Nuclear Cardiology, The Basics
In the USA, the performance of nuclear cardiology studies increased dramatically over the past 5 to 10 years. In 2001, the number of patient visits for myocardial perfusion imaging was 7.9 million. In 2005, the number of patient visits increased to 9.3 million. Roughly 96% of these studies used ECG-gated single-photon emission computed tomography (SPECT) imaging. Roughly half (47%) of these studies were performed in nonhospital settings (1).

The growth of nuclear cardiology as an expanded outpatient laboratory enterprise is readily apparent. In the USA, as well as in other parts of the world, this growth has been linked to the recognition of the ability of cardiologists to perform these studies.

Certification examination in nuclear cardiology is now an established cardiology phenomenon in the USA. Certification by one of several mechanisms is now generally required for hospital privileges in reading studies and is also often required to obtain reimbursement for study performance and interpretation.

Accreditation of laboratories is also well established. Indeed, at the time of this writing, we have learned that one large payor, responsible for 70 million lives, will require laboratory accreditation for reimbursement by March 2008.

Over the years, some of the most frequent questions asked of us by our former trainees after leaving the program relate to practical issues involved in the establishment of a nuclear cardiology laboratory. In view of the growth of the field, this is certainly not surprising.

There are a number of excellent texts on general nuclear cardiology available (2–5). These books generally deal with the overall concepts of the field, its scientific basis, techniques, clinical applications, and clinical value. However, to our knowledge, there does not presently exist a volume designed to provide the nuclear cardiologist with a manual dedicated specifically to how to establish and run a well organized and state-of-the-art nuclear cardiology laboratory.

Consequently, the purpose of this book is to provide the outline for the “nuts and bolts” establishment and operation of a nuclear cardiology laboratory. In so doing, we have attempted to deal with the relevant issues that a laboratory director must address in either setting up the laboratory or maintaining its competitive edge and clinical
competence over time. We primarily attempt to identify issues related
to outpatient imaging facilities. However, where appropriate, issues
related to in-patients in hospital-based laboratories are also discussed.

This book is aimed at cardiology fellows, nuclear cardiology fellows,
and nuclear medicine and radiology residents completing training as
well as established cardiologists, radiologists, or nuclear physicians
who want to establish a nuclear cardiology laboratory. The book
should also be of value to nuclear cardiology technologists, laboratory
managers, and health maintenance organizations. Attention has also
been paid to those factors relevant for laboratory accreditation.

The book is organized in what we feel is a logical progression. In
this new edition, we have kept the basic format established in the first
dition. In addition to reviewing, modifying, and updating each chapter
in the first edition, we have added entirely new chapters on positron
emission tomography (PET) imaging, hybrid imaging, and the clinical
appropriateness of nuclear cardiology procedures.

The initial chapter addresses what is required to establish the
laboratory in terms of equipment, availability of radiopharmaceuticals,
and staff qualifications. A chapter is devoted to the types of informa-
tion patients should be provided with, prior to arriving in the
laboratory. Chapters are devoted to laboratory logistics and appro-
riate clinical protocols for stress studies. Several chapters deal with
the technical aspects of performance of studies, such as those acquisi-
tion parameters relevant for high-quality studies, processing param-
eters, and quantification and display options. Sections on attenuation
correction have been expanded. Examples are given of commonly
encountered artifacts. We deal with issues relating to networking,
both within one laboratory and linking several laboratories. Issues
relating to dictation and reporting, coding and reimbursement, and
quality assurance are also separately addressed. Finally, we address
key policy issues that are relevant to high-quality clinical performance
and conclude with a chapter addressing issues relevant to laboratory
accreditation. The new chapter on PET imaging and hybrid imaging
reflects new clinical advances in the field since the first edition. It is
likely that these technologies will have an increasing clinical utilization
in the immediate and near future. The new chapter on appropriateness
guidelines reflects the recent joint attempt of ACC/ASNC to establish
clinical criteria for technology utilization. It is important for practioners
of nuclear cardiology to perform studies only when appropriate. It is
not enough to run a highly capable technologic enterprise; it must be
clinically relevant as well.
We are hopeful that this second edition will continue to fill an important clinical need within the cardiology and imaging communities. The book has been designed to be straightforward and to deal directly with the issues at hand and to build on the strengths established in the first edition. In many instances, we present several sides of a particular issue. The final decision on which approach to take will depend on local circumstances.

Finally, in conclusion, it is very important to acknowledge the multiple lessons we have learned from the many technologists and trainees, both in cardiology and nuclear medicine who have passed through our laboratory over the past two decades. Their input, as well as the opportunity to take part in their training, has helped us enormously in the conception and writing of this book. Some of the useful websites are http://www.asnc.org, http://www.cbnc.org, and http://www.icanl.org.

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Wendy Bruni, BS, CNMT
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Born in Echt, The Netherlands, Dr. Wackers received both his MD and PhD degrees from the University of Amsterdam School of Medicine in 1970. He completed training in Internal Medicine and Cardiology in the former Wilhelmina Gasthuis, Amsterdam in 1977. Dr. Wackers moved to the USA in 1977, where he was on the faculty of the Section of Cardiovascular Medicine at Yale University School of Medicine (1977–1981), the University of Vermont College of Medicine (1981–1984), and since 1984 at Yale University School of Medicine.

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Dr. Wackers is considered a pioneer in Nuclear Cardiology. He is the founder of the American Society of Nuclear Cardiology (1993), the Certification Board of Nuclear Cardiology (1996), and the Intersocietal Commission for Accreditation of Nuclear laboratories (1997). He was Co-Chair of the 6th and 7th International Conference of Nuclear Cardiology (2003 and 2005, respectively).

Dr. Wackers has published more than 300 articles on nuclear cardiology and clinical cardiology.

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Ms. Bruni is an active member of the American Society of Nuclear Cardiology, participating in the technologist, newsletter, and program committees. She was secretary of the New England Chapter of the Society of Nuclear Medicine (1999) and Chair of the Nuclear Cardiology Council of the Society of Nuclear Medicine Technologist Section. Ms. Bruni was selected to be on the panel of nuclear cardiology technologists who helped the NMTCB evaluate the Nuclear Cardiology Specialty Exam for technologists. She was one of the first to obtain the specialty certification of Nuclear Cardiology (NCT) in June 2001.
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He has received numerous awards and recognitions, including the Herrman Blumgart Award of the Society of Nuclear Medicine, New England Chapter (1978), the Louis Sudler Lecturer and Medalist, Rush-Presbyterian Medicacl College (1993), the Award for Contribution and Leadership in Noninvasive Cardiology, 4th International Conference on Noninvasive Cardiology, Cyprus (1993), the 29th Nathan J. Kiven Orator award, Providence RI (1996), The Solomon A. Berson Medical Alumni Achievement Award in Clinical Science, New York University
School of Medicine (1998), Co-Chair of the 1st and 2nd International Conference of Nuclear Cardiology (1993 and 1995, respectively), Co-Director of the 2nd, 3rd, and 4th Wintergreen Conference on Nuclear Cardiology (1994, 1996, 1998, respectively), First Samuel and Patsy Paine Lecturer, University of Texas (2001), 2nd Annual Mario Verani Lecture, American Society of Nuclear Cardiology (2003), the Ellis Island Medal of Honor (2003), and the American Society of Nuclear Cardiology Distinguished Service Award (2006).

Dr. Zaret is considered one of the founders and present leaders of the subspecialty of Nuclear Cardiology. He has made numerous contributions to cardiology literature on myocardial perfusion imaging and assessment of cardiac function using radionuclide imaging methodology.
All illustrations and movies in this book can be found in digital format on the accompanying CD. The images are best viewed on a high-resolution (1280 × 1280) color (24-bit or higher true color) computer monitor. The movies are best viewed at a display of 8–10 frames per second.
1

Getting Started

Whether planning a new nuclear cardiology imaging facility or renovating an existing laboratory, there are many factors to be considered and many decisions to be made. This chapter will highlight and discuss many of these practical decisions. The following issues will be considered:

- Physical space
- Equipment
- Radiopharmacy
- Additional miscellaneous supplies
- Staffing
- Radiation safety officer (RSO)
- Laboratory license

**Key Words:** Physical laboratory space, Imaging rooms, Stress rooms, Equipment (imaging and non imaging), Computer hardware and software, Supplies, Staffing (medical and technical), Training requirements staff, Radiation safety officer (RSO), Nuclear Regulatory Commission, Radiopharmacy, Radiopharmaceutical unit doses or kits, Laboratory license.

### PHYSICAL SPACE

#### Imaging Rooms

Imaging rooms should be spacious enough to accommodate gamma camera systems. Currently, a typical imaging room should be at the minimum 14 × 14 ft (4.3 × 4.3 m) (Fig. [L1]). Cameras of different vendors differ in space requirements. It is important to know the footprint of the imaging system selected and that all equipment can be accommodated in the available space. “Hybrid” systems [e.g., single photon emission computed tomography (SPECT)–CT, positron emission tomography (PET)–CT] require more space. Typically, they require at least a 20 × 16 ft (6.1 × 4.9 m) room plus a 12 × 4 ft (3.6 × 1.2 m) control room. If CT is used, lead shielding of the walls, floor, and ceiling may be necessary.
Fig. 1-1. Nuclear cardiology imaging room with triple-head gamma camera. After a patient is appropriately positioned on the imaging table, the table moves the patient feet-first into the gantry of the camera for SPECT image acquisition.

**Stress Rooms**

Stress rooms must be in close proximity to imaging rooms. A typical stress room requires at a minimum $8 \times 8 \text{ ft} (2.5 \times 2.5 \text{ m})$ (Fig. 1-2).

**Injection Room**

The injection room is useful for the injection of radiopharmaceuticals at rest. The minimal size required is $6 \times 6 \text{ ft} (1.8 \times 1.8 \text{ m})$.

**Patient Preparation Area**

This area is optional but will facilitate the flow of patients. A minimum size is $8 \times 8 \text{ ft} (2.5 \times 2.5 \text{ m})$. This area can also be used to monitor patients after stress testing when necessary.

**Reception/Waiting Rooms and Toilet Facilities**

These areas should be large enough to accommodate the expected patient volume and should be accessible to handicapped persons. A patient bathroom should be in close proximity of the waiting area.

**Bathroom(s)**

There should be separate bathrooms for patients (including handicapped-accessible) and for staff in the imaging area.
Fig. 1-2. Treadmill exercise testing (*movie*). It is good medical practice to have two people present during an exercise test. One person, a physician or experienced nurse supervises the test and observes the ECG during exercise and operates the controls of the treadmill. Another person is present for taking and recording vital signs.

**Radiopharmacy**

This area is a necessity whether one plans for a fully operational “hot lab” or merely for the storage of “unit doses.” Minimum required space is $6 \times 6$ ft ($1.8 \times 1.8$ m) (Fig. [1-3]).

**Reading/Interpretation Area**

A separate and quiet area for interpretation of studies is very convenient. In compliance with Health Insurance Portability and Accountability Act (HIPAA) regulations, patient’s protected health information (PHI) must be viewed and discussed with consideration of patient confidentiality. This space also serves to preserve patient privacy and confidentiality.

**Storage Area**

To store supplies, patient files, and digital image data.
Fig. 1-3. Interior of the radiopharmacy, also known as hot lab. On the left is the lead-shielded work area. In the middle is the dose calibrator. On the right are the logbooks for recording the use of radioisotopes.

**Staff Area**

Area for storage of personal items and for lunch breaks and staff meetings.

**Office Space**

Offices for medical and technical directors.

**EQUIPMENT**

**Acquiring a Gamma Camera**

Before one begins to explore the options of different gamma cameras on the market, one should decide on a number of important issues that may narrow down the search.

- Will the camera be a *dedicated* cardiac gamma camera, or will general nuclear medicine imaging procedures be performed as well? For dedicated cardiac cameras, one can purchase cameras with smaller detector heads and smaller field of view (FOV).
- How much physical space is available? Does the gamma camera fit in the room? Is there enough workspace around the camera? Vendors usually provide help with planning and the design of a floor plan.
- Will attenuation-corrected imaging be performed on the gamma camera?
Hardware Considerations

Size Field of View

If a camera will be used for other organ imaging in addition to cardiac imaging, a large FOV is needed. If the camera will be used only for nuclear cardiology imaging, a smaller FOV is appropriate.

Number of Heads

Triple-head or dual-head gamma camera? Dual heads are better for general nuclear medicine imaging. They are also cheaper.

Collimator Options

One should choose a collimator that will be adequate for different acquisition needs anticipated. Cardiac SPECT studies are acquired with parallel-hole collimators. For technetium-99m (Tc-99m) agents, usually parallel-hole low-energy high-resolution (LEHR) collimators are used, and for thallium-201 (Tl-201), parallel-hole low-energy all-purpose (LEAP) collimators are used.

SPECT/CT, PET/CT Option

These hybrid cameras require larger imaging space to accommodate the X-ray gantry. Consideration should be given to appropriate lead-shielded area for the technologist or a separate shielded monitoring room.

Attenuation Correction

One should make a choice between sealed sources and X-ray CT-based attenuation correction devices. Additional hardware and software are necessary for attenuation correction.

Automatic Collimator Changer

This feature is an excellent choice if collimators are to be changed frequently. However, close attention must be paid to floor leveling.

Patient Table: Manual or Automatic

The imaging table needs to be movable; this can be done by hand or with a motor. Manual tables are difficult to move when obese patients are on the table and require exact floor leveling.

Table Weight Limits

The maximal patient weight that the table can support is identified. The average weight of patients in one’s practice is considered. Maximal acceptable patient weight for imaging tables generally 350–400 lb (160–180 kg).
Gantry Size and Weight

Prior to committing to purchase of a camera, one should consult with an engineer concerning whether the floor of the imaging room has the capacity to support the camera’s weight. Reinforcement of the floor may be necessary, which adds to the overall cost of one’s purchase and increases installation time.

Power Requirements

Many gamma camera systems have special electrical power needs. This has to be checked with the manufacturer.

Universal Power Supply

If electrical power from the outlet fluctuates, one may need a universal power supply (UPS) to maintain power to the gantry and prevent system failures. Even if power supply is stable, it is a good optional feature.

Computer Speed

If quantitative processing is performed routinely, or if 16-bin ECG-gated studies are acquired, a fast(er) computer is required. Typical required speed is at least 2 GHz.

Computer Memory

It is preferred to acquire ECG-gated SPECT images with 16 rather than 8 frames per cardiac cycle. Extra computer memory may be needed, particularly if both stress and rest images are acquired in ECG-gated mode. The typical amount of required computer storage space and RAM memory is 2 GB. For the storage and access of prior studies at 500 GB, disk memory space is needed.

Networking Capabilities

Can the new system be networked to existing systems in the laboratory, and can image data be transferred back and forth? Does the system allow for remote access and/or web home reading? (see Chapter 18).

Acquisition Terminal

Is the acquisition terminal separate from the processing computer? Is there space in the imaging room for the extra computer?
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Service Issues

Is there local service for the equipment? What is their average service response time? What is their backup or support? Talk to an area hospital or other area users who have the same service and ask about the average downtime of the camera, the service response times, and the service technician’s capabilities. Negotiate prior to purchase for guaranteed minimal downtime.

Quality Control Requirements

How often is quality control (QC) required and how easy can QC be performed? What are acceptable limits? We recommend that new equipment be tested for uniformity and resolution by a physicist using the Jaszczack three-dimensional (3-D) phantom.

Display Computer

Cardiac SPECT imaging must be interpreted from a high-resolution (1280 x 1024 pixels) color monitor (24 bit or higher true color). Multiple color scales, including a linear gray scale, should be available. Flat panel monitors are currently of sufficient high quality that they can be used for diagnostic reading.

Storage of Digital Data

Computer memory and storage media are presently relatively cheap. Depending on volume of patient studies and ECG-gating parameters, one may need sufficient on-computer memory space, at least 500 GB. Raw image data can be stored on 2.3–4.2 GB optical disks or, if a large amount of data is to be stored, a 1.7 TB RAID (redundant array of independent drives) archiving system. Processed data, gif and tiff files, may be kept on 700 MB CDs. Unprocessed and processed imaging data should be kept for at least 3 years or as regulated by state laws. This is required also by Intersocietal Commission for Accreditation of Nuclear Laboratories (ICANL) for laboratory accreditation. Storage is also of clinical importance: when interpreting a current study of a patient, it is considered good practice to compare the current study with previous ones. Therefore, long-term storage is important.

Software Considerations

Quantitative Software

Does the system provide adequate quantitative software programs? What are the choices? Are the programs validated in the literature? How much extra do they cost?
Display Options

Are the display options easy to use and can they be modified to specific needs? Is the display of images in compliance with American Society of Nuclear Cardiology (ASNC) standardized display?

Transfer of Images

Is it possible to take screen captures (jpeg, gif, or tiff) of reconstructed slices and of movies (mpeg)? To apply for ICANL accreditation, it is required that one submits processed images with the application package.

Ease of Learning

Is the software user-friendly and easy to learn by the technical staff?

Applications

Can a staff member attend classes to learn about the equipment and use of software? Does the vendor provide application specialists who come on-site to teach the technical staff how to use the equipment and software? If so, for how many days? These are very important questions to have answered clearly.

Software Flexibility

Is the software flexible? Can the software easily be manipulated to perform nonstandard tasks? Some software is written in a way that processing steps are strung together in “macros,” which make it virtually impossible, or at least very difficult, to deviate from routine protocol. One should also consider whether software is in compliance with new HIPAA regulations (see Chapter 18).

Additional Ancillary Equipment

Printer

Networking Capabilities. In a laboratory with multiple camera systems, it important to purchase a printer that can be integrated into the local area network (LAN) and is capable of printing from all imaging equipment. However, because printing is rather expensive, many laboratories have elected in recent years to become “film-less.” At the present time, it is feasible to provide referring physicians with online access to patient image data through a secure network.

Quality. Some laboratories send hard copies of images with the reports to referring physicians. Glossy paper prints are expensive. For archiving and for documentation in the patient’s chart, less expensive plain printing paper is also available.
Paper and Ink Cost. Calculate the cost-per-print when comparing different systems.

Scanner. The storage and archiving of large volumes of hard copy patient records has become an increasing practical problem. Patient records, reports, ECGs, etc. can be scanned for digital archiving as jpeg, tiff, or gif files. The use of scanners and the uploading of digitized patient information also greatly facilitates remote web-based image interpretation.

Treadmill and ECG monitor

Software Options. Can the treadmill/ECG software easily be modified? Can laboratory-specific protocols be inserted in the program? Examples include printing ECGs at predetermined time intervals and the printing of selected exercise data in the final report.

Archiving. Some ECG machines have the option of digital storage of ECG tracings. Digital archiving of stress ECGs will be useful in an environment where other patient information also is stored electronically.

Test Setup. Is the setup of a patient, i.e., entering patient information in computer, placement of electrodes, and arrangement of ECG cables, easily performed?

Bicycle Compatibility. Can the ECG computer, if needed, also operate in conjunction with upright bicycle exercise?

Cardiopulmonary Exercise Testing Compatibility. With increasing numbers of patients with congestive heart failure, cardiopulmonary exercise testing with measurements of oxygen consumption has become a more common procedure. Is ECG computer compatible with cardiopulmonary testing equipment?

Stress Protocol Options. Are all required exercise and pharmacological stress protocol options available?

Treadmill Speed. Can the motorized treadmill start slowly enough so that the patient can easily step onto the belt? What is the maximal speed of the treadmill? The recommended range of speed is 1–8 mph (1.6–12.8 km/h).

Weight Limit. Is the weight limit of the treadmill adequate for the majority of patients who will come for testing?
Infusion Pump for Pharmacological Stress

**Ease of Use.** Make sure that the setup of the pump is easy and that infusion rates can be adjusted. This is especially important if dobutamine pharmacological stress is performed.

**Infusion Rates.** The pump must have the ability to infuse over a wide range of infusion rates, so that patients of all body weights receive the appropriate doses. Smaller pumps may have pre-set infusion rates and are not adjustable. Although these in general are very easy to use, they cannot be adequately adjusted for obese patients.

**Syringe Compatibility.** Make sure the pump works with the brand of syringes used in the laboratory. Syringes of different brands have slightly different diameters. The pump must be adjustable for each particular brand of syringe.

Exercise Bicycle

**Compatibility.** Is the bicycle compatible with the ECG computer equipment?

**Ease of Use.** Can the bicycle seat be adjusted easily for patients of different heights? Is it easy to monitor and to change the Watts during stress?

**Camera Compatibility.** If the bicycle is to be used in conjunction with exercise first-pass imaging, the handlebars must be removable so that the patient can be positioned with the chest close to camera head.

Emergency Equipment

The following are required emergency equipment and drugs:

- Oxygen tank and regulator
- Nasal cannula and extension tubing
- Mouth piece
- Ambu bag
- Code cart and defibrillator
- Portable ECG monitor(s)
- Nitroglycerin tablets
- Aminophylline
- Lidocaine
- Atropine
- Metoprolol
- Adenosine
• Aspirin
• Diltiazem
• Nebulizers
• Albuterol inhalers

Optional Emergency Drugs
• Furosemide
• Intravenous (IV) nitroglycerin
• Heparin

RADIOPHARMACY

Setting up the Hot Lab

Whether one decides to purchase Tc-99m generators and prepare radiopharmaceuticals on-site in the laboratory, or to buy “unit doses” from a local commercial radiopharmacy, one needs to make sure that there is a separate and dedicated area for radiopharmaceutical preparation and storage, the “hot lab.” The area is set aside from the usual work areas, has limited access, and therefore does not expose staff and patients to unnecessary radiation.

This area must be large enough to provide storage of isotopes received, to provide storage of radioactive trash, and to allow for preparation and calibration of radiotracers. The minimal size of a hot lab with a generator is approximately 6 × 6 ft (1.8 × 1.8 m). For the handling of unit doses, one needs to reserve an area of at least 4 × 4 ft (1.2 × 1.2 m).

It is prudent to plan this component of the imaging facility with an RSO and have him/her involved in the design of the facility from the very beginning. At least one cabinet, in which radioisotopes and radioactive trash are stored, needs walls with lead shielding. Whether or not the door and walls of the hot lab need lead shielding depends on what is being stored, where the hot lab is located, and the assessment by the RSO.

Supplies Needed for Radiopharmacy (Whether One Uses a Generator or Unit Doses)

Radiation Caution Sign

The door of the radiopharmacy, or area set aside as radiopharmacy, must be marked with the standard radiation warning decal “Caution Radioactive Materials” (Fig. 1-4). Containers of radioactive material (lead pigs, syringes) must be marked with the same radiation warning labels (Fig. 1-5).
Entrance door to the radiopharmacy must be locked at all times and show a caution sign for radioactive materials.

**Dose Calibrator**

Some of the newer models come with “Radiopharmacy manager” computers. This program requires QC data to be entered prior to use on each working day. This eliminates forgotten QC. This ensures that QC is always up to date, which is crucial for the Nuclear Regulatory Commission (NRC) inspections.

**Cesium-137 Source**

Needed for daily QC of the dose calibrator (see Chapter 19).

**Lead Molybdenum Coddle**

Necessary for QC of Tc-99m from generators.

**Dose Calibrator Dippers**

Multiple dippers should be available. A second or extra dipper is recommended in case the first dipper was contaminated.

**Lead Shield with Glass**

Necessary for visual control when drawing up doses.

**Lead Bricks**

Used for additional shielding. Necessary for use with molybdenum-99 (Mo-99) generators (Fig. 1-6).
Fig. 1-5. Caution sign for radioactive materials. This sign must be posted at the entrance of all areas where radioactive materials are being used.

*Lead Vials*

Necessary if preparing radiopharmaceuticals.

*Lead Pigs and Carrying Cases*

Necessary to reduce radiation exposure to personnel when carrying doses to different rooms.

*Lead Syringe Shields*

Necessary to reduce technologist radiation exposure.

*Lead-Lined Trash Containers*

Necessary to store radioactive trash. It is necessary to have a separate container for sharps/needles as well as one for all other waste.
Heat Block or Microwave

Some radiopharmaceuticals kits, e.g., sestamibi, require heating during preparation.

Refrigerator

Some radiopharmaceutical kits need to be refrigerated.

Long-Handled Tongs

These are used to minimize radiation exposure when handling radiopharmaceutical kits.

Survey Meter

This is mandatory for detecting spills and for performing daily room and trash surveys.

Syringes

Various sizes may be needed depending on the type of radiopharmaceutical kits to be prepared.

Alcohol Pads

These are necessary for drawing up doses and for preparation of radiopharmaceutical kits under aseptic conditions.