Deliverable 5.1

Questionnaire on industrial and clinical key players and needs

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Authors	**Maija Radzina, Edgars Mamis, Laura Saule, Elina Pajuste, Marika Kalnina (LU), Thomas Cocolios (KULeuven), Zeynep Talip (PSI), Thierry Stora (CERN)**
Reviewer	**Mikael Jensen (DTU), Ulli Köster (ILL)**

Point of Contact	**Maija Radzina**
Institution	**University of Latvia (LU)**
E-mail	**mradzina@gmail.com**
Phone	**+371 29623585**

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Contents

Abbreviations, Participant short names

Abbreviations

MR	Magnetic resonance imaging
NM	Nuclear Medicine
PET	Positron emission tomography
RND	Radionuclide
SPECT	Single-photon emission tomography

Participant short names

CERN	European organization for nuclear research
NPL	National Physical Laboratory
PSI	Paul Scherrer Institut
CEA	Commissariat à l’énergie atomique et aux énergies alternatives
IST-ID	Associação do Instituto Superior Técnico para a IST-ID Investigação e Desenvolvimento
DTU	Danmarks Tekniske Universitet
CHUV	Centre hospitalier universitaire vaudois
GANIL	Grand Accélérateur National d’Ions Lourds
SCK CEN	Studiecentrum voor Kernenergie / Centre d'étude de l'énergie nucléaire
ARRONAX	Groupement d’intérêt public ARRONAX
ESS	European spallation source ERIC
TUM	Klinikum rechts der Isar der technischen Universität München
KULeuven	Katholieke Universiteit Leuven
MedAustron	Entwicklungs- und Betriebsgesellschaft MedAustron GmbH
SCIPROM	SCIPROM Sàrl
MUI	Medizinische Universität Innsbruck
ILL	Institut Max von Laue - Paul Langevin
JRC	JRC -Joint Research Centre- European Commission
NCBJ	Narodowe Centrum Badań Jądrowych
GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH
LU	Latvijas Universitāte
INFN	Istituto Nazionale di Fisica Nucleare
UiO	Universitetet i Oslo

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Summary

This document is a summary of responses received from the public known European industrial manufacturing and research institution and clinical facility representatives. The responses were given to the PRISMAP Consortium questionnaire disseminated in January-August 2022, approaching radionuclides and radiopharmaceutical **manufacturers**, research institutions and clinical end users in nuclear medicine, with the aim to identify potential stakeholders in the industrial and clinical communities interested by a coordinated approach in Europe such as PRISMAP.

The summary from PRISMAP questionnaire stratifies the feedback from 114 respondents: radionuclide and radiopharmaceutical producers, research facilities and preclinical/clinical end users. In addition, it gives an insight into the location and capabilities of the main isotope-producing cyclotron facilities, many of which are known from the IAEA cyclotron database [2]). The questionnaire was offered with an opportunity to make new research and international collaboration partners, where all parties could benefit from harmonised supply and legislation procedures, expanding network and distribution routes, and subsequently gain visibility within the PRISMAP User Forum map at www.prismap.eu. The questionnaire was focused on the radionuclide use in medicine with emphasis on future needs for specific radionuclides and possible research developments with awareness of legislation, logistics and involved personnel education challenges and future perspectives.

The data allow to draw a map with the presently collected data in the Europe. The majority of responses come from Western Europe, most notably the Benelux, France and Italy. More emphasis will be needed for reaching out to responders from South-East Europe regions.

The most often used emerging imaging technologies at respondent's institutions are SPECT/CT software advances (quantification, 3D dynamics etc.) and PET new generation cameras with extended axial field of view, optimised image and dose reduction. Advances in radionuclide therapy are also reported, where radionuclides that would be of interest for use in the research institutions within next 2-5 years are ^{64}Cu (50%), Terbium radionuclide "family" (37%) and alpha emitters, such as ^{225}Ac (67%).

The data also confirmed needed improvements for preclinical/clinical users - unified licensing and registration of available radionuclides and kits in Europe, specified equipment/technology (e.g., collimators etc.), database of available radionuclide suppliers with geographic location and information about transport and logistics networks in the Europe.

The data found common aspects from all producer-facility respondents: the biggest challenge for the producers is the availability of target materials, which goes hand-in-hand with their purity/enrichment grade. Increased demand and focus on higher isotopic purity, as well as current geopolitical developments strain the supply chain, leading to price increases and availability issues. Ultimately these factors can limit the future output of some of our novel products.

From the responses we can confirm the necessity of PRISMAP not only as a web-based entry platform for the production and dispatch of non-conventional radionuclides, but also as a long-term platform for aiding an advancement in, at the moment, emerging radionuclide distribution and their use in research and clinical nuclear medicine. 86% of the respondents expressed that the PRISMAP Consortium efforts would bring benefit in their research and development activities and elaborated on their needs for higher availability of radiopharmaceuticals, sharing the new research protocols across countries, to produce more reliable and stronger evidence data and speeding up the implementation of new radiotracers in clinical practice and collaboration with producers of emerging radionuclides.

This document also contains the existing portfolio and the list of the facilities involved in the production and research of the radionuclides and radiopharmaceuticals to develop access and collaboration pathways to translational research facilities for the industrial and clinical communities (see Appendix Nr. 2).

The information collected will be used to evolve the PRISMAP common interface WP1-TNA1 and it will naturally interface with WP2-TNA2 and WP3-TNA3 services to evolve the services to meet the industrial and

clinical researcher needs. The feedback for further development will be collected through the Industrial Board and the User Forum, to foster the industrial and clinical collaboration. Identified needs of industrial and clinical end-users will enrich and help to update the PRISMAP product and service portfolio accordingly with the aim to unify the currently scattered industrial and clinical landscape in nuclear medicine.

1. Introduction

PRISMAP – The European medical isotope programme: Production of high purity isotopes by mass separation proposes 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 will create a single-entry point for a fragmented user community distributed amongst universities, research centres, industry and hospitals, in a similar way as how the National Isotope Development Centre NIDC, supported by the Department of Energy (DOE), has provided radionuclide sources for users in the USA.

PRISMAP brings together a consortium of 23 beneficiaries from 13 countries, one European Research Laboratory and an International Organisation (see Figure 1). It further receives 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).

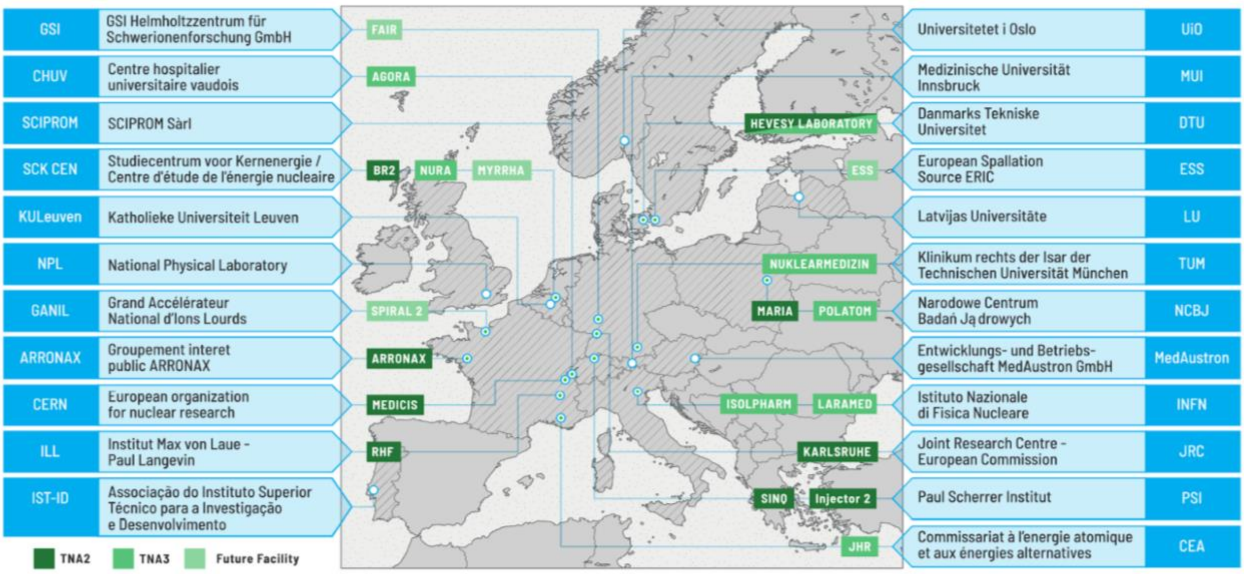

Figure 1. PRISMAP Consortium

The PRISMAP work package WP5-TNA2 takes care of the questionnaire on industrial and clinical key players and their needs. The PRISMAP Consortium questionnaire was disseminated in January-September 2022. The aim of the survey was to identify potential stakeholders in the industrial, research and clinical communities in the context of PRISMAP and investigate the needs of industrial, scientific and clinical end users in nuclear medicine and also analyse current facility profiles, geographic location, capabilities, licensing, logistics, future research and development perspectives, challenges and needs for collaboration and improvement.

2. The European medical radionuclides programme PRISMAP Questionnaire

2.1 General aspects

2.1.1 Respondents

A total of 114 respondents from 104 companies and institutions completed the survey. Respondent institutions were from 30 countries - 20 from Netherlands, 12 from France, 12 from Italy, 6 from United

Kingdom, 6 from Belgium, 5 from Switzerland, 3 each from Germany, Greece, Finland, Estonia, Czechia, Spain and Latvia, 2 each from Denmark, Austria, Romania, Armenia, Slovakia and Poland and 1 each from Sweden, Portugal, Turkey, Norway, Slovenia, Cyprus, Hungary, Azerbaijan, Croatia, Serbia, Lithuania and 1 from International Organisation across Switzerland-French border. The number of respondents may be amplified in some countries because several respondents filled the survey from the same institution, complementing the data or filling in different fields of interest - either as a manufacturer, researcher and end-user.

The survey responses covered most of the PRISMAP consortium member countries. The greatest activity comes from central Europe, but more emphasis is needed for reaching out to responders from South-East countries (see Figure 2)

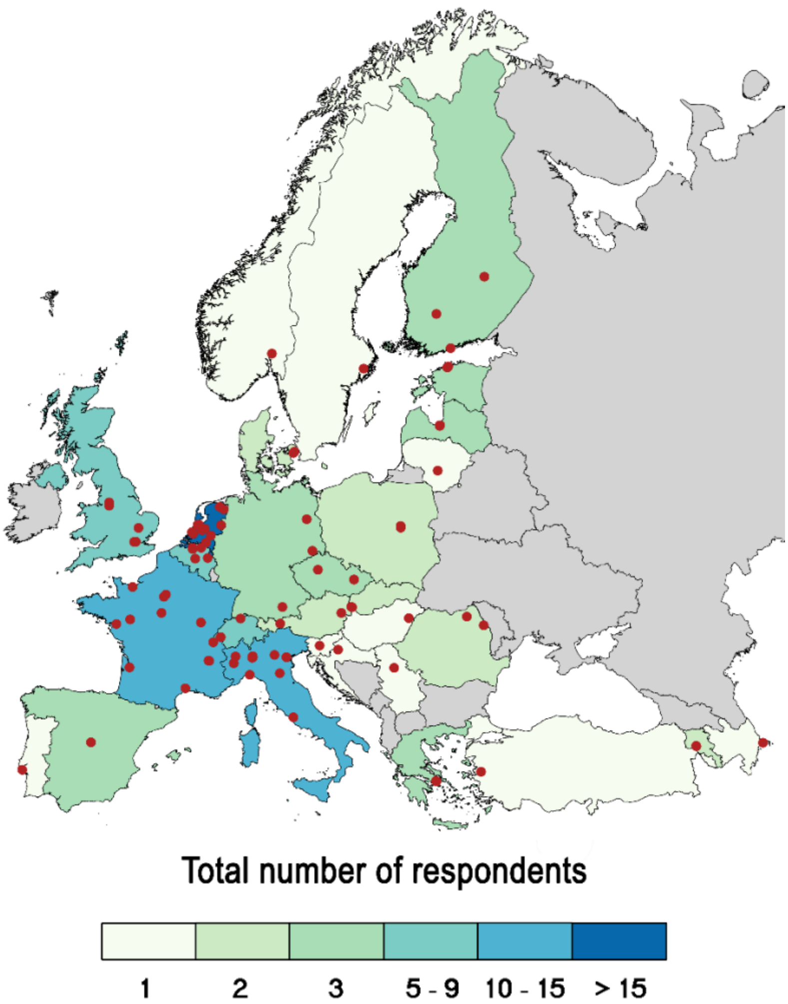

Figure 2. Map of respondent countries

2.1.2 General profile

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.).

40 respondent institutions are preclinical/clinical users (22 from clinical hospitals, 10 from research institution-hospital collaborations, 4 from preclinical research institutions, 2 CRO companies, 1 private clinic and 1 manufacturer and ambulatory clinical nuclear medicine centre). 16 respondents represent manufacturing facilities (4 radionuclide production and 12 radionuclide/radiopharmaceutical production facilities), see Figure 3 and Figure 4.

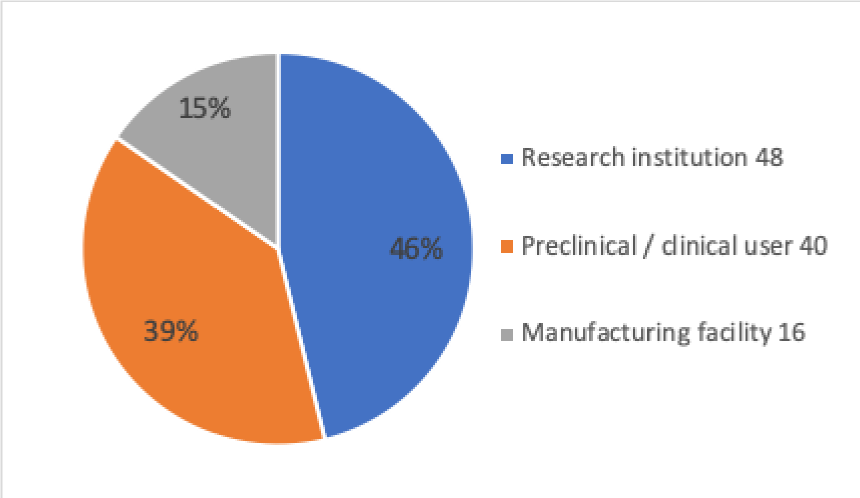

Figure 3. General profile of questionnaire respondents

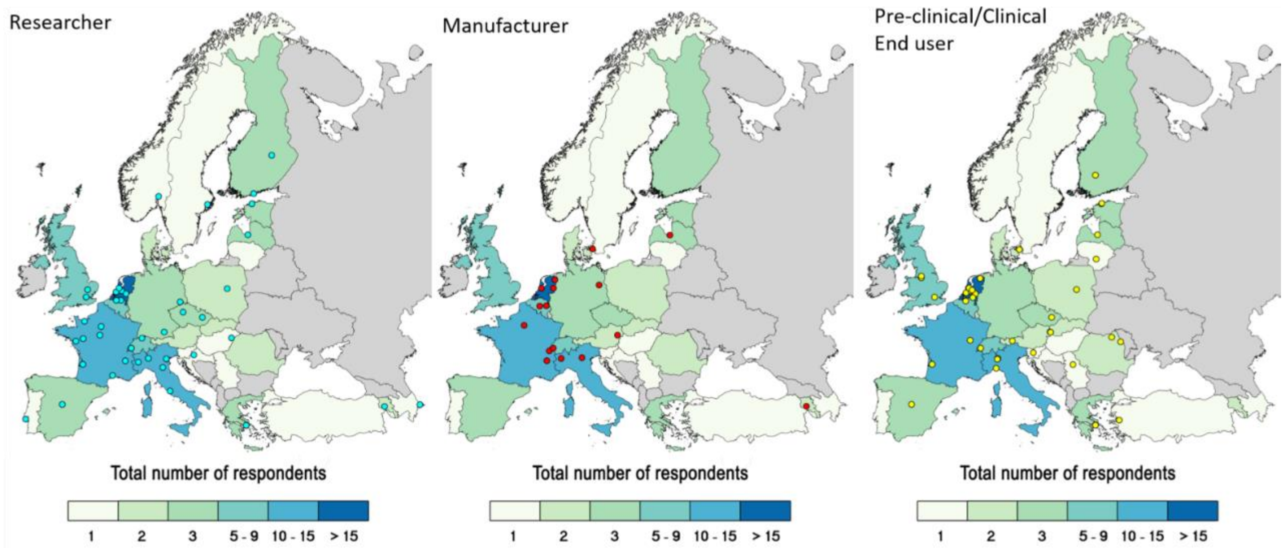

Figure 4. Questionnaire respondent map with representation by institutional type

2.1.3 Research field and interests

The main research areas of respondents were - radiopharmaceutical synthesis and development (40 respondents), pre-clinical studies (34 respondents), radiochemistry (32 respondents) radionuclide/radiopharmaceutical QC and analysis (26 respondents), radionuclide production (23 respondents), clinical trials and studies (19 respondents), radiopharmaceutical precursor development (16 respondents), radionuclide purification (15 respondents), radionuclide production target development (14 respondents) and radionuclide characterization and calibration (12 respondents).

Some other, more specific research interests were mentioned, such as neutron scattering and nuclear physics; radionuclide radiobiology; nanodosimetry; medical physics; synthesis of porous materials and characterization of solid materials by various tools (NMR, IR, Raman spectroscopy, DRX); biological effects of radionuclide therapies; policy-supporting research; studies for policy makers (availability of medical radionuclides); social sciences (patient perception); breast and vascular imaging and interventions; safety culture; clinical audit of medical exposures, dose measurements and modelling. Also included are a laboratory that has collaboration with the facility for Positron physics. A Pelletron low energy 3 MeV single-ended electrostatic accelerator plus a 1.5 MeV deuteron accelerator that can produce neutrons for material studies and radionuclide production was especially pointed out.

2.1.4 Research infrastructure

The most often mentioned equipment that respondents have for research purposes were - animal SPECT/CT or SPECT/MR (32 respondents), animal PET/CT or PET/MR (30 respondents), experimental long term animal facilities after radiation exposure (20 respondents), PET, PET/CT or PET/MR and SPECT, SPECT/CT or SPECT/MR (17 respondents each). Most popular SPECT, SPECT/CT and PET, PET/CT animal systems were Triumph, Siemens Simbya, Vetor 5 MILABS, Bruker and GE. In their practices, respondents also use planar scintigraphy (7 respondents), gamma spectrometers (4 respondents) but based on the research interest the actual users for such equipment must be higher. Alpha spectrometers (4 respondents) and autoradiography (3 respondents) were also mentioned.

Other equipment that participants mentioned were: LSC systems, detectors for ionising radiation measurements, dosimetry calculation systems, variable energy cyclotrons, hot-cells, high purity Germanium gamma detectors, e.g., for NAA and PGAA characterisation of samples or characterisation of radionuclides. Also identified was equipment for molecular and cell biology analysis, biochemistry, physico-chemistry, formulation, pharmaceutical sciences, ICP-MS/OES, dose calibrators and separation panels. More exotic equipment listed was the Vector 6_IMB Versatile Emission Computed Tomography system (VECTor) that enables simultaneous sub-millimetre imaging of single-photon and positron-emitting radiolabelled molecules.

In addition, the need for and use of Radiochemical Laboratories; Physics measurements Laboratories; micro-SPECT-PET-CT, small animal SPECT-PET-CT, IBA Cyclotron, MRI 3T and 7T, Radiochemical Laboratory; Physics measurements Laboratories and Siemens CT/PET Flow; FlowMotion; Discovery MI PET CT system, which is state-of-the art 5 ring 2022 installation.

Animal imaging facility with PET/CT, small animal MR and dose calculation and modelling tools, small animal imaging and radionuclide therapy facility, precision X-ray irradiator for animals, radio-HPLCs, radio-TLCs, gamma counters, phosphor imager, synthetic chemistry labs, radiochemistry laboratories and QC labs. Equipment for in-vitro studies, Endoradiotherapy in small animals intended, MRI (7T, 3T, 1T), optical imager, hot ICPMS, hot TIMS, LSC counters, optical/fluorescent imaging, radiochemistry laboratories, tissue and cell culture labs, 68Ge/68Ga generator, digital autoradiography equipment (e.g., Fujifilm FLA-5100 and Ai4R BeaQuant), scintillation counters, gamma counters, such as (Wizard) for ex vivo biodistribution, Microbeta for autoradiography and NMR. Irradiation facilities with 60Co source and X-ray source, radiopharmaceutical production laboratories, animal optical imaging equipment and animal ultrasound were also indicated.

2.1.5 End user questionnaire

A total of 40 respondent institutions of this survey were preclinical/clinical users. 19 of the respondents conducted both preclinical and clinical studies, 15 respondents only clinical studies, 2 respondents - only preclinical studies and 4 respondents - other types of studies, such as medical physics, drug biodistribution, drug selection, fundamental (analytical methods), medical research. 15 respondents represent personal/individual assessments, 8 respondents - private institutions, 7 respondents - governmental institutions, 4 respondents - non-governmental, national society, 2 respondents - non-governmental, international society, 4 respondents - other (Medical Cluster (non-governmental non-profit organisation), University Medical Centre). 34 of respondents provide diagnostic, therapeutic and theranostic services, 2 respondents - both diagnostic, therapeutic services, but not theranostic. 4 respondents provide just diagnostic services and one respondent - just theranostic services.

For routine clinical practice 36 respondents have PET, PET/CT or PET/MR, 33 respondents - SPECT, SPECT/CT or SPECT/MR, 28 respondents - planar scintigraphy, 16 respondents - animal PET/CT or PET/MR, 13 respondents - experimental long term animal facilities for radionuclide therapy studies and 12 respondents - animal SPECT or SPECT/CT. The most popular models were SIEMENS, GE-Healthcare, Philips Vereos, Siemens biograph mct flow PET/CT, GE DMI (2 scanner), GE discovery 860, GE discovery 830, Siemens Symbia T6 and Intevo Bold, PET/CT Biograph 64, Biograph Vision MILabs: Vector.

Frequently used emerging technologies that respondents' institutions have: SPECT/CT software advances (quantification, 3D dynamics etc.) (21 respondents), PET new generation cameras with extended axial field of view, optimised image and dose reduction (20 respondents). Respondents also mentioned Artificial Intelligence in Nuclear Medicine (7 respondents), Dedicated cardiac SPECT camera (6 respondents), and CZT cameras (4 respondents).

When questioned about emerging imaging technologies that respondents would like to work with in their facilities in 2-5 years, similar answers were obtained - Artificial Intelligence in Nuclear Medicine - 23 respondents, PET new generation camera with extended axial field of view, optimised image and dose reduction - 20 respondents, SPECT/CT software advances (quantification, 3D dynamics etc.) - 13 respondents, CZT camera - 8 respondents, dedicated cardiac SPECT camera - 3 respondents, PEM - positron emission mammography and Dedicated cardiac PET camera - 2 respondents each.

All respondents perform studies in oncology, while inflammation studies were reported from 32 respondents, cardiology - 31 respondents, neurology - 30 respondents, endocrinology - 29 respondents, nephrology - 24 respondents, pulmonology - 23 respondents, traumatology-orthopaedics - 22 respondents. A similar scene was seen about studies which respondent's facility plan to implement within the next 2-5 years. Most abundant answers were oncology (23 respondents), inflammation (20 respondents), neurology and cardiology (16 respondents each), endocrinology (13 respondents) and pulmonology and traumatology/orthopaedics (12 respondents each).

Nuclear medicine clinics, preclinical and clinical users currently use the following non-conventional radionuclides in their studies: 177Lu (32 respondents), 68Ga (29 respondents), 111In (23 respondents), 90Y (21 respondents), other alpha emitters (17 respondents), 225Ac (8 respondents), 64Cu (6 respondents) and Terbium isotopes (4 respondents) (see Figure 5). Other isotopes mentioned were 223Ra, 89Zr, 166Ho, 131I, 123I, 212Pb, 89Sr and 153Sm. Some of the radionuclides of terbium and scandium that are very promising, are not yet utilised in the clinical environment because of their poor availability at the time of the questionnaire.

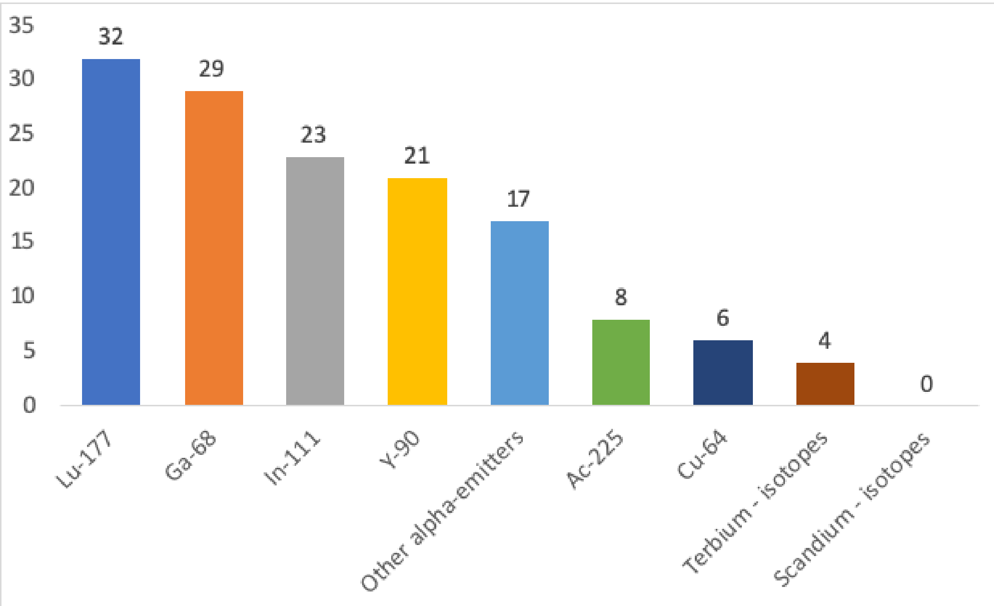

Figure 5. Novel radionuclides used by end users

Novel radionuclides that respondents would be interested to use in the next 2-5 years were ^{225}Ac (27 respondents), ^{64}Cu (20 respondents), ^{68}Ga (19 respondents), ^{177}Lu (17 respondents), and other alpha emitters (16 respondents) and Terbium isotopes (15 respondents). See Figure 6 for other radionuclides that end users would be interested in. Here we can conclude that the demand for ^{225}Ac and the terbium "family" from research institutes will increase significantly in the following years. The foreseen application possibilities and an increasing demand for these radionuclides also point out the low availability of them at the moment, either by production capacity or required amounts or purity grade.

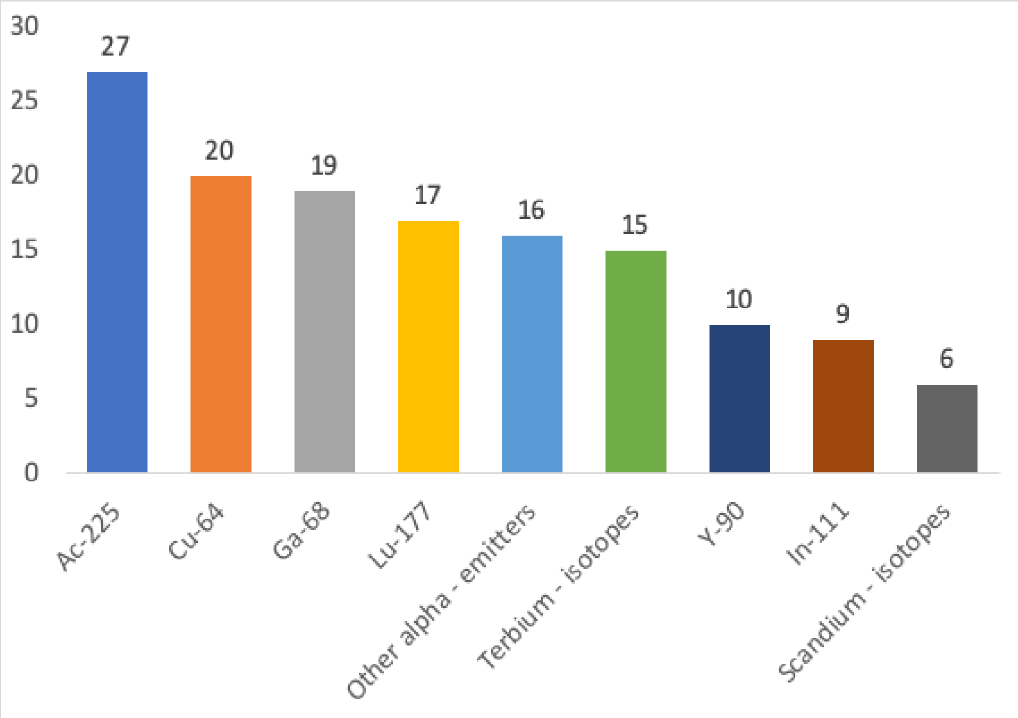

Figure 6. Radionuclides that respondents would be interested to use in the next 2-5 years

If we look at the current radionuclide use for theranostics, the most popular pairs were 123I-131I as Iodine (23 respondents), [68Ga] Ga- DOTA-peptides - [177Lu] Lu-DOTA-peptides (22 respondents), [64Cu] Cu-peptides- [177Lu] Lu-peptides (20 respondents), 99mTc-223RaCl2 for skeletal metastases (19 respondents), [18F] PSMA - [177Lu] Lu-PSMA (17 respondents) and [123I] mIBG – [131I]-mIBG (11 respondents).

Most often mentioned theranostic pairs that respondent would be willing to use in the future were [64Cu] Cu-peptides-[177Lu] Lu-peptides (17 respondents), [18F] PSMA - [177Lu] Lu-PSMA (16 respondents), [68Ga] Ga- DOTA-peptides - [177Lu] Lu-DOTA-peptides (14 respondents), [68Ga] Ga-PSMA - [177Lu] Lu-PSMA (13 respondents) and [18F] NaF – 223RaCl2 for skeletal metastases (8 respondents).

We observed that none (except for iodine radiopharmaceuticals) of the current responder institutions yet are interested in possibilities of "matched pair" from terbium and scandium radionuclides in the near future, this probably reflect the still insufficient pre-clinical data and/or availability of such radionuclides.

Improvements that preclinical/clinical users need for daily practice are unified licensing and registration of available radionuclides and kits in Europe (32 respondents), information about transport and logistics network in Europe (22 respondents), database of available radionuclides and the geographic location of the supply site (20 respondents), and some specified equipment/technologies (e.g., collimators etc.) (18 respondents). On-site training with the visit of international experts is also a wish (16 respondents) as is outsourced crucial training for technical personnel (13 respondents) and medical doctors (12 respondents).

There is a necessity to send patients to other countries for specified nuclear medicine examinations and/or treatment procedures due to unavailability of the specific radiopharmaceuticals (17 respondents), a lack of reimbursement by the national healthcare system (9 respondents) and unavailable radionuclide for radiopharmaceutical production (7 respondents).

2.2 Radionuclide production

Out of 64 respondents from research institutions and manufacturing facilities, 31 respondent companies or institutions produce radionuclides. Most respondents listed multiple methods and equipment of radionuclide production. For radionuclide production respondents mainly use cyclotrons (23 respondents), radionuclide generators (15 respondents) and nuclear reactors (8 respondents).

3 respondents indicated radionuclide production equipment, such as synchrotron high energy proton beam dump which in Europe is uniquely used by CERN-MEDICIS, natural thorium and accelerator driven subcritical neutron sources. None of the surveyed respondents indicated any other source for radionuclide production such as linear accelerators. See Figure 7.

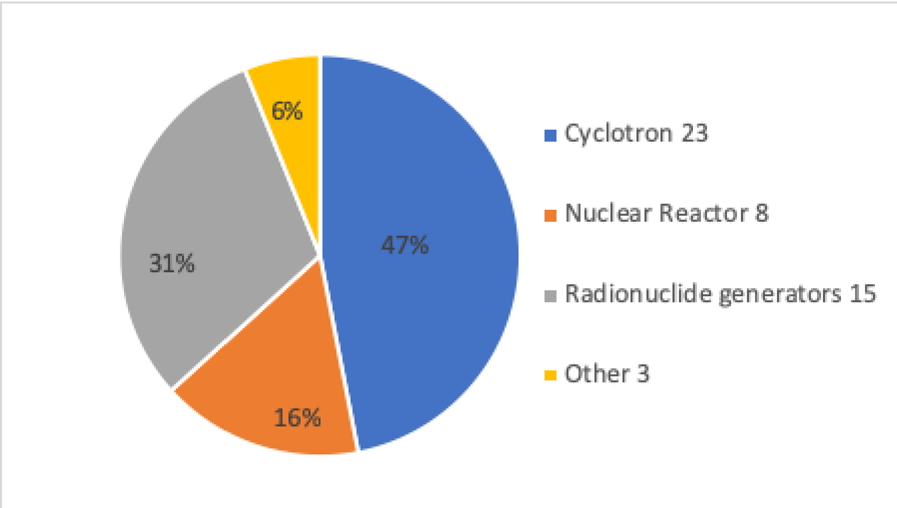

Figure 7. Radionuclide production source

Main radionuclides produced by the respondents are ^{68}Ga (15 respondents), ^{64}Cu (8 respondents), ^{99m}Tc (9 respondents), ^{11}C (8 respondents), ^{18}F (11 respondents), ^{161}Tb (7 respondents), ^{177}Lu (7 respondents), ^{67}Cu (6 respondents), ^{89}Zr (5 respondents), ^{44}Sc (2 respondents), ^{123}I (4 respondents), ^{124}I (4 respondents), ^{188}Re (4 respondents), ^{90}Y (3 respondents), ^{225}Ac (3 respondents), ^{52}Mn (4 respondents), ^{67}Ga (3 respondents), ^{165}Er (3 respondents), ^{223}Ra (2 respondents). See Table 1 for production of radionuclides by countries.

As it is proven by the end-user questionnaire there is amongst the research user community an increasing demand for the alpha emitting radionuclide ^{225}Ac, which has been indicated as being produced by three of the survey respondents. PRISMAP consortium members offer ^{225}Ac to the users from two sites - JRC Karlsruhe and CERN-MEDICIS. The aim to indicate more sites that would offer such increasing demand for radionuclides is still an open objective with high importance.

Table 1. Production of radionuclides

Nr.	Respondent	Radionuclides
1	Denmark Technical University (Denmark)	^{64}Cu, ^{67}Cu, ^{18}F, ^{52}Mn, ^{135}La
2	Sacro Cuore Hospital (Italy)	^{52}Mn, ^{53}Mn, ^{54}Mn,^{64}Cu,^{67}Cu, ^{68}Ga, ^{89}Zr, ^{99m}Tc, ^{123}I, ^{124}I, ^{155}Tb
3	Azienda Ospedaliero-Universitaria Policlinico S.Orsola Bologna (Italy)	^{11}C, ^{18}F, ^{68}Ga, ^{99m}Tc
4	Eckert & Ziegler Radiopharma (Germany)	^{68}Ga,^{90}Y, ^{177}Lu

5	GIP Arronax (France)	^{44}Sc, ^{64}Cu, ^{67}Cu, ^{68}Ge, ^{211}At
6	NUCLEO (Latvia)	^{11}C, ^{18}F, ^{68}Ga
7	ILL (France)	$^{47}Ca/^{47}Sc$, ^{103}Pd, ^{103}Ru, ^{111}Ag, ^{129m}Xe, ^{131m}Xe, ^{143}Pr, ^{149}Pm, ^{161}Tb, $^{166}Dy/^{166}Ho$, ^{169}Er,^{175}Yb, ^{177}Lu, ^{188}W, ^{195m}Pt
8	Cyceron (France)	^{11}C, ^{13}N, ^{15}O, ^{18}F
9	CEA (France)	^{67}Cu, ^{90}Y, ^{177}Lu
10	CERN-MEDICIS (Switzerland-France)	^{128}Ba, ^{153}Sm,^{155}Tb,^{165}Er, ^{169}Er, ^{225}Ac
11	Paul Scherrer Institute (Switzerland)	^{44}Sc, ^{64}Cu, ^{161}Tb, ^{165}Er
12	Oslo University Hospital (Norway)	^{212}Pb
13	Fondazione Policlinico Universitario Agostino Gemelli IRCCS (Italy)	^{64}Cu, ^{68}Ga, ^{89}Zr
14	University of Cambridge - Department of Radiology (United Kingdom)	^{68}Ga, ^{99m}Tc
15	King's College London (United Kingdom)	^{44}Sc, ^{62}Zn,^{62}Cu, ^{64}Cu, ^{67}Ga, ^{68}Ga, ^{99m}Tc, ^{111}In, ^{123}I, ^{124}I, ^{125}I, ^{131}I, ^{161}Tb, ^{177}Lu, ^{188}Re, ^{201}Tl
16	University of Antwerp (Belgium)	^{68}Ga, ^{99m}Tc, ^{18}F, ^{11}C,
17	Helmholtz-Zentrum Dresden-Rossendorf (Germany)	^{64}Cu, ^{67}Cu, ^{68}Ga, ^{123}I, ^{131}Ba, ^{133}La, ^{195}Hg, ^{197}Hg
18	KU Leuven (Belgium)	^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{68}Ga
19	SCK CEN (Belgium)	^{90}Y, ^{99}Mo, ^{213}Bi, ^{223}Ra, ^{225}Ac
20	CNRS CEMHTI (France)	^{52}Mn, ^{165}Er, ^{166}Ho
21	Radboud University Medical Center (Netherlands)	^{11}C, ^{18}F, ^{68}Ga, ^{99m}Tc
22	Institute for Nuclear Research (Hungary)	^{48}V, ^{52}Mn, ^{55}Co, ^{56}Co, ^{64}Cu, ^{67}Ga, ^{68}Ga, ^{103}Pd, ^{123}I, ^{124}I, ^{155}Tb, ^{203}Pb, ^{209}At
23	University of Helsinki, Department of Chemistry (Finland)	^{11}C, ^{18}F, ^{68}Ga
24	Orano (France)	^{212}Pb
25	Karolinska Institute (Sweden)	^{11}C, ^{18}F, ^{45}Ti, ^{67}Ga, ^{68}Ga, ^{89}Zr
26	Delft University of Technology (Netherlands)	^{64}Cu, ^{99m}Tc, ^{99}Mo, ^{153}Sm, ^{161}Tb, ^{166}Ho,^{177}Lu, ^{188}W, ^{188}Re
27	BV Cyclotron VU (Netherlands)	^{11}C, ^{18}F, ^{89}Zr
28	SHINE EUROPE (Netherlands)	^{177}Lu
29	The National Centre of Oncology (Azerbaijan)	^{18}F, ^{68}Ga, ^{99m}Tc

30	Czech Technical University in Prague (Czechia)	^{64}Cu, ^{67}Cu, ^{68}Ga, ^{99m}Tc, ^{161}Tb, ^{223}Ra
31	Radioisotope Production Center CSJC (Armenia)	^{18}F

Thirteen of respondent's companies/institutions produce, develop or study radionuclide generators. Five of the surveyed respondents work with $^{68}Ge/^{68}Ga$ generators, 3 institutions - $^{99}Mo/^{99m}Tc$, $^{224}Ra/^{212}Pb$, $^{225}Ac/^{213}Bi$ generators, 2 institutions - $^{188}W/^{188}Re$ and $^{82}Sr/^{82}Rb$ and one each $^{62}Zn/^{62}Cu$, $^{44}Ti/^{44}Sc$ generators (see Table 2).

Table 2. List of radionuclide generators produced used or studied by respondent institutions

Nr.	Respondent	Generators
1	Denmark Technical University (Denmark)	$^{68}Ge/^{68}Ga$
2	Eckert & Ziegler Radiopharma (Germany)	$^{68}Ge/^{68}Ga$
3	GIP Arronax (France)	$^{82}Sr/^{82}Rb$
4	Oslo University Hospital (Norway)	$^{224}Ra/^{212}Pb$
5	King's College London (United Kingdom)	$^{62}Zn/^{62}Cu$, $^{68}Ge/^{68}Ga$, $^{82}Sr/^{82}Rb$, $^{99}Mo/^{99m}Tc$, $^{188}W/^{188}Re$
6	Institute of Nuclear Chemistry and Technology (Poland)	$^{225}Ac/^{213}Bi$, $^{224}Ra/^{212}Pb$, $^{103}Pd/^{103m}Rh$
7	Lausanne University Hospital (Switzerland)	$^{44}Ti/^{44}Sc$
8	SCK CEN (Belgium)	$^{225}Ac/^{213}Bi$
9	CNRS CEMHTI (France)	$^{165}Tm/^{165}Er$
10	Orano (France)	$^{224}Ra/^{212}Pb$
11	Delft University of Technology (Netherlands)	$^{99}Mo/^{99m}Tc$, $^{188}W/^{188}Re$, $^{47}Ca/^{47}Sc$, $^{166}Dy/^{166}Ho$
12	Radboud University Medical Center (Netherlands)	$^{68}Ge/^{68}Ga$, $^{99}Mo/^{99m}Tc$
13	Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Department of nuclear chemistry (Czech Republic)	$^{68}Ge/^{68}Ga$, $^{225}Ac/^{213}Bi$, $^{227}Ac/^{227}Th/^{223}Ra$

2.3 Logistics and distribution

The most often used transportation types that respondents or their distributor/supplier use for radioactive material transport are by road (50 respondents) and air (39 respondents), see Figure 8. Transportation types. Only 3 of the respondents used transportation through the sea, possibly due to less time effective logistic chains. Such sea transportation would only become effective if it would be between 2 ports of short distance as, for example, countries around the Baltic Sea or in the middle of some more complex supply chains.

Here we see that the most common and less constrained type is road transport on a national, less frequent international level for short distance distribution. For large distance or short-lived radionuclide transportation, the most effective transport is by air.

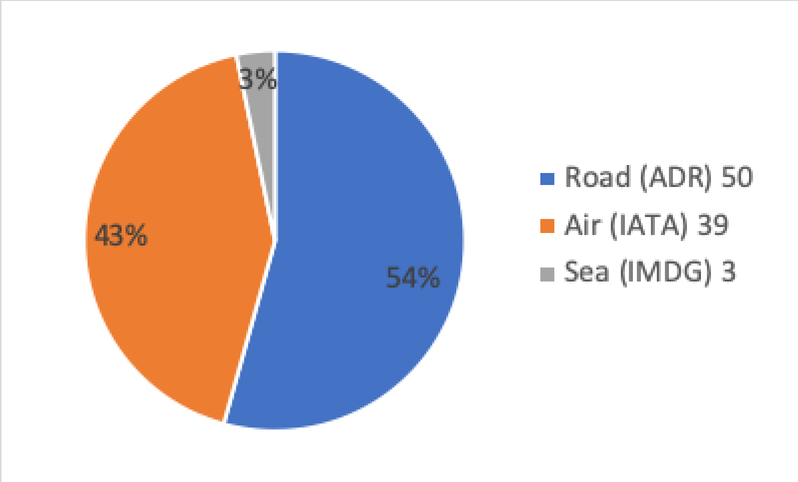

Figure 8. Transportation types

Nearest airports which respondents use for radioactive material transport - AMS, BLQ, BRU, BHX GVA, CDG, CPH, LIS, HAJ, HEL, LEJ, LIS, RIX, MAD, BLQ, ZRH, OSL, FCA, Heathrow, PRG, TLL, VNC, VCE, USA, etc. These airports support radioactive package shipment. Such information is important for establishing supply chains, by identifying airports and commercial airline companies that accept radioactive materials for shipment. Respondents also mention that some airports are close, but in neighbouring countries, therefore are used due to additional border crossing.

Thirty-one of respondents subcontract radioactive material (class 7) transport companies – see Table 3.

Table 3. Subcontracted radioactive material (class 7) transport companies of various institutes/companies

Nr.	Respondent	Company
1	Università degli Studi di Milano - UNIMI (Italy)	Gamma Servizi, Italy
2	Denmark Technical University (Denmark)	Junge Spedition, K.Sand Andersen Transport, Lorrys Eft.
3	University of Milan, Department of Physics (Italy)	Gamma Servizi srl,
4	CHUV (Switzerland)	SAR transport
5	IBA (Belgium)	N/A
6	Eckert & Ziegler Radiopharma (Germany)	Information can only be disclosed with a confidentiality agreement
7	GIP Arronax (France)	Isolife, Forestier
8	NUCLEO, Ltd. (Latvia)	KOLL (road) AirBaltic (Air)
9	ILL(France)	Company depends on the destination, e.g. SAR for Switzerland.
10	Cyceron (France)	Not disclosed (French national company)
11	CEA (France)	N/A
12	LRB (Laboratoire Radiopharmaceutiques Biocliniques, UGA, INSERM 1039) (France)	Transrad (IRE) PME Express (Arronax)
13	CERN-MEDICIS (Switzerland-France)	Not disclosed
14	Paul Scherrer Institute (Switzerland)	SAR

15	Oslo University Hospital (Norway)	Jekra AS, Norway
16	King's College London (United Kingdom)	N/A
17	University of Antwerp (Belgium)	ISI (www.isotopes.be)
18	Helmholtz-Zentrum Dresden-Rossendorf (Germany)	ADR (Road)
19	Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety, National Center for Scientific Research "Demokritos" (Greece)	Bollore Transport
20	Fundación para la Investigación Biomédica del Hospital Gregorio Marañón (Spain)	Fedex
21	Fundación de investigación Gregorio Marañón (Spain)	Fedex
22	University of Turin (Italy)	Crisago Trasporti
23	CNRS CEMHTI (France)	Isolife, Dangxpress ("Capelle"), Ulysse (CNRS internal structure to organize transport)
24	Advanced Accelerator Applications (Italy)	Crisago MIT
25	Institute for Nuclear Research (Hungary)	Eötvös Lóránd University, ADR
26	Orano (France)	N/A
27	Karolinska Institute (Sweden)	N/A
28	BV Cyclotron VU (Netherlands)	Fiege
29	Antoni van Leeuwenhoek/Netherlands Cancer Institute (Netherlands)	Fiege (Road) AAA (Air)
30	The National Centre of Oncology (Azerbaijan)	Turkish Airline, Lufthansa
31	SCK CEN (Belgium)	N/A

11 respondents expressed that there are restrictions on the availability or logistics and distribution of radionuclides/radiopharmaceuticals after 1st march, 2022, mostly indicating the shutdown of partner institutes that supply them with radionuclides. This should be noted as an important matter with increasing radionuclide demand across users.

A key element for radionuclide production is choice of appropriate target material. The most common issues with the enriched material supply/stock that companies/institutions experienced was availability (28 respondents), delivery time (15 respondents), purity/enrichment grade (13 respondents), quantity (11 respondents) and price (7 respondents).

The biggest bottleneck for the producers is the stable isotope availability, which goes in correlation with purity/enrichment grade and delivery time. With higher isotopic purity, the availability of the desired material decreases drastically. Availability is limited by the abundance of desired target material or companies that provide them for specific radionuclide production, therefore suggesting alternative desired radionuclide obtaining options, for example by utilising different production approach and supply from other institutions within reasonable distances and optimized supply routes.

The majority of respondents did not indicate the price as the main bottleneck, therefore suggesting that the cost of high purity target materials for certain radionuclide production is justified based on their availability and the product radionuclide necessity.

Out of 64 respondents from research institutions and manufacturing facilities, 24 respondent companies/institutions distribute radionuclides to national external research institutes, radiopharmaceutical producers or users. Twelve of the respondent institutions distribute radionuclides to international recipients (see Table 4).

The results show that half of respondents that supply institutes externally already have international distribution routes established. The longer distance distribution routes, such as between different continents are especially noteworthy, as they require more logistics and legal issues.

Table 4. Radionuclide distribution to international recipients

Nr.	Respondent	Radionuclides	International recipient
1	Sacro Cuore Hospital (Italy)	^{52}Mn, ^{53}Mn, ^{54}Mn, ^{64}Cu, ^{67}Cu, ^{68}Ga, ^{89}Zr, ^{99m}Tc, ^{123}I, ^{124}I, ^{155}Tb	NL
2	Eckert & Ziegler Radiopharma (Germany)	^{90}Y	USA, EU
3	GIP Arronax (France)	^{64}Cu, ^{82}Sr	CH, NL, USA
4	ILL (France)	^{47}Ca/^{47}Sc, ^{103}Pd, ^{103}Ru, ^{111}Ag, ^{129m}Xe, ^{131m}Xe, ^{143}Pr, ^{149}Pm, ^{161}Tb, ^{166}Dy/^{166}Ho, ^{169}Er, ^{175}Yb, ^{177}Lu, ^{188}W, ^{195m}Pt	AT, CH, DE, DK, FR, PL
5	CERN-MEDICIS (Switzerland-France)	^{128}Ba,^{153}Sm,^{155}Tb, ^{165}Er, ^{169}Er, ^{225}Ac	BE, CH, FR, LV, PK, UK
6	Paul Scherrer Institute (Switzerland)	^{64}Cu	CH, DE
7	Helmholtz-Zentrum Dresden-Rossendorf (Germany)	^{64}Cu	HU
8	Institute for Nuclear Research (Hungary)	^{103}Pd	South Africa
9	Orano (France)	Not disclosed	US
10	BV Cyclotron VU (Netherlands)	^{89}Zr	Europe: NL, BE, GB, FR, SP, IT, NO, SW, GE USA, CA Distribution worldwide. Australia, Asia, China and Singapore
11	SHINE EUROPE (Netherlands)	Not disclosed	Not disclosed
12	SCK CEN (Belgium)	Not disclosed	Not disclosed

It is confirmed by the survey responses that main limitations are fragmented and unharmonized procedures for import/export legislation of radionuclides across Europe and beyond (9 respondents each), complex supply chains (6 respondents) and licensing (5 respondents). Nine respondents indicated that they do not face any of the issues. Two respondents indicated they have other constraints, such as cost. Harmonized legislation therefore is one of main issues already indicated, discussed and therefore targeted by the PRISMAP consortium. For longer international radionuclide shipments also customs clearance was mentioned and due to some radionuclide short half-life, such delays must be mitigated.

Some of the information about logistics and distribution was not available to be disclosed due to company policies.

Out of 24 respondents that export the produced radionuclides, generators or radiopharmaceuticals 10 respondent institutions use an external company as distributor (see Table 5). Tendency for larger radionuclide manufacturing facilities to sub-contract external distributors is observed. Such approach eases the acquisition of radionuclides by the users and operations by the manufacturers.

Table 5. National radionuclide distribution by external companies

Nr.	Respondent	Radionuclides	External company
1	University of Padua (Italy)	Not indicated	Curium, GE
2	Eckert & Ziegler Radiopharma (Germany)	^{68}Ga, ^{90}Y, ^{177}Lu	Information can only be disclosed with a confidentiality agreement
3	ILL (France)	^{177}Lu	ITM in Garching
4	CEA (France)	^{90}Y, ^{67}Cu, ^{177}Lu	Novartis
5	CERN-MEDICIS (Switzerland-France)	^{128}Ba,^{153}Sm,^{155}Tb, ^{165}Er, ^{169}Er, ^{225}Ac,	Isovital, SAR, Asept
6	Oslo University Hospital (Norway)	^{212}Pb	Oncoinvent AS, Norway Nucligen AS, Norway
7	University of Antwerp (Belgium)	N/A	Curium, Cyclotron BV, Perkin Elmer
8	Delft University of Technology (Netherlands)	^{166}Ho microspheres	Terumo NL
9	BV Cyclotron VU (Netherlands)	^{89}Zr	PerkinElmer
10	SCK CEN (Belgium)	N/A	IRE, Fleurus

It should be noted that ITM Isotopen Technologien München AG is also a key n.c.a. 177Lu radionuclide supplier and the 68Ge/68Ga generator supplier in Europe.

Four of the above-mentioned 10 respondents subcontract with an external company to pack and/or do the Dangerous Goods Declaration (see Table 6).

Table 6. Respondents and their subcontracting with external companies (Dangerous Goods Declaration)

Nr.	Respondent	External company
1	Eckert & Ziegler Radiopharma (Germany)	Information can only be disclosed with a confidentiality agreement
2	CEA (France)	Novartis
3	BV Cyclotron VU (Netherlands)	PerkinElmer and SDG
4	SCK CEN (Belgium)	Not Disclosed

Out of 64 respondents from research institutions and manufacturing facilities, 19 respondent companies/institutions plan to export or extend the already existing export region of produced radionuclides in following years. Only 8 respondents were interested in both regions - within Europe and outside of Europe, 10 respondents - within Europe only and 1 respondent - outside Europe only. Involvement in an early stage of establishing these routes may help foster the radionuclide distribution as well as give the ability for users to gain access to desired radionuclides in a more foreseeable timeframe.

Main limitations that respondents face or foresee are lack of harmonised import/export legislation (10 respondents), complex supply chains (9 respondents), regulatory limitations (6 respondents) and licensing (5 respondents). Four respondents do not foresee any of the limitations. Respondents also indicate the main problems with air cargo transport, which are limitations due to the dose rate of the radiation, shielding of the radioactive source and packaging. Another issue is already mentioned - slow and bureaucratic administrative procedures such as customs clearance.

Furthermore, 30 respondent companies/institutions plan to increase manufactured volume of radionuclides in following years. Even without plans to expand, main limitations that respondents face or foresee are limitations in infrastructure (15 respondents), shortage of staff, expertise (15 respondents), "beam time" or production capacity and target material supply (11 respondents each) and other financial or managerial issues (3 respondents). Possibilities to teach and train students, staff and to transfer knowledge, as indicated by responders as one of the main limitations, can be addressed through more open communication between the institutions. As such, this is one of PRISMAP objectives that is already being addressed. Some respondents do not foresee any issues yet due to low or manageable demand at the moment.

Fifty respondents are involved in radiopharmaceutical synthesis, production and/or research. Out of these 50 respondents, 20 companies/institutions distribute radiopharmaceuticals to external research institutes or users (pre-clinical and clinical research/applications). Four from these 20 respondents distributed radiopharmaceuticals to international recipients within EU and outside EU borders.

In general radiopharmaceutical distribution is more even more demanding in terms of legal compliance than radionuclide or radiopharmaceutical precursor distribution. Often, radiopharmaceuticals for pre-clinical and clinical applications are produced "in-house". Therefore, we can conclude that the radiopharmaceuticals distributed at national and international level are labelled mainly with radionuclides outside the scope of PRISMAP. Nevertheless, the existing distribution routes and expertise in legislation and regulations are of great interest for the emerging radiopharmaceuticals coming into clinical trial phase.

Out of 64 respondents, 41 of respondent's companies or institutions obtained radionuclides from external suppliers for their radionuclide precursor, radiopharmaceutical production and/or research and development activities (see Table 7).

Table 7. Respondents and their obtained radionuclides by external suppliers

Nr.	Respondent	Radionuclides	External supplier
1	Denmark Technical University (Denmark)	$^{68}Ge/^{68}Ga$ generator, ^{103}Pd, ^{199}Au,	Not disclosed
2	CHUV (Switzerland)	Not disclosed	ITM in Garching Eckert&Ziegler Curium
3	IST-ID (Portugal)	Not disclosed	Mallinckrodt Polatom SCK-CEN
4	Istituto Oncologico Veneto (Italy)	Not disclosed	IRCCS Ospedale Sacro Cuore don Calabria di Negrar (Italy)
5	University of Padua (Italy)	^{44}Sc, ^{64}Cu, ^{67}Cu, ^{68}Ge, ^{211}At	Curium and GE
6	GIP Arronax (France)	^{177}Lu	Not disclosed supplier from Germany

		^{111}In	Not disclosed supplier from Netherlands
7	NUCLEO (Latvia)	^{68}Ge/^{68}Ga generator	Eckert & Ziegler
		^{177}Lu	ITM in Garching
8	Cyceron (France)	^{64}Co, ^{177}Lu	Arronax
9	CEA (France)	Not disclosed	Novartis
10	Laboratoire Radiopharmaceutiques Biocliniques, LRB (France)	^{68}Ge/^{68}Ga generator	IRE, Belgium
		^{177}Lu	ITG, Germany
		^{177}Lu	IDB (AAA-Novartis), Netherlands
		^{99m}Tc generator	charged with Grenoble Hospital
		^{125}I	Perkin-Elmer, USA
		^{111}In	Mallinckdrodt, Netherlands
		^{123}I	IBA, Belgium
		^{64}Cu	Arronax, France
		^{201}Tl	Curium pharma, France
11	Oslo University Hospital (Norway)	^{177}Lu	ITG, Germany
		^{223}Ra	Bayer
		^{224}Ra	Oncoinvent
12	Fondazione Policlinico Universitario Agostino Gemelli IRCCS (Italy)	^{68}Ge/^{68}Ga generator	ITM (DE)
13	INSERM (France)	Not disclosed	ORANO, ORANO MED, ITU
14	Department of Radiology, University of Cambridge (United Kingdom)	^{89}Zr	VUMC, Amsterdam, Netherlands
15	Barts Cancer Institute, Queen Mary University of London (United Kingdom)	^{18}F ([^{18}F]-FDG)	etNet, Alliance Medical UK
		^{64}Cu	King's College London, UK
		^{68}Ge/^{68}Ga generator	Curium, IRE, and other various generator suppliers
		^{89}Zr	Perkin Elmer
		^{111}In	Local - via hospital generators
		^{99m}Tc	Local radiopharmacy, generators
		^{177}Lu	ITM in Garching
		^{188}Re	Oncobeta
		^{225}Ac	ITM in Garching
16	Helmholtz-Zentrum Dresden-Rossendorf (Germany)	Not disclosed	TM, ITG, EZAG, IBA, iThemba, POLATOM
17	Lausanne University Hospital (Switzerland)	^{99m}Tc, ^{68}Ga, ^{177}Lu	Not disclosed

18	KU Leuven (Belgium)	Not disclosed	Karlsruhe, SCK-CEN
19	Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety, National Center for Scientific Research "Demokritos" (Greece)	Not disclosed	POLATOM, ITM
20	Fundación para la Investigación Biomédica del Hospital Gregorio Marañón (Spain)	^{89}Zr	Perkin Elmer, Netherlands
		^{18}F and ^{99m}Tc	CuriumPharma, Spain
		$^{68}Ge/^{68}Ga$ generator	France
21	Fundación de investigación Gregorio Marañón (Spain)	^{89}Zr	Perkin Elmer, Netherlands
		^{18}F, ^{99m}Tc	CuriumPharma, Spain
		$^{68}Ge/^{68}Ga$ generator	France
22	University of Turin (Italy)	^{18}F ([^{18}F]-FDG)	AAA
23	SCK CEN (Belgium)	^{177}Lu, ^{188}W, ^{225}Ac	Not disclosed
24	CNRS CEMHTI (France)	^{52}Mn, ^{165}Er (from irradiation)	DTU, Denmark
25	Radboud University Medical Center (Netherlands)	^{89}Zr	Cyclotron BV, NL
		^{111}In	Curium, NL
		^{177}Lu	ITM, Germany
		^{212}Zr	NRG Petten, NL
		^{225}Ac	ITU Karlsruhe GE, van Overeem nuclear BV, NL
26	King's College London (United Kingdom)	^{67}Ga	Not disclosed
		^{89}Zr	Perkin Elmer
		^{111}In	Not disclosed
		^{201}Tl	Not disclosed
		$^{188}W/^{188}Re$ generator	Various - Not disclosed
27	Advanced Accelerator Applications (Italy)	Not disclosed	Not disclosed
28	University of Helsinki, Department of Chemistry (Finland)	^{99m}Tc	Curium Pharma, BE
		^{89}Zr	Perkin Elmer, NL
		^{111}In	Curium Pharma, BE
		^{123}I	GE Healthcare, NL?
		^{125}I	GE Healthcare, NL?
		^{177}Lu	Curium Pharma, BE
29	University of Bordeaux (France)	^{89}Zr, ^{177}Lu, ^{64}Cu	Not disclosed
30	Charles River / Discovery (Finland)	^{18}F, ^{68}Ga	Finland
		^{89}Zr	Perkin Elmer, Netherland
		^{177}Lu	ITM, Germany

31	Karolinska Institute (Sweden)	^{125}I	PerkinElmer - NL
		^{89}Zr	BV Cyclotron - NL
32	Delft University of Technology (Netherlands)	Not disclosed	Perkin Elmer, ITU (JRC, Germany), van Overeem Nuclear (the Netherlands), Oak Ridge (USA), Center for Energy Research (Hungary)
33	BV Cyclotron VU (Netherlands)	^{81}Rb	Curium, Petten, NL
34	Antoni van Leeuwenhoek hospital/ Dutch Cancer Institute (Netherlands)	^{18}F ([^{18}F]-FPSMA, [^{18}F]-FAPI)	Cyclotron Noordwest, Noordwest Ziekenhuisgroep, Netherlands
35	OLVG (Netherlands)	^{89}Zr	Netherlands
		^{177}Lu	IDB, NL
36	Antoni van Leeuwenhoek/Netherlands Cancer Institute (Netherlands)	^{68}Ga	IRE, Belgium
		^{177}Lu	ITM, Germany
		^{18}F, ^{89}Zr	Cyclotron BV, Netherlands
		^{99m}Tc	Curium, Netherlands
37	The National Centre of Oncology (Azerbaijan)	$^{68}Ge/^{68}Ga$ generator, ^{177}Lu	ITM Germany
		^{99}Mo generator, ^{131}I	Monrol Turkey
		^{225}Ac	Oak Ridge National Laboratory
38	University of Zagreb School of Medicine (Croatia)	^{18}F ([^{18}F]-FDG)	Not disclosed
39	Palacky University (Czechia)	Not disclosed	NPI Rez (CZ), UJV Rez (CZ), MGP Zlin (CZ), KC Solid (CZ), HZDR (Germany)
40	Czech Technical University in Prague, Faculty of Nuclear Sciences and Physical Engineering, Department of nuclear chemistry (Czechia)	^{225}Ac	JRC ITU, Karlsruhe, Germany
41	Paul Scherrer Institute (Switzerland)	^{67}Ga, ^{99m}Tc, ^{111}In	Curium
		^{177}Lu	ITM in Garching

The main issues of obtaining/importing the radionuclides the respondents face are transport limitations (13 respondents), regulatory limitations (11 respondents), licensing and lack of harmonized import/export legislation (8 respondents each). Sixteen respondents did not face or indicate any of the limitations. Some respondents had already solved their constraints of regulatory and transport limitations. There are also limitations on the amount of radioactivity (activity cap) to be imported, both for regulatory reasons and because of supply restrictions.

Respondents of 44 institutions mentioned additional radionuclides they consider producing or obtaining in following years by external suppliers for any of their research and development activities. Most often mentioned radionuclides are - ^{149}Tb, ^{152}Tb, ^{155}Tb, ^{149}Tb, ^{161}Tb, ^{225}Ac, ^{89}Zr, ^{67}Cu, ^{64}Cu, $^{165}Er/^{169}Er$, ^{47}Sc, ^{44}Sc, ^{177}Lu, ^{211}At, ^{188}Re; The main limitations that respondents face again are regulatory limitations (15 respondents), lack of harmonised import/export legislation (13 respondents), licensing (11 respondents), transport limitations (10 respondents) and availability and sources (6 respondents). After Brexit, there are additional constraints with import/export involving the UK. A limitation often mentioned was also the amount of activity supplied.

In recent years, the Tb radionuclide "family" and ^{211}At, ^{177}Lu, ^{89}Zr, ^{67}Cu, ^{64}Cu, ^{47}Sc/^{44}Sc and others have become the main research topics towards theranostic/therapeutic use. Also identified as important is ^{225}Ac as alpha emitter in radionuclide therapy and radiopharmaceutical development, and the interest for such is only increasing, therefore supply of these radionuclides should address the demand.

From responses of the respondents, we can conclude the necessity of PRISMAP not only as a web-based entry platform for the production and dispatch of non-conventional radionuclides, but also as a long-term platform for aiding an advancement in, at the moment, emerging radionuclide distribution and use in research, translational research, pre-clinical/clinical research and nuclear medicine.

2.4 Research and development activities

Out of all respondents, 80% (90 respondents) indicated that their R&D activities would benefit from collaboration/cooperation in obtaining emerging radionuclides with centralised and harmonised procedures and legislation, offered by efforts of the PRISMAP consortium.

More than a third of the responders indicated the interest in novel radionuclides either for radiopharmaceutical development and labelling studies, for already ongoing projects or for new project applications and even new preclinical study equipment optimization with the novel radionuclides.

Twenty respondents indicated the interest in collaborating with PRISMAP consortium members to foster or use radionuclides and expertise offered for pre-clinical and clinical applications and studies.

Fifteen respondents expressed the need to collaborate with PRISMAP consortium members to have contacts and supporters of their future activities.

Members of PRISMAP consortium also mentioned the benefit of additional collaborating institutes, as additional sites to carry out research activities related to radionuclide production and purification.

Main emphasis on R&D activities in collaboration with PRISMAP is the availability of emerging medical radionuclides, workflow and access to mass-separated, pure medical isotopes.

2.5 Training and capacity building

83% of all the institutions (86 respondents) in this survey are involved in the training of industry experts, technicians, students and researchers at various expertise levels, considering that the respondents of this survey are almost equally from clinical, research and manufacturing fields (accelerator and particle physics, radionuclide production, synthesis and development, purification, calibration and characterization, quality control, analysis and radiochemistry).

Out of all respondents, 86 of respondent's companies/institutions provide training in nuclear physics, radiochemistry and radiopharmacy. The most often mentioned answers about training level were - PhD programmes (68 respondents), scientific visits (62 respondents) and workshops and seminars (60 responses). See Figure 9. Types of provided training in nuclear physics, radiochemistry and radiopharmacy for other types of provided training.

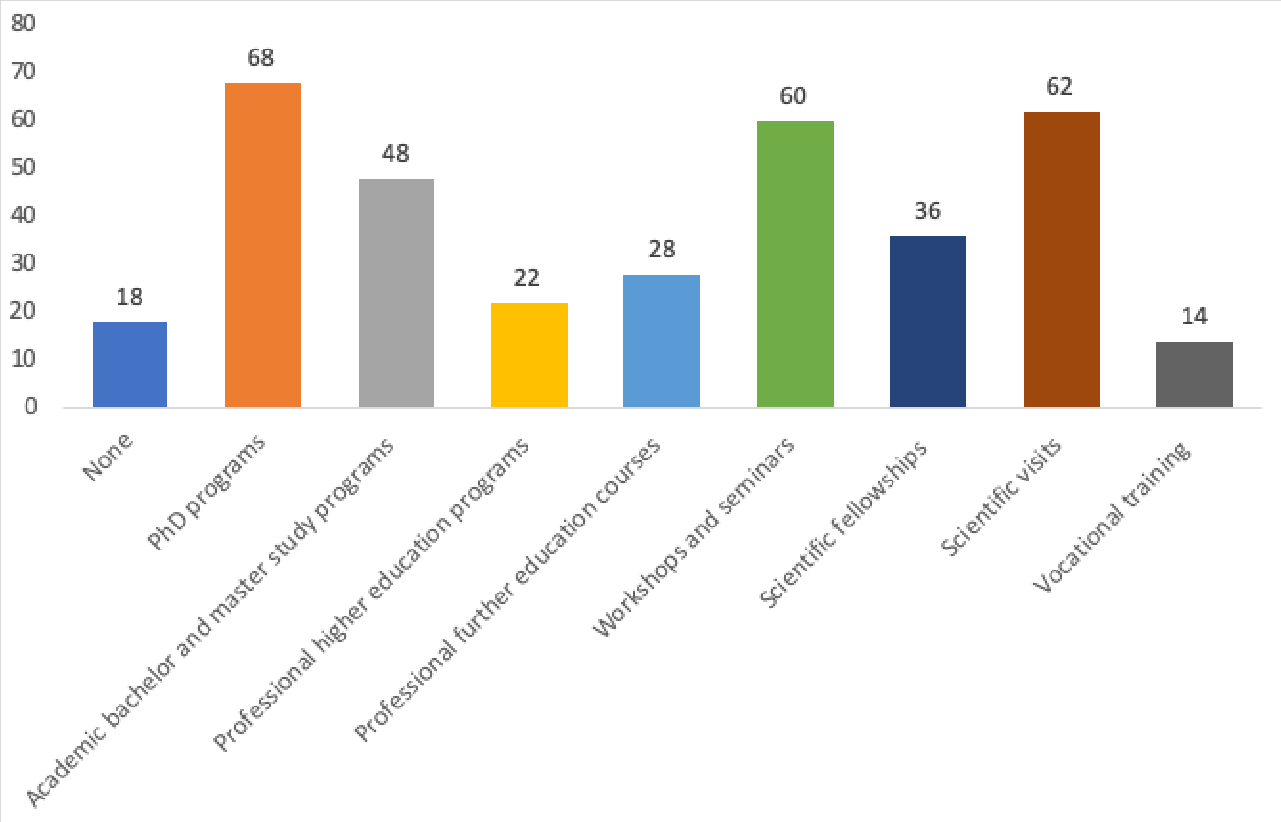

Figure 9. Types of provided training in nuclear physics, radiochemistry and radiopharmacy

The most popular training fields are radiopharmaceutical synthesis and development (59 respondents), radiochemistry (55 respondents), radionuclide/radiopharmaceutical QC and analysis (48 respondents), pre-clinical studies (47 respondents) and clinical trials/studies (47 respondents). See Figure 10 for provided training fields.

The target audience for training provided at respondent institutions are students (83 respondents), early-stage researchers (79 respondents), technologists (49 respondents), experienced researchers (44 respondents), nurses (23 respondents) and industry professionals (14 respondents).

Eighty percent of the respondents provide education for students, 76 % for early-stage researchers, 47% provide training for technologists/technicians and 42 % are training experienced researchers, although there were mentioned some limitations, such as capacity limitation to 2 persons or short training time periods, including funding and infrastructure limitation.

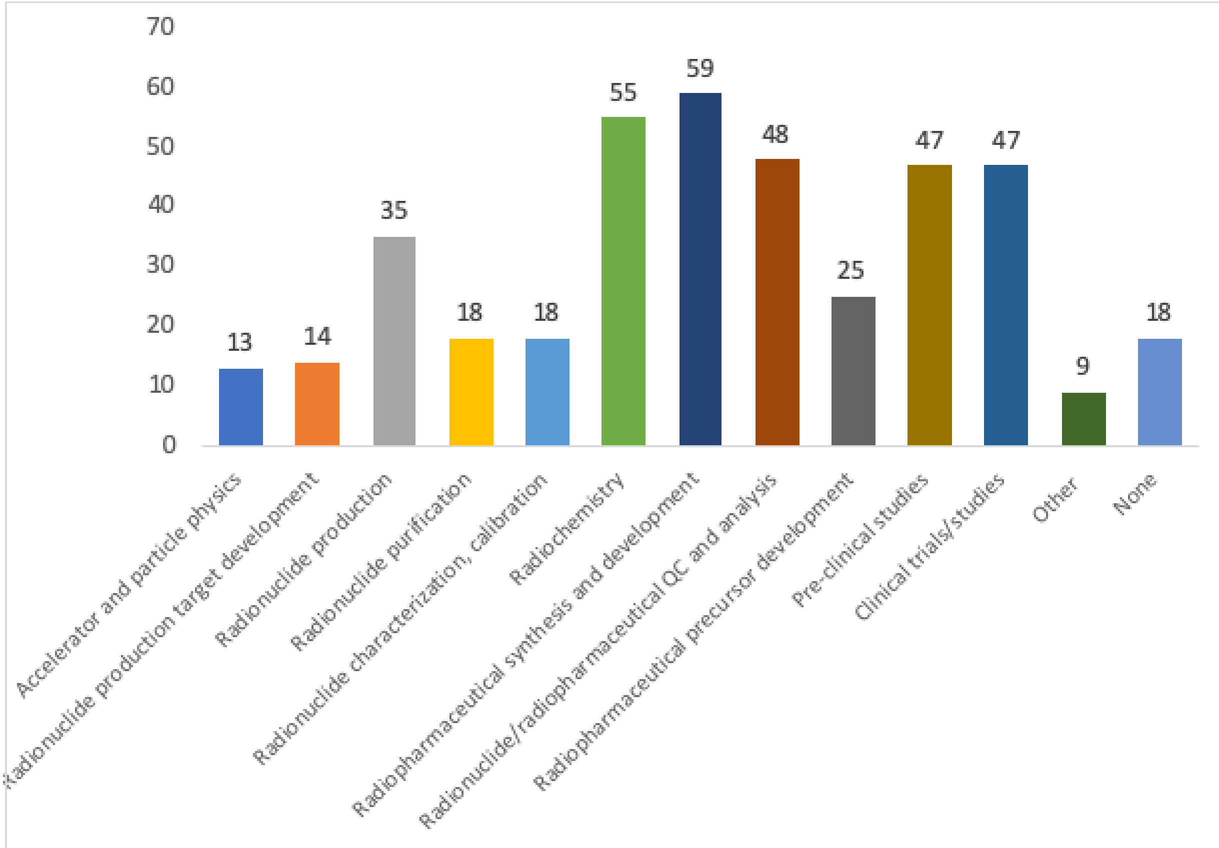

Figure 10. Training and knowledge transfer fields

The main limitations in the training process were unavailability for full hands-on training, access to infrastructure (e.g., accelerators), low funding, difficulties in recruiting students and above all the lack of technical staff; lack of integrating radiopharmaceutical research in faculty courses and student curricula. In some cases, the number of participants was too low to organise training courses.

Respondents also mention lack of teaching staff and even revisions in the educational programmes of the universities. However, an equal number of respondents indicate no issues in the training process itself.

It has also been indicated that there exists insufficient access to radioisotopes, no dedicated programme for nuclear medicine physicians, technologists and radiochemists in the universities; lack of trained pre-clinical scientists with a global view from radiochemistry to pharmacology. Often there is a lack of fundamental background knowledge on nuclear physics and the associated technology (reactors, accelerators) when candidates come from university.

2.6 Portfolio of radionuclide and radiopharmaceutical production in Europe

Through the survey already identified potential stakeholders in the industry and scientific community were asked to share their expertise in radionuclide production. Out of 64 respondents from research institutions and manufacturing facilities, 31 of respondent's companies/institutions indicated to produce radionuclides. 23 respondents indicated to use of cyclotrons and 8 respondents indicated the use of a research reactor.

It has been identified that there are at least 358 cyclotrons in Europe, with accelerated particle energies ranging from 3 MeV (for deuterons) up to 590 MeV for protons (in proton-synchrotrons). Most dominant are cyclotrons in the proton energy range of 16-18 MeV dedicated for conventional medical radionuclide production of F-18, O-15, C-11, Ga-68 and other standard PET radionuclides. Main cyclotron manufacturers mentioned are IBA, GE, Siemens and NIIEFA.

From the identified accelerators with indicated accelerated particle energy, 40 accelerators have the capability to produce beams of 30 MeV protons or higher, making them suitable for non-conventional radionuclide production and supply.

Seventeen cyclotrons are identified that can produce proton beams from 60-100 MeV, making them suitable for more exotic radionuclide production that require higher incident particle energies. PSI (Switzerland) operates a high energy proton accelerator with proton energy of up to 590 MeV. Here it is worth noting that high energy accelerators such as synchrotrons like the PSB operated at 1.4GeV at CERN are not covered in this survey.

Countries with the most proton accelerators in Europe are France, Germany, Italy, United Kingdom, Denmark, Sweden, Spain and Netherlands [1,2].

2.6.1 Cyclotron portfolio for radionuclide production

According to the available public data form IAEA about cyclotron facilities, we have grouped the sites depending on their proton energy and radionuclide production type (PET and SPECT), see Appendix 1 with the list of the facilities according to the official publicly available IAEA data [2].

2.6.2 Major research reactors in the Europe

Similarly, the main active research reactors producing radionuclides located in the European Union are listed in Table 8. There have been identified 7 research reactors. According to IAEA nuclear reactor database [3], main radionuclides produced by the reactors are listed below:

Table 8. Major research reactors in the Europe

Nr	Reactor	Country	Operator	Produced therapeutic radionuclides
1	MARIA	Poland	POLATOM	^{32}P, ^{89}Sr, ^{90}Y, ^{131}I, ^{153}Sm, ^{166}Ho, ^{177}Lu, ^{186}Re, ^{188}Re
2	HFR	Netherlands	NRG	^{89}Sr, ^{90}Y, ^{166}Ho, ^{169}Er, ^{177}Lu, ^{212}Pb
3	BR2	Belgium	SCK-CEN	^{89}Sr, ^{90}Y, ^{131}I, ^{153}Sm, ^{177}Lu, ^{186}Re, ^{188}Re
4	FRMII	Germany	Technical University of Munich	^{166}Ho, ^{177}Lu
5	ILL	France	Institut Laue-Langevin	^{47}Sc, ^{111}Ag, ^{161}Tb, ^{169}Er, ^{175}Yb, ^{177}Lu, ^{188}Re
6	LVR-15	Czech Republic	CVŘ Řež	^{131}I, ^{153}Sm, ^{166}Ho, ^{177}Lu, ^{186}Re, ^{188}Re
7	BRR	Hungary	BNC/AEKI	^{32}P, ^{90}Y, ^{131}I, ^{153}Sm, ^{166}Ho, ^{177}Lu

2.6.3 Therapeutic radionuclides and radiopharmaceuticals

As for diagnostic radionuclide production, there is a wide range of radionuclides for therapeutic use. Recently a survey study was carried out by JRC [4] to indicate the main therapeutic radionuclides and their use in Europe. Below is given a list of currently produced radionuclides and radiopharmaceuticals in Europe based on JRC published data (Ligtvoet et al, 2021) [4] in the Table 9 and Appendix Nr. 2.

It contains the list of Radionuclides and Radiopharmaceuticals, type of emission, production facility, indications for use (in Europe), available price per dose (euros), producer, supplier, supply issues and suggested solutions.

Table 9. Therapeutic radionuclide and radiopharmaceutical use in the European countries

Nr	Country	Radionuclides in use:	Radiopharmaceuticals in compassionate use:

1	Austria	^{131}I, ^{153}Sm, ^{169}Er, ^{177}Lu, ^{186}Re, ^{223}Ra, ^{225}Ac, ^{90}Y	
2	Belgium	^{90}Y, ^{131}I, ^{153}Sm, ^{166}Ho, ^{177}Lu, ^{186}Re, ^{223}Ra, ^{213}Bi	
3	Bulgaria	^{131}I, ^{223}Ra, ^{153}Sm	
4	Croatia	^{131}I, ^{177}Lu, ^{223}Ra, ^{90}Y	
5	Cyprus	^{131}I, ^{153}Sm, ^{177}Lu, ^{223}Ra, ^{225}Ac	
6	Czech Republic	^{131}I, ^{90}Y, ^{153}Sm, ^{89}Sr, ^{223}Ra, ^{186}Re, ^{169}Er, ^{177}Lu	
7	Denmark	^{90}Y, ^{131}I, ^{177}Lu, ^{223}Ra	
8	Estonia	^{131}I, ^{32}P, ^{223}Ra, ^{186}Re, ^{169}Er, ^{153}Sm, ^{89}Sr, ^{90}Y, ^{177}Lu	[^{177}Lu] Lu-DOTATATE
9	Finland	^{131}I, ^{177}Lu, ^{90}Y, ^{186}Re	[^{131}I]-NaI, [^{177}Lu] Lu-DOTATATE, ^{90}Y-glass microspheres, [^{131}I] I-mIBG, ^{186}Re-colloids
10	France	^{89}Sr, ^{90}Y, ^{131}I, ^{153}Sm, ^{166}Ho, ^{169}Er, ^{177}Lu, ^{186}Re, ^{223}Ra	
11	Germany	^{32}P, ^{67}Cu, ^{89}Sr, ^{90}Y, ^{131}I, ^{153}Sm, ^{166}Ho, ^{169}Er, ^{177}Lu, ^{186}Re, ^{188}Re, ^{211}At, ^{213}Bi, ^{223}Ra, ^{225}Ac, ^{227}Th	
12	Greece	^{89}Sr, ^{90}Y, ^{131}I, ^{153}Sm, ^{169}Er, ^{177}Lu, ^{186}Re, ^{188}Re, ^{223}Ra	
13	Hungary	^{32}P, ^{90}Y, ^{131}I, ^{153}Sm, ^{166}Ho, ^{177}Lu, ^{186}Re, ^{223}Ra	
14	Ireland	^{90}Y, ^{131}I, ^{177}Lu, ^{186}Re, ^{223}Ra, ^{153}Sm, ^{169}Er, ^{32}P	[^{177}Lu] Lu-PSMA-617, [^{177}Lu] Lu-DOTATATE
15	Italy	^{131}I, ^{166}Ho, ^{177}Lu, ^{169}Er, ^{188}Re, ^{223}Ra, ^{89}Sr, ^{90}Y	
16	Latvia	^{11}C, ^{18}F, ^{68}Ga, ^{90}Y, ^{131}I, ^{177}Lu, ^{223}Ra	[^{18}F]-FDG, [^{18}F] F-PSMA, [^{68}Ga] Ga-PSMA, [^{177}Lu] Lu-PSMA
17	Lithuania	^{90}Y, ^{131}I, ^{166}Ho, ^{223}Ra	
18	Luxembourg	^{32}P, ^{90}Y, ^{131}I, ^{153}Sm, ^{169}Er, ^{186}Re, ^{211}At, ^{213}Bi, ^{223}Ra, ^{225}Ac, ^{227}Th	
19	Malta	^{131}I, ^{90}Y	
20	Netherlands	^{32}P, ^{89}Sr, ^{90}Y, ^{103}Pd, ^{125}I, ^{131}I, ^{152}Eu, ^{154}Eu, ^{153}Sm, ^{166}Ho, ^{169}Er, ^{177}Lu, ^{186}Re, ^{188}Re, ^{213}Bi, ^{223}Ra, ^{225}Ac, ^{227}Ac, ^{227}Th	[^{177}Lu] Lu-DOTATATE, [^{225}Ac] Ac-PSMA
21	Poland	^{153}Sm, ^{89}Sr, ^{223}Ra, ^{90}Y, ^{169}Er, ^{186}Re, ^{131}I, ^{177}Lu	
22	Portugal	^{131}I, ^{166}Ho, ^{177}Lu, ^{223}Ra, ^{90}Y, ^{32}P, ^{89}Sr	[^{177}Lu] Lu-DOTATATE

23	Romania	^{89}Sr, ^{90}Y, ^{131}I, ^{153}Sm, ^{177}Lu, ^{188}Re	
24	Slovakia	^{131}I, ^{223}Ra, ^{177}Lu, ^{89}Sr, ^{90}Y	
25	Slovenia	^{131}I, ^{177}Lu, ^{90}Y, ^{223}Ra, ^{186}Re, ^{64}Cu	
26	Spain	^{32}P, ^{89}Sr, ^{90}Y, ^{131}I, ^{153}Sm, ^{166}Ho, ^{169}Er, ^{177}Lu, ^{186}Re, ^{188}Re, ^{223}Ra	
27	Sweden	^{131}I, ^{90}Y, ^{223}Ra, ^{153}Sm, ^{32}P, ^{177}Lu	
28	UK	^{90}Y, ^{131}I, ^{177}Lu, ^{223}Ra	[^{177}Lu] Lu-PSMA

3. Needs

80 % respondents expressed that PRISMAP Consortium efforts would bring benefit in their research and development activities and elaborated on their needs: higher availability for radiopharmaceuticals, sharing the new research protocols across countries, to produce more reliable and stronger evidence data, speeding up the implementation of new radiotracers in clinical practice. It was also expressed that there is a need for multicentric trial facilitation (both preclinical and clinical), extension of portfolio, theranostic advancements, access to radio-lanthanides and Auger emitters and options to collaborate with producers of emerging radionuclides. Some respondents expressed they were self-sufficient in terms of production and would not benefit from PRISMAP consortium efforts yet.

Few respondents directly indicated the need to use isotope mass-separator both for research and optimization of method itself as well as use of the mass-separator for already produced radionuclide purification.

4. Conclusions

From a first overview, some companies and research centres active in the field of radionuclide/radiopharmaceutical production, research and nuclear medicine are already self-sufficient and do not require additional access. A clear majority of respondents (80 %), however, indicated to gain benefit and foster their research and development from the PRISMAP consortium already at this stage. Either it is availability of the novel radionuclides, mass-separated isotopes, research partnerships or a platform for uniform educational capacities.

Manufacturing. The data confirmed common aspects in all respondents: the biggest challenge for the manufacturers is the availability of target materials. Respondents did indicate the most common issues with the enriched material supply/stock that companies/institutions experienced – availability, delivery time, purity/enrichment grade, quantity and price as well as transport and regulatory limitations, including lack of harmonized import/export legislation and complexity of supply chains.

The results show that there are sufficient national >38% or international >18% distribution routes and methods established, although having reported challenges due to legislation constraints, especially for novel radionuclides. For longer international radionuclide shipments - the customs clearance was indicated as obstacle due to medical radionuclide short half-life, obviously such delays must be mitigated. Some of the information about logistics and distribution matters were not available to be disclosed due to company policies. Furthermore, 30 respondent companies/institutions plan to increase manufactured volume of radionuclides in following years with certain limitations in infrastructure, shortage of staff and expertise, "beam time" or production capacity, target material supply and other financial or managerial issues.

Main novel radionuclides that would be of interest for this user community in the next 2-5 years are ^{225}Ac, ^{149}Tb, ^{152}Tb, ^{155}Tb, ^{161}Tb, ^{89}Zr, ^{67}Cu, ^{64}Cu, ^{165}Er/^{169}Er, ^{47}Sc, ^{44}Sc, ^{177}Lu, ^{211}At, ^{188}Re. Quite interestingly, there is not yet in the responses expressed interest in other PRISMAP portfolio radionuclides from respondents such as: ^{111}Ag, ^{135}La, ^{153}Sm, ^{213}Bi. We can therefore expect even more demand for ^{225}Ac, terbium radionuclides and ^{67}Cu production in the following years, while other radionuclides should be elaborated within the PRISMAP user forum. We must stress that none (except for iodine radiopharmaceuticals) of the current responder institutions are interested in possibilities of "matched pair" from Terbium and Scandium radionuclides in the near future, this reflects still insufficient pre-clinical data and/or availability of the forementioned radionuclides.

The main limitations that respondents foresee to face again are regulatory limitations and transport limitations, including activity limits of radionuclides. The elaboration of a list of potential transport companies able to deal with the transnational transport of non-conventional radionuclides on the web access platform, together with efforts from PRISMAP to provide data towards regulation authorities would address some of these findings.

Clinical use. Radiopharmaceuticals for pre-clinical and clinical applications are mainly produced on site. The existing and established import or distribution routes can reduce decay losses during transportation and foster translational research to bring emerging radiopharmaceuticals into clinical trial phase. Respondents expressed that PRISMAP consortium efforts would enhance their research and development activities towards higher availability for radiopharmaceuticals, sharing the new research protocols across countries, to produce more reliable and stronger evidence data and speeding up the implementation of new radiotracers in clinical practice and collaboration with producers of emerging radionuclides. All respondents from the nuclear medicine/user section perform studies in oncology, fewer in cardiology, inflammation, endocrinology, neurology, traumatology/orthopaedics, nephrology and pulmonology.

Necessity to transfer patients to other countries for specified Nuclear Medicine examinations and/or treatment procedures were required in up to 70 % of end user respondents for the following reasons - unavailable radiopharmaceutical access, unavailable radionuclide or no reimbursement by the national healthcare system.

The data also confirmed needed improvements for preclinical/clinical users such as unified licensing and registration of available radionuclides and kits in Europe, specified equipment/technology (e.g., collimators etc.) and information about transport and logistics networks in Europe.

The most often emerging technologies at respondents' institutions are the following - SPECT/CT software advances (quantification, 3D dynamics etc.) and PET new generation camera with extended axial field of view, optimised image and dose reduction. End users are interested not only in new radionuclides and pharmaceuticals for research and preclinical/clinical purposes, but also in technology advancements that shows their interest in development but first of all is responsibility of individual centres and not the purpose of this consortium.

Training. 83% of all the institutions in this survey are involved in the training of industry experts, technicians, students and researchers at various expertise levels in nuclear physics, radiochemistry and radiopharmacy. The most often offered training levels are PhD programmes, scientific visits, workshops and seminars. Main limitations in the training process are unavailability for full hands-on training, access to infrastructure (e.g., accelerator), low funding, difficulties in recruiting students and above all the lack of technical staff and pre-clinical scientists with a global view from radiochemistry to pharmacology. Often there is a lack of fundamental background knowledge on nuclear physics and research reactors due to non-existent dedicated programmes for trainees in the universities. To conclude, there is a need for hands-on and targeted trainings.

From the survey results, we can conclude that there is evident necessity of PRISMAP not only as a web-based entry platform for the production and dispatch of non-conventional radionuclides, but also as a long-term network for aiding an advancement in emerging radionuclide distribution. With centralised and harmonised procedures and legislation and their use in translational research, pre-clinical/clinical research and nuclear medicine, offered by efforts of the PRISMAP consortium and future initiatives. Hands-on and targeted trainings should also become an integral part of the PRISMAP activities to match the needs of the community.

Even though respondent activity has been considered optimal, there is still a need for reaching out to more responders from South-East regions (e.g., Balkan countries). Therefore, it would be advised to continue gathering the data from respondents even after the deliverable 5.1. term and to have a continuous update of the available facilities and their activities and include them in the PRISMAP map project supporting WP6 and WP7 concepts. The continuous data acquisition is crucial to maintain actual radionuclide map across Europe, therefore aiding radionuclide producer and user communities.

The information collected will be used to evolve the PRISMAP common interface WP1-TNA1 and it will naturally interface with WP2-TNA2 and WP3-TNA3 to evolve the services to meet the industrial and clinical research further needs.

References

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2. https://accelconf.web.cern.ch/c92/CycloData/Cyclist.html
3. Database of Cyclotrons used for Radionuclide production: https://nucleus-new.iaea.org/sites/accelerators/Pages/Cyclotron.aspx
4. The IAEA Research Reactor Database (RRDB)" https://nucleus.iaea.org/rrdb/#/home
5. Ligtvoet, A., Scholten, C., Dave, A., King, R., Petrosova, L. and Chiti, A., Study on sustainable and resilient supply of medical radioisotopes in the EU, Goulart De Medeiros, M. and Joerger, A. editor(s), EUR 30690 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-37422-0, doi:10.2760/642561, JRC124565. https://publications.jrc.ec.europa.eu/repository/handle/JRC124565

Appendices

Appendix 1: Cyclotrons for radionuclide production in Europe[1]

[1] Database of Cyclotrons used for Radionuclide production: https://nucleus-new.iaea.org/sites/accelerators/Pages/Cyclotron.aspx

Appendix 1 - Deliverable 5.1 - WP5-TNA2 - Questionnaire on industrial and clinical key players and needs

Cyclotrons for radionuclide production in Europe [1]

Nr	Facility	Country	City	Manufacturer	Model	Proton energy (MeV)	PET RND	SPECT RND
1	Alikhanyan National Science Laboratory (Yerevan Physics Institute)	Armenia	Yerevan	IBA	CYCLONE 18	18	Yes	No
2	Argos Zyklotron Klagenfurt	Austria	Klagenfurt	GE	PETtrace	16	Yes	No
3	Argos Zyklotron Linz	Austria	Linz	GE	PETtrace	16	Yes	No
4	Seibersdorf Laboratories	Austria	Seibersdorf	GE	PETtrace	16	Yes	No
5	AKH Wien	Austria	Wien	GE	PETtrace	16	Yes	No
6	Azerbaijan National Centre of Oncology	Azerbaijan	Baku	IBA	CYCLONE 18/9	18	Yes	No
7	NUCLEAR MEDICINE CENTRE	Azerbaijan	Baku	IBA	CYCLONE 18	18	Yes	No
8	N.N. Alexandrov National Cancer Centre of Belarus	Belarus	Lesnoy	IBA	CYCLONE 18/9 HC	18	Yes	No
9	Molecular Imaging Center Antwerp (MICA), University of Antwerp	Belgium	Antwerp	Siemens	ECLIPSE	11	Yes	No
10	University Hospital UZ Brussels	Belgium	Brussel	IBA	CYCLONE KIUBE	18	Yes	No
11	BetaPlus Pharma	Belgium	Bruxelles	IBA	CYCLONE 18	18	Yes	No
12	Université Libre de Bruxelles, Erasme Hospital	Belgium	Brussels	IBA	CYCLONE 30	30	Yes	Yes
13	IRE	Belgium	Fleurus	IBA	CYCLONE 14	14	Yes	No
14	University Hospital Gent	Belgium	Gent	IBA	Cyclone 18	18	Yes	No
15	Cyclotron UZGent	Belgium	Gent	IBA	CYCLONE 18	18	Yes	No
16	University Hopital KU Leuven	Belgium	Leuven	IBA	CYCLONE 18	18	Yes	No
17	Research Center University Liege	Belgium	Liège	IBA	CYCLONE 18	18	Yes	No
18	University Hospital CHU Liege	Belgium	Liège	IBA	CYCLONE KIUBE	18	Yes	No
19	UCL, Centre de Recherches du Cyclotron	Belgium	Ottignies-Louvain-la-Neuve	IBA	CYCLONE 30	30	No	Yes

20	Alexandrovska-University Multiprofile Hospital for Active Treatment	Bulgaria	Sofia	ABT	BG-75	7.5	Yes	No
21	The Institute for Nuclear Research and Nuclear Energy (INRNE)	Bulgaria	Sofia	ACSI	TR-24	24	Yes	Yes
22	ECZACIBASI-MONROL BULGARIA	Bulgaria	Sofia	IBA	CYCLONE 18	18	Yes	No
23	St. Marina - University Multiprofile Hospital for Active Treatment	Bulgaria	Varna	ABT	BG-75	7.5	Yes	No
24	Rudjer Boskovic Institute	Croatia	Zagreb	IBA	CYCLONE 18	18	Yes	No
25	Oncology Centre	Cyprus	Limassol	ABT	BG-75	7.5	Yes	No
26	Masaryk Memorial Cancer Institute, PET Center	Czech Republic	Brno	IBA	CYCLONE 18	18	Yes	No
27	unspecified	Czech Republic	Prague	IBA	CYCLONE 18	18	No	No
28	Nuclear Physics Institute of the Academy of Sciences of the Czech Republic	Czech Republic	Prague	NIIEFA	U-120	36	No	No
29	unspecified	Czech Republic	Peč	IBA	CYCLONE 18	18	No	No
30	unspecified	Czech Republic	Řež	IBA	CYCLONE 18	18	No	No
31	Nuclear Physics Institute of the Academy of Sciences of the Czech Republic	Czech Republic	Řež	ACSI	TR-24	18-24	Yes	Yes
32	Aarhus Sygehus	Denmark	Aarhus	GE	PETtrace	16		
33	unspecified	Denmark	Aarhus	GE	PETtrace	16	No	No
34	unspecified	Denmark	Aarhus	IBA	CYCLONE 18	18	No	No
35	University Hospital of Copenhagen	Denmark	Copenhagen	Scanditronix	MC 32NI	32		
36	unspecified	Denmark	Copenhagen	Siemens	ECLIPSE	11	No	No
37	Bispebjerg Hospital	Denmark	Copenhagen	GE	GENtrace	7.8		
38	unspecified	Denmark	Herlev	IBA	CYCLONE 18	18	No	No
39	Odense Universitetshospital	Denmark	Odense	GE	PETtrace	16		
40	unspecified	Denmark	Odense	GE	PETtrace	16	No	No
41	Forskningscenter Riso	Denmark	Roskilde	GE	PETtrace	16		

42	HUS Medical Imaging Center Cyclotron unit	Finland	Helsinki	IBA	Cyclone KIUBE	18	Yes	No
43	Docrates Facility	Finland	Helsinki	GE	PETtrace	16	Yes	No
44	University of Helsinki	Finland	Helsinki	IBA	Cyclone 10/5	10	Yes	No
45	University of Jyväskylä (JYFL)	Finland	Jyväskylä	NIIEFA	MCC-30/15	18-30	Yes	Yes
46	KYS	Finland	Kuopio	GE	PETtrace	16		
47	Turku PET Center	Finland	Turku	ACSI	TR-19	14-19	Yes	No
48	Turku PET Center	Finland	Turku	IBA	CYCLONE 3D	3	Yes	No
49	Turku PET Center	Finland	Turku	NIIEFA	MGC-20	3-20	Yes	No
50	Turku PET Center	Finland	Turku	NIIEFA	CC-18/9	18	Yes	No
51	unspecified	France	Caen	IBA	CYCLONE 18	18	No	No
52	Cyclopharma Laboratories	France	Dijon	GE	PETtrace	16		
53	unspecified	France	Fontenay aux Roses	IBA	CYCLONE 18	18	No	No
54	unspecified	France	Gif sur Yvette Cedex	IBA	CYCLONE 30	30	No	No
55	Laboratoires Cyclopharma Amiens	France	Glisy	GE	PETtrace	16		
56	University of Strasbourg/CNRS, Institut Pluridisciplinaire Hubert Curien	France	Strasbourg	ACSI	TR-24	24		
57	Laboratoires Cyclopharma Lyon	France	Janneyrias	GE	PETtrace	16		
58	CERMEP - Imagerie du Vivant	France	BRON (LYON)	IBA	CYCLONE 18	18	Yes	No
59	CIMGUA	France	Les Abymes	PMB	ISOTRACE	12	Yes	No
60	TECHNOPOLE DE CHATEAU GOMBERT	France	Marseille	GE	PETtrace	16		
61	Cerimed	France	Marseille	GE	PETtrace	16		
62	Arronax	France	Saint Herblain	IBA	CYCLONE 70	70	Yes	Yes
63	Cis Bio International	France	Nimes	GE	PETtrace	16		
64	CEA - SHFJ	France	Orsay	PMB	ISOTRACE	12	Yes	No
65	unspecified	France	Orsay	IBA	CYCLONE 18	18	No	No
66	unspecified	France	Paris	IBA	CYCLONE 18	18	No	No
67	unspecified	France	Paris	Siemens	ECLIPSE	11	No	No

68	Hopital Xavier Arnozan	France	Pessac	GE	PETtrace	16		
69	IBA RENNES	France	Rennes	GE	PETtrace	16		
70	unspecified	France	Saint Genis-Pouilly	IBA	CYCLONE 18	18	No	No
71	Institut Curie's René Huguenin	France	Saint-Cloud	GE	PETtrace	16		
72	GIP CYROI	France	Sainte Clotilde - Reunion	GE	PETtrace	16		
73	Réseau de Soins Cancérologie Onconord, Positron	France	Sarcelles	GE	PETtrace	16		
74	unspecified	France	Sarcelles	IBA	CYCLONE 18	18	No	No
75	Advanced Accelerator Applications, St Genis Pouilly	France	Saint Genis-Pouilly	GE	PETtrace	16		
76	Laboratoires Cyclopharma Toulouse	France	Toulose	GE	PETtrace	16		
77	unspecified	France	Toulose	IBA	CYCLONE 10	10	No	No
78	Cyclopharma Laboratories	France	Tours	GE	PETtrace	16		
79	Advanced Accelerator Application	France	Troyes	GE	PETtrace	16		
80	CSBIO Nancy Chu Brabois	France	Vandœuvre les Nancy	GE	PETtrace	16		
81	University Hospital Aachen	Germany	Aachen	GE	PETtrace	16.5	Yes	No
82	unspecified	Germany	Aachen	Siemens	ECLIPSE	11	No	No
83	unspecified	Germany	Bad Berka	GE	PETtrace	16	No	No
84	unspecified	Germany	Bad Berka	Siemens	ECLIPSE	11	No	No
85	Hertz- und Diabeteszentrum NRW	Germany	Bad Oeynhausen	GE	PETtrace	16		
86	unspecified	Germany	Bad Oeynhausen	IBA	CYCLONE 18	18	No	No
87	Diagnostisch Therapeutisches Zentrum Radiochemie am Frankfurter Tor	Germany	Berlin	GE	MiniTrace	10		
88	EUROPET BERLIN ZYKLOTRON GMBH	Germany	Berlin	GE	PETtrace	16		
89	Charité – Berlin	Germany	Berlin	IBA	CYCLONE 3	3	Yes	No
90	Umbra Medical AG	Germany	Bonn	GE	PETtrace	16		
91	unspecified	Germany	Bonn	Siemens	RDS112	11	No	No
92	Helmholtz-Zentrum Dresden-Rossendorf,	Germany	Dresden	ACSI	TR-FLEX	24	Yes	Yes

	Institute of Radiopharmacy							
93	unspecified	Germany	Dresden	NIIEFA	U-120	36	No	No
94	ZAG Zyklotron AG	Germany	Eggenstein-Leopoldshafen	ACSI	TR-19/9	19		
95	unspecified	Germany	Essen	IBA	CYCLONE 18	18	No	No
96	Institute for Medical Radiation Physics	Germany	Essen	TCC	CV 28	28		
97	EURO PET GMBH	Germany	Freiburg	GE	PETtrace	16		
98	Universitätsklinikum Hamburg-Eppendorf	Germany	Hamburg	Philips	140/IV	25		
99	Medizinische Hochschule Hannover (MHH)	Germany	Hannover	Scanditronix	MC 35	35		
100	German Cancer Research Centre (DKFZ)	Germany	Heidelberg	Scanditronix-Negative-Ion	MC 32-Negative-Ion	32	Yes	No
101	Forschungszentrum Jülich GMBH - Institute of Neuroscience and Medicine Nuclear Chemistry (INM-5)	Germany	Julich	IBA	CYCLONE 18	18	Yes	No
102	Forschungszentrum Jülich GMBH - Institute of Neuroscience and Medicine Nuclear Chemistry (INM-5)	Germany	Jülich	GE	PETtrace	16		
103	Forschungszentrum Jülich GMBH - Institute of Neuroscience and Medicine Nuclear Chemistry (INM-5)	Germany	Jülich	IBA	CYCLONE 30	30	No	No
104	Forschungszentrum Jülich GMBH -Institute of Neuroscience and Medicine Nuclear Chemistry (INM-5)	Germany	Jülich	Japan Steel Works	BC 1710	40	No	No
105	ZAG Zyklotron AG	Germany	Karlsruhe	ACSI	TR-19/9	19		
106	ZAG Zyklotron AG	Germany	Karlsruhe	TCC	CP-42	42		
107	unspecified	Germany	Kiel	Siemens	ECLIPSE	11	No	No
108	Max-Planck-Institut fuer Neurologische Forschung	Germany	Koln	Scanditronix	MC 16	16		
109	Universität Leipzig N.M.	Germany	Leipzig	GE	PETtrace	16		
110	unspecified	Germany	leipzig	IBA	CYCLONE 18	18	No	No
111	Johannes Gutenberg-Universität Mainz	Germany	Mainz	GE	MiniTrace	10		

112	University Hospital Muenster	Germany	Muenster	IBA	Cyclone KIUBE 18	18	Yes	No
113	unspecified	Germany	Muenster	Siemens	ECLIPSE	11	Yes	No
114	Klinikum Rechts der Isar AOER	Germany	Munich	GE	PETtrace	16		
115	Ludwig-Maximilians Universität	Germany	Munich	GE	PETtrace	16		
116	unspecified	Germany	Munich	Siemens	RDS112	11	No	No
117	ABX GmbH	Germany	Radeberg	GE	MiniTrace	10		
118	University Hospital Regensburg	Germany	Regensburg	Siemens	RDS111	11	Yes	No
119	unspecified	Germany	Rossendorf bei Dresden	IBA	CYCLONE 18	18	No	No
120	Universitätsklinikum Rostock AöR, Klinik und Poliklinik für Nuklearmedizin	Germany	Rostock	GE	MiniTrace	10		
121	Eberhard Karls University of Tübingen	Germany	Tübingen	GE	PETtrace	16		
122	Uni. Ulm - Eselsberg	Germany	Ulm	GE	PETtrace	16		
123	unspecified	Germany	Ulm	IBA	CYCLONE 18	18	No	No
124	Universitätsklinikum	Germany	Würzburg	GE	PETtrace	16		
125	BIOKOSMOS S.A.	Greece	Lavrion	GE	PETtrace	16.4		
126	BIOKOSMOS SA	Greece	Thessaloniki	GE	PETtrace 890	16.4	Yes	No
127	unspecified	Hungary	Budapest	Siemens	ECLIPSE	11	No	No
128	University of Debrecen Clinical Center Nuclear Medicine	Hungary	Debrecen	GE	PETtrace 800	16.5	Yes	No
129	Dept Applied Nuclear Physics, Institute for Nuclear Research of the Hungarian Academy of Sciences	Hungary	Debrecen	Rossatom (Sovietunion)	MGC-20E	18	Yes	Yes
130	IMC-Debreceni Egyetem Orvosi	Hungary	Debrecen	GE	PETtrace	16		
131	ATOMKI	Hungary	Debrecen	NIIEFA	MGC-20	20	No	No
132	Medicopus Nonprofit Ltd.	Hungary	Kaposvár	Siemens	Eclipse	11	Yes	No
133	Landspitali	Iceland	Reykjavík	GE	MiniTrace	10		
134	M2i Limited	Ireland	Dublin	GE	PETtrace	16.5		
135	S. Gaetano Nuclear Medicine Center	Italy	Bagheria	IBA	CYCLONE 18/9	18	Yes	No
136	Policlinico Sant'Orsola Malpighi	Italy	Bologna	GE	PETtrace	16		

137	A.O. Spedali Civili-Brescia	Italy	Brescia	GE	PETtrace	16		
138	A.O. Brotzu, Centro PET	Italy	Cagliari	GE	MiniTrace	10		
139	SPARKLE	Italy	Casarano	IBA	CYCLONE 18/9	18	Yes	No
140	Castelfranco Veneto Radiopharmacy-Cyclotron Unit	Italy	Castelfranco	Siemens	RDS112	11	Yes	No
141	Castelfranco Veneto Radiopharmacy-Cyclotron Unit	Italy	Castelfranco	Siemens	ECLIPSE	11	No	No
142	AZIENDA OSPEDALIERA CANNIZZRRO	Italy	Catania	IBA	CYCLONE 18	18	Yes	No
143	Azienda Sanitaria Ospedaliera S. Croce E Carle	Italy	Cuneo	GE	MiniTrace	10		
144	Ospedale Careggi	Italy	Florence	GE	MiniTrace	10		
145	AZIENDA OSPEDALIERA SAN MARTINO	Italy	Genova	Siemens	ECLIPSE	11	Yes	No
146	Joint Research Centre (European Commission)	Italy	Ispra	Scanditronix	MC-40	40		
147	AAA Colleretto Giacosa	Italy	Ivrea	GE	PETtrace	16		
148	Istituto Scientifico Romagnolo per lo Studio e la Cura dei Tumori (I.R.S.T.) S.r.l	Italy	Meldola	GE	PETtrace	16		
149	AZIENDA OSPEDALIERA POLICLINICO UNIVERSITARIO "G. MARTINO"	Italy	Messina	Siemens	ECLIPSE	11	Yes	No
150	Policlinico Ospedale Maggiare	Italy	Milan	GE	PETtrace	16		
151	IEO	Italy	Milan	GE	PETtrace	16		
152	San Raffaele Hospital	Italy	Milan	IBA	CYCLONE 18/9	18	Yes	No
153	IRCSS OSPEDALE SAN RAFFAELE	Italy	Milan	IBA	CYCLONE 18	18	Yes	No
154	CURIUM PHARMA c/o EUROPEAN INSTITUTE OF ONCOLOGY (IEO)	Italy	Milan	IBA	CYCLONE 18	18	Yes	No
155	Istituto Nazionale per lo Studio e la Cura dei Tumori	Italy	Milan	Scanditronix	MC 17E	17		
156	A.C.O.M. ADVANCED CENTER ONCOLOGY MACERATA S.r.l	Italy	Montecosaro	IBA	CYCLONE 18	18	Yes	No
157	S.D.N. SPA	Italy	Naples	GE	MiniTrace	10		

158	AZIENDA OSPEDALIERA UNIVERSITARIA FEDERICO II	Italy	Naples	GE	MiniTrace	10		
159	CROM	Italy	Avellino	GE	MiniTrace	10		
160	INSTITUTO NAZIONALE TUMORI - IRCSS FONDAZIONE PASCALE	Italy	Naples	IBA	CYCLONE 18	18	Yes	No
161	Consiglio Nazionale delle Ricerche Institute Pascale (CNR)	Italy	Naples	Scanditronix	MC 17	17		
162	Azienda Ospedaliera Villa Sofia CTO	Italy	Palermo	GE	PETtrace	16		
163	LA MADDALENA S.p.A. (private oncology center)	Italy	Palermo	IBA	CYCLONE 18	18	Yes	No
164	LABORATORY OF APPLIED NUCLEAR ENERGY (LENA), UNIVERSITY OF PAVIA	Italy	Pavia	IBA	CYCLONE 18	18	Yes	No
165	AZIENDA OSPEDALIERA DI PERUGIA	Italy	Perugia	GE	MiniTrace	10		
166	AREA DELLA RICERCA DI PISA C.N.R.	Italy	Pisa	GE	PETtrace	16		
167	ARCISPEDALE S. MARIA NUOVA	Italy	Reggio Emilia	GE	MiniTrace	10	Yes	No
168	CURIUM PHARMA c/o POLICLINICO TOR VERGATA	Italy	Rome	IBA	CYCLONE 18	18	Yes	No
169	Radius / Policlinico Gemelli Hospital	Italy	Rome	ACSI	TR-19	19		
170	Iason S.R.L.	Italy	Rome	GE	MiniTrace	10		
171	NSA S.R.L	Italy	Rome	GE	PETtrace	16		
172	ROZZANO	Italy	Milan	IBA	CYCLONE 18	18	Yes	No
173	ITEL TELECOMUNICAZ.S.R.L	Italy	Ruvo di Puglia	GE	PETtrace	16		
174	Ospedale San Raffaele	Italy	Milan	Siemens	ECLIPSE	11		
175	Ospedale Molinette	Italy	Turin	GE	PETtrace	16		
176	CURIUM PHARMA	Italy	Udine	IBA	CYCLONE 18	18	Yes	No
177	AAA Venafro	Italy	Venafro	GE	PETtrace	16		
178	IRCSS Ospedale Sacro Cuore Don Calabria	Italy	Negrar (Verona)	ACSI (Advanced Accelerator Applications)	TR-19	19	Yes	No
179	unspecified	Kazakhstan	Almaty	ABT	BG-75	7.5	No	No
180	The Institute of Nuclear Physics	Kazakhstan	Almaty	IBA	CYCLONE 30	30	Yes	No

181	The Institute of Nuclear Physics	Kazakhstan	Almaty	NIIEFA	U-150M	60	No	No
182	unspecified	Kazakhstan	Astana	IBA	CYCLONE 18	18	No	No
183	unspecified	Kazakhstan	Semey	IBA	CYCLONE 18	18	No	No
184	NUCLEO	Latvia	Riga	IBA	CYCLONE 18	18	YES	No
185	University Institution for positron emission tomography of Republic of Macedonia	Macedonia	Skopje	GE	PET Trace 860	16.5	Yes	No
186	unspecified	Netherlands	Alkmaar	IBA	CYCLONE 18	18	No	No
187	BV Cyclotron VU (1)	Netherlands	Amsterdam	IBA	CYCLONE 18	18	Yes	No
188	BV Cyclotron VU (2)	Netherlands	Amsterdam	IBA	Cyclone® KIUBE18	18	Yes	No
189	BV Cyclotron VU (3)	Netherlands	Amsterdam	IBA	Cyclone® KIUBE 18	18	Yes	No
190	unspecified	Netherlands	Amsterdam	IBA	CYCLONE 3	3	No	No
191	unspecified	Netherlands	Amsterdam	Siemens	ECLIPSE	11	No	No
192	unspecified	Netherlands	Eindhoven	IBA	CYCLONE 30	30	No	No
193	unspecified	Netherlands	Groningen	IBA	CYCLONE 18	18	No	No
194	Groningen University Hospital	Netherlands	Groningen	Scanditronix	MC 17F	17		
195	Radboud Translational Medicine	Netherlands	Nijmegen	Siemens	Eclipse HP	11	Yes	No
196	unspecified	Netherlands	Petten	IBA	CYCLONE 30	30	No	No
197	Mallinckrodt Medical	Netherlands	Petten	Philips	AVF	25		
198	Cyclotron Rotterdam B.V (Erasmus MC)	Netherlands	Rotterdam	GE	PETtrace	16		
199	Haukeland University Hospital	Norway	Bergen	GE	PETtrace	16	Yes	No
200	Oslo Univ. Sykehus Rikshosp.	Norway	Oslo	GE	PETtrace	16		
201	University of Oslo	Norway	Oslo	Scanditronix	MC 35	35		
202	unspecified	Norway	Tromso	GE	PETtrace	16	No	No
203	unspecified	Norway	Trondheim	GE	PETtrace	16	No	No
204	Maria Sklodowska-Curie memorial Cancer Center and Institute of Oncology	Poland	Gliwice	IBA	CYCLONE 18	18	Yes	No

205	Swietokrzyskie Oncology Center at Kielce	Poland	Kielce	Siemens	ECLIPSE	11	Yes	No
206	Voxel 5 WOJSKOWY SZPITAL KLINICZNY Z POLIKLINIKA	Poland	Krakow	GE	PETtrace 860	16.5	Yes	No
207	Kopernik Regional Oncology Center	Poland	Lodz	Siemens	ECLIPSE	11	Yes	No
208	Monrol Poland	Poland	Mszczonow	IBA	CYCLONE 18	18	Yes	No
209	SRODOWISKOWE LABOLATORIUM CIEZKI (Heavy Ion Laboratory)	Poland	Warsaw	GE	PETtrace	16	Yes	No
210	Military Institute of Medicine	Poland	Warsaw	Siemens	ECLIPSE	11	Yes	No
211	Eckert & Ziegler EURO-PET	Poland	Warsaw	Siemens	ECLIPSE	11	Yes	No
212	University of Coimbra-ICNAS (1)	Portugal	Coimbra	IBA	CYCLONE 18	18	Yes	No
213	University of Coimbra-ICNAS (2)	Portugal	Coimbra	IBA	Cyclone KIUBE 18	18	Yes	No
214	Hospital da Boavista	Portugal	Porto	GE	PETtrace	16		
215	Radiopharmaceutical Research Centre	Romania	Magurele Ilfov	ACSI	TR-19	19	Yes	Yes
216	ECZACIBASI-MONROL ROMANIA	Romania	Bucharest	IBA	CYCLONE 18	18	Yes	No
217	unspecified	Romania	Bucharest	NIIEFA	U-120	36	No	No
218	INSTITUTUL REGIONAL DE ONCOLOGIE IASI	Romania	Iasi	GE	MiniTrace	10		
219	unspecified	Russia	Ekaterinburg	NIIEFA	P-7		No	No
220	unspecified	Russia	Cheljabinsk	Siemens	ECLIPSE	11	No	No
221	unspecified	Russia	Dubna	NIIEFA	U-120	36	No	No
222	unspecified	Russia	Dubna	NIIEFA	U-150	60	No	No
223	unspecified	Russia	Dubna	NIIEFA	U-300	10 MeV/n	No	No
224	unspecified	Russia	Dubna	NIIEFA	Cytrack	2,5 MeV/n	No	No
225	Ural Federal University	Russia	Ekaterinburg	ACSI	TR-24	24		
226	Cancer Center	Russia	Elets	GE	PETtrace	16		
227	GUZ REPUBLICAN CLINICAL ONCOLOGICAL DISPENSARY	Russia	Kazan	GE	PETtrace	16		
228	Pet Center	Russia	Khabarovsk	GE	PETtrace	16		
229	unspecified	Russia	Khanti-Mansiysk	GE	MiniTrace	10	Yes	No

230	unspecified	Russia	Krasnoyarsk	IBA	CYCLONE 18	18	No	No
231	unspecified	Russia	Magnitogorsk	Siemens	ECLIPSE	11	No	No
232	Federal Medical Biophisics Centre	Russia	Moscow	ACSI	TR-24	24		
233	RONC	Russia	Moscow	GE	PETtrace	16		
234	RONC	Russia	Moscow	GE	PETtrace	16		
235	unspecified	Russia	Moscow	IBA	CYCLONE 18	18	No	No
236	unspecified	Russia	Moscow	IBA	CYCLONE 18	18	No	No
237	unspecified	Russia	Moscow	IBA	CYCLONE 70	70	No	No
238	unspecified	Russia	Moscow	NIIEFA	M-1		No	No
239	unspecified	Russia	Moscow	NIIEFA	M-C		No	No
240	unspecified	Russia	Moscow	NIIEFA	P-7		No	No
241	unspecified	Russia	Moscow	NIIEFA	MGC-20	20	No	No
242	unspecified	Russia	Moscow	NIIEFA	DC-3		No	No
243	Center for high-tech diagnostics	Russia	Moscow	NIIEFA	CC-18/9M	18	Yes	No
244	unspecified	Russia	Moscow	Siemens	ECLIPSE	11	No	No
245	unspecified	Russia	Moscow	Siemens	ECLIPSE	11	No	No
246	unspecified	Russia	Moscow	Siemens	ECLIPSE	11	No	No
247	GVKG IM.BURDENKO	Russia	Moscow	GE	MiniTrace	10	Yes	No
248	unspecified	Russia	Obninsk	NIIEFA	U-150	60	No	No
249	unspecified	Russia	Obninsk	NIIEFA	RIC-14		No	No
250	unspecified	Russia	Petrusko	GE	PETtrace	16	No	No
251	Cancer Center	Russia	Novosibirsk	IBA	CYCLONE Kiube 18	18	Yes	No
252	JSC Nuclear Medical Technologies – Snezhinsk	Russia	Snezhinsk	NIIEFA	CC-18/9	18	Yes	No
253	unspecified	Russia	St Petersburg	ABT	BG-75	7,5	No	No
254	Medical Institute Berezin Sergey (MIBS)	Russia	St Petersburg	IBA	CYCLONE KIUBE	18	Yes	No
255	Institute of Human Brain RAS	Russia	St Petersburg	Scanditronix	MC-17	17		
256	unspecified	Russia	St Petersburg	Siemens	ECLIPSE	11	No	No
257	unspecified	Russia	St Petersburg	Siemens	ECLIPSE	11	No	No
258	St Petersburg State University (Human Brain Institute)	Russia	St. Petersburg	GE	PETtrace	16		

259	NII KARDIOLOGII IM.ALMAZOVA	Russia	St. Petersburg	GE	PETtrace	16		
260	unspecified	Russia	St. Petersburg	GE	PETtrace	16	No	No
261	unspecified	Russia	St. Petersburg	NIIEFA	РИ		No	No
262	unspecified	Russia	St. Petersburg	NIIEFA	ФТИ		No	No
263	unspecified	Russia	St. Petersburg	NIIEFA	U-120	36	No	No
264	unspecified	Russia	St. Petersburg	NIIEFA	MGC-20	20	No	No
265	unspecified	Russia	St. Petersburg	NIIEFA	CC-18/9	18	No	No
266	unspecified	Russia	St. Petersburg	NIIEFA	CC-12	12	No	No
267	unspecified	Russia	St. Petersburg	NIIEFA	C-80	80	No	No
268	unspecified	Russia	Stavropol	GE	PETtrace	16	No	No
269	unspecified	Russia	Tomsk	NIIEFA	P-7		No	No
270	unspecified	Russia	Tver	NIIEFA	RIC-30	30	No	No
271	unspecified	Russia	Tyumen	Siemens	ECLIPSE	11	No	No
272	unspecified	Russia	Ufa	GE	PETtrace	16	No	No
273	unspecified	Russia	Voronezh	Siemens	ECLIPSE	11	No	No
274	FEDERAL PROTON THERAPY CENTRE	Russia	Dimitrovgrad	GE	MiniTrace	10		
275	John Mallard Scottish PET Centre	United Kingdom	Aberdeen	Siemens	RDS 111	11	Yes	No
276	unspecified	Serbia	Belgrade	NIIEFA	CC-1-3		No	No
277	HOSPITAL INFANTA CRISTINA SERVISION DE MEDICINA NUCLEAR	Spain	Badajoz	GE	MiniTrace	10		
278	HOSPITAL VIRGEN DE LA ARRIXACA	Spain	Barcelona	GE	PETtrace	16		
279	unspecified	Spain	Barcelona	IBA	CYCLONE 18	18	No	No
280	unspecified	Spain	Barcelona	IBA	CYCLONE 18	18	No	No
281	BARNATRON SA	Spain	El Palmar, Murcia	GE	PETtrace	16		
282	Molypharma S.A. / Clinica Lopez Ibor	Spain	Madrid	GE	MiniTrace	10		
283	unspecified	Spain	Madrid	IBA	CYCLONE 18	18	No	No
284	unspecified	Spain	Madrid	IBA	CYCLONE 18	18	No	No
285	Centro PET Complutense (CPC)	Spain	Madrid	Oxford	OSCAR 12	12		
286	unspecified	Spain	Madrid	Siemens	ECLIPSE	11	No	No
287	unspecified	Spain	Madrid	Siemens	ECLIPSE	11	No	No

288	Universidad de Malaga	Spain	Malaga	GE	PETtrace	16		
289	unspecified	Spain	Pamplona	IBA	CYCLONE 18	18	No	No
290	unspecified	Spain	San Sebastian	IBA	CYCLONE 18	18	No	No
291	Hospital Universitario Marques de Valdecilla	Spain	Santander	GE	PETtrace	16		
292	Instituto Galego de Medicina Tecnica S.a. (Galaria)	Spain	Santiago de Compostela	GE	PETtrace	16		
293	Centro Andaluz de Diagnostico Pet	Spain	Sevilla	GE	PETtrace	16		
294	unspecified	Spain	Sevilla	IBA	CYCLONE 18	18	No	No
295	unspecified	Spain	Tenerife	IBA	CYCLONE 11	11	No	No
296	unspecified	Spain	Valencia	Siemens	ECLIPSE	11	No	No
297	AAA Zaragoza	Spain	Zaragoza	GE	PETtrace	16		
298	Sahlgrenska Universitetssjukhus	Sweden	Göteborg	GE	PETtrace	16		
299	CORPUS	Sweden	Linköping	GE	MiniTrace	10	Yes	No
300	Skånes Universitetssjukhus, Lund	Sweden	Lund	GE	PETtrace	16		
301	Skånes Universitetssjukhus, Lund	Sweden	Lund	GE	PETtrace	16		
302	Karolinska Sjukhuset, Solna	Sweden	Solna	GE	PETtrace	16		
303	Karolinska Sjukhuset, Solna	Sweden	Solna	GE	PETtrace	16		
304	Karolinska Sjukhuset	Sweden	Stockholm	GE	PETtrace	16		
305	Norrlands Universitetssjukhus	Sweden	Umeå	GE	PETtrace	16		
306	Uppsala Universitet	Sweden	Uppsala	Scanditronix	MC 17	17		
307	SWAN / Uni. Bern	Switzerland	Bern	IBA	CYCLONE 18/18 HC	18	Yes	No
308	unspecified	Switzerland	Genève	IBA	CYCLONE 18	18	No	No
309	Universitätsspital Zueurich, Labor Schlieren, Klinik für Onkologie (Wagi)	Switzerland	Schlieren	GE	PETtrace	16		
310	Paul Scherrer Institute	Switzerland	Villigen	PSI	72 MeV	72		
311	Universitätsspital Zürich (USZ)	Switzerland	Zürich	GE	PETtrace	16		

312	ECZACIBAŞI-MONROL NÜKLEER ÜRÜNLER SAN. VE TİC. A.Ş. Adana Tesisi	Turkey	Adana	GE	PETtrace	16.5	Yes	No
313	ECZACIBAŞI-MONROL NÜKLEER ÜRÜNLER SAN. VE TİC. A.Ş. Ankara Üniversitesi Tesisi	Turkey	Ankara	GE	PETtrace 880	16.5	Yes	No
314	HACETTEPE UNIVERSITY RECTORATE	Turkey	Ankara	GE	MiniTrace	10	Yes	No
315	Sarayköy Nuclear Research and Training Center	Turkey	Ankara	IBA	CYCLONE 30	30	Yes	Yes
316	Eczacıbaşı-Monrol Ankara	Turkey	Ankara	IBA	CYCLONE 18	18	Yes	No
317	ECZACIBAŞI-MONROL NÜKLEER ÜRÜNLER SAN. VE TİC. A.Ş. Gebze Tesisi (1)	Turkey	Kocaeli	IBA	CYCLONE 18/9	18	Yes	No
318	ECZACIBAŞI-MONROL NÜKLEER ÜRÜNLER SAN. VE TİC. A.Ş. Gebze Tesisi (2)	Turkey	Kocaeli	IBA	Cyclone 18 Twin	18	Yes	No
319	ECZACIBAŞI-MONROL NÜKLEER ÜRÜNLER SAN. VE TİC. A.Ş. İstanbul Tesisi (2)	Turkey	Istanbul	IBA	Cyclone 18 Twin	18	Yes	No
320	Eczacıbaşı-Monrol Gebze	Turkey	Gebze - Kocaeli	IBA	CYCLONE 18	18	Yes	No
321	Moltek	Turkey	Gebze - Kocaeli	ACSI	TR-19	19		
322	MEDICHECK -1	Turkey	Istanbul	GE	PET TRACE 890	16.5	Yes	No
323	MEDICHECK-2	Turkey	Istanbul	GE	PET TRACE 890	16.5	Yes	No
324	MEDICHECK -3	Turkey	Istanbul	GE	PET TRACE 890	16.5	Yes	No
325	ECZACIBAŞI-MONROL NÜKLEER ÜRÜNLER SAN. VE TİC. A.Ş. İstanbul Tesisi (1)	Turkey	Istanbul	IBA	Cyclone 18/9 (Upgraded to twin)	18	Yes	Yes
326	ECZACIBAŞI-MONROL NÜKLEER ÜRÜNLER SAN. VE TİC. A.Ş. İzmir Tesisi (1)	Turkey	Izmir	Siemens	CTI RDS-111 Eclipse S/N :DV26	11	Yes	No
327	ECZACIBAŞI-MONROL NÜKLEER ÜRÜNLER SAN. VE TİC. A.Ş. İzmir Tesisi (2)	Turkey	Izmir	Siemens	CTI RDS-111 Eclipse S/N :DV108	11	Yes	No
328	Kiev City Oncology Hospital	Ukraine	Kiev	GE	PETtrace	16		

329	unspecified	Ukraine	Kiev	NIIEFA	P-7		No	No
330	unspecified	Ukraine	Kiev	NIIEFA	U-240	80	No	No
331	unspecified	Ukraine	Kiev	Siemens	ECLIPSE	11	No	No
332	AMERSHAM INTERNATIONAL PLC	United Kingdom	Amersham	GE	PETtrace	16		
333	Douglas Cyclotron Centre	United Kingdom	Bebington	Scanditronix	MC-62	62	No	No
334	Belfast Health and Social Care Trust	Northern Ireland	Belfast	GE	PETtrace	16	Yes	No
335	unspecified	United Kingdom	Birmingham	Scanditronix	MC-40	40	Yes	No
336	WOLFSON BRAIN IMAGING CENTRE	United Kingdom	Cambridge	GE	PETtrace	16		
337	Wales Research and Diagnostic PET Imaging Centre	United Kingdom	Cardiff	IBA	CYCLONE 18/9	18	Yes	Yes
338	Edinburgh Imaging / University of Edinburgh	United Kingdom	Edinburgh	GE	PETtrace8	16.5	Yes	Yes
339	Gartnaval Hospital	United Kingdom	Glasgow	GE	PETtrace	16		
340	unspecified	United Kingdom	Guilford	IBA	CYCLONE 18	18	No	No
341	unspecified	United Kingdom	Hammersmith	Siemens	ECLIPSE	11	No	No
342	unspecified	United Kingdom	Hammersmith	Siemens	ECLIPSE	11	No	No
343	University of Hull PET Research Centre	United Kingdom	Hull	ABT	BG-75	7.5	Yes	No
344	Keele University Science Park	United Kingdom	Keele Staffordshire	GE	PETtrace	16		
345	King's College London-1	United Kingdom	London	GE	PETtrace	16.5	Yes	No
346	King's College London-2	United Kingdom	London	Siemens	RDS 112	11	Yes	No
347	St. Thomas Hospital, Pet Centre	United Kingdom	London	GE	PETtrace	16		
348	unspecified	United Kingdom	London	IBA	CYCLONE 3	3	No	No
349	unspecified	United Kingdom	London	IBA	CYCLONE 3	3	No	No
350	WOLFSON MOLECULAR IMAGING CENTRE	United Kingdom	Manchester	GE	PETtrace	16		
351	unspecified	United Kingdom	Middlesex	Siemens	ECLIPSE	11	No	No
352	unspecified	United Kingdom	Newcastle	ABT	BG-75	7.5	No	No

353	unspecified	United Kingdom	Nottingham	Siemens	ECLIPSE	11	No	No
354	Royal Preston Hospital	United Kingdom	Preston	GE	PETtrace	16		
355	unspecified	United Kingdom	Sheffield	IBA	CYCLONE 18	18	No	No
356	Alliance Medical	United Kingdom	Sheffield	ACSI	TR-24	24		
357	Royal Marsden NHS Foundation Trust	United Kingdom	Sutton Surrey	GE	PETtrace	16		
358	Castle Hill Hospital	United Kingdom	Yorkshire	GE	GENtrace	7.8		

References:

1. Database of Cyclotrons used for Radionuclide production: https://nucleus-new.iaea.org/sites/accelerators/Pages/Cyclotron.aspx Updated 11.04.2022.

Appendix 2: Radioisotopes in EU[2]

[2] Ligtvoet, A., Scholten, C., Dave, A., King, R., Petrosova, L. and Chiti, A., Study on sustainable and resilient supply of medical radioisotopes in the EU, Goulart De Medeiros, M. and Joerger, A. editor(s), EUR 30690 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-37422-0, doi:10.2760/642561, JRC124565.
https://publications.jrc.ec.europa.eu/repository/handle/JRC124565

Appendix 2 - Deliverable 5.1 - WP5-TNA2 - Questionnaire on industrial and clinical key players and needs

Radioisotopes in EU [1]

Radio-nuclide	Full name	Type of emis-sion	Production	Indications for use (in Europe)	Radiopharma-ceutical name in Europe (if available)	Remarks	Price per dose, EUR	Radiopharmaceutical	Radionuclide producer/ processor	Radiopharmaceutical producer/ supplier	Causes of experienced supply issues	Solutions suggested for supply issues
32P	Phosphorous-32	β	Nuclear reactor (inefficient through cyclotron): Irradiation of 32S targets	Myeloproliferative disease Bone metastases	n/a	The first radionuclide used in therapeutic applications more than 50 years ago.		32P-sodium-phosphate ([32P]-Na3PO4)	POLATOM (PL); BRR (HU)	Curium Pharma; GE Healthcare	• Product no longer offered	
47Sc	Scandium-47	β	Nuclear reactor (inefficient through cyclotron): Irradiation of 32S targets	Under investigation for liver metastases					Institut Laue-Langevin (FR)	Unknown: likely hospital preparation as still experimental	• Product no longer offered	
67Cu	Copper-67	β	Accelerator/cyclotron (most effective route):High-energy proton irradiation of natural Zn targets (typical route)	Under investigation for meningioma and neuroblastoma					unknown	Unknown: likely hospital preparation as still experimental		
89Sr	Strontium-89	β	Nuclear reactor: Irradiation of highly enriched 88Sr target (high flux)	Bone pain palliation arising from skeletal metastasis	Metastron®			[89Sr]SrCl2	POLATOM (PL) SCK-CEN (BE)	GE Healthcare; MGP POLATOM		
90Y	Yttrium-90	β	Nuclear reactor: CA: irradiation of stable/natural 89Y (100% abundant) target (high flux); NCA: decay of 90Sr (fission product of 235U in reactors) to 90Y following separation from 90Sr (elution from industrial generator)	90Y-glass and resin microspheres (TheraSphere®/SIR-Spheres®) are used in intra-arterial treatments in the liver 90Y-colloids are used in radiation synovectomy [90Y]Y-ibritumomab-tiuxetan (Zevalin®) is used in B-cell lymphoma and non-	TheraSphere® Zevalin® SIR-Spheres® Ytracis® Yttriga®	Yttrium-90 is effective in forming complexes with a variety of agents and can be broadly used in therapy for various indications.	561 11500	90Y-colloids 90Y-glass microspheres	POLATOM (PL) - precursor; NRG (NL) SCK-CEN (BE) BRR/IZOTOP (HU)	Curium Pharma/CIS Bio; GE Healthcare Boston Scientific	• Product failed quality control • Vector for labelling unavailable (ibritumomab-tiuxetan)	

				Hodgkin lymphoma 90Y-somatostatin is used for treatment of neuroendocrine tumours			11923	[90Y]Y-ibritumomab-tiuxetan		Bayer; Curium Pharma; Eckert & Ziegler; IBA		
							9,214	90Y-resin microspheres		Sirtex Medical Curium Pharma		
131I	Iodine-131	β	Nuclear reactor: CA: extraction of 131I from 235U fission product (by-product from 99Mo production, similar processing); CA: irradiation of (enriched) 130Te target	[131I]-NaI is used in benign thyroid diseases, thyroid remnant ablation and thyroid cancer and adult neuroendocrine tumours [131I]I-mIBG (IOBENGUANE) is used in neuroblastoma	Generics and Theracap®	One of the most important and widely used radionuclides for thyroid diseases.	2150	[131I]I-mIBG	POLATOM (PL); SCK-CEN (BE); IRE (BE) BRR/IZOTOP (HU) CVŘ Řež (CZ)	GE Healthcare, Curium Pharma POLATOM	• Product failed quality control • Reactor maintenance or outage • Shipping delayed (esp. air travel)	• Improve quality control throughout value chain • Better anticipation of demand/orders
							255	[131I]-NaI		GE Healthcare Curium Pharma IZOTOP POLATOM Monrol Europe		
153Sm	Samarium-153	β	Nuclear reactor:CA: irradiation of enriched 152Sm targets	Bone metastases	Quadramet®		1426	[153Sm]Sm-EDTMP	POLATOM (PL) SCK-CEN (BE) BBR/IZOTOP (HU) CVŘ Řež (CZ)	Curium Pharma/CIS Bio; GE Healthcare	• Reactor maintenance or outage	
166Ho	Holmium-166	β	Nuclear reactor: CA: Irradiation of 165Ho (100% abundant) target (common route); NCA: elution of 166Dy/166Ho generator, with 166Dy produced by irradiation of enriched 164Dy with high flux (experimental, not yet available)	166Ho-microspheres are used in intra-arterial treatment in the liver and against recurrences of head and neck squamous cell carcinoma [166Ho]Ho-chitosan is used in hepatocellular carcinoma (HCC) [166Ho]Ho-DOTMP is used in bone metastasis	QuiremSpheres®			[166Ho]Ho-chitosan	NRG (NL) ITM/FRMII (DE) POLATOM (PL) BRR/IZOTOP (HU) CVŘ Řež (CZ)	Unknown	• Reactor maintenance or outage • Product failed quality control	•Increase the number of suppliers/sources for the radionuclide
								[166Ho]Ho-DOTMP		Unknown		
								166Ho-microspheres (HoMS)		Quirem Medical/Terumo Europe		
169Er	Erbium-169	β	Nuclear reactor: CA: irradiation of (enriched) 168Er target (fairly scarce)	169Er-colloids are used in radiation synovectomy	n/a		431	169Er-colloids	NRG (NL) CVŘ Řež (CZ); Institut Laue-Langevin (FR)	Curium Pharma	• Reactor maintenance or outage • Product failed quality control	• As demand is low, supply is less (frequent), which makes supply chain weaker. Higher demand could solve these issues, but depends on needs.

177Lu	Lutetium-177	β	Nuclear reactor: CA: irradiation of highly enriched 176Lu targets (direct route, efficient, but contains long-lived 177mLu impurity); NCA: irradiation of 176Yb targets (indirect route, requires elaborate processing)	177Lu-antibodies (Betalutin®) are used in non-Hodgkin lymphoma [177Lu]Lu-DOTATATE (Lutathera®) is used in gastroentero-pancreatic neuroendocrine tumours (GEP-NETs) [177Lu]Lu-PSMA is used in therapy of castration resistant prostate cancer (pc) and pc-metastases [177Lu]Lu-somatostatin is used in neuroendocrine tumours (NETs))	Betalutin® Lutathera® EndolucinBeta®	Lutetium-177 is a therapeutic radioisotope of rapidly increasing importance.	2200 18056 3050 3050	177Lu-antibodies [177Lu]Lu-DOTATATE 177Lu-peptides [177Lu]Lu-PSMA	POLATOM (PL) – CA, precursor; NRG (NL); Eckert & Ziegler (DE, GMP in 2021); CVŘ Řež Institut Laue-Langevin (FR) SCK-CEN (BE) FRMII/ITM (DE) – NCA BRR/IZOTOP (HU);	ITM; Nordic Nanovector AAA/Novartis ITM ITM in collaboration with Edocyte/Novartis	• Problems with labelling (PSMA/DOTA-TATE) • Reactor maintenance or outage • Shipping delayed (esp. air travel – flight activity limit reached) • Miscommunication with supplier	• Expand the network of suppliers/sources for the radionuclide • Optimising transport/flight bookings by better monitoring flight activity limits
186Re	Rhenium-186	β	Nuclear reactor (commonly used): CA: Irradiation of metallic enriched 185Re target; Accelerator/cyclotron: NCA: proton or deuteron irradiation of 186W target (arising)	Radiation synovectormy			661	186Re-colloids	POLATOM (PL) SCK-CEN (BE) CVŘ Řež (CZ) NRG (NL)	Curium Pharma/CIS BIO	• Changes in production schedule • Product failed quality control	Better coordination within supply chain • Increase number of suppliers/sources for the radionuclide
188Re	Rhenium-188	β	Nuclear reactor: CA: irradiation of (highly) enriched 187Re target; NCA: elution of 188W/188Re generator, with 188W produced by irradiation of enriched 186W in (very) high flux reactors	Treatment of non-melanoma skin cancer [188Re]Re-HEDP used in painful bone metastases	Rhenium-SCT®			188Re [188Re]Re-HEDP	POLATOM (generator) (PL); SCK-CEN (generator) (BE); CVŘ Řež (generator) (CZ)	Curium Pharma Curium Pharma		

211At	Astatine-211	α	Accelerator/cyclotron: Alpha particle irradiation of natural 209Bi (100% abundant) targets	Under investigation for a range of tumours					NPI Řež cyclotron (CZ); University Hospital Copenhagen (DK); CNRS/CERI (FR); Forschungszentrum Karlsruhe cyclotron (DE); Medizinische Hochschule Hannover cyclotron (DE); JRC IHCP Ispra cyclotron (IT); HNIP cyclotron Krakow (PL)	Unknown: likely hospital preparation as still experimental		
212Pb	Lead-212	β	Generator: Elution from 224Ra/212Pb generator	Under investigation for a range of tumours					NRG (NL) – production; Orano Med (FR)	Orano Med/Roche		
213Bi	Bismuth-213	α, β	Generator: Elution from 225Ac/213Bi generator (limited availability, high costs, see also 225Ac production)	Under investigation for a range of tumours					JRC Karlsruhe (DE)	Unknown: likely hospital preparation as still experimental and very short half-life		
223Ra	Radium-223	α, β	Nuclear reactor: NCA: Irradiation (high flux) of 226Ra target, resulting in 227Ac which days into 223Ra (industrial generator); Accelerator/cyclotron:Proton irradiation of 232Th (naturally abundant) target (not yet industrialised)	Castration-resistant prostate cancer Symptomatic bone metastases and no known visceral metastases	Xofigo®		4041	[223Ra]RaCl2	IFE (NO); Supply from abroad, only disclosed source: Oakridge National Laboratory, part of US DOE	Bayer (NO)	• Long delivery times • Reactor maintenance or outage (for parent radionuclide) • Shipping delayed (esp. air travel)	• Increase number of suppliers/sources for the radionuclide (capacity has increased after long delivery times)
225Ac	Actinium-225	α, β	Nuclear reactor: Extraction from natural decay of 229Th, obtained from fissile 233U, originally reactor	[225Ac]Ac-PSMA is used for metastatic castration resistant prostate				[225Ac]Ac-Lintuzumab	JRC Karlsruhe (DE) Eckert&Ziegler (DE), Rest of	Unknown: likely hospital preparation as still experimenta		

			produced by irradiation of natural 232Th targets (limited, too small amounts to serve market); Extraction from natural decay of 229Th, obtained from 233U legacy waste from US weapon programme (limited, inefficient, costly, long half-life); Accelerator/cyclotron:Proton irradiation of 226Ra target (few producers)	cancer [225Ac]Ac-Lintuzumab is used for acute myeloid leukemia (AML)				[225Ac]Ac-PSMA	suppliers abroad in US and Russia	Unknown: likely hospital preparation as still experimental		
227Th	Thorium-227	α	Nuclear reactor: Irradiation of 226Ra target	227Th-conjugate is used for (CD22 positive) non-Hodgkin lymphoma 227Th-antibody is used for ovarian cancer and mesothelioma [227Th]Th-PSMA is used for metastatic castration resistant prostate cancer				227Th-antibody	Irradiator unknown Eckert&Ziegler (DE)	Bayer (NO)		
								227Th-conjugate				
								[227Th]Th-PSMA				

Main research reactors in EU [1]

Nr	Reactor	Country	Operator	Produced therapeutic radionuclides
1	MARIA	Poland	POLATOM	32P, 89Sr, 90Y, 131I, 153Sm, 166Ho, 177Lu, 186Re, 188Re
2	HFR	the Netherlands	NRG	89Sr, 90Y, 166Ho, 169Er, 177Lu, 212Pb
3	BR2	Belgium	SCK-CEN	89Sr, 90Y, 131I, 153Sm, 177Lu, 186Re, 188Re
4	FRMII	Germany	Technical University of Munich	166Ho, 177Lu
5	ILL	France	Institute Laue-Langevin	47Sc, 169Er, 177Lu, 188Re
6	LVR-15	the Czech Republic	CVŘ Řež	131I, 153Sm, 166Ho, 169Er, 177Lu, 186Re, 188Re
7	BRR	Hungary	BNC/AEKI	32P, 90Y, 131I, 153Sm, 166Ho, 177Lu

Radionuclides and radiopharmaceuticals used in EU [1]

Nr	Country	Radionuclides in use:	Radiopharmaceuticals in compassionate use:
1	Austria	131I, 153Sm, 169Er, 177Lu, 186Re, 223Ra, 225Ac, 90Y	
2	Belgium	90Y, 131I, 153Sm, 166Ho, 177Lu, 186Re, 223Ra, 213Bi	
3	Bulgaria	131I, 223Ra, 153Sm	
4	Croatia	131I, 177Lu, 223Ra, 90Y	
5	Cyprus	131I, 153Sm, 177Lu, 223Ra, 225Ac	153Sm
6	Czech Republic	131I, 90Y, 153Sm, 89Sr, 223Ra, 186Re,169Er, 177Lu	
7	Denmark	90Y, 131I, 177Lu, 223Ra	
8	Estonia	131I, 32P, 223Ra, 186Re, 169Er,153Sm, 89, 90Y, 177Lu	[177Lu]Lu-DOTATATE
9	Finland	[131I]-NaI, [177Lu]Lu-DOTATATE, 90Y-glass microspheres, [131I]I-mIBG, 186Re-colloids.	
10	France	89Sr, 90Y, 131I, 153Sm, 166Ho, 169Er, 177Lu, 186Re, 223Ra	
11	Germany	32P, 67Cu, 89Sr, 90Y, 131I, 153Sm, 166Ho, 169Er, 177Lu, 186Re, 188Re, 211At, 213Bi, 223Ra, 225Ac, 227Th	

12	Greece	89Sr, 90Y, 131I, 153Sm, 169Er, 177Lu, 186Re, 188Re, 223Ra	
13	Hungary	32P, 90Y, 131I, 153Sm, 166Ho, 177Lu, 186Re, 223Ra	
14	Ireland	90Y, 131I, 177Lu, 186Re, 223Ra, 153Sm, 169Er, 32P	[177Lu]Lu-PSMA-617, [177Lu]Lu- DOTATATE
15	Italy	131I, 166Ho, 177Lu, 169Er, 188Re, 223Ra, 89Sr, 90Y,	
16	Latvia	18F, 68Ga, 90Y, 131I, 177Lu 223Ra	
17	Lithuania	90Y, 131I, 166Ho, 223Ra	
18	Luxembourg	32P, 90Y, 131I, 153Sm, 169Er, 186Re, 211At, 213Bi, 223Ra, 225Ac, 227Th	
19	Malta	131I, 90Y	
20	Netherlands	32P, 89Sr, 90Y, 103Pd, 125I, 131I, 152Eu, 154Eu, 153Sm, 166Ho, 169Er, 177Lu, 186Re, 188Re, 213Bi, 223Ra, 225Ac, 227Ac, 227Th	[177Lu]Lu-DOTATATE, [225Ac]Ac-PSMA
21	Poland	153Sm, 89Sr, 223Ra, 90Y, 169Er, 186Re, 131I, 177Lu	
22	Portugal	131I, 166Ho, 177Lu, 223Ra, 90Y, 32P, 89Sr,	[177Lu]Lu-DOTATATE
23	Romania	89Sr, 90Y, 131I, 153Sm, 177Lu, 188Re	
24	Slovakia	131I, 223Ra, 177Lu, 89Sr, 90Y	
25	Slovenia	131I, 177Lu, 90Y, 223Ra, 186Re, 64Cu	
26	Spain	32P, 89Sr, 90Y, 131I, 153Sm, 166Ho, 169Er, 177Lu, 186Re, 188Re, 223Ra	

27	Sweden	131I, 90Y, 223Ra, 153Sm, 32P, 177Lu	
28	UK	90Y, 131I, 177Lu, 223Ra	Lu-177 PSMA

Reference:

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