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Design of Rooms Where Unsealed Nuclear Substances Are Handled

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Preface

This regulatory document is part of the CNSC's physical design series of regulatory documents, which also covers activities that impact the ability of structures, systems and components to meet and maintain their design basis given new information arising over time and taking changes in the external environment into account. The full list of regulatory document series is included at the end of this document and can also be found on the CNSC's website.

Regulatory document REGDOC-2.5.6, *Design Guide for Rooms Where Unsealed Nuclear Substances Are Handled* provides guidance and a recommended approach for meeting the room design requirements under paragraph 3(1)(l) of the *Nuclear Substances and Radiation Devices Regulations*. It also provides guidance on performing shielding design analyses as a component of keeping doses as low as reasonably achievable (ALARA) pursuant to paragraph 4(a) of the *Radiation Protection Regulations*.

This document is the first version and supersedes GD-52, *Design Guide for Nuclear Substance Laboratories and Nuclear Medicine Rooms* (May 2010).

The information in this document is consistent with modern national and international practices for addressing issues and elements that control and enhance nuclear safety. In particular, this document establishes a modern, risk-informed approach to the design of rooms where unsealed nuclear substances are used.

For information on the implementation of regulatory documents and on the graded approach, see REGDOC-3.5.3, *Regulatory Fundamentals*.

The words "shall" and "must" are used to express requirements to be satisfied by the licensee or licence applicant. "Should" is used to express guidance or that which is advised. "May" is used to express an option or that which is advised or permissible within the limits of this regulatory document. "Can" is used to express possibility or capability.

Nothing contained in this document is to be construed as relieving any licensee from any other pertinent requirement. It is the licensee's responsibility to identify and comply with all applicable regulations and licence conditions.

Table of Contents

Design of Rooms Where Unsealed Nuclear Substances Are Handled

Draft REGDOC-2.5.6, *Design of Rooms Where Unsealed Nuclear Substances Are Handled*, contains references to the draft regulatory documents listed below. In addition to comments received on draft REGDOC-2.5.6, following public consultation, revisions to this regulatory document will be informed, as appropriate, by feedback on:

- REGDOC-1.4.1, *Licence Application Guide: Class II Nuclear Facilities and Prescribed Equipment*
- REGDOC-2.7.1, *Radiation Protection*

1. Introduction

1.1 Purpose

REGDOC-2.5.6, *Design of Rooms Where Unsealed Nuclear Substances Are Handled* provides requirements and guidance for designing a nuclear medicine room or a nuclear substance laboratory where unsealed nuclear substances are to be handled. This document also outlines an approach for submitting an application for a nuclear medicine room or a nuclear substance laboratory to the Canadian Nuclear Safety Commission (CNSC).

1.2 Scope

This document provides the requirements for and guidance on the design of rooms where unsealed nuclear substances are to be handled. The requirements and guidance include information on finishings and fixtures, emergency facilities and general contamination, plumbing, access control, shielding and radiation dose control, waste, ventilation and dose estimation for the various room classifications (basic, intermediate-level, high-level room, containment or nuclear medicine).

1.3 Relevant legislation

The following provisions of the *Nuclear Safety and Control Act* (NSCA) and the regulations made under it are relevant to this document:

- NSCA, subsection 24(4)
- *General Nuclear Safety and Control Regulations* (GNSCR), section 3
- GNSCR, paragraph 12(1)(c)
- *Nuclear Substances and Radiation Devices Regulations* (NSRDR), paragraph 3(1)(l)
- *Radiation Protection Regulations*, (RPR, 2000), paragraph 4(a)(iii)

2. Licensing process for using unsealed nuclear substances

As part of the process to obtain a licence for the use of unsealed nuclear substances, applicants must submit a completed licence application in accordance with section 3 of the GNSCR,

section 3 of the NSRDR and section 4 of the RPR, 2000. More information about the design of rooms being proposed in a licence application can be found in:

- REGDOC-1.4.1, *Licence Application Guide: Class II Nuclear Facilities and Prescribed Equipment* [1]
- REGDOC-1.6.1, *Licence Application Guide: Nuclear Substances and Radiation Devices*, version 2 [2]

If required, a dose estimation will also need to be submitted.

For ease of application, the CNSC recommends that applicants complete the Design Assessment Form (DAF) when applying for any new construction, major renovation and/or change to the licensed activities in a room where unsealed nuclear substances will be handled. The DAF follows the same order as section 4 of this document. For example, a DAF should be completed when:

- demolishing walls
- changing existing shielding
- changing workload
- changing the amount of nuclear substances handled
- adding nuclear substances
- increasing activity of nuclear substances
- installing new fume hood or changes to ventilation systems
- undergoing renovations which change the shielding of the room or the source-receptor distance
- using mobile units

The completed DAF should be submitted to the CNSC as early as possible in the design stage in order to facilitate the processing of the licence application or amendment. If multiple rooms of similar design and function are to be constructed or renovated, only one DAF needs to be submitted. Where more than one room for the handling of unsealed sources is to be constructed or renovated, and the designation or use of each one is different, a separate DAF should be submitted for each room. CNSC staff may request additional information after the initial design or renovation assessment is completed.

After a licence for a nuclear substance laboratory or nuclear medicine room has been issued, for future additional rooms, renovations or requested changes in room classification, all pertinent information must be submitted, including the DAF.

3. General information – section A of the Design Assessment Form

Section A of the DAF contains general information about the applicant and the room(s) to be classified for the use of unsealed nuclear substances. The following subsection provides information on room classification.

3.1 Classification of rooms

Areas, rooms or enclosures where nuclear substances are prepared for or administered to a person (via injection, inhalation or ingestion) for the purpose of diagnosis or treatment of patients, or for

human research studies (excluding medical diagnostic x-rays or the medical use of sealed sources for brachytherapy or teletherapy treatments) are classified as nuclear medicine rooms.

For the purpose of this document, nuclear medicine rooms are separated into one of two classifications: nuclear medicine – radiopharmacy and nuclear medicine – other. The classification nuclear medicine – other includes injection rooms, imaging rooms, therapeutic in-patient rooms, or any other rooms that are routinely occupied by patients undergoing diagnosis or therapy.

Table 1 outlines the classifications of rooms where unsealed nuclear substances are handled and their respective criteria/descriptions. With the exception of basic-level rooms, all other room classifications require the written approval of the Commission or a person authorized by the Commission for the use of unsealed nuclear substances.

With the exception of rooms classified as nuclear medicine – other, all areas, rooms or enclosures where more than one exemption quantity of an unsealed nuclear substance is handled or used must be classified as basic, intermediate, high or containment-level laboratories, according to the maximum activity of any nuclear substances to be handled in the room at one time (see table 1). This includes all veterinary nuclear medicine rooms. The radiopharmacy located in a nuclear medicine department will be classified as a nuclear medicine room; however, for design purposes, the licensee must follow the guidance and requirements described for the high-/containment-level room classification.

Table 1: Classification of rooms where unsealed nuclear substances are handled

Classification of room	Criteria/description
Basic-level room	The quantity of unsealed nuclear substance used at a single time does not exceed 5 times its corresponding annual limit on intake (ALI)
Intermediate-level room	The quantity of unsealed nuclear substance used at a single time does not exceed 50 times its corresponding ALI
High-level room	The quantity of unsealed nuclear substance used at a single time does not exceed 500 times its corresponding ALI
Containment-level room	The quantity of unsealed nuclear substance used at a single time exceeds 500 times its corresponding ALI
Nuclear medicine – hot lab	Hot lab * must follow the guidance and requirements described for the high-/containment-level room classification
Nuclear medicine – other	Radiopharmaceutical administration room, imaging room, therapeutic in-patient room or any other room routinely occupied by patients undergoing diagnosis or therapy

Notes:

1. The appropriate ALI value is the one that best represents the risks associated with the nuclear substance. If it is not possible to determine whether the greater risk is related to the inhalation or ingestion of the substance, then the more restrictive value should be used. For a list of ALIs, refer to appendix B.

2. Table 1 does not apply to the following:

- rooms or enclosures used solely for storage of unsealed nuclear substances
- rooms or enclosures for the use or storage of sealed nuclear substances or radiation devices

4. Design requirements and guidance for sections B to H of the Design Assessment Form

Section 4 of this regulatory document outlines requirements and guidance for the design of rooms in which unsealed nuclear substances are handled. The following requirements and guidance are risk-informed and align with sections B to H of the DAF. The DAF also provides opportunities to propose alternate means of achieving the intent of the requirements outlined in this section. Basic-level rooms do not require the written approval of the Commission or a person authorized by the Commission, therefore, a DAF is not necessary for rooms with this classification.

4.1 Finishing and fixtures (for use and storage area)

Requirements

Licensees with intermediate-level, high-level, containment-level and nuclear medicine–hot lab rooms shall:

- B1 – Use flooring, work surfaces, chairs, cupboards and shelving that have a smooth, impervious, washable and chemical-resistant finish in areas where nuclear substances are handled.

Guidance for all licensees

Containing spills and other accidents is a prime concern in all rooms in which unsealed nuclear substances are handled. As a result:

- B2 – Flooring should have a one-piece design. If the flooring is more than one piece, all joints in the flooring material should be sealed. The flooring should also be coved up walls and cabinets to prevent spills from getting underneath them. Flooring should have a strippable coating to make decontamination easier should an accident occur.
- B3 – All joints on work surfaces, including bench tops, should either be sealed or have a seamless one-piece design.
- B4 – Counter tops should include a lip to prevent runoff onto the floor. If the countertop abuts a wall, either the wall should be coved or the countertop should have a backsplash.

- B5 – Walls should be finished with a smooth and washable surface, and all joints should be sealed. This can make cleanup easier if a room is contaminated by back-spray from a vial or some other similar event occurs.
- B6 – The ceiling should be finished with a smooth, washable surface, and all the joints should be sealed. Applicants can suggest suitable alternatives, such as easily replaceable modular ceilings (e.g., drop ceiling with tiles).

4.2 Emergency facilities and general contamination control considerations

Requirements

Licensees with high-level, containment-level and nuclear medicine – hot lab rooms shall:

- C1 – Have personnel decontamination facilities appropriate to the activities and the isotopes and chemicals used.
- C2 – Have emergency lighting.

Guidance for all licensees

- C3 – An accessible area should be designated to store materials and equipment used for decontamination and monitoring. Materials and equipment should include spill kits, survey meters and contamination meters appropriate for the isotopes and chemicals being handled.
- C4 – Decontamination facilities should include a separate hand-washing sink near the entrance to the room.
- C5 – An emergency eye-wash station and an emergency shower should be located in or near the room.
- C6 – Personal contamination monitoring equipment suitable for the isotopes being used should be available at all points of entry/exit.
- C7 – Nuclear medicine departments should have washrooms dedicated for use by patients undergoing nuclear medicine procedures.

Areas for food and drink preparation, consumption or storage must not be located inside any room in which unsealed nuclear substances are handled. The only exception is where the patient's consumption of food or drink is a necessary part of a nuclear medicine procedure. In such cases, only food and beverages intended for patients may be stored in the room, and only patients undergoing such studies may consume this food or beverages. Staff are strictly prohibited from storing or consuming personal food or beverages in these areas.

Amenities like coat hooks, active laundry bins, storage lockers, etc., should be provided in the room near the entrance. This can facilitate the removal and proper storage of potentially contaminated personal protective equipment, such as lab coats, before leaving the room.

4.3 Plumbing – section D of the Design Assessment Form

The use of municipal sewage systems for the disposal of unsealed nuclear substances is not normally an acceptable practice. However, sinks or other sanitary facilities may be necessary for non-radioactive lab processes, or in the case of nuclear medicine, patient hygiene.

Licensees with intermediate-level, high-level, containment-level and nuclear medicine–hot lab rooms shall:

- D1 – Where routine releases occur via the sewer, or where the potential for accidental releases exists, have mechanisms in place to ensure that these releases are both below the applicable dose limits and ALARA. For further information on meeting ALARA goals, see appendix A.

Guidance for all licensees

Sinks

- D2 – Sinks should be made of material that is readily decontaminated.
- D3 – Each sink should have an overflow outlet.

Faucets

- D4 – Faucets should be operable by a means that does not require direct hand contact.
- D5 – Faucets with vacuum or cooling line attachments should include backflow protection devices.

Drains

- D6 – Drains should be constructed of a corrosion-resistant material suitable for the chemicals used in the laboratory.
- D7 – Drains and sink traps that may contain transient quantities of nuclear substances must be marked accordingly and be clearly identified on any plans provided to maintenance personnel or contractors.

Guidance specific to therapeutic nuclear medicine in-patient rooms (nuclear medicine – other)

- D8 – Each room should have its own dedicated washroom.

4.4 Access control – section E of the Design Assessment Form

Requirements

Licensees with intermediate-level, high-level, containment-level and nuclear medicine – hot lab rooms shall:

- E1 – Have an access control system (key, keypad, key fob, other) in place to ensure that only authorized workers can enter the restricted room.
- E2 – Ensure rooms have lockable doors that will remain closed and locked when nuclear substances are present and the room is unoccupied.
- E3 – Have a secondary lockable storage area (refrigerator, freezer, cupboard) for rooms that are shared with workers who are not authorized to use nuclear substances.
- E4 – Have clearly delineated designated areas where unsealed nuclear substances are handled when an area in the room is also to be used for other types of work.

Licensees with high-level, containment-level and nuclear medicine – hot lab rooms shall:

- E5 – Ensure ground-floor windows are secure to prevent unauthorized access to the room.

4.5 Shielding and radiation control – section F of the Design Assessment Form

Requirements

Licensees with high-level, containment-level and nuclear medicine – hot lab rooms shall:

- F1 – Include the dose estimates to nuclear energy workers (NEWs) and non-NEWs in the proposed room and adjacent areas.

Guidance for all licensees

If shielding analyses yield annual doses below 50 µSv per year for members of the public, and doses to NEWs are unlikely to exceed 1 mSv per year, no further optimization is required. Extensive guidance on estimating doses is provided in appendix C.

- F2 – Localized shielding should be used in areas where nuclear substances are to be used or stored. The extent of shielding depends on the quantities of nuclear substances that emit penetrating radiation. It may be necessary to reinforce work surfaces to bear the weight of any shielding material required.
- F3 – When appropriate, shielding should be incorporated into the structure of the room.
- F4 – To minimize the movement of nuclear substances, areas between which nuclear substances are to be moved should be located as close to each other as operationally possible.
- F5 – For nuclear medicine, a separate waiting room should be available for patients to whom nuclear substances are administered.

Guidance specific to therapeutic nuclear medicine in-patient rooms

- F6 – The dose rate outside the room should be less than 2.5 µSv/h.
- F7 – The room should not be adjacent to another occupied room; preferably, it should be located at the end of the hall and have the fewest shared walls possible.

4.6 Waste – section G of the Design Assessment Form

Guidance for all licensees

- G1 – Adequate space should be available for radioactive waste generated by work within the area where unsealed nuclear substances are handled. This space may be in the classified room or in a separate dedicated storage area for radioactive waste.
- G2 – Potential doses to persons occupying adjacent areas should be addressed explicitly as part of the shielding and dose assessment.

4.7 Room ventilation and air flow – section H of the Design Assessment Form

Typically, dedicated ventilation systems consist of a suitably designed fume hood or hot cell and have an exhaust system with sufficient air flow to prevent backflow into the laboratory. Hot cells

are heavily shielded enclosures for processing radioactive material. They can be used to control risks from both radiation exposure and contamination.

The requirements and guidance in this section only apply to rooms where volatile, aerosolized or gaseous nuclear substances are used.

Requirements

Licensees with high-level, containment-level and nuclear medicine – hot lab rooms (where volatile, aerosolized or gaseous nuclear substances are used) **shall:**

- H1 – Prevent atmospheric releases of nuclear substances to the environment wherever possible.
- H2 – Have dedicated systems to capture and contain volatile, aerosolized or gaseous nuclear substances and prevent their release into the general work area.
- H3 – Have exhaust systems that incorporate filtration, gas storage decay tanks or other measures appropriate to the activities and types of nuclear substances handled, to eliminate or minimize releases to the environment.
- H4 – Ensure fume hoods and hot cells, including exhaust fans, remain on at all times when nuclear substances are present.
- H5 – Ensure fume hoods and hot cells have a continuous monitoring device to ensure proper functioning of the hood.
- H6 – Ensure fume hoods are not the sole means of room air exhaust. If this is unavoidable, a bypass shall be installed to ensure ventilation when the sash is closed.
- H7 – Ensure that nuclear exhaust systems are not inadvertently modified in a manner that interferes with their design function. (e.g., loss of required airflow, connection to general room ventilation systems).
- H8 – Ensure that nuclear exhaust systems are not connected to the normal room ventilation systems.
- H9 – Detailed information about all filtration used is provided to the CNSC, including filtration monitoring and exchanges.

Guidance for all licensees

- H10 – Fume hoods, including exhaust fans, should be supported by automatic backup or emergency power to ensure continuous operation.
- H11 – Each fume hood should have an alarm, either visual or audible, to indicate reduced air flow.
- H12 – Upon installation, each fume hood should be tested to verify flow rate and confirm the absence of counter-currents.
- H13 – The minimum face velocity of the fume hood should be higher than the velocity of air currents in the room to prevent any airborne radioactivity from escaping the fume hood.

4.8 Fume hood and hot cell design – section I of the Design Assessment Form

Requirements

Licensees with high-level, containment-level and nuclear medicine – hot lab rooms shall:

- I1 – Have fume hoods or hot cells which are constructed of smooth, impervious, washable and chemical-resistant material.
- I2 – Have fume hoods and hot cells that are designed to contain spills so that they cannot readily spread beyond their interior surfaces.
- I3 – Have hot cells for handling nuclear substances in liquid or gaseous forms equipped with measures to control airborne radioactive contaminants.
- I4 – Select fume hoods and hot cells based on adequacy for the intended work.
- I5 – Have hot cells equipped with shielding adequate for the intended work.
- I6 – Maintain negative pressure inside the hot cell with respect to the room in which it is located.
- I7 – Have backup power installed for hot cell exhaust fans.

Guidance for all licensees

- I8 – The interior of the fume hood should have coved corners for easy decontamination and cleanup.
- I9 – Fume hoods should be labelled to show the connection to a specific fan or ventilation system.
- I10 – Hot cells have a means of transferring radioactivity in and out safely. For example, radioactive solutions may be pumped into the back of the hot cell via transfer lines from an accelerator producing radioisotopes. Once the radioactive material has been processed, it is placed in a shielded container to be transferred out of the hot cell, usually through a drawer on the side of the hot cell.
- I11 – Hot cells are equipped with manipulators for remotely handling objects inside the hot cell. This prevents extremity doses and reduces the risk of spills.
- I12 – The lid of the shielded container should be securely attached to the body of the shielded container while it is still inside the hot cell. Shielding should be placed between any unprocessed radioactivity and the hands of the person removing the shielded container from the hot cell.
- I13 – Hot cells have a window to allow the visual observation of processes inside the hot cell. The window should have a level of shielding equivalent to that of the hot cell walls. In modern hot cells, windows are usually constructed of lead glass.
- I14 – Radiation monitors should be installed inside hot cells. This is especially important for protecting staff who may have to open the hot cell in order to install, modify or repair equipment inside.
- I15 – Hot cells should be equipped with a monitoring device for airflow. Often, a pressure sensor is installed inside the hot cell with a display visible from outside. If the airflow fails and volatile radioactive materials are present in the hot cell(s), staff should leave the facility–
- I16 - Laminar flow hoods should be used for procedures that require sterility.

4.9 Fume hood and hot cell location – section J of the Design Assessment Form

Guidance for all licensees

- J1 – Fume hoods and hot cells should be located away from air currents or turbulence, such as high traffic areas, doors, operable windows and air supply (vents, windows, etc.).
- J2 – Fume hoods and hot cells should not be adjacent to the single means of access to an exit due to the possible volatility of contents.
- J3 – Supply air vents should be installed or directed away from fume hoods to avoid interference.

4.10 Ducts, vents and stacks – section K of the Design Assessment Form

Requirements

Licensees with high-level, containment-level and nuclear medicine – hot lab rooms shall:

- K1 – Ensure that all ductwork is constructed of corrosion-resistant materials appropriate for the nuclear substances used in the fume hood or hot cell.
- K2 – Ensure that all connections and joints are sufficiently sealed to prevent nuclear substances from leaking into adjacent air spaces.
- K3 – Clearly identify nuclear exhaust ducts on both the ducts themselves and any plans provided to maintenance personnel or contractors.
- K4 – Locate exhaust stacks or vents on the roof as far away as possible and downwind from any air intakes to prevent recirculating the nuclear substances being released.
- K5 – Demonstrate via atmospheric dispersion modelling or other calculations that doses to the public arising from both routine releases and foreseeable worst-case scenarios are ALARA and will not exceed the applicable dose limits.
- K6 – Locate fume hood exhaust fans close to the discharge point.

Guidance for all licensees

- K7 – If horizontal sections are to be used, detailed information should be submitted to the CNSC to show how the collection of condensates or liquids coming in from the discharge point will be limited. Horizontal ducts should slope at least 2.5 cm per 3 metres (1 inch per 10 feet) downward in the direction of the airflow to a suitable drain or sump.
- K8 – Do not use rain caps on stacks, because they limit vertical dispersion.
- K9 – Ensure that stack velocity is at least 1.5 times the average wind velocity to avoid entrapping any radioactive releases on the downwind side of the stack. [3]
- K10 – Ensure that the stack height is at least 3.0 m above the highest point on any adjacent roofline. It should be above head height so that there is no risk that anyone will lean over the stack.
- K11 – Air intakes should be located as far away as practicable from any stack or fume hood exhaust to prevent the recirculation of any airborne releases.
- K12 – Fume hood exhaust fans should be located outside the building.
- K13 – Post a cautionary sign and contact information where the stack is located on the roof.

5. Dose estimates for rooms classified as high-level, containment-level and nuclear medicine

For rooms classified as high-level and containment-level, doses shall also be considered at the planning stage. In this case, localized shielding is typically used to ensure that the dose rates in the surrounding areas are acceptable.

The main sources of radiation and the shielding materials shall be considered, and the resulting dose rates shall be provided (by measurement or by calculation) to the CNSC.

Occupancy by persons in adjacent or nearby areas shall be considered and the resulting annual doses determined. The intended use of procedural and work practice controls should also be considered and included in the application.

The ALARA principle is considered when designing any areas, rooms, or enclosures where nuclear substances will be handled. At the planning and design stage, the impact that design decisions will have on potential doses to persons (excluding the patient) should be a prime consideration. With nuclear medicine, this is especially important given that the source, once administered to a person, will not be in a fixed location.

The assessment of applications with respect to any nuclear medicine room will include a review of the dose estimates for persons (excluding the patient) in the area, including persons in adjacent rooms. Appendix C provides guidance on how to determine and demonstrate that radiation dose estimates are ALARA prior to building the room and carrying out any licensed activities.

REGDOC-2.7.1, *Radiation Protection* [4], provides guidance on keeping doses ALARA.

For these types of room classification, dose estimates are required. The same approach may be followed as described in appendix C, Estimating Doses.

Appendix A: Clearance Levels for Release of Common Nuclear Substances to Municipal Sewers and the Atmosphere

The *Nuclear Substance and Radiation Device Regulations* state that the conditional clearance level refers to an activity concentration that does not result in an effective dose greater than 1 mSv in a year due to a low-probability event, or greater than 10 µSv in a year. [5]

The following clearance levels represent specific values expressed in terms of release rates (air and liquid to sewer) of radionuclides to the environment or activity concentrations in solid materials below which no further justification is required to demonstrate the principle of ALARA. Licensees may use this information to determine whether or not potential releases from their rooms are low enough to be deemed ALARA without further justification or mitigation.

TECDOC-1000, *Clearance of Materials Resulting from the Use of Radionuclides in Medicine, Industry and Research* (IAEA 1998) [6] provides generic clearance levels for various radionuclides. It also provides limits for additional radionuclides, determined using the methods and dose modelling parameters. Tables A.1 and A.2 include generic clearance levels outlined in TECDOC-1000.

Table A1: Conditional clearance levels for liquids to municipal sewer based on IAEA TECDOC-1000

Radionuclide	Release limit (MBq/a)	Radionuclide	Release limit (MBq/a)	Radionuclide	Release limit (MBq/a)
F-18	0.1	Ce-139	1	Fe-59	1
P-33*	10	Ce-141	10	Tl-204	100
Sc-46	0.1	Ce-143	1	Bi-210+	10
Cr-51	100	Nd-147	1	Po-208	10
Mn-56	0.1	Pm-142	1	Po-209	10
Co-60	0.1	Sm-153	10	Po-210	10
Ni-63	10,000	Eu-152	1	Ra-223+	1
Cu-64	1	Eu-154	1	Ra-224+	0.1
Ge-68+	0.1	Gd-153	10	Ra-228+	0.1
Br-82	0.1	Pd-103	10	Ac-227+	1
Rb-83	1	Ag-110m	0.1	Th-230	100
Sr-82+	0.1	Cd-109	10	Th-228	100
Sr-90+	1	Mn-54	1	Th-228+	0.1
Y-88	0.1	Zn-65	1	Th-229	1
Sb-124	0.1	Tm-170	100	U-232+	0.1
Sb-125	1	Yb-169	1	Np-237	10
I-124	10	Lu-177	10	Pu-238	1
I-125	100	Lu-177m	0.1	Pu-239	1
I-131	10	Re-186	10	Pu-240	1

Radionuclide	Release limit (MBq/a)
Cs-125 (for Cs-124)	100,000
Cs-134	0.1
Cs-137	1
Ba-133	1
La-140	0.1

Radionuclide	Release limit (MBq/a)
Ir-192	1
Hg-194	10
Pb-210	1
Rb-86	10
Fe-55	10,000

Radionuclide	Release limit (MBq/a)
Am-241	10
Am-243+	1
Cm-244+	0.1

Table A2: Conditional clearance levels for atmospheric releases

Radionuclide	Release limit (MBq/a)	Concentration (Bq/m3)
C-11	100,000	33,000
F-18	10,000	3,300
Ar-37	1E+11	3.3E+10
Ca-45	1,000	330
Co-60	1	0.33
Zn-65	10	3.3
Rb-83	1,000	330
Sr-82+	100	33
Sr-90	1	0.33
Y-88	10	3.3
Cd-109	100	33
Sb-125	100	33
I-124	100	33
I-131	100	175[1]
Ce-139	100	33
Eu-152	1	0.33
EU-154	1	0.33
Tm-170	1,000	330
Yb-169	100	33
Lu-177	1,000	330
Re-186	1,000	330
Ra-228+	0.1	0.03
Th-228+	0.1	0.03
U-233	1	0.33
U-235	1	0.33

Radionuclide	Release limit (MBq/a)	Concentration (Bq/m3)
U-234	1	0.33
U-238	1	0.33
Pu-238	0.01	0.003
Cm-244+	0.1	0.03
Am-241	0.1	0.03

Note: Parent nuclides and their progeny included in secular equilibrium.

Radionuclide processing facilities should conduct further dose assessments, taking into account stack height and proximity to adjacent occupied areas.

Site-specific dose modelling may be required when potential atmospheric releases cannot be demonstrated to be below the values specified in this appendix. Additional filtration or other measures may be necessary within the nuclear ventilation system to mitigate potential doses.

Note that releases of solid materials to municipal landfills is regulated via the exemption and unconditional clearance values identified in Schedules 1 and 2 of the *Nuclear Substance and Radiation Device Regulations*.

Appendix B: Dose Conversion Factors (DCFs) and Annual Limits on Intake (ALIs) for Common Nuclear Substances

DCF and ALI values for common nuclear substances
[Source: DCFs from ICRP-68 [7] and NRPB-W22 [8]; ALIs derived from DCFs (ALI = 20 mSv/DCF)]

Note: ALIs listed are for a particle size (activity median aerodynamic diameter (AMAD)) of 5 µm. The solubility selected from ICRP-68 [7] was that which results in the lowest ALI for each listed radionuclide and intake route (inhalation or ingestion).

Table B1: Dose conversion factors (DCFs) and annual limits on intake (ALIs) for common nuclear substances

Nuclear substance	DCF (Sv/Bq) inhalation	ALI (Bq) inhalation	DCF (Sv/Bq) ingestion	ALI (Bq) ingestion
Actinium 227 (^{227}Ac)	6.3×10^{-04}	3.2×10^{01}	1.1×10^{-06}	1.8×10^{04}
Aluminum 26 (^{26}Al)	1.4×10^{-08}	1.4×10^{06}	3.5×10^{-09}	6.0×10^{06}
Americium 241 (^{241}Am)	2.7×10^{-05}	7.4×10^{02}	2.0×10^{-07}	1.0×10^{05}
Antimony 124 (^{124}Sb)	4.7×10^{-09}	4.3×10^{06}	2.5×10^{-09}	8.0×10^{06}
Arsenic 74 (^{74}As)	1.8×10^{-09}	1.1×10^{07}	1.3×10^{-09}	1.5×10^{07}
Barium 133 (^{133}Ba)	1.8×10^{-09}	1.1×10^{07}	1.0×10^{-09}	2.0×10^{07}
Barium 140 (^{140}Ba)	1.6×10^{-09}	1.3×10^{07}	2.5×10^{-09}	8.0×10^{06}
Beryllium 7 (^{7}Be)	4.6×10^{-11}	4.3×10^{08}	2.8×10^{-11}	7.1×10^{08}
Beryllium 10 (^{10}Be)	1.9×10^{-09}	1.1×10^{06}	1.1×10^{-09}	1.8×10^{07}
Bismuth 207 (^{207}Bi)	3.2×10^{-09}	6.3×10^{06}	1.3×10^{-09}	1.5×10^{07}
Bismuth 210 (^{210}Bi)	6.0×10^{-08}	3.3×10^{05}	1.3×10^{-09}	1.5×10^{07}
Bromine 82 (^{82}Br)	8.8×10^{-10}	2.3×10^{07}	5.4×10^{-10}	3.7×10^{07}
Cadmium 109 (^{109}Cd)	9.6×10^{-09}	2.1×10^{06}	2.0×10^{-09}	1.0×10^{07}
Calcium 45 (^{45}Ca)	2.3×10^{-09}	8.7×10^{06}	7.6×10^{-10}	2.6×10^{07}
Californium 252 (^{252}Cf)	1.3×10^{-05}	1.5×10^{03}	9.0×10^{-08}	2.2×10^{05}
Carbon 11 (^{11}C)	2.2×10^{-12}	9.1×10^{09}	2.4×10^{-11}	8.3×10^{08}
Carbon 14 (^{14}C)	2.0×10^{-11}	1.0×10^{09}	5.8×10^{-10}	3.4×10^{07}
Cerium 141 (^{141}Ce)	3.1×10^{-08}	6.5×10^{06}	7.1×10^{-10}	2.8×10^{07}
Cerium 144 (^{144}Ce)	2.9×10^{-08}	6.9×10^{05}	5.2×10^{-09}	3.8×10^{06}
Cesium 134 (^{134}Cs)	9.6×10^{-09}	2.1×10^{06}	1.9×10^{-08}	1.1×10^{06}
Cesium 137 (^{137}Cs)	6.7×10^{-09}	3.0×10^{06}	1.3×10^{-08}	1.5×10^{06}
Chlorine 36 (^{36}Cl)	5.1×10^{-09}	3.9×10^{06}	9.3×10^{-10}	2.2×10^{07}
Chromium 51 (^{51}Cr)	3.6×10^{-11}	5.6×10^{08}	3.8×10^{-11}	5.3×10^{08}
Cobalt 57 (^{57}Co)	6.0×10^{-10}	3.3×10^{07}	2.1×10^{-10}	9.5×10^{07}
Cobalt 58 (^{58}Co)	1.7×10^{-09}	1.2×10^{07}	7.4×10^{-10}	2.7×10^{07}
Cobalt 60 (^{60}Co)	1.7×10^{-08}	1.2×10^{06}	3.4×10^{-09}	5.9×10^{06}
Copper 64 (^{64}Cu)	1.5×10^{-10}	1.3×10^{08}	1.2×10^{-10}	1.7×10^{08}
Copper 67 (^{67}Cu)	5.8×10^{-10}	3.4×10^{07}	3.4×10^{-10}	5.9×10^{07}
Curium 244 (^{244}Cm)	1.7×10^{-05}	1.2×10^{03}	1.2×10^{-07}	1.7×10^{05}
Fluorine 18 (^{18}F)	9.3×10^{-11}	2.2×10^{08}	4.9×10^{-11}	4.1×10^{08}

Nuclear substance	DCF (Sv/Bq) inhalation	ALI (Bq) inhalation	DCF (Sv/Bq) ingestion	ALI (Bq) ingestion
Gadolinium 153 (^{153}Gd)	2.5×10^{-09}	8.0×10^{06}	2.7×10^{-10}	7.4×10^{07}
Gallium 67 (^{67}Ga)	2.8×10^{-10}	7.1×10^{07}	1.9×10^{-10}	1.1×10^{08}
Gallium 68 (^{68}Ga)	8.1×10^{-11}	2.5×10^{08}	1.0×10^{-10}	2.0×10^{08}
Germanium 68 (^{68}Ge)	7.9×10^{-09}	2.5×10^{06}	1.3×10^{-09}	1.5×10^{07}
Gold 198 (^{198}Au)	1.1×10^{-09}	1.8×10^{07}	1.0×10^{-09}	2.0×10^{07}
Hydrogen 3 (HT) (^{3}H)	2.0×10^{-15}	1.0×10^{13}	---	---
Hydrogen 3 (HTO) * (^{3}H)	2.0×10^{-11}	1.0×10^{09}	2.0×10^{-11}	1.0×10^{09}
Hydrogen 3 (OBT) † (^{3}H)	4.1×10^{-11}	4.9×10^{08}	4.2×10^{-11}	4.8×10^{08}
Indium 111 (^{111}In)	3.1×10^{-10}	6.5×10^{07}	2.9×10^{-10}	6.9×10^{07}
Indium 113m (^{113m}In)	3.2×10^{-11}	6.3×10^{08}	2.8×10^{-11}	7.1×10^{08}
Indium 114m (^{114m}In)	1.1×10^{-08}	1.8×10^{06}	4.1×10^{-09}	4.9×10^{06}
Iodine 123 (^{123}I)	2.1×10^{-10}	9.5×10^{07}	2.1×10^{-10}	9.5×10^{07}
Iodine 124 (^{124}I)	1.2×10^{-08}	1.7×10^{06}	1.3×10^{-08}	1.5×10^{06}
Iodine 125 (^{125}I)	1.4×10^{-08}	1.4×10^{06}	1.5×10^{-08}	1.3×10^{06}
Iodine 129 (^{129}I)	9.6×10^{-08}	2.1×10^{05}	1.1×10^{-07}	1.8×10^{05}
Iodine 131 (^{131}I)	2.0×10^{-08}	1.0×10^{06}	2.2×10^{-08}	9.1×10^{05}
Iodine 132 (^{132}I)	3.1×10^{-10}	6.5×10^{07}	2.9×10^{-10}	6.9×10^{07}
Iridium 192 (^{192}Ir)	4.9×10^{-09}	4.1×10^{06}	1.4×10^{-09}	1.4×10^{07}
Iron 55 (^{55}Fe)	9.2×10^{-10}	2.2×10^{07}	3.3×10^{-10}	6.1×10^{07}
Iron 59 (^{59}Fe)	3.2×10^{-09}	6.3×10^{06}	1.8×10^{-09}	1.1×10^{07}
Krypton 85 (gas) Bq/m^3 ‡ (^{85}Kr)	2.2×10^{-11}	9.1×10^{08}	---	---
Lanthanum 140 (^{140}La)	1.5×10^{-09}	1.3×10^{07}	2.0×10^{-09}	1.0×10^{07}
Lead 210 (^{210}Pb)	1.1×10^{-06}	1.8×10^{04}	6.8×10^{-07}	2.9×10^{04}
Magnesium 28 (^{28}Mg)	1.7×10^{-09}	1.2×10^{07}	2.2×10^{-09}	9.0×10^{06}
Manganese 54 (^{54}Mn)	1.2×10^{-09}	1.7×10^{07}	7.1×10^{-10}	2.8×10^{07}
Manganese 56 (^{56}Mn)	2.0×10^{-10}	1.0×10^{08}	2.5×10^{-10}	8.0×10^{07}
Mercury 194 (organic) (^{194}Hg)	1.9×10^{-08}	1.1×10^{06}	5.1×10^{-08}	3.9×10^{05}
Mercury 197 (organic) (^{197}Hg)	8.5×10^{-11}	2.4×10^{08}	1.7×10^{-10}	1.2×10^{08}
Mercury 197 (inorganic) (^{197}Hg)	2.8×10^{-10}	7.1×10^{07}	2.3×10^{-10}	8.7×10^{07}
Mercury 203 (organic) (^{203}Hg)	7.5×10^{-10}	2.7×10^{07}	1.9×10^{-09}	1.1×10^{07}
Mercury 203 (inorganic) (^{203}Hg)	1.9×10^{-09}	1.1×10^{07}	5.4×10^{-10}	3.7×10^{07}
Molybdenum 99 (^{99}Mo)	1.1×10^{-09}	1.8×10^{07}	1.2×10^{-09}	1.7×10^{07}
Nickel 63 (^{63}Ni)	5.2×10^{-10}	3.8×10^{07}	1.5×10^{-10}	1.3×10^{08}
Niobium 95 (^{95}Nb)	1.3×10^{-09}	1.5×10^{07}	5.8×10^{-10}	3.4×10^{07}
Phosphorus 32 (^{32}P)	2.9×10^{-09}	6.9×10^{06}	2.4×10^{-09}	8.3×10^{06}
Phosphorus 33 (^{33}P)	1.3×10^{-09}	1.5×10^{07}	2.4×10^{-10}	8.3×10^{07}
Plutonium 239 (^{239}Pu)	3.2×10^{-05}	6.3×10^{02}	2.5×10^{-07}	8.0×10^{04}
Plutonium 240 (^{240}Pu)	3.2×10^{-05}	6.3×10^{02}	2.5×10^{-07}	8.0×10^{04}
Polonium 209 (^{209}Po)	2.3×10^{-06}	8.8×10^{03}	3.0×10^{-07}	6.6×10^{04}
Polonium 210 (^{210}Po)	2.2×10^{-06}	9.1×10^{03}	2.4×10^{-07}	8.3×10^{04}
Potassium 42 (^{42}K)	2.0×10^{-10}	1.0×10^{08}	4.3×10^{-10}	4.7×10^{07}
Promethium 147 (^{147}Pm)	3.5×10^{-09}	5.7×10^{06}	2.6×10^{-10}	7.7×10^{07}
Protactinium 233 (^{233}Pa)	3.2×10^{-09}	6.3×10^{06}	8.7×10^{-10}	2.3×10^{07}

Nuclear substance	DCF (Sv/Bq) inhalation	ALI (Bq) inhalation	DCF (Sv/Bq) ingestion	ALI (Bq) ingestion
Radium 223 (^{223}Ra)	5.7×10^{-06}	3.5×10^{03}	1.0×10^{-07}	2.0×10^{05}
Radium 226 (^{226}Ra)	2.2×10^{-06}	9.1×10^{03}	2.8×10^{-07}	7.1×10^{04}
Rhenium 186 (^{186}Re)	1.2×10^{-09}	1.7×10^{07}	1.5×10^{-09}	1.3×10^{07}
Rhenium 188 (^{188}Re)	7.4×10^{-10}	2.7×10^{07}	1.4×10^{-09}	1.4×10^{07}
Rubidium 86 (^{86}Rb)	1.3×10^{-09}	1.5×10^{07}	2.8×10^{-09}	7.1×10^{06}
Ruthenium 103 (^{103}Ru)	2.2×10^{-09}	9.1×10^{06}	7.3×10^{-10}	2.7×10^{07}
Scandium 46 (^{46}Sc)	4.8×10^{-09}	4.2×10^{06}	1.5×10^{-09}	1.3×10^{07}
Selenium 75 (^{75}Se)	1.7×10^{-09}	1.2×10^{07}	2.6×10^{-09}	7.7×10^{06}
Silicon 31 (^{31}Si)	1.1×10^{-10}	1.8×10^{08}	1.6×10^{-10}	1.3×10^{08}
Silicon 32 (^{32}Si)	5.5×10^{-08}	3.6×10^{05}	5.6×10^{-10}	3.5×10^{07}
Silver 110m (^{110m}Ag)	7.3×10^{-09}	2.7×10^{06}	2.8×10^{-09}	7.1×10^{06}
Sodium 22 (^{22}Na)	2.0×10^{-09}	1.0×10^{07}	3.2×10^{-09}	6.3×10^{06}
Sodium 24 (^{24}Na)	5.3×10^{-10}	3.8×10^{07}	4.3×10^{-10}	4.7×10^{07}
Strontium 85 (^{85}Sr)	6.4×10^{-10}	3.1×10^{07}	5.6×10^{-10}	3.6×10^{07}
Strontium 89 (^{89}Sr)	5.6×10^{-09}	3.6×10^{06}	2.6×10^{-09}	7.7×10^{06}
Strontium 90 (^{90}Sr)	7.7×10^{-08}	2.6×10^{05}	2.8×10^{-08}	7.1×10^{05}
Sulphur 35 (inorganic) (^{35}S)	1.1×10^{-09}	1.8×10^{07}	1.9×10^{-10}	1.1×10^{08}
Sulphur 35 (organic v) (^{35}S)	1.2×10^{-10}	1.7×10^{08}	7.7×10^{-10}	2.6×10^{07}
Technetium 99m (^{99m}Tc)	2.9×10^{-11}	6.9×10^{08}	2.2×10^{-11}	9.1×10^{08}
Technetium 99 (^{99}Tc)	3.2×10^{-09}	6.3×10^{06}	7.8×10^{-10}	2.6×10^{07}
Thallium 201 (^{201}Tl)	7.6×10^{-11}	2.6×10^{08}	9.5×10^{-11}	2.1×10^{08}
Thallium 204 (^{204}Tl)	6.2×10^{-10}	3.2×10^{07}	1.3×10^{-09}	1.5×10^{07}
Thorium 228 (^{228}Th)	3.2×10^{-05}	6.3×10^{02}	6.9×10^{-08}	2.9×10^{05}
Thorium 229 (^{229}Th)	6.9×10^{-05}	2.9×10^{02}	4.8×10^{-07}	4.2×10^{04}
Thorium 230 (^{230}Th)	2.8×10^{-05}	7.1×10^{02}	2.1×10^{-07}	9.5×10^{04}
Tin 113 (^{113}Sn)	1.9×10^{-09}	1.1×10^{07}	7.3×10^{-10}	2.7×10^{07}
Uranium (natural) ††	6.3×10^{-06}	3.2×10^{03}	9.5×10^{-09}	2.1×10^{06}
Uranium (depleted) ††	5.9×10^{-06}	3.4×10^{03}	1.1×10^{-08}	1.9×10^{06}
Uranium 232 (^{232}U) ††	2.6×10^{-05}	7.7×10^{02}	3.3×10^{-07}	6.1×10^{04}
Uranium 233 (^{233}U) ††	6.9×10^{-06}	2.9×10^{03}	5.0×10^{-08}	4.0×10^{05}
Uranium 235 (^{235}U) ††	6.1×10^{-06}	3.3×10^{03}	4.6×10^{-08}	4.3×10^{05}
Uranium 236 (^{236}U) ††	6.3×10^{-06}	3.2×10^{03}	4.6×10^{-08}	4.3×10^{05}
Uranium 238 (^{238}U) ††	5.7×10^{-06}	3.5×10^{03}	4.4×10^{-08}	4.5×10^{05}
Xenon 133 (gas) Bq/cm^3 ‡ (^{133}Xe)	1.2×10^{-10}	6.7×10^{05}	---	---
Xenon 135 (gas) Bq/cm^3 ‡ (^{135}Xe)	9.6×10^{-10}	8.3×10^{04}	---	---
Yttrium 87 (^{87}Y)	5.3×10^{-10}	3.8×10^{07}	5.5×10^{-10}	3.6×10^{07}
Yttrium 90 (^{90}Y)	1.7×10^{-09}	1.2×10^{07}	2.7×10^{-09}	7.4×10^{06}
Zinc 65 (^{65}Zn)	2.8×10^{-09}	7.1×10^{06}	3.9×10^{-09}	5.1×10^{06}

* Hydrogenated tritium oxide (HTO), also referred to as “tritiated water.”

† Organically bound tritium (OBT).

‡ The concentration equivalent of 20 mSv per year (assuming 250 working days and 8-hour workday).

†† Type S (slow) insoluble compounds.

Appendix C: Estimating Doses

This appendix provides one method for estimating the radiation doses in a nuclear medicine department. The same approach can be used to estimate radiation doses for other classifications of rooms (high- and containment-level) where unsealed nuclear substances are handled.

The following table presents the characteristics of the main categories of nuclear medicine procedures: conventional diagnostic nuclear medicine, positron emission tomography (PET) and therapeutic nuclear medicine. For the purpose of estimating annual doses, the primary difference between these categories lies in the isotopes and activities used and/or the location and duration of treatment.

Table C1: Characteristics of the main categories of nuclear medicine procedures

	Conventional diagnostic	PET	Therapeutic
Most commonly used isotope	Tc-99m	F-18	I-131
Isotope half-life	6 hours	110 minutes	8 days
Principal gamma energy	141 keV	511keV	364 keV
Γi (μSv h-1 MBq-1 m-2)	1.853 E-2	1.398 E-1	5.471 E-2
Typical activities used	≤ 1 GBq	≤ 1 GBq	≤ 10 GBq
Administered by	Injection	Injection	Ingestion
Duration of procedure	A few hours	A few hours	A few days
In-patient/outpatient	Outpatient	Outpatient	Outpatient or in-patient
Comments	The most common category of nuclear medicine procedures	High energy gamma waves require greater shielding than conventional diagnostic nuclear medicine isotopes. They also require isolating the patient between injection and scanning times.	Due to the potential for contamination, patients may be required to stay in a designated room at the hospital after the radioisotope is administered.

General framework for dose estimation

Doses from nuclear medicine operations can be estimated in a number of ways. All methods are extensions of the basic radiation safety principles of time, distance and shielding. Each method requires an initial review of:

- the isotopes and activities to be used for the nuclear medicine procedures performed
- the locations at which these isotopes and activities will be used
- the annual number of procedures to be performed
- the occupancy of the rooms in the nuclear medicine department and all adjacent areas by staff, patients and the general public
- the layout of the facility
- the construction materials used to construct the facility

Accurate dose estimate representation is contingent on the proper characterization of the operation and design of the facility.

Five-step method for radiation dose estimation

The overall approach to radiation dose estimation can be broken down into the following five steps:

Step (1) Facility layout

Obtain architectural drawings or make an accurate, scaled and dimensioned drawing of the facility and surrounding areas. The drawings need to show the locations where significant quantities of nuclear substance will be present. They will also show occupied locations where persons might be exposed to radiation as a result of licensed activity. If available, scaled architectural drawings are ideal for this purpose.

Identify the locations where nuclear substances are to be used. This includes rooms where nuclear substances will be administered to the patient and the main post-administration locations.

Figure C1 shows a hypothetical nuclear medicine department layout, with dimensions and basic shielding details. Letters A to E_2 identify the locations with the greatest potential for exposure. The same method used to estimate radiation dose to these areas can be used for other areas, such as designated waiting areas, reception areas, changing rooms or washrooms.

Step (2) Estimating workload

The workload needs to be identified for each key location. Workload refers to the number of procedures per year, as well as the typical activity (MBq) per procedure.

For any given nuclear medicine facility, several different gamma-emitting isotopes may be used regularly and be present at a number of locations within the facility (e.g., Cr-51, Ga-67, Se-75, Tc-99m, In-111, I-123, I-131 and Tl-201). Most of these isotopes are poly-energetic (they have multiple gamma emission energies) which is attenuated to varying degrees in any given shielding material.

Initially, all possible procedures are considered. If it can be demonstrated that some procedures are insignificant to the total doses incurred, the doses from such procedures may not require detailed estimates.

This can be determined by multiplying the typical activity for a procedure by the number of annual procedures of that type and by exposure duration per procedure.

Example:

For illustrative purposes, assume that the nuclear medicine department shown in figure C1 primarily performs three types of outpatient diagnostic procedures: cardiac analysis, diagnostic bone scan and thyroid uptake analysis. The typical daily workload and details of the isotopes and activities used are presented in table 2. The annual number of procedures performed is estimated from the daily workload by assuming five days of operation per week (no procedures are done on the weekends), 50 weeks per year.

Figure C1: Hypothetical nuclear medicine department layout

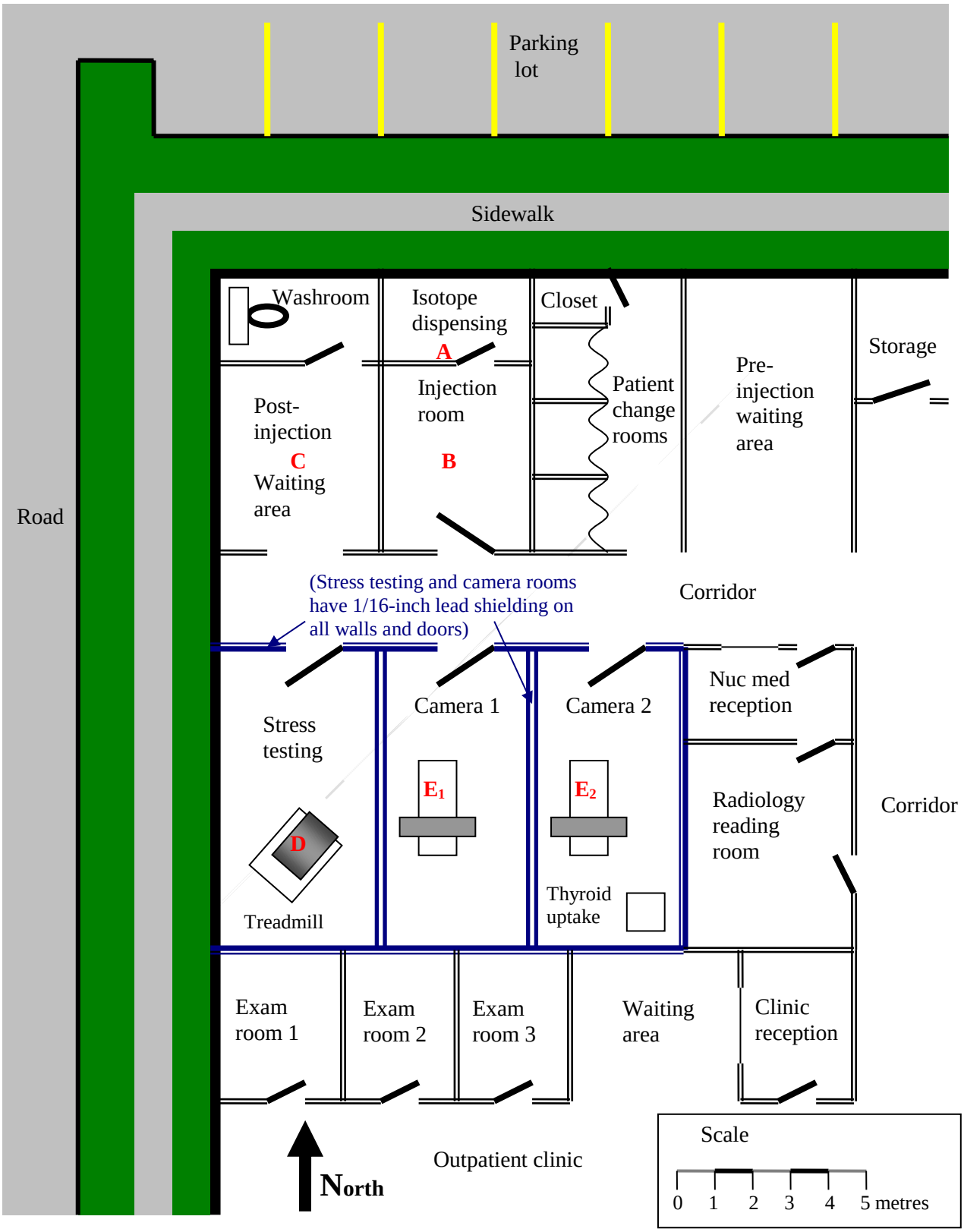


Table C2: Main procedures performed, isotopes and activities used

Procedure	Nuclear substance	Number of patients (N)		Average procedure duration	Average activity per treatment	(No. of proc.) x (Duration) x (Activity)
		Per day	Per year			
Cardiac analysis	^{99m}Tc	7	1750	1 ½ hrs *	370 MBq (rest)* 1100 MBq (stress)*	259,000 MBq-h* 1,210,000 MBq-h*
Bone scans	^{99m}Tc	5	1250	¾ hr	800 MBq	300,000 MBq-h
Thyroid uptake	^{131}I	1	250	½ hr	0.37 MBq	18.5 MBq-h

** Assumes 35 minutes for rest test and 55 minutes for stress test (90 minutes total, or 1 ½ hours)*

From this, it is clear that the radiation doses incurred by staff or the general public as a result of thyroid uptake procedures is likely to be negligible in comparison with cardiac analyses or bone scans and can be omitted from the dose estimation.

Step (3) Estimating workload

Identify the purpose, type of occupancy and occupancy factor of those areas within or in the immediate vicinity of the nuclear medicine department that will be occupied while nuclear substances are in use. These are the areas in which staff and the general public (other than the patient) would be expected to receive a radiation dose as a consequence of the nuclear medicine activities. For each area, determine:

- what the area is used for (e.g., reception desk, waiting room, radiopharmaceutical injection rooms, gamma camera room, washroom)
- who is normally present in the area (e.g., staff who are NEWs, non-NEWs performing work or members of the general public, such as persons accompanying patients or hospital staff performing work unrelated to the licensed activity)
- the occupancy factor (T) for each location and exposed group (e.g., the fraction of time a person spends in an area during which a radiation field is present)

The occupancy factor (T) should be determined for each location and exposed group. (i.e., the fraction of total time during which a radiation field may be present at a particular location, for which another individual may be present at that location). When evaluating T, an important consideration is whether or not a person may be at the location of interest *while there is a radiation field present in that area.* For example, a technologist will be in many different locations throughout the course of a normal workday, but will always be in close proximity to the patient when injecting radiopharmaceuticals or while setting them up on the scanner bed. Conversely, cleaning staff may only be in the nuclear medicine department after normal operating hours, and consequently, may be exposed to little or no radiation despite spending appreciable lengths of time in the department.

For additional information, refer to the National Council on Radiation Protection and Measurements (NCRP) Report No. 151: *Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities* [9].

The determination of occupancy is probably the most difficult aspect of the dose assessment. To begin, you must first determine who (other than the patient) is exposed to radiation as a consequence of the operation of the nuclear medicine department. For nuclear medicine operations, these persons are normally divided into three categories: NEWs, non-NEWs and members of the public (which include staff performing work unrelated to the licensed activity).

Generally, when calculating dose estimates, nuclear medicine technologists, radiologists and any other technical staff working in the department will be identified as NEWs.

Non-NEWs are staff members performing work related to the licensed activity with annual doses below 1 mSv.

Members of the public generally fall into three very broad groups:

- persons accompanying patients undergoing nuclear medicine scans
- persons who may be present in adjacent corridors or rooms, including pedestrians outside the building, patients in adjacent areas of the building (e.g., the outpatient clinic) and persons occupying areas above and below the department
- non-NEW staff performing work/duties unrelated to the licensed activity (e.g., porters, nurses, couriers)

Trying to assess the doses received by every individual from every possible source is clearly impractical, so the second step is to simplify the problem. This can be done by evaluating the proximity, frequency and duration of exposure of persons in each group to identify the most exposed persons. You need then only evaluate these "worst case" exposures within each group, because it can be safely assumed that all other persons in each group receive lesser doses.

The final stage of the occupancy review is to determine where and how long. That is:

- Where are the nuclear substances present and for how long?
- Where are the most exposed individuals present and for how long?

Implicit in this part of the evaluation is that only the locations that will contribute significantly to the doses incurred need to be considered. For instance, consider a nuclear medicine technologist working with a patient on the treadmill in the stress-testing room in figure C1. At the same time, the technologist will be receiving some radiation dose from injected patients who may be present in camera rooms 1 and 2 or the post-injection waiting area. However, because of the longer distances between the technologist and these sources of exposure and the intervening shielding, these doses will be negligibly small in comparison with the dose received from the patient on the treadmill. Thus, while the technologist is in the stress-testing room, only the dose received from the patient on the treadmill needs to be evaluated.

Example:

For the purpose of the example, the following assumptions have been made:

- All work is shared equally between three nuclear medicine technologists. In comparison with the technologists, radiologists are present in the department only periodically, for relatively short periods of time and with minimal direct exposure to injected patients or radiopharmaceuticals.
- There are one or more full-time receptionists for the nuclear medicine department who spend essentially all of their time in the reception office. The same is true for the adjacent outpatient clinic.

- Other ancillary staff, such as porters, cleaning and maintenance staff, are present only infrequently, with restricted access to areas in which radioisotopes are used and with minimal direct exposure to injected patients or radiopharmaceuticals.
- Family members accompanying patients who are undergoing nuclear medicine procedures are present only for a few hours per year.
- Physicians working in the adjacent outpatient clinic spend approximately one half of their time in the examining rooms immediately adjacent to the camera suites and the stress-testing room.
- The clinic is a single-story building, built on grade, so there is no occupancy below and very minimal occupancy above (e.g., during roof repairs).

From these assumptions and the facility layout given in figure C1, it is reasonable to expect that:

- The nuclear medicine technologists are the most exposed persons amongst the NEWs, and since the work is divided equally among them, the doses they receive should be very similar.
- The receptionists in the nuclear medicine department and the physicians performing work related to the licensed activity in the adjacent rooms are likely to receive the highest non-NEW occupational exposures due to their lengthy exposure times and relatively close proximity to the camera and stress-testing rooms.
- Members of the public (other than the patients themselves) should receive doses well below those received by the receptionists and/or physicians, but staff performing work unrelated to the licensed activity whose offices are in near proximity (beside or above/below the nuclear medicine department) will receive the highest doses among the individuals in this category.

Therefore, doses need to be estimated for only three representative individuals: a nuclear medicine technologist, a nuclear medicine receptionist and a physician performing work unrelated to the licensed activity in the adjacent outpatient clinic.

The key parameters needed to estimate the total annual dose for each of these workers are listed in table C3 on the next page.

Table C3: Occupancy summary

Persons exposed	NEW	Important location(s) occupied	Source location(s) making significant contribution to dose	Occupancy factor (T)	Rationale/comment
Nuclear medicine technologist	Yes	Dispensing	A	1/3	An occupancy factor of ⅓ is applied to each location because the total number of procedures performed is split equally between three technologists. Although procedures will be split between camera rooms 1 and 2, when evaluating the dose to a technologist, it can be assumed that all of the procedures are performed in one room, since this will not alter the total dose received by the technologist.
		Injection	B		
		Stress-testing	D		
		Camera 1 or Camera 2	E_1 or E_2		
Receptionist	No	Nuclear medicine reception	A, B and C	1	An occupancy factor of 1 is used because it is assumed that the receptionist remains in the reception area for the entire workday. The contributions from source locations A, B and C are evaluated because there is no shielding between these source locations and the reception area. The contribution from E_2 is evaluated because it is immediately adjacent to the reception area. D and E_1 can probably be omitted because the radiation that injected patients emit in these rooms must pass through multiple shielded walls to reach the reception area. However, it is prudent to evaluate E_1 to confirm that the dose contribution from this point to the reception area will be negligible.
			E_2		
			E_1 (see comments)		

Physician in adjacent clinic	No	Exam room 2	D, E_1 or E_2	1/2	An occupancy factor of ½ is used because the example states that each physician spends approximately ½ of their time in the exam rooms. A physician may be present in any of exam rooms 1, 2 or 3. The central room, exam 2, is reasonably representative of their average location. Source locations A, B and C are distant from the exam rooms and are doubly shielded by the lead lining of the intervening stress-testing and camera rooms; thus, they will make a negligibly small contribution to the dose in comparison with source locations D, E_1 and E_2.

Step (4) Dose rate calculations

Radiation dose rate calculations should be made for each potentially occupied area. There are two basic methods of estimating the radiation dose rates to which staff and the general public (excluding the patient) will be exposed as a result of typical nuclear medicine operations.

The first method is to take direct measurements of the dose rates in surrounding areas using a sufficiently sensitive, properly calibrated radiation survey meter. The type, model, energy range and energy response of the dose rate meter to be used should be provided. Because dose rates in the surrounding rooms and areas are typically very low, the survey meter used should have a scaler function to allow for long counting times (e.g., 10 minutes or more) to reduce uncertainty in the measurement. Background radiation is to be subtracted from the measured target dose rate. The background dose rate measurement should be made with the same long counting time in an area or room that is physically isolated and at a distance from any nuclear substances. This method is generally useful when evaluating an existing department or when conducting a comparative analysis for designing a new room or department that is similar in layout and design to an existing site. It is particularly useful when an applicant needs to analyze the impact of proposed changes, such as increased workload or changes to the facility layout.

Such measurements can be performed after normal operating hours by placing source vials that contain the typical average quantities of the appropriate nuclear substances at representative locations (e.g., the centre of the scanning bed to represent a patient undergoing a scan). Alternatively, sample measurements could simply be made at each location over the course of a typical working day. In either case, care must be taken to ensure that the activities and isotopes being used when the measurements are made are truly representative of normal operating conditions, when an average is taken over a suitably representative timeframe (e.g., daily, weekly, yearly). It is also important to stress that in many cases, very low dose rates (just barely above background) need to be measured in order to ascertain annual doses. In such cases, dose rate meters with scalar counting must be employed in order to capture statistically significant data. The lower the dose rate, the longer the integration time should be. Aim for five-minute integration times for very low dose rates, and always make sure to subtract the background values, which should be captured using the same integration time.

The second method is a mathematical approach that relies on the known physical properties of the nuclear substances being used, the distances to each occupied area and the shielding properties and thickness of the building materials. As such, it is generally useful when designing a new room or department.

The following is a general formula for performing dose rate calculations.

Equation {1}:

$$R = \frac{\Gamma \times A \times 10^{-(\frac{t}{TVL1})}}{d^2}$$

if *t* is thicker than *TVL1*, then:

$$R = \frac{\Gamma \times A \times 0.1 \times 10^{-(\frac{t-TVL1}{TVL2})}}{d^2}$$

Where:

R	is the dose rate produced by nuclear substance at location	(μSv h^{-1})
Γ	is the specific gamma ray constant for nuclear substance	(μSv h-1 MBq-1 m2)
A	is the activity of nuclear substance	(MBq)
d	is the distance between nuclear substance and location	(m)
t	is the thickness of shielding material in any shielded barrier between nuclear substance and location	(mm)
TVL (1&2)	is the first and second tenth-value layer (TVL) thicknesses of material for a given nuclear substance (i.e., the thickness of material that would be required to reduce the photon radiation dose rate produced by the nuclear substance to 1/10 of its initial value for the first tenth-value layer and a subsequent 1/10 of its value for the second tenth-value layer)	(mm)

Specific gamma ray constants are defined in terms of the dose rate (e.g., μSv h^{-1}) at one metre from the source (m^2), per unit of source activity (e.g., MBq^{-1}), but the exact units used may vary between different references. When performing dose rate calculations, care must be taken to ensure the consistency of units between *R*, Γ and *A*. For consistency, the CNSC has published the Radionuclide Information Booklet (RIB) [10], which provides dose rate constants, half- and tenth-value layers, as well as other useful information for a variety of commonly used nuclides. Note that the CNSC RIB provides first and second half- and tenth-value layers; using both will yield more accurate results than using the first layer only, especially for poly-energetic nuclides. The RIB also provides an Excel formula for calculating dose rates using the first and second half- and tenth-value layers. For simplicity, the examples below show the calculation using the first tenth-value layer only.

Example:

Table C5 on the following page summarizes the parameters required to perform the dose rate estimates for this example. The distances *d* were measured directly from figure C1 for the nuclear medicine reception area and exam room 2. To calculate doses to the nuclear medicine technologists, their proximity to the patient when performing diagnostic procedures was estimated based on internal room dimensions and typical work procedures. Lead thicknesses are based on the assumption that all interior walls of the stress-testing room, camera room 1 and camera room 2 are lined with 1/16-inch (1.6 mm) lead.

All other interior walls are assumed to be constructed of ordinary drywall (gypsum board) and to provide minimal attenuation.

The last column of table C5 lists the calculated dose rates at each location for each of the exposed groups considered, for bone scan and cardiac stress-testing procedures. A sample calculation for one representative source location (E_2), exposure group (receptionist) and procedure (cardiac stress-testing, stress component) is given below:

Table C4: Values for Tc-99m dose calculation example

Isotope	99mTc
Γ	1.853×10^{-5} mSv h^{-1} MBq^{-1} m^2
TVL1/TVL2	1.1 mm/1.0mm
Total activity *A* used for the procedure (by the stress-testing stage, patient has already been given both the rest injection of 370 MBq and the stress injection of 1100 MBq)	1470 MBq
Thickness *t* of lead shielding in wall between camera 2 and nuclear medicine reception	1.6 mm (1/16 inch)
Distance *d* from patient on bed of camera 2 and nuclear medicine reception (from figure H1)	5 metres

Using equation {1}:

$$R = \frac{\Gamma \times A \times 0.1 \times 10^{-(\frac{t-TVL1}{TVL2})}}{d^2}$$

$$R = \frac{1.853 \times 10^{-5} mSvh^{-1} \times 1470MBq \times 0.1 \times 10^{-(\frac{1.66mm-1.1mm}{1mm})}}{5m^2}$$

$$R = 3.44 \times 10^{-5}$$

For simplicity, there was no correction for the decay of 99mTc in this calculation. While decay will cause some reduction in the calculated dose rate, the reduction will be relatively small. For example, if the procedure lasts 1.5 hours, the initial rest injection will have decayed to the following, which is still 84% of its initial value, by the end of the procedure:

$$R = 370MBq \times 2^{-(\frac{1.5h}{6.02h})}$$

$$R = 311MBq$$

In the context of the requirement to keep radiation doses ALARA, corrections of this magnitude are unlikely to be the difference between an acceptable or unacceptable design. However, applicants may choose to explicitly account for decay in their design analysis.

Table C5: Dose rate calculations

Isotope is ^{99m}Tc for all
$\Gamma = \Gamma_{Tc99m} = 1.853 \times 10^{-5}$ mSv h^{-1} MBq^{-1} m^2
TVL1 = 1.1mm *TVL2* = 1 mm

Persons exposed	NEW	Occupied location	Source location	Distance d (m)	Lead thickness t (mm)	Activity A (MBq) which may temporarily be present at each source location due to each procedure			Dose rate R (mSv h-1) at occupied location while source activity A is present at each source location		
						Cardiac (rest)	Cardiac (stress)	Bone scan	Cardiac (rest)	Cardiac (stress)	Bone scan
Nuclear medicine technologist	Yes	Dispensing	A	0.75	0	370	1100	800	1.2×10^{-2}	3.6×10^{-2}	2.6×10^{-2}
		Injecting	B	0.75	0	370	1470	800	1.2×10^{-2}	4.8×10^{-2}	2.6×10^{-2}
		Stress-testing	D	3	0	N/A	1470	N/A	N/A	3.0×10^{-3}	N/A
		Camera 1 or camera 2	E_1 or E_2	3	0	370	1470	800	7.6×10^{-4}	3.0×10^{-3}	1.6×10^{-3}
Receptionist	No	Nuclear medicine reception	A	13	0	370	1100	800	4.1×10^{-5}	1.2×10^{-4}	8.8×10^{-5}
			B	10	0	370	1100	800	6.9×10^{-5}	2.0×10^{-4}	1.5×10^{-4}
			C	13	0	370	1470	800	4.1×10^{-5}	1.6×10^{-4}	8.8×10^{-5}
			E_2	5	1.6	370	1470	800	8.7×10^{-6}	3.4×10^{-5}	1.9×10^{-5}
			E_1	9	4.8	370	1470	800	1.7×10^{-6}	6.7×10^{-9}	3.7×10^{-9}

Persons exposed	NEW	Occupied location	Source location	Distance d (m)	Lead thickness t (mm)	Activity A (MBq) which may temporarily be present at each source location due to each procedure			Dose rate R (mSv h-1) at occupied location while source activity A is present at each source location		
						Cardiac (rest)	Cardiac (stress)	Bone scan	Cardiac (rest)	Cardiac (stress)	Bone scan
Physician in adjacent clinic	No	Exam room 2	D	5	1.6	N/A	1470	N/A	N/A	3.4×10^{-5}	N/A
			E_1	5	1.6	370	1470	800	8.7×10^{-6}	3.4×10^{-5}	1.9×10^{-5}
			E_2	7	1.6	370	1470	800	4.4×10^{-6}	1.8×10^{-5}	9.6×10^{-65}

Step (5) Annual Dose Rate Calculations

Patients typically occupy several different locations over the course of the nuclear medicine procedure and may contribute to the dose received by a person occupying a single location (e.g., the dose from patients in the injection room, scanner rooms and post-injection waiting areas may all contribute to the dose received by the receptionist at the front desk). Exposed persons may also occupy several different areas over the course of any given day, some of which may contribute far more significantly to the total radiation dose they receive.

Once the dose rate in each occupied area – generated by each combination of procedure, source location and occupancy factor – has been either calculated or measured, the resulting annual dose received by persons in that area can be estimated by multiplying the dose rate by the total exposure duration per year.

For a given combination of procedure, source location, occupied location and exposed person, the total exposure duration per year is given by the product of: the total number of procedures performed per year (*N*, see table C2); the occupancy factor for the exposed person and occupied location (*T*, see table C2); the dose rate (*R*, see table C5); and the duration of time (*S*) the source/injected patient is present at the designated source location (in hours). The annual dose (*D*) is then:

Equation {2}:

$$D = N \times T \times R \times S$$

Example:

Table C6 summarizes the parameters required to estimate the dose rate for the example. Estimated total procedure times were given in table C2. These are broken down into the approximate times the source/patient spends at each key location (*S*) in table C6.

For example, cardiac stress-testing was estimated to require 1.5 hours.

This has been divided into:

2 minutes for the test injection	0.033 h
20 minutes in the post-injection waiting room	0.33 h
15 minutes scanning in either camera room	0.25 h
2 minutes for the stress test injection	0.033 h
20 minutes in the waiting room	0.33 h
15 minutes in the treadmill room	0.25 h
15 minutes scanning in either camera room	0.25 h
Total:	**1.48 h**

The last column of table C6 lists the calculated annual doses at each location, for each of the exposed groups considered, for both the bone scan and cardiac stress-testing procedures. A sample calculation for

one representative source location (E_2), exposure group (receptionist) and procedure (cardiac stress-testing, stress component) is given below:

N	1750 procedures per year (1750 y^{-1})
T	1
R	3.8×10^{-5} $mSvh^{-1}$
S	0.25 hr

Using equation {2}:

D $= N \times T \times R \times S$

$D_{camera\ 2,\ reception}$ $= 1750\ y\text{-}1 \times 1 \times 3.8 \times 10^{-5}\ mSv\ h^{-1} \times 0.25\ hr$

$= 1.66 \times 10^{-2}$ mSv

Explicit calculations of the dose a nuclear medicine receptionist would receive as a result of scans in camera room 1 have been dropped, since it is clearly demonstrated in table C5 that the dose rate in nuclear medicine reception due to patients on camera 1 will be trivially small (< 1 nSv h-1). When calculating the annual dose to a nuclear medicine receptionist and to a physician in the adjacent outpatient clinic, the total scanning workload, including both cardiac stress-testing and bone scans, is presumed to be split evenly between camera rooms 1 and 2. The total doses listed are the sum of each of the doses from the individual procedures for each of the exposed persons.

A few interesting aspects about the calculated doses should be mentioned. First, note that 60% of the nuclear medicine technologists' dose is estimated to be received in the relatively short periods of time they spend either directly handling the 99mTc or in very close proximity to the patient while delivering the injection. This suggests that when examining operating procedures with the aim of keeping doses ALARA, improvements to these procedures are likely to have the greatest benefit.

Similarly, the receptionist at this hypothetical clinic potentially receives the greatest dose from injected patients waiting to be scanned, despite having a designated "hot" patient waiting area well removed from the reception desk. If dose reduction were deemed to be necessary, adding shielding to the east wall of the injected-patient waiting area could be considered.

Finally, note that despite the extended periods of time physicians in the adjacent outpatient clinic spent in the examining rooms located very close to the scanning rooms, their doses are negligibly small due the shielding incorporated into the walls of the scanning rooms.

Table C6: Annual dose calculations

Persons exposed	Occupied location	Source location	Number of procedures N			*T*	Duration of time S (h) the source/patient is present at each location per procedure			Dose rate R (mSv h-1) at the occupied location while source/patient present at each source location			Annual dose D (mSv) at the occupied location		
			Card. (rest)	Card. (stress)	Bone scan		Card. (rest)	Card. (stress)	Bone scan	Cardiac (rest)	Cardiac (stress)	Bone scan	Card (rest)	Card. (stress)	Bone scan
Nuclear medicine technologist	Dispensing	A	1750	1750	1250	1/3	.008	.008	.008	1.2×10^{-2}	3.6×10^{-2}	2.6×10^{-2}	.0569	.1691	.0878
	Injection	B	1750	1750	1250	1/3	.033	.033	.033	1.2×10^{-2}	4.8×10^{-2}	2.6×10^{-2}	.2346	.8474	.3624
	Stress-testing	D	N/A	1750	N/A	1/3	N/A	.25	N/A	N/A	3.0×10^{-3}	N/A	N/A	.4414	N/A
	Camera 1 or camera 2	E_1 or E_2	1750	1750	1250	1/3	.25	.25	.33	7.6×10^{-4}	3.0×10^{-3}	1.6×10^{-3}	.1111	.4414	.2265
	Total annual dose received by each nuclear medicine technologist												2.9786 mSv		
Receptionist	Nuclear medicine reception	A	1750	1750	1250	1	.008	.008	.008	4.1×10^{-5}	1.2×10^{-4}	8.8×10^{-5}	.0006	.0017	.0009
		B	1750	1750	1250	1	.033	.033	.033	6.9×10^{-5}	2.0×10^{-4}	1.5×10^{-4}	.0040	.0107	.0061
		C	1750	1750	1250	1	.33	.33	.33	4.1×10^{-5}	1.6×10^{-4}	8.8×10^{-5}	.0234	.0931	.0362
		E_2	875	875	675	1	.25	.25	.33	8.7×10^{-6}	3.4×10^{-5}	1.9×10^{-5}	.0019	.0075	.0042
	Total annual dose received by each receptionist												0.1902 mSv		
Physician in adjacent clinic	Exam room 2	D	N/A	1750	N/A	1/2	N/A	.25	N/A	N/A	3.8×10^{-5}	N/A	N/A	.0075	N/A
		E_1	875	875	625	1/2	.25	.25	.33	8.7×10^{-6}	3.4×10^{-5}	1.9×10^{-5}	.0009	. 0038	.0019
		E_2	875	875	625	1/2	.25	.25	.33	4.4×10^{-6}	1.8×10^{-5}	9.6×10^{-6}	.0005	. 0019	.0010
	Total annual dose received by each physician working in the adjacent outpatient clinic												0. 0176 mSv		

PET shielding calculations

The basic approach to PET shielding calculations or any other high-energy gamma-emitting isotope, such as I-131, is similar to that for conventional diagnostic nuclear medicine, as outlined in the previous example. The only significant difference is the thickness of shielding required due to higher energies. In such cases, the use of lead may be impractical due to weight and structural considerations. Concrete, either in poured slabs or one solid block, is generally a more viable solution to PET shielding issues.

To illustrate this, consider the previous example in which 1/16-inch (1.6 mm) lead shielding was used to line the camera rooms. For 99mTc, which emits 141 keV gamma rays, this equates to 1.6 mm/1.1 mm = 1.45 tenth-value layers of shielding, which reduces the radiation dose rates and corresponding doses in surrounding areas to 3.5% of their unshielded values.

By contrast, PET isotopes all decay via positron emission and thus emit two 511 keV annihilation gammas per decay. At this energy, the first TVLs for lead and concrete are approximately 17 mm and 24 cm, respectively. Note that because PET isotopes all emit gammas at the same energy, the TVLs do not change from isotope to isotope. To achieve the same degree of attenuation for PET isotopes would therefore require 1.45 x 17 mm = 24.6 mm of lead, or 1.45 x 24 cm = 34.8 cm of concrete.

In such cases, the use of lead becomes impractical because of weight and structural considerations. For example, an 8-foot by 12-foot wall of lead 30 mm thick would weigh 3000 kg and would require a structural support wall capable of retaining this load. Thus, concrete – either in poured slabs or as a solid concrete block – is a much more viable solution to PET shielding problems. The heavy shielding requirements for PET make it difficult to retrofit an existing room to accommodate a PET scanner.

The periodical *Medical Physics* (33, 1; January 2006) provides useful technical information and guidance on shielding requirements and dose estimates specifically related to PET operations [11].

Shielding calculations for in-patient I-131 therapy

There is very little difference between the shielding calculations for conventional diagnostic nuclear medicine and for in-patient nuclear medicine therapy treatments, such as 131I thyroid cancer treatment. The patient location is essentially fixed inside what is usually a dedicated treatment room on one of the wards. The primary occupationally-exposed group to be considered is the nursing staff attending to the patients while they are in hospital. Doses to members of the general public in adjacent rooms must also be considered.

As a condition of the licence, the design must be such that the dose rate in occupied areas around the treated patient's room does not exceed 2.5 µSv/h or that other patients do not receive a dose in excess of 500 µSv per hospital stay.

For these room classifications, dose estimates are required. The same approach may be followed as described in Step (4) *Dose rate calculations*.

Calculating dose rate and doses outside of hot cells

Licensees involved in the production of radioisotopes and/or the chemical processing of those isotopes into radiopharmaceuticals must be equipped to handle much greater quantities of radioisotopes than nuclear medicine departments or research laboratories can handle. Typically, they will have one or more heavily shielded hot cells in which processing activities are performed with remote manipulators that

enable staff to safely perform any required handling of the radioisotopes. Hot cells are normally sealed when in use to prevent volatile, gaseous or fine-particulate radioactive material from contaminating the lab. In addition, they will normally have a dedicated nuclear exhaust ventilation system, with filters to minimize any such releases to the external environment. Hot cells are equipped with manipulators for the remote handling of objects inside the hot cell. This prevents extremity doses and reduces the risk of spills.

A typical hot cell might be roughly 2 m high, 1.5 m wide and 1 m deep, and shielded with 75 mm of lead (Pb) encased in steel. This provides ~5 TVLs of shielding against PET isotopes. For further information on TVLs for commonly used isotopes, see the CNSC's *Radionuclide Information Booklet* for more information on TVLs for commonly used isotopes [10].

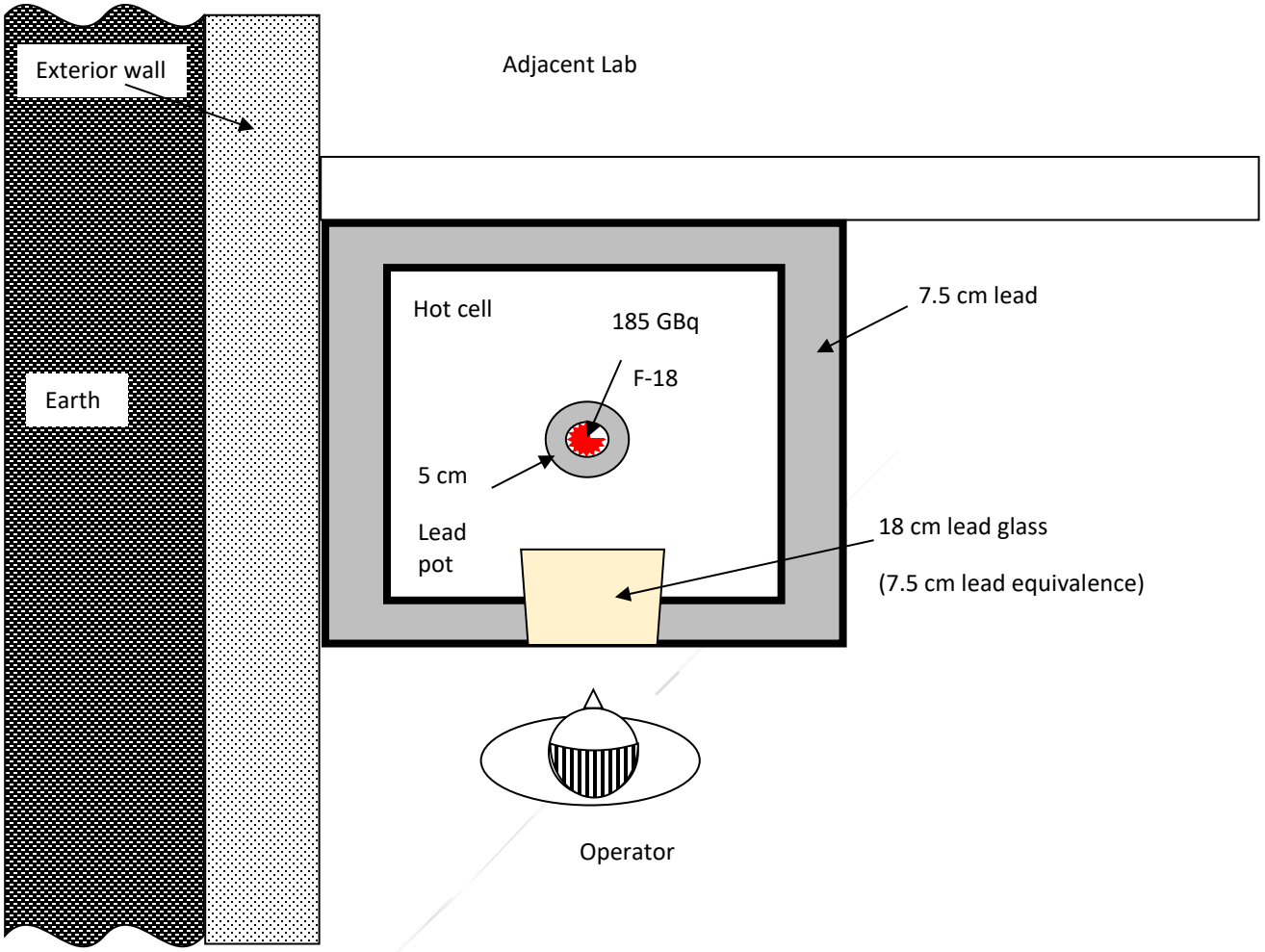
Two typical hot cells with manipulators are shown below:

Both hot cells shown have 7.5 cm lead shielding in the walls, floor and ceiling. The lead glass windows are 18 cm thick and have a lead equivalence of 7.5 cm (courtesy of UOHI)

The five-step dose calculation method described previously can easily be extended to estimate the doses incurred by staff performing work using the hot cells:

Step (1) Prepare a reasonably accurate, dimensioned sketch of the facility and surrounding areas.

The following diagram is used for the purpose of this example.



Step (2) Identify the key locations where radioactive materials are to be used and the workload for each of these locations.

- F-18, 185 GBq (5Ci) produced per run
- F-18 is present in hot cell for one hour
- Assume one production run of F-18 per day x 250 operating days per year

Step (3) Identify the purpose, type of occupancy and occupancy factor of areas within, or in the immediate vicinity of, the nuclear substances.

- Restricted access area (NEWs only)
- Operator at manipulators for ⅓ hour per run
- Occupancy of adjacent lab is intermittent, T = ½

Step (4) Estimate the radiation dose rates in each potentially occupied area.

Equation {1}

$$R = \frac{\Gamma \times A \times 10^{-(\frac{t-TVL1}{TVL2})}}{d^2}$$

If *t* is thicker than *TVL1*, then:

$$R = \frac{\Gamma \times A \times 0.1 \times 10^{-(\frac{t-TVL1}{TVL2})}}{d^2}$$

Where:

R	is the dose rate (μSv h^{-1}) produced by F-18 at each location
Γ	0.1398 μSv h^{-1} MBq^{-1} m^2
A	185,000 MBq
d	Assume operator is 1 m from source
t	75 mm Pb equivalent in walls/window/floor of hot cell (plus, 50 mm Pb in walls and bottom of Pb pot containing F-18, but top is open and is visible from the operator position)
TVL1	17 mm
TVL2	14 mm

Therefore, outside the hot cell at one metre from the F-18, the dose rate is:

R = (0.1398 μSv h^{-1} MBq^{-1} m^2) x (185,000 MBq) x 0.1 x $10^{-((125-17/14))}$

R = 0.00005 μSv h^{-1}, which is effectively ZERO

Direct line of sight between the operator and the product should also be considered by excluding the lead pot shielding:

R = (0.1398 μSv h^{-1} MBq^{-1} m^2) x (185,000 MBq) x 1.0 x $10^{-((75-17/14))}$

$R = 0.186$ or for simplicity, $\approx 0.2\ \mu Sv\ h^{-1}$

Step (5) Extrapolate the calculated dose rates to annual doses.

Worst-case exposure assumes no lead pot. Ignoring decay over the exposure duration:

- Operator dose = 250 days/y x 1/3 h/day x 0.2 $\mu Sv\ h^{-1}$ or $\approx 17\ \mu Sv\ y^{-1}$
- Lab staff dose = (250days/y x 0.5h/day x 0.2 $\mu Sv\ h^{-1}$)/$(3m)^2 \approx 3\ \mu Sv\ y^{-1}$

Thus, for the parameters assumed in the example, the shielding in the hot cell is more than adequate. This is in fact the case for typical automated PET processing operations. The majority of staff's dose generally comes from handling the quality control (QC) samples once they have been dispensed and extracted from the hot cell. The approach to QC dose calculation is effectively the same as that for nuclear medicine dispensing and injection operations in the previous dose calculation example.

Conclusion

The annual dose to the receptionist and reception area, assuming 100% occupancy, is less than 50 µSv.

To complete the dose assessment, the annual doses are estimated for other staff and members of the general public, other than the patient, who are in and around the nuclear medicine rooms at the facility. The CNSC may consider that an ALARA assessment is not required when individual occupational doses are unlikely to exceed 1 mSv per year, when the dose to individual members of the public is unlikely to exceed 50 µSv per year, and when the annual collective dose (both occupational and public) is unlikely to exceed 1 person-Sv (as recommended in REGDOC-2.7.1, *Radiation Protection*, as amended from time to time) [4].

Glossary

For definitions of terms used in this document, see REGDOC-3.6, *Glossary of CNSC Terminology*, which includes the terms and definitions used in the *Nuclear Safety and Control Act* and its regulations, and in CNSC regulatory documents and other publications. REGDOC-3.6 is provided for reference and information.

References

The CNSC may include references to information on best practices and standards, such as those published by CSA Group. With permission of the publisher, CSA Group, all nuclear-related CSA standards may be viewed at no cost through the CNSC web page "How to gain free access to all nuclear-related CSA standards."

1. Canadian Nuclear Safety Commission (CNSC), draft REGDOC-1.4.1, *Licence Application Guide: Class II Nuclear Facilities and Prescribed Equipment*, Ottawa, Canada, 2017.

2. CNSC, REGDOC-1.6.1, *Licence Application Guide: Nuclear Substances and Radiation Devices*, Version 2. Ottawa, Canada. TBD.

3. Canadian Standards Association (CSA). N288-1-14, *Guidelines for calculating derived release limits for radioactive material in airborne and liquid effluents for normal operation of nuclear facilities*. 2014.

4. CNSC, REGDOC-2.7.1, *Radiation Protection*, Ottawa, Canada, 2004.

5. International Atomic Energy Agency (IAEA). RS-G-1.7, *Application of the Concepts of Exclusion, Exemption and Clearance*, Vienna, 2004.

6. IAEA. TECDOC 1000, *Clearance of Materials Resulting From the Use of Radionuclides in Medicine, Industry and Research*. Vienna, 1998.

7. International Commission on Radiological Protection. ICRP 68: Dose Coefficients for Intakes of Radionuclides by Workers.

8. National Radiological Protection Board. NRPB-W22, Industrial Uranium Compounds: Exposure Limits, Assessment of Intake and Toxicity After Inhalation. 2002.

9. National Council on Radiation Protection and Measurements, NCRP Report No. 151: *Structural shielding design and evaluation for megavoltage x- and gamma-ray radiotherapy facilities*, Maryland, United States, 2005

10. CNSC, *Radionuclide Information Booklet*, Ottawa, Canada, 2017

11. Madsen, Mark, et al. *AAPM Task Group 108: PET/CT Shielding Requirements*. *Medical Physics* 33, 1 (January 2006): 4-15.

Additional Information

The following documents provide additional information that may be relevant and useful for understanding the requirements and guidance provided in this regulatory document:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). *Method of Testing Performance of Laboratory Fume Hoods*. ANSI/ASHRAE 110-1995.
- ASTM International. C 1533-02 *Standard Guide for General Design Considerations for Hot Cell Equipment*. ASTM International, 2007.
- ASTM International. ASTM C 1554-03 *Standard Guide for Materials Handling Equipment for Hot Cells*.
- ASTM International. ASTM C 1572-04 *Standard Guide for Dry Lead Glass and Oil-Filled Lead Glass Radiation Shielding Window Components for Remotely Operated Facilities*.
- ASTM International. ASTM C 1615-05 *Standard Guide for Mechanical Drive Systems for Remote Operation in Hot Cell Facilities*.
- ASTM International. ASTM C 1217-00 *Standard Guide for Design of Equipment for Processing Nuclear and Radioactive Materials*. ASTM, 2006.
- Diberardinis, J., Baum, J., First, M., Gatwood, G., Seth A. *Guidelines for Laboratory Design: Health and Safety Considerations*. John Wiley and Sons Inc. 2001.
- European Committee for Standardization. BS EN 12469:2000 *Biotechnology-Performance Criteria for Microbiological Safety Cabinets*. 2000.
- Furr, A. Keith. *CRC Handbook of Laboratory Safety*, 5th Edition. CRC Press, 2000.
- Health Canada, *Laboratory Biosafety Guidelines*, 3rd edition, 2004.
- IAEA, TRS-468, *Cyclotron Produced Radionuclides: Physical Characteristics and Production Methods*, Vienna, 2009.

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