CENTRO DE MICRO-ANÁLISIS DE MATERIALES: STRATEGIC PLAN 2021-24

1. Fulfilment analysis of previous plan

The Centro de Micro-Análisis de Materiales (CMAM) is applying for its inclusion in the ICTS map for this period (2021-24). Therefore this is the first strategic plan, thus the revision of fulfilment for the previous one is not applicable. A detailed explanation on prior scientific and technological activities is available in section a) (RI overview) of the ICTS application currently under evaluation and may be consulted therein.

2. Mission and vision

The mission of CMAM is to conduct, in collaboration with a wide multidisciplinary user community, research activities using ion beam and complementary instruments, generating scientific impacts, technology spillovers and contributing to training of students through the singular elements available at the facility.

The vision of CMAM is threefold: 1) to become a reference ion beam facility with some unique techniques at the European level; 2) to become a Spanish hub for multidisciplinary science initiatives, where ion beam techniques and other experimental possibilities are synergically applied to ambitious experimental cases; 3) to offer a unique training environment for students, profiting from the singular instruments available at CMAM, from the excellent science involved in the previous two elements of this vision, and from the fact that CMAM is fully integrated into the UAM-CSIC excellence campus.

3. SWOT analysis

Strengths

The CMAM accelerator is very stable and reaches very interesting energy ranges (up to 10 MeV for protons, tens of MeV for heavy ions, reaching the production of Pb and Bi).

CMAM has state of the art beamlines implementing different techniques useful for the user community.

ERD-TOF BL is a singular instrument, available only at a few European facilities and extremely powerful for thin film analysis.

The combination Implantation beamline – femtosecond laser is unique and opens very attractive research possibilities.

Weaknesses

Scientific staff is mainly formed by university professors with only partial dedication.

Technical staff is pending consolidation and is at the moment very limited for full development of the facility potential.

Opportunities

CMAM is located at one of the most dynamic campuses of Spain: the UAM-CSIC excellence campus. This is extremely relevant both from the point of view of the rich user community present therein, the potential to engage industry collaborations and from the perspective of future development possibilities involving other institutions in addition to UAM for full development of the CMAM scientific potential.

CMAM has the ideal instrumentation conditions to become an important player in hadrontherapy research, which is an emerging niche in Spain, stimulated by the recent opening of the first two clinical facilities in Madrid and by the expectation that others may open soon in other areas of Spain.

CMAM has large potential for Nuclear Physics studies of interest for Astrophysics, as well as for testing of instrumentation.

CMAM is very well connected to ARIE (Analytical Research Infrastructures of Europe) and has the opportunity to develop a relevant status in European projects and the European Research Area, as an active member of the ion beam network.

Threats

CMAM is already 20 years old and some basic infrastructure elements and parts of the scientific equipment need investment to mitigate obsolescence risks and improve the control layer.

The current staffing situation is fragile and may deteriorate if advances are not consolidated during the next few years.

The ERD-TOF beamline is at the moment not fully operational and an effort is required to develop its scientific capabilities at its maximum level.

The experiments to fully exploit the synergy between ion beam and laser, one of the strongest points of CMAM, are difficult and require very strong scientific engagement by different actors, which is not easy to achieve.

4. Objectives 2021-24

In order to improve the readability of this section we have listed objectives in subsection 4.1 and strategies to achieve those objectives in subsection 4.2. These two subsections are therefore used as reference lists for quick consultation, with just a brief global view of the relationship between different objective in 4.1. Subsection 4.3 is then used to present coherently the hierarchy of objectives, strategies and specific actions linked to each strategy, with additional comments and explanations. Reading of 4.3 will allow then to get a global picture of the overall plans for CMAM during the period 2021-24. Objectives have been designed to discharge the mission and take definite steps towards fulfilling the vision as given in section 2. The elements of the DAFO analysis (section 3) are key in shaping the strategies and specific actions therein, so that the objectives may be reached.

4.1. **Objective description**

The main objectives for the 2021-24 period are the following:

- O1. Consolidate operation with the existing instruments and techniques
- O2. Consolidate and further develop research activities in the different areas where CMAM is already active

- O3. Bring the ERD-TOF beamline to full scientific exploitation
- O4. Exploit scientifically the ion-laser synergy present in the IMP beamline
- O5. Develop new capabilities for application in protontherapy research
- O6. Build new station for in-situ measurement of Kerr effect during irradiation

One may immediately notice that the first two objectives are very different from the last four ones. Indeed O1 and O2 correspond to the basic and most essential view of how CMAM should operate and develop, and are very complementary to one another. In the text below devoted to these two first objectives some overview of the most relevant aspects either from the point of view of staffing and instruments, or from that of scientific exploitation, have been addressed. As CMAM is going through the process of evaluation to enter the ICTS map in this period, we have avoided to replicate the exhaustive information about the current activities given in the ICTS application.

Objectives O3-6 correspond to specific initiatives, which have enough weight and complexity with respect to the overall plans to require individualization at the objective level. They correspond to a qualitative improvement of both an instrument and its scientific exploitation (O3), to push forward a given scientific niche with a qualitative change with respect to the previous activity (O4-5) or to develop and build a new instrument (O6).

It shall be kept in mind that CMAM is inherently multidisciplinary. Multiple science areas are covered and planned to have a very important activity. All of them are included in objective O2 and shall be regarded as extremely important for the development of the center, even if they have not been singled out as a separate objective.

As indicated above, further explanation of these objectives is given below in 4.3, where objectives, strategies and tasks are explained coherently in further detail.

4.2. **Strategies to achieve the objectives**

- Strategies linked to objective O1:
  - S1.1. Consolidate technical and scientific staff, by combining UAM staff positions and temporary personnel funded by projects
  - S1.2. Maintain and upgrade CMAM base infrastructure taking into account that the laboratory is now 20 years old
  - S1.3. Implement systematic improvements and acquire spares for accelerator and BLs
- Strategy linked to objective O2:
  - S2.1. Actively engage in scientific projects of areas not singled-out in other objectives of this plan, bringing together the interests of CMAM scientific staff and the user community
- Strategy linked to objective O3:
  - S3.1. Prioritize the efforts on the ERD-TOF BL, as a singular instrument for flexible multielement depth profiling overcoming the limitations of other (simpler) instruments and techniques, combining different types of actions in the proper sequence along the full period object of this strategic plan
- Strategy linked to objective O4:
  - S4.1. Prioritize the full exploitation of the combination ion beam-laser in the Implantation BL, as a unique instrument with huge scientific potential, including the possibility of doing time-resolved experiments.

- Strategy linked to objective O5:
  - S5.1. Collaborate with key external groups from the public and private sector, profiting from the circumstance that two clinical protontherapy facilities in Spain have started to operate recently and more will likely come in the coming years, to make CMAM a relevant actor and a key hub for protontherapy research in Spain.
- Strategy linked to objective O6:
  - S6.1. Collaborate with other institutions to develop and optimally exploit the new station for irradiation of magnetic materials with in-situ characterization.

4.3. **Actions planned to develop the strategies**

In this section the full hierarchical picture of objectives, strategies for achieving the objectives and tasks to implement the strategies, is developed and explained. The previous subsections are then left as quick reference lists, whereas further details are given here.

4.3.1**. Objective O1**

The first and basal objective for CMAM during the period 2021-24 is to consolidate operation with the existing instruments and techniques. This is as a general rule the highest priority objective, as all the rest depend on it in a way or another. Nevertheless it comprises several complementary strategies implemented in specific tasks, which imply different levels of criticality. The most essential tasks should be deemed as absolutely necessary, whereas there are others which may wait somewhat longer to be implemented, or even some which would be clearly advantageous, but still the facility could operate without them in a scenario of limited resources.

The three strategies to achieve O1 act respectively on staffing and maintenance and improvement of basic infrastructure and accelerator and beamlines, respectively. The first one (S1.1) is basically developed in actions related to the interplay of CMAM with the general UAM structure, as CMAM is a center owned by this university. The second one (S1.2) focuses on the conventional infrastructures which provide the basic conditions for scientific instruments to operate efficiently and reliably. The period 2021-24 should be an inflection point in this respect, as CMAM reaches the age of 20 years and some refurbishment is necessary. Depending on the funds available the necessary actions may be spread out over a more or less extended period, assuming some failure risks if the overall timescale is longer. The third strategy (S1.3) corresponds to scientific equipment itself, both accelerator and beamlines. Again, the age of the facility plays a major role here, in particular in relation to the accelerator and its control system, whereas continuous development, operational improvements and new technological opportunities (in particular in the area of detectors and readout electronics) are most important for beamlines. No particular actions are proposed within this period for complementary instruments, not directly linked to beamlines. The detailed list of tasks is given below in separate paragraphs for each strategy.

4.3.1.1**. Strategy S1.1**

As indicated above, S1.1 is formulated as ´´ Consolidate technical and scientific staff, by combining UAM staff positions and temporary personnel funded by projects ´´. This strategy shall be implemented by combining structural and third-party funding actions. In a longer term collaborative options involving institutions other than UAM could be the ideal way to fully develop the scientific potential of CMAM. Notice that, for the sake of simplicity, we are including here in a coherent strategy all staffing aspects, which are partly related to objective O2 described below. The following actions have been designed to fully develop this strategy:

- A1.1.1. Work with UAM governance team to stabilize existing technical positions, cover those not occupied at the moment and foresee additional ones.

  This action is devoted to CMAM technical and direct user support staff, and the plans are to map this clearly to a fixed number of structural UAM technical positions, a large fraction of which are already existing, whereas a few others need to be created. Implementation of these actions over the period 2021-24 is very important ingredient of this strategic plan, and is already being explored and planned for.

- A1.1.2. Work with collaborating groups in the area of Fusion materials to take part as laboratory in a new project of Comunidad de Madrid (currently Technofusion) for the period 2023-26, providing funding to hire additional technicians.

  CMAM is currently taking part in the project TECHNOFUSION(III)CM, REF. S2018/EMT-4437, funded by the Madrid region. The Project is coordinated by CIEMAT and focuses on development and testing of materials for fusion technologies. CMAM is involved in the project as a support laboratory (lab 171). The different research groups have then the possibility to get an important share of CMAM´s beamtime to develop the different projects, which include irradiation (mimicking with suitable ion beams the conditions relevant to a future fusion reactor) and analysis of materials previously irradiated with other types of radiation (such as neutrons). This project in its current shape essentially provides funds to train technical staff at CMAM, which is very complementary to the previous action and allows CMAM to generate impacts in terms of contributing to career development of (frequently) young technical profiles. As the project finishes in December 2022, the plan is to collaborate with other institutions to apply for and obtain a new project to continue contributing to the fusion research program, for the period 2023-26, which would therefore cover the full period object of this strategic plan and part of the following one.

- A1.1.3. Consider different calls to complement during the next 4 years the present technical team.

  Third party funding opportunities for technical staff training, both by the central government and the region of Madrid, have been and will be considered as a very interesting complement to the previous two actions. At the moment CMAM has one of these projects approved (Personal técnico de apoyo, PTA; funded by the central Government), which is expected to start by January 2022 and with a duration of three years, that is, just until the end of this period. The position is devoted to extending and improving the CMAM capabilities for direct user support, with special emphasis on promoting industrial usage. The plan is to use these funding opportunities as a complement of structural staff and the specific collaboration in the fusion area (as mentioned in action A1.1.3), in order to improve user support and develop further capabilities in collaboration with the user community in different topical areas. The aim would be having always one or two of these positions funded, which would be used to train new people and get the best out of CMAM in collaboration with users. Training of the candidates involved for subsequent development of their careers will always be an essential ingredient. One of the areas which could be the object of a third-party funded training position application during the remaining few years is support to users in the field of Cultural heritage, as this area has many specificities and features at the moment very good opportunities of development. A collaborative approach to this initiative with SECYR (Archaeological heritage conservation, restoration and scientific studies service) at UAM is being explored.

- A1.1.4. Attract talented scientific staff via competitive calls

  Scientific staffing of CMAM is based on teaching/research university positions, co-ascribed to a given department and CMAM, and full-time researchers attracted via third-party funding. Some of the funding programs available (as the Ramón y Cajal one) generally imply a subsequent integration of the successful candidates in the permanent structure of university, and thus require a collaborative approach with one of the departments. The target funding programs for this task are both national (such as, for example, Ramón y Cajal or Juan de la Cierva), regional (as the talent attraction program by the Madrid region) and international (such as MSCA). CMAM is actively pursuing these opportunities and will continue doing so. It is to be expected that the increasing scientific activity of the facility, with the additional impulse of its incorporation to the ICTS network, will yield positive results. This action has transversal character and applies to the other objectives included in this strategic plan.

- A1.1.5. Explore and develop with UAM and other collaborating institutions new formulas to engage full-time scientific staff to CMAM activities.

  Although the development of strategy S1.1 by implementing tasks A1.1.1-4 as described above provides a coherent and complete framework for operating CMAM at the service of the user community, the fact that permanent scientific staff is unavoidably only part-time assigned to the facility implies a limitation to the scientific ambition which may be aimed at. One of the keys to success of a research infrastructure which incorporates complex scientific instruments and develops techniques requiring high specialization, as is the case for CMAM, is a good equilibrium between user service and own research. Too much weight on user service works for less complex instruments, but leads with time to stagnation and loss of competitivity for cases such as those involving particle accelerators; too much emphasis on own research risks making the facility work effectively as a research group which some external collaborations. In the case of CMAM, the possibility of incorporating, in the mid-long term, permanent scientific staff full-time dedicated to research activities at the facility, and opening the opportunities generated by such research to the benefit of the user community, would allow to boost performance and impact of the facility to levels higher than the ones feasible today. Such a scheme would require collaboration with institutions other than university, such as CSIC, IMDEA and/or CIEMAT. The task herein described looks into the future, as it implies developing the necessary discussions with the relevant actors, during the period 2021-24, to make possible an eventual implementation of this ambitious vision.

4.3.1.2. Strategy S1.2

S1.2 is formulated as ´´Maintain and upgrade CMAM base infrastructure taking into account that the laboratory is now 20 years old´´. It is well-known that in advanced research infrastructures the so-called ´´conventional´´ infrastructures meet complex requirements and are, in fact, an integral part of the scientific instrument in terms of functionality and performance. Therefore it is not rare that the most pressing practical difficulties for RIs arise from what one could call ´´low-tech´´ subsystems. This inherent difficulty emerges as a particular challenge at two stages during the life of an RI: at the moment of initial design and construction, where the effort on defining and deploying the scientific instruments may lead to limited attention for the necessary conventional elements making their operation possible; and when the facility reaches a given level of maturity and both scientific instruments and base infrastructure have increased risk of failure. The latter is the case of CMAM, which was built during the first few years of the 2000 decade and will be 20 years old during this ICTS strategy period, as the center was formally inaugurated and started operations in 2003. The tasks enumerated and developed below go through the different conventional subsystems which require an upgrade, with different levels of priority. In some cases, there is already now a substantial risk for severe failure, which could lead to a long unprogrammed shutdown, or even to severe damage to some of the key accelerator components. In other cases the timeline for upgrade may be extended, depending on the funds available, assuming a gradually increasing risk of loss of efficiency.

- A1.2.1. Launch tender and implement new HVAC system and controls for the accelerator Hall.

  This is the most urgent action to be implemented in order to develop strategy S1.2 as described above. The HVAC system which regulates temperature and humidity inside the experimental hall hosting accelerator and beamlines gives rise to numerous incidences during the past few two years, which imply frequent interventions by the UAM maintenance service and in some cases delay of operations, in case the hall temperature goes out of range for a safe operation of the accelerator. In the event of a failure during a period of high outdoor ambient temperature even with the accelerator not in operation a risk of damage exists, as the accelerator tubes form a column of ca. 9 m length suspended from its two endpoints, and differential thermal expansion is expected to generate too high stress for the tube materials if the temperature would ever come close to or above 40 C. Humidity control is also an important issue, which generates some operational difficulties due to the limited reliability of the current HVAC system. The main problem in this case is that some accelerator components are water cooled with inlet temperature in the 10-12 C range, with the risk of developing condensation on inlet pipes if the dewpoint goes above the desired limit in the hall. The action proposed has been thoroughly studied and implemented in an engineering project, including the hardware and control system, and is now ready to tender for the execution as soon as budget becomes available. Depending on the budget availability it may be launched in 2022 or 2023. The latter would imply assuming an additional risk, as the situation with the current system is already now somewhat fragile.

- A1.2.2. Implement redundancy and upgrade of control layer to chilled deionized water circuit

  The chilled deionized water circuit refrigerates a number of critical elements, such as the accelerator RF driver, the dipole magnets guiding the ion beam and some beamline elements. The current system has a secondary loop with deionized water, thermally linked (by a heat exchanger) to a primary loop with a chiller. This equipment has generated some failures during the last few years, requiring some interventions and occasionally some unprogrammed short shutdowns. In order to improve the reliability of the system a project has been elaborated to add a second chiller for redundancy, in such a way that a swap may be done in case of failure, continuing with operation as the root problem is solved. In addition the project would include the implementation of a new user control layer, for more friendly and transparent operation from the accelerator control room. Whereas this is an important action, the level of priority is not as high as for the previous one

- A1.2.3. Upgrade of control layer for other conventional equipment

  In addition to the two subsystems mentioned in the previous actions, it is very convenient to improve the level of redundancy and supervision of the environmental situation affecting the scientific instruments present at the CMAM accelerator hall. In particular the compressed air system is continuously used to operate pneumatic valves and other purposes in the accelerator injector, and the monitoring of temperature and humidity at several locations specifically linked to the accelerator operation are important inputs to anticipate difficulties and correlate to the machine performance both online and offline. This action is important to fully profit from the excellent stability of the accelerator system (e.g. terminal voltage ripple below 10^{-5} at 5 MV, as it may be consulted in ¨Performance and Applications of the first 5MV Tandetron at the University of Madrid¨, D.J.W. Mous, A. Gottdang, R.G. Haitsma. G. García López, A. Climent-Font, F. Agulló-López, D.O. Boerma, Proceedings CAARI 2002, AIP Conference Proceedings, Volume 680, Issue 1, pp. 999-1002. To that end this action would implement a network of additional sensors and the corresponding control layer. The level of criticality of this project is comparable to A1.2.2

- A1.2.4. Complementary portable monitors and upgrade of control layer for radiological protection area monitors

  Area radiation monitoring is performed at CMAM with two sets of gamma-ray and neutron monitors, connected to other elements of the system with proper signals and interlocks. This system works well and has shown no need to be replaced. The monitoring of this detector network from the accelerator control room for registry and archiving of the dose rates at the different detectors is however running in a very old computer, via a program which can not be easily transported to an updated platform. Therefore it would be necessary to launch a project to upgrade the control system and transfer it to a new platform. In addition CMAM provides to the team of radiological supervisors and operators a few portable detectors. In order to gain flexibility and provide more useful tools for verifying radiation levels at specific points of the accelerator hall, including activation whenever applicable, a new gamma-ray dose detector and gamma spectrometer for radionuclide identification would be of great benefit. The investment included in this action comprises both the control system upgrade for area monitors and these two new portable devices.

4.3.1.3. Strategy 1.3

S1.3 is formulated as ´´Implement systematic improvements and acquire spares for accelerator and BLs´´. Together with staffing (S1.1) and base infrastructure (S1.2), it completes objective O1 guaranteeing the optimal performance of existing instruments and techniques. The underlying approach is to concentrate on having very well covered with spares all the important elements whose failure may imply an unprogrammed shutdown for the accelerator or for one of the BLs, while in addition incorporating new technologies selectively, wherever this may imply a relevant positive impact, particularly in detectors and data acquisition electronics. The specific actions focus on types of equipment transversal to accelerator and beamlines (such as vacuum), components specifically related to the accelerator, and BL components. As indicated in detail below a very ambitious specific action is proposed on the accelerator and BLs control system, which is at the moment generating a bottleneck for further development of the systems, due to an obsolete configuration which can not be expanded further in its current shape.

- A1.3.1. Replace old equipment and acquire spares for vacuum equipment for both accelerator and BLs.

  Vacuum technology is one of the essential elements of the system formed by accelerator and beamlines. It comprises mainly pumps, gauges and valves. Pumps and gauges require periodic replacement and some stock to react to unexpected failure, whereas valves are expected to be very robust instruments. However some small improvements are possible, by combining primary and turbo pumps in the best possible way and protecting the interface between both with pneumatic valves, replacing manual ones present in some cases, and implementing automatic protection protocols. Altogether this investment includes the need for regularly acquiring vacuum equipment for improvement, replacement and spares, according to the experience gained over the last years and with the aim of gaining some additional safety margin. The investment is formulated as annual, fine-tuning the specific items to be purchased each year depending on the failure dynamics observed.

- A1.3.2. Acquire spares of critical accelerator components

  The CMAM tandem accelerator has numerous specific components giving rise to periodic failure. The most relevant ones are some of the injector subcomponents, in particular those related to the ion sources. Elements such as the sputtering source ionizer, the plasma source filament and feedthroughs, or the accelerator column diodes, to cite but a few, have a limited lifetime. A continuous investment to acquire and keep the proper stock of those elements which are known to fail periodically, plus some funds to react on unexpected failure of other subsystems, is the object of this investment. As in the case of vacuum it is formulated as a yearly investment of a given amount, which is fine tuned in its specific scope depending on the failure trends.

- A1.3.3. Implement upgraded control system to accelerator and BLs

  The CMAM tandem accelerator and part of the BLs are integrated in a control system originally deployed by the company which supplied the accelerator. The system is based on fiber optics connections, to keep ground separation protocols and decrease noise input to precision electronics. The system is currently obsolete, and not supported for further expansion. This has led to a situation in which some beamline elements are controlled directly from separate ad-hoc control interfaces, whereas other are even controlled locally. In addition some monitoring signals are at the moment not readout. Finally, the existing system, with its current limitations is running on a very old computer platform and depends on some obsolete hardware elements which would be hard or impossible to replace in case of failure. During the last year some spares of those elements becoming obsolete but still reachable in the market have been gathered, so as to have some resilience capabilities. Nevertheless it is unavoidable to confront the fact that CMAM needs to go for a new control system, which could be an upgrade of the existing technology, with new and fully supported standards, or go in a different direction by developing a TANGO-based system, which would likely depend much more on internal resources for its development. Although it is unclear at the moment which of the two options shall be adopted, it is absolutely certain that within the next few years this task must be performed, and the outsourcing approach must be adopted as the baseline option, even if alternatives may be considered. Therefore this would be one of the large investments to be done by the end of the current ICTS period. The complexity of this action is particularly high and even if outsourcing is considered as the primary options, some additional human resources are essential as an integral part of the project in order to accompany and support the project implementation and properly implement its full exploitation and further development, as detailed in the annex.

- A1.3.4. Implement motorization of slits for BLs and accelerator with a unified control standard

The complex accelerator/beamlines includes an important number of moving elements, mainly collimating slits, which need to be operated in order to define the beam in the transversal plane, insert a diagnostic, etc… Such elements have been incorporated gradually along the years and although in some cases remote control is already implemented, in many others they are operated manually. Whereas a few of them are moved only occasionally, others need to be operated routinely. This generates a problem of efficiency, in particular in cases in which the experiment produces non-negligible radiation levels locally, since the beam needs to be interrupted before the acceleration stage (at the low energy side of the accelerator) in order to enter the hall and operate the moving element manually. Even with such protocol, in some cases activation generates some radiation above background level without beam. Although legal radiation levels are of course strictly respected, following the radiological protocols of CMAM, the ALARA principle bounds CMAM to take additional actions to reduce dose even when it is below legal limits, if technically reasonable. Therefore a project is to be initiated to motorize moving elements, allowing for remote control from the accelerator control room. In order to do this systematically the Icepap protocol has been considered for the motor controllers. This standard, widely spread in European synchrotrons and systematically used at the ICTS ALBA, allows for a collaboration which makes things easier to implement and more robust to sustain. The mechanical coupling is case-dependent, as many different types of moving elements exist. The approach will be to implement the controls for the full set of moving elements and then incorporate the mechanical coupling and motors gradually, with a sequence which focuses first on elements where the safety and efficiency arguments are more relevant. As in the previous case, the fact that each moving element requires an ad-hoc design to mechanically couple to motorized stage, makes essential to incorporate project-oriented additional human resources as an integral part of this effort.

- A1.3.5. Implement standardized charge measurement diagnostics (Faraday cups) with secondary electron suppression and friendly GUI at all relevant points where beam current needs to be monitored.

This action points at complementing the existing diagnostic instruments at CMAM, as in some of the diagnostic points there are instruments (Faraday cups, FC) which do not incorporate bias rings for secondary electron suppression, which leads to inaccurate measurements. In addition it is proposed to implement additional diagnostics at some points, in order to improve traceability of the beam and enhance efficiency and reliability of the measurements. The investment proposed consists of purchasing two additional FCs, as a way to gradually improve the situation, and continue in this same direction during the following period.

- A1.3.6. Implement improved detection systems in selected BLs and acquire spare detectors for the different BLs where no detector upgrades are applied.

  Detectors are one of the key elements in the scientific exploitation of CMAM. Whereas some detector types (X-ray, gamma) are very expensive, but at the same time very robust and may be used without replacement for a long time, when properly maintained, others (such as Silicon barrier detectors, SBD, for detection of charged particles) require periodic replacement, as they deteriorate as a function of the dose received. On the other hand detector technologies advance continuously and incorporating novel instruments is a very important boost for scientific competitivity. During this period a number of specific actions on beamlines, including both new detectors and replacement of the existing types, is considered as an essential element of the plan. A detailed list of needs, beamline per beamline, and including as well some transversal pool of instruments, is detailed and justified in the annex.

4.3.2. Objective O2 and strategy 2.1

Objective O2 is formulated as ´´consolidate and further develop research activities in the different areas where CMAM is already active´´. CMAM has developed over the last years a substantial level of scientific activity, both including CMAM own researchers and external users, in a number of scientific areas, as detailed below. A summary on the status and prospects of the facility in this respect may be found in *A. Redondo-Cubero et al, The European Physical Journal Plus volume 136, Article number: 175 (2021).https://doi.org/10.1140/epjp/s13360-021-01085-9*, and it may also be consulted in further detail in the CMAM application to become part of the ICTS network. The detailed description of CMAM scientific possibilities and current activities has not been included in this document, due to the limited space available and to the fact that such information has been submitted separately and is currently undergoing evaluation.

S1.4 is formulated as ´´Actively engage in scientific projects of areas not singled-out in other objectives of this plan, bringing together the interests of CMAM scientific staff and the user community´´. One of the key strategic aspects for the optimal exploitation of an advanced facility is the equilibrium between own science program and user service, as explained above in this document. The current portfolio of science areas where CMAM has ongoing activities where the interplay own-science/users has high potential may be summarized as follows: optical and space-application materials; materials for quantum applications; materials processing with emphasis on biomaterials; cultural heritage studies; fusion technologies; Nuclear Physics; medical applications and in particular protontherapy (developed in further detail in objective O5 below); magnetic materials (specifically in focus for objective O6 below). The general strategy for all these scientific areas is to map the own-science activities to third-party funding research project applications; use systematically the synergies generated by these activities in connection to the user program, for mutual benefit of external users and CMAM scientists; and consider all these science areas and their needs as a transversal inspiring framework for all the specific actions related to staffing, infrastructure and scientific instruments contained in this strategic plan and the subsequent ones. Therefore, no specific investment actions are assigned to a given scientific area in this plan, as they typically serve several of them.

From a different perspective, the continuous development of CMAM capabilities and its interaction with the user community is best implemented by exploiting the synergies within the ICTS network and beyond. Collaboration with the other two ion beam facilities in Spain and Portugal is here crucial. CNA (Seville) is an ICTS whose scientific offer to the user community is complementary to that of CMAM, as explained in detail in the ICTS application, currently under evaluation. A very good example of this has recently happened in the area of Nuclear Physics, where a collaboration involving both CNA and CMAM, along with a number of other Spanish institutions, has been started to study nuclear reaction cross sections of the (α,n) type, of great interest for Astrophysics models as well as low-background experiment preparation. The complementarity of CMAM and CNA has been particularly prominent and enriching in this case.

In particular, CMAM opens the possibility to access higher beam energies, especially for heavy ions, the ERD-TOF beamline and the combination of ion beams and femtosecond laser. In order to exploit and use positively for both parties this complementarity, a systematic communication and collaboration is foreseen, transversally to all activities, both from the scientific and technical point of view. This collaboration is made extensive to the ion beam facility in Lisbon. The three institutions had a formal collaboration agreement, in the past, which was not fully implemented and we have now reestablished contacts and are working on a new agreement, whose development and implementation will be one the main guiding lines for the period 2021-24 from the CMAM point of view. The agreement is foreseen to contemplate: joint actions for technical and scientific staff, collaborations in international project applications and joint actions to engage and expand the user community, just to cite the most important aspects.

As strategy S2.1 has a transversal character affecting many other aspects of this strategic plan, it is not developed explicitly into specific actions in this document. Actions A1.1.4-5 as defined above when going through staffing aspects have particular relevance in this respect, as mentioned therein.

4.3.3 Objective O3 and strategy S3.1

The ERD-TOF beamline is one of the singular instruments available at CMAM, allowing for the usage of a heavy ion beam to obtain depth profiles of all the atomic species present in the sample with excellent depth resolution and very good sensitivity, to a depth in the micron range. This is achieved by event-by-event coincidence measurement of both time of flight and energy of elastic recoils, in such a way that events map different curves in the time-energy plane, parametrized by the recoil mass. The beamline incorporates all the necessary elements, but requires a commissioning effort and likely some refurbishing to be fully operational. In addition, once the BL is ready for routine operation, and extra effort to optimize its features with specific scientific highlight cases and to disseminate and attract the user community shall be performed. Already during the period 2020-21 some users who utilize other beamlines at CMAM have expressed their interest on having access to this more sophisticated technique, providing thus an ideal starting point for full scientific exploitation of ERD-TOF. The actions listed below develop the strategy to achieve the objective O3 in a stepwise way:

- A3.1.1. Collaborate with external experts if necessary to have the ERD-TOF BL fully operational
  This action is deemed very convenient to speed up the commissioning of the beamline and it is to be supported by base facility funds.
- A3.1.2. Implement hardware improvements to the ERD-TOF BL according to the problems detected

  As an outcome of the commissioning phase, it is expected that some elements in the beamline are identified which need replacement or upgrade. These are tentatively described in the investment included in the annex below, although some level of uncertainty is in this case unavoidable, as it is usual in some crucial aspects of any strategic planning.

- A3.1.3. Conduct an ambitious dissemination program to attract users to the ERD-TOF BL.

  As explained above this is the third and final action of the sequence. Attraction of additional researchers via a suitable third-party funding program would be an important add-on. Specific actions such as ad-hoc workshops, targeted seminars, or featuring of scientific highlights involving the ERD-TOF beamline in suitable conferences are among the specific implementations which may be contemplated for this action, which again does not require investment, but rather support based on base facility funds and competitive funding opportunities.

4.3.4. Objective O4 and strategy S4.1

The combination of a wide-area implantation BL reaching energies of tens of MeV for different heavy elements, with a femtosecond laser whose beam may be made to illuminate the ion beam-sample interaction point, allowing for in-situ experiments and even to perform time-resolved science, is a unique feature of CMAM. The scientific exploitation of this combination opens up many possibilities, which involve in many cases challenging experimental approaches requiring the combined expertise of different groups. One of the key elements of the strategic landscape of CMAM in the period 2021-24 is precisely to take the proper actions so that this synergy is best exploited. To that end the following actions have been foreseen:

- A4.1.1. Complement the current laser and IMP setup with further capabilities, such as pulse-by-pulse laser control, in-situ RBS measurement, flexible sample holder systems in and ex-vacuum, other in-situ capabilities for sample treatment and detection, including fast electronics.

  This action requires an investment effort, together with the proper involvement by scientific and technical staff in order to implement and optimize the instruments involved. The level of own-manpower involvement is very different for the different elements of this action. Therefore a proper grading of the different steps along the period 2021-24 shall be applied, assuring an incremental progress of the beamline and laser capabilities which does allow an equilibrated share between scientific experiments and commissioning activities.

- A4.1.2. Actively foster external collaborations for novel experiments exploiting laser-ion combination and time-resolved science.

As depicted in the introduction to this objective and strategy above, finding the right partners is one of the crucial elements for success in this case. Ongoing efforts shall be pursued during the full period 2021-24. One of the key institutions wherein some collaborative discussions are already ongoing and which may play an important role in this respect is IMDEA-nanoscience.

- A4.1.3. Implement pulsed beam capability for heavy ions in the accelerator.

  As it will be detailed below, the upgrade of the CMAM accelerator to allow for pulsing of light ion beams (H and He) is a high priority plan, already object of recently granted project. Complementing this capability with the option of pulsing also heavy ion beams means, from the instrumentation point of view, acting on a different ion source (i.e. the presently used sputtering ion source, which is used to produce beams of practically any atomic species from a solid target), and from the scientific point of view, opening new capabilities for the laser-ion synergy, in particular with the approach of moving into time-resolved science for the most relevant cases where materials are damaged by ion beams (i.e. swift heavy ions). As a gradual approach to facility upgrading is essential, in order to progress robustly and implement manpower resources realistically, this upgrade action is considered as very interesting for the last part of this strategic planning period, or even for the beginning of the following period. It is thus ranked as low priority, foreseeing the upgrading of its priority in the next period, in case it can not be funded in this one.

- A4.1.4. Conceptualize an ambitious upgrade of the laser-ion system for time-resolved experiments, for implementation in the next strategic plan period (2025-28).
  The future option of performing time-resolved experiments in the Implantation beamline needs careful elaboration of highlight scientific cases and conceptualization of the experimental approach. The type of experiments one may imagine could follow two different routes: during continuous ion irradiation the timestamp of individual ion impacts, with a suitable fast detection method based on secondary electrons or luminescence, could be correlated to the laser pulse timing, doing offline analysis of the data in such a way that the material response (e.g. with a PIXE detector or CCD camera) can be analyzed as a function of the time elapsed between ion impact and laser pulse; alternative, with a pulsed ion beam, a pump-probe experiment may be conducted by a controlled delay between ion bunch and laser pulse, where each of them could play the role of either pump or probe, or even considering both as pump element and probing delayed ionoluminescence for different pump-pump temporal configurations. All these tentative options need intensive discussion and interplay with key user groups, to be done during the current strategic planning period, with the aim of elaborating a detailed implementation proposal for the coming period (2025-28), with associated investments.

4.3.4. Objective O5 and strategy S5.1

As mentioned above protontherapy is a research niche which we would like to single out in this strategy plan, for a twofold reason: it is seen as a particularly strategic area in terms of scientific interest, societal impact, and specific circumstances in Spain, where the first clinical facilities have just started operations in the area of Madrid; on the other hand it is a type of research which has not been present in the CMAM portfolio of activities during the previous years and it is therefore considered that an effort is needed to activate it. The strategy to do so is formulated as ´´collaborate with key external groups from the public and private sector, profiting from the circumstance that two clinical protontherapy facilities in Spain have started to operate recently and more will likely come in the coming years, to make CMAM a relevant actor and a key hub for protontherapy research in Spain´´. In order to develop this strategy three different actions are foreseen, as detailed below, including a large investment in upgrading the capabilities of the accelerator, a specific improvement in the beamlines allowing for more reliable in-air irradiation, and a transversal action to enhance the scientific activity in this area.

- A5.1.1. Implement pulsed beam of light ions at the CMAM accelerator, together with the proper beam diagnostics at the BLs.

  This is undoubtedly the flagship investment planned at CMAM during year 2021. A project application has been submitted to the national call for infrastructure investments during this year, and partly granted during the writing of this document. The project application included the upgrade of the accelerator by incorporation of a new dual ion source with chopper and buncher, together with the proper scientific instruments in some key beamlines to diagnose and exploit this capability. The implementation of this granted upgrade will require an intensive effort during the period 2021-24, and complementary investment to incorporate the proper diagnostic elements necessary for an optimal exploitation of the pulsed beam is required, as detailed in the annex.

- A5.1.2. Improve online dose measurement tools for experiments with biological samples in external beam.

  For the sake of clarity, this subsystem, whose usage is strongly coupled with the availability of the pulsed beam as detailed in action A4.1.1 above, has been separated and included in this separate action. The system would combine, as a baseline solution, online monitoring of the X-ray signal produced at the exit window where the beam leaves the vacuum chamber and exits to open air, with a suitable in-air stage containing fast detection and current measurement, as detailed in the investment list included in the annex. Part of the instruments contained herein were also part of the project application of the pulsed beam upgrade, as natural diagnostics necessary to operate the pulsed beam when extracted outside the vacuum chamber.

- A5.1.3. Actively engage with other groups in protontherapy research.

  As mentioned above this transversal action is essential to make the best use of the investment efforts described in the previous ones, in close connection to A1.1.4-5, where development of scientific capabilities in many different research areas is contemplated. Networking and collaborative efforts in radiobiology and more specifically in protontherapy research have been a constant priority for CMAM since the end of 2019, based on prior experience is some experiments involving biological samples, which present many specificities as compared to other types of experiments. Intense contacts and collaboration at different levels with key groups has been established (Radiation-matter interaction modelling group from UAM Chemistry department, Nuclear physics group from Complutense Madrid university, IEM-CSIC, Quirón Salud protontherapy clinical facility, among others). In addition several user groups have been actively performing experiments related to protontherapy at CMAM during the past two years (UCM, IMDEA-Nanoscience, IEM-CSIC, IFF-CSIC). In addition an effort has been done to attract researchers to work full-time at CMAM in this area via third-party funding or supported by UAM. At the moment a postdoctoral researcher is working at CMAM in this area and two further project applications are pending result on different third-party funding programs. Continuing with this effort will be a constant commitment during the full strategic planning period and beyond.

4.3.6. Objective O6 and strategy S6.1

Research in magnetic materials is one of the important science application areas of CMAM, as indicated when describing objective O2. This area is singled out in this strategic plan due to the fact that a new experimental setup has been conceptualized and is ready to be implemented as a new investment project. This end station would allow to study in-situ evolution of magnetic properties as a material is undergoing ion irradiation with increasing dose levels, including the possibility of profiting from the pulsed beam. The steps to develop this concept are given below as separate tasks.

- A6.1.1. Design new in-situ Kerr-effect irradiation station jointly with IMDEA-Nanoscience.

  The initial stage is to fine-tune the concept of the new end station into a detailed equipment breakdown scheme. Work has been advanced in this respect during 2021 and therefore this first task is already in progress at the moment of writing this document. The collaboration with IMDEA-Nanoscience is crucial in this case, both from the point of view of the instrument design and detailed implementation, and of the subsequent scientific exploitation, which is also gathering support from user groups of several other institutions, such as CIEMAT. The instrument is defined in further detail in the list of investments given in the annex, and part of it is strongly coupled to the pulsed beam project, although it would also operate independently of it, with a continuous ion beam.

- A6.1.2. Acquire and implement elements for basic setup.
  A stepwise approach has been adopted, to start equipping this new end station gradually. The location foreseen is an extension of the current ERD-TOF beamline. Whereas the fully detailed design is not yet available, fair estimates of the cost are ready to move into the investment phase in case funds are made available.

- A6.1.3. Actively foster external collaborations for experiments devoted to in-situ magnetic properties during irradiation.
  As mentioned above several groups from different institutions have already expressed their support to this new end station. However, in case it is funded, an additional systematic effort to extend the user community would be done.

4.4. Resources

The resources for tasks A1.1.1-6 shall be covered by yearly base operation budget, structural UAM staffing budget and third-party funding as indicated in the different tasks. Per-task cost quantification is provided for most of the other tasks in the list above, excluding those related to networking and collaboration, wherein base costs (travel, organization of visits and meetings) shall be covered by the base UAM funds allocated to CMAM on a yearly basis. All the investment projects are listed and detailed in annex I, and proposed for inclusion in the funding program for

ICTS. In a complementary way, it is foreseen to use third-party funding infrastructure calls at the national and regional level, either to complement the investments herein included which may not be covered by the ICTS program, or by targeting some additional instrument to complement the scientific technique portfolio of CMAM, as deemed convenient. The overall financial resources considered in this strategic plan are summarized in the annex Excel file attached to this document in the submission and therefore it is not replicated here.

The base funds for facility operation come from university on a yearly budget approval basis, and may be described in three separate parts: funds for human resources; funds invested on transversal services which cover the needs of CMAM, shared with other university centers; and ad-hoc funds for operation and basic operational investments which are allocated to CMAM each year and directly managed from the center. The detailed contents of these three groups of costs have been given in the ICTS application currently under evaluation (see section j from the self assessment on fulfillment of the ICTS requirements and criteria). The overall yearly funds, as detailed therein, are slightly above 1 ME, with small variations from year to year.

5. Chronogram and follow-up

5.1. Chronogram

The chronogram of this strategic plan has been elaborated in a Microsoft Project file, including the foreseen development for the investments included in the plan, grouped into objectives, following the hierarchy described in section 4. We have concentrated on those actions which involve an investment and are thus included in the annex. An overview of the chronogram is given in Figure 1. The Microsoft project file is available for consultation upon request. Particular care has been taken to balance resources and guarantee that the most complex actions have enough time to be completed in accordance to the rules corresponding to the foreseen funding sources.

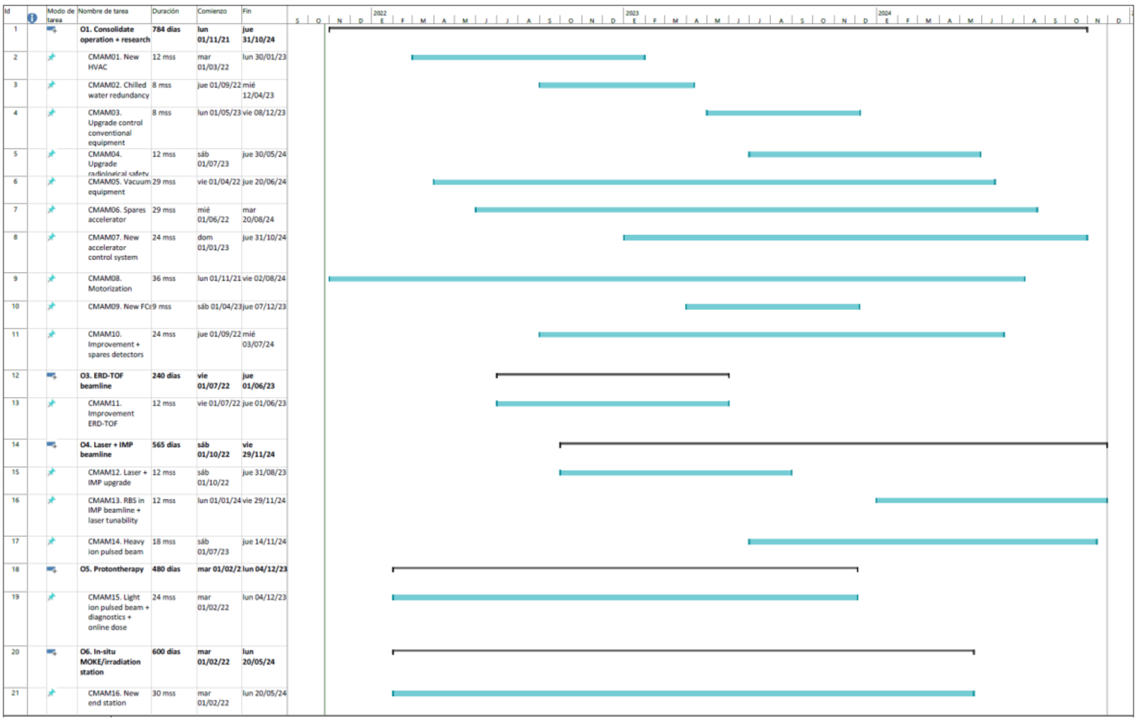

Fig. 1: *Chronogram of the strategic plan.*

5.2. Performance indicators

A simple set of performance indicators is proposed to follow-up the development of this strategic plan and the evolution of CMAM as a whole. The rationale is impact driven, and thus considers the main impact pathways of an accelerator-based facility, as developed in the European project RIpaths (https://ri-paths.eu). The main impact areas are as follows:

- Scientific production. Indicators to monitor this pathway are: number of users, number of experiments, number of publications. Statistics with the provenance of the users (geographical, per institution, new users, etc…) will also be considered to gain more insight into these results. These indicators are already considered in the periodic CMAM activity reports published during the past years.
- Implementation of investment projects as included in this plan, which includes new possibilities at the service of the user community. This is an essential metric to be used, following-up how many of the funded projects have been completed within the foreseen period.
- Technology spillovers. This pathway is difficult to explore, as direct proxies tend to yield very low or inexistent numbers, whereas indirect proxies are very difficult to monitor. We will consider for this pathway the number of patents, number of industrial users and number of projects in which a private actor collaborates or wherein the user group involved declares a potential interest by industrial partners.
- Training and education impacts. The parameters to be monitored in this pathway are the number of postdocs, PhD, master and degree students supervised by a CMAM member. In addition we will monitor the number of experiments involving students and the number of experiments fully devoted to educational activities.
- Impact on the general public in terms of highlighting the relevance of science and promoting scientific vocations. We will monitor the total number of outreach activities and the total number of persons reached (estimated in the case that direct monitoring is not possible or very difficult).

Whereas these are the core indicators we consider most useful to follow-up impact, all the set of indicators as defined by the ICTS network methodologies will be naturally kept and reported as requested.

5.3. Risk management

A number of risks have been identified when analyzing the contents of this strategic plan. Corporate risks (including those corresponding to staffing, as indicated in strategy S1.1) have not been included in this section, as they affect CMAM as a whole and they are better reflected in the SWOT analysis. We concentrate here on risks associated to more specific actions planned as part of this plan. For each risk the risk level (how likely it is to happen) and severity (how important the negative impact is if it happens) are evaluated, and mitigation measures are anticipated. Table 1 summarizes the risks considered most important.

Risk description	**Strategy concerned**	**Risk level**	**Severity level**	**Mitigation measures**
Major failure of some basic infrastructure before the actions of this	S1.2	Medium	High	Identify ad-hoc solutions with provisional (portable) equipment,

strategic plan have been implemented				accelerate planned actions as much as possible
Major failure of accelerator control system	S1.3	Medium	High	Have spares of as many as possible obsolete hardware elements, do frequent backups, advance as much as possible corresponding investment action as planned in this strategic plan
User engagement smaller than expected	S2.1	Low	Medium	Increase effort in dissemination events, profit from collaboration with CNA for these actions, explore collaboration with other ICTS such as ALBA
Problems in ERD-TOF worse than expected and not solvable with funding as planned	S3.1	Medium	Low	Once problems have been fully diagnosed, request for proper funds by using other competitive funding tools, the main impact would be a delay of the objective, but would not really compromise its final achievement
Usage of laser and ions for synergetic experiments not fully exploited from the scientific point of view	S4.1	Medium	Medium	Intensify collaboration with external groups, consider ad-hoc (workshop-like) actions, network with other ICTS (such as CLPU and/or ALBA) and eventually larger facilities (such as FELs)
Impact on protontherapy research smaller and/or slower than expected	S5.1	Low	Low	Extend present collaboration with Spanish clinical facilities to international facilities with intensive research programs (such as CNAO, Pavia, Italy)

Table 1: *Risk analysis of the actions included in this plan.*

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