



Report on TransNational Activities at LNL-LNS of INFN

PUBLICITY CONCERNING THE OPPORTUNITIES FOR ACCESS TO TNA03

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

ENSAR opportunities were presented during the following event:

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

SCIENTIFIC COMMITTEES

During the third reporting period no change occurred in the compositions of the local Programme Advisory Committees (PAC) of both INFN laboratories (LNL and LNS) and the User Selection Panel for Interdisciplinary Research (USIP) of LNL which are available at:

- <http://www.lnl.infn.it/~lnldir/UE/PAC-USP.html> (LNL) and
- http://www.lns.infn.it/index.php?option=com_content&view=article&id=477&Itemid=223 (LNS).

No change also occurred in the composition of the ENSAR User Selection Panel (ENSAR USP) available at <http://www.lnl.infn.it/~ENSAR/>. The list of the ENSAR USP members for the reporting period can be found in Annex 1.

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

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

MEETINGS OF THE SCIENTIFIC COMMITTEES

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

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

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

SELECTION CRITERIA

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



TRANSNATIONAL ACCESS ACTIVITY DURING THE REPORTING PERIOD

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

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

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

In total during the reporting period:

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

Objectives and achievements of the funded experiments

Acronym

Project Title

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

Objectives – To measure accurately the fusion cross-sections of the ^{24}Mg on ^{30}Si reaction at energies around and below the Coulomb barrier in order to search for a fusion hindrance effect at the lowest energies investigated.

Achievements – The evaporation residues were identified with the **LNL electrostatic deflector** in its upgraded configuration. The $^{24}\text{Mg}+^{30}\text{Si}$ fusion cross section was measured at seven ^{24}Mg bombarding energies between 52.0 and 37.2 MeV. An *S*-factor maximum has been observed for this large positive *Q*-value system, which is the best developed maximum observed thus far.

LNL 13.16 – *Fusion hindrance and quadrupole collectivity in collisions of $A\sim 50$ nuclei*

Objectives – To measure the fusion excitation function of the system $^{48}\text{Ti}+^{58}\text{Fe}$ from above the barrier to very low energies, where the phenomenon known as “fusion hindrance” is expected to show up, and to put in evidence similarities and differences with respect to the behaviour of heavier systems like $^{60}\text{Ni}+^{100}\text{Mo}$, and $^{64}\text{Ni}+^{100}\text{Mo}$, recently studied at Argonne National Laboratory (USA).

Achievements – The fusion excitation function of the system $^{48}\text{Ti}+^{58}\text{Fe}$ has been measured from above the barrier to below by using the set-up based on the **LNL electrostatic deflector**. After five days of beam on target, a problem with the ion-source emerged, consequently the measurement could not be completed. The very low energy region, which is very important for the fusion hindrance phenomena, could not be measured.

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

Objectives – To investigate the reaction dynamics for the system $^7\text{Be}+^{208}\text{Pb}$ at two energies around the Coulomb barrier by detecting charged particles (^3He and ^4He breakup fragments as well as ^7Be elastically scattered secondary beam) with the detector array **EXPADES** (16 Double-



Sided Silicon-Strip detectors arranged in 8 two-stage ΔE -E telescopes in a cylindrical configuration).

Achievements – A ${}^7\text{Be}$ secondary beam has been produced by using a primary ${}^7\text{Li}$ beam impinging on a H_2 -filled gas target and the **EXOTIC** facility at LNL allowed to select the ${}^7\text{Be}$ ions and to focus them on a ${}^{208}\text{Pb}$ secondary target. The reaction ${}^7\text{Be}+{}^{208}\text{Pb}$ was studied at three different energies. One of these values was that obtained from the production reaction using a gas target cooled with liquid nitrogen; the second value was obtained by inserting a degrader after the production target while for the third one the production target at room temperature was used. The data analysis is still in progress.

LNL 13.04 – *Elastic scattering and reaction mechanisms of ${}^7\text{Be}+{}^{28}\text{Si}$ at near barrier energies*

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

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

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

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

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

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

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

Achievements – As it was impossible to deliver a secondary beam of ${}^8\text{B}$ by using the **EXOTIC** facility at LNL with the appropriate flux for achieving our objective, a ${}^8\text{Li}$ beam was finally delivered and elastically scattered at two energies in a ${}^{90}\text{Zr}$ target. A preliminary analysis of the



elastic scattering angular distribution of the first energy at 18.9 MeV has already been done. A more detailed analysis “pixel by pixel” will follow.

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

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

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

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

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

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

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

Objectives – To determine the final yields of both, “light” and “heavy” reaction products in the reaction $^{197}\text{Au}+^{130}\text{Te}$. In particular, via the 2-proton stripping and 4-neutron pick-up channel one should be able to populate ^{132}Sn , which represents a benchmark neutron-rich nucleus for different physics cases. The importance of secondary processes, which may significantly modify the final yields, will be investigated by measuring the yield distribution of heavy transfer products.

Achievements – Multi-neutron and multi-proton transfer channels were studied at $E_{\text{lab}}=1070$ MeV using a ^{197}Au beam delivered by the PIAVE+ALPI accelerator complex of LNL and detecting via kinematic coincidence with **PRISMA** + the **second arm** (MCP+PPAC+BC), for the first time, both projectile-like and target-like ions. Inverse kinematics was used in order to exploit the unique performance of PRISMA in terms of both resolution and efficiency. The complex data analysis (the tracking through the spectrometer “event-by-event”) is in progress. The collected data look promising.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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



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

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

In total during the third reporting period:

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

Objectives and achievements of the funded experiments

<i>Acronym</i>	<i>Project Title</i>
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LNL USIP13.40 – *Investigation of light-ion track structure (ILITS)*

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

Achievements – The ionisation cluster size distributions generated by ¹²C⁶⁺ ions with kinetic energies of 48 MeV, 78 MeV, 96 MeV, 102 MeV and 156 MeV in a target gas consisting of 1.2 mbar C₃H₈ have been measured. The data analysis is still in progress.

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

Objectives – To determine the chemical composition of 60 Byzantine ceramics shards excavated on Romanian territory from the site of Oltina (10th-11th centuries A.D.) using **micro-PIXE facility** at AN2000 accelerator of LNL. The measurements will also be used to estimate the thickness and composition of the green glaze superficial layers decorating some of these pottery fragments.



Achievements – During the first experimental run (November 2013) 30 samples coming from different types of ceramics were measured as pelletised powders. Due to some technical problems with the AN-2000 accelerator, during the second run (May 2014) only one day (out of the 3 days of assigned beam-time) has been used. As a consequence only half of the samples have been analysed. The interpretation of the obtained results is in an incipient stage, being made in close collaboration with the archaeologist who discovered the Byzantine ceramic shards, and took part in the PIXE experiments, assuring the adequate sample preparation.

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

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

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

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

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

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

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

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

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

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



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

Objectives – From the radiobiological point of view the most important lesions produced by ionising radiation are the DNA double-strand breaks (DSB). One of the first steps in the cellular response to DSB is phosphorylation of histone H2AX (γ -H2AX) at the damage sites that are DSB very soon after irradiation. The number of γ -H2AX foci is considered as one to one DNA DSB. They seem to have an important function in the activation of the DNA repair system of the cell. Therefore, kinetics of the appearance of the γ -H2AX foci after irradiation of the human malignant cell monolayers by different types of radiation was studied. The chosen time points cover the interval up to 24 h after irradiation. Detection and quantification of γ -H2AX foci is performed by Western blot and immunohistochemical analyses.

Achievements – The measurements were carried out on the **0° beam line** at LNS. One melanoma, a breast carcinoma and two non-small cell lung carcinomas were irradiated by γ -rays, protons and carbon ions at low doses. Immunofluorescent staining followed by laser scanning confocal microscopy was used for the detection and quantification of γ -H2AX. This allows quantification of radiation response in individual cells. γ -H2AX foci appeared in cells just a few minutes following irradiation. Their number reached maximum at ~ 60 min and then decreased, thus reflecting the kinetics of DNA DSB repair. The data analysis is currently in progress.

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

Objectives – To investigate the DNA repair, bystander signalling and out-of-field effects and to complete the preliminary senescence studies since the effectiveness with which this sub-lethal effect is induced does vary along the Bragg curve, and particularly along the SOBP. The experiment also planned to test a new irradiation set-up using solid water phantom and hypoxia chambers.

Achievements – Over 350 samples have been irradiated for senescence and chromosomal aberration studies by using the **CATANA** facility at LNS. A new set-up using solid water slabs was successfully implemented allowing investigation of the biological effectiveness at the end of the beam (scattered particles) and use of oxygen scavengers for mimicking hypoxia conditions. Data analysis is still in progress.

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

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



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

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

SCIENTIFIC OUTPUT OF THE USERS AT THE FACILITIES

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

LNL 13.18

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

The results of this experiment have been published in Physical Review Letters in July 2014 (see Annex 4).

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

New data concerning the nature of the pygmy dipole states in ^{208}Pb were obtained using the $^{208}\text{Pb}(^{17}\text{O},^{17}\text{O}'\gamma)$ reaction at 340 MeV and measuring the γ decay with high resolution with the AGATA Demonstrator array. In particular, cross sections and angular distributions of the emitted γ rays and of the scattered particles (two segmented ΔE - E silicon telescope prototypes for the TRACE project) were measured. The results were compared with (γ, γ') and (p, p') data. The $E1$ transitions cross sections for ^{208}Pb were analysed for the first time using a microscopic form factor and the isoscalar potential was found to depend on the presence of the neutron skin. A consistent description was obtained for elastic and inelastic excitations of $E2$ and $E3$ states.

The inelastic scattering of ^{17}O was also used to study the pygmy dipole resonance in ^{140}Ce nucleus. Gamma-rays were registered by AGATA Demonstrator and 9 large-volume scintillators (LaBr_3) of the HECTOR+ array. Very preliminary results of the study have shown a strong domination of $E1$ type transitions in the region of 'pygmy' energies. However, some indication of possible 'isovector' states is also visible. This will soon be confirmed as the analysis is still in progress (~20% of the data not analysed yet). The results of this project have been published in Physical Review Letters and Physica Scripta in 2014 (see Annex 4).

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

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



The results of this experiment have been published on Physical Review Letters in 2014 (see Annex 4).

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

Fusion excitation functions for $^{40}\text{Ca}+^{58}\text{Ni}$ and $^{40}\text{Ca}+^{64}\text{Ni}$ were measured at energies around and below the Coulomb barrier. The barrier distributions were also extracted for the two systems. Good agreement was found between the measured and calculated fusion cross sections for the $^{40}\text{Ca}+^{58}\text{Ni}$ system. The situation is different for the $^{40}\text{Ca}+^{64}\text{Ni}$ system where the coupled-channels calculations (CC) with no nucleon transfer clearly underestimate the fusion cross sections below the Coulomb barrier. The fusion excitation function for this system was, however, well reproduced at low and high energies by including the coupling to the neutron pair-transfer channel in the calculations. Experiments to measure directly the transfer cross sections would also be of the highest interest to better understand the influence of nucleon-transfer channels on $^{40}\text{Ca}+^{58,64}\text{Ni}$. This work has been published in Physical Review C in 2014 (see Annex 4).

LNL 13.04

The elastic scattering data were analysed in a BDM3Y1 framework and the normalisation factors of the optical potential were deduced. These are compared with the normalisation factors of $^6,7\text{Li}+^{28}\text{Si}$ obtained previously in the same framework. The indication is that ^7Be resembles rather the behaviour of ^6Li and not that of ^7Li . More data at other energies are necessary to confirm this conclusion.

The results of this experiment were presented in the Carpathian Summer School of Physics 2014 Exotic Nuclei and Nuclear/Particle Astrophysics (V) "From nuclei to stars", 13-26 July 2014, Sinaia, Romania and the 2nd Workshop on New Aspects and Perspectives in Nuclear Physics, 12 April 2014, Thessaloniki (Greece).

LNL USIP13.62

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

LNL USIP13.52

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

LNS DNA-BRAGG (*supported in the second reporting period*)

Glioblastoma (U87) and Fibroblasts (AG01522) have been exposed to different depth positions along a clinical proton beam with unprecedented $\sim 50\ \mu\text{m}$ accuracy. By comparison with X-ray, the Relative Biological Effectiveness (RBE) has been estimated as a function of dose, depth and intrinsic cellular sensitivity. Data have been used to evaluate shortfall of current clinical practice employing a fix RBE value of 1.1 and to develop a parameterised RBE model.

This work has been published in 2014 in International Journal of Radiation Oncology - Biology - Physics (see Annex 4).

**LNL USP13.03** (supported in the second reporting period)

The ion-beam techniques Rutherford Backscattering Spectrometry (RBS) and micro-Particle Induced X-Ray Emission (μ PIXE), available at the AN2000 accelerator of LNL, were selected to study radionuclide diffusion and surface retention within heterogeneous rocks. Diffusion coefficients and retention parameters at the micro-scale were determined for U and Se on granite selected minerals, both under oxic and anoxic conditions.

The Se data have been published in 2014 in Applied Geochemistry Journal (see Annex 4).

LNS PIXE (supported in the second reporting period)

Proton-induced X-ray emissions (PIXE) from gold and silver markers were detected at different penetration depths of a 59 MeV proton beam at the CATANA proton facility at INFN-LNS (Italy). This study establishes that proton induced X-ray emissions (PIXE) from implanted metal markers, could potentially be used to verify in real-time beam range overshoots during eye proton treatments. Preliminary results from silver are more promising. Further investigations are needed to demonstrate the feasibility of the technique in a clinical set-up.

Results of this work have been published in Physics in Medicine and Biology in 2014 (see Annex 4).

The list of publications that appeared in peer-reviewed journals (or peer-reviewed conference proceedings) resulting from the experiments carried out at LNL and LNS under the Transnational Access activity and supported through the EC grant agreement ENSAR (no. 262010) can be found in Annex 4. These publications have never been reported in previous ENSAR activity reports.

USERS MEETINGS

A meeting of the LNL User Board was held on 8 November 2013 at LNL. Three meetings of the LNS User Committee were held on 6 December 2013, 1 October 2014 and 21 November 2014 at LNS. Moreover, several meetings and workshops, related to the Transnational Access activity, were also held at LNL and LNS during the third reporting period (see table below).

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

Annexes: Annexes 1 to 4 are included in the MS Database. Annex 5 is attached to the periodic report.