ACTIVITY REPORT
2017-2019

Laboratório de Aceleradores e Tecnologias de Radiação (LATR)

Campus Tecnológico e Nuclear
Instituto Superior Técnico, Pólo de Loures
Estrada Nacional 10, km 139,7, Bobadela LRS, Portugal
Many thanks to researchers and technicians in providing material for this annual report.

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**Cover Photo:** Norberto Catarino at Van de Graaff Accelerator, under the JET ILW (ITER Like Wall) Eurofusion project.

**Date:** August 2020
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FOREWORD

The Laboratório de Aceleradores e Tecnologias de Radiação (LATR, Laboratory of Accelerators and Radiation Technologies), is a laboratory for development and technology (LDT) of Instituto Superior Técnico (IST) conducting services and research in the area of charged particle beams and radiation technologies. Among the infrastructures and equipment, it hosts a 2.5 MV Van de Graaff Accelerator and an Ion Microprobe end-station, a 3 MV Tandem Accelerator with a micro-AMS system and a 210 kV High Flux Ion Implanter as well as a semi-industrial $^{60}$Co gamma radiation unit.

Around these infrastructures and equipment, different groups of users develop their activities, from research to industrial applications (as it is the case of irradiations services performed at the $^{60}$Co source), focused on areas related with Material Science, Environment, Health and Biomedical Sciences and Conservation and Cultural Heritage. These broad ranges of applications promote and attract strategic collaborations with several institutions and universities, both at national and international levels.

Alongside these activities, strong emphasis has been continually put on postgraduate teaching and training, by actively enrolling graduate students in research activities, leading to masters and doctoral theses.

During 2017-2019, the activities in the Laboratory were focused in two major pillars: advanced services and support to research activities and teaching. Services were mostly provided under radiation technologies and nuclear instrumentation, while the team responsible for the accelerators and X-ray operation supported the research and teaching activities. All these activities were performed under the coordination of the 3 units integrating LATR which is organized according the organigram below.

**Radiation Technologies** unit explores the Unidade Tecnológica de Radioesterilização (UTR, Radioesterilization Technological Unit) using the $^{60}$Co source for sterilization, decontamination, disinfection and conservation with applications mostly to medical devices, pharmaceuticals, cosmetics, raw materials, packing, and laboratory equipment. Moreover, the unit provides assistance to institutions in the field of radiation technology transfer under industrial environment and is partner in several International Atomic Energy Agency (IAEA) technical programmes.
Nuclear Instrumentation unit is active in two areas: development of nuclear instrumentation for measurement and control, with applications in productive sectors of the economy and service sectors as well as the sale and supply of equipment and specialized services, including technical assistance and consulting.

Accelerators and X-ray Diffraction unit has a long standing research activity on charge particle interactions with solids leading research projects and collaborating in several research programmes both National and European. Currently the unit is partner in the project INFRAIA-01-2018-2019 (H2020): Research and Development with Ion Beams – Advancing Technology in Europe (RADIATE) and very active in the European Fusion Programme, EUROfusion.

All the LATR Members belong to the Departamento de Engenharia de Ciências Nucleares (DECN, Department of Engineering and Nuclear Sciences) and during 2017-2019 contributed for the outputs on R&D and services highlighted in the next pages.

The Deputy-Director

Eduardo Jorge da Costa Alves
STATISTICAL TRACK RECORD

Scientific Production 2017-2019

<table>
<thead>
<tr>
<th>Category</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journals &amp; Books</td>
<td>50</td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>Invited Talks</td>
<td>6</td>
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<td>4</td>
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<tr>
<td>Oral Talks</td>
<td>12</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Poster</td>
<td>16</td>
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<td>12</td>
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<tr>
<td>Other Seminars</td>
<td>2</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Education: 2017-2019

- PhD: 9
- MSC: 3
Scientific Projects: 2017-2019

Total Funds: 1.524.456,15 €
# PEOPLE | 1: WORKING TEAM

## R&D | PERMANENT STAFF

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eduardo Alves</td>
<td>Full Researcher</td>
</tr>
<tr>
<td>Katharina Lorenz</td>
<td>Senior Researcher (September 2018)</td>
</tr>
<tr>
<td>Nuno Barradas</td>
<td>Senior Researcher</td>
</tr>
<tr>
<td>Carlos Cruz</td>
<td>Auxiliary Researcher</td>
</tr>
<tr>
<td>José Neves</td>
<td>Auxiliary Researcher</td>
</tr>
<tr>
<td>Luís Cerqueira Alves</td>
<td>Auxiliary Researcher</td>
</tr>
<tr>
<td>Rodrigo Mateus</td>
<td>Auxiliary Researcher</td>
</tr>
<tr>
<td>Rui Silva</td>
<td>Auxiliary Researcher</td>
</tr>
<tr>
<td>Rui Martins</td>
<td>Researcher Contract</td>
</tr>
<tr>
<td>Marta Dias</td>
<td>Researcher Contract</td>
</tr>
<tr>
<td>Victoria Corregidor</td>
<td>Researcher Contract</td>
</tr>
<tr>
<td>Sérgio Magalhães</td>
<td>Postdoctoral Researcher (PhD 2013)</td>
</tr>
<tr>
<td>Marco António Peres</td>
<td>Postdoctoral Researcher</td>
</tr>
<tr>
<td>Hélio Luís</td>
<td>Postdoctoral Researcher</td>
</tr>
<tr>
<td>Adam Przemyslaw Jozwik (Nattan)</td>
<td>Postdoctoral Researcher</td>
</tr>
</tbody>
</table>
R&D | STUDENTS

Djibril Faye, PhD Student (until 2019)
Norberto Catarino, PhD Student (until 2018); Post-doc Researcher
Dirkjan Verheij, MSc Student (until 2018); PhD Student
Daniela Pereira, MSc Student (until 2017); PhD Student
Miguel Sequeira, Researcher Grantee (2018-2019); PhD student
Francisco Antão, MSc Student (until 2019)

TECHNICIANS

Ana Faria, Graduated Technician/Executive Assistant and Accounting
Jorge Rocha, Graduated Technician/Accelerators Operator
Paula Matos, Graduated Technician/Technical Director of UTR
Teresa Pires, Graduated Technician/Multimedia/Logistics
Nuno Inácio, Graduated Technician/Irradiator Operator Chief
Filomena Baptista, Assistant Technician/Irradiator Operator
Tiago Jesus, Assistant Technician/Irradiator Operator
Tiago Sena, Assistant Technician/Irradiator Operator
Ion Beam Applications and Materials
1. Thematic Highlights

**Nano-engineering of wide bandgap semiconductors using ion beams (NASIB)**

In the NASIB project, in collaboration with the Universities of Aveiro and Helsinki and INESC-MN, we are studying the effects of ion irradiation on wide bandgap semiconductors such as GaN, MoO$_3$ and Ga$_2$O$_3$. Understanding ion-solid interactions in semiconductors is important to develop device-processing techniques based on ion implantation as well as to understand the performance of different semiconductors in radiation environments such as space. The figure shows a surprising recrystallization effect of GaN when hit by a swift heavy ion.

This self-recovery of the crystal, revealed by Molecular Dynamics simulations, explains the high radiation resistance of GaN to strongly ionizing radiation. NASIB furthermore exploits the radiation hardness of wide bandgap materials for the development of radiation sensors. Sensors based on GaN microwires as well as thin Ga$_2$O$_3$ membranes have been fabricated and successfully tested for proton and UV light detection.

![Figure showing recrystallization effect of GaN](image)

**Hysteretic photochromic switching (HPS) of europium-magnesium defects in gallium nitride: a potential route to a new solid-state qubit**

In this project, in collaboration with the Universities of Strathclyde and Cambridge and Unipress, Warsaw, we implanted europium ions into Mg-doped GaN. After implantation and annealing in optimised conditions, hysteretic photochromic switching (HPS) is observed.

This switching between the two optically active Eu$^{3+}$ centres, Eu0 and Eu1(Mg), is evidenced in strikingly different photoluminescence lines, as shown in the figure. These distinct Eu$^{3+}$ emission lines...
reveal a change in the microscopic nature of the Mg-Eu defect upon cooling. Interestingly, this 2-level defect system can be switched and read optically. Learning to manipulate these states with more precision has the potential to open up new applications in quantum technologies.

Study of deposition on JET components

The activities during this research were focused on the data analysis of the spectra recorded in the LATR laboratory using WiNDF code, considering the Total-IBA approach. Ion beam analysis results support the general picture of erosion during limiter configurations with local deposition on tile ends far into the scrape off layer. Similar trends of fuel concentrations are observed in all JET operating periods.

Figure 1. Schematic representation of JET ILW materials. Main chamber complied of bulk Be in upper dump plates (DP), inner wall guard limiters (IWGL), outer poloidal limiters (OPL) — highlighted and in green colour; and divertor containing W coated CFC components—highlighted in purple red.
Data on erosion and melting of beryllium upper limiter tiles, so-called dump plates (DP), are presented for all three campaigns in the JET tokamak with the ITER-like wall-IBA analysis performed across the affected tile ridge in both poloidal and toroidal direction revealed a low D concentration, in the range $1–4 \times 10^{17}$ D atoms cm$^{-2}$.
Figure 3. (a) IBA analysis performed on DP-8 along poloidal and toroidal direction; (b) D concentration along toroidal direction highlights a lower D presence on the melted areas along the top ridge of DP-8; (c) D concentration along poloidal direction shows a lower D presence across the melted area of DP-8 with the lowest values reached where the most damage is achieved, in the low field side of the tile and where the Be waterfall structure is generated.

**Divertor tile: 14N HFGC - RH (ILW1+2+3)**
JET had completed three operating periods, ILW1, ILW2 and ILW3, giving an opportunity to make comparisons between tiles exposed to different plasma regimes and compare tiles exposed for all the three periods, ILW1-3 (2011-2016).

Our results give updated fuel inventories and provide comparisons of individual mid-plane limiter tiles exposed during ILW1, ILW2, ILW3 with ones exposed throughout the full operation, ILW1-3. For example, results for D concentration in deposits at the ends of the mid-plane IWGL tile are of the order of $0.1-1 \times 10^{18}$ D/cm$^2$ for tiles exposed in individual campaign, whereas results from a tile exposed for all campaigns show D concentrations at least a factor of three higher. This indicates continual accumulation of fuel in deposits, with no release due to heating. In the central eroded region, exposed to highest heat flux, retention values remain low for all tiles analysed.

Analysis of IBA data from ILW1, ILW2, ILW3 along the inner and outer wall limiters extending poloidally shows the complex fuel retention and erosion/deposition pattern from the top to the bottom.
of the vessel. Most interaction occurs in the central region, which correlates with the heat flux patterns
seen from infrared cameras.

In addition, divertor tiles also reveal a similar deposition patterns after each individual campaign. The
cumulative results after the 3 campaigns show are shown in figure below. The high deposition rate of
Be occurs on tile 1 together with deuterium. Shadowed areas of tile 4 reveal the presence of different
impurities (C and O) as well as Be and D. A detailed overview of all the results can be found in the
contributions presented at conferences and published in reference journals.

The studies on the chemical reactivity and phase formation in materials involving Be/C/N/O/W prove
the impact that temperature and impurities (O, C) represent on the retention of D in the mixed deposits
during plasma wall interactions.

Optical activation of different optical centres based on rare earths in Ga2O3

During the last two years a special effort has been done in order to optimize the implantation conditions
of different optical active centres based on rare earths. Two publications resulted from these studies,
about the Eu implantation in Ga2O3 and several oral and poster presentations. More recently promising
results were obtained about optical activation of Pr in Ga2O3 (not published yet). Regarding this recent
study about Pr implantation it is being exploited the potential of the up conversion process involving
the interionic lowest level 4f5d with a short lifetime, for the development of single photon emitters in
Ga2O3 for applications in quantum technologies.

FCT Grant PTDC-FIS-PLA-31629-2017

“Liquid metal walls for plasma reactors (LMwalls)”

The LMwalls project is dedicated to the production of Li-Sn alloys with Li contents as high as 25 at.%,
and to the chemical and structural modifications imposed by their irradiation with 2H plasmas. In 2019,
the project was focused in the production and analysis of some of the alloys involving Li contents
down to 1 at.%. IBA techniques were used to quantify the depth profiles of Li by NRA down to depth
ranges close to 15 μm by following the depth yield of the 7Li(p,α)4He nuclear reaction.

Simultaneously, the Sn depth profile and possible C and O environmental contamination at the surface
were measured by EBS with 2000 keV 1H+ ion beams. The microprobe facility was also used to
investigate the homogeneity of Li in the alloys by μ-NRA and μ-EBS, as the amounts and areal
distribution of heavier impurities by μ-PIXE.

EUROfusion work programme WP19 PFC SP5.4/IST

“Preparation of efficient PFC operation for ITER and DEMO (SP5: Post-mortem analysis and
material migration SP5): Development of mixed-material reference coatings”
**W-based Coatings**

W-based coatings with distinct morphologies, W columnar (c-W) and W-O porous (p-W), were deposited on Mo plates by pulsed laser deposition (PLD) at ENEA, Milan, and sent to IST aiming to prepare coatings with high $^2$H contents by ion implantation. The c-W and p-W coatings were implanted simultaneously using three different implantation stages with a sequential decrease in the energy of incident ions. The corresponding ion beam energies and fluencies of the first, second and third stages were, respectively, 150 keV and $2\times10^{17}$ ion/cm$^2$, 100 keV and $2\times10^{17}$ ion/cm$^2$, and 50 keV and $1\times10^{17}$ ion/cm$^2$, being the total dose equal to $5\times10^{17}$ ion/cm$^2$. The main goal is to produce square-like depth profiles for the retained $^2$H. Earlier experiments performed with similar coatings implanted by $^4$He$^+$ ions evidenced the same expected effect as shown by simulations using the SRIM code (see Surf. Coat. Technol. 355 (2018) 215).

The as-deposited and as-implanted coatings were analysed by EBS using a 1750 keV $^1$H$^+$ ion beam to profile the O and W contents and by NRA using both 1000 keV $^3$He$^+$ and 2300 keV $^3$He$^+$ to quantify the final $^2$H$^+$ retained amounts taking advantage of the $^2$H($^3$He,p)$^4$He nuclear reaction.

As expected, the analytical results showed significant O contents and higher $^2$H$^+$ retention in porous p-W coatings.

![IBA analysis of as-implanted c-W and p-W coatings: EBS spectra collected with 1750 keV and related fit lines (a); individual NRA spectra collected with 1000 keV $^3$He$^+$ and 2300 keV $^3$He$^+$ to quantify the final $^2$H$^+$ retained amounts taking advantage of the $^2$H($^3$He,p)$^4$He nuclear reaction.](image)

**Al-based and Be-based Coatings**

Experiments with Al-based coatings are important in the nuclear fusion domain, while most of the European laboratories cannot work with Be samples and both Al-based and Be-based materials present some similar physical and chemical properties. In other tasks within the EUROfusion work programme, Al-based and Be-based coatings were sent to IST for IBA quantifications.

In Be activities, IST is quantifying the retained contents of $^2$H in coatings grown with plasma deposition techniques. In one of the experiments, coatings with nominal $^2$H contents of 5 at.% or 10
at.%, Be-D(5 at.%) and Be-D(10 at.%), respectively, were deposited in W plates at the same plasma parameters under distinct buffer temperatures, from room temperature up to 400º C. An additional Be-D(10 at.%) coating was also deposited under a temperature regime that mimics the environment filled in the walls of the Joint European Torus (JET) under 2H plasma operation, i.e., JET-like pulses. The as-deposited coatings were analysed by EBS with a 1800 keV 1H+ ion beam to profile Be and W and by NRA using a 2200 keV 3He+ ion beam to quantify the retained 2H amounts. As expected, the analytical results shown a deeply decrease in the retained amounts by increasing the buffer temperature, and retained amounts in the JET-like coating that typically corresponds to a constant buffer temperature close to 100º C. The result is in agreement with the measured temperatures in the JET walls.

![EBS spectrum](image)

**Fig. 1.** EBS spectrum collected with 1800 keV H+ incident ion beams and related fit line achieved from the IBA analysis of coating #03, Be+D(5 at.%) deposited at 400 ºC (a); particular 2H(3He,p)4He emissions in the NRA spectra and related fit lines for coatings #02 Be+D(5 at.%), #05 Be+D(5 at.%), #04 (Be+D(10 at.%)) and #03 Be+D(5 at.%) (b) and also for #06 Be+D(10 at.%) referring to the JET-like pulses (c).

The activities during this period were focused on the installation of the depth profiling system at the micro-AMS system at LATR, the development of an in-house built oven for the ionizer assembly, measurement of deuterium profiles as well as W isotopic ratios in fusion samples. Among all the activities, some results are worth highlighting:

**Depth profiling of Pt implantation in Si samples by micro-AMS**
The Micro-AMS system at LATR has been upgraded in order to perform high-resolution depth profiles. This capability, allied with its bouncing system makes it a unique tool for stable isotope studies. To demonstrate these new capabilities, a study of the quality of a selective implantation of platinum isotopes in Silicon (to be used in isotopic optical studies) was performed with the CTN-IST implanter. Micro-AMS sensitivity, due to its use of a tandem accelerator to resolve molecular interferences, along with its ability to perform spatial and in-depth analysis makes it ideal for this type of studies.

Pure $^{28}$Si isotope single crystals were implanted, at energies of 60 keV with two Pt isotopes, $^{194}$Pt and $^{198}$Pt, with a nominal fluency for each of the isotopes of $1x10^{14}$ cm$^{-2}$. A natural Pt cathode was used for the implantation, and despite the rigorous mass selection, some isotopic contamination is expected. In the figure, a depth profile of $^{194}$Pt in Si can be seen.

In the context of my research, focused on materials characterization and modification using ion beams, it stands out a study about the role of the defects induced by proton irradiation and their relation with the optical activation of Cr in intentionally doped Ga$_2$O$_3$ with Cr and co-doped with Mg. By ionoluminescence complemented with PIXE it was observed that there is a direct relation of the optical properties of Cr with the content with Mg.

On the other hand it was observed that the defects induced by proton irradiation contributes to enhance the Cr luminescence suggesting that a deep defect level introduced by the irradiation can work as a channel of energy transfer from the Ga$_2$O$_3$ host to Cr. It cannot be excluded the possibility that small changes in the local environment around Cr can affect its charge state, and consequently its optical properties.
It was also observed that the defects introduced by proton irradiation can be removed by a thermal annealing at temperatures higher than 600 °C. In this context, Ga$_2$O$_3$ doped with Cr can have a huge potential as red-emitter scintillator detector.

**Multiple reflection optimization package for X-ray diffraction: simultaneous fitting**

The activities during this period were focused on the implementation of the MROX code, acronym for Multiple Reflection Optimization package for X-ray diffraction radial and omega scans. The software employs the principles of the dynamical theory of X-ray diffraction on $\omega$ and $2\theta$-$\omega$ scans of several layered structures such as bulk materials, single layers, single quantum wells, quantum heterostructures and complex superlattices. Allow to simulate and fit different types of measurements of any implanted species. Simple to use, layers can be deleted, added, edited and crystalline layered structure easy to obtain.

Combined with the new developed code of X-ray reflectivity simulations and fittings, MROX is a powerful tool to simulate and fit the effect of ion implantation into crystals. At this moment, the effect of threading dislocations and stacking faults are being added in the code and it is planned to include special structures such as quantum dots/wires.

So far, it has been possible to publish 3 papers and 2 Master degree thesis combining pure research and academics.

**IBA techniques for perovskite active layers**

Perovskite (PSC) films based on CH$_3$NH$_3$PbI$_3$ prepared in a planar architecture and in a mesoporous TiO$_2$ scaffold were characterized by means of the nuclear microprobe. Proton and helium micro-beams at different energies were used in the analysis of PSC active layers.

Self-consistent fit of all the obtained PIXE and RBS spectra through Total IBA approach provided depth profiling of perovskite, its precursors and TiO$_2$ and assess their distribution in the films. PbI$_2$
presence and location on the active layer may hinder the charge transport and highly affect the cell performance.

IBA techniques allowed to identify regions of non-uniform surface coverage and homogeneous areas and it was possible to establish the undesired presence of PbI₂ and its quantitative depth profile in the planar architecture film. The good agreement between the best fits obtained in a Total IBA approach and the experimental data granted reliability to depth profile results for the studied perovskite films.

![Figure: Experimental data and NDF best fits assuming a pure PSC layer on top of TiO₂. From 10.1016/j.nimb.2017.01.019.](image)

**Development of thermal barriers for nuclear fusion**

The activities during this period were focused on the development of thermal barriers for nuclear fusion divided in two research lines: (i) thermal barriers materials made of Y₂O₃ reinforced Cu and CuCrZr and (ii) production of Cu based high entropy alloys.

The Cu-Y₂O₃ and CuCrZr-Y₂O₃ materials were prepared in a glove box and consolidated with spark plasma sintering between 775-800 °C with pressures of 57 MPa with a holding time of 5-8 min. The densifications achieved are between 90-98 and decrease with the increasing of Y₂O₃ volume content. The microstructure revealed dispersions of Y₂O₃ regions in the Cu matrix with the presence of Cu oxide and Y₂O₃ agglomerates.

TEM confirmed the presence of CuO in the Cu-Y₂O₃ materials. Moreover, the microstructure of samples with CuCrZr were similar to those with Cu however without the formation of Cu oxides. The functional graded material with Cu and with CuCrZr did not exhibit the interfaces between layers, which is a strong point on these materials.

![Figure: SEM image of the 85CuCrZr – 15Y₂O₃ % (V/V) sample.](image)
Moreover, Cu$_x$CrFeTiV (x = 0.21, 0.44, 1 and 1.7 molar ratio) were prepared using mechanical alloying (MA), to mix the elemental powders, followed by consolidation with spark plasma sintering (SPS) at 1178 K and 65 MPa. The equiatomic CuCrFeTiV sintered sample was irradiated at room temperature with 300 keV Ar$^+$ beam (to a fluence of $3 \times 10^{20}$ at/m$^2$) in order to simulate the irradiation damage in the material. The results showed the presence of heterogenous and multiphasic microstructures in all samples. Moreover, with the increase of the Cu content it is possible to observe the formation of Cu-rich structures.

The diffractogram of the CuCrFeTiV sample revealed major peaks of a BCC crystal structure and minor peaks of a FCC crystal structure. In addition, irradiation damage in the microstructure surface was only observed in samples irradiated with fluences of $3 \times 10^{18}$ to ions/cm$^2$. Moreover, in those samples blisters were observed with a diameter less than 1 µm.

**Nuclear microprobe applications: from Cultural Heritage to Functional Materials**

Research work was performed under national and international funded research contracts or under collaboration with internal and external group members. Most relevant applications included characterization of advanced materials (Ga$_2$O$_3$; GaN; MoO, perovskites and CIGS solar cells) together with archaeological/historical samples (glass, stained glass, tiles, silver coins and metallic artefacts) and biology/biomedicine studies like the one for determining 3D distribution in cells of metallic nanoparticles using MeV ion beams. In terms of experimental development, automatization and tests of the ion beam tomography system at the Nuclear Microprobe beam line were accomplished.

Concerning the work on silver artefacts, Portuguese silver coins from the 15th-17th centuries were analysed by non-destructive PIXE technique in order to create an elemental data base composition in major, minor and trace elements of the silver alloys which allowed to:

1) determine a chronological framework of the silver alloy used, allowing establishing the silver ore provenance and metallurgical procedures;
2) differentiate production centers (Lisbon and Oporto);
3) allow comparison with coeval Portuguese silver objects, namely Indo-Portuguese silver jewellery from the Ancient Art Nacional Museum (MNAA);
4) help for detecting forgeries (well in accordance with the goals of the IAEA CRP F11021).

The work was performed in collaboration and using the silver coin collections from the Portuguese Mint House (ICNM – Imprensa Nacional Casa da Moeda) and from the Bank of Portugal (BdP).

The introduction in the Portuguese territory of silver coming from the “New World” Potosí mineral ore is well identified and ascribed to Au contents <100 ppm and very low Bi contents [Bor2018].

IBA and cultural heritage

Cultural Heritage artefacts were studied in the nuclear microprobe, using both alternatives: measurements on vacuum and on open air. Results allowed to identify surface silver enrichment in ancient high silver alloys and also to identify European silver sources from the 15th to the 17th century.

The combination of PIXE and RBS spectra allowed the characterization of corrosion layers grown on ancient coins. Ancient manuscripts were also characterized, in this case using the external beam set-up. Low beam currents were used in order to avoid eventual radiation damage on paper. It was possible to study iron gall inks (reals and manufactured under lab conditions), the initial ingredients and paper.

The reduced penetration of the ink into the paper (less than 1 μm) makes it difficult to separate the signals from the paper and the ink by means of the characterization techniques used in this study.

Since all samples were under identical exogenous factors that can affect the paper stability, as external temperature, humidity or oxygen content, the loss of crystallinity observed in all samples, should be then related to endogenous factors, and more specifically linked to the ink.

The acidic elements of the inks result in the acid-hydrolysis of cellulose shortening the chains, thus reducing the content of the crystalline form.

Figure: Pixe spectra from inked and bare areas of paper. 10.3390/heritage2040166.
2. Scientific Output

(Articles in scientific journals or conference proceedings, books/chapters, theses, internal reports/services, duly approved by the Unit and registered in the Library)

BOOKS (BOOK CHAPTERS)

2018


JOURNALS

2019


2018


COMMUNICATIONS

Invited Talks

2019


[4] E. Alves, Structural and optical studies of aluminosilicate films doped with (Tb$^{3+}$, Er$^{3+}$)/Yb$^{3+}$ by ion implantation, 13th European Conference on Accelerators in Applied Research and Technology (ECAART13), Split (Croatia), May 05-10th 2019.


2018


[9] E. Alves, Laboratory of Accelerators and Radiation Technologies: An Overview, 2nd Workshop of the European Network of Small-scale Accelerator Facilities (ENSAF), Institute of Nuclear and Particle Physics (INPP) of the National Center for Scientific Research "Demokritos" (NCSR-D), Athens (Greece), October 3-6th 2018.


2017


Oral Talks

2019

1. J. Cruz, R. J. C. Silva, V. Corregidor, L. C. Alves, $\mu$-PIXE/$\mu$-EBS and SEM analysis of surface spots in gold coins/discs from the Portuguese Mint House, 16th International Conference on Particle Induced X-ray Emission, Caldas da Rainha, Portugal (24-29 March 2019).


10. V. Corregidor, M. A. Barreiros, P. M. P. Salomé, M. J. Brites, L. C. Alves, “PIXE and RBS on CIGS solar cells to study the elemental distribution In-depth inhomogeneities on solar cells materials by PIXE and RBS”, PIXE (2019).


2018


[14] D. Verheij, M. Peres, S. Cardoso, E. Alves, C. Durand, J. Eymery, K. Lorenz, “Radiation sensors based on GaN microwires grown by MOVPE”, 1st Iberian meeting of materials science (CNMAT), Salamanca, Spain, July 4-6, 2018 (oral).


2017


[22] M. Dias, HHFM 3.3.2.D1 "Fabrication and characterization of optimized WC-Cu materials with and without functional gradient", Project Monitoring Meeting, Lisbon Portugal, June 2017.


**Poster Presentations 2019**


2018


P. Almodóvar, M. Peres, C. Díaz-Guerra, J. Ramírez, K. Lorenz, J. González-Calbet, “Laser-induced localized optical activation of Eu ions in implanted h-MoO3 microrods”, 1st Iberian meeting of materials science (CNMAT 2018), Salamanca, Spain, July 4-6 (2018).


2017


**Other Seminars**

**2019**


2018


2017


PROJECTS

Running Projects


EDUCATION

PhD Theses

2019
[1] K. Lorenz, Supervisor (E. Alves, Co-Supervisor) of Djibril Nd. Faye, PhD in Materials Engineering: Ion implantation in Al\textsubscript{x}Ga\textsubscript{1-x}N alloys and GaN nanostructures, IST/Univ. Lisboa, January 2019.

2018

2017
[3] E. Alves, Supervisor of Maria Isabel Guerreiro Fialho, PhD in Technological Physical Engineering: Study of the Influence of Al Content on Optical Activity and Lattice Site Location of Rare Earth Implanted Al\textsubscript{x}Ga\textsubscript{1-x}N, IST/Univ. Lisboa, SFRH/BD/78740/2011, July 2017.
MSc Theses

2019


2018


2017


CLASSES/TEACHING

2019


2018


2017


[12] M.Peres, Invited Auxiliary Professor at IST. Discipline: “Laboratório de Física Experimental Avançada (LFEA4)” in the Curricular Plans for MSc Students on “Mestrado Integrado em Engenharia Física”.


TRAINING COURSES

2019


2018


2017


JURY MEMBERSHIP

2019


2018


2017

[10] E.Alves and K.Lorenz, PhD thesis of Maria Isabel Fialho, Study of the influence of Al content on optical activity and lattice site location of rare earth implanted Al_{x}Ga_{1-x}N (PhD in Physics), IST, Lisbon, 2017.


EVALUATOR

2019


[4] E.Alves, Professor Associado, Notice n.º 486/2019, IST, field of “Nuclear Technologies and Radiological Protection from the Department of Nuclear Sciences and Engineering”, disciplinary field of “Particle and Nuclear Physics from the Department of Physics” (2019).


2018


2017


HABILITATION


CONFERENCE/COURSE ORGANIZATION

Conferences Organization


TECHNICAL COMMITTEES


E. Alves, Member of “Nuclear Physics European Coordination Committee, NuPECC”. Portuguese Representative, since 2016.

E. Alves, Member of “Scientific Review Panel” of CERIC-ERIC (European Research Infrastructure Consortium), since 2016.

E. Alves, Chair of “International Programme Advisory Committee (iPAC)”, CIMAP-CIRIL, Caen, since 2015.

E. Alves, Member of “Comissão de Vagas” of DECN, since 2014.

E. Alves, Deputy Director of “Laboratório de Aceleradores e Tecnologias de Radiação”, since 2013;

E. Alves, Member of the “Executive Board of Instituto de Plasmas e Fusão Nuclear”, Group leader of Materials Processing and Characterisation, since 2013.

E. Alves, Member of “Scientific Council of IST”, since 2012 (2nd term.).


K. Lorenz, Member of the “Advisory Editorial Board of Nuclear Instruments and Methods in Physics research, Section B: Beam Interactions with materials and Atoms”, since 2019.

K. Lorenz, Member of the “EMIR&A Scientific Committee”, French National network of accelerators for irradiation and analysis of molecules and materials, since 2019.

K. Lorenz, Member of the “ISOLDE and Neutron Time-of-Flight Experiments Committee – INTC”, CERN, Switzerland, since 2019.


K. Lorenz, Evaluator of “Research Project of the National Science Centre,” Poland, 2017.


K. Lorenz, Member of the “User Selection Panel at the Ion Beam Centre, Helmholtz-Zentrum Dresden-Rossendorf”, Germany, since 2014.

K. Lorenz, Member of the “Panel of Reviewers of beam time proposal at Centro de Micro-Análisis de Materiales, Madrid”, Spain, since 2011.

M. Peres, Member of the “Scientific Council of IPFN”, since 2015.

**COLLABORATIONS**

A. Barreiros, Unidade de Materiais para a Energia (UME), LNEG. Characterization of materials for solar energy conversion.

Andres Redondo Cubero, June 17 – 18, 2019, U Autonoma de Madrid, project meeting.

Bruno Daudin, June 17-18, 2019, CEA Grenoble, project meeting.

Daniel Galaviz, Professor FCUL, Collaboration in detector testing measurements at LATR.

Flyura Djurabekova, June 17-18, 2019, University of Helsinki, project meeting.

J. Cruz, Universidade Nova de Lisboa. Characterization of materials using IBA techniques.


[12] Maria Fonseca, Professor FCT/UNL, Collaboration in PIGE measurements at LATR.


[16] Rosário Correia, June 17 – 18, 2019, Universidade de Aveiro, project meeting.

[17] Susana Cardoso de Freitas, June 17 – 18, 2019, INESC-MN, project meeting.

Accelerators, Nuclear Instrumentation and Irradiation
SERVICES | 3: R&D AND INDUSTRY

SECTOR 1 | R&D Services: Accelerators

IBL | 1: Description

Ion Beam Laboratory Group (IBL) have experimental beam lines for in situ analysis of samples for R&D purposes. Established a network of collaborations with researchers from all over the world to perform studies on this areas taking advantage of the non-destructive and quantitative nature of the ion beam techniques.

IBL | 2: Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Category</th>
<th>Time Allocated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eduardo Alves</td>
<td>Full Researcher (Coordination)</td>
<td>100%</td>
</tr>
<tr>
<td>Katharina Lorenz</td>
<td>Senior Researcher (Permanent Member), sept.2018</td>
<td>100%</td>
</tr>
<tr>
<td>Nuno P. Barradas</td>
<td>Senior Researcher (CERN Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Carlos Cruz</td>
<td>Auxiliary Researcher (Permanent Member)</td>
<td>50%</td>
</tr>
<tr>
<td>Luis Alves</td>
<td>Auxiliary Researcher (C2TN Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Rodrigo Mateus</td>
<td>Auxiliary Researcher (Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Rui Silva</td>
<td>Auxiliary Researcher (Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Marta Dias</td>
<td>Researcher Contract (Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Rui M.S. Martins</td>
<td>Researcher Contract (Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Victoria Corregidor</td>
<td>Researcher Contract (Permanent Member)</td>
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<tr>
<td>Hélio Luís</td>
<td>Postdoctoral Researcher (Permanent Member)</td>
<td>100%</td>
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<tr>
<td>Marco Peres</td>
<td>Postdoctoral Researcher (Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Norberto Catarino (PhD 2018)</td>
<td>Postdoctoral Researcher (Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Sérgio Magalhães (PhD 2013)</td>
<td>Postdoctoral Researcher (Permanent Member)</td>
<td>100%</td>
</tr>
<tr>
<td>Adam Przemyslaw Jozwik (Nattan)</td>
<td>Project Collaboration (Oct.2018-Sept.2020)</td>
<td>100%</td>
</tr>
<tr>
<td>Daniela Pereira (MSc 2017)</td>
<td>PhD Scholarship Student</td>
<td>100%</td>
</tr>
<tr>
<td>Djibril Faye (PhD 2019)</td>
<td>PhD Scholarship Student</td>
<td>100%</td>
</tr>
<tr>
<td>Isabel Fialho (PhD 2017)</td>
<td>PhD Student</td>
<td>100%</td>
</tr>
<tr>
<td>Miguel C. Sequeira (MSc 2017)</td>
<td>PhD Scholarship Student (2019)</td>
<td>100%</td>
</tr>
<tr>
<td>Dirkjan Verheij (MSc 2018)</td>
<td>PhD Scholarship Student</td>
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</tr>
<tr>
<td>Francisco Antão (MSc 2019)</td>
<td>MSc Scholarship Student</td>
<td>100%</td>
</tr>
<tr>
<td>Jorge Rocha</td>
<td>Principal Specialist Technician</td>
<td>100%</td>
</tr>
<tr>
<td>Ana Faria, Income/Logistics</td>
<td>Graduated Technician</td>
<td>30%</td>
</tr>
<tr>
<td>Teresa Pires, Web Designer/Logistics</td>
<td>Graduated Technician</td>
<td>30%</td>
</tr>
<tr>
<td>Filomena Baptista</td>
<td>Assistant Technician (2017-2018)</td>
<td>30%</td>
</tr>
</tbody>
</table>

IBL | 3: Experimental Equipment

The Ion Beam Laboratory (IBL) hosts two electrostatic accelerators and an implanter. A 2.5 MV Van de Graaff with three experimental beam lines, with all the relevant ion beam techniques available, RBS, PIXE, NRA, Channeling, ERDA and a Nuclear Microprobe.

A 3.0 MV Tandem with a micro AMS (Accelerator Mass Spectrometry) line with depth scan profiling capabilities, high resolution PIXE (10-12 eV) setup, a Universal Ion Beam Analysis End Station and a dedicated line for nuclear physics experiments. A 210 kV Danfysik Ion Implanter with an implantation
area of 20x20 cm$^2$ allowing implantations of nearly all the chemical species of the periodic table in the temperature range of 77 K up to 1273 K, in a controlled way. The connection of the implantor to the RBS chamber of the van the Graaff Accelerator, allows situ analysis during the implantation.

**IBL | 4: External Visits**

Due to the mandatory confinement resulting from the Covid-19 epidemic, 2020 was an atypical year, with no study visits to the campus allowed after March. Follow-up visits to the Ion Beam laboratory, as indicated below:

<table>
<thead>
<tr>
<th>Description</th>
<th>2016 Visits</th>
<th>2017 Visits</th>
<th>2018 Visits</th>
<th>2019 Visits</th>
<th>2020 Visits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary Schools</td>
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<td>188</td>
<td>9</td>
<td>317</td>
<td>6</td>
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<tr>
<td>Universities</td>
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<td>80</td>
<td>3</td>
<td>92</td>
<td>4</td>
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<tr>
<td>Other Visits*</td>
<td>1</td>
<td>50</td>
<td>1</td>
<td>43</td>
<td>1</td>
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<tr>
<td><strong>Sub-Total</strong></td>
<td><strong>13</strong></td>
<td><strong>452</strong></td>
<td><strong>12</strong></td>
<td><strong>382</strong></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>

*Other Visits:
- MEFT - Cadeira de Laboratório de Física Experimental Avançada, February 2020 (36).
- Seniores – Ciência Viva, May 2018 (12).
- Encontro Nacional de Estudantes de Física 2017, February 2017 (43).
- Universidade Senior, S. João da Talha, IST/CML, 2016 (50).

**IBL | 5: Statistical Record**

*In-situ* characterization samples:

![Graph showing I&D Research income and expenses from 2017 to 2019]

- Total Income: € 7.280,25 vs Total Expenses: € 0,00
SECTOR 2 | Nuclear Instrumentation: design, marketing and consulting

NI | 1: Description

The Nuclear Instrumentation (IN) group is the successor of a multidisciplinary group that, for many long years, has accumulated substantial experience in several areas of peaceful applications of Nuclear Technologies. In particular, in the development of instruments, devices and applications, directed to the various sectors of the national economy, to the industries foremost, but also collaborating with diverse research groups, participating in scientific projects inside and outside the IST/CTN institution, in Portugal and abroad.

Main activities summary:

- Consulting, project, installation, repairing and maintenance of nuclear equipment for industrial enterprises and scientific institutions (external services);
- Participation in R&D projects;
- Design and maintenance of electronic equipment for CTN’s Groups and external clients;
- Marketing and sale of nuclear instrumentation (brand IST/LATR) for the national and international markets;
- Small series manufacturing and quality control of equipment (brand IST/LATR).

NI | 2: Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Category</th>
<th>Time Allocated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eduardo Alves, Coordination</td>
<td>Senior Researcher</td>
<td>---</td>
</tr>
<tr>
<td>José Neves, Electrotechnical Engineer</td>
<td>Auxiliary Researcher</td>
<td>100%</td>
</tr>
<tr>
<td>Nuno Inácio, Repairing/Maintenance</td>
<td>Graduated Technician</td>
<td>50%</td>
</tr>
<tr>
<td>Tiago Jesus, Repairing/Maintenance</td>
<td>Assistant Technician (left April 2018)</td>
<td>30%</td>
</tr>
<tr>
<td>Ana Faria, Income/Logistics</td>
<td>Graduated Technician</td>
<td>35%</td>
</tr>
<tr>
<td>Teresa Pires, Web Designer/Logistics</td>
<td>Graduated Technician</td>
<td>5%</td>
</tr>
</tbody>
</table>

NI | 3: Main Achievements

We have increased our client base in order to enlarge sales (nationally and internationally), in the field of nuclear equipment fabrication (made in Portugal, brand IST/LATR), as well as in consulting and technical assistance in Portugal.

CONSULTING, DESIGN & TECHNICAL ASSISTANCE IN THE FIELD OF ENGINEERING APPLICATIONS OF RADIATION AND RADIOISOTOPES

Major tasks carried out over the 2017-2020 period:

- Collaboration with the *Gas Discharges and Gaseous Electronics Group* (GEDG) of “Instituto de Plasmas e Fusão Nuclear” (IPFN), in the experimental work on methane conversion using Dielectric Barrier Discharge (DBD), searching for new connected applications.
- Technical / Lab support work, to the new IST “Mestrado em Proteção e Segurança Radiológica” (MPSR).
• Part in the Development / Improvement work of the Linear Electron Accelerator (LINAC), which can produce beams with energies from 4 MeV to 10 MeV.

• We have carried out some training of electro-technical and electronic nature for the chemical Eng. Pedro Santos, intended to the regular operation launch of this large and complex equipment. It should be noted that this great instrument involves a wide spectrum of uncommon technologies, such as electron gun, microwave beam acceleration, magnetron, thyratron, EM waveguides, collimator/ quadrupoles, BT, AT, MAT and UPS Power Supplies, programmable logic controller (PLC), high-vacuum pumps, complex software and “intensive” and wide-ranging electronics.

• In 2018, we have carried out some work to improve/ modernize the RPI Model (Reactor Português de Investigação), to be exhibited in several events including on Técnico Day.

2017 - TOTAL INCOME: € 22.708,09

In 2017, we have carried out several maintenance and repair works, including some calibration and quality control actions on diverse instruments/ equipment. Several electronic / nuclear devices and equipment were manufactured and sold as well.

For example:

• Four digital instruments “RADX100” (Personal Radiation Dosimeter) were produced and sold;

• One electronic equipment “Detetor Gama de Nível de Líquidos em Garrafas” was tested and repaired as well as one RADX100;

• Two Packs of special stainless steel cathode disks, for the Irish Environmental Protection Agency, Dublin (the disks are used in the Electrodeposition laboratory equipment, made in IST/LATR).

2018 - TOTAL INCOME: € 49.646,84

In 2018, the group carried out a lot of maintenance and repair works on diverse instruments/ equipment, mainly for industrial Portuguese companies.

For example:

• Check-up and Technical Certification of 25 nuclear equipment, for Navigator (Figueira da Foz)

• Annual multi-equipment Check-up for CELBI (Leirosa/ Figueira da Foz)

• Annual multi-equipment Check-up for Navigator (Cacia)

• Annual multi-equipment Check-up and removal of several radioactive sources for Navigator (Figueira da Foz)

• Removal of several radioactive sources and a number of other works for Repsol Polímeros, SA (Sines)

• Removal and storing of several radioactive sources for Super Bock Bebidas.
• Annual multi-equipment Check-up (13 equipment) for **EQS GLOBAL-Centro Petroquímico** (Galp/ Leça da Palmeira)

Several electronic/ nuclear devices and equipment were manufactured and sold:

• Seven digital instruments **“RADX100”** (Personal Radiation Dosimeter).

**2019 - TOTAL INCOME: € 37,299,75**

As usual, we have provided numerous services to some large Portuguese companies/ institutions such as:

• Arsenal do Alfeite/ Marinha Portuguesa
• Repsol Polímeros, SA (Sines)
• TecniLab (Lisbon)
• Celbi - Celulose da Beira Industrial, SA (Leirosa/ Figueira da Foz)
• Cimpor/Intercement (Souselas)
• Cimpor - Indústrias de Cimentos, SA (Souselas)
• Caima - Indústria de Celulose, SA (Constância, Santarém)
• Galp (Sines)
• CMP/Secil (Maceira e Pataias)

We have increased our client base in order to enlarge sales (nationally and internationally), in the field of nuclear equipment fabrication (made in Portugal, brand IST/LATR), as well as in consulting and technical assistance in Portugal.

**NI | 4: New Markets**

Local customers:

• 2018 – SUPER BOCK BEBIDAS
• 2018 – EQS-Global, for services to be held on GALP Energia (Refinaria de Matosinhos).

**IN | 5: Internationalization**

Presence on foreign markets:

• 2017 – EPA - Environmental Protection Agency (Ireland): Electrodeposition spare parts.
• 2018 – National Center for Nuclear Sciences and Technologies (Tunisia): Electrodeposition spare parts.

**NI | 6: Infrastructures**

Small electronic workshop for nuclear instrumentation purposes.

**NI | 7: Income Track Record**

Fluctuation of revenues over these years was due essentially to the loss of human factors, namely our milling machine specialist that was retired (responsible for the fabrication and assembling of the electrodeposition equipment, that stopped being sold - only sold until stock runs out -, with losses of about €5000/year), as well as the lack of other inside labour resources (locksmith workers and painters) that should have accompany our nuclear instrumentation technician to the factories for helping him in other specialized tasks.
Total Income: € 109,659,68 vs Total Expenses: € 5,002,49
SECTOR 3 | Application of ionizing radiation technology to the industry

UTR | 1: Description

The Portuguese Gamma Radiation Facility (UTR) was installed in 1981 at Campus Tecnológico e Nuclear from Instituto Superior Técnico, Loures Pole, Bobadela.

Actually, this unit plant is a Cobalt-60 dry storage continuous facility with a nominal capacity of ≃170 kCi and designed for the sterilization of medical devices. However, it can be used for the irradiation of other products such as medical prosthesis, cork stoppers, plastics and a limited number of food and feed.

This plant was developed with the support of IAEA under the Programme of Cooperation and Technical Assistance (POR/8/002), for the period 1983-1988.

The initial capacity is 1.1x10^{16} Bq (295 kCi) and the throughput capacity 103 ton for product with a bulk density of 0.2 g/cm³ treated with a minimum absorbed dose of 25 kGy. Complementary control devices were installed: ventilation system, closed water refrigeration circuit, internal TV system, detection and extinction fire system and emergency power group. It must be emphasized that the best attention was given to the conception and efficiency of the interlock safety system.

The irradiation cell, which is of high-density concrete, has walls 1.8 to 2 m thick, with an area of 30.75 m². The labyrinth surround the irradiator cell is 23.3 m long. The irradiator, with an over-all area of 0.864 m², consists of 30 stainless-steel tubes. The Cobalt-60 sources, stainless steel double encapsulated are enclosed in those tubes.

In the storage, the irradiator is in a concrete pit, shielded with iron steel blocks. An electromechanical system raises the sources to the working position. The product is carried by 40 carriers, suspended from an overhead monorail conveyor. There are two rows of 7 carriers each side of the source, each one can be loaded with 4 product boxes (0.4x0.4x0.4 m³). An irradiation cycle has 56 different irradiation positions. Between the 14th and the 15th position, the carriers rotate 180º and present the opposite face of the box to the source. After the 28th position, each carrier returns to the loading/unloading station.
The two boxes of the upper level take place on the lower level, which is empty as the other two boxes were unloaded. A new pair of boxes are loaded on the upper level and the carrier goes back to the irradiation cell. In each half cycle, the two boxes of the lower level receive the dose fixed and the two boxes of the upper level receive the first half of this dose. The dwell-time is set according the product density and the required dose.

The facility is operated and controlled from the control desk inside the control room. A visual survey of the loading/unloading area can be made from there. The loading/unloading station consists of charge, rearrange and discharge mechanisms, associated with a rolling carpet at the inlet and outlet of products. The plan design gives good dose uniformity, the efficiency is about 19% for 0.2 g/cm$^3$ density and 25 kGy. The facility is fully automatic and works in continuous mode.

A preventive maintenance plan has been set up for all several types of electrical and mechanical systems of the facility. The labyrinth entrance has no physical barrier, therefore to guarantee the necessary radiological protection and furthermore to insure a correct sequence of operations several kinds of interlocks systems were installed.

### UTR | 2: Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Category</th>
<th>Time Allocated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eduardo Alves, Coordination</td>
<td>Senior Researcher</td>
<td>---</td>
</tr>
<tr>
<td>Paula Matos, Technical Director/Quality</td>
<td>Agro-food Engineer</td>
<td>100%</td>
</tr>
<tr>
<td>Carlos Cruz, Radiological Protection/Maintenance</td>
<td>Auxiliary Researcher</td>
<td>50%</td>
</tr>
<tr>
<td>Ana Faria, Income/Logistics</td>
<td>Graduated Technician</td>
<td>35%</td>
</tr>
<tr>
<td>Teresa Pires, Web Designer/Logistics</td>
<td>Graduated Technician</td>
<td>10%</td>
</tr>
<tr>
<td>Nuno Inácio, Irradiator Operator Chief</td>
<td>Graduated Technician</td>
<td>50%</td>
</tr>
<tr>
<td>Filomena Baptista, Irradiator Operator</td>
<td>Assistant Technician (since 2018)</td>
<td>70%</td>
</tr>
<tr>
<td>Tiago Jesus, Irradiator Operator</td>
<td>Assistant Technician (since 2018)</td>
<td>70%</td>
</tr>
<tr>
<td>Tiago Sena, Irradiator Operator</td>
<td>Assistant Technician (since 2016)</td>
<td>100%</td>
</tr>
</tbody>
</table>

### UTR | 3: Advantages of Ionizing

Are the following:

- Process safe and environmentally friendly;
- Treatment in the final package (eliminating cross contamination risk);
- Treatment nonthermal;
- Leaves no residue (the product does not require quarantine period).

### UTR | 4: Process Control

To establish the dwell-time and ensure the application of the dose required, according the product density, an electronic cycle timer was installed. This cycle timer allows resuming the process at the same point where it stopped wherever any accident or system failure occurs. It is adjusted only to compensate the radioisotope decay.

During the irradiation of products, routine dosimeters are placed inside a number of selected boxes in the zones of minimum and maximum doses.

The dosimeters are removed, read and the results recorded. Colour-changed indicators to distinguish irradiated from non-irradiated products are used.
**UTR | 5: Responsibility and Organization**

As a basic principle, the irradiator operator has the responsibility for delivering the absorbed dose specified by the primary manufacturer.

In 2017, provisions are being made to train the convenient and qualified plan staff capable to accomplish the safe operation of the plan and a correct irradiation process. When operating, the product unit dimension and density should be verified upon reception. After this control, each product unit will receive an identifying label with the following data: name and address; minimum absorbed dose; date and reference client number, colour change indicator.

Irradiation Certificates complying with international recommend Good Radiation Practice is issued as well as the Quality Certificate, issued by TÜV Rheinland, stating conformity assessment of quality management practices according to EN ISO 9001-2008 (30-12-2016 to 14-09-2018) and EN ISO 9001-2015 (03-12-2018 to 29-12-2019), for the scope “Sterilization an decontamination of products by gamma radiation”.

In addition to those, UTR Unit accomplished in December 2017:

- **Dosimetry Certificate**, issued by Laboratory for Measurements of Technological Doses (LMTD/Poland), accredited by Polish Centre of Accreditation: attesting the "First phase of the dose intercomparision exercise conducted to improve QA/QC procedures in radiation processing", obtained under the framework of TC Project RER/1/017 (IAEA).

To keep in track with clients’ opinions, Customer Satisfaction Surveys are made annually.

**UTR | 6: Main Achievements**

**Quality Management System Compliance**


**Training Courses**

- **2017/2018**: “Curso de Formação para Operadores de Instalação de Irradiação Gama Co-60/Training Course for Gamma Irradiation Installation Operators Co-60”, 200h (140h on job-training), UTR/IST. Trainees: Paula Matos, Nuno Inácio, Tiago Sena and Filomena Baptista.


**UTR | 7: Internationalization**

Presence on foreign markets: mainly Spain.
UTR | 8: Projects


UTR | 9: Facility Visits

Follow-up visits to the UTR Unit, as indicated below:

<table>
<thead>
<tr>
<th>Description</th>
<th>Visits / Visitants 2017</th>
<th>Visits / Visitants 2018</th>
<th>Visits / Visitants 2019</th>
</tr>
</thead>
<tbody>
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<td><strong>12 / 253</strong></td>
<td><strong>10 / 272</strong></td>
<td><strong>11 / 349</strong></td>
</tr>
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</table>

*Other Visits:

- VF Pharmaceuticals, July, 2020 (Dr. Miguel Santos).
- Câmara Municipal de Loures: Visite o Concelho, UTR, October 19, 2018 (28).
- Seniores – Ciência Viva, May 2018 (12).
- CITEFORMA – Centro de Formação Profissional. Curso de Especialização Tecnológica de Técnico Especialista em Gestão da Qualidade, Segurança e Ambiente, no âmbito das UFCD’s “Agentes Físicos” e “Agentes Químicos e Biológicos”, June 2017 (16).
- Encontro Nacional de Estudantes de Física 2017, February 2017 (43).

Local Auditors:


External Auditors:

• LUSOMEDICAMENTA – Client (Recipharm Lisbon): Quality Manual; Procedures; Quality Processes and Records; Contrato de Prestação de Serviços. Teresa Ferreira, 21/07/2017.


**UTR | 10: Future Goals**

- To enlarge application of ionizing radiation to industry (in particular the food one), through legalization of ISO standards and accreditation processes;
- To increased our client base in order to enlarge sales (nationally and internationally). This can be afforded with a targeted marketing program to enlarge audience and a better presence on internet;
- Rechargment of Cobalt sources in near future.

**UTR | 11: Income Track Record**

<table>
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<tr>
<th>CLIENTS</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>TOTALS</th>
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**UTR INCOME 2017-2019: € 508 205,39**
INCOME: 2017-2019 (CLIENTS)

INCOME: 2019 (SECTORS)
**UTR | 11: Working Hours**

**UTR PLANT: 2019**

- **Industry / I&D**: 3538; 88%
- **Dosimetry**: 360; 9%
- **Maintenance**: 142; 3%

Coincident hours: 127