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REPORT ON THE STATE OF THE ART OF TARGET ACTIVITIES FOR NUCLEAR PHYSICS

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Abstract:

The present document reports on the state-of-the-art in the field of targets for Nuclear Physics and collect the requests from the institutions participating in the first phase of the WP2-5-2 work package of EURO-LABS.

For more information on EURO-LABS, its partners and contributors please see https://web.infn.it/EURO-LABS/

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Executive summary

The present document reports on the state of the art in the field of "targets for Nuclear Physics" and collects the needs from the institutions participating in the first phase of the WP2-5-2 work package of the EURO-LABS project. The document is structured in two parts. The first part summarizes the aims and tasks of the working group WP2-5-2. The second part of the document gives an overview of target fabrication techniques and characterization procedures already available at each institution participating at WP2-5-2. Needs or plans for the coming years, regarding target production and characterization, which have emerged at this initial stage of the project, are also reported. The resulting document is a crucial starting point to foster the connection between different nuclear physics institutions in Europe and associated countries, with the aim to create and maintain a distributed infrastructure for target development, production and characterization.

1. INTRODUCTION

The present document reports on the state of the art in the field of "targets for Nuclear Physics" and collects the requests and needs from the institutions participating in the first phase of the WP2-5-2 work package of the EURO-LABS project.

The document is structured in two parts. The first part summarizes the aims and tasks of the WP2-5-2 working group which, in the this first phase of the project includes 12 institutions. The second part of the document gives an overview of target fabrication techniques and characterization procedures already available at each institution participating at WP2-5-2 and a list of needs or plans regarding target production and characterization activities for the coming years.

2. TASKS AND OBJECTIVES OF WP2-5-2 – SERVICE IMPROVEMENTS – TARGETS

2.1. OBJECTIVES

The goal of the activities of WP2-5-2 is to gather, at a European level, the community of nuclear target makers and users having specific expertise in the field of target manufacturing and characterization, both for nuclear and applied physics purposes. Different research areas and applications, indeed, require high quality targets, ranging from fundamental physics (nuclear reaction studies, nuclear data measurements etc.) passing through specific targets for strippers and neutron converters, up to the development of (usually) isotope-enriched targets for high quality standard medical radioisotope production. Target preparation is often a crucial step on the path towards the achievements of nuclear physics experimental results, or specific final nuclear "products".

Therefore, WP2-5-2 proposes the creation of a distributed research infrastructure across the participating research centres, aiming at an improvement and sharing of the already existing and available target activities, contributing to production and characterization of targets of interest for European and international nuclear physics research programs, as well as for the applied physics community. Such an infrastructure would promote the collaboration and networking among different laboratories in Europe and research groups, interested in those aspects, and in the related sharing of ideas and projects, with the final goal to improve the service of the participating European research infrastructures (RI) for their internal and external users.

As known, the community of nuclear target makers is restricted and spread over Europe and none of them can cover all the expertise and know-how at a given skill level at each accelerator RI. Such a mutual exchange of know-how is thus necessary to guarantee high-quality production capabilities at all participating sites with potential benefits for future partners. The ultimate objective is the creation of a "distributed service" by supporting periods of visiting researchers for training, education, and mutual know-how exchange.

2.2. DESCRIPTION OF THE WORK

In addition to the "standard" target manufacturing techniques, aimed at nuclear physics studies, already provided on a routine basis by target laboratories in some research centres across Europe, the new frontier in nuclear fundamental-, as well as applied-physics studies (e.g., medical radioisotope production) is oriented towards the need to efficiently exploit the high intensity beams nowadays available at high-performance accelerators. This goal is critically related to target production techniques and procedures, pushing the already available techniques. Therefore, such a "target" service should follow the main steps summarized by the following proposed tasks:

- **Task 1** - Target materials: To set the state of the art of the used materials (e.g., enriched isotopes including actinides and other radioactive species, alloys, doped materials, highly oriented pyrolytic graphite etc. which could withstand higher working temperatures) often provided by suppliers in chemical forms or with characteristics different from the expected ones. Moreover, low-Z targets, working at cryogenic temperatures (either in gaseous or liquid/semi-solid state) and e.g., inverse kinematics reaction studies with their implications for target robustness and the choice of the target material, are considered as well.
- **Task 2** – Improvement of already available fabrication techniques: Not always the standard manufacturing techniques, already available and used in the field (e. g. electrodeposition, evaporation, electrophoretic, conventional sintering and brazing, mechanical rolling, laser

melting etc.), meet the requirements to get targets having uniform layer thickness, a high heat transfer effectiveness, good mechanical properties, high chemical purity. Moreover, when highly-enriched actinide and other radioactive isotope targets (very costly and/or rare) are needed, it is mandatory to limit material losses to a minimum. Task 2 proposes to improve (i.e. pushing the limits) already available target production techniques, such as Vacuum deposition – PVD, Spark Plasma Sintering (SPS), High-Energy Vibrational Powder Plating (HIVIPP), ion implantation, drop-on-demand deposition.

- **Task 3** – Target characterization procedures: In order to assess the most suitable manufacturing procedures the main target properties (i.e. deposited layer thickness and uniformity, homogeneity, areal density, quantification & identification of contaminants and impurities, damage during irradiation etc.) need to be determined. Indeed, this aspect has a direct impact on the quality of the measured physical parameters during an experimental run, as well as on the quality of radionuclide yields. A set of instrumentation is therefore necessary in equipped characterization laboratories, that will allow studying the samples, before and after the different manufacturing steps. For example, techniques like the Scanning Electron Microscopy (SEM), Energy-dispersive X-ray spectroscopy (EDS), X-ray photoelectron spectroscopy (XPS), Rutherford Backscattering Spectroscopy (RBS), Particle Induced X-ray Emission (PIXE), infrared and Raman Spectroscopy, Alpha-particle Transmission Spectroscopy (APT), Inductively Coupled Plasma – Mass Spectrometry (ICP-MS), electron-beam diagnostics during irradiation etc., are already existing, although not all available in all laboratories and for all the interested users. A distributed service network, among different laboratories performing such transverse activities, is thus necessary. In-beam test activities at some accelerator facilities are anyway needed, to assess the prototype targets under real experimental conditions.
- **Task 4 –** Sharing of knowledge: Fostering the connection between different nuclear physics institutions in Europe and associated countries with the aim to create and maintain a distributed infrastructure for target development, production, and characterization. A fundamental feedback and exchange of information is necessary among researchers involved in target developments, target makers and final users. Synergies with existing associations such as the International Nuclear Targets Development Society (INTDS) are envisaged.

3. PARTICIPATING INSTITUTIONS

In the present Section, an overview of target fabrication techniques and characterization procedures already available at the institutions involved in the initial stage of the EURO-LABS project and of the needs and challenges for the coming years are listed. The Section is organized in different subsections, one for each of the institutions participating at this stage. The participation of other institutions and laboratories is welcome and is part of the objectives of the project.

3.1. INFN – LABORATORI NAZIONALI DEL SUD (INFN – LNS)

The Target Laboratory (laboratory of physical-chemical techniques) of INFN - Laboratori Nazionali del Sud (LNS) – Italy provides targets for nuclear physics experiments performed at LNS using the two accelerators, the Tandem Van de Graff and the K800 Superconducting Cyclotron. It typically produces foils of metal and non-metal materials, salt compounds, organic compounds for a wide variety of stable isotopes, as listed in https://www.lns.infn.it/en/targets.html. The laboratory produces targets for LNS researchers and collaborators who perform their experimental activities at LNS and at collaborating institutions. Moreover, it deals with the preparation of the stripper foils for the accelerator machines and the cathodes for the sputtering negative ion sources, and develops and carries out chemical treatments and special chemical cleaning. It also takes care of the deposition of specific BaF2 viewers for beam diagnostic.

At the LNS target laboratory three main machines for target preparation are presently available:

- a Leybold L300 evaporator with two thermic sources;
- a Leybold-Heraeus L560 with a thermic and an electron beam sources;
- a rolling mill

Both the evaporators are equipped with a quartz crystal microbalance which monitor the thickness measurement of the deposited material during the evaporation process. It is possible to set the distance between the source and the substrate by using cylindrical glasses of several heights. Moreover, the L560 evaporator has a halogen heating element to fix the temperature of the substrate, if needed.

The physical vapor deposition technique is typically used to produce thin foils (thickness less than 1 μm) by thermal evaporation or using an electron beam source depending on the fusion temperature of the material. The depositions are done on thin backing foils (made of C, Al, Au, etc.) or self-supporting. Cold lamination (rolling) techniques are used in the case of metal targets with thicknesses greater than 1 μm. The metal foil is progressively thinned with a cold rolling mill in a sandwich process between two hardened stainless steel plates until it reaches the desired thickness. Solvent casting techniques are also used to prepare polyethylene or deuterated polyethylene films.

The targets produced at LNS are typically characterized in terms of thickness and uniformity. During the evaporation procedure, the thickness of the deposited material is continuously monitored using a quartz micro-balance (quartz crystal monitor), placed inside the evaporation chamber. When high precision in the thickness determination of the produced thin foil is needed, it is further analysed by using a dedicated machine, based on alpha-particle energy-loss measurements. The machine consists of a high vacuum chamber with four movable plates which hold the foils to be characterised. The measuring system is made of an arm containing a collimated ^{241}Am alpha source located in front of a surface barrier silicon detector. The target to be characterized is located in between the source and the detector. The arm has been designed to scan the whole target size. A software has been developed for the control of the machine which automatically performs the measurement of a sequence of targets. This system also provides the uniformity of the targets, determining the thickness on different points of the surface of the same target with a precision better than 1 mm. When the thickness of the film is greater than about 1 μm and can be handled without breaking, its weight can be determined also by an analytical balance and the thickness deduced accordingly.

Other equipment available at the LNS target laboratory are:

- an optical microscope;
- an analytical balance with precision 10^{-5} g;
- a technical balance with precision 10^{-2} g;
- a chemical hood;
- an oven to heating up till 200°C

In the coming years the laboratory will be equipped with a new evaporator with two thermal sources, one electron beam source, a heating/cooling system to set the substrate temperature and a system to change the distance between the source and the target substrate.

The possibility to produce thin targets, high performing in terms of thickness uniformity, together with an accurate measurement of thickness, is an important challenge in present and forthcoming years at LNS. This task is crucial especially when the targets are used for nuclear physics experiments where absolute reaction cross sections need to be measured with high precision. This request is even more stringent for experiments with relatively low energy beams or medium to heavy beams (such as the ones available at LNS), where the energy and angular straggling of the beam in the target foil plays a crucial role.

The production of thin and uniform targets of quite large area (10 cm^2 or more) for their application with large spot size beams, such as radioactive beams, has also required and will require some effort at LNS.

In addition, in view of the high beam intensities expected after the LNS upgrade, which is presently ongoing, the development of targets which are tolerant to high beam rate conditions is becoming a crucial task. As an example, the study of deposition procedures on specific substrates of graphene-based foils is ongoing.

The minimization of the amount of material used for the preparation of the targets is another challenge in view of the limited availability and of the increasing cost of many compounds or isotopic materials. Improvements of the parameters of the already used vapor deposition techniques or further development of chemical deposition techniques can help in specific cases.

The use of noble-gas targets is a request of different nuclear physics experiments. Ion-implantation techniques based on the use of ion implanters, such as the one present at the physics and astronomy department of the University of Catania, are being explored at LNS. In addition, the possibility to exploit the already available technology of Electron Cyclotron Resonance (ECR) source for ion-implantation purposes is also an interesting opportunity. Other techniques, such as the magnetron sputtering based methodology to produce amorphous silicon coatings with closed porosity, have been developed at Instituto de Ciencia de Materiales (Sevilla, Spain) as a strategy to fabricate solid helium targets, and used for tests and experiments at LNS and ISOLDE.

3.2. INFN – LABORATORI NAZIONALI DI LEGNARO (INFN – LNL)

The main activities of the Targets Laboratory for Nuclear Physics (NP) studies are the study and preparation of targets for nuclear physics experiments to be conducted at LNL or in foreign laboratories. In most cases, thin films of isotopically enriched metals are obtained using different techniques. Different types of targets can be obtained:

- Self-supporting;
- With backing;
- Strip-targets;
- Sandwich-targets;
- Plunger-targets;
- Cryogenic $^{3,4}He$ targets at 9 °K are also being developed to achieve thicknesses of 3-5 10^{20} at/cm^2 to carry out inverse kinematic nuclear reactions' studies.

The instrumentation to carry out these activities includes many devices, including a fume hood designed to work with powders, equipped with a high precision scale. Moreover, a roller working under inert atmosphere (glove-box used also to manage reactive substances), three high vacuum evaporators including a cryogenic one, a tube furnace capable of working in inert or reactive gas or vacuum that can operate at temperatures up to 1500 °C. About the cryogenic target, a Gifford McMahon device is used as cryogenic source. It is conceived to be a portable device.

At the time being, the following target preparation techniques for thin films and foils are available:

- Thermal evaporation from crucibles and boats;
- Thermal resistance heating of high-purity carbon;
- DC ion-beam sputtering;
- Electron beam evaporation;
- Rolling mills;
- Rolling mills under inert gas atmosphere.

Thickness as well as characterization of produced target are controlled by:

- Quartz Crystal Monitor QCM during vacuum evaporation;
- Weighing the obtained film after determining the exact area with a proper software;
- Alpha source and proton/alpha beams from the CN accelerator for the cryogenic target.

For the coming years:

- Development multi-isotope standard and plunger targets;
- Upgrade ion-beam sputtering device to develop new type of targets.

Another activity started a few years ago is the development of innovative techniques to produce targets for beam irradiations at cyclotrons aimed at:

- nuclear cross section measurements;
- medically relevant (either innovative or already used) radionuclides production.

Targets for nuclear cross section measurements have usually thicknesses in the range 1-20 µm. Targets for radioisotopes production are instead thicker, ranging between 100 µm – 1 mm. At LNL, the three following manufacturing techniques are under continuous development and constantly improved, (the first one in the list is used for producing xs targets only):

- High Energy Vibrational Powder Plating (HIVIPP);
- Magnetron Sputtering (MS);
- Spark Plasma Sintering (SPS).

The laboratory is also equipped with a cryogenic mill for grinding at a few micrometric sizes inhomogeneous, sponge-like, isotope-enriched powders delivered by manufactures.

The Target Materials characterizations Laboratory for NP studies is involved in different experiments and collaboration regarding solid targets production and characterization.

The laboratory is equipped with different PVD magnetron sputtering apparatuses, dedicated to the synthesis of novel materials for NP experiments. The target thickness achievable by using the existing setups are in the range from a few nanometres to several micrometres.

- Reactive and non-reactive magnetron sputtering system for high purity materials, oxides, nitrides and hydrides;
- Reactive magnetron sputtering system for NP target production by using isotopically enriched gas

The sputtering plasma technologies available are:

- DC, pulsed-DC, RF, HiPIMS;

- Different active optical emission spectroscopies (OES) for reactive sputtering process' control;
- Static and rotation sample holders;
- Magnetic field confinement;
- Plasma cleaning in situ before sputtering deposition.

The characterization of developed targets includes morphological and compositional analysis with standard techniques (Laboratory of Material for NP) and Ion Beam Analysis (IBA) nuclear techniques (using the Van de Graaff CN and AN2000 accelerator facilities present at LNL).
The main characterization techniques are:

- Optical microscopy (OA);
- Scanning electron microscopy (SEM);
- Energy Dispersive X-ray spectroscopy (EDX);
- Atomic Force microscopy (AFM).

Nuclear IBA techniques:

- Elastic Backscattering Spectrometry (EBS);
- Nuclear Reaction Analysis (NRA (d,p), (p,α), (d,α));
- Elastic recoil detection;
- Proton Induced X-ray Emission (PIXE and micro-PIXE)
- Proton Induced Gamma-ray Emission (PIGE)

3.3. INFN – TURIN AND POLYTECHNIC OF TURIN

The equipment and facilities available in Turin (Italy) for target manufacturing studies belong both to the INFN (Sezione di Torino) and Polytechnic of Turin. The INFN mechanical workshop has a proved experience in producing custom items for a variety of purposes. The produced items, such as sample holders, target holders, upgrades for existing target production equipment, can be used to improve or ease the target fabrication. A few experimental areas for prototype testing are also available. At Polytechnic of Turin, more specifically at the Department of Applied Sciences and Technologies, a large array of equipment for target characterization is available. A non-exhaustive list includes:

- Alpha Particle Spectroscopy setup;
- X-ray transmission setup;
- Field Emission Scanning Electron Microscope – XPS;
- Atomic Force Microscope;
- Micro-Raman spectroscopy;
- FIB-TEM;
- XRD

Among the target properties that can be studied, one can include thickness, thickness uniformity, surface imaging, elemental purity, crystal structure and order.

3.4. GSI/FAIR

The target laboratory of GSI / FAIR has a conventional lab space with three different areas for coating, for analytics, and for chemistry and preparation. In addition, there is a lab under radiation surveillance where we have an allowance to work with natural uranium and with in ^{235}U depleted uranium and its compounds.

Eight high-vacuum coaters are available in the conventional lab and one in the radiation surveillance area.

In the moment, the following target preparation techniques for thin films and foils are available:

- Thermal evaporation from crucibles and boats;
- Thermal evaporation from a ceramic heater;
- Thermal resistance heating of high-purity carbon;
- DC and RF magnetron sputtering with 1” and 3” magnetrons;
- DC magnetron sputtering of magnetic materials;
- Electron beam evaporation;
- Cleaning of the substrate surface with glow discharge is available in several machines.

For preparation of thicker foils two cold rolling mills are available, one in the conventional lab and one in an argon glove box in the surveilled area. For thick and bulk targets, we have two machines for lapping and polishing to prepare thin sections and polished surfaces with optical quality.

For thermal pre- and post-treatment we have different furnaces for heating up to 1600 °C in air, in vacuum, in inert, reducing or oxidizing atmosphere. The furnaces can also run in a walkable fume hood.

For analytics and quality control of targets and backings, the following equipment is available:

- A 3D digital microscope;
- Optical microscopes;
- A Scanning Electron Microscope with an energy Dispersive X-Ray Analysis;
- Several high precision balances (two in argon glove boxes);
- Mechanical target scanner for thickness measurement of large samples;
- Optical scanner for thickness and surface measurement;
- UV-vis Photometer;
- Mechanical gauges.

For safe preparation, storage and packing of oxygen-sensitive or hygroscopic materials we have one argon glove box in the conventional lab and one in the surveilled area that has another box with a built-in roller attached.

We have a large inventory for pure and rare materials, and for highly enriched isotopes.

The main requirements for the coming years are:

- Development for electro deposition and molecular plating for conventional materials;
- Reduction of isotopically enriched material, beginning with rare earth oxides.

3.5. GANIL

The target laboratory was set up at GANIL in 2002 in order to produce isotopically enriched targets for nuclear physics experiments and metallized foils for detectors. Targets are mainly produced for GANIL’s user and occasionally for experiments performed outside the laboratory.

The used methods are mainly based on mechanical, thermal evaporation or sublimation and polymerisation principles and rarely with chemical methods.

The equipment of the laboratory consists of:

• 1 12T manual press for pellets or powder mixture preparation;

• 2 cold rolling mills: one manual and one motorized placed in a glove box to work under inert atmosphere for thick foils production used as backings or targets;

• 4 vacuum chambers equipped with following Physical Vapor Deposition techniques and associated systems:

o One thermal resistance heating of high-purity carbon rods (3 mm diameter, 75 mm length) for large carbon foils (20*20 cm²; 10-70 µg/cm²);

o 2 resistive heating of crucibles or boats for thermal evaporation of metallic, low melting point materials, one dedicated to isotopically material for targets and one to natural material for metallisation of foils for detectors;

o One electrostatically focussed electrons system heating a crucible for oxide material to reduce and evaporate them as metallic form;

o One electron gun system (3 to 6 kw) heating directly the material in a cooled crucible for high-melting point material because they are highly reactive at elevated temperature;

o Quartz Crystal Monitors controlling the deposit thickness during the PVD processes;

o A rotating wheel with up to 8 frames and backing;

• A fume hood;

• A heating plate and auxiliary equipment for large –(CH)2- or –(CD)2- targets made by polymerisation;

• An electro-deposition cell, i.e. used for osmium targets in collaboration with CIMAP;

• 2 glove box;

• 2 microbalances for density areal measurements.

To evaluate the thickness homogeneity, the methods of alpha particle energy loss and electron attenuation with a 20 keV electron gun are commonly applied at GANIL.

More precise analyses (target composition, chemical purity, thickness, structure, morphology) are performed with advanced techniques of collaborative laboratories (JANNuS-SCALP, CIMAP...)

In the coming year, we plan to upgrade the target laboratory with new evaporators as described above and a DC and RF magnetron sputtering system for monoisotopic natural material. Moreover, we plan to get a XRF system to evaluate the chemical composition of produced targets. A program of R&D will focus on reduction of isotopically enriched lanthanides required for heavy & super-heavy elements, astrophysics or radioisotopes for medical application studies. With this new equipment, we should be able to manufacture targets of various kinds, on a large scale number, characterized by rigorous quality control.

Indeed, with the commissioning of SPIRAL2 and the new experimental areas NFS and S3, a new era is dawning for GANIL, which will increase its capacity to supply beams and attract new scientific communities. The requirements of high-quality targets in large quantity are then enlarged to actinide targets, lanthanides and new metals not already produced at GANIL. For some metallic and actinide targets, collaborative programs are set up with French and European partners for the development of chemical deposition techniques and of backings withstanding high intense beams.

3.6. UNIVERSITY OF WARSAW

The target service at Heavy Ion Laboratory, University of Warsaw has very basic equipment allowing targets production with:

- mechanical reshaping: by rolling (rolling mill with adjustable rolling speed/rate) and pellet pressing with help of hydraulic press. The pellets are formed in the die assuring the air removal while forming the pellet.
- high vacuum thermal evaporation. The deposit thickness is controlled during the deposition process with Quartz Crystal Monitor QCM and the thickness of the final product/target and its distribution over the target area is cross-evaluated with APEL (Alpha Particle Energy Loss) measurements.

Thickness of the product/target is controlled by:

- mechanical and electrical thickness measuring tools such as: micrometer screw and calliper, and induction gauge (range 1±0.1 ÷ 500 ±10 µm);
- weighing defined area (using microbalance with 1 µg precision);
- Alpha Particle Energy Loss (APEL) measurements. The APEL technique is used as well for thickness homogeneity evaluation.

The target composition analyses are planned to be performed applying RBS (Rutherford Back Scattering) technique in collaboration with Institute of Nuclear Physics in Kracow on case to case bases.

Additional equipment are:

- chemical fume food;
- small glove box allowing simple procedures to be carried under an inert atmosphere.
- optical microscope;
- small oven with maximum temp 1100 °C;
- home made small desiccators for storing the air and humid sensitive targets and materials during preparation process. For longer storage the classical vacuum desiccators are used.

The main requirement for coming years is the replacement the electron beam heating system.

3.7. CNRS – IJCLAB

Target activities exist at IJCLab around two platforms, ALTO and JANNuS-SCALP.

The JANNuS-SCALP facility (IJCLab, Orsay) is centred around ion accelerators and microscopies for materials science, used for various topics and applications. It is open to external academics and industrial users.

The three ion accelerators are:

- ARAMIS, a 2 MV home-made Tandem-Van de Graaff ion accelerator, equipped with two ion sources Penning and Middleton;
- IRMA, a 190 kV home-made ion implanter equipped with a Bernas-Nier ion source;
- SIDONIE, a 40 kV home-made isotope separator equipped with a Bernas-Nier source.

A large diversity of ions is available for deposit, implantation and irradiation, in a large range of energies (50 eV – 10 MeV) and temperatures (from LN_2 to 1000°C). Ion beams are also used for analysis of materials. *In situ* characterization is one of the specificities of the facility.

The available elements are listed here: https://jannus-scalp.ijclab.in2p3.fr/en/irradiations/.

Complementary techniques are available for characterizing materials in terms of elementary composition, crystallographic structure, damage and defects, deformation, morphology, and thickness (no capabilities for radioactive or toxic element, except depleted UO_2):

- Ion beam analysis (IBA) techniques (Rutherford Backscattering Spectrometry (RBS), Channelling, Elastic Recoil Detection Analysis (ERDA), Proton Induced X-ray Emission (PIXE), …); RBS-C can be performed *in situ* with one ion beam coming from IRMA ion implanter;
- Atomic Force Microscopy (AFM);
- Scanning Electron Microscopy (SEM), coupled to Energy Dispersive X-ray Spectroscopy;
- Transmission Electron Microscopy (TEM); the microscope is coupled to two ion beam lines coming from IRMA and ARAMIS accelerators, allowing *in situ* observation and analysis at the nanoscale of ion-irradiation induced effects in a material;
- X-Ray diffractometry (XRD); will be available in the next two years, the diffractometer will be coupled to one ion beam line of ARAMIS accelerator (SIXPAC project).

Requirements for the coming years are:

- Update the EDXS system on our Scanning Electron Microscope;
- Re-start the production of isotopically pure stable targets using SIDONIE (depending on human resources available and on-going renovation).

The ALTO facility target Laboratory (IJCLab, Orsay) is part of the ALTO accelerator facility (https://alto.ijclab.in2p3.fr). It exists for research into the development of thin films, with and without support, which form the basis for a wide range of products used in various scientific and industrial fields. Targets, filters and deposits range from a few micrograms to several milligrams. It has the technical capability to evaporate most natural and isotopic materials. Thin film targets and filters are manufactured using the following three techniques

- Electron gun
- Joule effect
- Electron bombardment

As an example, natural isotopes can be used: Ag, Au, Al, C, Cu, Si, etc. Enriched isotopes such as Ca, Ge, Mg, Ni, Sn can also be used. Particular deposition studies can be envisaged for specific experiments or for targeted applications (surface coatings, aluminisation of scintillants, rare or difficult to make isotopes).

The experience and know-how acquired in this field enables the ALTO targets department to carry out self-supported deposits and films with a large surface area under good conditions and within the shortest possible time. IJCLAB's Target Department produces targets for experiments at ALTO and other national and international laboratories: GANIL in Caen, CEA in Saclay, LULI Polytechnique, CEA in Bruyeres le châtel, Belgium, Netherlands, etc.

The electric arc technique is used to make thin carbon targets of 10 to a few microns. Equipment for measurements with the Joule effect technique is used for targets of various materials. The Electron Gun technique can be used for all types of large surface materials up to 400 mm. Electron Bombardment techniques are used for rare isotopic materials from 100 $\mu g/cm^2$ to 1 mg/cm^2. Chemical techniques are used for polymers and plastics. Lamination cab be used for high thicknesses from 5 to 20 µm and more. Thickness measurements are performed by alpha particles from ^{241}Am energy loss measurements through targets for small thicknesses below one micron.

3.8. CNRS – IPHC STRASBOURG

The DNE group from IPHC Strasbourg is actively involved in the spectroscopy and synthesis of new superheavy elements and the superheavy program of S3-SIRIUS. Intense metal beams and targets that can withstand these extreme conditions are essential for such programs.

The group had developed a rotating target for the first prompt spectroscopy of a superheavy, the ^{256}Rf at Jyväskylä. Following this success, we took part in real-conditions target tests at RIKEN.

With the support of a USIAS grant (Institute for Advanced Studies of the University of Strasbourg), we are developing target backing development lab at IPHC. The aim is to be able to find target backing material able to support beam intensities up to 10 pμA (^{48}Ca, ^{50}Ti, ^{51}V, ^{54}Cr). We work on two major issues:

- thermal dissipation;
- structural defects induced by high dose effects.

The main requirements regarding target production and characterization for the coming years are the following:

- The lab will enable to produce, anneal and characterize the foils (mechanical characteristics, thickness measurements with submicrometric precision, lamination, annealing…) but also to make metal deposits using our induction oven, and potentially to deposit the target materials directly to the IPHC. We are in the process of procuring the necessary equipment and expect to be ready in the first half of 2023;
- Testing of these foils will be done at GANIL and RIKEN depending on the availability of irradiation time. We hope to make several test-runs per years.

3.9. CEA - SACLAY

The Super Separator Spectrometer (S3) facility is developed in the framework of the SPIRAL2 project at GANIL. S3 has been designed to extend the capability of the facility to perform experiments with extremely low cross sections, taking advantage of the very high intensity stable beams of the superconducting linear accelerator of SPIRAL2. One of the main areas of research will be the production and studies of Super-Heavy Elements (SHE) synthesis, and very heavy elements (VHE) produced by fusion-evaporation reactions. Detailed decay spectroscopy studies and high precision mass measurements will be possible at S3.

The development of S3 has required the solution of three major technological challenges: the need for very intense heavy ion-beams to access very low cross section reactions (picobarn), the need for a powerful recoil separator with high mass resolution to ensure the selection of the ions of interest, large transmission capabilities, and the need of the developments of targets and target stations able to withstand the high beam intensity provided by the LINAG accelerator.

In the first years of the S3 spectrometer's use, there will therefore be a need for a large quantity of stable targets that will serve during the first day's experiment at S3 (^{208}PbS (350 μg/cm^2), ^{209}Bi (450 μg/cm^2)). The CEA will therefore support this development in collaboration with the GANIL laboratory.

At CEA, a measuring system has been put into operation in order to verify the thickness and uniformity of the carbon foils produced at GANIL, which will then be used in combination with the different stable targets for charge state equilibration. The system consists of:

- Vacuum chamber;
- Alpha-particle source;

- Silicon detector;
- A motorized support to move the sample foils.

In the medium term, for the mass production of super heavy elements, it will be crucial to develop targets based on actinide nuclei (^{248}Cm (200-300 µg/cm²), ^{243}Am (350 µg/cm²), ^{238}U(350 µg/cm²)). New methodology for the production of actinides targets needs to be developed, in collaboration with the GANIL.

3.10. IFIN-HH

The laboratory has high performance equipment that allows the production of targets using the following main methods:

- PVD- physical vapor deposition methods;
- cold rolling;
- tablet pressing techniques.

Beside these, other methods are available in the frame of our collaboration with other laboratories of IFIN-HH or of other physics institutes from the same campus in Magurele – an example in this respect is the PLD method.

The equipment we currently use in the laboratory for target production consists in:

- 2 PVD sistems with resistive heating, electron beam-based systems and RF magnetron sputtering with 1" – used for self-supporting and backing supported targets with thicknesses from tens of µg/cm2 up to mg/cm2;
- 2 electrically controlled rolling mills - for thicker foils production;
- 2 automated hydraulic presses of 25T and 40T respectively, with 40mm, 32mm, 20mm, 13 mm, 20mm and 5mm evacuable pellet dies - for self-supported thick targets production;

Other auxiliary equipment used to provide support for the numerous other activities required for target fabrication are:

- 2 analytical balances;
- 1 tube furnance with a gas supply system for protective gas or vacuum operation which can be operated at temperatures up to 1300°C;
- 1 microcentrifuge for high-speed laboratory applications as ultrafiltration;
- 1 incubating orbital thermal shaker for heating applications;
- 1 inert gas glove box for handling of targets that may oxidize quickly;
- oven, vacuum oven and constant climate chamber for different thermal treatments.

The obtained targets are characterized in terms of thickness, phase composition, crystalline structure, chemical purity and morphology by using multiple advanced techniques such as:

- Rutherford Backscattering Spectrometry;
- Proton Induced X-ray Emission;
- Proton Induced Gamma-ray Emission;
- X-ray Diffraction;
- Optical microscopy;
- Atomic Force Microscopy;
- Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy.

The main requirements regarding target production for the coming years are:

- Development of methodology for production of isotopically enriched oxygen (Ta_2O_5) targets by anodisation of tantalum backings in enriched water, for inverse kinematic nuclear reactions and nuclear astrophysics studies. This method will be developed in collaboration with the group from INFN, Laboratori Nazionali del Gran Sasso, Assergi, Italy.
- Development of electro deposition and molecular plating methods.

3.11. LIP - LISBON

The target laboratory at the LIP/FCUL (Laboratory of Instrumentation and Experimental Particle Physics (Lisbon) and the Faculty of Science, University of Lisbon), has a laboratory space, where the thermal evaporator is installed. This is a Balzers cylindrical shape chamber equipped with two pumping (primary and turbo) systems, allowing to reach pressure down to 1e-7 mbar. Additional water cooling of the chamber is installed with a chiller to reduce the exhaust from the walls and thus reach better pressure values.

The thermal evaporator is equipped with two sets of anode-cathode pairs allowing for the production of sandwich targets or simultaneous evaporated targets from crucibles, wires and boats. Presently, the system is equipped with a support to hold glass slides on a horizontal platform, movable in distance and allowing for a deposition surface of about 70 cm2.

For analytical and quality control of the targets, the following equipment is available, or we have access to:

- Local setup to determine the loss of energy through a thin film with two different alpha emitting sources;
- X-ray fluorescence setup to determine impurities;
- Atomic microscope (within the faculty of science);
- Access to a 3 MV van de Graaff accelerator at the CTN / IST facility, RBS analysis can be carried out using either protons or alpha particles (this laboratory is included in the TNA CLEAR, as part of the EURO-LABS consortium).

The laboratory is managed and predominantly used by the nuclear reaction group NUC-RIA, a group whose main activities are focused on the execution and analysis of nuclear reactions at various energies. Targets have been manufactured so far for experiments proposed by the group, as well as for other experiments in the framework of collaborations with other nuclear physics groups. As we are a small laboratory we entered in the Consortium as associate members.

3.12. PSI

The Isotope and Target Chemistry group at Paul Scherrer Institute (PSI) is not only concerned with target fabrication, but also with the extraction and processing of exotic radionuclides, which are of great importance for many scientific applications. Our portfolio makes us one of the few laboratories in Europe that can produce and handle this type of samples and – after manufacturing – provide unique targets tailored for a considerable number of scientific experiments.

We have laboratories in controlled zones in all three categories as well as the appropriate measurement equipment to detect a-, b-and g-radiation (HPGe, LSC, Silicon detectors).

One of our focal points is the extraction of radionuclides from activated components of the accelerator facilities at Paul Scherrer Institute. PSI operates the Spallation Neutron Source SINQ, which is driven by one of the most powerful high-energetic proton accelerators world-wide (590 MeV, up to 2.4 mA), and is therefore best-suited as a source of rare exotic radionuclides, which can hardly be produced by other means. In the frame of the ERAWAST (Exotic Radionuclides from Accelerator Waste for Science and Technology) initiative, a complex program for isotope separation from different matrices has been established at PSI within the past decade.

Currently, we have a range of radioactive isotopes such as ^{44}Ti, ^{10}Be, ^{26}Al and many others separated and purified available.

The methods we use for radiochemical separation and preparation are distillation/evaporation, precipitation, extraction, ion exchange chromatography and extraction chromatography.

We use the common target preparation methods like droplet deposition and molecular plating, whereas we are currently also working together with master and bachelor students on the improvement of the method using ionic liquids.

For the quantification of the wanted isotopes we use radiation measurement technology as well as mass –spectrometric methods, in particular in cases, where information on the isotopic composition in the target is needed (ICP-MS). Thickness measurements can be performed using α-spectrometry in cases of thin backings and we apply autoradiography for determination of the radionuclides distribution within the target.

For the production of isotopically pure samples and targets we plan to install a dedicated mass separator.

Further details on what we are doing can be found on our webpage: https://www.psi.ch/en/lrc/isotope-and-target-chemistry.

4. SUMMARY

The present document represents the first milestone delivered by the WP2-5-2 work package on “targets for Nuclear Physics” of the EURO-LABS project. It is part of the work package “Access to Research Infrastructure for Nuclear Physics” and in particular of the task “Service Improvements”.

The goal of the activities of WP2-5-2 is to gather the community of nuclear target makers and users having specific expertise in the field of target manufacturing and characterization, both for nuclear and applied physics purposes. Different research areas, ranging from fundamental nuclear physics passing through targets for strippers and neutron converters, up to the development of targets for medical radioisotope production, indeed, require high quality targets. Therefore, WP2-5-2 proposes the creation of a distributed research infrastructure across the participating research institutions, aiming at an improvement and sharing of the already existing and available target activities, contributing to production and characterization of targets of interest for European and international nuclear physics research programs. Such an infrastructure would promote the collaboration and networking among different laboratories and research groups, interested in those aspects, and the related sharing of ideas and projects, with the final goal to improve the service of the participating research infrastructures for internal and external users.

The initial phases of EURO-LABS, from the preparation of the proposal to the kick-off meetings, have led to an intense and constructive activity of networking and exchange of information among the involved research institutions, already in the first months of the project. The results of such interactions have been summarized in the present document, where the aims and objectives of WP2-5-2 have been discussed. Moreover, in the document, an overview of target fabrication techniques and characterization procedures already available at each institution participating at WP2-5-2 is presented, in some case also in view of the needs or plans for the coming years. The resulting document is a crucial starting point to foster the connection between different nuclear physics institutions in Europe and associated countries, with the aim to create and maintain a distributed infrastructure for target development, production, and characterization.