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Report on HR needs in non-power nuclear sector applications

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EXECUTIVE SUMMARY

The objectives of this task were to assess the workforce needs for a variety of non-power applications using ionising radiation. The most important one is the use of radioisotopes for medical applications which include both therapy (e.g. internal or external radiation therapy) and diagnosis (e.g. imaging). Others include environment and space applications. In terms of methodology, data collection through a survey has been chosen, complemented by literature review and secondary data sources, depending on the sector of interest. The survey was prepared in the framework of other ongoing projects. Specific data analysis of the responses has been conducted consistently with ENEN2+ strategic objectives. The main take home messages are listed below, while a more exhaustive list of recommendations for organisations and/or policy makers are included at the end of this document.

- In the field of medical applications, there are 10000 medical physicists in the EU countries representing 4% of the overall workforce within the medical applications field using ionizing radiation (including medical doctors and radiographers/technologists working in the fields of radiology, radiotherapy, nuclear medicine). There is a demographic issue with 7% retiring within the next 5 years and 22% >51 years old.
- Based on existing publications the number of radiopharmacists / radiochemists correspond to between 3.5% and 5.2% of the nuclear medicine workforce (including medical physicists, nuclear medicine physicians, radiographers/technologists, nurses).
- Radionuclide therapies are expected to play an increasing role in nuclear medicine with an associated expected impact in the recruitment of medical physicists/ radiopharmacists/radiochemists.
- Human resources needs for nuclear space applications are closely related to the market demand in all the segments of power related nuclear applications. In the field of nuclear techniques for environmental applications they are largely concentrated in a few specialised centres for monitoring environmental radioactivity. In both these areas there is a need for specialized training schemes in a similar fashion to existing programs for medical physicists.
- There is a clear need for harmonising training throughout the EU countries for scientific professionals in non-power nuclear applications.
- Initiatives to harmonise certification throughout the EU countries for scientific professionals in non-power nuclear applications should be encouraged.
- Funding of residency training programs for scientific professionals in non-power nuclear applications should be encouraged to reduce variability training standards throughout the 27 EU country members.

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1 INTRODUCTION

1.1 Common introduction (I2EN)

Context

Nuclear power and non-power technologies are technically very complex facilities that operate in an increasingly challenging regulatory framework and difficult market conditions. In such a fast-changing world, the nuclear sector can be impacted by many different factors:

- Political change, socio economic situation, country by country,
- Public opinion perception, sensitivity to environment and climate change issues, impact of social networks on public information,
- Energy context including, as we experienced it painfully recently, high intensity crisis impacting energy supply for EU countries,
- Innovation in technologies (renewables, SMR, etc.), digital transformation (Smart Grids, digital twins for construction activities, new applications for medical diagnostics and therapies, etc.) and artificial intelligence

Among context factors which should be considered when looking at the consequences in terms of Human Resources needs in each specific country context:

- Background country by country regarding nuclear science and technology: is there already a nuclear history in the country (research reactor operated locally, use of nuclear applications in medicine or in any other non-energetic nuclear application, etc.)? Are there E&T structured opportunities for students who wish to embark in nuclear sector in the country's education system?
- Scenario for the future of nuclear in the energy mix of the country (number and size of nuclear power plants, consideration of SMR option, wish to develop a local nuclear value chain or rely on international cooperation up to a "plug & light" contractual model, strategy regarding fuel cycle and waste management, etc.).
- Other initiatives of large projects / energy infrastructures engaged in the country (or to be engaged soon) in other sectors (renewable energies for example) and that may interfere (mutualisation or competition) with the nuclear sector in terms of needed skills and available HR on the labour market (identify tension areas for specific skills / skill levels), but also may be used as benchmark for the development of human resources for the nuclear sector.

Challenges

The scope of organizations and stakeholders that are involved in the analysis of HR needs is large. It is essential to keep as main goal the achievement of a highly resilient organization of the HR capabilities assessment and preparation for the nuclear sector in EU. As a consequence, the quantification process for HR needs is to be considered and managed as an iterative process, as well as the definition of HR development solutions. Only such an organization will be able to adapt to the changing environment, evolving needs of the sector, encompassing all stakeholders, while providing attractivity and sustainable career solutions to the workforce embarked, especially young talents. Excellent workforce should remain the basic enabler of safe long-term operation of existing facilities and development of future advanced ones.

In the end, such an analysis for anticipating HR needs (numbers, skills, timing, budget, etc.) and identifying gaps between needs and E&T local capabilities providing solutions might be considered as performing a risk analysis. Building such an analysis at the EU level, rather than at a country-by-country level, is clearly a way to minimize and mitigate these risks. It is also a path to consolidate both the EU's low carbon energy strategy, and EU leadership to face international nuclear technologies development opportunities.

It should be strongly emphasized that, while the focus is usually placed on experts, nuclear sector does not require only nuclear specialists to be maintained and developed. Experience has shown that the technicians and semi-skilled form a very large portion of the needed workforce.

As a compulsory first step, skills assessment system should rely on a commonly established skills inventory and jobs / skills mapping using qualitative and quantitative non ambiguous criteria in terms of knowledge, knowhow, behaviour, experience and recycling frequency. The level of detail can vary from one job to another depending on its sensitivity. Skills assessment system must also define skill levels and on the field know-how needed for the various jobs, and determine the assessment criteria to measure the skills of staff members. Rules need also to be established in order to deliver certification / qualification to staff members and facilitate movements of staff members inside, between, and outside stakeholder organizations, thus contributing to people employability within the nuclear sector and more broadly to serve large projects in the country or abroad, especially among EU Member States.

1.2 Introduction to task 1.3

Leader: EFOMP European Federation of Organisations for Medical Physics, contribution from GIFEN-I2EN, NCBJ, ENEN, JRC, BME, UCLAN, ENEA, IST, WEF, duration 12 months

There is a variety of non-power applications using radioactive elements or radiation rays. The objectives of this task have been to assess the workforce needs for a variety of non-power applications using ionising radiation. The most important one is the use of radioisotopes for medical applications which include both therapy (e.g., internal or external radiation therapy) and diagnosis (e.g., imaging). Others include environment and space applications. It could be foreseen from the beginning of the work that such specific application areas will exhibit low numbers of nuclear staffing compared to the medical field, since they are largely dedicated to answering needs of some specific projects. On the other hand, all these applications need some specialised skills and knowledge but also some generic nuclear competences such as for example radiation protection and production/handling of radioactive materials. Interactions with TF 1.2 have been developed on these aspects. Moreover, some of these non-power nuclear applications (space for example) might further develop in the future. Therefore, a summary of the necessary competences for the different non-power applications is also provided.

2 METHODOLOGY

In terms of methodology, data collection through a survey has been chosen, complemented by literature review and secondary data sources. The survey was prepared in the framework of other projects described in the following sections. Specific data analysis of the responses has been conducted consistently with ENEN2+ strategic objectives.

The first approach concerned the use of secondary data sources through documents that have been already published in the subject. These included:

- reports on the situation of human resources compiled by international organisations (public and private) containing information relevant to the targeted professional categories for EU countries,
- reports from EU projects containing relevant information on human resources for the targeted professional categories and associated applications,
- reports from national authorities or professional associations on the subject of human resources for the targeted professional categories and associated applications in specific countries.

These reports were either available on the internet or provided by other international organisations upon request.

Specific applications such as space and environment were targeted uniquely through this literature review since they involve relatively niche activities, in certain cases restricted to very few projects and competent bodies, mostly funded by specific international organisation research and development programmes (such as is the case in the application field of space). As such it is rather difficult to gather information concerning human resources requirements which are clearly very limited compared to the medical field which is clearly the largest in terms of non-power applications requiring skilled personnel in the field of nuclear sciences.

The second source of information was based on survey results. Two specific surveys were used. The first one was carried out by EFOMP at the end of 2022 on behalf of other European projects concerned by Medical Physics Expert workforce issues at the EU level. This survey provided data on the status of the Medical Physics Expert professionals and the required level of competences. The second survey was that performed by task 1.2 of the ENEN2plus project concerned by the human resources needs of research centres, waste management and safety operators. A few questions within this survey concerned the needs of these research centres in terms of radiochemists for the production of isotopes that may be used for medical applications. These responses were therefore exploited and confronted to the data that was derived for radiopharmacists / radiochemists specific professionals from the literature review.

3 RESULTS

3.1 Literature studies

These studies have specifically targeted the field of radiopharmacy/radiochemistry for medical applications as well as space and environment applications. In the case of Medical Physicists given the availability of the recent survey results concerning the current workforce numbers presented in section 3.2.2 below the literature research concerned only the existing education and training activity guidelines.

3.1.1 Medical Physics *(EFOMP Dimitris Visvikis)*

Different guidelines/core curricula exist for medical physics training considering the different areas of activity using ionizing radiation, namely nuclear medicine, radiology and radiotherapy. Some of them are very recent but most are dating from over a decade ago. A summary of the most important conclusions can be found below:

- The minimum entry to a medical physics training programme is a BSc degree in physics. In certain cases, alternative degrees including BSc in engineering sciences is considered as an appropriate entry level. A postgraduate degree (MSc in medical/radiation physics) is included as a requirement amongst the most recently revised core curriculum guidelines issued for radiotherapy medical physics experts[1]. This is also the case in the IAEA guidelines for medical physics training in nuclear medicine[2].
- The duration of the training recommendations is on average 4 years, including a 2-year minimum clinical training. This largely corresponds to a 50% partition of the training to a theoretical and a practical component. This partition may vary from 25% to 75% for the practical component depending on the EU country.
- Most guidelines recommend a 10-15% of the total ECTS dedicated to radiation protection. The requirements for certification in radiation protection varies largely depending on the EU country.
- Following training and qualification as a Medical Physics Expert, continuous education for professional development is considered mandatory.

3.1.2 Radiopharmacy / Radiochemistry *(IST Antonio Paulo / NCBJ Katarzyna Deja, M Kirejczyk)*

<u>*Surveys on Human Resources*</u>

Having in mind the elaboration and release of a survey on the HR needs in radiopharmacy/radiochemistry in Europe for the years to come, we have looked for previous and recent available data at European level. For that, we have searched the web and we have contacted the EANM and the IAEA. Following these efforts, we have realized that most of the available data are related to medical physicists and nuclear medicine physicians. Previous data on HR in radiopharmacy / radiochemistry in Europe are scarce. We could specifically obtain: i) one report from the British Nuclear Medicine Society (published in the journal Nuclear Medicine Communications); ii) a survey from the IAEA (available online), as summarized below.

- **“Report of the 2020 British Nuclear Medicine Society survey of nuclear medicine equipment, workforce and workload”** (A. G. Irwin, C. L.Turnera, S. Redman, Nucl. Med. Commun. 2022 43(6):731-741. doi: 0.1097/MNM.0000000000001561)”.

This report accounts for the most recent British Nuclear Medicine Society (BNMS) survey on equipment, workforce and workload concerning the practice of nuclear medicine in the UK, which was collected during 2019 and 2020. In the case of the workforce, the data were collected based on existing online records created or updated by the participants. The collected data (expressed as Whole Time Equivalent (WTE)) were the following for the different staff types:

- Technologists (469 WTE)
- Radiographers (260 WTE)
- Clinical scientists (226 WTE)
- Doctors (100 WTE)
- Imaging assistants (79 WTE)
- Nurses (52 WTE)
- Radiopharmacists/ radiochemists (43 WTE)

Based on these numbers the radiopharmacists / radiochemists correspond to 3.5% of the NM workforce in the UK.

- **IAEA statistics on the Nuclear Medicine (NM) workforce including “Eastern Europe and Northern Asia”**

  (available: http://nucmedicine.iaea.org/statistics/hr-and-personnel)

These data, available online, were obtained based on the “International Research Integration System (IRIS)”, which is an online data collection platform launched in 2020 by the IAEA. The data were provided on a voluntary basis and were focused on low- and middle-income countries, from the following regions: i) Africa; ii) Asia; iii) Eastern Europe and Northern Asia; iv) Latin America & Caribbean; v) Middle East. The survey included a total of 1427 institutions. No data from high-income countries, namely from Western Europe, was included at this stage. The survey included the following categories for the Nuclear Medicine staff: i) NM physicians; ii) Physicians in-training; iii) Medical physicists; iv) Nurses; v) Radiopharmacists and radiochemists; vi) Technologists/Radiographers; vii) Other scientific staff. In the particular case of the Eastern Europe and Northern Asia, the survey involved 225 institutions employing 126 radiopharmacists and radiochemists.

Based on the numbers available in this platform, the radiopharmacists / radiochemists correspond to 5.2% of the total NM workforce in this geographical area (Eastern Europe and Northern Asia).

Other Surveys/Documents related to the NM field

Although not focusing directly on data for the NM workforce, recent surveys/reports might be helpful for forecasting the impact of nuclear medicine modalities in the years to come. These surveys/documents are: i) the "Questionnaire on industrial and clinical key players and needs" issued by the PRISMAP project; ii) The Nuclear Medicine Report & Directory, Edition 2022 by MEDraysintell.

- **"Questionnaire on industrial and clinical key players and needs"**, Deliverable 5.1 of PRISMAP project (https://www.prismap.eu), 09/2022

This survey/questionnaire has been produced by the PRISMAP project, corresponding to a deliverable (D5.1) that can be freely accessed in the project webpage (https://zenodo.org/record/7154340#.Y9Kl8XbP2Uk). The PRISMAP – The European medical isotope programme: Production of high purity isotopes by mass separation is an European project (INFRAIA funded project) aiming to federate a consortium of the key European intense neutron sources, isotope mass separation facilities and high-power accelerators and cyclotrons, with leading biomedical research institutes and hospitals active in the translation of the emerging radionuclides into medical diagnosis and treatment. PRISMAP brings together a consortium of 23 beneficiaries from 13 countries, receiving support from leading associations and institutions in the field such as the European Association of Nuclear Medicine (EANM) and the International Atomic Energy Agency (IAEA). Two of the ENEN2plus partners (NCBJ/Poland and IST/Portugal) are also partners of the PRISMAP project.

The survey issued by PRISMAP has been produced based on the data provided by 114 respondents from 104 companies and institutions from 30 European countries. Forty-eight research institutions were represented (25 from universities, 15 from public laboratories other than universities, 1 from a private institution, 7 from other institutions - national public institution collaborations, University Medical Centre, Institute for Cancer Research, National Research Institution, etc.). The forty respondent institutions were preclinical/clinical users. 16 respondents represent manufacturing facilities (4 radionuclide production and 12 radionuclide/radiopharmaceutical production facilities).

The PRISMAP survey was primarily focused on research field and interests, research infrastructure, and on the portfolio of radionuclide and radiopharmaceutical production. There were no sections dedicated to HR in radiopharmacy/radiochemistry in Europe but the training capability in the field was addressed in the questionnaire. The major part (83%) of the respondent institutions is involved in the training of industry experts, technicians, students and researchers at various expertise levels (accelerator and particle physics, radionuclide production, synthesis and development, purification, calibration and characterization, quality control, analysis and radiochemistry). ***The survey results point out that radiopharmaceutical synthesis and development, radiochemistry, radionuclide/radiopharmaceutical QC and analysis are amongst the most popular training fields.***

- **"Nuclear Medicine Report & Directory,** edition 2022 by MEDraysintell**"**

These reports published by MEDraysintell (https://www.medraysintell.com) provide a comprehensive and exhaustive review of the worldwide NM landscape, describing about 970 products, together with the comprehensive profile of 380 companies active in NM and radiopharmaceutical development. The reports are organized in three parts: i) marketed radiopharmaceuticals; ii) clinical radiopharmaceuticals; iii) early-stage radiopharmaceuticals.

Some highlights from the reports concerning the objectives of this report are the following:

- The increasing role of radiotherapeutics in NM: according to the reports, radiotherapeutics represented 20% of the global NM market in 2021 and are expected to reach ~70% by 2031.
- The global market for NM reached over US$ 6 billion in 2021, growing by >10% from 2020.
- Over 150 companies are currently developing one or more radiodiagnostic or radiotherapeutic product from their own pipeline.
- Several new radiotherapeutics with strong revenues' potential to reach the market before 2027 (estimated a +17%/year increase from 2022 to 2027).

In brief, the data from these reports show that radiotherapeutics will play an increasing role in nuclear medicine with an expected impact in the recruitment of radiopharmacists/radiochemists by the different entities involved in the field (companies, hospitals, research centres, etc). Based on the projected increases in expected radiotherapeutic products and associated revenues there should be an increase of >10% within the next ten years on the number of radiopharmacists/radiochemists in the field of radiotherapeutics.

3.1.3 Space *(ENEA Barbara Ferrucci)*

Fifty years after the last Apollo mission in 1972, the exploration of space has returned to the centre of attention, along with the intention to establish human outposts on the moon. However, the establishment of human outposts on planetary surfaces, and the utilization of *in situ* resources, require the production of large amounts of electrical power. To this end, nuclear fission reactor-based power technology represents a very competitive option. In this context, in September 2022, the European Nuclear Society High Scientific Council launched its Position Paper "Nuclear Energy for Space Exploration ", *to highlight the fundamental contribution that nuclear energy has made to space exploration, and to highlight the need to develop new space nuclear systems to meet the future challenges of space exploration*.

Today, many countries are interested in missions to the moon and beyond. Russia scheduled the first mission of the nuclear-powered spacecraft, also known as the transport and energy module (TEM), for 2030, and in 2018 announced its plan to establish a lunar colony by 2040[3]. China[4] and NASA are planning to build a fission surface power system on the moon by 2028 and by 2026, respectively; while, Belgium's Tractebel (tractebel-engie.com/en/company-profile) has been recently selected by the

European Space Agency (ESA) to head the consortium of PULSAR, a project aimed to develop nuclear technology to power space missions. In this context a new geo-strategic competition is ongoing that brings together space agencies and private and commercial companies worldwide to develop innovative technologies to go to the moon and beyond. Dozens of public and private missions worldwide, are setting their sights on the lunar surface in the coming years (www.esa.int/Science_Exploration/Human_and_Robotic_Exploration).

Worldwide, there are several space agencies, the most notable is the NASA, the USA National Aeronautics and Space Administration, but there are also important agencies in Russia, China, Europe, Canada, Japan, and India that are responsible for exploring space, conducting space research, and managing space programmes. In Europe the main space agency is represented by ESA, an intergovernmental organization with 22 Members States (MS) (Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Norway, Netherlands, Poland, Portugal, Romania, United Kingdom, Czech Republic, Spain, Sweden, Switzerland, and Hungary; Slovenia is an Associate Member and Canada participates in some projects under a cooperation agreement), with the goal of exploring space and joining forces and knowledge for a stronger development of the space sector in the European continent (www.solar-mems.com/main-space-agencies-in-the-world/). The agency employs about 2,200 workers, as well as numerous collaborators, external suppliers and subcontractors. ESA's annual budget for 2021 is 6.4 billion euros (www.esa.int).

Working closely with the European industry, national space agencies, research centres, and the European Union, ESA is involved in eight main fields of application: space science, human and robotic exploration, observing the earth, telecommunications, satellite navigation, space transportation, technology, and operations. In addition to ESA, also Austria, France, Germany, Italy and the United Kingdom have their own space agencies:

- In Austria the Austrian Research Promotion Agency (FFG) is the national funding agency for industrial research and development (www.ffg.at/en/FFG/The-FFG). The Aeronautics and Space Agency (ALR) of the FFG is the docking station to the international aerospace world for Austrian business and science. The agency implements national aerospace policy and represents Austria on international aerospace committees. Austrian representation in the European Space Agency ESA is of special strategic importance in this context.

- France is the country that contributes the most, on a budget level, to ESA, through its National Centre for Space Studies (CNES), a body dependent on the French Government and responsible for space development in that country (cnes.fr/en). The CNES is based in Paris and had a 2.7 billion euros budget in 2019, an amount that makes it the third largest space agency in the world, only surpassed by NASA and ESA, and with an economical investment superior to the Japanese JAXA. The CNES works in particular with research bodies such as the CNRS, the IN2P3, the CEA and the centres of data sharing or the thematic poles.

- Germany also has its own national research centre for aviation and space flight, the German Space Agency and the German Aerospace Centre (DLR). The DLR has its headquarters in Cologne (Germany), and several subsidiaries in other German cities. 8,200 employees work there and in 2017 its budget was 1.2 billion euros (www.solar-mems.com/main-space-agencies-in-the-world/).

- The Italian Space Agency (ASI) is a Rome-based governmental organization directing and promoting the Italy's space activities. ASI has about 200 employees and a budget of 1 billion dollars. Italy is the third largest country contributing to the ESA (after France and Germany). ASI also works with NASA and has been part of some very important missions such as the construction and commissioning of the International Space Station.
- The UK Space Agency (UKSA) is the British government agency responsible for the civil space programme. It is a young agency created in 2010 with a budget of 414 million euros for the year 2017/2018. Like the rest of the European space agencies, UKSA has a close relationship with ESA and focuses its efforts on telecommunications and space exploration.

In the Table 1 below is reported a summary of some of the ESA, and the ESA's MS projects (past, ongoing, planned) addressed to the use of nuclear technologies or applications for space. All the information in Table 1 is collected from space agencies websites and digital news sources.

Table 1. Europe nuclear applications and research for space

Space Agency/ Country	Projects involving Nuclear Technologies
ESA	**Project RocketRoll** (pReliminary eurOpean reCKon on nuclEar elecTric pROpuLsion for space appLications): (call for tenders[5], deadline November 2022) the project is aimed to explore the advantages of using a Nuclear Electric Propulsion (NEP) and to identify main safety features for the design, highlighting contingency and mitigation measures. Moreover, the study will determine what are the existing and missing key elements in Europe (technologies, modelling capabilities, testing facilities, etc.) that shall be matured for a nuclear electric tug operational after 2035. **Project ALUMNI**[6] (preliminAry eLements on nUclear therMal propulsioN for space applIcations): the project aims to explore the advantages of using a Nuclear Thermal Propulsion (NTP) over classical propulsion systems and to highlight its potential profitability. More importantly, it is aimed to assess the key elements (technologies, modelling capabilities, testing facilities, etc.) and safety design features to make NTP possible. **Artemis:** is a NASA's programme in which ESA is a key partner. It is aimed to return people to the moon by the end of the decade. NASA and the U.S. Department of Energy (DOE) are working together to advance space nuclear technologies. The agencies have selected three design concept proposals for a fission surface power system design that could be ready to launch by the end of the decade for a demonstration on the moon. This technology would benefit future exploration under the Artemis umbrella.

	PULSAR project: ESA has recently awarded the Belgium's Tractebel to head the consortium of PULSAR, a research and innovation project funded by the European Commission to develop nuclear technology to power space missions. Tractebel will conduct research on dynamic radioisotope power systems (RPS) fuelled by plutonium 238 (Pu-238) for space applications. The PULSAR project brings together leading stakeholders in the fields of aerospace and nuclear. The consortium includes the Joint Research Centre (JRC) of the European Commission, the Belgian Nuclear Research Centre (SCK-CEN), the French Alternative Energies and Atomic Energy Commission (CEA), INCOTEC, ArianeGroup, Airbus Defense and Space, the University of Bourgogne Franche-Comté and Arttic. Each partner will bring state-of-the-art expertise in its respective field, to contribute to the success of this Europe-wide project. **Irradiation test facilities:** ESA collaborates and supports irradiation test facilities for the purpose of characterising Displacement Damage (DD) Effects and Single Event Effects (SEE) in electronic components for flight on ESA missions. • RADEF, RADiation Effects Facility, is specialized in applied research related to nuclear and accelerator based technologies, to study radiation effects in electronics and related materials. RADEF officially became an ESA supported European Component Irradiation Facility (ECIF) in 2005. RADEF offers wide variety of different sorts of radiations from gammas and electrons to protons and heavy ions for research. For these beams the RADEF group utilizes the LINAC electron accelerator, and combination of JYFL's ECR ion sources and K-130 cyclotron. • Proton Irradiation Facility (PIF, www.psi.ch/en/pif), was constructed under the contract between the European Space Agency (ESA) and the Paul Scherrer Institute (PSI) for testing of spacecraft components. The facility enables generating of realistic proton spectra encountered at any potential orbit in space. PIF is a member of the ESA supported European Component Irradiation Facilities (ECIF).
Austria	**Project name**: DOSIS[7] **(2008-2011)** **Coordinator:** Vienna University of Technology Institute of Atomic and Subatomic Physics **Partners**: German Aerospace Centre, Christian-Albrechts-Universität zu Kie, Dublin Institute for Advanced Studies, Health Protection Agency, UK, Polish Academy of Sciences (Institute of Nuclear Physics), Università degli Studi di Roma La Sapienza, Lawrence Berkeley National Laboratory (USA), Hungarian Academy of Sciences (Atomic Energy Research Institute), NASA Johnson Space Center, Oklahoma State University (USA), Physikalisch-Technische Bundesanstalt, Russian Academy of Sciences, Japan Aerospace Exploration Agency, National Institute of Radiological Sciences. **Objectives**: to determine absorbed dose, particle flux density and energy spectra at eleven differently shielded locations inside the European Columbus module of the International Space Station.
	Project name: MATSIM Phase-A&B[8] **(2009-2010)**

	Coordinator: AIT Austrian Institute of Technology GmbH Health & Environment Department Nano Systems Unit. **Partners**: Vienna University of Technology Institute of Atomic and Subatomic Physics (ATI), German Aerospace Centre (DLR) Institute of Aerospace Medicine Department for Radiation Biology, NASA – Johnson Space Center. **Objectives**: The main aim of the MATSIM-Phase A project was to perform the full numerical simulation of the MATROSHKA phantom with the use of a Monte Carlo radiation transport code. The phase-B was aimed to the validation of the numerical simulation model of MATROSHKA for photon and neutron reference radiation fields, which are available in Austria. The project MATSIM is a co-investigation of the ESA ELIPS-project MATROSHKA, a worldwide collaboration that comprises 21 research institutes. MATROSHKA is a facility designed to determine the radiation exposure of an astronaut during an intra- and extravehicular activity at the International Space Station (ISS). The model MATSIM1.0 will be used for space dosimetry to calculate the depth dose distribution within the phantom due to the complex radiation fields present at ISS, on Mars or for further space missions.
Germany	**MARE** - The MATROSHKA AstroRad Radiation Experiment: Space radiation is a major health risk for humans and thus a decisive factor for planned long-term human space missions in the future. With the MARE experiment (Matroshka AstroRad Radiation Experiment), DLR and other partners are now making a major contribution to determining this radiation risk and developing protective measures. On the NASA Artemis I mission, the MARE experiment will for the first time fly two anthropomorphic female phantoms to determine the radiation risk on its way to the moon. Both phantoms will be equipped with radiation detectors, and one will wear a radiation protection vest. Both are modelled on humans, so that the radiation dose can be measured in the particularly radiation-sensitive organs. MARE experiment involves numerous universities and research institutions in Austria, Belgium, Poland, Hungary, the Czech Republic, Greece, Switzerland, Japan and the USA (www.dlr.de/me/en/desktopdefault.aspx/tabid-14114/) **DLR-Biophysics Working Group**: in the last few years, the Biophysics Working Group of the Institute of Aerospace Medicine of the German Aerospace Centre (DLR) started the development of a small low power consumption radiation detector system (DLR M-42 detectors) for the measurement of the absorbed dose to be applied in various environments, such as onboard aircraft, in space, and also as a demonstration tool for students. The M-42 systems were already applied for measurements in airplanes, during two MAPHEUS (Materialphysikalische Experimente unter Schwerelosigkeit) rocket missions and are currently prepared for long-term balloon experiments[9].
Italy	**Italian Space Nuclear Reactor design**: recently, it has been signed a collaboration agreement between the Italian Space Agency (ASI) and the Department of Fusion and Technology for Nuclear Safety and Security (FSN) of ENEA (The Italian National Agency for New Technologies, Energy and Sustainable Economic Development) for the design of a

	compact nuclear reactor for space applications to produce energy for future lunar bases and subsequent colonization of Mars and deep space. Through a scientific and technological research funding programme, ASI intends to also support studies on radiation protection for astronauts and materials (shielding, dosimeters, radiation environment monitoring)
UK	**Nuclear-powered space engine**: The Pulsar Fusion (pulsarfusion.com/about/) is a private industrial company. It is getting funding from UKSA for the development of an innovative nuclear-powered space engine[10]. The goal is to centre on a powerful space engine that can bring humans from the earth to the outside of the solar system, one that would be achievable in people's lifetime. Rolls-Royce has signed (2021) an innovative contract with the UK Space Agency for a study into future nuclear power options for space exploration[11]. This first contract between both organisations represents an exciting opportunity to define and shape the nuclear power solutions required in space in the decades to come. In 2022 the UKSA announced €1.8 million funding for the eight projects through its Enabling Space Exploration fund on Mars Day, led by STEM Learning to celebrate innovations in space exploration and promote career opportunities in the sector. Among those projects, Bangor University focuses on nuclear thermal fuel systems and thermal-based characterisation. The project led by the Welsh university will demonstrate the additive manufacturing techniques to create nuclear-based fuels (metallic and ceramic zirconium-containing nuclear fuels) for space propulsion and assess their performance. Furthermore, the University of Southampton will develop a coherent design concept of a nuclear fission power system to drive space exploration to be integrated with a high-power electric propulsion technology. Substantial high power electric propulsion systems are needed to make large-scale activity near and further from the earth feasible and nuclear fission reactors are required to power them.[12]

Based on the collected information, the key nuclear technologies for space applications, are:

- ***energy propulsion: nuclear thermal propulsion (NTP), nuclear electric propulsion (NEP))***
- ***electricity generation: static systems (thermoelectric and thermionic), dynamic systems (Rankine cycle, Brayton cycle, Stirling cycle)***
- ***radiation detectors***

It should be note that the expertise and resources required to develop, improve, and produce the above technologies (namely experts in nuclear engineering, reactor physics, nuclear materials and chemistry, reactor systems and engineering, thermal hydraulic, safety and radiological protection), are already present in the community of scientists, technologists, engineers, and physicists, involved in nuclear field worldwide. ***Therefore, the trend of the human resources needs for nuclear space applications is closely related to the market demand in all the segments of power related***

nuclear applications and could therefore follow the recommendations of the TF1.1 report.

One point worth noting however is that recruitment sources might be different, as experts as well as young talents interested in these developments might also come from space training curricula, following nuclear education and training in a second step.

In the frame of the International Space Exploration Group (ISECG), many space agencies are coordinating their capabilities and needs for nuclear space technology. ESA is currently chairing a gap assessment team with the objective to establish an efficient roadmap to certified nuclear capabilities in energy provision and in-space propulsion shared by participating space agencies. Considering the IAEA analysis reported by Alam et al (2019)[13], the number of technically skilled staff required for to full-fledged operation of a nuclear power plant is estimated to be around 700 to 1,000. Moreover, each type of job requires training time from 3 to 6 years, as reported in , and will most probably need to include at least some specialised training in space applications.

Table 2, and will most probably need to include at least some specialised training in space applications.

Table 2. Type of jobs and training lead time required for work function at a nuclear power plant.

Nuclear work task	Job responsibility	Time required to train
Project Management	• Responsible for bid process and award of contracts; • Direct, control and monitor contractor and in-house design packages; • Establish and monitor project milestones.	3 years
Maintenance/ Construction	➢ Perform maintenance and construction work within the power block; ➢ Responsible for job package development and work documentation.	3 years apprentice training program Planners: 5 years
Operations	• On-shift staff, supervisors and shift managers responsible for operating primary, secondary and liquid radwaste systems; • Non-shift personnel support operations staff as procedure writers, scheduling coordinators, technical specialists and training coordinators.	Shift: 2–5 years Non-shift: 6–10 years
Reactor Engineering	✓ Analyze fuel performance, monitor core performance; ✓ Provide technical direction to operations during refueling, startup and shutdown.	2 years
Nuclear Fuels	• Performs core analysis, reload safety evaluation, reload design analyses, and thermal/ hydraulic/ transient analyses; • Responsible for nuclear fuel management, licensing and acquisition.	5 years
Radiological Engineering	➢ Plan and control the radiation as low as reasonably achievable (ALARA) program; ➢ Calculate radiation dose and shielding and review radiation work permits.	5 years
Outage Management	▪ Plan and coordinate all outage activities; ▪ Central contact point for refueling, maintenance and forced outage management.	5 years
Nuclear Safety Review	• Responsible for off-site and on-site safety review activities, such as operating abnormalities, license and technical specification changes, and human performance program.	5 years
Quality Assurance	➢ Implement approved QA program through periodic audits and surveillances, ➢ Establish QA policy, develop QA procedures, and review organizational self-assessments.	6 years
Training	• Provide formal training for nuclear staff and instructors, • Coordinate training schedules and operate plant simulators.	5 years on the job experience

The ESA Academy provides training and learning programmes (www.esa.int/Education/ESA_Academy/About_the_training_and_learning_programme) addressed to different topics of the space sector. The ESA Academy Training and Learning Facility (TLF) is a facility of the ESA Education Office dedicated to hosting training sessions for university students. The training sessions, in different fields of expertise, are delivered by ESA scientists and engineers, ESA retired staff, University professor, Experts from space industry and research organizations. Other national space agencies like ASI (www.asi.it), FFG (www.ffg.at/en/service/education), and DLR (https://www.dlr.de/EN/organisation-dlr/dlr/education-and-outreach.html), have education and training programmes aimed to attract young people and graduate and PhD students. However, it is not specified if the mentioned education and training activities include also nuclear engineering topics and related aspects.

3.1.4 Environment *(ENEA Chiara Telloli / IST Rosa Marques)*

The use of environmental tracers and isotopic hydrology techniques help to characterize groundwater and surface water resources, recharge times, processes, etc., becoming a useful tool to counteract environmental damage due to climate change. The use of nuclear technologies in the field of hydrology has helped to improve the management of water resources not only in developed countries but in all countries of the world.

In recent years, isotope hydrology is developing more and more. Hydrologists use radioisotope analyses to characterize the presence of pollutants moving through groundwater and to assess the level of vulnerability of aquifers. This is important to evaluate water resources in different areas and to ensure the presence of adequate drinking water for human health, essential for life. Yet in many parts of the world fresh water has always been scarce and in others it is becoming so due to rapid climate change around the globe. For any new development, agricultural, industrial or human settlement, a sustainable supply of clean water is essential. Due to the scarcity of drinking surface water (also due to human pollution), groundwater is the largest source of fresh water, constituting 30% of the world's total.

Isotopic hydrology, based on the use of isotopes naturally present in water resources, makes it possible to characterize waters, since water has a specific "fingerprint" or isotopic composition. The isotopes within a source can be natural or man-made and can be stable or unstable (radioisotopes). Radioisotopes are generally used to know water age and processes, while stable isotopes can be used to determine source history, rainfall conditions, mixing/interaction characteristics of related water bodies, pollution processes and evaporation processes. The results enable the planning and sustainable management of these water resources. For example, the use of isotopes in surface waters can provide information on losses through dams and irrigation channels, lake and reservoir dynamics, flow rates, river flows and sedimentation rates. Neutron probes, increasingly used as environmental monitoring tools, can measure soil moisture very accurately, allowing for better management of soils affected by salinity, especially as regards irrigation.

There are about 60 countries, developed and developing, that have used isotope techniques to survey their water resources in collaboration with the IAEA. In addition to this, most countries use isotopic techniques to personally survey their water resources.

Every year there are research projects (HORIZON and other important research projects) and many scientific publications on the use of stable and radioactive isotopes for water characterization.
The use of radioisotope tracers is also used in food traceability, above all to evaluate the rate of possible pollutants present. Some radioisotopes harmful to the environment and to human health, following a nuclear accident, remain in the environment for a long time and if not monitored can cause serious damage. For this reason, the food is also monitored and controlled from a radiological point of view, using isotopic techniques such as gamma spectrometry. Other radioisotopes are naturally present in the environment, such as Rn-222 for example, which however must be continuously monitored using alpha radiometry isotopic techniques.

Based on the information gathered, the main nuclear technologies for environmental applications are:

- ***alpha spectrometry*** *for the characterization of alpha emitters (eg Rn-122) in the environment or emitted by building materials;*
- ***beta spectrometry*** *for the determination of tritium or chlorine-36 in water (aquifer dating); for the determination of 14C for archaeological and paleoclomatic dating (knowing the past we can imagine the future)*
- ***gamma spectrometry*** *for the determination of gamma radioisotope emitters in the environment linked to nuclear accidents or to identify any illicit nuclear tests (e.g. Xenon-133, Cesium-137)*

To apply these technologies, laboratory personnel must have scientific skills, but not only.

- *Radon danger chemist, geoscientist; geologist, physicist; environmental science*
- *Gamma radiation at the earth's surface to provide insight into microphysical processes occurring high in the clouds, astronomy; aerospace engineer; calculation methods; physicist*
- *Characterization of tritium to define aquifers chemist, geoscientist; geologist, physicist; environmental science*
- *Pollution of sediment/soil/water by radioactive contaminants chemist, geoscientist; geologist, physicist; environmental science*
- *Radioxenon background astronomy, chemistry, geoscientist; geologist, physicist; environmental science*
- *Waste water from industry or hospital chemist, geoscientist; geologist, physicist; environmental science*
- *Radioactivity in food chemistry, geoscientist; geologist, physicist; environmental science*

Nuclear techniques are not applied on a daily basis by all research centres, but by specific centres for monitoring environmental radioactivity. The IAEA is the world's center for cooperation in the nuclear field and seeks to promote the safe, secure and peaceful use of nuclear technologies. Through the website (https://www.iaea.org/) they promote initiatives, events, training courses, projects to improve the use of nuclear technologies in favour of the environment.

Besides that, each country has its own research centre that can develop and use such technologies, with a few examples given below:

In Portugal, the national regulator APA (Portuguese Environment Agency) Serviços Centrais, Rua da Murgueira, 9 - Zambujal - Alfragide | 2610-124 Amadora (pedro.rosario@apa.pt)

CTN - Technological and Nuclear Campus (IST) (jgalves@ctn.tecnico.ulisboa.pt and jmarques@ctn.tecnico.ulisboa.pt) is a research centre where R&D is performed, Advanced Training & Education, Consulting and other Services in Nuclear Sciences and Technologies, being a strategic center for the Portuguese R&D and innovation policies in this area.

The National Regulatory Authority of Portugal is composed of the competent authority, the Portuguese Environment Agency (APA) and the inspection authority, the General Inspectorate of Agriculture, Marine, Environment and Planning territory (IGAMAOT), both controlled by the Ministry of the Environment. Both the APA and IGAMAOT are functionally separate from any other bodies or organizations interested in promoting or using practices, ensuring effective independence from undue influence on their regulatory functions. APA represents Portugal at ENSREG, OECD/NEA and IAEA.

In Italy, ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) - Fusion and Technology for Nuclear Safety and Security Department - which deals with the monitoring of environmental radioactivity linked to research projects.

In Budapest, the Centre for Energy Research, Department of Nuclear Analysis and Radiography, 29 33 Konkoly Thege street, 1121 Budapest, Hungary
juhasz.peter@ek-cer.hu; kasztovszky.zsolt@ek-cer.hu; baranyai.rozsa@ek-cer.hu

In Hungary, ATOMKI - Institute for Nuclear Research, Hungarian Academy of Sciences. Radiation and Environmental Protection Group director@atomki.hu; Dajko@atomki.hu

3.2 Data analysis of surveys

3.2.1 Radiopharmacy / Radiochemistry *(IST Antonio Paulo / NCBJ Katarzyna Deja)*

Although a specific survey on Human Resources (HR) in Radiopharmacy/ Radiochemistry in Europe was not launched in task 1.3, some data on the radiochemistry workforce could be obtained from the more general ENEN2+ survey on HR in the nuclear sector. There were answers to this survey from ten European organizations, including regulatory authorities, R&D institutes and technical safety organisations (TSO). ***The data from this survey showed that the employees involved in radiochemistry account for 2.5% of the nuclear experts operating research reactors.*** Less than 1% of the utility workforce staff are radiochemistry experts and ~2% are involved in the regulatory authority and technical safety organization. In the ENEN2plus survey on HR in the nuclear sector, only one answering organization was involved in the study/production of medical radionuclides. The surveyed organisations were asked to estimate the percentage of the change in their organization's staff number in 10 years, regarding today's numbers. Through responses it is reported that ***the majority of the participants believe that in 10 years their radiochemistry staff will have increased less than 10 percent.*** Institutions answered also open-end-questions. ***Survey results show that organizations have problems finding skilled workers specialized in radiochemistry. Such issues need to be addressed in order to support the increased production of radiopharmaceuticals through the development of existing and new nuclear power facilities.***

3.2.2 Medical Physics *(EFOMP Dimitris Visvikis)*

Data reported here was gathered by a survey carried out by EFOMP at the end of 2022 interrogating all 27 EU countries' national medical physics organisations, members of EFOMP. The information gathered from this survey concerned (i). education and training; (ii). workforce availability and (iii). workforce planning. According to the results there are 9809 medical physicists in Europe, with a mean of 21 per 1,000,000 inhabitants. These numbers concern all different medical specialties within medical physics (radiology, radiotherapy, nuclear medicine). The specialty training programmes for medical physicists varies largely from 1 to 7 years depending on the country with an average of 3.2 years. Similar disparities can be noted within the context of radiation protection training which varies from none to more than 52 weeks. In terms of demographics approximately 7% will retire in the next 5 years and 22% are more than 51 years old.

Table 3: Statistics on medical physicists and training duration in the EU countries

Country	***Medical Physicists numbers***	***Medical Physicists numbers / 1M inhabitants***	***Specialty training (years)***	***Training in radiation protection (weeks)***
Austria	239	27	3	2
Belgium	250	21	1	N/A
Bulgaria	82	12	5	2
Croatia	67	17	N/A	N/A
Cyprus	30	24	1	N/A
Czech Republic	153	15	5	N/A
Denmark	150	26	3	2-4
Estonia	27	20	2	N/A
Finland	150	27	5	>52
France	850	13	2,5	None
Germany	3000	36	5	>52
Greece	350	33	2	12-24
Hungary	80	8	4	4-12
Ireland	160	32	2	N/A
Italy	1200	20	3	>52
Latvia	30	16	N/A	None
Lithuania	12	4	2	16-24
Malta	18	35	2	16-24
Netherlands	420	24	4	28-52
Poland	369	10	N/A	N/A
Portugal	120	12	7	N/A
Romania	250	13	2	N/A
Slovakia	120	22	2	16-24
Slovenia	32	15	N/A	16-24
Spain	1200	25	3	16-24

Sweden	450	43	5	N/A
Total	***9809***	***550***		
Mean		***21***	**3.2y**	
Max		***43***	**7y**	**>52 weeks**
Min		***4***	**1y**	**None**

Within the context of overall professionals' numbers working within the medical field using ionising radiation (including radiologists, nuclear medicine physicians, radiation oncologists and radiographers both in therapy and diagnostic applications), a survey carried out by the EU-REST project (http://www.eurosafeimaging.org/eu-rest) reveals that ***the medical physicists represent 3,9% of the overall workforce within the medical applications field using ionizing radiation***.

4 GENERAL CONCUSIONS

This report contains information on the current situation of the workforce and associated education and training requirements for non-power applications using ionising radiation. These applications include the fields of medical, space and environment. Within the medical field only physics and radiochemistry/radiopharmacy were considered, with no specific consideration for other purely medical specialities (radiology, radiation oncology, nuclear medicine doctors) and other support roles (diagnostic and therapy radiographers/technologists) which were deemed outside the scope of ENEN2+ programme. The information was obtained through both literature review but also within the context of medical applications through surveys sent out to relevant professional societies in the EU member countries. No hard numbers were obtained for the human resources requirements in the field of space and environment since they represent niche applications based on well identified national metrology institutions (in the case of environment) and publicly funded research and development projects (in the case of space). In terms of education and training requirements in these areas physicists clearly need the basic training required in the nuclear power sector as competences are similar. These need to be complemented by additional specialised training in the space or environmental applications that can be achieved through specialised postgraduate degrees and/or spending time within appropriate institutions carrying out this type of work.

Below there is a compilation of the main conclusions for the different application fields in terms of human resources:

- Based on a survey of the EU countries' professional societies in medical physics, there are a total of nearly 10,000 medical physicists representing 3.9% of the overall workforce within the medical applications field using ionizing radiation (including medical doctors and radiographers/technologists). These numbers concern all different medical specialties within medical physics (radiology, radiotherapy, nuclear medicine).
- A mean of 21 physicists per 1M inhabitants with large variations amongst EU countries (4 to 43 per 1M inhabitants)

- Substantial demographic issue with 7% retiring within the next 5 years and 22% >51 years old.
- Based on existing publications the numbers of radiopharmacists / radiochemists correspond to between 3.5% and 5.2% of the nuclear medicine workforce (including medical physicists, nuclear medicine physicians, radiographers/technologists, nurses).
- Based on survey results from ten European organizations, including regulatory authorities, R&D institutes and technical safety organisations, the radiochemists represent 2.5% of the nuclear experts operating research reactors.
- Based on the same survey, most of the participants believe that in 10 years their radiochemistry staff will have increased by <10%.
- Radionuclide therapies will play an increasing role in nuclear medicine with an expected impact in the recruitment of medical physicists / radiopharmacists /radiochemists by the different entities involved in the field (companies, hospitals, research centres, etc).
- Human resources needs for nuclear space applications are closely related to the market demand in all the segments of power related nuclear applications.
- In the field of nuclear techniques for environmental applications they are largely concentrated in a few specialised centres for monitoring environmental radioactivity.

Below there is a compilation of the main conclusions for the different application fields in terms of education and training:

- The minimum entry to a medical physics training programme is a BSc degree in physics. In certain cases, alternative degrees including BSc in engineering sciences is considered as an appropriate entry level. A postgraduate degree (MSc in medical/radiation physics) is included as a requirement amongst the most recently revised core curriculum guidelines issued for radiotherapy medical physics experts.
- The specialty training programmes for medical physicists varies largely from 1 to 7 years depending on the country with an average of 3.2 years. 25% to 75% of this period (depending on each EU country) covers the practical component within an appropriate clinical environment.
- Most guidelines recommend a 10-15% of the total ECTS dedicated to radiation protection.
- Following training and qualification as a medical physics expert, continuous education for professional development is considered mandatory.
- Survey results show that organizations have problems finding skilled workers specialized in radiochemistry.
- There is a need for standardisation and harmonisation of certification systems of professionals within the medical field using ionising radiation (physicists, radiochemists/radiopharmacists).

- The core curriculum for the training of medical physicists in radiotherapy have been recently revised from EFOMP/ESTRO. Similar revisions are needed for nuclear medicine and radiology. During these revisions it is necessary to consider new topics such as artificial intelligence (AI).
- Main nuclear technologies for environmental applications are alpha, beta, and gamma spectrometry. Expertise required in the field include chemistry, physics, geology, environmental science.
- Main nuclear technologies for space applications, are energy propulsion and generation, radiation detectors. Expertise required in the field include nuclear engineering, reactor physics, nuclear materials and chemistry, reactor systems and engineering, thermal hydraulic, safety and radiological protection), already present in the community of scientists, technologists, engineers, and physicists, involved in nuclear field worldwide.

5 RECOMMENDATIONS

5.1 RECOMMENDATIONS FOR EDUCATION

- Development of updated core curricula should feed through postgraduate courses for training of medical physicists in the different areas related to the use of ionizing radiation.
- Development of continuous education programmes for the different professional categories in order to allow existing professionals to become familiar with new technologies and AI.
- Promote, organize, and value double training (Space + Nuclear, Environment + Nuclear) for students interested in these interdisciplinary areas. These programs should follow similar training practices already implemented in the medical applications sector for Medical Physicists.
- Information / sensibilization initiatives could be organized towards engineering universities or engineering schools in order to identify and motivate possible young candidates for these very high potential careers
- A more effective connection between industry and both, research and academic fields, to establish a sustainable network gathering industrial facilities and research infrastructures, all over Europe, allowing to perform specific and effective E&T programmes in non-power nuclear applications.

5.2 RECOMMENDATIONS FOR POLICYMAKERS

- The estimations vary depending on the country therefore a pan-European overview of HR situation, periodically updated, is strongly recommended. The successful HR planning of the European nuclear workforce should be based on reliable numbers of staff in all organizations mentioned

- Harmonise training throughout the EU countries for scientific professionals in non-power nuclear applications
- Harmonise certification throughout the EU countries for scientific professionals in non-power nuclear applications. There are specific efforts currently underway by pan-European professional organisations (such as the EFOMP in the medical physics applications arena) but such efforts need to be supported by future EU legislation (such as for example the specialist definition of a medical physicist in ESCO).
- Fund training residency programs throughout the 27 EU country members to reduce variability in RP training (RP 174) of medical physicists in the EU.
- Encourage specialisation of priority areas in non-power nuclear applications through economic incentives and simplified procedures for the mobility within and towards Europe, of new graduates or students in relevant scientific fields.
- Demographics need to be followed closely and more systematically in order to appropriately account for the number of new trainees needed to cover the responsibilities of different categories of scientific professionals in non-power nuclear applications. This applies certainly to medical physicits but also to other non-power nuclear based professions
- Large variations are observed in the mean number of professionals / 1M inhabitants throughout the 27 EU country members. The source of these variations need to be further investigated and authorities should harmonise guidelines for service providers in each of the professional categories considered.

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