EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Institute for Reference Materials and Measurements (Geel)
**Unit Standards for Nuclear Safety, Security and Safeguards**

# EUFRAT NUCLEAR FACILITIES AT JRC-IRMM

To carry out its projects defined in the EURATOM Work Programme JRC-IRMM is hosting specialised nuclear facilities of pan-European relevance:

- **Nuclear data facilities**: the neutron time-of-flight facility GELINA and the Van de Graaff mono-energetic neutron beam facility.
- **Radionuclide metrology laboratories**: the HADES low-level gamma underground laboratory and a cluster of instruments for high precision radioactivity measurements.
- **Nuclear reference materials laboratories** for the preparation and provision of certified nuclear reference materials and reference measurements.

At its nuclear data facilities and radioactivity laboratories JRC-IRMM has an extensive **transnational access programme**, called EUFRAT (European Facilities for Nuclear Reaction and Decay Data Measurements) offering experimental possibilities to external users from the Member States. Selection of the experiments is based on peer review by international experts representing the stakeholder community. In addition, **Education and Training** has always been an integral part of the JRC-IRMM work at its facilities, in form of trainee programmes and grant holders schemes at PhD and post-graduate levels. Training of students and professionals has been realised through periodic hands-on training courses at the accelerator facilities, and by dedicated schools and workshops in nuclear safety.

## 1. Nuclear data facilities: GELINA and the Van de Graaff accelerator

The nuclear data activities of the Nuclear Data group (ND sector) at JRC-IRMM can be subdivided into four core domains:

- Performance of **neutron reference data measurements** for safety assessments of present-day and innovative nuclear energy systems.
- Measurements of **nuclear data standards**.
- Investigations for a better understanding of the **nuclear fission process**.
- **Post-Fukushima collaborations** with JAEA: development of a method for the isotopic assessment of the molten fuel and a method for criticality detection in high background conditions.

JRC-IRMM is equipped with a scientific infrastructure for the measurement of neutron data for nuclear energy applications, which is unique in Europe. This research infrastructure includes two accelerator facilities, GELINA and the Van de Graaff, especially designed for high-resolution nuclear data measurements, covering the neutron energy range from a few meV to about 24 MeV.

To perform accurate neutron data measurements a source of neutrons in the relevant energy range is needed. In addition the energy of the neutrons used for the measurements must be known with the best possible accuracy. There are two main approaches to reach a good energy definition:

- a neutron beam with a well-defined energy is generated using a particle accelerator accelerating protons, deuterons or alpha particles. Neutrons of a fixed energy are produced via nuclear reactions. These quasi-monoenergetic sources provide a moderate energy resolution and are mainly used in the energy above 5 keV. The Van de Graaff facility of IRMM belongs to this group.

- in the second approach, a 'white' beam of neutrons (covering a whole range of energies) is produced with a particle accelerator. Neutrons of a particular energy can be selected for the measurements from the continuum by a neutron time-of-flight measurement over a fixed flight path. A much better energy resolution can be obtained in this second approach, so that these sources are ideally suited for measurements in the resonance region and above. GELINA is a time-of-flight facility, specially designed for high-resolution neutron data measurements. It has the best energy resolution in the world for neutron data measurements.

GELINA and the Van de Graaff accelerator are complementary. The combination of both facilities makes JRC-IRMM one of the few laboratories in the world which is capable of producing the required accuracy for neutron data needed for the safety assessments of present-day and innovative nuclear energy systems. JRC-IRMM is the major provider of neutron cross-section data for nuclear energy in Europe. It focuses on nuclear reaction standards and on reactions relevant for the safe operation of current reactors (Gen. II, III) and the design of improved new concepts (Gen. IV reactors). Measurements carried out at the GELINA neutron time-of-flight facility and the Van de Graaff accelerator play a major role in establishing and improving the evaluated nuclear data files maintained at the OECD-NEA databank and at IAEA.

The IRMM accelerator facilities are run by the technicians that also perform the maintenance and the development projects.

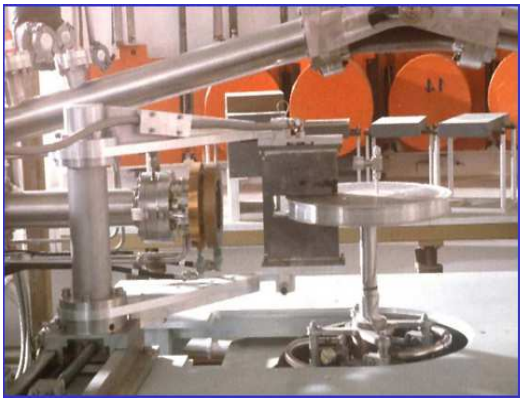
### 1.1. <u>Geel Linear Accelerator (GELINA)</u>

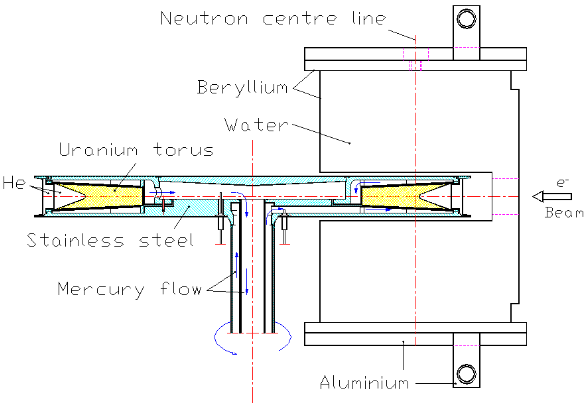
The Geel Electron Linear Accelerator GELINA is a pulsed white neutron source, where the time-of-flight (TOF) method is used to determine the energy of the interacting neutrons in the energy range covering 11 decades (1 meV – 20 MeV). The resulting excellent neutron energy resolution is made possible by a combination of four specially designed and distinct units:

- a high-power 150 MeV pulsed linear electron accelerator, delivering 800 electron pulses per second with a peak current of 12 A and a pulselength of 10 nsec.
- a post-accelerating beam compression magnet system, that compresses the electron pulses to a peak current of 120 A and a pulselength of 1 nsec.
- a mercury-cooled uranium target for the production of neutrons, and
- twelve long neutron flight paths.

150 MeV pulsed linear electron accelerator

Post-acceleration relativistic beam compression magnet system






Mercury-cooled depleted uranium neutron production target

With its twelve completely independent flight paths GELINA is a multi-user facility serving up to twelve different experiments simultaneously. The up to 400 m long flight paths, which point radially to the uranium target, lead to experimental stations at distances of 10, 30, 50, 60, 100, 200, 300 and 400m. These experimental stations are equipped with a wide variety of sophisticated detectors, and data acquisition and analysis systems, especially designed for neutron-induced cross-section measurements with an exceptional precision and energy resolving power. Modern detection techniques such as advanced HPGe Compton-suppressed detectors and data acquisition systems based on fast signal digitisers are in use.

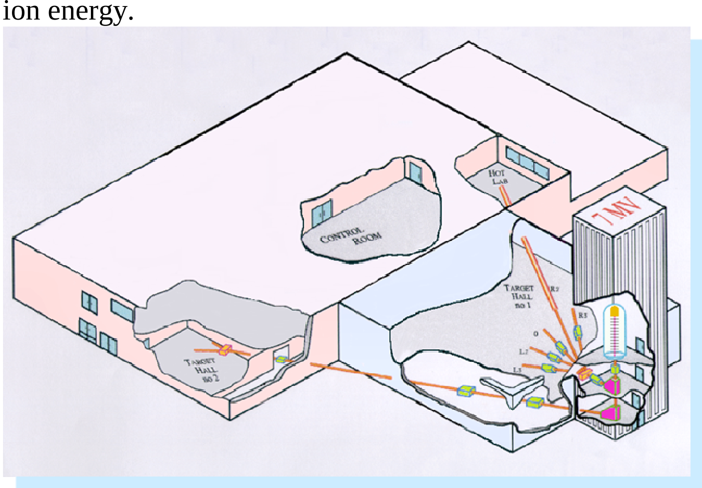
Aerial view of GELINA time-of-flight area

The facility is operated in shift work on a 24-hours/day basis, for about 100 hours per week.

**1.2. Van de Graaff accelerator**

The high intensity quasi mono-energetic neutron source at JRC-IRMM is driven by a vertical 7 MV Van de Graaff (VdG) accelerator producing either continuous or pulsed ion beams. This facility is complementary to the GELINA neutron time-of-flight facility. Quasi mono-energetic beams of neutrons are produced in the energy range up to 24 MeV. Especially in the MeV neutron energy domain where the resonance structure of the cross-sections is averaged out, the high-resolution measurements at GELINA can be complemented by measurements at the VdG, where the experimental conditions are more favourable for weak cross sections and low sample quantities.

The Van de Graaff facility is a 7 MV electrostatic accelerator for the production of continuous and pulsed proton-, deuteron- and helium ion beams. Ion beams can be produced with a current of up to 60 μA on target in DC mode and up to 5 μA in pulsed mode. The pulse repetition rates are 2.5, 1.25 or 0.625 MHz and the ion pulse-lengths are 2.50-1.25 ns FWHM depending on the ion energy.




7 MV Van de Graaff accelerator

The neutrons are produced by the nuclear reactions Li(p, n), T(p, n), D(d, n) or T(d, n).
The energy of the mono-energetic neutrons used for the measurements is defined by a combination of three factors:

- type and energy of the accelerated particle (protons, deuterons or helium ions);
- neutron production target (lithium, deuterium or tritium targets);
- emission angle under which the neutrons for the experiments are selected.

Neutron fluence fields can be produced with peak energies in the regions 0.3 – 10 MeV and 16 - 24 MeV at 0 degree measurement angle.

Six beam lines with dedicated experimental set-ups for activation, fission and scattering experiments are attached to the accelerator. In contrast to GELINA, here, only one set-up can be used at a time. The facility is operated continuously during weeks, on a 24-hours/day basis, 5 days per week basis.

### 1.3. <u>Research activities carried out at the JRC-IRMM nuclear data facilities</u>

Measurements at GELINA and the Van de Graaff accelerator provide data which form the basis for a wide range of evaluated neutron cross-section data. These data are needed for the safety assessments of present-day and future nuclear energy systems.

They can be subdivided into two groups:

1. neutron reaction cross-sections:
   - high energy resolution measurements of the neutron cross section for total absorption, capture, elastic and inelastic scattering.
   - neutron cross section for activation, fission and light charged particles emission.
2. other important reaction parameters:

- neutron-induced fission: fission fragments (mass, kinetic energy), fission neutrons (multiplicities, spectra), fission gamma rays and ternary fission.
- resonance parameters.

These data are essential for estimates of nuclear criticality, residual heat production, activities and dose rates, all important quantities of immediate concern to safety and security of nuclear energy.

JRC-IRMM contributes also substantially to the high precision measurements of nuclear reaction standards. Since the majority of measurements in neutron physics are made relative to neutron data standards, the quality of these data standards is a key issue for improved safety of present day and innovative reactor systems. Hence JRC-JRC-IRMM has been committed itself to a continuous improvement of these standards and also investigate the underlying physical mechanisms.

To ensure stakeholder orientation each measurement project is embedded in collaborations with parties outside the JRC, either through bilateral agreements with nuclear research institutions of the Member States, through competitive projects supported by DG-RTD, or through collaborations coordinated by the OECD Nuclear Energy Agency or the IAEA Nuclear Data Section.

## 2. Radionuclide metrology laboratories: A cluster of instruments for high precision radioactivity measurements.

The activities of the Radionuclide Metrology group (RN sector) at JRC-IRMM unit can be subdivided into five core domains:

- **Primary standardisations** of radioactivity (the most accurate type of measurements) independent of any other radioactivity standard and for the provision of reference values in interlaboratory comparisons (ILC).
- Production of **general reference materials and specific reference materials for ILCs**, and performance of reference nuclear-decay measurements.
- Organisation of **proficiency tests and ILCs** used to ensure the quality of radiation monitoring results obtained by Member State laboratories.
- Performance of **ultra-low level radioactivity measurements**.
- **Standardisation** in radiological and nuclear security (CBRN Action Plan).

The core activities are to provide radioactive reference measurements and reference materials for all aspects of society (food safety, nuclear safety, radioactive waste management, nuclear medicine etc.). As all radionuclides decay in different ways, it is essential that JRC-IRMM has a unique cluster of laboratories with a multitude of high accuracy radioactivity measurement techniques. JRC-IRMM is among the few laboratories world-wide to provide reference data on the 100 most relevant radionuclides. To measure the lowest radioactivity levels, it also performs low background measurements in the 225m deep underground laboratory HADES. This is important for many reasons like checking homogeneity of reference materials and detecting specific processes in industry and nature.

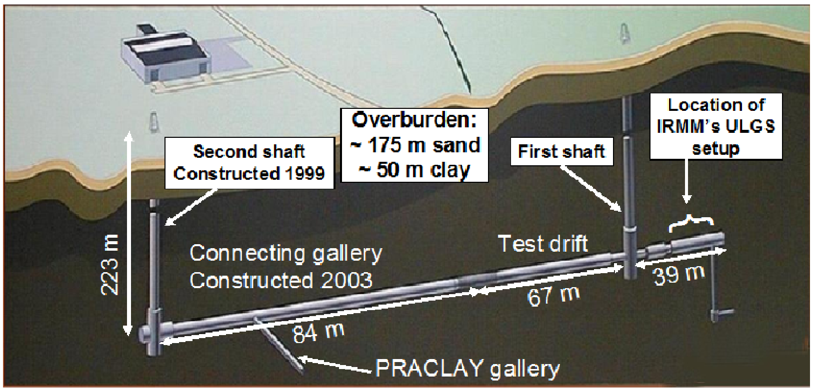
One of the most important projects of the Radionuclide metrology Sector is linked to the implementation of the Euratom Article 35 by ensuring equivalence on the results that the Member State -laboratories report for monitoring radioactivity in the environment. This work requires expertise in various fields. Each year different radionuclides in a new matrix are characterised and a new a new matrix characterised and the reference materials used an ILC (InterLaboratory Comparison) requested by the Article 35 experts. The four groups comprising the RN-Sector all have important contributions to this work. The reference materials group produces the samples for the ILC. The primary standardisation group provides the reference values, the low-level group ensures the purity of the materials and performs independent checks of activities and finally the ILC group coordinates the work and carries out the ILC. This activity would not be possible if one of the groups was stopped.

As there are many radionuclides and each decays in a different way it is evident that it is not possible to have a few types only of radiation detectors. Several different radiation measurement systems are needed for accurate measurements as one can optimise the detection for each radionuclide. Many of the instruments in the RN-laboratories have been built in–house and are unique. Therefore the RN-Sector is really the legacy of the former CBNM (Central Bureau for Nuclear Measurements). It is thus logical to refer to the RN-Sector as the JRC reference centre for radioactivity measurements as it is, in many ways, the world leading group for radioactivity measurements.

The Radionuclides group operates several laboratories with state-of-the-art equipment for radioactivity measurements at the IRMM site and in the underground laboratory for very low background measurements at the SCK facility HADES.

### 2.1 HADES: a 225 m deep underground laboratory

At the premises of SCK•CEN there is a 225 m deep underground laboratory named HADES. It is an acronym for High Activity Disposal Experimental Site. In HADES Belgium performs long term geological studies on the final disposal of Belgian nuclear waste (note that there is NO waste in HADES and there will never be). In 1993, the RN-Sector placed its first HPGe-detector in HADES. This was part of an exploratory research project to investigate the gains of performing gamma-ray measurements deep underground. It turned out that the gains are huge. Since the cosmic ray flux in HADES is 10000 times lower compared to above ground, the background reduction is about the same. It is, however, not possible to achieve this background reduction with “common” detectors as they contain too much natural radioactivity (1 Bq gives a huge background when trying to measure 1 mBq). Therefore both the detectors and the shieldings in HADES need to be made from specially selected radiopure materials.




Location of ultra-low level γ-spectrometry laboratory in HADES

One can say that the change from exploratory research to an important infrastructure supporting many activities was taken in 1999. In connection to the Tokai-mura accident in JAPAN the European Commission offered help to Japan. It turned out that the most important help they needed from the EC was measurement in HADES of spoons activated in the houses of people living near to the accident site, in order to calculate the dose received by the population and assess the effects of the accident. Since then, HADES measurements has been performed in some 250 different projects covering a wide field from radioprotection, fundamental physics and fusion research to characterisation of reference materials and tracing radionuclides in the environment.

Typically mBq-levels of activity are measured in HADES. A mBq is about 1 decay per hour. Given that the detection efficiency varies between 1% and 10% it is clear that a sample needs long measurement time (typically 1 week). The main limitation of the technique is thus throughput. It is thus necessary to use a large number of detectors. At present there are 11 HPGe-detectors in HADES. It was also a logical step by IRMM to start the network CELLAR in 2000 (Collaboration of European Low-level LAboRatories), which Mikael Hult (from IRMM) coordinated from 2000 to 2006, to cope with large projects by using detectors in several laboratories.

### 2.2. Radionuclide laboratories at IRMM

The Radionuclide laboratories located at the premises of IRMM have a long tradition of more than 55 years. The laboratories are equipped with a variety of instruments, many of them unique in their kind, in order to perform measurements of a large number of radionuclides in samples as diversified as reference materials, solutions for standardisation, determination of nuclear data, environmental samples and monitoring. The instruments are operated by very competent staff members, both scientific and technical, albeit not enough manpower is assured to cover all projects currently under execution.

Below is a non-exhaustive list of laboratories and instruments available in the RN-laboratories:

### 2.2.1 Sample preparation

A dedicated controlled area for preparing radioactive sources of different types. This laboratory is equipped with state-of-the-art mass metrological equipment so that very precise sources can be made.

### 2.2.2 Chemical Laboratory

This relatively small but fit for purpose laboratory is used for advanced chemical separation methods and to prepare samples from various matrices by isolating the necessary elements.

### 2.2.3 Methods for primary standardisation

Primary methods are those methods where one in principle does not need to calibrate the detector. Here the activity follows from basic physical principles. An example of one technique is $4\pi\beta\gamma$-coincidence counting, another is defined solid angle X-ray or alpha-particle counting. In specific applications, also liquid scintillation counting is considered a primary method. It is not always evident which method is most suitable for a specific radionuclide. Therefore it is important to have access to different methods to discover bias or problems with a certain method.

### 2.2.4. Methods for secondary standardisation

Secondary methods are those methods where it is explicitly needed to calibrate a detector. Amongst these methods there are gamma-ray spectrometry, alpha-particle spectrometry and measurements using ionisation chambers. These methods are highly used as some of them (e.g. gamma-ray spectrometry) require little sample preparation and have the possibility of generating data for several radionuclides in one analysis. These methods are commonly used in industry so it is essential for us to use these techniques not only for fully characterising reference materials but also to be able to give training and advice on these techniques.

## 2.3. Research activities carried out at the JRC-IRMM radionuclide facilities

The HADES laboratory is in excellent condition and the results obtained are world-class both when it comes to low background and robust results. Within CELLAR we have worked to promote underground science and the number of laboratories is increasing due to the great benefits that can be obtained. However, HADES stands out as the laboratory that has the most diversified programme. The other underground laboratories have generally only 1 key task which can be e.g. fundamental physics or environmental monitoring. The measurements performed in HADES concentrate on gamma-ray spectrometry with detection limits of the order of mBq/kg.

The measurements in the Radionuclide laboratories located at IRMM focus on nuclides relevant for current and future reactors, waste management, decommissioning, and nuclear medicine. They encompass:

- reference measurements: nuclear decay data (half lives, spectra, emission probabilities), standardisation of radionuclide activity.
- radionuclide analysis of environmental and industrial samples: comparison samples needed for ICS-REM, reference materials.
- organisation of laboratory comparisons for DG ENER: ICS-REM
- all mentioned activities are enabling and feeding into policy support

For this work, the laboratories rely on a broad set of experimental techniques, partly specifically developed in the RADMET laboratories in Geel including:

- 4π β−γ coincidence counting systems
- 4πγ counting
- 4π β−γ sum counting
- 4π e-,β,γ,X-ray counting (unique CsI sandwich detector)
- defined solid angle alpha-particle and X-ray counting
- liquid scintillation counting:
- CIEMAT/NIST method
- TDCR method
- ionisation chambers
- gamma-ray spectrometry
- radiochemistry laboratory

## 3. Nuclear reference materials laboratories for the preparation and provision of certified nuclear reference materials and reference measurements

**(these facilities cannot be used by external users in the framework of EUFRAT)**

The activities of the nuclear safeguards group (NS-sector) at JRC-IRMM can be subdivided into four core domains:

- Provision of **certified nuclear reference materials** (CRMs).
- Provision of state-of-the-art **reference measurements** on nuclear material and environmental samples.
- Provision and/or coordination of **Inter-laboratory comparisons** on samples analysed in fissile material control and for environmental traces characteristic for the nuclear fuel cycle.
- Development and production of **well characterised targets** for measurements in nuclear physics for nuclear safety and nuclear safeguards applications.

The nuclear reference materials laboratories and target preparation laboratories encompass 2 nuclear controlled areas MS1 and MS2 and a few laboratories outside the controlled area. In addition, in MS2 the so-called bunker is used as the storage of IRMM's nuclear material.

The combination of having the 3 nuclear laboratories (nuclear chemistry, mass spectrometry and target preparation) at one site in one building is the basis for IRMM to have a leading position in the production of nuclear CRMs as well as in the preparation of targets for the accelerators.

### 3.1. Nuclear reference materials laboratories: nuclear chemistry and mass spectrometry laboratory

The nuclear reference materials laboratories located in controlled area MS1 have the following equipment:

- Mass spectrometry equipment
- Equipment for chemical sample preparation in glove boxes
- Equipment for substitution weighing in glove boxes
- Robot systems for dispensing of radioactive solutions (tailor-made for IRMM application)
- Equipment for production of reference particles and UF6 reference measurements (IRMM home-tailor-made for respective application)

URANUS
UF6 gas source
mass spectrometer

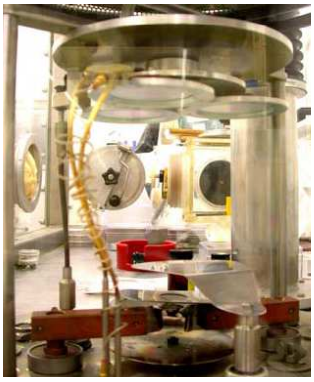
The nuclear chemistry and mass spectrometry laboratory also hosts equipment that was tailor made for the respective applications, such as the robot systems, the carburisation device and all equipment linked to the production of uranium reference particles.

Robot systems for dispensing of radioactive solutions

### 3.2. Laboratories for the development and production of well characterised nuclear targets

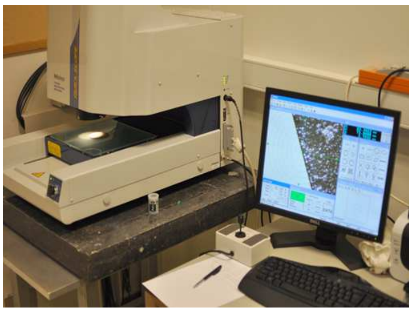
The laboratories for the development and production of well characterised nuclear targets located in controlled area MS2 have the following equipment:

- Equipment for actinide target preparation and characterisation carried out in glove boxes
- Equipment for physical vapour deposition
- Equipment for molecular plating
- Equipment for alpha counting
- Equipment for pressing, punching etc….



Vapour deposition equipment

Laboratories outside the controlled area are used for the preparation of non-active targets and the preparation of polyimide foils – again some of the equipment (evaporators) is unique and tailor-made for the application.



Thin target characterisation equipment

The complete target preparation laboratory for active and non-active target preparation is unique and one of the last of its kind world-wide.

## 3.3. Research activities carried out at the JRC-IRMM nuclear reference materials laboratories

The research activities carried out in the nuclear reference materials facilities are:

- nuclear chemistry,
- nuclear mass spectrometry,
- actinide target preparation, and
- outside the controlled area, non-active target preparation.

These activities are carried out in support to the projects as defined in the AWP2014-2016 in support to nuclear safeguards, security and safety. The core activities carried out in the laboratories are:

- Development and production of certified nuclear reference materials (CRMs). IRMM is one of the 3 major providers of nuclear CRMs to policy DGs, international organisations and industry
- Development and provision of state-of-the-art mass spectrometry reference measurements on nuclear material and environmental samples. IRMM is developing and improving state-of-the art reference methods for nuclear material analysis
- Production of certified test samples for Inter-laboratory comparisons for samples analysed in fissile material control and for environmental traces characteristic for the nuclear fuel cycle. IRMM runs 2 interlaboratory comparisons schemes REIMEP and NUSIMEP.
- Development and production of well characterised targets for measurements in nuclear physics for nuclear safety and nuclear safeguards applications. IRMM is one of the very few institutes world-wide that has unique facilities and know-how in the preparation of thin film deposits (called targets) tailor-made for nuclear physics measurements at IRMM and international accelerator sites. High quality nuclear targets produced by the best available techniques and characterised by state-of-the-art methods are indispensable. Without these high quality targets with uncertainties below the target nuclear data uncertainties, no measurement effort may reach the desired goal.