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[1]Chesbrough H.: Open Innovation and Open Business Models: A new approach to industrial innovation. Presentation to Joint OECD/Dutch Ministry of Economic Affairs. Conference on “Globalisation and open innovation”. 2006.

[2]Chesbrough H.: Open Innovation. The new imperative for creating and profiting from technology. Harvard Business School Press. Boston. 2003.

[3]Committee on the Assessment of and Outlook for Nuclear Physics. Nuclear Physics: Exploring the Heart of Matter 2013

[4]Center for Nuclear Science and Technology Information. Using Nuclear Technology to Explore Space. http://nuclearconnect.org/know-nuclear/applications/space

[5]Cirrone P., Colautti P., Dosanjh M., Magrin G., Petringa G., Scholz M.: Use of nuclear physics tools to support biological effectiveness assessment in ion-beam therapy. D 5.4 ENSAR 2 – 30.11.2019

[6]Curley M., Salmelin B.: Open innovation 2.0. The New Mode of Digital Innovation for Prosperity and Sustainability. Springer. 2018.

[7] ENSAR 2 Activities - http://www.ensarfp7.eu/activities

[8]Espacent - European Patent Office - https://worldwide.espacenet.com/patent/

[9]Gardini B., Gianfigilio G., Summerer L.: ESA’a Approach to Nuclear Power Sources for Space Applications. Nice, France 2007.

[10]Jain K.R., Triandis H.C, Weick C.W.: Managing research, development, and innovation. Wiley. New Jersey. 2010

[11]Magrin G., Thirolf P.G.: Clarifying and adopting nuclear concepts to the medical field – Deliverable D5.2 ENSAR 2-2017.11.30

[12] Pantechnik - http://www.pantechnik.com/

[13]Patenscope – WIPO https://patentscope.wipo.int/search/en/search.jsf

[14]Spasic O.: Business Model of Innovation – “Closed Innovation” and “Open Innovation”. National workshop on innovation promotion and technology transfer”. Belgrade. 2011.

[15]Tengblad O., Hull G. Camera F: Status of new scintillator materials and their basic characterisation. Deliverable 9.1 ENSAR 2 – 2017.02.25

[16]Thirolf P.G.: Nuclear Physics Instrumentation for Medicine. D5.3 ENSAR 2 – 15.02.2019

LIST OF ACRONYMS AND ABBREVIATIONS

APXS	Alpha Particle X-Ray
CFSP	Common Foreign and Security Policy
CT	Computed Tomography
DANCE	Detector for Advanced Neutron Capture Experiments
ECR	Electron Cyclotron Resonance
ESDP	European Security and Defences Policy
FRIB	Facility for Rare Isotope Beams
IORT	Intraoperative Electron Radiation Therapy
IPR	Intellectual Property Rights
LANSCE	Los Alamos Neutron Science Center
LEO	Low Earth Orbit
LHC	Large Hadron Collider
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MOX	Mixed Oxide Fuel
MRI	Magnetic Resonance Imaging
LHC	Large Hadron Collider
PET	Positron Emission Tomography
PIXE	Particle Induced X-ray Emission
RTG	Radioisotope Thermoelectric Generator
R&D	Research and Development
SPECT	Single Photon Emission Computed Tomography
TES-PIXE	Transition Edge Sensor Particle Induced X-ray Emission
TOF-PET	Time of Flight Positron Emission Tomography

FOREWORD

Nuclear physics brings many innovations for economy and society. Nuclear physics designates future directions in important areas such as energy, medicine, pharmacy, scientific instruments and many others. Innovative products, processes and inventions in this field arise thanks to the efforts of many scientists from different countries working in the field of basic and development research.
There is still much to be done in the field of nuclear physics innovation. Achieving effects in the form of new products, processes and inventions requires not only efforts to obtain results from the conducted research but also the skilfulness of their transfer to industry. The modern world expects scientists not only to solve problems in various areas of science but also to cooperate with the industry, which is supposed to result in innovations.
When preparing this report, we concluded that one should focus on the areas on which the socio-economic progress of the modern world depends. We have concluded that among the areas of the industries that challenge science there are areas such as nuclear energy and medicine. Of course, we realise that many other areas are important for the modern economy, but these two areas have a significant impact from the point of view of socio-economic needs.
In the report, we tried to identify future investment directions, enterprises of significant importance for progress in the field of new technologies and their financial capabilities, directions of development of technological innovations. Taking into account social needs and the pace of an aging population, as well as the lifestyle, we see the essential nature of nuclear physics in the creation of medical innovations. Therefore, medicine is an important industry domain that requires researchers to engage in long-term research and development cooperation.

The survey of innovativeness of ENSAR2 laboratories showed that cooperation between individual centres can focus on innovations in such areas as: medicine (devices for diagnosing cancer), pharmacy (radiopharmaceuticals to fight cancer), energy (Nuclear Fusion, Nuclear fission, Nuclear Safety, Nuclear instrumentation), radiation protection

(covers), aerospace technologies (covers, on-board equipment materials, measuring instruments), lasers (medical, industrial), and material engineering (membranes), as well as (materials with increased strength and resistant to destructive effects radiation).
The most important part of our report is the survey on the innovativeness of ENSAR2 laboratories and the resulting conclusions for the future development of Europe. In the report, we tried to show the role of research and development in developing innovations in the field of nuclear physics, directions of technology transfer from laboratories to industry, possible investment areas, enterprises cooperating actively with laboratories, start-ups created at laboratories. We believe that the areas of nuclear physics research requiring special attention and investment support is the area of nuclear physics in medicine and pharmacy. The study shows that these are the areas with the largest transfers from laboratories to industry. The application of the achievements of nuclear physics in medicine and pharmacy results from some of the demographic phenomena (aging European societies) but also civilisation and lifestyle changes. Thus, innovations in nuclear physics in these areas are currently most desirable.

SOCIETAL APPLICATIONS OF NUCLEAR INNOVATIONS AND BENEFITS

Medicine

Nuclear physics is ubiquitous in our lives. Many of today's most important advancements in medicine, materials, energy, security, climatology, and dozens of other sciences emanate from the wellspring of basic research and development in nuclear physics. Answers to some of the most important questions facing our planet will come from nuclear science, interdisciplinary efforts in energy and climate, and marketplace innovations. The economic impact of the applications of nuclear physics is significant. As an example, particle beams from accelerators are used to process, treat or inspect a wide range of products with a collective value of more than $500 billion. At the same time, approximately 23 million nuclear medicine procedures are carried out each year in the United States to diagnose and treat cancers, cardiovascular disease, and certain neurological disorders. In the future, basic nuclear science will be a key discipline that provides ideas and insights leading to the intellectual properties and patents with which venture capitalists and entrepreneurs will shape the economies of the future.
Nuclear physics techniques have been revolutionary in medical diagnostics and cancer therapy. Of the 23 million nuclear medicine imaging and therapeutic procedures performed each year in the United States, typically 40-50 percent are for cardiac applications, while 25-40 percent are for cancer identification and therapy. In addition, nuclear medicine procedures are used to diagnose Alzheimer's disease, treat hyperthyroidism, assess coronary artery disease, localise tumours, and diagnose pulmonary emboli.
The science of nuclear medicine, however, goes far beyond the radiopharmaceuticals used for imaging and treatment. Advances in the field are inevitably tied to basic research in nuclear physics at all levels. These advances include accelerators, detectors, understanding the interaction of radiation with matter, and creating complex statistical algorithms for identifying relevant data.
Over the past few decades, new nuclear imaging technologies have enhanced the effectiveness of health care and enabled physicians to diagnose different types of cancers, cardiovascular diseases, and neurological disorders in their early stages. Today there are over 100 nuclear imaging procedures available. These procedures have the additional advantage of being non-invasive alternatives to biopsy or surgery. Unlike other imaging procedures that are designed mainly to identify structure, nuclear medicine can also provide information about the function of virtually every major organ system within the body [3].

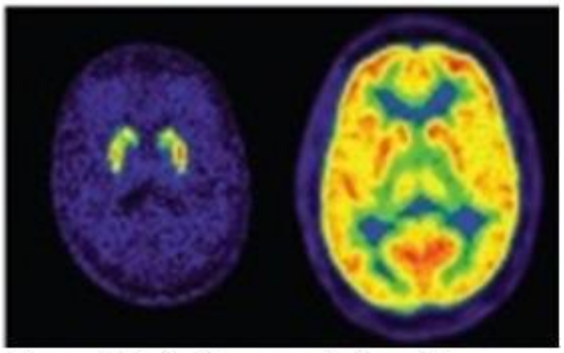


Figure 1. Radiopharmaceutical used in medical-imaging PET scans.
Source: Committee on the Assessment of and Outlook for Nuclear Physics. Nuclear Physics: Exploring the Heart of Matter 2013.

The most important modern advances in nuclear imaging are positron emission tomography (PET) and single-photon emission computed tomography (SPECT). PET, especially when coupled to X-ray computed tomography (CT) scans, has become a highly sensitive probe.

8F-fluorodeoxyglucose (18F-FDG) is a radiopharmaceutical used in medical-imaging PET scans. This is a glucose analogue that is absorbed by cells such as those in the brain and kidneys as well as cancer cells, which use high amounts of glucose. This procedure yields scans such as those displayed in Figure and can be used for the study of organ functions and, in the case of cancer cells, for therapeutic applications. The 1.8-hour half-life t1/2 of fluorine-18 results in very high specific.
PET is a powerful tool to probe the functions of the brain. In these images of the brain, the radionuclide is fluorine-18 while the molecules for each image obviously have different bio-distributions. The left-hand figure shows fluorodopa (to probe dopamine integrity) while the right-hand figure shows fluorodeoxyglucose (to probe sugar metabolism).
Radionuclides that emit gamma rays have a long history as imaging tools in the diagnosis of cancer. SPECT has been built around the gamma ray associated with the decay of molybdenum-99. Molybdenum-99 decays (t1/2 = 66 hours) into an isomer of technetium-99m (m indicating metastable), which in turn decays (t1/2 = 6 hours) by emitting a 140-keV gamma ray. The cameras for this imaging technique are typically made with a cluster of photomultipliers coupled to a large NaI crystal. In recent years, the semiconductor material CdZnTe (CZT) has gained favour because of its higher energy resolution. Having this type of capability means that multiple tracers can be imaged simultaneously using different energy windows.
Worldwide, the molybdenum-99/technetium-99m radionuclide pair is used in four out of five, or in about 12 million diagnostic-imaging procedures in nuclear medicine every year. However, the reactors that have been producing molybde-num-99 are approaching the end of their useful lives, which is expected to trigger an “isotope crisis.” One of the reactors, the Canadian National Research Universal (NRU) reactor at Chalk River, is scheduled to stop isotope production in 2016, while potential replacement reactors around the world may not be available until 2020. Research is now focused on exploring accelerator-based production of molybdenum-99 as an alternative technology using, among other reactions, the ^{100}Mo(γ,n)^{99}Mo and the ^{100}Mo(p,2n)^{99m}Tc reactions [3].
Another option centres on rhenium-186, which has a favourable half-life (t1/2 = 90 hours) and emits beta decay electrons of 0.9 MeV with a 10 percent branch emitting a gamma ray with energy similar to that of technetium-99m. Since rhenium is in the same chemical family as technetium, much of the technology developed for technetium-99m can be applied to rhenium-186. Current efforts are concentrated on reactor production of rhenium-186 via the ^{185}Re(n,γ) reaction, followed by mass separation to yield a sample with the high specific activity needed for therapy.
Radiopharmaceuticals have been developed that can be targeted directly at the organ being treated. These therapy radiopharmaceuticals rely on the destructive power of ionising radiation at short ranges, which minimises damage to neighbouring organs. A frontier direction is targeted radiopharmaceuticals. This involves attaching a relatively short-lived radioactive isotope that decays via high-energy transfer radiation (alpha-particle emission, for example) to a biologically active molecule, like a monoclonal antibody that has a high affinity for binding to receptors on cancer tumours. When the radioactive nuclei decay, the radiation they produce loses energy quickly and because it does not travel far, a lethal dose of radiation is delivered only to adjoining tumour cells. By careful construction of the targeting molecule, the radioactive nuclei will pass through the body quickly if they do not bind to tumour cells, thus minimising the exposure of healthy tissue to the high-energy transfer radiation. Presently, the most common radionuclides are iodine-131 and yttrium-90, though neither is ideal. Two radiopharmaceuticals, Bexxar (using iodine-131) and Zevalin (using indium-111 or yttrium-90), are now in use to treat non-Hodgkins lymphoma.
Many research efforts are focused on the production of alternative isotopes with superior cytotoxicity for use in therapy. A promising class of isotopes is those that decay by alpha emission, since alpha particles have a very short range in tissue, resulting in an enhanced cytotoxicity. The radionuclide actinium-225 combines several favourable properties, including a half-life of 10 days, high alpha-particle energy, versatile coordination chemistry, and several alpha-emitting daughter isotopes.

The future impact of nuclear science on medical science is difficult to predict. If history is an indicator, one can expect more significant and exciting contributions. At the least, advances in nuclear medicine will likely remain closely connected with advances in nuclear techniques.

One future direction is personalised medicine, the attempt to identify and treat disorders based on an individual's response to the disease process. This will require more sophisticated nuclear tools. As an example, chemistry systems will be reduced to the size of a postage stamp, thus making patient-specific diagnostic tools and treatment truly individualised. An example of an integrated device, designed for multistep radio-synthesis of PET tracers.

Other important new directions involve the coupling of advances in genetically engineered antibodies with radionuclides and the use of nuclear imaging to help us understand the underlying causes of disease by extracting functional and anatomical information in the same image [3].

Using nuclear technology to explore space

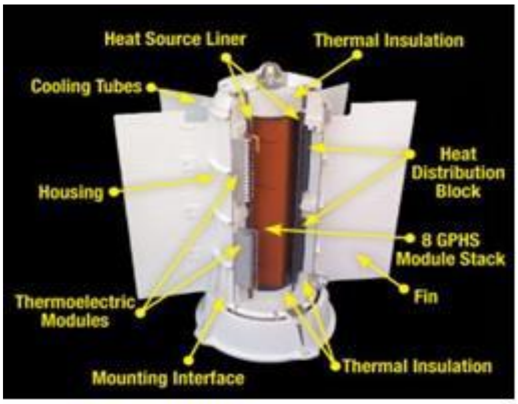


Figure 2. Radioisotope Thermoelectric Generators (RTG) application in spacecraft.
Source: Center for Nuclear Science and Technology Information. Using Nuclear Technology to Explore Space. http://nuclearconnect.org/know-nuclear/applications/space

Radioisotope Thermoelectric Generators (RTG) are a nuclear technology attached to a spacecraft that supplies power and heating. When the radioactive isotope plutonium-238 in the RTG decays, it gives off heat, which can be used to generate electricity using a thermocouple device. This process is known as thermoelectric conversion. The decay heat warms one end of the thermocouple, and the cold environment of space cools the other. This process produces an electric current that then powers the spacecraft. Excess decay heat is also pumped through the spacecraft's systems in order to warm up its instruments and subsystems, allowing it to operate in cold environments.

According to NASA, eight generations of RTGs have been used in U.S. spacecraft since 1961. Currently, they use the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) in the vacuum of space or in planetary atmospheres.

- MMRTGs carry approximately 10.6 lbs of plutonium-238
- They support spacecraft for at least 14 years and supply heat to maintain proper functioning
- They provide around 110 watts of power (a 13'' colour TV uses approximately 150 watts)
- They are also modular, meaning that if more power is needed for a mission, several can be used together to meet this higher power requirement.

Nuclear technology in space exploration is not limited to the use of decay heat from radioisotopes for power. There are many instruments used to detect radiation and determine the composition of distant stars or another planet's rocks, atmosphere, and soil, among many other things. One of these instruments is called the Alpha Particle X-Ray Spectrometer (APXS). This instrument determines the composition of rocks and soils using alpha particles and X-rays. To do this, alpha particles are generated in the APXS and directed at a target. The alpha particles interact with the materials in the target, which then emits X-rays of certain energies. Each nuclide emits its own unique X-ray energy "fingerprint", enabling the APXS to determine the makeup of the target.

While there is no current space application for the large energy generation capability of nuclear reactors, future applications include manned exploration of much of the solar system and reduced trip times between planets. Radiation exposure during space exploration can be dangerously high even for short periods, making the use of nuclear-powered rockets is almost requisite for interplanetary visits. Additionally, nuclear reactors can be used for electricity production in inter-planetary missions with large power requirements, such as manned missions and missions with a large scientific payload [4].

Based on current physics knowledge, preliminary assessments and past experience, Europe will need to use radioisotope power sources for its missions to the outer Solar System. Europe might also need radioisotope heater units and possibly radioisotope thermo-electric generators for longer lasting lunar and Mar-tian surface missions, among which the ExoMars mission would be the first candidate [9].

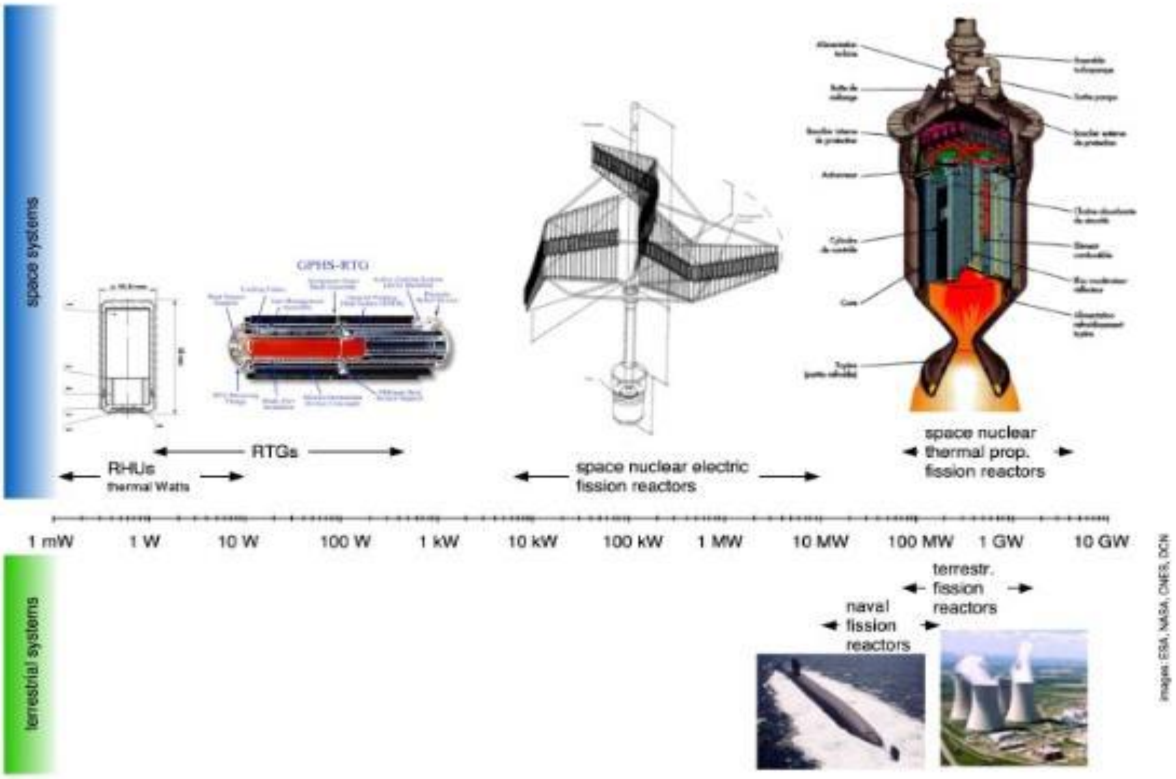


Figure 3.Power range of nuclear power sources for space applications with standard terrestrial nuclear power application. Source: Gardini B., Gianfigilio G., Summerer L.: ESA'a Approach to Nuclear Power Sources for Space Applications. Nice, France 2007.

Experience of radiobiological effects in the space environment comes mostly from manned spaceflight in Low Earth Orbit (LEO). For long-duration interplanetary missions, most of the radiation dose will arise from cosmic ray, solar particle ions and secondary particles from which future astronauts will have to be shielded.
It is widely acknowledged that the best solution to overcome this critical problem is to accommodate space vehicles and habitats in such a way that any radiation hazard is significantly reduced. However, designing such structures is not straightforward. Prior to design work, particle interaction with materials must be clearly understood.
Therefore, this activity aims primarily at studying physics models to simulate radiation transport in space structures. Models and data for nuclear-nuclear interactions will be assessed and relevant physics will be implemented and tested building upon an already existing radiation transport toolkit. Further recommendations will be made in order to bridge the identified gaps relevant to the simulation of nuclear-nuclear interaction.
As follow-up work, these models will be applied by the Aurora Exploration Programme to studies of shielding and effects in the interplanetary/planetary radiation environment. This work is of overwhelming importance in the framework of long-duration manned planetary missions as no rescue mission can be envisaged in case of emergency.
Many spacecraft, especially those that travel deep into the solar system, beyond the practical use of solar cells, already make use of nuclear power. They use radioactive material to heat one junction of a thermocouple and so generate electricity by the thermoelectric or Seebeck effect. This is then used to power the electrical systems of the spacecraft, rather than to provide propulsion. The amount of power generated this way though is quite low; nothing higher than around 600 W has ever been flown. In comparison ESA's Smart 1 used solar cells to generate the 1.2 kW necessary to power the ion thrusters that carried it to the Moon.
However, plans have been made to fly fully functional nuclear reactors in order to provide propulsion, as well as power some spacecraft. The simplest design just involves passing hydrogen propellant over the core of a standard, lightweight nuclear reactor. The hydrogen propellant would then leave the reactor through the nozzle, just like a standard rocket. The exhaust would not be radioactive (in most proposed designs) but its temperature and so the

specific impulse of the rocket, would be limited by the melting point of the materials used in the reactor core. A specific impulse of around 900 s might be achievable [9].
Many companies use the beams produced at GANIL to test certain electronic components used in spacecraft for resistance to radiation: Airbus/Atmel, CNES, EADS, ESA, Infineon, JAXA, ST Microelectronics, and Thales.

Nuclear Fission Reactor

The majority of the world's nuclear power is generated using reactors based on designs originally developed for naval use. These and other so-called second-generation nuclear reactors are safe and reliable, but they are being superseded by improved designs. Over the past decade, nuclear engineers have been researching advanced reactor designs, and there is a worldwide movement toward to a new generation of reactors. Some of the advanced designs include fast reactors, high-temperature graphite-moderated reactors, thorium-uranium-fuelled reactors, pebble bed designs, and mixed oxide fuel (MOX) plutonium reactors. Developing these designs requires detailed information about the reactions and other physics involved in the processes that are expected to take place. Such measurements are quite challenging. The fact that many of them are also important to stockpile stewardship and nuclear forensics greatly enhances our ability to bring together the teams of scientists needed for these experiments.
The energy released during radioactive decay in post fission processes, commonly called "decay heat," accounts for about 8 percent of the energy produced in the fission process itself. The accurate characterisation of decay heat is crucial for the reactor shutdown process, since it is the main source of heating after neutron-induced fission is terminated. The decay heat, and in particular the high-energy part of the radiation, is a key aspect in the proper design of shielding and storage casks for transporting and storing spent nuclear fuel.
Irradiation of both nuclear fuel and structural materials in reactors produces material defects that limit the safe lifetime of these materials. Numerous irradiation effects can cause material damage. A number of ongoing collaborations between nuclear physicists, material scientists, and reactor engineers are examining and characterising these effects in detail [3].
One example is the helium build-up at grain boundaries and its effect on the embrittlement of reactor structural materials. The embrittlement of metals such as nickel, iron, and copper has been demonstrated to be a function of both temperature and helium concentration. Most of the helium is produced by neutron-induced reactions (n, α), but many of the cross sections for these reactions were not well known. New cross section measurements have resulted in significant changes in estimates of the probable safe lifetime of structural reactor materials.
In nuclear fuels, a major cause of damage is the build-up of bubbles of noble gases and their migration through the fuel. Gas bubbles can cause changes in internal gas pressure, thermal conductivity, temperature gradients, and material stress and strain, thus inducing damage or even failure in fuel and cladding materials over time. Understanding the formation and properties of these bubbles, and how to detect the gases if released, is the focus of a joint collaboration between materials and nuclear scientists.
One advanced concept is the fast reactor, wherein the neutron flux is considerably higher in energy than in standard thermal reactors. The dominant neutron energies for a fast reactor are 0.1-0.6 MeV. Fission cross sections are considerably less well known at fast reactor energies than at thermal energies. Moreover, the situation is most serious for the transuranic fuels. New programmes are under way to measure the fission cross sections, where experimentally feasible, on less abundant isotopes of plutonium and uranium, as well as the minor actinides such as isotopes of americium, curium, and neptunium. In addition to the fission cross sections, accurate knowledge of the neutron capture cross sections on the minor actinides is important. Many of these actinides are radioactive, restricting measurements to small targets. International collaborations are addressing these problems using the DANCE detector at LANSCE, which is designed to study neutron capture reactions on small quantities, about 1 mg, of radioactive and rare stable nuclei [3].
One major attractive characteristic of fast reactors is their enhanced ability to burn up highly toxic transuranic fuel produced as waste from light water reactors. At these higher neutron energies, there are a number of nuclear properties of reactor fuels that need to be determined to considerably higher accuracy than is presently possible, including reactions of neutrons with unstable fission products. In the future, FRIB will extend capabilities by allowing studies of a considerably larger class of unstable isotopes. For several key nuclides that have longer half-lives, FRIB will provide separated samples that can be used to measure neutron-capture probabilities at neutron beam facilities. For isotopes with shorter lifetimes, indirect reaction measurements at FRIB will provide information to help constrain theoretical models for neutron-capture probabilities, using techniques that will also advance basic nuclear science and nuclear astrophysics [3].

Nuclear Fusion

When two light nuclei interact, they can fuse to form a heavier nucleus, accompanied by the release of a large amount of energy. The conditions found in stellar environments are ideal for sustained fusion chains, and our sun is a natural fusion reactor. However, achieving these hot, dense conditions in the laboratory is very challenging, and to date the only successful terrestrial events have been thermonuclear explosions. Currently there are two main research approaches to fusion: magnetically driven fusion and laser-driven fusion.

Probing physics at high energy densities is central to several subfields of nuclear physics, including the study of nucleosynthesis, the quark-gluon plasma, and neutron stars.

Plasmas are an important phase of matter, from the flames of candles to the quark-gluon plasma generated for a fraction of a second in a relativistic heavy ion collision. The temperature in kelvins as a function of the number of charged particles per cubic meter for a wide range of physical systems is displayed.

Laser pulses, directed into a hohlraum cylinder containing the target capsule, create an X-ray bath sufficient to compress the capsule through ablation of an outer layer of material. Achieving the conditions needed for ignition is challenging but is made more tractable with the use of advanced diagnostics, many of which are based on nuclear physics.

The main fusion reaction is the $d + t \Rightarrow n + \alpha$ reaction, which releases 17.6 MeV of energy per reaction in the form of a 14-MeV neutron (n) and a 3.6-MeV alpha particle. If successfully ignited, an NIF capsule will burn about 1018 d + t reactions, with a corresponding release of over 2.5 MJ of fusion energy. One of the important diagnostics for understanding capsule behaviour is neutron imaging [3].

Nuclear weapons

Nuclear weapons remain the unquestioned core of the defence postures of both France and the United Kingdom. After Brexit, France will be the only EU member state that has nuclear weapons. At the same time, the European Union is progressively enhancing its Common Foreign and Security Policy (CFSP), notably through the establishment of a European Security and Defence Policy (ESDP). Yet, despite evident progress in the CFSP, whose ultimate purpose is to lead to a 'common defence policy', EU member-states still deal with nuclear issues on a predominantly national basis. What is the alleged purpose of European nuclear forces? How is the raison d'être of the French nuclear deterrents conceptualised against the background of progressing European (defence) integration? How can EU members without a nuclear arsenal support France at the level of research and development in the development of nuclear technologies aimed at defending all members of EU? These are new challenges that go beyond the scope of the report. However, we are signalling them because of the EU's defence needs. In this report, we suggest that dual-use technology research projects should be considered by EU commissioners in terms of innovation in nuclear weapons.

Accelerators

Beams of high-energy particles, produced by accelerators, are essential for both fundamental and applied research and for technical and industrial fields. Accelerators have become prevalent in our lives, and there are now over 30,000 accelerators worldwide. Of these, the largest number (about 44 percent) are used for radiotherapy, while 41 percent are used for ion implantation, 9 percent for industrial research, and about 4 percent for biomedical research. The remaining 1 to 2 percent of accelerators are very high-energy accelerators used in nuclear and particle physics to probe the fundamental nature of the matter making up our universe.

All accelerators can be described as devices that use electric fields to accelerate charged particles (such as electrons or ions) to high energies, in well-defined beams. Since the discovery of the X-ray in 1895 by Roentgen, many famous nuclear physicists have made seminal contributions to new accelerator technologies, including John D. Cockcroft, Ernest Walton, Earnest O. Lawrence, and Robert Van de Graaff. Today accelerator technologies range from the Large Hadron Collider (LHC) capable of producing TeV particles to the lowest energy accelerators used by industry [3].

Accelerators form the basis for many diagnostic systems, from chest X-ray machines to whole-body X-ray scanners capable of creating a three-dimensional image of the living body. Accelerators such as cyclotrons enable protons and other light nuclei to be used to produce radioactive nuclei that are used in diagnostic medicine. Radioisotopes such as thallium-201 are used to diagnose heart disease. The production of the unstable isotopes of the elements of life, such as oxygen-15, carbon-11, nitrogen-13, and the pseudo-hydrogen fluorine-18, has led to the field of PET. These positron-emitting radionuclides are attached to biologically active molecules. When the tagged molecules are injected, the annihilation radiation can be imaged and the functional capacity of the patient can be determined, as discussed in the PET highlight. Today PET scanners are combined with computed tomography (CT) scanners so that in one setting, the structural (CT) and functional (PET) capacity of the patient can be determined. CT and PET scanners have revolutionised nuclear medicine [3].

Intense X-rays are now one of the primary modes of treating cancer. Accelerators throughout the world generate beams of electrons that are directed to targets that create X-rays, which are then directed at the tumours to destroy them. The modern therapy machine has become extremely sophisticated in that the electron beam can be modulated to increase and decrease the flux to alter the dose of X-rays and thereby spare healthy tissue while maximising the dose to the tumour. While the standard of care for cancer treatment includes X-ray therapy, there is a growing use of high-energy protons to ablate the tumours. The idea is to deposit as much energy as possible in the tumour cells while sparing the surrounding tissues.

There is a vast enterprise of techniques that use accelerators in a wide range of industries, e.g., to polymerise plastics, to sterilise food and medical equipment, to weld materials using an electron beam, to implant ions into materials, to etch circuits on electronic devices, to examine the boreholes of oil wells, and to search for dangerous goods. There are approximately 8,500 such devices worldwide.

Electron beams dominate the industrial uses, with the curing of wire-cable tubing and of ink accounting for more than 60 percent of the market. Other electron beam uses include shrinking films, cross bonding of fibres in tires, and irradiation of food. Here, electron beams replace traditional thermal heating approaches because of the gain in efficiency that comes from the more uniform distribution of energy.

A number of major accelerator developments related to nuclear energy are being pursued, including plasma heating for fusion reactors, inertial fusion reactors, nuclear waste transmutation, electronuclear breeding, and accelerator-driven subcritical reactors.

The breadth of scientific disciplines that make use of accelerators to perform their studies is considerable. Cutting-edge materials research makes use of synchrotron radiation having a wide range of wavelengths. Muon beams and neutrons produced from spallation sources probe the properties of materials such as the high-temperature superconductors. Mass spectroscopy is a standard analytical technique for chemists. High-resolution mass spectrometry is used in archaeology and geology for dating artefacts by determining the ratio of stable to long-lived isotopes [3].

Cosmic rays are continuously bombarding Earth: more during active solar periods, more at the poles, and less at the equator. When cosmic rays, or radiation from their secondary products, interact with an electronic device, the function of that device can be compromised. The resulting errors in the functionality of an electronic device can have very serious consequences for technologies used by such disparate industries as aerospace and autos.

A single event upset (SEU) refers to a change in the state of the logic or support circuitry of an electronic device caused by radiation striking a sensitive location or node in the device. SEUs can range from temporary non-destructive soft errors to hard error damage in devices. The detailed physics determining the rate at which SEUs occur is both complicated and device dependent. Circuit manufacturers try to design around the risks posed by cosmic ray interactions by introducing redundancy or other protective measures to compensate for the radiation-induced errors. To do so requires detailed knowledge of the expected rates and types of SEUs that can occur. Thus, experimental testing of semiconductor device response to radiation requires beams of particles that provide realistic analogues of cosmic rays and their secondary products. The main particles responsible for SEUs are neutrons, protons, and alpha particles, as well as heavy ions. Thus, the beams needed for this large experimental programme require a range of nuclear accelerator facilities to test for device vulnerabilities and to characterise the radiation-induced failure modes of the electronic chips. For this, nuclear physics accelerator facilities are a unique resource, and agencies and companies, from all over the world, purchase beam time at accelerator facilities to test for device vulnerabilities and to characterise the radiation-induced failure modes of the electronic chips.

Applications of nuclear techniques are used to advance other scientific disciplines, including climate science, cosmo-chemistry, geochronology, paleoclimate, paleo-oceanography, and geomorphology. Since 1949, when Willard Libby first demonstrated carbon dating, the field of trace analyses of long-lived cosmogenic isotopes has steadily grown. Because they are chemically inert, noble gases play a particularly important role as tracers in environmental studies. Owing to their inertness, the geochemical and geophysical behaviour of these gases and their distribution on Earth is simpler to understand than that of reactive elements [3].

THE PURPOSE OF THE INNOVATION SURVEY

Work package WP8 NuPIA (Nuclear Physics Innovation) is a transversal network activity meant to reinforce the partnership of Nuclear Infrastructures and Institutions with Industry and to promote the use of Nuclear Physics Infrastructures by industrial researchers. It is also a link between innovation officers of the institutions, research groups in various ENSAR2 WPs and industry.
WP8 has been divided into 3 tasks, as listed below:

- Task 1: Survey of innovation within the ENSAR2 WPs (coordinator: UniWarsaw)
- Task 2: Bridging and Dissemination (coordinators: UniWarsaw, GANIL)
- Task 3: Training in nuclear techniques: schools for employees of industrial companies (coordinators: JYU, ULIV)

The objective of Task 1 is to highlight the innovative capacity of the ENSAR2 partners and quantify the impact in terms of direct and indirect benefits for industry and society. For this purpose, a survey of the innovative developments done within the different ENSAR2 WPs of possible interest for industry or other scientific domains has been carried out. The first work consisted in defining the methodology and choosing the impact indicators.

The impact indicators adopted for this Task concern the potential or established benefit for both industry and other domains of science that could arise from the technologies developed within ENSAR2. Examples are:

- Innovation of interest for industry or other domains of science
- Technology transfer
- Patents
- Licensing
- Valorisation/selling (to other labs or to industry) of products developed for our physics programmes.

The innovation research was based on the implementation of individual stages: development of indicators, preparation of a survey, collection of survey data, data analysis, and development of conclusions.

RESULTS OF THE SURVEY OF INNOVATION

Patents, licenses, commercialisation of products

To the question "Please give the number of patents registered in the last 5 years", 22 laboratories participating in the project ENSAR2 replied. Of these 22 laboratories, 13 have patents. In terms of the number of patents, the leaders include laboratories such as GSI - 133 patents, IRFU-CEA - 60 patents, INFN-LNL - 36 patents, and CIEMAT - 23 patents. These laboratories belong to the so-called large research centres that have adequate infrastructure to enable a wide range of research and development, which significantly favours the emergence of new patents. The next group is the so-called medium and small laboratories. This group includes UoL - 12 patents, IFJ-PAN - 9 patents, IFIC-7 patents, GANIL - 5 patents, USC-3 patents, CNA-2 patents, HIL-UW, KVI-CART, and JYFL-ACCLAB - one patent each. This group includes medium and small laboratories whose infrastructure potential is limited. It is worth emphasising that along with the investment process in new infrastructure, intensification of cooperation with industry and the effects of network cooperation under ENSAR 2, these laboratories will increase their application potential for patenting innovative technologies.

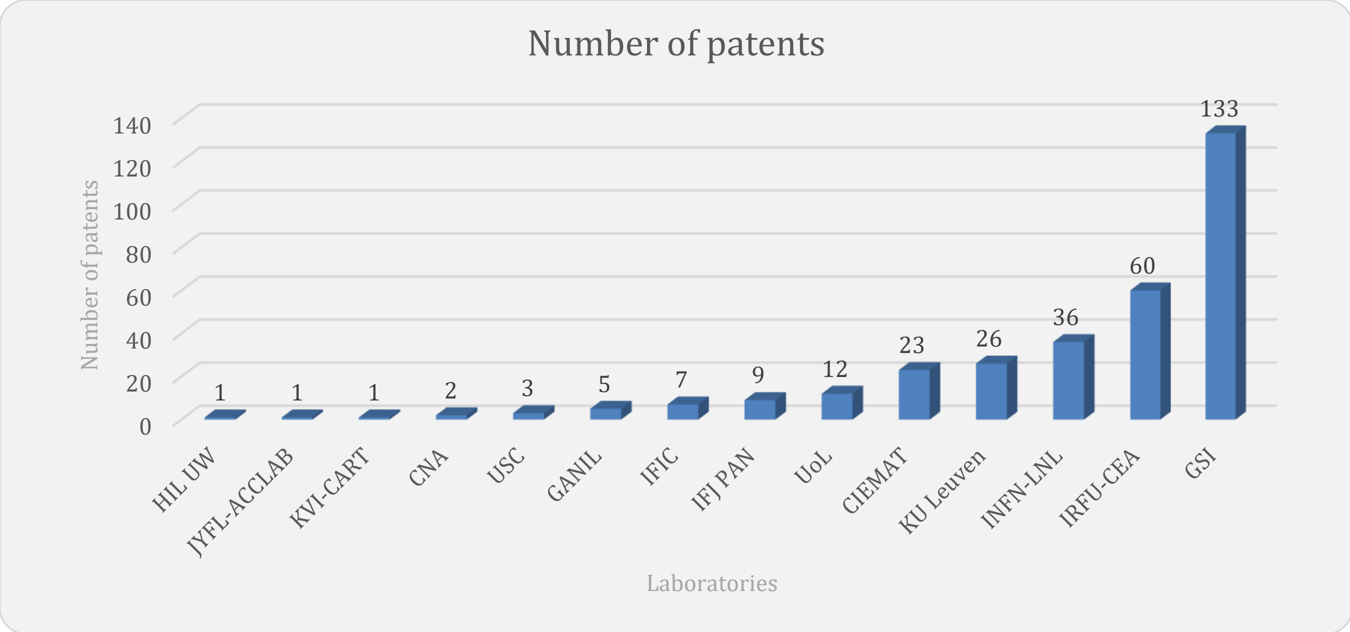


Figure 4: Number of patents ENSAR2 laboratories.
Source: Created by NUPIA

The following are descriptions of selected patents identified by the laboratories:

GSI laboratory:
US9318863B2
A laser-pulse-shaper device includes shaper unit with first dispersive element for spatially separating spectral components of laser pulses, second dispersive element for parallelising and deflecting spectral components into Fourier plane of dispersive elements, and mirror for back-reflecting of laser pulses via dispersive elements. It also includes a light modulator in Fourier plane of dispersive elements, which is capable of modulating spectral components of laser pulses, wherein beam path of shaper unit includes forward beam path from first dispersive element via second dispersive element to mirror and return beam path from mirror via second dispersive element to first dispersive element. A focusing device is arranged at input side of forward beam path before first dispersive element for focusing spatially separated spectral components of laser pulses to Fourier plane of dispersive elements [8,13].

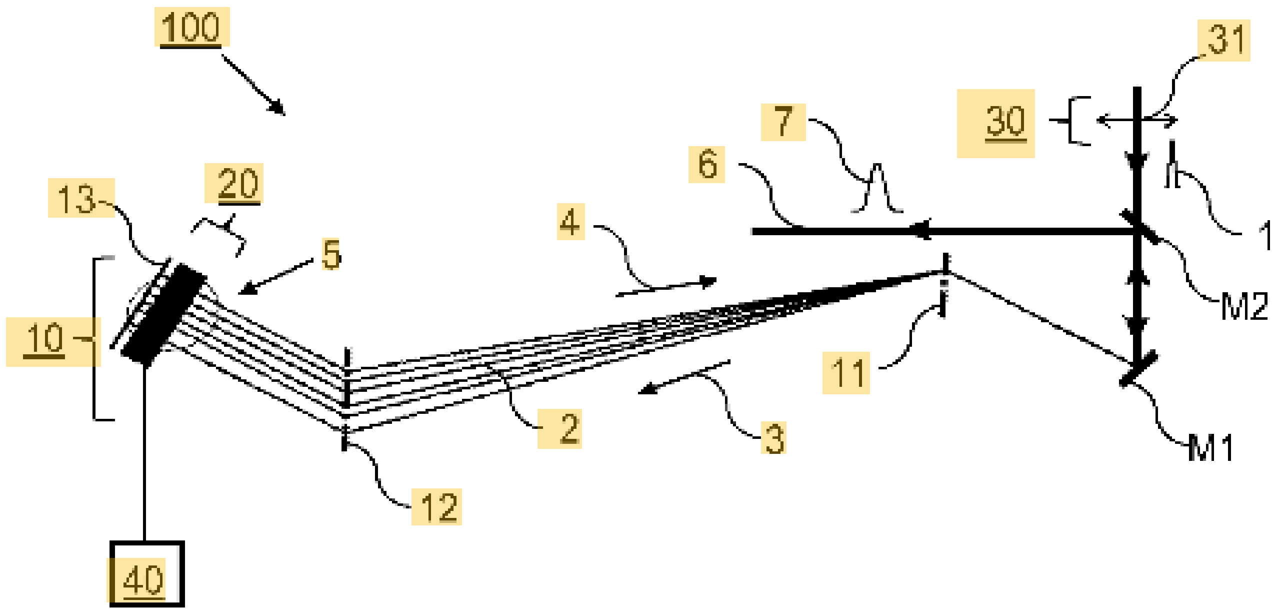


Figure 5: A laser-pulse-shaper device.
Source: Espacent - European Patent Office - https://worldwide.espacenet.com/patent/

Europäisches Patentamt (EPA) 16781065

Disclosed is a novel rotary module) for a measuring device of an accelerator system. The rotary module comprises a first radial bearing with a first bearing side designed to be paired with an accelerator-side flange connection, and with a second bearing side for supportively receiving the measuring device on the first radial bearing, so that the measuring device is connected to the accelerator system by means of the first radial bearing. The rotary module also has a drive for controlling a rotary motion of the measuring device about an axis of rotation [8,13].

IFJ PAN

PCT/PL2018/050059

The subject of the invention is the method of detecting and diagnosing the progression of diabetes using Raman spectroscopy, which involves the examination of the changes in the composition of urinary extracellular vesicles, which confirm the existence of the condition and its progression. The invention can be applied in clinical practice, in particular in the early clinical diagnostics of diabetes and in the monitoring of its progression, in particular diabetic nephropathy and advanced renal impairment caused by diabetes [8][13].

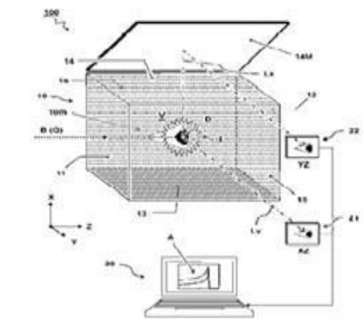


Figure 6. An imaging method and system for verification of a treatment plan
Source: Patenscope - WIPO World Intellectual Property Organization - https://www.wipo.int/portal/en/index.html

KVI-CART

WO/2016/099264

An imaging method and system for verification of a treatment plan (A). A phantom volume (V) is provided consisting of a material (10m) having dose absorbing properties similar to a biological tissue according to the treatment plan (A). Dose parameters (Q) of a hadron beam (B) are set according to the treatment plan (A). The hadron beam (B) is directed into the phantom volume (V) according to the dose parameters (Q). Light (L) emitted from the phantom volume (V) is measured. A dose distribution (D) of the hadron beam (B) in the phantom volume (V) is calculated based on the measured light (L). The light (L) is measured by imaging a lateral side (14,15) of the phantom volume (V) while the material (10m) of the phantom volume (V) comprises at least 90 mass percent water[8][13].

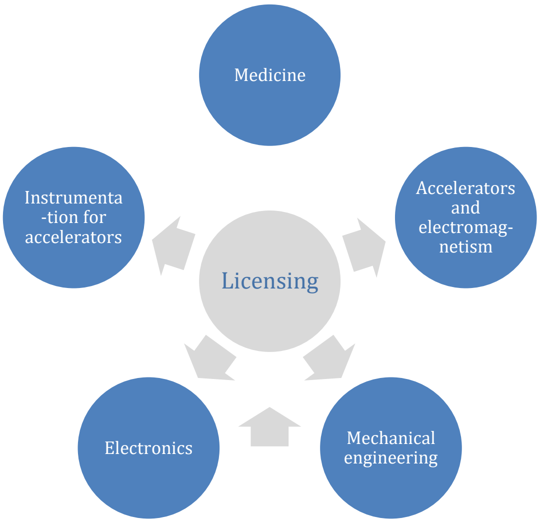
Centro Nacional de Aceleradores and University of Seville
PCT/ES2015/070149

The object of the present invention is an ionising-radiation sensor having energy levels of 0.1 keV to 100 MeV, which is sensitive to both the type of radiation and to the energy thereof. The detector comprises a stacked structure having multiple layers of material that have different luminescences [8,12].

University of Lisbon
PCT/PT2016/000016

Nanosystem composed of gold nanoparticles produced using a plant extract as a reducing agent adsorbed in the surface of a gold metal core and a coating consisting of a polymer and a peptide , having an essentially spherical shape and a near infrared absorption range, and method for preparing same from hyaluronic acid and oleic acid . The nanosystem has therapeutic activity against superficial tumours, namely those located at less than 5 cm depth, and deep tumours, namely those located at more than 5 cm depth, and against dermatological pathologies when hyperthermally activated by a laser or a light source having a similar application [8][12].

To the question, "Please give the number of licenses which has been granted in the last 5 years", 22 laboratories answered of which 9 laboratories have been granted a license. The following laboratories have licenses: INFN-LNL - 23, GSI - 6, GANIL - 5, UoL - 6, IRFU-CEA - 3, CIEMAT - 2, IFIC -1, JYFL-ACCLAB - 1, CNA-1.



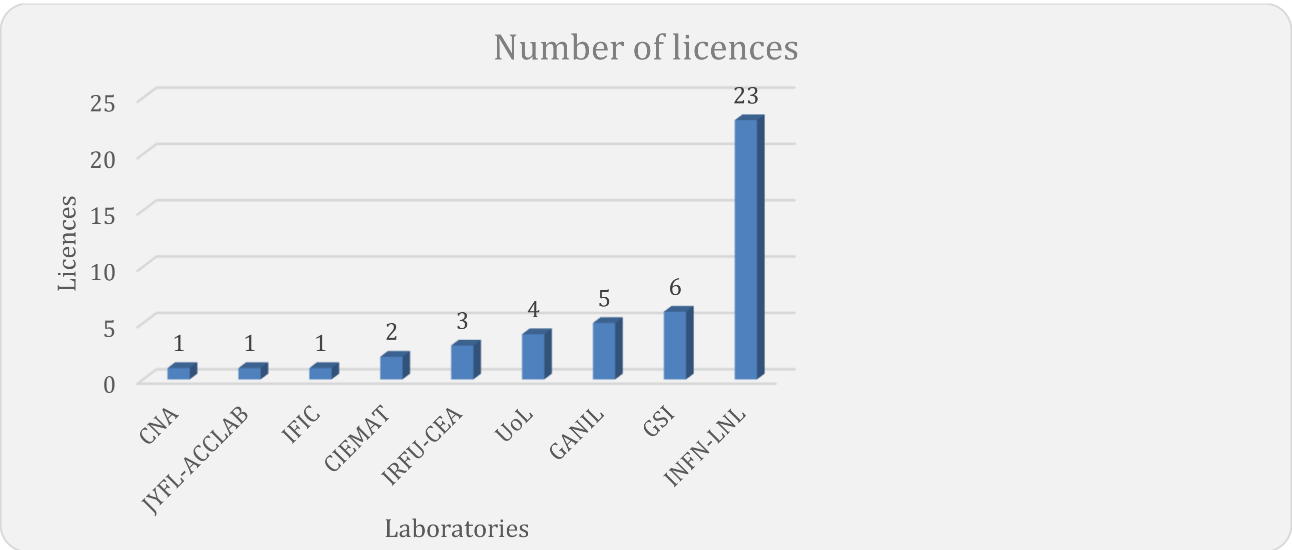


Figure 7: Number of licences ENSAR2 laboratories.
Source: Created by NUPIA

To the question, "Please name the thematic scope and licenses for 3 of licenses granted", 22 laboratories answered. Thematic areas in the licensing area include the following: Medicine - 34.78%, Instrumentation for Accelerators - 17.39%, Accelerators and Electromagnetism -17.39%, Electronics - 10.87%.

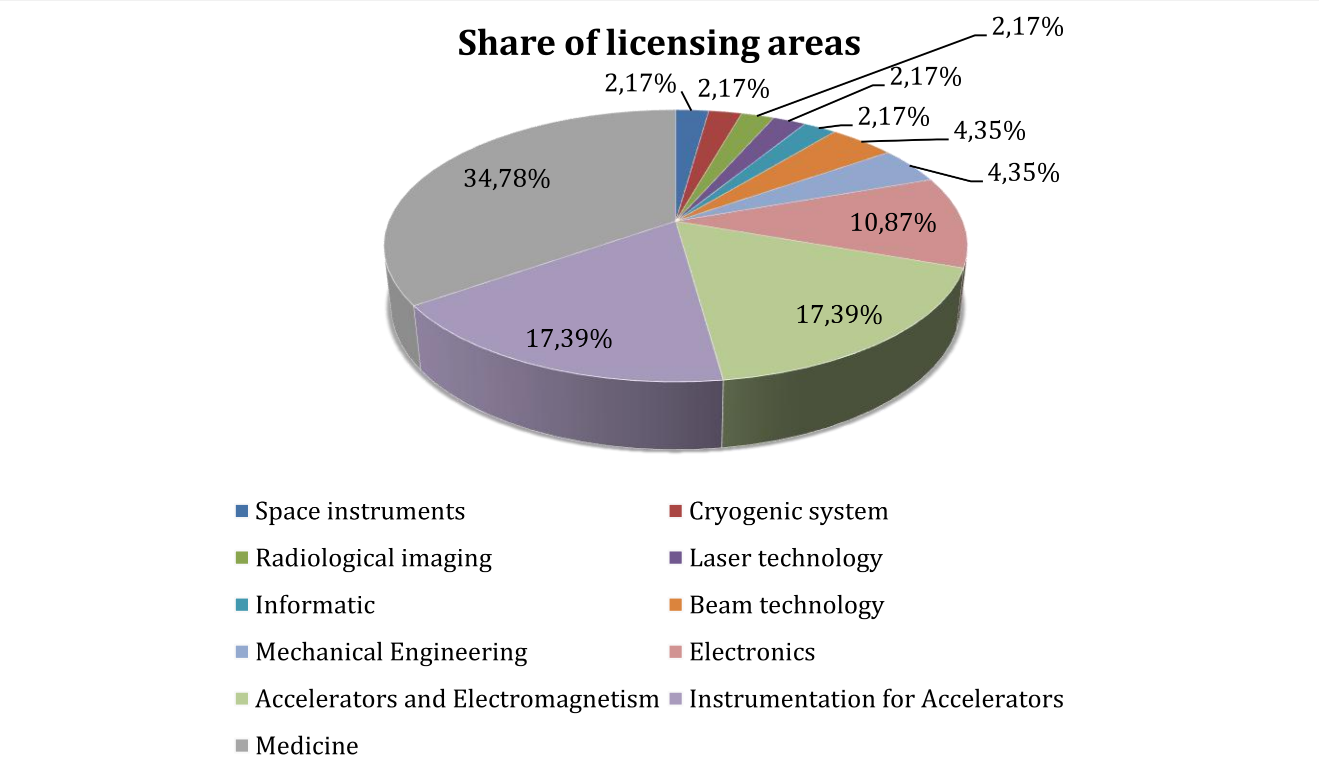


Figure 8: Share of licensing areas.
Source: Created by NUPIA

To the question, "Please give the estimated number of products or patents commercialised in the last 5 years", 22 laboratories answered of which 10 laboratories have been granted a market commercialisation. The following laboratories have commercialisation: CIEMAT - 7, INFN-LNL - 5, GSIU - 4, UoL - 4, UoL - 4, IFJ-PAN - 2, CIEMAT - 2, ARRONAX - 2, UNI-MAINZ - 1, GANIL - 1, USC - 1, JYFL-ACCLAB - 1, and HIL UW - 1.

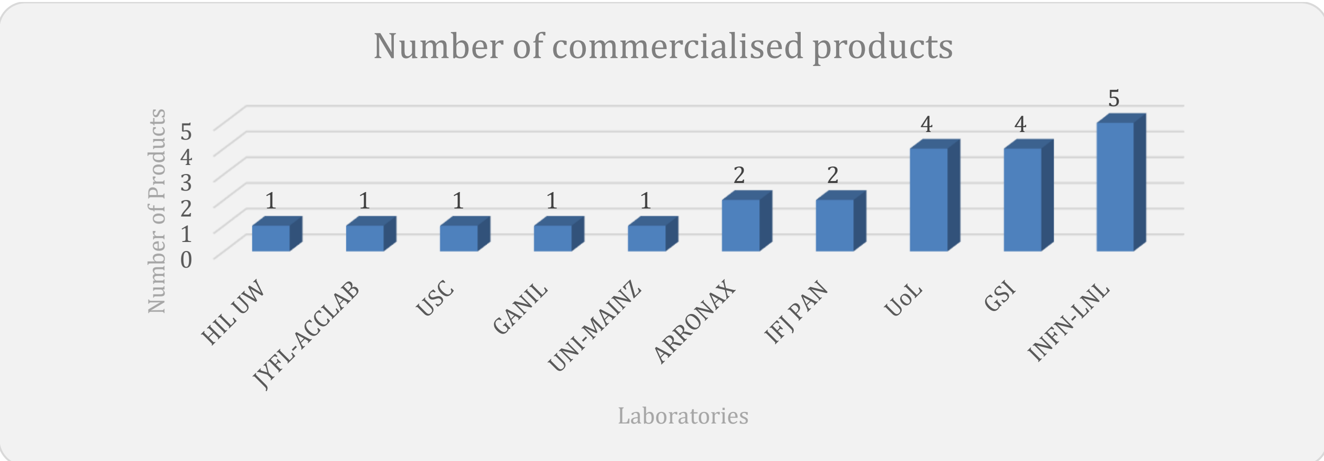


Figure 9: Number of commercialised products.
Source: Created by NUPIA

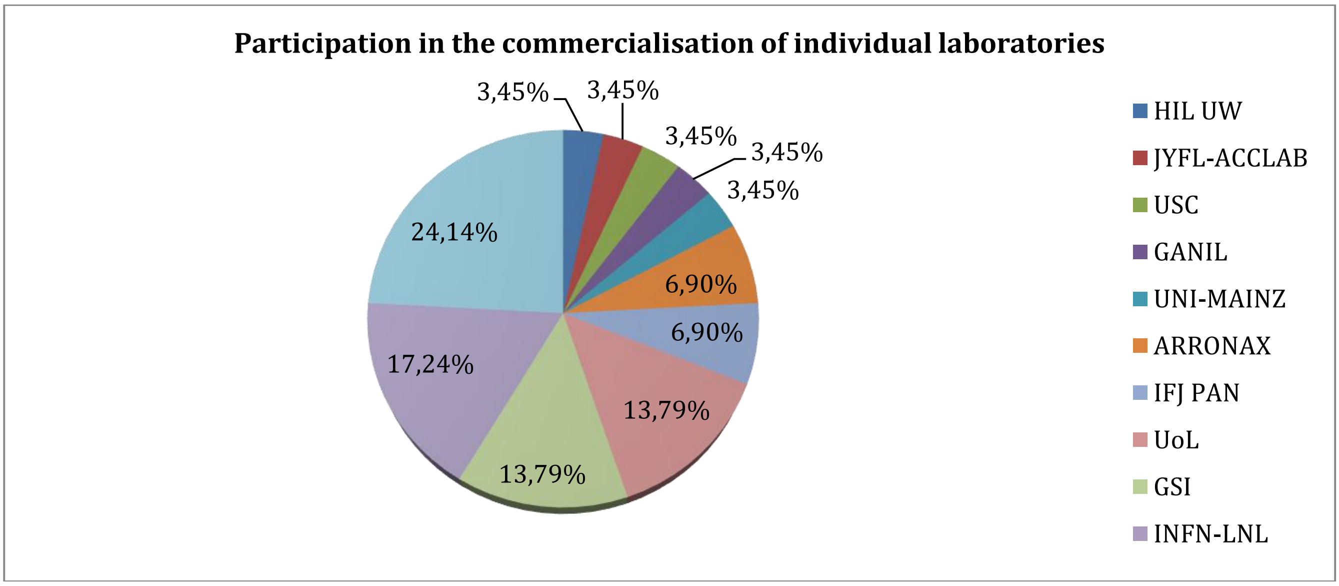
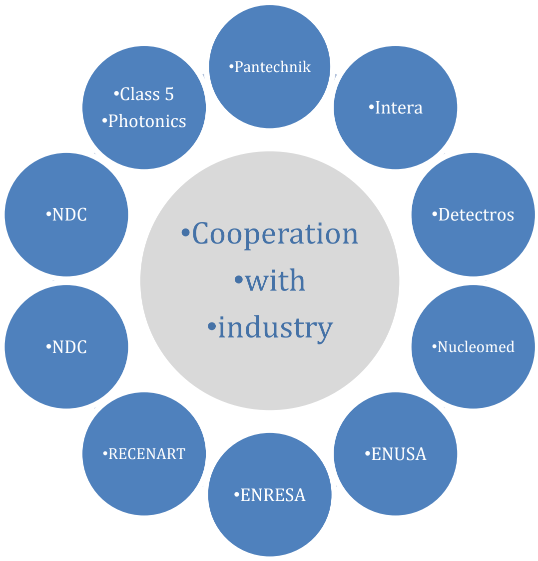


Figure 10: Participation in the commercialisation of individual laboratories.
Source: Created by NUPIA

Among the products targeted at the market are electronic modules, detectors, membranes, radiopharmaceuticals, medical imaging techniques, technologies for laser-driven proton acceleration for bio-medical applications. CIEMAT is one of the laboratories distinguished in the area of commercialisation. CIEMAT has performed 552 technical services to industry with a turnover above 1.3 M € (in one year) in the following areas: renewable energies and energy savings, nuclear fission, nuclear fusion, biology and biomedicine, environment, ionising radiations, scientific instrumentation and medical physics, materials analysis and characterisation, computation and information technology sciences, energy and environmental system.
In terms of profitability of production, the radiopharmaceutical market is the most interesting. According to the report (Radiopharmaceutical Market by Type, Cardiology, Neurology, Oncology and Other Applications and Forecast, 2015 - 2021), global radiopharmaceutical market was valued at around USD 4.32 billion in 2015, is expected to reach approximately USD 7.13 billion in 2021, growing at a CAGR of more than 8.8% between 2016 and 2021. Radiopharmaceutical is a medication used in nuclear medicine that has the radioactive part and pharmaceutical part. Nuclear medication is given to a patient in a small amount; this makes patient body radioactive for the short time span.

Cooperation with industry

Cooperation between individual laboratories and industry representatives is mainly focused on national contacts. At this stage, commercialisation of research and development results for industry has a mainly national dimension. Ten laboratories answered the question "Please give 3 names of companies involved in the commercialisation of your organisation products or patents". Fourteen enterprises were identified in which the research and development results of laboratories were commercialised. Below are the characteristics of selected companies.



Pantechnik

The company developing, designing, producing and installing equipment for accelerators, from ECR ion sources up to diagnostics, going through transport elements whilst providing high quality. It is a spin-off of CNRS/GANIL laboratory, created in 1991.

Electron Cyclotron Resonance Ion Sources are the most important products of the company. The company offers different models, matching to customer needs of high intensity and/or high charge states beams. ECR ion sources are reliable and virtually chemical independent, producing beams of all elements with upmost ionisation efficiencies. The company produces turnkey systems well adapted to applications in the domain of Atomic, Surface and Nuclear physics. The company instruments are also used in Nano-science, Biology and Medicine, like Hadron therapy.

Nucleomed S.r.l.

Nucleomed S.r.l. is a company specialised in design and production of detectors for surgical and diagnostic purposes. It is a spin-off of the pol.hi.tech company located in Carsoli (AQ). Twenty-year experience in particles detectors design for High energy Physic and Medical Physic makes Nucleomed one of the most qualified companies in this field. Research, Development and Design of high technology systems is the main mission of the company.

Radiant Dyes

Radiant Dyes has 35 years of experience in Laser Dyes and Dye Laser development. The company is the oldest existing manufacturer of tuneable laser and laser accessories. The dye laser "NarrowScan" has been developed further over the last years and is now the most advanced product of Radiant Dyes. Similarly, Radiant Dyes kept the cw-ring and Titan-Sapphire lasers up to date. For more than 20 years, the company offers successfully, excimer lasers.
Since 2009 the company selling a tuneable narrowband Diode Laser with interference-filter stabilisation and external cavity, our "NarrowDiode", and now available with amplifier. The company participate in the preparation of experiments and the equipment of laboratories, which is highly appreciated by universities and research centres worldwide.

Laboratories and start-ups

Laboratories associated within the ENSAR2 network have created 14 start-ups. We believe that the potential of the ENSAR2 network in creating new start-ups is definitely greater. Appropriate conditions are needed in this area. First of all, a larger share of Venture Capital investment funds is needed that will be able to invest in the seed phase. Secondly, they are needed for EU programmes supporting start-up projects. These programmes should be similar in budgetary and organisational terms to the activities of Venture Capital funds. We believe that what is needed to accelerate start-ups in the area of nuclear physics is easier access to investment funds that are ready to enter with capital in innovative and risky innovative ventures.

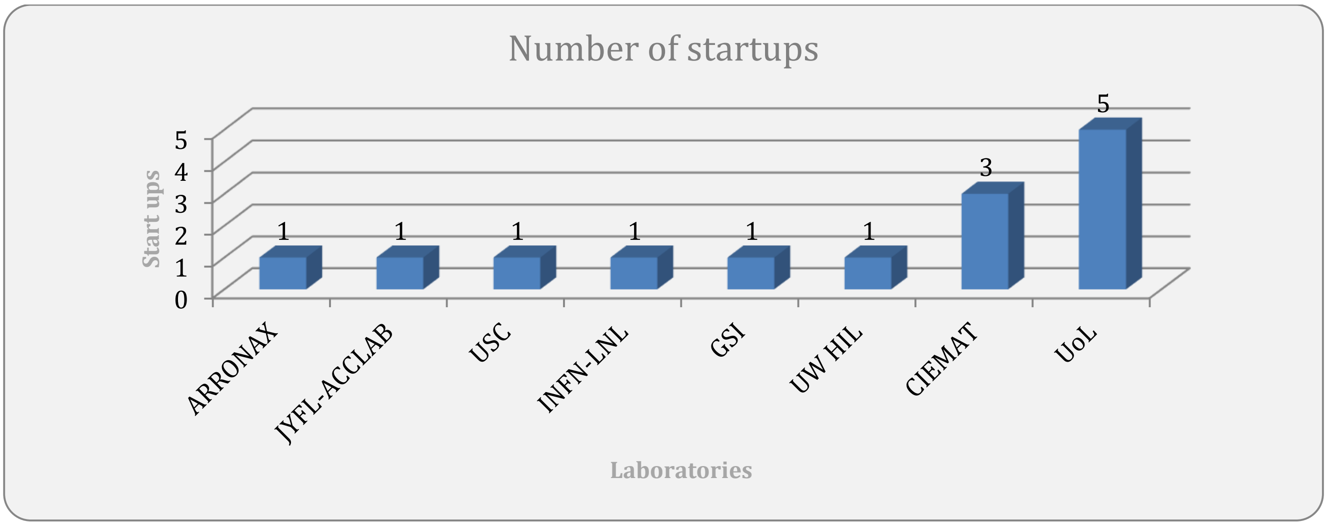


Figure 11: Number of start-ups.
Source: Created by NUPIA

Below are selected start-ups created within the ENSAR2 network:

Class 5 Photonics

Class 5 Photonics from GSI is dedicated to deliver high power femtosecond lasers that inspire the worldwide scientific and industrial community with the fastest, brightest and sharpest laser pulses commercially available to enable leading-edge scientists to understand how life, matter and interactions work and to find new ways to observe, manipulate or control diseases, structures and processes.

Class 5 Photonics offer powerful and high-performance femtosecond lasers. Accelerate your research and ultrafast applications to discover new frontiers.

Award-winning products with high reliability at extreme average power - enabling researchers in physics, chemistry, and biology to conduct outstanding research at the frontiers of their fields.

An experienced team with a strong background in ultrafast research - achieving maximum benefit for the customer's application by a tailored laser design.

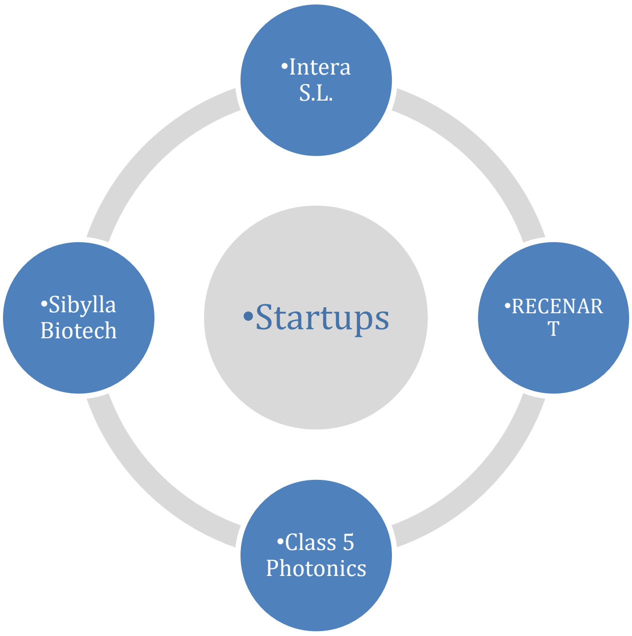
A vast experience with nonlinear amplifier crystals and the critical thermal management - realising high power scalability in different spectral regions from the visible to the mid-infrared. A close and long-term partnership with pump laser manufacturers - maximising performance and compatibility, including high quality, worldwide customer service.

RECENART

Recenart is run by a team of art historians, who are supported by natural scientists. The team members operate as Professors, University lecturers, Docents in the University of Jyväskylä. Everybody in the team has achieved the scientific excellence in his or her own field.

Recenart applies the latest technology in researching fine art, archaeological artefacts and minerals. The team constantly develops existing and new research technology.

RECENART applies the latest technology in analysing fine art and archaeological objects. The team constantly develops existing and new research technology.



The company serve art buyers, sellers and intermediaries who are interested in knowing more about a work of art or the whole collection.

The company has Principal Investigators in Finland, London and New York and are leaders in their field. By combining scientific analysis solutions with their expertise, the company can help with the questions about art object.

RECENART applies state-of-the-art techniques in analysing fine art and archaeological objects.

Scientific analysis, such as material analysis and technical imaging, enables us to find out the hidden features and the materials used in the artwork. This information can lead to attribution the work of art to certain artist.

The following scientific techniques are available in RECENART:

- Materials analysis and dating techniques: TES-PIXE, PIXE, XRF, SEM-EDS, Raman, FTIR, XRD, C14
- Technical imaging techniques: hyperspectral imaging, X-ray, photogrammetry, raking light, UV- and IR spectrographic analysis, stereomicroscopy

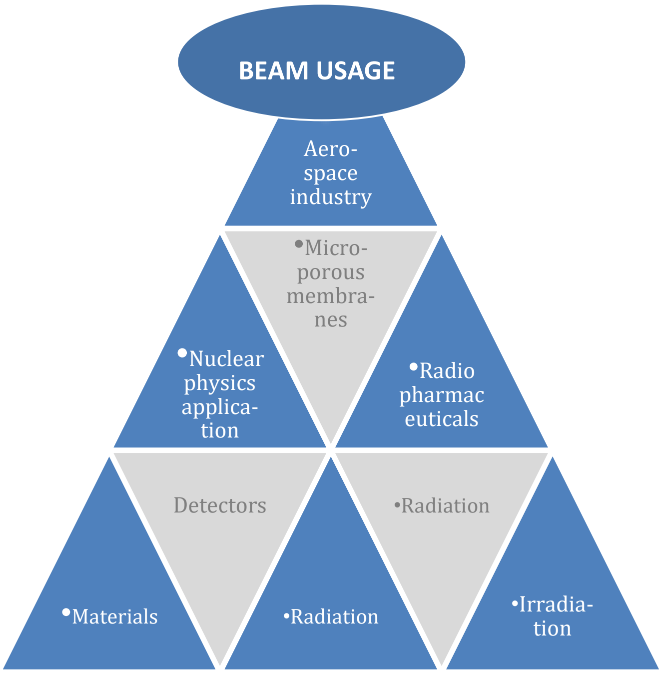
Sibylla Biotech

The Sibylla provide the research, which is based on the development of innovative algorithms, derived from advanced mathematical methods of theoretical physics, and ad-hoc drug discovery protocols. These new powerful techniques enable the company to reveal with atomic resolution the folding and misfolding mechanisms of bio-medically relevant proteins, thereby unveiling entirely new classes of pharmacological targets and drug candidates. Powered by company research experience and knowledge passion for finding things out, together with academic and industrial partners, company opening new paths in rational drug discovery research.

The company's Drug discovery protocols are based on original reaction path sampling and data reduction algorithms, developed through more than a decade of research at the Physics Department of Trento University. This line of investigation is inspired by the conviction that the quest for overcoming the existing limitations of computational biochemistry should not be limited to building increasingly powerful supercomputers. To access the biologically relevant timescales we need a new generation of algorithms, possibly based on more advanced and powerful mathematical frameworks.
Following this guiding principle, the company developing and implementing innovative reaction path sampling algorithms based on the mathematical framework of Path Integration and Stochastic Calculus. The company data reduction protocols are derived from Nobel Prize-winning concepts that define the so-called Renormalisation Group Theory, originally introduced to study critical phenomena in condensed matter physics, combined with the notion of Effective Field Theory, a pivotal concept in contemporary nuclear and particle physics.

Naogen Pharma
Naogen Pharma is a radiopharmaceutical company installed in Nantes, France and aiming at developing innovative radiopharmaceutical agents in cardiology and oncology using radionuclides produced by high-energy, high-intensity Arronax cyclotron.
Founded in September 2016 after completion of a research project termed Quanticardi and financed by French Public Bank and Pays de la Loire Region, the company developed in premises of Arronax site with private investor funds. Its expertise relies on the availability and mastery of a rubidium-82 generator and an infuser necessary for the non-invasive diagnosis of myocardial ischemia in cardiology using Positron Emission Tomography (PET).
Naogen participate with Arronax laboratory in project ArronaxPlus'. The objective of the project is to structure, strengthen and coordinate five technology platforms in order to develop molecular imaging and "vectorised" radiotherapy (irradiation of a tumour with a radioactive element, alone or linked to a vector) for the improvement in the diagnosis and treatment of cancer. These platforms will be exploited to increase knowledge on the impact of ionising radiation on matter, produce medical radioisotopes and radiopharmaceuticals, validate these products in the context of translational research projects and undertake the training of users. ArronaxPlus high quality equipment is spread over several academic laboratories including GIP ARRONAX, Nantes-Angers Cancer Research Centre (CRCNA), subatomic research laboratory Subatech, research laboratory in organic chemistry CEISAM, Oniris veterinary school, Nantes University Hospital nuclear medicine department and West Cancer Institute. Carried out by GIP ARRONAX, it was funded in 2012 by the state as part of the call for projects EQUIPEX within the future investment programme (PIA) and by local authorities, supervisory bodies and private investors up to € 8 million over 8 years, including € 6 million investment in equipment.

Beam used for an industrial partner or client needs



To the question, "Please give an estimated number of contracts with industry involving laboratory resources, for example, the beam used for an industrial partner or client needs", 16 laboratories answered. In terms of the number of contracts, the leaders include laboratories such as GSI - 108 contracts, INFN-LNL-85 contracts KVI-CART – 50 contracts, CIEMAT-46 contracts. The next group called medium contractors are: GANIL - 10 contracts, Arronax - 8 contracts, CNA-5 contracts, JYFL ACCLAB- 3 contracts, IFJ-PAN – 2 contracts, USC – 2 contracts. Below are descriptions of two centres. GSI, which is a leader in the group of largest contractors, and GANIL, which is a leader among laboratories standing out in the group of medium-sized contractors.

The GSI operates a large–scale, worldwide-unique accelerator facility for heavy ions. This facility offer researchers from all over the world use the buildings blocks of matter and the evolution of the universe. In addition, they develop new applications in medicine and technology.

GANIL – Grand Accélérateur National d'Ions lourds – i.e. Large National Heavy-Ion Accelerator – is one of the large-scale infrastructure available for French, European and international research. GANIL is one of the largest laboratories in the world for research using ion beams: physics of the atom and its nucleus, condensed matter, astrophysics, radiotherapy. In this context, the CIMAP and LARIA laboratories, situated on GANIL site (partially for the CIMPA laboratory) have an essential role. GANIL is a host laboratory for a large community of users, 700 scientists from more than 100 laboratories and institutions come each year.

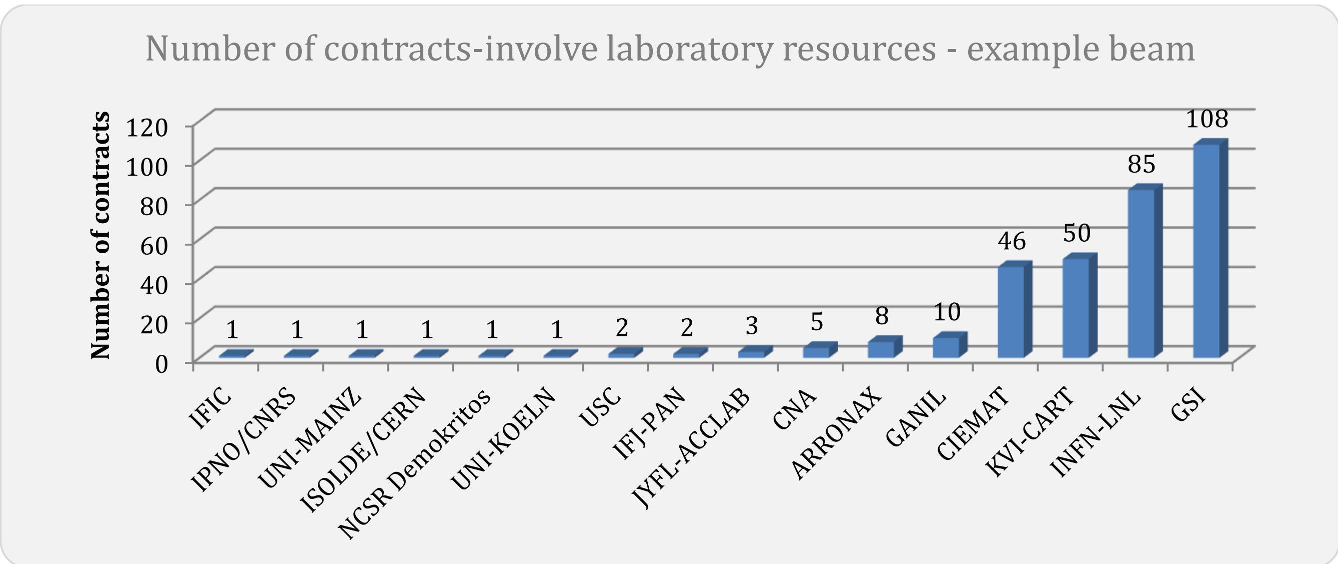


Figure 12: Number of contracts-involve laboratory resources-example beam.
Source: Created by NUPIA

The largest share in the field of use of laboratory resources concerns applications for the aerospace industry. Secondly, it concerns production for the needs of nuclear physics and applications. The production of Microporous membranes and radiopharmaceuticals also has a significant share of the beam application.

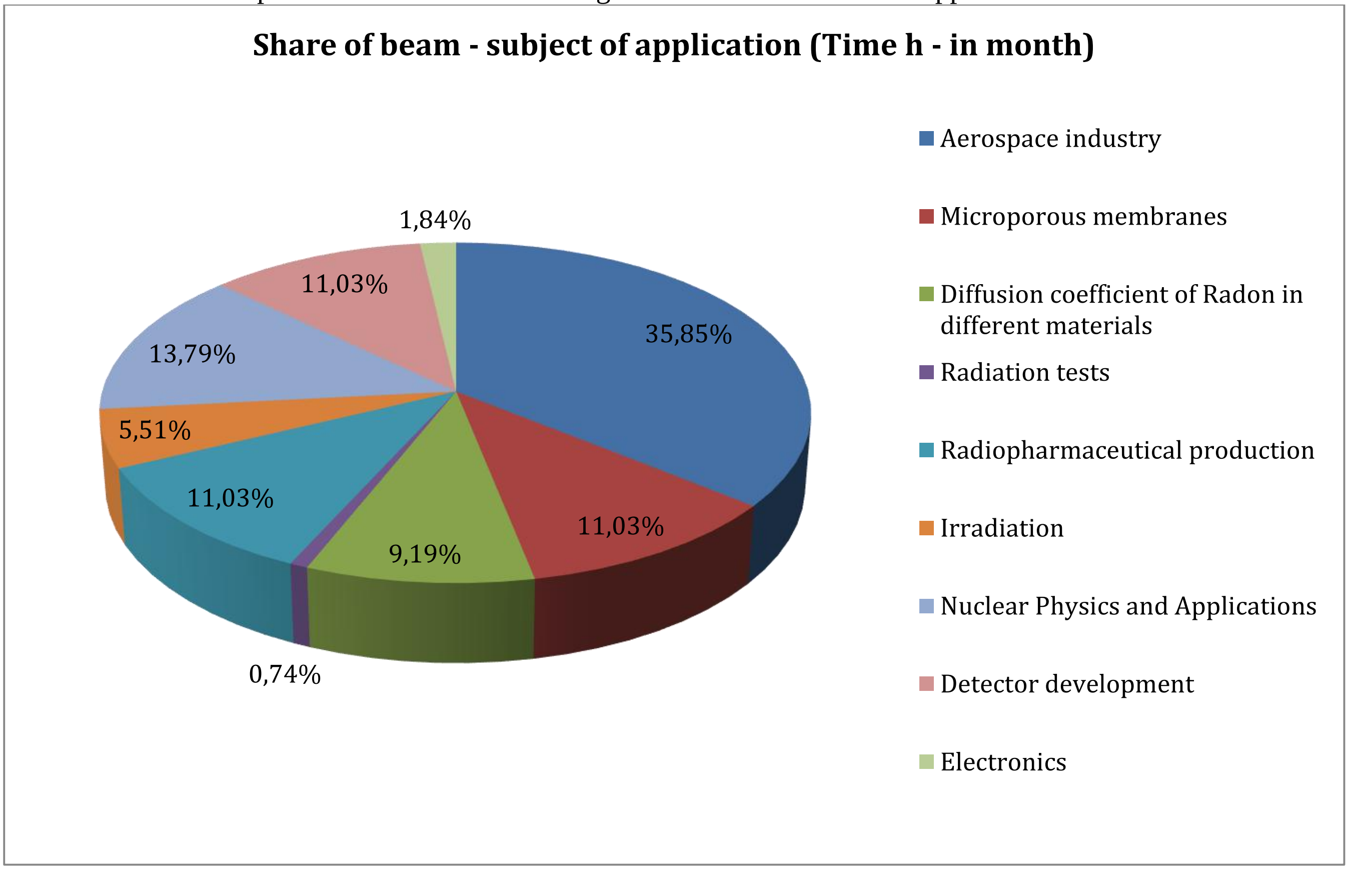


Figure 13: Share of beam – subject of application (Time h – in month).
Source: Created by NUPIA

Partnership with industry

To the question, "Please give an estimated number of projects in partnership with industry involving laboratory resources, for example, the beam used for industrial partners" 13 laboratories answered. In terms of the number of projects, the leaders include laboratories such as KVI CART - 50 projects, Arronax-11 projects CNA – 10 project, CIEMAT-7 projects. The next group called medium group are: UoL - 6 projects, GSI - 5 projects, IFIC-3 projects, IFJ-PAN- 2 projects, KU Leuven – 2 projects, Compostella – 2 projects. Below are descriptions of two centres. KVI-CART, which is a leader in the group of largest number of projects in partnership with industry.

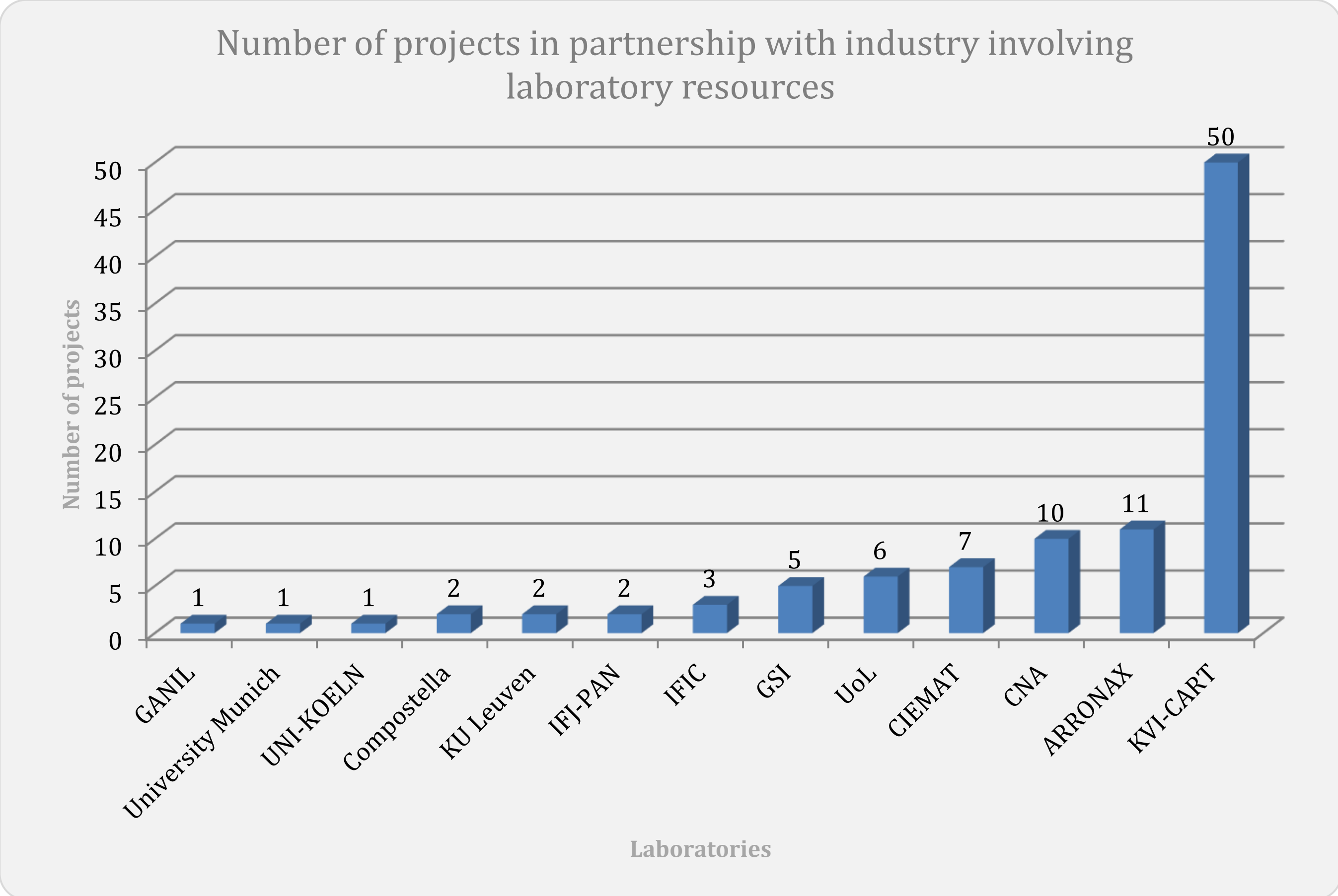


Figure 14: Number of projects in partnership with industry involving laboratory resources.
Source: Created by NUPIA

The mission of the KVI-Centre for Advanced Radiation Technology (KVI-CART) is to perform basic research on subatomic and astroparticle physics and application-driven research on accelerator physics and physics in medicine. They work, in close collaboration with the scientific community, healthcare and industry, on long-term solutions for science and society. Through the development of state-of-the-art detection techniques, KVI-CART fosters the cross-fertilisation between basic and application-driven research. KVI-CART educates young researchers in physics and medical technology at BSc, MSc and PhD level.
KVI-CART is a centre of the University of Groningen performing basic research on subatomic and astroparticle physics and application-driven research on accelerator physics and physics in medicine. Along this two different lines they develop together advanced detection system and detection technologies which can be applied in science and society.
KVI-Centre for Advanced Radiation Technology (KVI-CART) and UMCG, together with several other parties, have established the PARticle Therapy REsearch Center (PARTREC), a research collaboration with a broad research programme aiming to further improve the quality of proton therapy treatment. In the framework of PARTREC, KVI-CART has a physics research programme that focuses on the following topics:

- Combining advanced X-ray imaging techniques with proton imaging to reduce the uncertainty in the stopping power predictions to below 1%
- Methods for in-vivo verification of the irradiation by imaging the very weak secondary radiation produced by the interaction of the protons and helium ions with tissue
- A standard for dosimetry in proton therapy that will ensure that treatments in all treatment centres can be compared

In addition, they facilitate the research programme of the UMCG Radiation Biology group on biological damage in healthy tissues induced by irradiations with protons and carbon ions.
The largest share in the field of areas and time (in hours) of the beam usage in reference partnership with industry concerns applications for the ion beam analysis. Secondly, it concerns detector development. The greatest usage of beam has materials research, irradiation and radiocarbon dating.

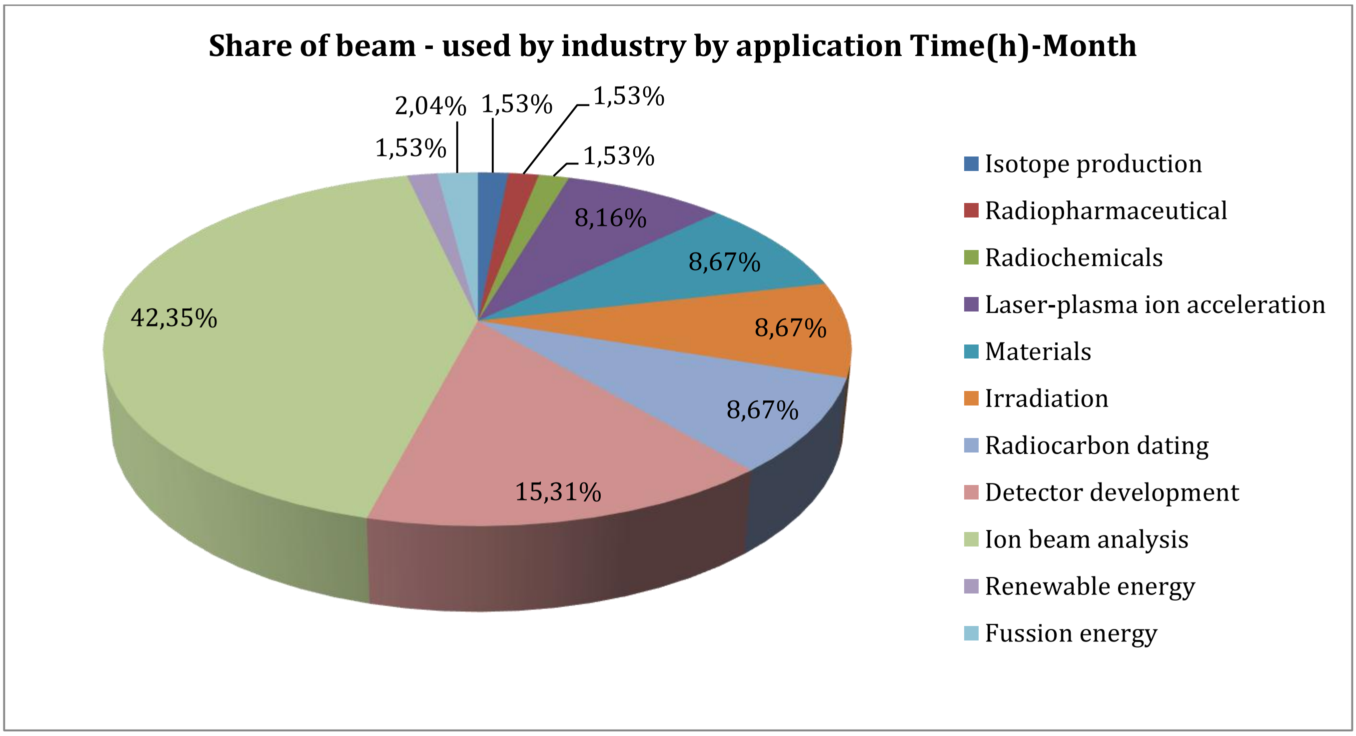


Figure 15: Share of beam – used by industry by application Time (h) – Month.
Source: Created by NUPIA

Co-financed by public funds

To the question, "Please give an estimated number of projects financed or co-financed by public funds and which are aimed at supporting innovations", 16 laboratories answered. In terms of the number of projects financed or co-financed by public funds supported innovation, the leaders include laboratories such as CIEMAT - 30 projects, KVI-CART – 10 projects, GSI-9 projects, IFJ-PAN-6 projects, ARRONAX – 5 projects.

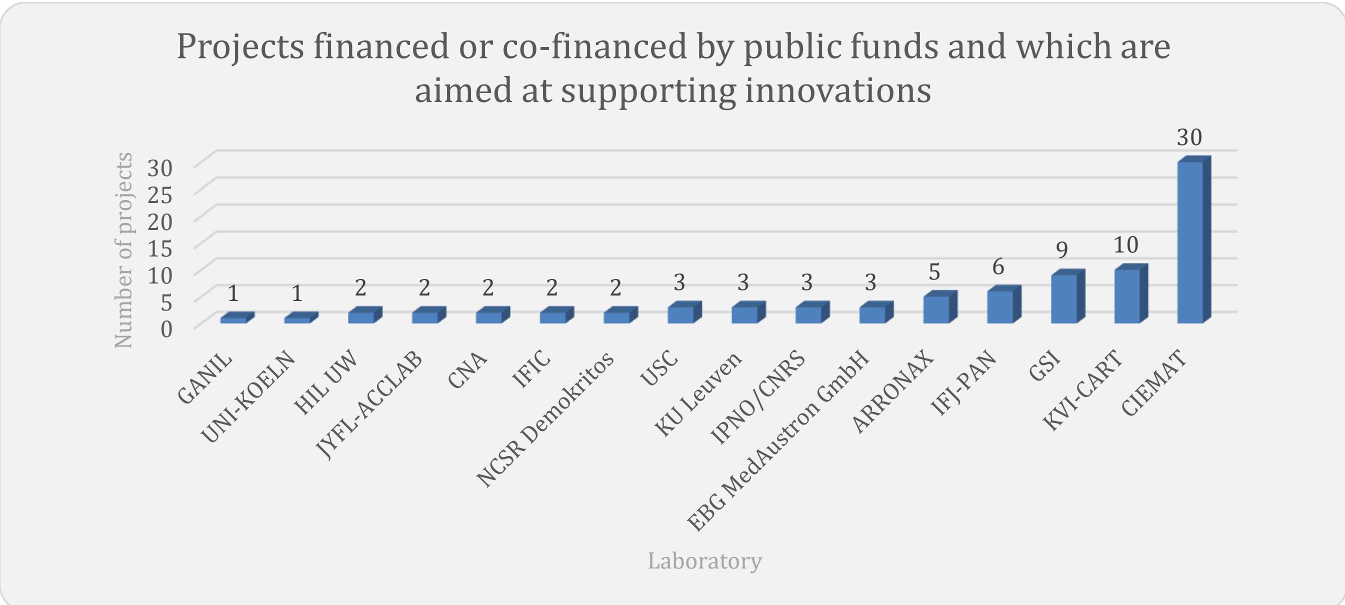


Figure 16: Projects financed or co-financed by public funds that are aimed at supporting innovations.
Source: Created by NUPIA

Eighty-four projects were obtained from 16 laboratories. The picture below shows the participation of individual laboratories in obtaining public funds for innovative projects.

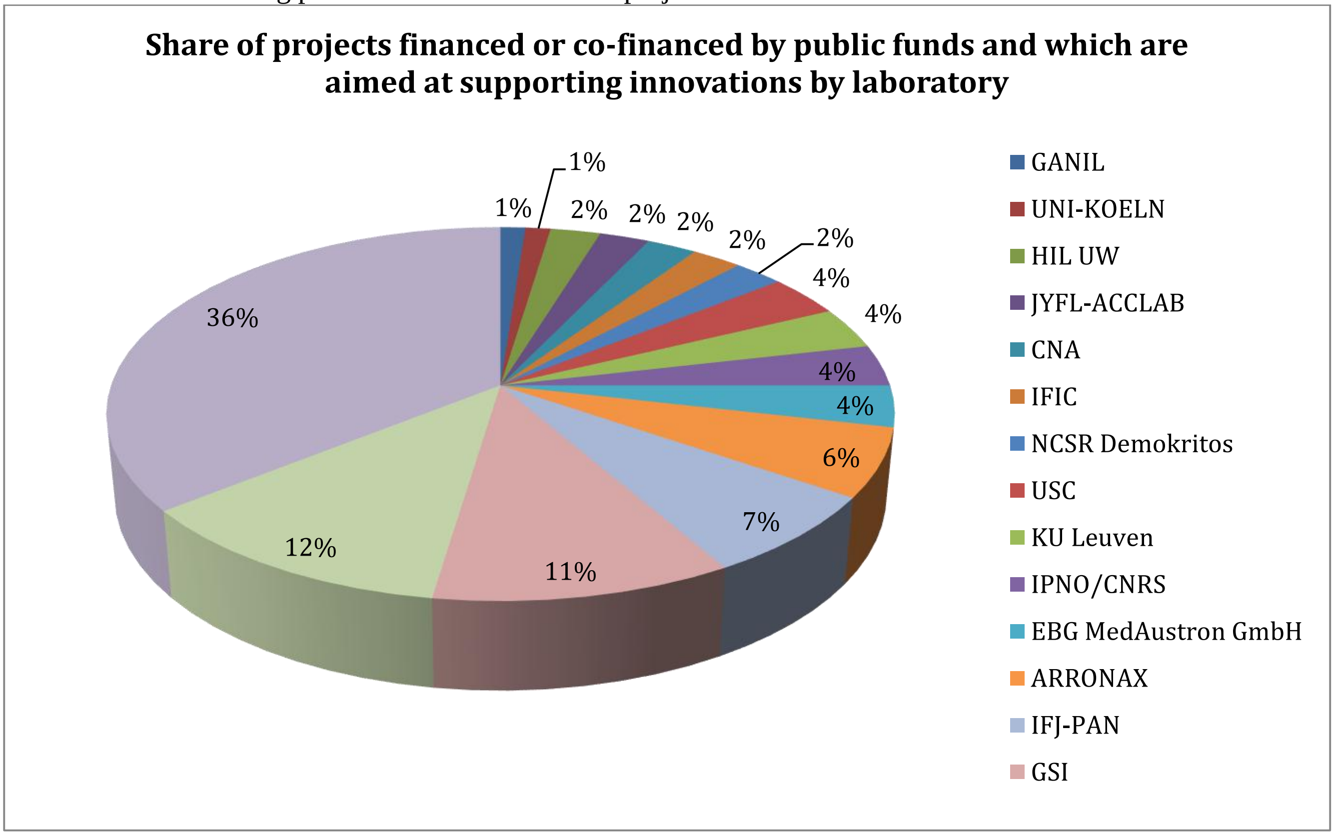


Figure 16: Projects financed or co-financed by public funds that are aimed at supporting innovations.
Source: Created by NUPIA

IFJ-PAN has a significant share in the acquisition of public funds for research into innovative technologies among the leaders. The scope of activities of this centre is presented below.

The Institute is currently the largest research institute of the Polish Academy of Sciences. The Minister of Science and Higher Education in Poland has granted the Institute the prestigious status of the Leading National Research Centre (KNOW) in physics for the years 2012-2017 (together with the other members of the Marian Smoluchowski Kraków Research Consortium: "Matter-Energy-Future"). Furthermore, the Institute was awarded twice, in 2013 and in 2017, the A+ Category (leading level in Poland) in science and engineering. In 2017, the European Commission granted the Institute of Nuclear Physics Polish Academy of Sciences the HR Excellence in Research award.
The IFJ PAN has wide scope of interests including theoretical and experimental research in the following fields:

- particle physics and astrophysics
- nuclear and strong interaction physics
- condensed matter physics (including nano-materials)
- interdisciplinary and applied research, which involves applications of physics in medicine, biology, dosimetry, environmental protection, nuclear geophysics, radiochemistry, high-temperature plasma diagnostics, the study of complex systems, such as the human brain, financial market or linguistics

The key activity of the Institute is participation in large-scale experiments carried out through global research collaborations. IFJ-PAN physicists actively participate in three major experiments (ALICE, ATLAS, LHCb) at the Large Hadron Collider (LHC) of CERN, Geneva, as well as in the following projects: European Laser on Free Electrons (E-XFEL, DESY, Hamburg), Large Hadron Collider (LHC, CERN, Geneva), European Spallation Source (ESS, Lund, Sweden), Système de Production d'Ions Radioactifs Accélérés en Ligne (SPIRAL2, GANIL, Caen, France), Facility for Antiproton and Ion Research (FAIR , Darmstadt), Cherenkov Telescope Array (CTA), Pierre Auger Observatory (Argentina), High Resolution Neutron Spectrometer (HNRS), Belle2 experiment (KEK, Tsukuba, Japan).

The “National Centre for Hadron Radiotherapy-Cyclotron Centre Bronowice,” funded by the European Innovative Economy Operational Programme, is a flagship project of the Institute. The Cyclotron Centre Bronowice (CCB) is an infrastructure unique in Central Europe, serving as a clinical and research centre in the area of medical and nuclear physics. Since 2013, the Proteus C-235 cyclotron of the Centre has been delivering beams of protons with energies in the range of 70-230 MeV. With two experimental halls and three treatment rooms, since 2016 serviced by two rotating gantries with Pencil Scanning Beam as well as a horizontal line for eye treatment, CCB is a modern clinical centre for the treatment of cancer patients.

Applied and interdisciplinary physics research is also an important activity at CCB. It is carried out in the area of radiotherapy and radiobiology. Research in the field of clinical medicine is another line of activity at CCB. It aims at performing trials, which show the clinical efficacy of the state-of-the-art scanned proton beam technique in the treatment of selected tumours.

Areas of projects with supporting innovation components

To the question "Please list three areas of projects with supporting innovations component" answered 18 laboratories. Every laboratory indicates different areas of projects. The table below show the scope of areas of innovation projects.

Areas	
Radioprotection	Radiobiology
Isotope production	Monte-Carlo simulation
Radiochemistry	Detectors
Laser-plasma ion acceleration	Cyber security
Micro-dosimetry	Neuroimaging analysis
Nuclear Instrumentation	Medical physics
Nuclear safety	Beam diagnostics
Nuclear Fission	Informatics and biotechnology
Nuclear Fusion	Radiobiology
Renewable energies and environment	Monte-Carlo simulation
Material sciences	

Table 1: Projects with supporting innovations component
Source: Created by NUPIA

Ph.D. theses co-financed by industry

To the question, “Please give an estimated number of Ph.D. theses co-financed by industry”, 8 laboratories answered. In terms of the number of projects, CIEMAT is the leader in this activity – 8 Ph.D. theses co-financed by industry. Second is Arronax – 3 theses co-financed by industry. GSI is in third place with 2 theses co-financed by industry.
The laboratories indicated the following Ph.D.-thesis areas co-financed by industry: high-repetition rate targets for laser-plasma ion acceleration, micro dosimetry, nuclear instrumentation, nuclear safety, nuclear fission, nuclear fusion, renewable energies, material sciences, radiobiology.

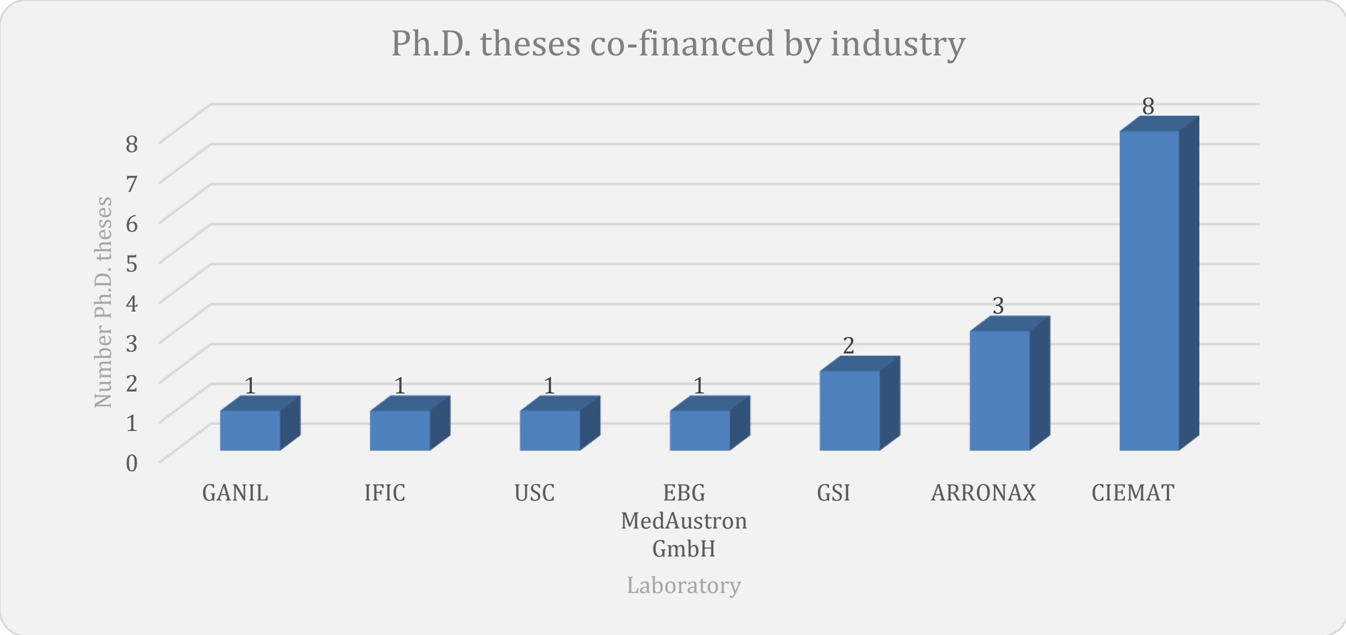
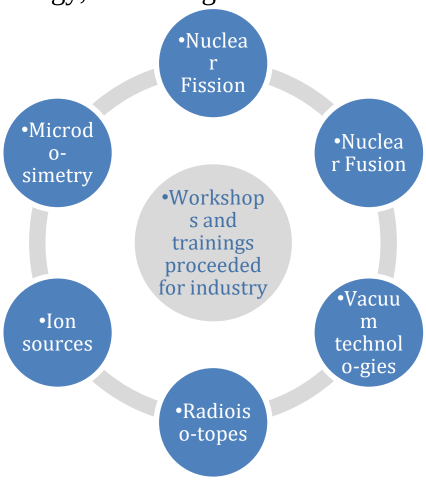


Figure 17: Ph.D. theses co-financed by industry.
Source: Created by NUPIA

Workshops and trainings proceeded for industry

To the question, "Please give an estimated number of workshops and trainings proceeded for industry**",** 12 laboratories answered. They proceeded 54 workshop and trainings. Every laboratory indicates different areas of workshop and trainings. The laboratories indicated the following areas of workshop and trainings for industry: Control systems, ion sources, mechanical manufacturing, vacuum technology, radioisotopes, accelerator physics, accelerator usage, micro dosimetry, surface treatments, coating (PVD), materials, HPGe detectors with highly segmented contacts, nuclear Fission, nuclear fusion, renewable energies, training for radiation environment, ion beam analysis for ALD community, nanotechnology, beam diagnostic.



ENSAR2 – INNOVATION ACTIVITIES

MediNet: Medical Network

The MediNet networking activity within ENSAR2 is dedicated to strengthen the application of nuclear-physics related knowledge, technology and expertise to advance tumour treatment and thus to address one of the questions of highest societal relevance. The optimisation of radiation therapy in general and particle therapy in particular requires research on a variety of topics such as beam delivery optimisation, in-vivo monitoring of the delivered dose, dosimetry, radiobiology and radiation quality. Expertise in nuclear techniques for the detection and characterisation of charged particles and photons is crucial to each of these objectives. Large efforts are therefore devoted to the development of innovative detector technologies and modelling in several European research groups, focusing on both clinical and pre-clinical applications of particle therapy. MediNet is providing a platform to bring together these experts for exchange of existing and development of new ideas, as well providing a training opportunity for young researchers. Current research performed in the MediNet Networking Initiative in the field of nuclear imaging is oriented to-ward TOF-PET, multimodal imaging and innovative SPECT with Compton cameras. TOF-PET is already commercialised by major imaging companies. However, there is still a gap between available time resolutions (400-600 ps) and resolutions of less than 100 ps that would be necessary to reach ~1 cm accuracy along a LOR, and thus almost suppress the reconstruction phase of an image. Such resolution may be achieved with very fast scintillators and electronic readout, or with non-scintillating materials such as resistive plate chambers. A competing alternative to TOF-PET is the use of three-photon decays that are available for some particular iso-topes such as 44Sc, a β+ and γ emitter. The combination (or integration) of a SPECT with a PET detection device reduces the LOR to a single point, which makes reconstruction useless. Several devices are under construction that may lead to such a multi-modality. Compton cameras that were primarily dedicated for online control of particle therapy may be used for SPECT, opening the way to high-energy γ imaging [11,16].

Since 20 years ago, PET-CT and SPECT-CT have replaced the single PET or SPECT clinical systems, as the high spatial resolution of X-ray CT images increased several folds the diagnostic capabilities of PET and SPECT images. However, the better contrast in soft tissue and the huge versatility is increasing the interest in combining Magnetic Resonance Imaging (MRI) with PET or SPECT. However, MRI requires large magnetic fields, which are totally incompatible with the old-fashioned photomultiplier vacuum tubes (PMT) employed in traditional PET and SPECT systems. While solid-state detectors, such as avalanche photodiodes (APDs) have been at play for decades, these have proven unreliable and difficult to incorporate into stable designs (however, a few commercial systems based on APDs are available). However, a newcomer, the Silicon Photomultiplier (SiPM), being marketed regularly less than 10 years ago, is now widely used. They are also solid state detectors, small and less power consuming than PMTs, insensitive to magnetic fields and conventional or digital SiPM [Dam 2013, Schaart 2016] are much easier to use than APDs. The available systems seem to be changing overnight thanks to APDs and SiPMs, and new combined PET/MRI or PET/SPECT systems, as well as PET inserts for MRI scanners, are being announced several times per year [10][15].
In the X-ray CT arena, the quest towards multi-energy spectral CT, high quality low-dose imaging is progressing with giant steps. LaBr3 CT systems are being commercialised, offering faster imaging with reduced dose. Indeed, the combination of new scintillators or solid-state detectors with powerful tomographic image reconstruction methods is enabling ultra-low-dose, high-quality CT images as well as enhancing the contrast in soft tissues. Moreover, CT scanners using photons of different energies, and/or detectors with spectral (i.e., the ability of dis-entangling the energy of the X rays detected) capabilities are under heavy research.

The limited scope of this overview does not allow for covering in detail also the new generation of silicon-based, high-resolution charged particle and/or photon detectors (like MediPIX and its derivatives). These chips are directly derived from the ones developed to satisfy the needs of high energy and nuclear physics experiments, yet hold the potential to change the way nuclear imaging is performed [11,16].

Below are presented some examples of innovation activities chosen participants of MediNet:

Universidad Complutense de Madrid (UCM, Spain):

1) Monte Carlo and hybrid algorithm for phase space generation and fast dose calculations for Intrabeam IORT,

electron IORT and high rate brachytherapy.

Status: Licensed to GMV (multinational company). Working on extensions to different devices.

2) Prompt gamma ray / in beam PET monitor for range verification in proton therapy.

Status: drafting agreements with the future proton-therapy centres in Madrid.

3) Preclinical PET detectors, DAQ system and reconstruction software.

Status: Licensed to SMI, present in scanners all over the world.

Working on the extension to real time PET imaging and motion correction.

IPN Lyon/ LPSC Grenoble (France):

The French collaboration, gathering labs from Lyon, Grenoble, and the Centre Antoine Lacassagne in Nice, developed a method for online control of proton therapy, called prompt-gamma peak integral (PGPI). The basic idea is that the total number of prompt gamma photons issued from the patient, and detected at a given position, depends on the total energy deposited in the patient, and on the relative positions of the beam and the detector. A set of detectors located at different positions may enable to detect beam position and beam range variations. In comparison with prompt-gamma imaging devices, this method is quite simple and affordable. A French patent has been submitted in 2016.

The principles and the first results of feasibility studies have been published and presented in various international conferences. Presently the academic partners are searching for an industrial partner for clinical valorisation.

IFIC (CSIC-UVEG), Valencia (Spain): (G. Llosá, J.F. Oliver, A. Ros et al.)

The IRIS group at IFIC Valencia is developing a three-layer Compton telescope (CT) for treatment monitoring in ion beam therapy. The system is composed of three LaBr3 scintillation detector planes coupled to SiPM arrays. (Conventional) two-layer Compton cameras can be employed when the photon energy is known or when it is low, so that the second detector can fully absorb the photons. Since this is not the case in this application, a three-layer version is an interesting option, given that three distinguishable interactions in known order allow the photon energy to be determined. However, this comes at the price of a much lower efficiency than the double-interaction solution. The aim of the IRIS group at Valencia is to combine two- and three-interaction events and to estimate the initial photon energy through the data analysis process in the two-interaction case. LaBr3 crystals have a high Compton scattering probability and a good energy resolution, and their operation coupled to silicon photomultipliers (SiPMs) results in a simple and compact device, well adapted to a clinical environment.

The first prototype of MACACO (Medical Applications CompAct COmpton camera) was fully characterised in the laboratory and during in beam tests demonstrating the feasibility of the proposed technology and identifying the main limitations [Munoz 2017, Munoz 2018, Solevi 2018]. A second prototype, MACACO II, is currently under development to improve performance. The first step has been the replacement of the SiPM arrays employed as photodetectors by newer versions with better performance, with the aim of improving the detector energy resolution. New LaBr3 crystals have been acquired, matching the size of a single SiPM array with 8x8 pixel elements instead of the four arrays per detector previously employed. The external dimensions of the device are 25.8x25.8 mm2. Each of the 64 pixels of the SiPM array is 3x3 mm2 in size [11,16].

OncoRay (Dresden, Germany): (G. Pausch et al.)

The In-vivo Dosimetry group at OncoRay in Dresden (Germany) has intensely dealt with the problem of in-vivo range verification in proton therapy. The latter has become a widely accepted and promising option for tumour treatments complementing conventional radiotherapy. The finite range of protons in tissue with a final dose maximum (Bragg peak) followed by a sharp distal dose fall-off allows focusing the dose in the tumour, while minimising the damage of surrounding normal tissue. The proton range is, however, sensitive to factors that are hard to assess in clinical routine. This constrains the potential benefit of a proton treatment over conventional therapies performed with megavolt X-rays and electrons. Reducing proton range uncertainties would improve the precision and lower the normal-tissue toxicity of proton therapy. Therefore, research groups all over the world have tried to develop clinically applicable instruments for measuring the proton range just during dose delivery, ideally with a precision of one or two millimetres. Prompt gamma rays are generally considered the most appropriate probe. This hard radiation is produced in nuclear reactions by beam particles hitting atomic nuclei of the penetrated tissue [11,16].

In this context, OncoRay has dealt with nuclear instrumentation for in-vivo range verification and other medical applications.
Reverting the original flow of technology transfer from basic nuclear physics to applications in the medical field, nowadays the activities of many nuclear physics groups are receiving a boost thanks to the need to evolve nuclear imaging detectors. Multi-national nuclear physics experiments make it possible to train and shape the best technicians, PhD students, researchers and other experts in technology for nuclear detection. Nuclear physics groups are increasingly aware (although this should be promoted and stimulated) that their work in radiation detector development, simulations, signal processing electronics, and data processing, may enable important new possibilities in nuclear medicine and particle therapy-related imaging. The activities in these two fields are complementary and synergetic. On the one hand, the existing dedicated equipment at nuclear detector laboratories, as well as the related manpower in academia, associated with nuclear physics groups working in international collaborations on nuclear detectors, outnumber by far the very few instrumentation development groups existing in medical schools. Not even the largest hospitals can afford dedicated laboratories for radiation detection and electronics development. While the synergies between the nuclear physics and medical field are outstanding, academia still needs an incentive, and specific combined training programmes are still scarce, giving even more emphasis to initiatives like the MediNet network that brings together groups from both fields, united by their interest in developing state-of-the-art detection tools for medical applications.
As of today, the never-ending development of nuclear application in the medical field is offering more and more opportunities either in diagnosis or treatment or both (Theranostics). From the technological perspective, mod-ern micro-dosimeters and nano-dosimeters allow for the measuring of dose and specifying radiation quality in a very small volume with online measurements. Moreover, modern diagnostic techniques such as Positron Emission Tomography (PET) and Magnetic Resonance Imaging (MRI) allow acquiring physiological features in-vivo and in real time. These data are ideal to develop mathematical models of physiological processes because they are direct measurement of the process in-vivo and not a reproduction in-vitro. More specifically, the same approach can be used to monitor the efficacy of the radiation-therapy treatment, where the model to study is the regression of tumour tissue [11,16].
Combining the microscopic results from the in-vivo micro-dosimetry together with the imaging readout from PET and MRI, it is possible in principle to define the efficacy of the treatment and minimise the damage to the healthy tissue at a microscopic level for each patient. These concepts are beyond the standard approach in clinical routine, but they can be easily translated from the research environment to clinics in a reasonable period.
Commercialisation and standardisation of key technologies, via a fruitful cooperation between academia and industry, play a key role in the process of advancing the impact of physical concepts in the medical field.
This approach makes possible the translation from conceptual physics studies into mature industrial products in the fields of accelerators, detectors and electronics components, accompanied by suitable computational tools, via a fruitful cooperation between academia and industry play a key role in the process of advancing the impact of physical concepts in the medical field and ultimately to the society.
Along with the continuously softening borderline between pure and applied physical sciences, an interdisciplinary cooperation between medical doctors and medical physicists in clinical practice is developing. This is assisted by professional networks like the Particle-Therapy Cooperation Group (PTCOG) in the worldwide growing field of hadron therapy, national and international professional societies of medical physicists or last but not least networking activities like the MediNet network within the European ENSAR2 Integrating Initiative, bringing together research physicists, medical physics practitioners at clinical centres[11][16].

MIDAS: MInimisation of Destructive plASma processes in ECR ion source Network

MIDAS-NA brings together the participant research teams developing ion sources and beams for the needs of ENSAR2 facilities, and industrial partners (AVS and PANTECHNIK) having wide technological know-how. The transfer and dissemination of knowhow will ensure that the latest results are available for all infrastructures participating in MIDAS-NA and for social and economy application.

The results of the research were used in the PANTECHNIK Company for which Electron Cyclotron Resonance Ion Sources is most important products. This is the one of the good cases of cooperation between WP and external company [7].

ECR ion sources are reliable and virtually chemical independent, producing beams of all elements with upmost ionisation efficiencies. The use of electron cyclotron resonance (ECR) ion sources for the production of intense beams of highly charged ions has immensely grown over the last decade. ECR ion sources are used as injectors into linear accelerators, Van-de-Graaff generators or cyclotrons in nuclear and elementary particle physics. In atomic and surface physics, ECR ion sources deliver intense beams of highly charged ions for collision experiments or for the investigation of surfaces.

One main advantage of this kind of ion source is that principally ions of all elements can be produced. Furthermore, there are practically no wearing parts, like filaments, in the ion source. Therefore, stable ion beams can be realised for long periods (days - weeks) limited only by the material consumption of the used element. In the case of metals which are fed into the source as wires, where atoms are sputtered into the plasma, or which are evaporated from an oven, the material has to be replaced after a certain time.

ECR ion sources work at a relatively low gas pressure and have a high ionisation efficiency of the plasma. Therefore, they are well suited for the production of ion beams of radioactive, rare or very expensive elements.

Since the first ECR ion source has been reported in 1975 (Richard Geller, CEA Grenoble), there has been a rapid improvement of the performance concerning the achievable charge states as well as their intensity. There are two main directions of development.

On the one hand, higher and higher intensities of higher and higher charges states are produced for atomic physics collision experiments, which have not been feasible so far. Empirical scaling laws show that the maximum achievable charge state as well as the intensity grow with increasing microwave frequency. However, the necessary magnetic fields have to be increased simultaneously to fulfil the resonance conditions and to have a good confinement. Therefore, at a microwave frequency of 18 GHz there is a limit for the use of conventional solenoids and multipole structures made of permanent magnets. To go to higher frequencies, several projects have been started which use super-conducting structures. At a given microwave frequency, the performance can be improved by a better magnetic confinement or through the increase of the electron density in the plasma (e.g., electron gun, biased disk). These "conventional" ECR ion sources, however, are relatively large (typical dimension: 80 cm long, 60 cm diameter), have a high electrical power consumption of about 100 kW and are expensive.

For certain applications, like the use on high-voltage terminals, Van-de-Graaff generators or microtrons, where there is usually only limited space and electrical power available, these ion sources are not well suited. This is the second direction in the development of ECR ion sources.

The use of modern permanent magnet materials allows the replacement of the solenoids for the axial confinement by structures made of permanent magnets only. Furthermore, these ion sources can be miniaturised and microwave frequencies of 14 GHz have been realised already. This kind of ion source does not have the same performance as the "conventional" type. On the other hand, they are small, have a low electrical power consumption of a few 100 W and they are relatively cheap [12].

PASPAG: Phoswich scintillator assemblies: Application to the Simultaneous detection of Particle and Gamma radiation

PASPAG do R&D for the simultaneous detection of gamma rays and particles using scintillators. PASPAG will develop detection systems for applications within medical & homeland security. Further, this activity might lead to industrial or medical applications that can take advantage of advanced nuclear imaging technologies.

PASPAG aims for Simultaneous detection of Gamma and Particle Radiation by the use of new scintillator materials combined with the phoswich technique. Digital electronic and DAQ with improved throughput and more effective storage will be developed. R&D on new Secondary Electron Emission (SEE) materials will be performed in order to develop thin detectors for Low-Energy beam. The JRA aims for cost effective, reduced systems in size and complexity that can be used at several facilities.

The research groups involved in PASPAG have a consolidated experience in detector design and R&D activity in scintillator detectors. Their joint efforts in the accurate test of new scintillator materials will provide the basis of know-how and knowledge for the design of future detector arrays. All these brand new scintillator detectors need an intense R&D activity to be fully understood and characterised. In fact, in one or two years the very first 'large' volume CLYC or CLLB or co-doped detectors will be available. In addition, all these high light yield crystals could potentially provide good position sensitivity within continuous crystals (as LaBr3:Ce). This feature could be used to reduce the Doppler Broadening effect in basic research and be extremely useful in several fields of applications as for example in homeland security, medical imaging or radiotherapy. A consolidated knowledge of detector materials and detection techniques in European laboratories and Universities is the basis for the usage and the dissemination of such technologies.

Scintillators, particularly novel scintillators with improved energy resolution, coupled to silicon photomultipliers may provide a route forward for realising these goals. Timing resolutions better than 1 ns for silicon photomultipliers such as those produced by SensL now mean that this technology is fully relevant to PET imaging. In particular, the insensitivity to magnetic fields can be relevant for further applications in nuclear medicine. Applications are also foreseen, and have already begun to be exploited, in the area of homeland security where illicit movement of fissile material and dirty bombs are of particular concern, which can be addressed only in a common European effort. This can range from large portal monitors where He-3 replacement is a priority, to hand-held gamma-ray spectrometers. There is also a significant market for the latter in the aftermath of the Fukushima incident. Another potential market is the oil and gas sector. In well logging, novel scintillators with improved energy resolution such as cerium bromide may be used to capture details on strata more rapidly, and scintillator materials such as CLYC offer the potential for discriminating gamma rays from thermal neutrons in these applications. Advances in signal processing and digital electronics offer considerable scope for development and improvements for many of the application fields identified above. Greater sensitivity can be envisaged in radionuclide identification and characterisation. The availability of ASICs and other highly-integrated digital electronics, an area in which nuclear physics excels, are widely applicable to applications work. Modern filter algorithms like Kalman or moving window de-convolutions allow here for a simple control by parameter settings to provide an unprecedented flexibility in the different fields of applications. This would allow for a variable scaling in such system useful in small lab applications as well as in large-scale detector arrays. An area of application that should not be neglected is that to other areas of basic science. Here, there is strong potential for knowledge exchange and combined efforts. For example, gamma-ray astronomy was the initial driver of novel scintillator technology such as lanthanum bromide [15].

INTERMEDIATE CONCLUSIONS ON SURVEY OF INNOVATION

Survey on innovativeness of ENSAR2 laboratories leads to the following conclusions:

- Laboratories participating in the project as a consolidated network ENSAR2 have significant innovation potential on a European scale. The mere fact of cooperation of laboratories from various EU countries in the field of nuclear physics research is proof that this is the right direction from the point of view of innovative processes on an EU scale. Research on the innovativeness of the ENSAR2 network laboratories indicates that, in addition to the research network that works in practice, actions are needed to create the PAN-European platform in the field of nuclear physics based on laboratories and enterprises. At the same time, there is huge potential for commercialisation of innovation through small and medium enterprises. The concept of start-ups is particularly interesting here. Survey shows that in many laboratories, such have been created and function efficiently in a market economy. We believe that this is a good direction. Of course, large companies will continue to be an important recipient of innovation in nuclear physics. We mean large companies from such industries as medicine, pharmacy, aerospace, energy and defence.
- Medicine and pharmacy are a leading research field for applications of nuclear physics research results. We believe that this is the right direction conditioned by the real needs of an aging society across the European Union
- Aerospace industry is another important field in the area of nuclear physics applications. Important here are both research related to the impact of cosmic rays on space vehicles, e.g. satellites but also airplanes. In this aspect, research related to the operation of electro-electric components is important, but also research on the impact on living matter. Research to develop isotope generators for satellites and space vehicles is another important research innovation patch. In future European laboratories with ESA should take effort at research of nuclear propulsion to space vehicles.
- Nuclear physics research creates a large area for innovation in the field of materials engineering such as structural strength as well as machinery and mechanical devices. In this filed, there exists a huge area for research and development cooperation with industry.

INNOVATION MODEL OF COOPERATION BETWEEN LABORATORIES AND INDUSTRY

In reference to those indicated industry we propose models of cooperation between and transfer innovative technologies between laboratories and business partners. The success of partnership between scientific organisations and industry depend on the degree of openness to cooperation based on the transfer of knowledge and technology. Proposed model of cooperation is based on the concept of an open innovation model.
Open innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology. However, many enterprises and research centres are still working according to the closed innovation model. The logic behind is that informed closed innovation thinking was an internally focused logic. This logic was not necessarily written down in any single place, but it was tacitly held to be self-evident as the “right way” to innovate [6].

Here are some of the implicit rules of closed innovation:

- We should hire the best and the brightest people, so that the smartest people in our organisation work for us.
- In order to bring new solutions and technologies to the market, we must discover and develop these ourselves.
- If we discover it ourselves, we will get it to market first.
- The organisation that gets an innovation to the market first will usually win.
- If we lead the industry in making investment in research and development (R&D), we will discover the best and the most ideas and will come to lead the market as well.
- We should control our intellectual property, so that our competitors do not profit from our ideas.

The logic of closed innovation created a virtuous circle; see Figure 18. Organisation invested in internal R&D, which led to many breakthrough discoveries. These discoveries enabled the organisation to bring new products, solutions, services to the market, to realise more sales and higher margins because of these products, and then to reinvest in more internal R&D, which led to further breakthroughs. Furthermore, because the intellectual property (IP) that arises from this internal R&D is closely guarded, others could not exploit these ideas for their own profit. For most of the twentieth century, this paradigm worked, and worked well. Moreover, many government institutions created *ad hoc* central research laboratories to make projects based on this paradigm [2].

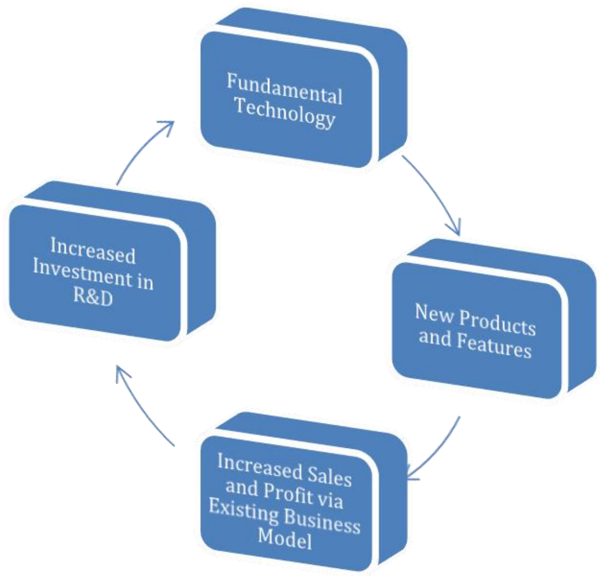


Figure 18. The Virtuous Circle.
Source: Chesbrough H.: Open Innovation. The new imperative for creating and profiting from technology. Harvard Business School Press, Boston, 2003[2].

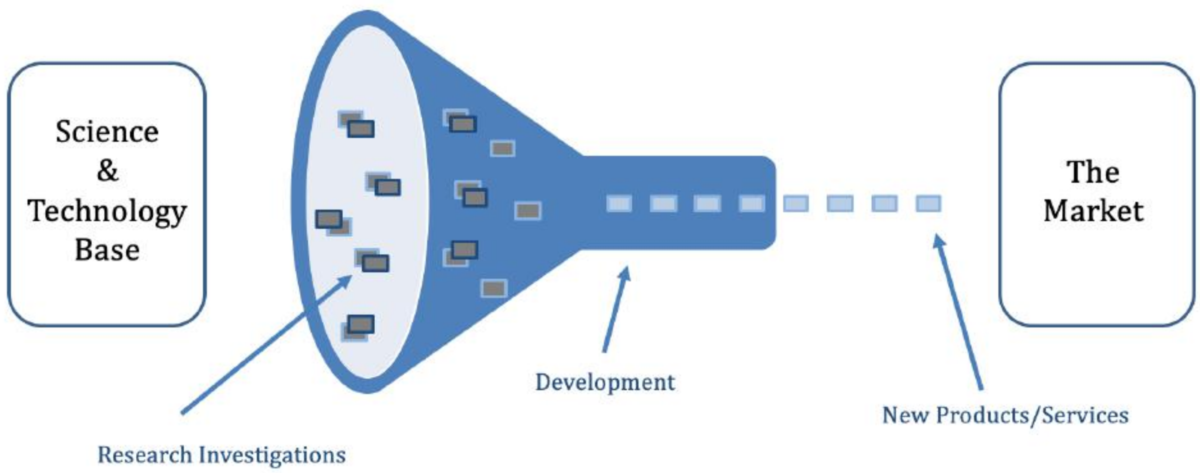


Figure 19. The closed paradigm for managing industrial R&D.
Source: Chesbrough H.: Open Innovation and Open Business Models: A new approach to industrial innovation. Presentation to Joint OECD/Dutch Ministry of Economic Affairs. Conference on “Globalisation and open innovation” December 2006 [1].

Figure 19 depicts this Closed Innovation paradigm for managing R&D. The yellow solid lines show the boundary of the organisation. Ideas flow into the organisation on the left and flow out to the market on the right. They are screened and filtered during the research process, and the surviving ideas are transferred into development and then to market. The linkage between research and development is tightly coupled and internally focused. Our extant theories of managing R&D are built on this conception. Examples of this thinking are the stage gate process, the chain link model, and the product development funnel or pipeline found in many cases on managing R&D. Projects enter on the left at the beginning, and proceed within the organisation until they are shipped to customers on the right of the

figure. The process is designed to weed out false positives, i.e. projects that look initially appealing, but later turn out to be disappointing. The surviving projects, having survived a series of internal screens, hopefully have a greater chance of success in the market [2].
The factors, like the growing mobility of highly experienced and skilled people, growing new firms that commercialised external research, products life cycle, adoption of innovation, new standards in managing of innovation projects, managing of risk investment of innovation projects and managing of IP, have influence for erosion of closed innovation. When fundamental technology breakthroughs occurred, the scientists and engineers who made these breakthroughs were aware of an outside option that they formerly lacked.
In situations, in which these erosion factors have taken root, closed innovation is no longer sustainable. For these new situations, a new approach, open innovation, is emerging in place of closed innovation. Open innovation is the paradigm that assumes that organisations can and should use external ideas as well as internal ideas, and internal and external paths to market, as the organisations look to advance their technology. Open innovation combines internal and external ideas into architectures and systems whose requirements are defined by a business model. This model utilises both external and internal ideas to create value, while defining internal mechanisms to claim some portion of that value. Open innovation assumes that internal ideas can also be taken to market through external channels, outside the current businesses of the organisation, to generate additional value [2].

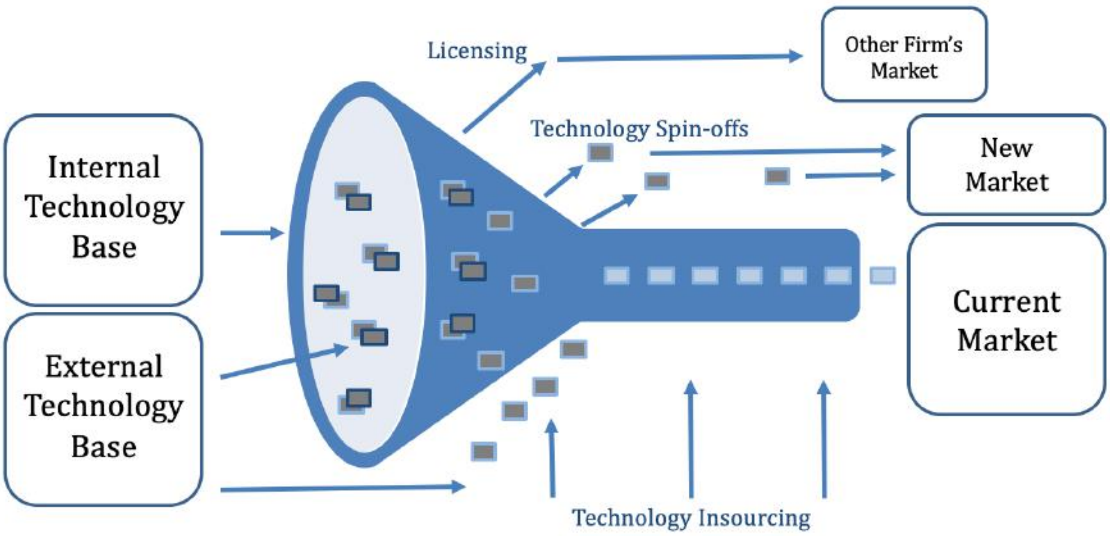


Figure 20. The open innovation paradigm for managing industrial R&D.
Source: Chesbrough H.: Open Innovation and Open Business Models: A new approach to industrial innovation. Presentation to Joint OECD/Dutch Ministry of Economic Affairs. Conference on "Globalisation and open innovation" December 2006 [1].

In Figure 20, ideas can still originate from inside the organisation's research process, but some of those ideas may seep out of the firm, either in the research stage or later in the development stage. A leading vehicle for this leakage is a start-up company, often staffed with some of the organisation's own personnel. Other leakage mechanisms include external licensing and departing employees. Ideas can also start outside the organisation's own labs and can move inside. As Figure 22 shows, there are a great many potential ideas outside the organisation. In the figure of the closed model, the solid lines of the funnel represented the boundary of the organisation. In the figure of the open model, the same lines reflect the more porous boundary of the organisation, the interface between what is done inside the organisation and what is accessed from outside the organisation.
Although the open innovation process still weeds out false positives (now from external as well as internal sources), it also enables the recovery of false negatives, that is, projects that initially seem almost worthless, but turn out to be surprisingly valuable. Often these projects find value in new markets, rather than in the current markets, or they may be worthwhile if they can be combined with other projects. These opportunities were frequently overlooked by the earlier closed innovation process.
At root, the logic of open innovation is based on a landscape of abundant knowledge, which must be used readily if it is to provide value to the organisation that created it. The knowledge that a company uncovers in its research cannot

be restricted to its internal pathways to market. Similarly, its internal pathways to market cannot necessarily be restricted to using the company's internal knowledge. This perspective suggests some very different organising principles for research and for innovation.

In contrast to closed innovation, the open innovation shows new paradigm and logic (see also Table 2):

- Not all the smart people work for us. We need to work with smart people inside and outside our organisation.
- External R&D can create significant value; internal R&D is needed to claim some portion of that value.
- We do not have to originate the research to profit from it.
- Building a better organisation model is better than getting to market first.
- If we make the best use of internal and external ideas, we will win.
- Good ideas are widely distributed today. No one has a monopoly on useful knowledge anymore.
- Innovation is now done within networks of firms, rather than within a single firm.
- We should profit from other's use of our IP, and we should buy others' IP whenever it advances our own organisation model [2].

Closed innovation	Open innovation
- Exclusive use of internal R&D - Technology invented, protected, developed, brought to the market and distributed by the same company - Full internal control of the innovation – from R to D to C - Technology exploited only through internal business model - IP generators of new technologies – mainly Companies - Companies usually selling but not buying IPRs (advantage – no confusion about IP ownership) - IP valuation method – Discounted Cash Flow – "Net Present Value" of the technology - Lack of IP market	- Use of internal and external R&D and inventions – corresponding to the particular business models - Openness to external business models - Variety of IP generators and collaborators – other companies, public universities and R&D institutions, users, customers, suppliers… - Active IP asset management of the companies' IP portfolio – matching technologies with innovative (inside or external) business models to add value to IP - More proactive assertion of IP policy - Development of Intermediate IP Markets –semiconductors, biotechnology, chemicals and other - Use of more complex IP valuation methods – such as "Real Option" – imposed by very intensive and diversified IP commercialisation models – reassignment of the IP to different partners during its legal life, selling/buying, licensing (to companies or start-ups) - IP an asset which can (and should) be managed through an adequate business model in order to increase value and become a reliable source of revenue.

Table 2. The comparison of close and open innovation model on the IP level.
Source: Spasic O.: Business Model of Innovation – "Closed Innovation" and "Open Innovation". National workshop on innovation promotion and technology transfer", Belgrade, June 2011 [14].

Plan for Transfer Technology strategy at Research Laboratories

A generalised tech-transfer strategy development plan for laboratories from ENSAR2 is depicted in Figure 23, and a description of major activities of this plan follows.

1. Technology Transfer activities and documents

Based upon the knowledge of the R&D staff and the user community, prepare a preliminary list of tech transfer activities and documents that foster or enhance technology transfer. For larger and more complex projects, this list preparation may require extensive interviews; for smaller projects, telephonic information from selected participants would be sufficient. The general approach of allocating resources based on the size and complexity of the project and, indeed, based on the availability of resources is the prudent course of action.

Some examples of tech transfer activities and documents are:

- User involvement in research project identification
- User involvement in research programme execution
- Sponsor at high levels
- Effective information brochures, audio-visuals, and so on
- User manual
- Design criteria

• Patents
• Licensing for manufacture
• Operation and maintenance document
• Support centre for training and the like
• Hot line to respond to questions
• Demonstration projects
• Successful implementation for selected users

2. Activities and Technology Transfer stages

Relate these activities to the five tech transfer stages or steps (knowledge, persuasion, decision, implementation, confirmation) discussed earlier. Use some relevance scale. As an example, using a matrix, activities having the most relevance to a given stage could be rated A, those with least relevance could be rated C, and others without relevance could be left blank [10].

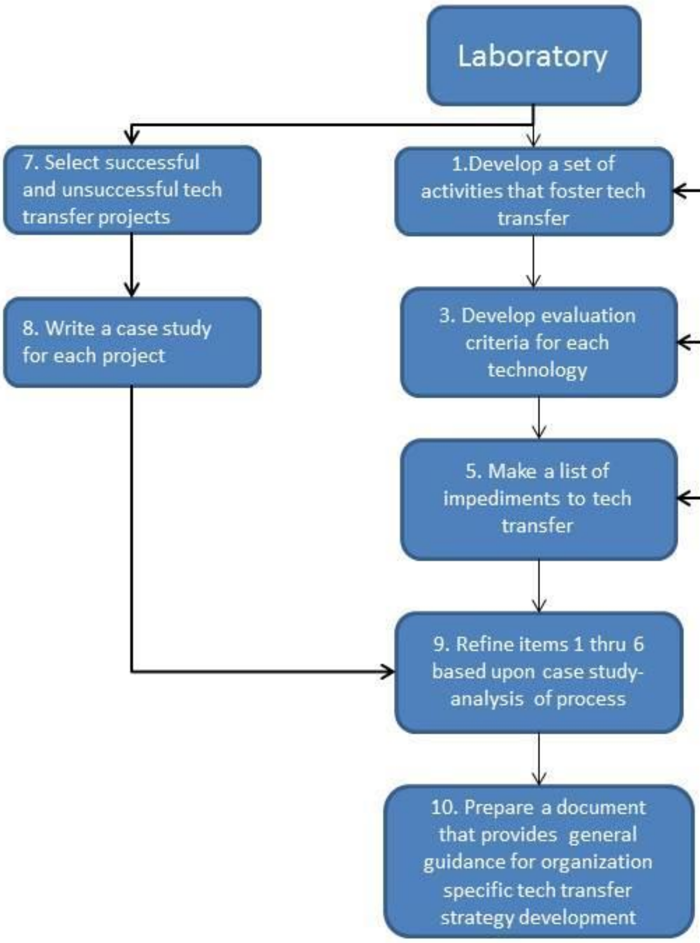


Figure 21. Tech transfer activities – recommendation for laboratories.
Source: Jain K.R., Triandis H.C, Weick C.W.: Managing research, development, and innovation. Wiley, New Jersey, 2010 [10].

3. Technology Evaluation Criteria

It must be recognised that, fundamentally, the ability to transfer a new technology is limited by its utility. Utility encompasses such items as relative advantage, marketability, economic feasibility, and user acceptability. Trying to push a new technology that is marginally utilitarian will result in failure in the end. At times one must deal with a technology in which considerable R&D resources have been invested and which seems utilitarian to the R&D community, but which the user community judges to be of marginal utility. It is a poor strategy for the R&D community and its top management zealously to push marginally useful technology without making a genuine effort to understand and to overcome the user community's objections. Not only is the effort likely to fail, but it could

adversely affect future worthwhile efforts. In such situations, it would be prudent to recall that the focus of tech transfer is supposed to be on marketing the product rather than selling it. Thus, user needs and preferences should be given proper consideration. Emphasis then should be on activities (discussed earlier) that enhance user acceptance, though this is not always an easy course of action.
A list of evaluation criteria should be developed. Based on the discussion of characteristics of innovation and key issues in technology transfer, a suggested list follows:
Relative Advantage. To what degree is the innovation more advantageous to existing technologies? Does it reduce cost, save time, or improve quality?
Compatibility. To what degree is the innovation compatible with existing values, experiences, capabilities, felt needs, and organisational and cultural settings?
Complexity. To what degree is the innovation complex and difficult to adopt by the users? What degree of specialised training is required before the innovation can be adopted? What specialised equipment is needed?
Trialability. To what degree can the innovation be tried on a limited basis?
Observability. To what degree can the advantages of the innovation be easily communicated to decision-makers and users?
Technical Understanding. To what degree does the research personnel fully understand the main technology?
Resource Requirement. What level of resources is required to implement the new technology? Is this resource requirement compatible with previous user experiences? Is the capital needed for the new technology available?
Advanced Development Concepts. Are the research activities going to continue to debug problems and further supplement the technology?
Growth Potential. Does the technology have a potential for growth and product applicability? Will the new technology overcome “stretching” of existing technology capabilities?
Advocate. Are there advocates at higher levels and at user level?
Market Pull. To what degree is there a market pull?
External Pressures. To what degree are there external pressures (such as regulations, competitor development, and so on)?

4. Activities to Enhance Evaluation Criteria

The purpose of the evaluation criteria is not necessarily to determine whether the project should be tech transferred or not, but rather to see how the viability of the tech transfer can be improved. It would seem that if the evaluation criteria are used to make a “go or no-go” decision, there may be a natural, though unfortunate, tendency on the part of the researchers to be less objective about the criteria. In actual practice, this is a crucial point and needs to be emphasised. If, for example, the evaluation criteria show that the product (a new concept, process, system, or design) is not compatible with existing and past experiences, then the emphasis should be on how the innovation can be improved so that it becomes compatible.

5. Impediments to Technology Transfer

Make a list of impediments to technology transfer. This list should include organisational items, resource requirements, and general behavioural-related items.

6. Suggestions to Overcome Technology Transfer Impediments

For every impediment to technology transfer, it would be useful initially to develop suggestions for overcoming the impediment. As an example, if at the higher management level there is a tepid response concerning the immediate benefits from the new technology, showing evidence of tangible, intangible, and unexpected benefits should help. Some examples of such benefits that might accrue from tech transfer include:

- Improved quality of the product
- Increased market share due to improved quality
- Flexibility to use the new technology for purposes other than those intended at this time
- Strategic advantage over competitors if the new technology can provide the flexibility for necessary product lines
- Reduced time required to do the job; even though savings in time have already been used as a savings in cost, reduced time can often provide a crucial advantage (for instance, in a military tactical situation)

7. Selection of Successful and Unsuccessful Projects
Based on the past experience of the R&D organisation, select a number of projects in which tech transfer was or was not successful. The number of projects selected would depend on the total domain, diversity, and resource availability of the study. A minimum of three of each type of project is recommended, with a higher number of successful ones when more than three projects are selected.

8. Case History
Prepare a case history for each project.

9. Refine Items 1 through 6
After analysing the cases, items 1 through 6 should be modified. Considerable effort would be involved in executing this activity. Input from R&D and user community personnel is needed.

10. Guidance Document for Technology Transfer
A guidance document should be prepared based on analysis performed to provide information for R&D performers. The focus of the document should be on flexible general guidance. Rigid, mandatory requirements will only be counterproductive. The document can provide a framework that allows R&D managers to develop policy and implement strategies that foster technology transfer. The format of the document and level of detail will depend on the nature of technology, characteristics of the R&D organisation, and the user community among other things. It needs to be recognised that not all research outputs can or should be pushed to tech transfer. This is because need and technology may change during the R&D process, and R&D may not be able to produce what was thought possible during the planning stages. This type of uncertainty in R&D results should be accepted if an organisation is ever going to undertake challenging R&D projects. Not being able to transfer technology successfully should not be viewed as a loss or necessarily a poor investment in the unsuccessful R&D project. Projects with unsuccessful tech transfer records can be useful as building blocks for future related research activities. There could be other unintended benefits to ongoing research efforts, though the links may seem less obvious at the time.
In developing an effective management strategy for technology transfer, it is important to understand stages of technology transfer and fundamental issues and factors affecting adoption or rejection of new technologies [10].

CONCLUSIONS REGARDING THE INNOVATION ACTIVITY OF LABORATORIES FROM ENSAR2

The information contained in the report leads to significant conclusions that set the direction for the future development of innovation in nuclear physics. The development of disruptive technologies and new models of cooperation with industry and transfer technology are important in furthering EU economic growth.
ENSAR2 as the sum of European laboratories has enormous innovation potential that can meet the needs of European society in such important areas as medicine, pharmacy, security and defence, aerospace industry, new materials. To fully develop this potential, specific actions should be taken, which we have indicated below:

- Developing a long-term innovation strategy for nuclear physics solutions at European level
- Cooperation with industry and public makers based on an open innovation model.
- Transfer of technology and knowledge through licensing agreements and know-how from the ENSAR2 project to industry in the area of basic research, research and development.
- Cooperation between individual laboratories should focus on innovations in such areas as**: medicine (devices for diagnosing cancer), pharmacy (radiopharmaceuticals to fight cancer), aerospace technologies (covers, on-board equipment materials, measuring instruments)**, energy (Nuclear Fusion, Nuclear fission, Nuclear Safety , Nuclear instrumentation), radiation protection (covers), lasers (medical, industrial), material engineering (membranes), material engineering (materials with increased strength and resistant to destructive effects radiation).
- Cooperation with medicine and pharmacy companies at the subject of medicine and pharmacy innovative solutions.
- Closer research cooperation with WHO (World Health Organisation), ESA (European Space Agency), NATO Research and Technology organisation, IAEA (International Atomic Energy Agency).
- Active promotion of the offer of laboratories in the area of applications of their resources (including beam) for the needs of industry.

- Active IP asset management of the laboratories' IP portfolio – matching technologies with innovative (internal or external) innovation models to add value to IP.
- Developing a model that will be a recommendation for ENSAR2 laboratories in the area of creating start-ups.
- Participation in brokerage meetings with the participation of enterprises in the area of basic research, research and development activities, design and development activities, production.
- Identification of enterprises from the end-user set and establishing cooperation with them as the main actors of the commercial network.
- Actions aimed at identifying and cooperating with SMEs at the levels of activity of basic research, R&D, design and development, production. These activities are to focus on the creation of an international network of SMEs in the field of nuclear physics. An important aspect in creating this network will be the regional activities of the centres participating in the project. Established regional contacts with SMEs will enable ENSAR2 participants to transfer them to the international network. The element connecting the network will be cooperation based on offers and queries in the areas of research and development, design, development and production.

To achieve all points listed above ENSAR2 needs in future a support of European Commission and the leader (country) which will be responsible for long-term strategy at European level of nuclear physics innovation.

Appendices

Appendix 1 (questionnaire form)

Nuclear Physics Innovation
Questionnaire M.27 *

Contact details. First name and family name: *

……………………………………………………………………………

Contact details. E-mail address: *

……………………………………………………………………………

Contact details. Organisation: *

……………………………………………………………………………

Definitions.
*- registered – applications registered in national or European patent office or patents granted
**- 5 years – starting with 2014 to current date (2019 included)

1. Please give the number of patents registered* in the last 5 years**.

Number: ……………………………………………………………………………

1.1. Please give identification numbers of 3 patents registered in the last 5 years.

……………………………………………………………………………

2. Please give the number of licenses which has granted in the last 5 years.

Number:……………………………………………………………………

2.1. Please name the thematic scope and licensee for 3 of licenses granted:
1. Thematic Scope, Name of licensee, 2. Thematic Scope, Name of licensee, 3. Thematic Scope, Name of licensee.
Please use commas to separate.

……………………………………………………………………………

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3. Please give the estimated number of products or patents commercialised in the last 5 years.

Number:………………………………………………………………

3.1. Please give 3 names of companies involved in the commercialisation of your organisation products or patents: (Please use commas to separate)

…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

4. Please give the number of start-up companies linked to your organisation, which were established in the last 5 years.

Number:………………………………………………………………

4.1. Please give 3 names of start-up companies linked to your organisation, which were established in the last 5 years.
(Please use commas to separate)

…………………………………………………………………………

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5. Please give an estimated number of contracts with industry involving laboratory resources, for example, the beam used for an industrial partner or client needs.

Number:………………………………………………………………

5.1. Please list three areas and time (in hours) of the beam involvement:
(area, time in h) - please use commas to separate.

…………………………………………………………………………

…………………………………………………………………………

…………………………………………………………………………

6. Please give an estimated number of projects in partnership with industry involving laboratory resources, for example, the beam used for industrial partners.

Number:………………………………………………………………

6.1. Please list three areas and time (in hours) of the beam usage:
(area, time in h) - please use commas to separate.

…………………………………………………………………………………

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7. Please give an estimated number of projects financed or co-financed by public funds and which are aimed at supporting innovations.

Number:(please use commas to separate)

…………………………………………………………………………………

7.1. Please list three areas of projects with supporting innovations component:
(please use commas to separate)

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…………………………………………………………………………………..……………………………

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8. Please give an estimated number of Ph.D. theses co-financed by industry.

Number:………………………………………………………………………

8.1. Please give three areas of PhD theses co-financed by industry.
(please use commas to separate)

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

9. Please give an estimated number of workshops and trainings proceeded for industry.

Number:………………………………………………………………………

9.1. Please give three areas of workshops and trainings proceeded for industry:
(please use commas to separate)

…………………………………………………………………………………

…………………………………………………………………………………

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Appendix 2 (e-mail about the survey of innovation)

"Dear ENSAR2 Partner,

As part of the ENSAR2-NUPIA (Nuclear Physics InnovAtion), we are conducting the survey on innovation. The main goal of the survey is to define the ENSAR2 potential in areas like patents, licenses, cooperation with industry, start-ups, and workshops. Your answers will be gathered, analysed and published in the report „Intermediate Innovation Survey - ENSAR2 – NUPIA".

Please find direct link to the online survey: https://forms.gle/dFCHzTo3eRjxbFCd9

Completing the survey is mandatory due to reporting for the European Commission.

We kindly ask you to complete the survey by **October 16, 2019**, at the latest.

If you have questions about the survey, please contact:

Deputy Leader of ENSAR2-NUPIA: Tomasz Krawczyk - tj.krawczyk@uw.edu.pl
Deputy Director Heavy Ion Laboratory UW: Pawel Napiorkowski - pjn@slcj.uw.edu.pl

Best regards

Tomasz Krawczyk – Warsaw University

Marie-Helene Moscatello – GANIL Caen

Appendix 3 (Laboratories that completed the survey.)

Number	Laboratory	Country
1	University of Warsaw	Poland
2	ARRONAX	France
3	GANIL	France
4	Instituto Galego de Física de Altas Enerxias	Spain
5	Ludwig-Maximilians-University Munich	Germany
6	IPNO/CNRS	France
7	Johannes Gutenberg University Mainz	Germany
8	Centro Nacional de Aceleradores and University of Seville	Spain
9	EBG MedAustron GmbH	Austria
10	Istituto Nazionale Fisica Nucleare	Italy
11	IFIC (CSIC-University of Valencia)	Spain
12	ISOLDE/CERN	Switzerland
13	KU Leuven	Belgium
14	CIEMAT	Spain
15	NCSR Demokritos	Greece
16	Institut für Kernphysik	Germany
17	KVI-CART, University of Groningen	Holland
18	University of Jyväskylä	Finland
19	GSI Helmholtzzentrum für Schwerionenforschung mbH	Germany
20	Faculty of Sciences University of Lisbon	Portugal
21	IFJ PAN	Poland
22	ELI-NP	Romania