reaction dynamics and nuclear structure, Journal of physics, Conference series 282 (2011) 012021.

Matko Milin, researcher from University of Zagreb, attended the 2nd Workshop on 'State of the Art in Nuclear Cluster Physics', held at the Université Libre de Bruxelles Belgium, from May 25th to 28th 2010. The topics of the Workshop included cluster structure of stable and unstable nuclei, alpha clustering and nuclear molecules, and clustering aspects of nuclear reactions, all of these strongly overlapping with the research program behind the CLUNA project. Matko was invited speaker and presented results of our research performed in collaborations with the INFN-LNS and University of Birmingham researchers, entitled 'Clustering in A=10 nuclei'. He also presented CLUNA project and its activities. The workshop proceedings was published in the International Journal of Modern Physics E, reference is M.Milin, Int. J. Mod. Phys. E 20 (2011) 759.

Presentations used in the talks at these conferences are available at the CLUNA web site: http://lnr.irb.hr/cluna

All the expected objectives of the WP6 were fully achieved: the collaboration between all the four partner research groups is stronger than it was before the CLUNA project, knowledge and experience on experimental techniques and methods for nuclear clusters studies have been spread over all participating researchers, and acquired knowledge and experience have helped in successful realization of all planned activities in other project work packages.

While during the first project year we did not have major activities under this WP, during the second year one realized action was participation at one conference, with the RBI staff efforts of 0.4 person-months and the costs of EUR 1 431.76.

During the last project period, RBI staff efforts were 6.75 p-m, for UoZ it is 1.5 p-m, for INFN-LNS it is 2.75 p-m and UoB staff efforts are 4 p-m. In the same period the costs of WP6 were: for RBI costs include transport of the research equipment to GANIL for the

practical training and travelling expenses in amount of EUR 15 241, cost for UoZ is EUR 3 486, EUR 8 240 for INFN-LNS and EUR 15 341.65 for UoB.

Total cost of the WP6 in the project was EUR 43 740, close to 90% of the planned work package funding.

Total staff efforts for the all project duration

Beneficiary NO.	Beneficiary short name	WP1	WP2	WP3	WP4	WP5	WP6	WP7	Total person-month
1	RBI	5.08	22.75	40.5	2.75	7.85	7.15	5.63	91.71
2	INFN-LNS	0.5	-	-	-	8.75	2.75	-	12.0
3	UoB	0.5	-	-	2.65	0.6	4.0	-	7.75
4	UoZ	0.5	1.0	-	-	0.8	1.5	1.0	4.8
	Total	6.58	23.75	40.5	5.4	18.0	15.4	6.63	116.26

Distribution of expenses

Net amount of pre-financing received from European Commission was EUR 197 333.33. The second payment was EUR 38 503.62 and the third was EUR 78 613.05. Distribution of funds among partners and the summary of expenditures for all the reporting periods are as follows:

Partner Total cost	Total funding	Pre-financing	Spent first year	2nd year	3rd period
RBI 322883.88	291402.00	155414.40	38503.62	110349.41	174030.85
INFN-LNS 19596.91	28165.00	15021.33	0	8204.50	11392.41
UoB 20981.82	36637.00	19539.73	0	4566.25	16415.57
UoZ 6781.12	13796.00	7.357.87	0	1768.88	5012.24
Total 370243.73	370000.00	197333.33	38503.62	124889.06	206851.07

Redistribution of the funding from other partners to the RBI was 8.5 % of the total project funding from EC. Total figures of expenses are 25.3% for personnel costs, 24.6% for travel expenses, 29.1% for equipment costs, 10.9% for materials costs, 0.7% for subcontracted work, 2.7% for management costs and 0.8% for other direct costs.

Potential Impact:

The immediate impact of the CLUNA project is greatly improved research potential of the RBI/UoZ groups for nuclear physics experimental work. In addition to the improved experimental facility and expertise, the project has a synergetic effect on the scientific cooperation between the project partners and their cooperation with the other nuclear physics groups from Europe. Apart from an increased contribution to existing collaborations, the successful realization of CLUNA provided opportunities to enter new collaborations at both national and European level. The upgraded experimental end station for nuclear physics research at the RBI Tandem Accelerator facility is unique in Croatia and South-East Europe, with large potential benefits to the broader scientific community, to the national and regional universities and wider.

With CLUNA, partnership has been strengthened at several levels with three prominent partner organizations: Universities of Zagreb and Birmingham (UoZ and UoB), and with the Italian National Institute of Nuclear Physics, Laboratory in Catania (INFN-LNS). With all of them RBI had already established cooperation. CLUNA strengthened this partnership, especially through human mobility actions and exchange of know-how. Through CLUNA partnerships between Zagreb and EU groups has been strengthened by more frequent personal contacts, exchange of knowledge and experience between researchers, upgrading of experimental end station at RBI with the aim to serve as research facility for collaboration measurements and via future commonly planned and performed experiments at RBI, INFN-LNS and other European accelerator facilities. Due to overlapping research interest of involved groups and access to upgraded RBI and INFN-LNS facility for all members of the collaboration, partnership between these four research groups will continue after the end of this project. During CLUNA implementation, new partnerships were established with researchers from other R&D organizations, like from University of Huelva in Spain and GANIL and LPC, Caen, France.

All partners benefited from results of this project: RBI obtained more competitive research infrastructure with significantly increased number of external users, INFN-LNS have access to improved low energy accelerator facility and increased number of international users at home facility, UoB obtained a new site for low energy measurements at RBI and additional site for intermediate energy measurements at INFN-LNS, and finally UoZ obtained access to better local site at RBI for research and educational purposes.

RTD capacity and capability at RBI has been upgraded with new researchers employed, training of research staff, improvement of research management, and upgrade of scientific equipment.

New researchers: Three outstanding graduated students were employed. They were nicely incorporated into the RBI nuclear physics research groups. They are all now employed as PhD students on national research grants supported by the Ministry of Science, Education and Sport (MSES). Without CLUNA it would be difficult to attract these young researchers and keep them during the period of uncertainty while waiting for approvals of local funds for hiring new staff.

Training of research staff: Exchange of knowledge, know-how and experience on modern experimental nuclear physics, including measurement methods, interpretation - validation of data, interpretation of experimental data and modelling resulted in a well educated and skilled staff, able to perform complex R&D work required in collaborative projects. Altogether the RBI/UoZ staff spent about 12.5 person-months for training activities at partner organizations and top international research laboratory (GANIL), and staff from partner organizations spent about 10 person-months at RBI and GANIL. Two workshops were held, one at the INFN-LNS and one at the RBI, and one training event at the GANIL Caen, France, resulting with intensive transfer of knowledge and experience. Further, intensive exchange visits program between RBI/UoZ and partners resulted in significantly enlarged knowledge and experience of the RBI/UoZ staff.

Improvement of research management: CLUNA project increased the research management capabilities of the RBI, realized through WP1. Staff from the respective RBI support department assigned to this project visited UoB to exchange know-how and experience in R&D project management. Experience and knowledge on research management acquired both by the RBI researchers and administration during the project implementation are valuable background for future larger projects.

Scientific equipment: the RBI experimental end station for nuclear physics research is fully upgraded according to the project description of work, with some additional improvements which required small additional investment. Upgrade and renewal of the existing nuclear physics experimental end station increased its experimental capabilities. The RBI detection system for nuclear physics research is enlarged with the large silicon detector array for charged particles detection, neutron detector array, associated front-end electronics and data acquisition system. In the enlargement of the RBI experimental capabilities, large part of funds and work has been used for purchase and commissioning of fast neutron detectors. Merging of the neutron detectors with the silicon detector array on improved end station greatly expanded the research topics for future collaborative research. The system is fully operable and in usage for nuclear structure and reaction studies as well as for research in nuclear astrophysics. Availability of helium beams for future research have been secured and new ion beams of 9Be, 10,11B, 13C and 18O are available for experiments at the RBI Tandem accelerator facility. New detection system at RBI is compact and transportable. It can be used for research not only at the local RBI experimental facility, but also at the INFN-LNS accelerator centre and other accelerator laboratories worldwide. The detection system is fully compatible with research equipment of our partners from University of Birmingham and INFN-LNS.

Quality of research carried out: With realization of CLUNA, capabilities for experimental nuclear physics experiments at the RBI Tandem Accelerator facility have been significantly enhanced. The upgraded end station has been already used for two measurements performed in collaboration with researchers from University of Birmingham and INFN-LNS. The first publication from these measurements has been recently published in Physical Review C (M. Freer et al, Phys. Rev. C 84 (2011) 034317), one of the major journals in nuclear physics. The RBI detection system can be used in combination with the systems owned by our partners for building and usage of very large and complex detection systems for collaborative research activities previously unreachable for our collaboration. Therefore, successful realization of CLUNA largely increased research potential not only of the RBI research group, but also for collaborative research performed by all four partners of the CLUNA project.

Unique expertise for the region: Enlargement of the capacities for experimental nuclear physics research at RBI significantly improved the scientific and technical infrastructure for this kind of research in the WBC region. Even more of that, after the upgrade of the scattering chamber, renewal of the detection system by inclusion of very thin silicon and fast neutron detectors and development of the new beams, RBI research capacities for nuclear structure and reaction research are competitive with the European small facilities. The RBI experimental end station is the only one of this kind in WBC region. In the broader region, SouthEast and NorthEast Europe covered by the EastWestOutreach Nuclear Physics Network (EWON), the EURONS networking activity of 18 institutions from East Europe, RBI is one of the only six existing facilities which satisfy prerequisites for high quality research (others are Rez, Athens, Debrecen, Warsaw and Bucharest). These facilities are now working together in one of ENSAR (FP7 infrastructure project of European nuclear physics community) work packages.

Reducing brain drain: Increased potentials for high quality experimental and collaborative R&D in the field of experimental nuclear physics increased the desirability by graduate students to join the research activities of the RBI/UoZ group. Students become aware that high quality research can be performed also at Croatian institutions. This helps to reduce the large brain drain from Croatia, improving the national education level, and increase the number of Ph.D. thesis carried out at RBI. The RBI Tandem Accelerator facility is actively involved in educational activities. In partnership with the UoZ, students in physics use the accelerator facility to perform seminars, BSc, MSc and PhD theses. With the upgraded nuclear research end station, possibilities for the expanded educational programmes are opened. Recently University of Zagreb and RBI started joint post-graduate studies in Nuclear Physics. The RBI Tandem Accelerator facility has been used for practical demonstrations and experiments for students. Additional potential users of the facility in educational and applicative activities are other universities with Physics Departments from Croatia (Split and Rijeka), as well as the universities from the WBC region.

Increased opportunities for popularization of science: The RBI Tandem Accelerator facility is open for general public on regular RBI Open Days and for visits of students and pupils. According to our experience modern experimental facilities are very attractive to general public and attract positive interest of general public for research and development activities in general.

Improvement of RBI participation in FP7 projects and other collaborative projects: Thanks to the experience and research equipment partially gained through the CLUNA project, RBI researchers also participate in two recently approved FP7 infrastructure projects: SPIRIT - Support of public and industrial research using ion beam technology (project web page is http://spirit-ion.eu/) and ENSAR, successor of the FP6 EURONS project (http://www.gsi.de/informationen/jofu/EURONS/). Experience and equipment gained through CLUNA also helped the RBI group to get the research project managed by European Science Foundation in its EUROCORES program EuroGENESIS - Origin of the Elements and Nuclear History of the Universe (web page is http://www.esf.org/activities/eurocores/runningprogrammes/eurogenesis.html). Our project is part of the collaborative project on explosive stellar phenomena in compact objects 'Physics of compact objects: explosive nucleosynthesis and evolution' - EXNUC which involves research groups from Spain, Greece, Austria, Germany, Belgium, Canada and USA.

Dissemination of the information on upgraded experimental facility at RBI and our recent activities, including the CLUNA project, resulted in significantly increased interest of European nuclear physics community for measurements at the RBI facility. Apart of our partners at the CLUNA project, who already run two measurements at RBI and plan more in near future, our other collaborators are interesting for experiments at the RBI accelerator facility. In particular, nuclear physics groups from the Institut pluridisciplinaire Hubert Curien Strasbourg France (leader F. Haas), University of Huelva Spain (leader I. Martel) and Laboratori Nazionali di Legnaro INFN Italy (PRISMA-CLARA collaboration) are planning to do different measurements at the RBI facility.

The very fact that our four research groups are partners in the FP7 project and our increased communication have very positive influence on strengthening of the collaboration between partner institutions. In the recent period two new proposals for experiments at international experimental facility were approved in which researchers from all partnering institutions involved in the CLUNA project are participating with work power and equipment. Another proposal is submitted to GANIL two weeks ago for expert committee evaluation. Further research projects with participation of all CLUNA partners are planned for the near future, some of them also at the upgraded RBI experimental facility.

Interdisciplinary research: CLUNA helped to expand possibilities for development and usage of new applications of nuclear techniques in interdisciplinary research. The knowledge obtained on silicon strip detectors through CLUNA, and availability of the nuclear microbeam and related expertise at the RBI Tandem Accelerator Facility, helped to start investigations of detector response functions of such detectors and study of observed anomalies at the strip borders. The first experiment of this kind will be performed in October 2011 at RBI in collaboration with the INFN-LNS researchers.

Dissemination:

Main dissemination activities were grouped within WP7. Objectives of this WP were:

1) to realize dissemination of knowledge and project results to international nuclear physics community and general public; and
2) to present to general public methodology, goals and results of research in nuclear physics, particularly positive influence of this research on today's life of people.

The design and development of web site on activities of the CLUNA project, including some general content on the nuclear reaction and structure studies, was performed during the first project year, and the web site was launched in February 2009, with continuous updating. During the second project year the project web site was enlarged to include pages in Croatian language, written by RBI/UoZ staff with general content on nuclear physics and related research presented on level understandable to high school students, with aim to popularize nuclear physics and science in general.

Presentations of upgraded RBI experimental end station for new experimental activities to broader European nuclear physics community were performed in several occasions, during international nuclear physics conferences and similar events attended by the CLUNA

researchers as well as during collaborative experiments at international accelerator facilities, following invitations for the new collaborative experiments at RBI facility.

One excellent occasion for dissemination was international nuclear physics conference 'Nuclear structure and dynamics 09' (web page is http://www.phy.hr/~dubrovnik09/) co-organized by CLUNA researchers from RBI and UoZ (scientific secretary was M. Milin, conference co-chair was S. Szilner, member of the local organizing committee was N. Soic) in Croatia on May 4th - 8th 2009. Neven Soic had short oral and poster presentation on CLUNA project and other recent activities at RBI aiming to increase research quality and impact of Zagreb research groups.

Neven Soic also gave talk on results and perspectives of Croatian nuclear physics research including presentation of the CLUNA project during the meeting of the NuPECC in Zagreb, June 2008 (NuPECC stands for The Nuclear Physics European Collaboration Committee, which is the committee of the European nuclear physics community working on directions, strategy and perspectives of nuclear physics research, expert committee for nuclear physics of the European Science Foundation and EC).

Another dissemination activity was presentation of the CLUNA project at the meeting of the Croatian Physical Society on 8th -11th October 2009. At this meeting S. Fazinic (the CLUNA project manager) and N. Soic (the CLUNA coordinator) were moderators and presenters at the round table on FP7 projects in Croatia. S. Fazinic and N. Soic also attended couple of other workshops and round tables on FP7 projects organized by Croatian National Contact Person Suzana Karabaic, RBI and other Croatian scientific institutions and agencies where they presented CLUNA project.

Next dissemination activities were regular seminars (twice a month) for RBI and UoZ researchers on nuclear physics and related research (coordinated by M. Milin of UoZ) given by the RBI/UoZ staff and participation in the RBI Open Days 2010. RBI researchers from the CLUNA project were involved in organization of the event, gave lectures and prepared presentation point on nuclear physics research where they also presented the CLUNA project. During the second project year we also hosted several groups of high school and university students presenting nuclear physics research at the RBI and our activities.

RBI Open Days were organized also in 2008 and both Nuclear physics group and LIBI presented research activities, including the CLUNA project, to general public. In 2009 Open Days were not organized, but several groups of high school and university students were hosted and nuclear research activities at the RBI were presented to them.

RBI and UoZ research staff participated at international conferences and workshops on nuclear physics, where they presented results of the research work performed in collaborations with researchers involved in the CLUNA project, as well as on new possibilities for experiments at the RBI nuclear research end station upgraded through the CLUNA project. Attendance of RBI/UoZ researchers to six conferences was planned, but at the end travel expenses for three conferences were covered using CLUNA funds. However, RBI/UoZ researchers attended some international meetings, schools, conferences and workshops using other funding sources, using these occasions to disseminate results of the CLUNA project and present enlarged research capability and capacity of the RBI nuclear physics research instrumentation.

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Presentations used in the talks at these conferences are available at the CLUNA web site: http://lnr.irb.hr/cluna

Neven Soic (RBI) presented CLUNA in talks given at two international events: the first EuroGENESIS workshop (http://lnr.irb.hr/eurogenesis_workshop/) held in Dubrovnik November 23th - 26th 2010 and Symposium 'Highlights in Heavy-Ion Physics' (http://symposium-cindro.irb.hr/index.html) held in Split September 22nd - 24th 2011. Researchers from RBI/UoZ attended during the last project period more than ten collaborative experiments at various international accelerator facilities and used these opportunities to present RBI nuclear physics research facilities.

Neven Soic gave popular science lectures on nuclear astrophysics which also included presentation of CLUNA project and our research activities, at the Zagreb Observatory in

February 2011, at the Zagreb Association of high school physics teachers in March 2011 and at the Science Festival Zagreb 2011 (main national event for science popularization, http://www.festivalznanosti.hr/2011/) in April 2011. Neven Soic is co-proposer and co-organizer of series of popular science lectures at RBI 'Science for public' which started in October 2010. Idea of the event is that invited speakers from all RBI departments present their research in a popular way for general public. Lectures are mainly attended by university and high school students, who are our targeted public.

The RBI/UoZ researchers prepared and printed promoting brochure on nuclear physics and nuclear astrophysics, including presentation of CLUNA project. Booklet is written in Croatian with the title 'CLUNA - Svijet egzoticnih atomskih jezgara' (CLUNA - The World of the exotic nuclei). Editor was Suzana Szilner with help of Desa Jelavic Malenica, Tea Mijatovic and Matko Milin. Edition is 1000 copies. Targeted public are high school and university students, but it is also accepted well by the RBI staff outside our research field (administration, researchers from chemistry, biology and medicine). We have distributed it to Ministry of Science, Education and Sport, national agencies, organizations and associations related to science. Several hundred copies are still on hand for distribution to visitors during popular science events at the RBI. PDF file of the booklet is available on CLUNA web site http://lnr.irb.hr/cluna/. The booklet contents is: Nuclear Physics, Atomic Nuclei, Inside the Nucleon, Fundamental Forces, Chemical Elements and Isotopes, Nuclear Chart, How the atoms and nuclei have been produced, Accelerators, Nuclear Clustering and The CLUNA project.

Exploitation of results:

Implementation of WP2 resulted with the availability of helium beams for future research. In addition, expertise has been acquired for the production of new ion beams of 9Be, 10,11B, 13C and 18O at the RBI Tandem accelerator facility. These ion beams are not available only for nuclear physics experiments, but also for interdisciplinary research and services.

As explained earlier, CLUNA helped to expand possibilities for development and usage of new applications of nuclear techniques in interdisciplinary research. The knowledge obtained on silicon strip detectors through CLUNA, and availability of the nuclear microbeam and related expertise at the RBI Tandem Accelerator Facility, helped to start investigations on detector response functions of such detectors and study of observed anomalies at the strip borders. The first experiment of this kind will be soon performed (scheduled for end of October 2011) at RBI in collaboration with the INFN-LNS researchers. The research could result with improved detector systems. In addition, such modern particle detectors could be used for interdisciplinary research in materials science, development of advanced materials, and other interdisciplinary fields where such detection systems are used for characterization of materials.

The expertise that has been gained in complex data acquisition systems is prerequisite for such possible applications of silicon strip detector arrays, and therefore also has potential as exploitable knowledge.

In short, the exploitable knowledge of the CLUNA project can be summarized as follows:

1) exploitable knowledge on production of new ion beams can be used in accelerator running services with aim on applications of low energy accelerators. It is know-how available from 2010 owned by RBI,
2) expertise in use of silicon strip detectors can be used in interdisciplinary research and analytical services for material analysis and development of advanced materials. It is know-how available from 2011 owned by RBI,
3) expertise in data acquisition systems can be used in interdisciplinary research and analytical services for running complex experimental instrumentation. It is know-how available from 2010 owned by RBI,
4) exploitable knowledge on measurements with unstable beams including specificities of experimental setup and data analysis will be used in nuclear physics research for general advancement of knowledge in nuclear physics, but also can be used in interdisciplinary research for highly specialized analytical services (for example deposition of long-lived radio-isotope in materials, biological or medical samples etc.). It is know-how available from 2011 owned by RBI,
5) expertise in use of neutron detectors can be used in interdisciplinary research and analytical services for material analysis, development of advanced materials and homeland security (neutron detection from radioactive materials). It is know-how available from 2011 owned by RBI.

In addition, project CLUNA exploitable foreground is commissioned research instrumentation:

1) upgraded experimental end station for nuclear physics research can be used not only for basic research in nuclear physics, but also for interdisciplinary research (astrophysics, materials characterization). Fully upgraded is from 2010,
2) detection system for charged particles can be used for nuclear physics research and interdisciplinary research at RBI, INFN-LNS and other European accelerator facilities from 2010. It is owned by RBI,
3) neutron detection system also can be used for nuclear physics research and interdisciplinary research and applications (material analysis, detection of radioactive materials in homeland security) at RBI, INFN-LNS and other European accelerator facilities from 2010. It is owned by RBI.

List of Websites:

Web site: http://zef.irb.hr/cluna

Mailing lists:

all staff: cluna-team@lnr.irb.hr

management staff: cluna-admin@lnr.irb.hr

Coordinator:

Neven Soic

Division of Experimental Physics, Ruder Boskovic Institute

Bijenicka 54, HR-10 000 Zagreb, Croatia

Phone: +3851 4561026, Email: soic@lnr.irb.hr

Project Manager

Stjepko Fazinic

Division of Experimental Physics, Ruder Boskovic Institute

Bijenicka 54, HR-10 000 Zagreb, Croatia

Phone: +385 1 457 1254

Email: stjepko.fazinic@irb.hr

Representative of INFN-LNS and member of Project Management Board

Pierpaolo Figuera

INFN Laboratori Nazionali del Sud

via S. Sofia 62, I-95123 Catania, Italy

Tel. +39 095 542297

Email: figuera@lns.infn.it

Representative of University of Birmingham and member of Project Management Board

Martin Freer

School of Physics and Astronomy, University of Birmingham

Edgbaston, Birmingham, B15 2TT, UK

Tel. +44 121 414 3384

Email: mf@np.ph.bham.ac.uk

Representative of University of Zagreb and member of Project Management Board

Matko Milin

Department of Physics, Faculty of Science, University of Zagreb

Bijenicka c. 32, HR-10 000 Zagreb, Croatia

Tel. +385 1 4605545

Email: matkom@phy.hr