Eur J Nucl Med Mol Imaging (2016) 43:583–596
DOI 10.1007/s00259-015-3244-x

UEMS/EBNM

Nuclear medicine training in the European Union: 2015 update

Alain Prigent[1] · Roland Hustinx[2] · Durval C. Costa[3] · On behalf of the Education and Syllabus Committee and the Executive Committee, Union Européenne des Médecins Spécialistes/European Union of Medical Specialists, Section of Nuclear Medicine/ European Board of Nuclear Medicine (UEMS/EBNM). Other committee members actively participating in the planning, discussion and writing of the present syllabus update are for the UEMS/EBNM Education and Syllabus Committee F. Brunotte (France), H. Sayman (Turkey), D. Huic (Croatia), for the UEMS/EBNM Executive Committee M. Bajc and L.S. Maffioli and T. Bogsrud as Chair of the Fellowship Examination Committee (FEBNM)

Published online: 20 November 2015

Introductory remarks

Nuclear medicine (NM) as an independent medical specialty for more than 25 years (recognised by the European Directives 1988) continues to progress and impact on clinical management of patients with a wide variety of diseases. The particular characteristics of the radiopharmaceuticals have made it possible to open up new avenues in the diagnosis, staging, restaging and evaluation of response to therapy. In addition, they made it possible to systemically treat some diseases with the same molecule used for diagnosis, but labelled with a different radionuclide. This approach, nowadays called theranostics, may find its beginnings in the early 1930s when ^{131}I was made available to evaluate the thyroid function by imaging "cold" (non-functioning) and "hot" (functioning) nodules and to treat thyroid cancer metastases as well as hyperthyroidism later on. This continues to be the current practice with small procedural changes.

The use of radiopharmaceuticals is now well established in the status of several diseases from oncology to neurodegenerative diseases, encompassing many others such as endocrine, cardiovascular, renal and skeletal, just to mention a few amongst a wide spectrum of applications.

The continuous evolution of knowledge, as well as research and development, imposes a permanent rethinking of the methodologies and practices that need to be taught to youngsters before and after the compulsory specialization training period. Similarly to all other specialties Continuing Medical Education and Professional Development programmes (CME-CPD) in addition to accreditation and re-accreditation necessitate frequent reassessment of the requirements for training of physicians desiring to become NM specialists.

We at the UEMS Section and European Board of Nuclear Medicine (UEMS/EBNM) and in particular the Education and Syllabus Committee pay attention to these issues and therefore present herein the revised and updated "Training requirements for the specialty of nuclear medicine".

It is our wish and hope that soon the combined efforts of UEMS/EBNM and the European Association of Nuclear Medicine (EANM) will succeed in producing a combined more extensive description of NM diagnostic and therapeutic procedures that will include clinical research and translational protocols. To achieve this, a "working group" has already been created to develop a preliminary "kick-off" document written by ourselves.

A related editorial can be found at DOI 10.1007/s00259-012-2076-1.

✉ Alain Prigent
alain.prigent@aphp.fr

Roland Hustinx
rhustinx@chu.ulg.ac.be

Durval C. Costa
durval.c.costa@gmail.com

[1] Service de Biophysique et Médicine Nucléaire, Centre Hospitalier, Universitaire de Bicêtre, Universitè Paris-Sud, 78, Rue du Général Leclerc, 94275 Le Kremlin-Bicêtre Cedex, France

[2] Service de Médecine Nucléaire, Centre Hospitalier Universitaire de Liège, Sart Tilman B35, 4000 Liège, Belgium

[3] Nuclear Medicine—Radiopharmacology, Champalimaud Centre for the Unknown, Champalimaud Foundation, Avenida Brasília, Doca de Pedrouços, 1400-038 Lisbon, Portugal

Training requirements for the specialty of nuclear medicine

European standards of postgraduate medical specialist training

NM is a branch of medicine that uses unsealed radioactive substances for diagnosis and therapy. These substances are used to investigate disorders of metabolism and function most often at the molecular level, under physiological and physiopathological conditions. The procedures within the scope of this definition include in vivo imaging with radiopharmaceuticals, correlative/multimodality imaging, radionuclide-guided surgery, dosimetry, therapy with radioactive substances, techniques related to nuclear physics in medicine, as well as the medical applications of radiobiology, in vitro procedures and radiation protection.

The aim and scope of this document are to set the standards for training NM specialists which are competent to serve as directors of nuclear departments, with responsibility for establishing and reviewing imaging protocols, supervising other non-specialist nuclear image interpreting practitioners, and establishing and reviewing laboratory and physician quality metrics. They should be competent to perform all radiopharmaceutical therapies.

This document will be revised every 5 years.

I. Training requirements for trainees

1. Content of training

(a) **Theoretical knowledge**

A good general background in medicine (e.g. internal medicine, oncology, cardiology, endocrinology, surgery, etc.) is assumed. More detailed knowledge of those conditions which may need to be investigated or treated by NM techniques is required.

NM specialists also use complementary methods related to NM procedures. These include: ultrasound, ECG (including dynamic+pharmacological stress testing) and management of emergencies and adverse reactions, correlative/multimodality imaging methods, such as CT, MRI and MRS, laboratory assays, bone densitometry, other available techniques complementary to NM procedures, such as optical imaging.

NM specialists may cooperate in the assessment, prevention and treatment of physical or medical accidental contamination or incorporation of radionuclides.

Required theoretical knowledge comprises scientific principles, clinical NM and integrative objectives:

(i) ***Scientific principles:***

- Basic knowledge in physics, statistics, mathematics and computer science
- Basic knowledge in biology (including molecular biology), physiology and physiopathology
- Radiation physics
- Radiobiology
- Radiochemistry
- Radiopharmacy
- Clinical radiopharmacology
- Tracer kinetic modelling
- Applications of radiopharmaceuticals and administrable or implantable medical devices: indications, justification, procedures/protocols and results, methodology and dosimetry
- Radiation protection: justification and optimization [as low as reasonably achievable (ALARA), as low as reasonably practicable (ALARP) and limitation of doses (only for medical workers)] and radiation hazards
- Instrumentation
- Quantitative techniques in NM and their standardization

- Data acquisition and image processing techniques, including SPECT, SPECT/CT, PET, PET/CT and PET/MRI
- Statistics of radioactive counting
- Quality control

(ii) ***Clinical NM****—comprehensive list of procedures is in the Annexes I and II*:

- **Diagnostic imaging:**
  - Patterns of radiopharmaceutical uptake; normal and abnormal appearances of images, normal variants and common artefacts in images
  - Cross-sectional anatomy—basic clinical CT and MRI including those findings requiring further action
  - Comprehensive knowledge of imaging diagnostic thinking (e.g. advantages and limitations of various CT protocols that can be used in PET/CT)

- Correlative imaging of NM images and those from other imaging techniques
- Special diagnostic investigations in cardiology, lung disease, gastroenterology, hepatobiliary dysfunction, nephro-urology, neurology and psychiatry, endocrinology, haematology, oncology and infection
- Radionuclide-guided surgical techniques
- Radiotherapy treatment planning using NM techniques
- Types and applications of X-ray contrast materials and gadolinium chelates, contraindications of contrast agents and management of their adverse reaction

• **Therapeutic applications:**

- Benign and malignant thyroid diseases
- Haematological disorders (e.g. lymphoma, polycythaemia).
- Metastatic bone disease
- Radiosynoviorthesis
- Neuroendocrine tumours
- Primary and secondary liver tumours

(iii) ***Integrative objectives:***

- Obtain a pertinent history and perform an appropriate physical examination
- Select the most appropriate NM examination to address the clinical problem
- Integration and evaluation of the diagnostic findings with the clinical data and the results of other imaging procedures and laboratory results
- Comprehensive knowledge of the diagnostic algorithms in clinical fields with a high added value of NM examinations
- Recommend further study or treatment as appropriate
- Communicate effectively and promptly with patients and referring physicians in both written and verbal reports
- Methodology for targeted imaging and treatment
- Prescription and administration of diagnostic and therapeutic radiopharmaceuticals as well as administrable or implantable medical devices
- Principles of other diagnostic imaging techniques (including ultrasound, CT, MRI, MRS)
- Basic principles of scientific research methodology including clinical trial design
- Radionuclide labelling of cells, subcellular structures and biological molecules
- Participate in lifelong education and development of new skills
- Assume responsibility for patient management or be an active participant in the management team when NM therapy is indicated
- Develop and supervise programmes for quality assurance and quality control
- Regulations related to the transportation, storage, disposal and use of radioactive material
- Principles and applications of radioimmunological and immunoradiometric techniques in vitro (country specific)
- Organization and management of an NM department

(iv) ***Development, new trends and research:***

- Approaches to identification of targets for molecular imaging
- Testing and validation of new imaging tracers for molecular targets
- Reporter gene strategies
- Optical bioluminescence and fluorescence imaging
- Regulatory requirements for clinical translation of new molecular imaging agents

(b) **Practical skills**

Training in other specialties is required during NM training, for example oncology (medical and radiation), cardiology, endocrinology and neurology. The proportion of the total training period devoted to clinical training in other specialties may vary according to several factors, amongst them the total length of the training.

Dedicated training in cross-sectional imaging using CT and MRI is highly recommended.

Postgraduate trainees are obliged to play an active in-service role in the practice of NM in order to familiarize themselves with all the techniques required from a NM practitioner, such as:

- Protocols of in vivo and therapeutic procedures
- Data acquisition and processing with various types of equipment, quality control of instruments and labelled agents
- Interventional procedures, including physiological, pharmacological and mental stress related to diagnostic applications, and also all therapeutic interventions
- In vitro protocols and procedures (country specific)

At the end of the training programme, postgraduate trainees must be able to plan, perform, process, analyse, report and archive any type of diagnostic procedure in vivo related to the following clinical areas:

- Central nervous system
- Bone and joints
- Cardiovascular system
- Respiratory system
- Gastrointestinal (GI) system
- Nephro-urinary and genital system
- Endocrine system
- Haematopoietic and lymphatic system
- Oncology
- Inflammatory and infectious diseases

Training should include initial evaluation for indication, justification, administration and therapeutic applications of radiopharmaceuticals and administrable or implantable medical devices, dosimetry, radiation protection and follow-up after therapy.

The trainee must complete a minimum of 3,000 documented diagnostic procedures. The minimum recommended number for each procedure is as follows:

(a) Oncology	800 (80 % at least PET or PET/CT)
(b) Bone and joint	600 (50 % at least SPECT or SPECT/CT)
(c) Cardiovascular	400
(d) Endocrinology	300
(e) Neurology	200
(f) Respiratory system (50 % combined V/Q)	100
(g) Urinary and GI track	100
(h) Others or additional from the above	500

It is recommended that at least 150 procedures have been performed in paediatric patients. Some flexibility may be accepted, but a broad spectrum of most currently used procedures has to be covered. This list will be subject to periodic revision. It is strongly recommended that a period of training is spent away from the main department in at least one other recognized training centre (this must always be emphasized).

Therapeutic applications should cover the following:

(a) Patient selection, including the diagnostic procedures necessary to establish the need for and safety of radionuclide therapy, the indications and contraindications for the use of radionuclide therapeutic procedures, and the effectiveness of these procedures in relation to other therapeutic approaches
(b) Absorbed radiation dose, including calculation of dose to the target area, to the surrounding tissue, to other organ systems, and to the total body
(c) Patient care during radionuclide therapy, including understanding potential early and late adverse reactions, additive toxicity when combined with other therapy, the timing and parameters of anticipated response, and follow-up care and evaluation
(d) Potential adverse effects of radiation, including carcinogenic, teratogenic, and mutagenic effects and doses to family members and to the general public
(e) Specific therapeutic applications, including radioiodine treatment in benign and malignant thyroid diseases, radionuclides for metastatic bone disease, radiosynoviorthesis, radiolabelled antibody therapy, intra-arterial radiolabelled microspheres for therapy of primary and secondary liver tumours, and radiolabelled peptide therapy

The trainee must take part in at least 100 therapeutic procedures.

(c) **Professionalism**

The trainee should be prepared for the basic responsibilities of an NM specialist

- Define the patient's and clinician's rationale for the request or referral, i.e. justify all referrals
- Inform the patient about the entire procedure and administration of radiopharmaceutical or therapeutic applications
- Determine and organize the appropriate tests and protocols according to accepted guidelines
- Adapt the protocols to the needs and condition of the patient
- Prescribe radiopharmaceutical and appropriate activity
- Prescribe appropriate medication needed for patient preparation (before or after) the examination or therapy
- Organize or accomplish interventions (physiological, pharmacological or thyroid fine-needle aspiration biopsy)
- Regulate the study analysis and interpretation according to the clinical information
- Interpret the results and their clinical, biological and pathological implications
- Consider follow-up consultations
- Guarantee the safety of both the patient and staff
- Participate in training and education of medical students, residents and technical staff

The trainee should have received education in NM clinical audit (including quality control and quality assurance), in the management of NM services and cost-effectiveness of the NM procedures.

The trainee must acquire regulatory expertise in health care problems related to unsealed radionuclide sources.

Further practice and experience of techniques should also be learned in this training period:

- Ethics
- Legal and regulatory requirements including telemedicine when relevant
- Clinical audit including quality control and quality assurance
- Departmental and hospital management
- Research techniques and evaluation
- Teaching and training

2. **Organization of training**

(a) **Assessment and evaluation**

The quality of the entire training has to be objectively assessed after satisfactory completion of a minimum number of courses and/or workshops and a formally organized and controlled practical training. Each training programme should contain a standard against which the progress of the trainee can be assessed for each element of the syllabus.

Trainees must pass qualification tests that cover both theoretical knowledge and practical abilities in the day-to-day practice of NM. A board or similar form of academic or national authority will award a certificate. It will be based upon:

- Final examination (covering basic science and clinical knowledge) on a national basis and/or
- Satisfactory completion of accredited, regional or national (international) courses or workshops in different fields (physics etc.) and/or
- Regularly evaluation of skill and progress by an accredited trainer/supervisor
- Radiation protection and regulatory issues have to obey local/national requirements

The final examination may take the form of an interview, a written paper, an essay, a set of multiple-choice questions or an oral examination of displayed images of various NM techniques in clinical practice. Continuous assessment is an alternative. Each end of year or training programme assessment should carry a score that indicates how the candidate has progressed against the set target. Successful trainees are awarded with a final certificate, degree or diploma that is recognized by the government.

(b) **Schedule of training**

The period of training should be a minimum of 4 and preferably 5 calendar years. Any candidate who fulfilled the requirements of the NM training programme is granted access to the specialty.

II. **Training requirements for trainers**

Trainers should have a minimum experience of 3 years in the practice of NM and must be recognized as NM specialist by its national accreditation body.

III. **Training requirements for training institutions**

Training centres should be both nationally accredited and capable of fulfilling the quantitative criteria presented in the section training requirements for trainees of the present document, in particular the number of therapeutic and diagnostic procedures.

Annex I—diagnostic applications

Central nervous system

BRAIN PERFUSION

- **Radiopharmaceuticals:**

  ^{99m}Tc-Hexamethylpropyleneamineoxime (^{99m}Tc HMPAO) or ^{99m}Tc-ethyl cysteine dimer (^{99m}Tc ECD), ^{15}O-H_2O (^{15}O water)
- **Indication:**

  – Evaluation of cerebrovascular disease
  – Presurgical localization of epileptogenic foci
  – Dementia
  – Traumatic brain injury
  – Inflammation
  – Assessment of brain death
- **Possible intervention:**

  Carbonic anhydrase inhibitor (acetazolamide, Diamox®) for testing cerebrovascular flow reserve
- **Methodology:**

  SPECT or SPECT/CT

DOPAMINE TRANSPORTER

- **Radiopharmaceuticals:**

  ^{123}I-2β-carboxymethoxy-3β-(4-iodophenyl) tropane (^{123}I-β-CIT) or ^{123}I-N-ωfluoropropyl-2β-carbomethoxy-3β-(4-iodophenyl) nortropane (^{123}I-FP-CIT)
- **Indications:**

  – Differentiate neurodegenerative parkinsonian syndromes from patients with parkinsonian symptoms unrelated to neurodegeneration (essential tremor, vascular parkinsonism, side effects of neuroleptica) but unable to differentiate among Parkinson's disease, multiple system atrophy and progressive supranuclear palsy
  – Early diagnosis of Parkinsonian syndromes
  – Differential diagnosis between dementia of Lewy bodies and other dementias
- **Methodology:**

  SPECT or SPECT/CT

D2 RECEPTOR IMAGING

- **Radiopharmaceuticals:**

  ^{123}I-(*S*)-2-hydroxy-3-iodo-6-methoxy (1-ethyl-2-pyrrolidinylmethyl) benzamide) (^{123}I-IBZM), ^{123}I-(*S*)-N-((1-ethyl-2-pyrrolidinyl) methyl)-5-iodo-2,3-dimethoxybenzamide (^{123}I epidepride)
- **Indications:**

  – Differentiation of Parkinson's disease from essential tremor or other neurodegenerative parkinsonian syndromes (e.g. multiple system atrophy, progressive supranuclear palsy)
- **Methodology:**

  SPECT or SPECT/CT

BRAIN METABOLISM

- **Radiopharmaceutical:**

  2-deoxy-2-^{18}F-fluoro-D-glucose (^{18}F-FDG), ^{11}C methionine (^{18}F-MET) or O-^{18}F-fluoro-L-tyrosine (^{18}F-FET)
- **Indications:**

  FDG:

  – Presurgical assessment (functional deficit zone) of medical refractory complex partial seizures (should be combined with ictal SPECT/CT with ^{99m}Tc-HMPAO or ^{99m}Tc-ECD)
  – Differentiate cerebral tumour from infection in immunocompromised patients with indeterminate lesions on CT and/or MR
  – CNS lymphoma

  MET or FET

  – Identify the grade of malignancy of brain tumours
  – Suspected relapse of brain tumour
  – Assess transformation of low-grade glioma to high-grade glioma
- **Methodology:**

  PET/CT or PET/MRI

CISTERNOGRAPHY AND CSF LEAK

- **Radiopharmaceutical:**

  ^{111}In- or ^{99m}Tc-labelled diethylenetriaminepentaacetic acid (^{111}In- or ^{99m}Tc-DTPA)
- **Indications:**

  – Hydrocephalus patients with normal pressure hydrocephalus to determine whether the patient might benefit from CSF shunting or not

– Shunt patency
– Cerebrospinal fluid leak
• **Methodology:**

Planar imaging or SPECT/CT

Bone and joints

BONE SCINTIGRAPHY

• **Radiopharmaceutical:**

^{99m}Tc-bisphosphonates
• **Indications:**

Neoplastic disease
Post-traumatic assessment
Arthritides
Reflex sympathetic dystrophy
Osteomyelitis
Unexplained bone pain
• **Methodology:**

Depending on the indication, flow images and blood pool images may be useful. Delayed images (skeletal phase) may include spot images, possibly with a pinhole collimator, whole-body images and SPECT or SPECT/CT, in varying combinations.

Cardiovascular system

MYOCARDIAL PERFUSION

• **Radiopharmaceuticals:**

^{201}Tl or ^{99m}Tc-sestamibi or ^{99m}Tc-tetrofosmin for SPECT
^{82}Rb or ^{13}N-ammonia for PET
• **Indications:**

– Depict the distribution of blood flow in the myocardium at rest and or during stress to assess myocardial ischaemia and scar
• **Intervention:**

Stress testing performed either by exercise or pharmacologically using vasodilators (adenosine or dipyridamole) or inotropic (dobutamine ± atropine) drugs
• **Methodology:**

SPECT synchronized to ECG (gated SPECT or gSPECT)
PET/CT with ECG gating whenever possible

MYOCARDIAL VIABILITY

• **Radiopharmaceuticals:**

^{201}Tl or ^{99m}Tc-sestamibi or ^{99m}Tc-tetrofosmin
^{18}F-FDG
• **Indications:**

– Identify myocardium with potentially reversible contractile dysfunction in patients with chronic coronary artery disease (CAD)
• **Intervention:**

– Nitrate administration for SPECT (optional)
– Fasting followed by glucose loading and insulin injection for PET
• **Methodology:**

SPECT at rest, with either thallium after reinjection (optional) and/or redistribution imaging between 4 and 24 h after injection
PET

CARDIAC FUNCTION

Equilibrium radionuclide angiography

• **Radiopharmaceuticals:**

In vivo or in vitro ^{99m}Tc-labelled red blood cells (^{99m}Tc RBC) or ^{99m}Tc-human serum albumin (^{99m}Tc-HSA)
• **Indications:**

– Measurement of left and right, diastolic and systolic, global and regional ventricular function. The most commonly measured parameter being the Left ventricular ejection fraction (LVEF)
• **Interventions:**

Usually performed at rest. Stress study is possible either exercise on a bicycle ergometer or pharmacologically by injecting an inotropic agent.
• **Methodology:**

ECG-gated planar imaging in LAO or gated SPECT imaging
First pass radionuclide angiography

• **Radiopharmaceuticals:**

^{99m}Tc-DTPA, ^{99m}Tc-pertechnetate, ^{99m}Tc-labelled myocardial perfusion agents

- **Indications:**

– Measurement of left and right, diastolic and systolic, global and regional ventricular function
– Measurement of left to right shunt

- **Interventions:**

Usually performed at rest

- **Methodology:**

Planar dynamic acquisition with ECG gating is necessary for ventricular function
Myocardial perfusion SPECT, see above
Myocardial perfusion PET, see above

Respiratory system

LUNG SCINTIGRAPHY

- **Radiopharmaceutical:**

^{99m}Tc-macroaggregated albumin (^{99m}Tc-MAA) for perfusion imaging
^{81m}Kr, ^{99m}Tc-labelled ultrafine carbon suspension (Technegas®) or ^{99m}Tc-DTPA aerosol for ventilation imaging

- **Indications:**

Pulmonary embolism diagnosis
Quantify regional lung function prior to surgery or radiation therapy
Evaluate cystic fibrosis

- **Methodology:**

Static images of ventilation and perfusion when both ventilation and perfusion agents are labelled with ^{99m}Tc. When the ventilation agent is ^{81m}Kr, alternating imaging is possible. SPECT or SPECT/CT is increasingly used.

Gastrointestinal and hepatobiliary system

Salivary gland scintigraphy

- **Radiopharmaceuticals:**

^{99m}Tc-pertechnetate

- **Indications:**

Sjögren's disease
Pleomorphic adenoma
Wharton's tumour
Adenoid cystic carcinoma
Mucoepidermoid carcinoma

- **Methodology:**

Planar dynamic imaging followed by delayed static imaging

Oesophageal transit scintigraphy

- **Radiopharmaceuticals:**

^{99m}Tc-sulphur colloid

- **Indications:**

Achalasia
Diffuse oesophageal spasm
Scleroderma
Diabetes mellitus

- **Methodology:**

Planar dynamic imaging during liquid swallowing phases

Gastro-oesophageal reflux scintigraphy

- **Radiopharmaceuticals:**

^{99m}Tc-sulphur colloid

- **Indications:**

– Gastro-oesophageal reflux evaluation

- **Methodology:**

Planar dynamic imaging after liquid nutrition

Enterogastric reflux scintigraphy

- **Radiopharmaceuticals:**

^{99m}Tc-hydroxy-iminodiacetic acid (^{99m}Tc-HIDA) or ^{99m}Tc-iminodiacetic acid (^{99m}Tc-IDA)

- **Indication:**

– Assessment of enterogastric reflux

- **Methodology:**

Planar dynamic imaging.

Gastric emptying scintigraphy

- **Radiopharmaceuticals:**

^{99m}Tc-sulphur colloid

- **Indications:**
  - Dumping syndromes
  - Gastroparesis (diabetic, postsurgical or idiopathic)
  - Functional dyspepsia
  - Pyloric stenosis
- **Methodology:**

  Planar dynamic imaging after liquid/solid phase nutrition

GI bleeding scintigraphy

- **Radiopharmaceuticals:**

  ^{99m}Tc-sulphur colloid or ^{99m}Tc-labelled RBC
- **Indications:**
  - Lower or upper GI tract bleeding assessment
- **Methodology:**

  Planar dynamic imaging and preferably SPECT/CT

Meckel's diverticulum scintigraphy

- **Radiopharmaceuticals:**

  ^{99m}Tc-pertechnetate
- **Indications:**
  - Assessment of ectopic gastric mucosa (Meckel's diverticulum)
- **Interventions:**

  Premedication with oral cimetidine (20 mg/kg) 48 h before or ranitidine (1 mg/kg) 1 h before test
- **Methodology:**

  Sequential dynamic imaging and preferably SPECT/CT

Spleen imaging

- **Radiopharmaceuticals:**

  ^{99m}Tc-sulphur colloid or ^{99m}Tc-labelled RBC
- **Indications:**

  Confirming the patency of hepatic arterial perfusion catheters and evaluating the pattern of blood flow via these catheters, including aberrant perfusion and shunting

  Assessing the size, shape and position of the spleen
  Detecting, measuring and monitoring masses of the spleen
  Identifying functioning splenic tissue (accessory spleen)
  Evaluating suspected functional asplenia
- **Methodology:**

  Planar static images or SPECT/CT

Hepatobiliary system

- **Radiopharmaceuticals:**

  ^{99m}Tc-HIDA or ^{99m}Tc-IDA, ^{99m}Tc-mebrofenin, ^{99m}Tc-lidofenin/^{99m}Tc-disofenin, ^{99m}Tc-MAA (HSA)
- **Indications:**

  Evaluating hepatic biliary system function and patency
  Calculation of gall bladder ejection fraction (GBEF)
  Assessment of biliary enteric bypass (Kasai procedure)
  Bile leakage
  Biliary atresia
  Sphincter of Oddi dysfunction
  Enterogastric (duodenogastric) reflux assessment
  Chronic cholecystitis
  Hepatic perfusion in planning selective internal radiation or drug therapy in liver tumours (HSA)
- **Interventions:**

  Cholecystokinin or morphine or phenobarbital when appropriate
- **Methodology:**

  Planar dynamic imaging

Nephro-urinary and genital system

ASSESSMENT OF RENAL FUNCTION AND TRANSIT

- **Radiopharmaceuticals:**

  ^{99m}Tc-DTPA, ^{99m}Tc-betiatide, ^{99m}Tc-bisicate, ^{123}I-iodo-ortho-hippurate
- **Indications:**

  Estimation of differential renal function
  Assessment of renal and pyelocalyceal transits
  Anterograde (descending or direct) radionuclide cystogram

- **Pharmaceutical interventions:**

  Angiotensin-converting enzyme inhibitor (captopril scintigraphy) po administration
  Furosemide (furosemide scintigraphy) IV injection
- **Methodology:**

Planar dynamic imaging

RENAL CORTICAL IMAGING

- **Radiopharmaceuticals:**

  ^{99m}Tc-dimercaptosuccinic acid (^{99m}TcDMSA)
- **Indications:**

  Estimation of sequelae of pyelonephritis and/or vesicoureteral reflux
  Detection of parenchymal lesions in untypical acute pyelonephritis
  Detection of ectopic kidneys
  Estimation of differential renal function (secondary choice)
- **Methodology:**

  Planar imaging and SPECT optional

RETROGRADE (ASCENDING OR DIRECT) RADIONUCLIDE CYSTOGRAM

- **Radiopharmaceuticals:**

  ^{99m}Tc-sulphur colloid, ^{99m}Tc-DTPA or ^{99m}Tc-pertechnetate
- **Indications:**

  Detection (during feeling and voiding) and quantification of vesicoureteral reflux
- **Methodology:**

Planar dynamic imaging

CLEARANCE METHODS (PLASMA AND URINARY METHODS)

- **Radiopharmaceuticals:**

  ^{51}Cr-ethylenediamine tetraacetic acid (^{51}Cr-EDTA), ^{99m}Tc-DTPA, ^{123}I-iodo-ortho-hippurate
- **Indications:**

  Measurement of glomerular filtration rate (GFR) with ^{51}Cr-EDTA (or ^{99m}Tc-DTPA as second choice)
  Estimation of the plasma renal flow rate (ERPF) with ^{125}I-iodo-ortho-hippurate
- **Methodology:**

  Blood samples (and time urinary collections, optional), in vitro counting and kinetics modelling
  Planar dynamic imaging (camera-based techniques with radiopharmaceuticals labelled with either ^{99m}Tc or ^{125}I)

Endocrine system

THYROID IMAGING AND FUNCTION

Radiopharmaceuticals 1: ^{99m}Tc pertechnetate

- **Indications:**
  - Evaluation of thyroid nodules [mainly in low thyroid-stimulating hormone (TSH) state]nd goiter
  - Locating ectopic thyroid tissue
  - Determining the function of thyroglossal cyst
- **Methodology:**

  Planar imaging scintigraphy and SPECT or SPECT/CT

Radiopharmaceuticals 2: ^{123}I-iodine

- **Indications:**

  Evaluation of thyroid function
  Locating ectopic thyroid tissue
  Thyroid aplasia
- **Interventions:**

  Perchlorate washout
- **Methodology:**

  Planar imaging or SPECT or SPECT/CT

Radiopharmaceuticals 3: ^{131}I-iodine

- **Indications:**

  Dosimetry for ablative therapies
- **Interventions:**

  TSH stimulation
- **Methodology:**

  Planar imaging thyroid and/or whole-body scan, additional SPECT/CT when indicated

Radiopharmaceuticals 4: ^{99m}Tc-sestamibi

- **Indications:**

Assessment of malignancy risk in thyroid cold nodules

- **Methodology:**

  Planar imaging or SPECT or SPECT/CT

MEDULLARY THYROID CANCER

- **Radiopharmaceuticals:**

  ^{123}I- or ^{131}I-metaiodobenzylguanidine (^{123}I-MIBG), ^{99m}Tc (V)DMSA, ^{111}In-octreotide
  ^{18}F-FDG, ^{18}F-DOPA, ^{68}Ga-labelled somatostatin analogues
- **Indications:**

  Medullary thyroid cancer recurrence
- **Patient preparation:**

  Lugol's solution preparation for iodine-labelled RP
- **Methodology:**

  Planar thyroid and whole-body imaging, and SPECT or SPECT/CT
  PET or PET/CT

PARATHYROID LOCATION IN HYPERPARATHYROIDISM

- **Radiopharmaceuticals:**

  ^{201}Tl, ^{99m}Tc-sestamibi
- **Indications:**

  Parathyroid adenoma or hyperplasia
  Ectopic parathyroid gland
- **Methodology:**

  Planar imaging of neck and mediastinum (with either coregistration or subtraction when using either ^{99m}Tc-pertechnetate **or** ^{123}I for double radionuclide technique), SPECT or SPECT/CT recommended

ADRENAL MEDULLA TUMOUR LOCATION

- **Radiopharmaceuticals:**

  ^{123}I- or ^{131}I-MIBG
- **Indications:**

  Phaeochromocytoma
  Paraganglioma
  Neuroblastoma
- **Patient preparation:**

  Protection of thyroid iodine uptake with Lugol's solution
- **Methodology:**

  Planar imaging, whole-body imaging, SPECT or SPECT/CT

ADRENAL CORTEX IMAGING

- **Radiopharmaceuticals:**

  ^{131}I-Noriodocholesterol
- **Indications:**

  Cushing's syndrome
  Primary aldosteronism
  Hyperandrogenism
- **Patient preparation:**

  Dexamethasone suppression
- **Methodology:**

  Planar imaging, SPECT or SPECT/CT

Haematopoietic and lymphatic system

BODY FLUID VOLUME DETERMINATION

- **Radiopharmaceutical 1:**

  ^{51}Cr-labelled RBC
- **Indications:**

  RBC volume measurement and RBC life span
- **Radiopharmaceutical 2:**

  ^{99m}Tc- or ^{125}I-labelled HSA
- **Indications:**

  Plasma volume measurement
- **Radiopharmaceutical 3:**

  ^{51}Cr-EDTA
- **Indications:**

  Extracellular volume measurement
- **Methodology (common to the three radiopharmaceuticals):**

  Blood sampling, in vitro counting and kinetics modelling

PLATELET SURVIVAL STUDY

- **Radiopharmaceutical:**

  ^{111}In-labelled platelets
- **Methodology:**

  Planar imaging

SPLENIC FUNCTION

- **Radiopharmaceuticals:**

  ^{99m}Tc-labelled heat-treated RBC
- **Methodology:**

  Planar imaging

LYMPHOSCINTIGRAPHY

- **Radiopharmaceuticals:**

  ^{99m}Tc-nanocolloids
- **Indications:**

  Lymphoedema
- **Methodology:**

  Planar imaging

Oncology

TUMOUR IMAGING AND CHARACTERIZATION

- **Radiopharmaceutical 1:**

  ^{18}F-FDG
- **Indications:**

  Differentiating benign and malignant tumours
  Tumour staging
  Monitoring the effect of therapy
  Detecting residual tumour or recurrence
- **Methodology:**

  PET/CT
- **Radiopharmaceutical 2:**

  ^{18}F-choline or ^{11}C-choline
- **Indication:**

  Restaging of patients with biochemical failure after local treatment of a prostate carcinoma
- **Methodology:**

  PET/CT
- **Radiopharmaceutical 3:**:

  Analogues of somatostatin such as ^{111}In-octreotide or ^{68}Ga-somatostatin analogues
- **Indications:**

  To identify primary neuroendocrine tumours and metastases that express somatostatin subtype 2 receptors
- **Intervention:**

  To withdraw (or temporarily lower as much as possible) somatostatin analogue treatment before the scintigraphy
- **Methodology:**

  Planar imaging or SPECT/CT when using ^{111}In-labelled somatostatin analogues
  Whole-body PET or PET/CT when using ^{68}Ga-labelled somatostatin analogues
- **Radiopharmaceutical 4:**:

  ^{18}F-DOPA
- **Indications:**

  To identify neuroendocrine tumours and their metastases expressing the L-type amino acid transporter 1 (LAT1)
- **Interventions:**

  Carbidopa has been reported to increase tumour uptake
- **Methodology:**

  PET/CT
- **Radiopharmaceutical 5**:

  ^{18}F-NaF
- **Indications:**

  Detection and localization of bone metastases in cases of cancer in adults
- **Methodology:**

  PET/CT

LYMPHOSCINTIGRAPHY AND INTRAOPERATIVE PROBE FOR SENTINEL LYMPH NODE LOCALIZATION

- **Radiopharmaceuticals:**

^{99m}Tc-labelled colloid particles or nanocolloid

- **Indication:**

  Surgical localization of the sentinel node

- **Methodology:**

  Planar imaging or SPECT (optional), and radioguided surgery

Inflammatory and infectious diseases

Infection/inflammatory site imaging

- **Radiopharmaceutical 1:**

  ^{18}F-FDG

- **Indications:**

  Localization of abnormal foci guiding the aetiological diagnosis in cases of fever of unknown origin
  Fever in an AIDS patient
  Detection of the extension of inflammation in cases of:

  – Inflammatory bowel diseases
  – Vasculitis involving the great vessels
  – Vascular prosthesis
  – Sarcoidosis

  Suspected chronic infection of bone and/or adjacent structures:

  – Osteomyelitis and/or soft tissue infection
  – Spondylitis
  – Discitis
  – Osteitis including when metallic implants are present
  – Diabetic foot with suspicion of Charcot's neuroarthropathy
  – Painful hip prosthesis

  Therapy follow-up of unresectable alveolar echinococcosis

- **Methodology:**

  PET or PET/CT

- **Radiopharmaceuticals 2:**

  ^{99m}Tc- (or ^{111}In)-labelled white blood cells or ^{99m}Tc-labelled anti-granulocyte antibodies

- **Indications:**

  Localization of abnormal foci guiding the aetiological diagnosis in cases of fever of unknown origin
  Detection of musculoskeletal infection such as septic arthritis and osteomyelitis and/or soft tissue infection
  Diabetic foot with suspicion of Charcot's neuroarthropathy

- **Methodology:**

  Planar whole-body imaging or SPECT or SPECT/CT

Annex II—therapeutic applications in nuclear medicine (marketed or in development)

1. Palliation of painful sclerotic and mixed bone metastases
   (a) ^{89}Sr-chloride
   (b) ^{153}Sm-ethylenediamine tetramethylene phosphonic acid (^{153}Sm-EDTMP or ^{153}Sm-lexidronam)
   (c) ^{186}Re–hydroxyethylidene diphosphonate (^{186}Re-HEDP or ^{186}Re-etidronate)
   (d) ^{177m}Sn-DTPA
2. Treatment of sclerotic metastases
   (a) ^{223}Ra–dichloride
3. Radiosynoviorthesis
   (a) Small joints
      i. ^{169}Er-citrate and ^{169}Er-colloids
      ii. ^{166}Ho-ferric hydroxide macroaggregate
   (b) Medium-sized joints
      i. ^{186}Re-colloids
   (c) Knee joint
      i. ^{90}Y-citrate and ^{90}Y-silicate and ^{90}Y-colloids
      ii. ^{153}Sm-particulate hydroxyapatite
4. Thyroid diseases
   (a) Well-differentiated thyroid cancer:
      i. ^{131}I
   (b) Radioiodine-refractory differentiated thyroid cancer
      i. ^{177}Lu-[DOTA^0, Tyr^3]octreotate or ^{177}Lu-DOTATATE and ^{177}Lu-[DOTA^0-1-Nal^3]octreotide or ^{177}Lu-DOTANOC
   (c) Benign thyroid diseases (hyperthyroidism and volume reduction in goiter)
      i. ^{131}I

5. Malignant neural crest tumours (neuroblastoma, phaeochromocytoma, paraganglioma, medullary thyroid carcinoma…)
   (a) ^{131}I (^{131}I-MIBG)
6. Neuroendocrine tumours [peptide receptor radionuclide therapy(PPRT) or PRRT using radiolabelled somatostatin analogues]
   i. ^{111}In-DTPA-octreotide
   ii. ^{177}Lu-[DOTA^{0}, Tyr^{3}]octreotate or ^{177}Lu-DOTATATE and ^{177}Lu-[DOTA^{0}-1-Nal^{3}]octreotide or ^{177}Lu-DOTANOC
   iii. ^{90}Y-[DOTA^{0}, Tyr^{3}]octreotide or ^{90}Y-DOTATOC
7. Hepatocarcinoma and liver metastases [selective internal radiation therapy (SIRT)]
   (a) ^{131}I-Lipiodol
   (b) ^{90}Y-microspheres
   (c) ^{188}Re-hyaluronic acid
8. Polycythaemia vera
   (a) ^{32}P
9. Melanoma
   (a) $^{64}CuCl_2$
10. Internal vectorized radiotherapy using labelled tumour-specific monoclonal antibodies
    (a) Non-Hodgkin's lymphoma
       i. ^{90}Y-Ibritumomab tiuxetan or ^{90}Y-epratuzumab tetraxetan
       ii. ^{177}Lu-DOTA-rituximab
       iii. ^{211}At-labelled anti-CD45 antibody
    (b) Prostate carcinoma
       i. ^{90}Y- or ^{177}Lu-radiolabelled monoclonal antibody targeting the epitope prostate-specific membrane antigen (PSMA) (^{90}Y or ^{177}Lu-J591 mAb)
       ii. ^{89}Zr-desferrioxamine B-J591 mAb
    (c) Glioma
       i. ^{211}At-labelled Me1-14F(ab′)2
    (d) Head and neck carcinoma
       i. ^{211}At-labelled U36 chimeric monoclonal antibody
11. Disseminated cancer
    (a) ^{211}At-EGFRvIII monoclonal antibody
12. Prevention of reactive hyperplasia after stent placement (intravascular, intraurethral…)
    (a) ^{188}Re-filled balloon dilation