Chapter 9
Radiation Protection and Shielding

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1. What is the annual regulatory limit for the total effective dose equivalent for an adult that is occupationally exposed to radiation from radioactive materials?

   A. 1 mSv
   B. 50 mSv
   C. 100 mSv
   D. 150 mSv
   E. 500 mSv

   Answer: The correct answer is B [1]. Note that strictly speaking, this limit is not applicable to radiation-producing equipment, unless it is explicitly referenced by the regulations of a specific state. In general, the "whole body" (head and trunk) limit of radiation-producing equipment is 12.5 mSv per calendar quarter, as referenced in the OSHA regulation [2].

2. What is the dose limit in any 1 h, to an individual member of the public, in any unrestricted area, from external sources of radioactive materials?

   A. 0.02 mSv
   B. 0.05 mSv
   C. 0.10 mSv
   D. 0.15 mSv
   E. 0.50 mSv

   Answer: The correct answer is A [3]. This limit excludes the dose contributions from patients administered radioactive material and released in accordance with 10CFR35.75 [4].

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3. What is the 1-h dose equivalent threshold from radioactive materials for a *high-radiation area***?**

   A. 0.02 mSv
   B. 0.05 mSv
   C. 0.1 mSv
   D. 0.5 mSv
   E. 1.0 mSv

   Answer: The correct answer is E [5]. Note that this threshold is measured at 30 cm from the radiation source, or 30 cm from any surface that the radiation penetrates. In addition, this definition is applicable for radioactive material sources. For radiation-producing equipment, a similar threshold exists as described in the OSHA regulations [2] with the caveat that this is for "a major portion of the body." Practical follow-up question: What are the designated high-radiation areas in your clinic?

4. What is the annual regulatory limit for the lens dose equivalent for an adult that is occupationally exposed to radiation from radioactive materials?

   A. 1 mSv
   B. 50 mSv
   C. 100 mSv
   D. 150 mSv
   E. 500 mSv

   Answer: The correct answer is D [1]. Note that strictly speaking, this limit is not applicable to radiation-producing equipment, unless it is explicitly referenced by the regulations of a specific state. In general, the dose to the "lens of the eyes" limit of a radiation-producing equipment is 12.5 mSv per calendar quarter, as referenced in the OSHA regulation [2]. If summed over four quarters, this results in an annual limit of 50 mSv, not 150 mSv as cited by the US NRC.

5. What percentage of the annual regulatory limits for adults is applicable to minors who are occupationally exposed to radiation?

   A. 1%
   B. 5%
   C. 10%
   D. 20%
   E. 50%

   Answer: The correct answer is C. Minors are allowed to work with, and be exposed to radiation from, radioactive materials, but the annual thresholds are significantly lower [6]. This limit is also applicable for exposure from radiation-producing equipment, as referenced in the OSHA regulation [2].

6. What is the average effective dose attributed to natural background for an individual in the USA?

   A. 3.1 mSv
   B. 3.6 mSv
   C. 5.0 mSv
   D. 5.4 mSv
   E. 6.2 mSv

   Answer: The correct answer is A [7, 8].

7. What is the annual regulatory limit for the shallow dose equivalent to the skin of the whole body for an adult that is occupationally exposed to radiation from radioactive materials?

   A. 1 mSv
   B. 50 mSv
   C. 100 mSv
   D. 150 mSv
   E. 500 mSv

   Answer: The correct answer is E. The regulatory annual shallow dose equivalent limit to the skin of any extremity is similar to the "organ dose limit." This limit is similar to the limit for skin of any extremity [1]. Note that strictly speaking, this limit is not applicable to radiation-producing equipment, unless it is explicitly referenced by the regulations of a specific state. In general, the dose limit to the "skin of the whole body" of a radiation-producing equipment is 75 mSv per calendar quarter, as referenced in the OSHA regulation [2]. If summed over four quarters, this results in an annual limit of 300 mSv, not 500 mSv as cited by the US NRC.

8. Radioactive materials that are commonly delivered to radiation oncology (e.g., I-125 eye plaque seeds, Ir-192 HDR source) or nuclear medicine departments (e.g., Tc-99 m MDP, F-18 FDG) should be shipped using what kind of package?

   A. Type A
   B. Type B
   C. Type II
   D. Type III
   E. Type 7

   Answer: The correct answer is A [9]. More detailed description of a Type A package is provided in the US Department of Transportation regulations [10]; relevant values are referenced in the NCRP Report No. 184 [8].

9. What is the annual regulatory limit for the sum of the total effective dose equivalent to an individual *member of the public* from the use of radioactive materials?

   A. 1 mSv
   B. 50 mSv
   C. 100 mSv
   D. 150 mSv
   E. 500 mSv

   Answer: The correct answer is A [3]. This limit excludes the dose contributions from background radiation, from any administration the individual has received, from exposure to individuals administered radioactive material and released under § 35.75, from voluntary participation in medical research programs, and from the licensee's disposal of radioactive material into sanitary sewerage in accordance with § 20.2003.

10. What is the regulatory limit for the dose equivalent to the embryo/fetus during the entire pregnancy, due to the occupational exposure of a declared pregnant woman?

   A. 0.5 mSv
   B. 1 mSv
   C. 5 mSv
   D. 10 mSv
   E. 50 mSv

   Answer: The correct answer is C [11]. Note that this threshold is hinged on the written declaration of pregnancy of the radiation worker. If the dose equivalent to the embryo/fetus exceeds 4.5 mSv by the time the woman declares the pregnancy, the additional dose equivalent to the embryo/fetus should not exceed 0.5 mSv during the remainder of the pregnancy.

   For pregnant patients undergoing photon radiation therapy, AAPM TG 36 talks about the effects of radiation on developing fetus and the professional considerations to minimize the dose [12].

11. What is the 1-h dose equivalent threshold from radioactive materials for a designated *radiation area*?

   A. 0.02 mSv
   B. 0.05 mSv
   C. 0.1 mSv
   D. 0.5 mSv
   E. 1.0 mSv

   Answer: The correct answer is B [5]. Note that this threshold is measured at 30 cm from the radiation source, or 30 cm from any surface that the radiation penetrates. In addition, this definition is applicable for radioactive material sources. For radiation-producing equipment, a similar threshold exists as described in the OSHA regulations [2] with the caveat that this is for "a major portion of the body," with an additional caveat of a 1 mSv threshold for any 5 consecutive days. Practical follow-up question: What are the designated radiation areas in your clinic?

12. Which of the radiopharmaceuticals listed below *does not* require a written directive, signed and dated by the authorized user prior to administration to a patient?

    A. Ra-223 Xofigo, 100 microcuries
    B. F-18 FDG, 15 millicuries
    C. I-131 sodium iodide, 2 millicuries
    D. Y-90 TheraSphere, 5 GBq (135 millicuries)
    E. Lu-177 Lutathera, 200 millicuries

    Answer: The correct answer is B. 15 millicuries of F-18 FDG is typically used for PET/CT oncologic imaging. It is relevant to note that the correct answer is not solely based on the magnitude of the activity administered. The emission type is a relevant consideration, where alpha-emitters and beta-emitters usually require a written directive in typical clinical use.

13. What is the annual regulatory limit for the sum of the deep-dose equivalent and the committed-dose equivalent to any individual organ or tissue other than the lens of the eye for an adult that is occupationally exposed to radiation?

    A. 1 mSv
    B. 50 mSv
    C. 100 mSv
    D. 150 mSv
    E. 500 mSv

    Answer: The correct answer is E. The annual occupational dose limit for each organ is 500 mSv [1]. Note that strictly speaking, this limit is not applicable to radiation-producing equipment, unless it is explicitly referenced by the regulations of a specific state. In general, the dose limit to active blood-forming organs or the gonads from radiation-producing equipment is 12.5 mSv per calendar quarter, as referenced in the OSHA regulation [2]. If summed over four quarters, this results in an annual limit of 100 mSv, not 500 mSv as cited by the US NRC.

14. Which of the following is *not* a standard procedure for receiving and opening radioactive White I, Yellow II, or Yellow III packages?

    A. Monitor the package within 3 h of receipt if delivered during normal working hours.
    B. Monitor the radiation levels at 1 m away from the external surface of the package.
    C. Monitor the external surface of the package for removable radioactive contamination.
    D. Monitor the external surface of the package for degradation of package integrity.
    E. Monitor the access of the delivery courier to the hot lab once every quarter.

Answer: The correct answer is E. The required procedures for receiving and opening packages containing radioactive materials are described in [13]. Additional details on model procedures for safely opening packages containing radioactive materials for medical use are provided in the US NRC Technical Report NUREG 1556 [14].

15. A state that has signed an agreement with the US Nuclear Regulatory Commission receiving authorization to regulate certain uses of radioactive materials within the state is called a/an [15]:

    A. NRC-approved state
    B. NRC-controlled state
    C. NRC-agreement state
    D. NRC-dependent state
    E. NRC-supervised state

    Answer: The correct answer is C. The US NRC relinquishes to the (agreement) state portions of its regulatory authority to license and regulate by-product materials (radioisotopes), source materials (uranium and thorium), and certain quantities of special nuclear materials.

16. What is the largest contributor to an average individual's effective dose from "man-made" radiation sources in the USA?

    A. Computed tomography scans
    B. Nuclear medicine and PET imaging
    C. Cosmic, solar, and satellite radiation
    D. Interventional radiology procedures
    E. 5G mobile broadband communication

    Answer: The correct answer is A. The relevant values are referenced in the NCRP Report No. 184 [8].

17. A radioactive material package was delivered to the clinic, with a measured maximum surface exposure rate of 15 mR/h and a maximum exposure rate of 1.8 mR/h at 1 m away. What should the package be labeled as?

    A. Yellow III
    B. Yellow II
    C. White III
    D. White II
    E. White I

    Answer: The correct answer is A. A Yellow II package has a maximum surface exposure rate reading between 0.5 mR/h and 50 mR/h (satisfied by this package), as well as a maximum surface exposure rate reading at 1 m away between 0.05 mR/h and 1.0 mR/h (not satisfied by this package).

18. Which of the following is *not* required when calculating the barrier protection factor (B)?

    A. Workload
    B. Occupancy

C. Shielding material
D. Dose limit (at shielding point)
E. Distance (source-to-shielding point)

Answer: The correct answer is C. Accounting for the shielding material is relevant after calculating the barrier protection factor.

19. What is the weekly permissible dose limit for a controlled area where a radiation worker may be exposed?

A. 0.02 mSv/week
B. 0.05 mSv/week
C. 0.1 mSv/week
D. 1 mSv/week
E. 5 mSv/week

Answer: The correct answer is C. This stems from the regulatory limit of 5.0 mSv for the total effective dose equivalent for a minor radiation worker. It is also relevant for the regulatory limit to the embryo/fetus of a declared pregnant woman spanning the entire course of pregnancy. Although pregnancy covers a 40-week period, assuming an effective cumulative exposure of 50 weeks provides an additional safety factor.

20. When calculating the *primary barrier* protection factor for an HDR brachytherapy suite, what is the appropriate use factor (U)?

A. 1
B. 1/2
C. 1/5
D. 1/8
E. 1/40

Answer: The correct answer is A. All barriers of an HDR brachytherapy suite are for the "primary beam."

21. What is the typical occupancy factor (T) assigned to an adjacent clinical area such as a patient exam room, procedure or imaging suite, or a linear accelerator vault?

A. 1
B. 1/2
C. 1/5
D. 1/8
E. 1/20

Answer: The correct answer is B. This is described in the NCRP 147 and NCRP 151 [16, 17].

22. For a linear accelerator vault designed to be operated such that neutron production is not an issue, the total barrier protection factor (B_{tot}) can be calculated from the primary (B_{pri}), secondary (B_{sec}), and leakage (B_{leak}) barrier protection factors using ______. Note that HVL is half value layer and TVL is tenth value layer:

    A. $B_{tot} = B_{pri} + B_{sec} + B_{leak}$
    B. $B_{tot} = B_{pri} \times B_{sec} \times B_{leak}$
    C. $B_{tot} = B_{pri} + B_{sec} + B_{leak} + 1\text{HVL}$
    D. $B_{tot} = B_{pri} \times B_{sec} \times B_{leak} \times 1\text{HVL}$
    E. $B_{tot} = B_{pri} + B_{sec} + B_{leak} + 1\text{TVL}$

    Answer: The correct answer is B. The total barrier protection factor is a product of the primary, secondary, and leakage barrier protection factors.

23. The "protection point" located on the same floor/level (neither above nor below) is taken at what distance behind the protective barrier?

    A. 0.1 m
    B. 0.3 m
    C. 0.5 m
    D. 1.0 m
    E. 3.0 m

    Answer: The correct answer is B. This is described in the NCRP 147 and NCRP 151 [16, 17].

24. When considering secondary and leakage shielding, what additional shielding needs to be added to the thicker barrier of the two (secondary and leakage) if these are within one tenth value layer (TVL) of each other?

    A. None.
    B. 1 HVL
    C. 3 HVLs
    D. 1 TVL
    E. 3 TVLs

    Answer: The correct answer is B. As a rule of thumb, when the secondary and leakage shielding barriers are calculated to be within one TVL, one additional HVL is expected for the final barrier to be installed.

25. What is the weekly permissible dose limit for an uncontrolled area where a member of the public may be exposed?

    A. 0.02 mSv/week
    B. 0.05 mSv/week
    C. 0.1 mSv/week
    D. 1 mSv/week
    E. 5 mSv/week

    Answer: The correct answer is A. This stems from the annual regulatory limit of 1.0 mSv for a member of the public, assuming an effective cumulative exposure of 50 weeks.

26. Which of the following clinical modalities listed below will need consideration for the use of borated polyethylene (BPE) as a barrier shielding material?

    A. Linac, 15X
    B. Cyberknife
    C. Gamma Knife
    D. Linac, 12 MeV
    E. HDR brachytherapy

    Answer: The correct answer is A. BPE is an effective material for shielding neutrons which are produced when photons exceeding 10 MV are used. A Cyberknife emits 6 MV photons, a Gamma Knife emits 1.17 MeV and 1.33 MeV Co-60 photons, a 12-MeV linac produces electrons, and an HDR unit emits a variety of gamma photons, beta particles, and electrons, but not one of these treatment modalities provide the suitable conditions for neutron production.

27. Which of the following is *not* required when calculating the primary barrier protection factor (B_{pri}) for a dedicated room where radioactive materials are used?

    A. Use factor
    B. Workload
    C. Radioisotope
    D. Exposure rate constant
    E. Maximum (radio)activity

    Answer: The correct answer is A. The use factor is one (1) for a dedicated room where radioactive materials are used, such as a Gamma Knife vault or an HDR brachytherapy vault.

28. What is the typical occupancy factor (T) assigned to the point behind the door of a dedicated room where radiation is produced or emitted?

    A. 1
    B. 1/2
    C. 1/5
    D. 1/8
    E. 1/20

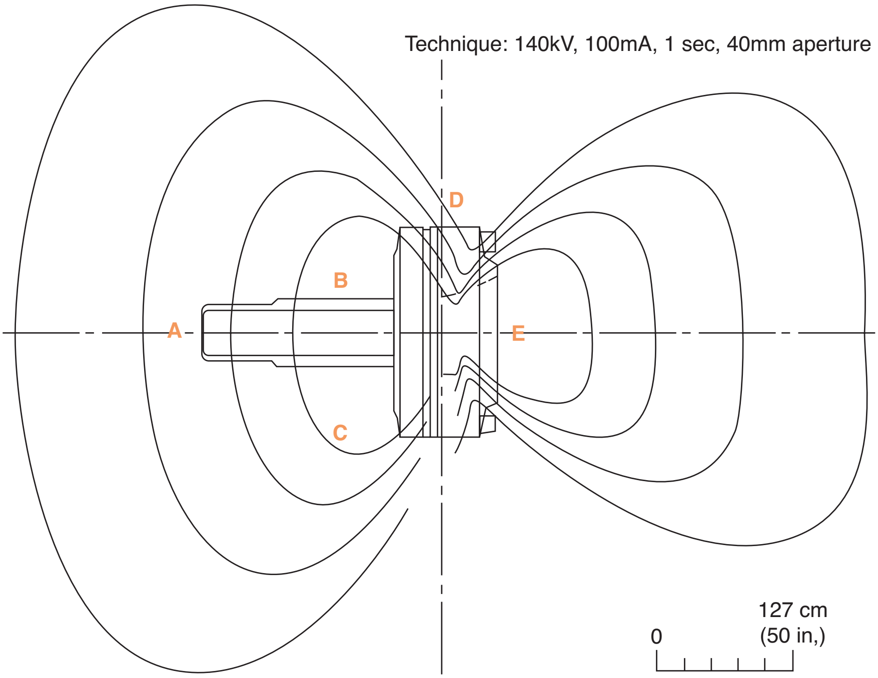
    Answer: The correct answer is D. The location behind the door leading to a room that is dedicated for the use of radiation (e.g., linac vault, CT simulator suite scanner, HDR vault) is assigned an occupancy factor of 1/8, as described in both the NCRP 147 and NCRP 151. Note that surgical suites and procedure rooms such as those used for LDR brachytherapy are not dedicated radiation-use areas.

29. When calculating the *secondary barrier* protection factor for a CT scanner used either as a CT simulator or as a diagnostic CT scanner, what is the appropriate use factor (U)?

    A. 1
    B. 1/2
    C. 1/5
    D. 1/8
    E. 1/40

    Answer: The correct answer is A. The detectors of the CT scanner serve as the primary barrier. All barriers of a CT scanner are for the scattered and leakage photons.

30. A caregiver present *in* the CT-sim room during image acquisition of an "eyes-to-thighs" scan will receive the least radiation dose by standing at ____:



    A. Point A, the foot of the patient scanner bed
    B. Point B, to the side of the patient scanner bed
    C. Point C, three feet away from the side of the patient scanner bed
    D. Point D, next to the CT scanner gantry
    E. Point E, near the head-end of the scanner bore

    Answer: The correct answer is D. The "self-shielding" provided by the detectors that serve as the primary barrier, as well as other CT scanner components mounted on the gantry, significantly reduces the radiation dose adjacent to the scanner gantry.

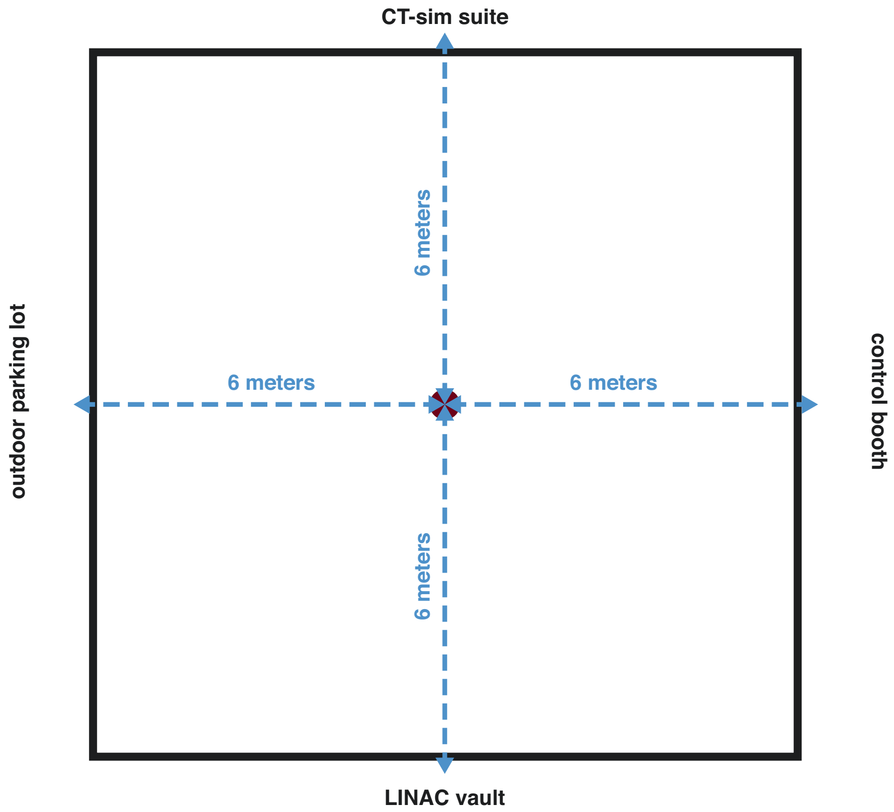
31. What is a typical minimum barrier (thickness and material) of a CT-sim suite wall?

A. 1.6 mm lead equivalent
B. 3.2 mm lead equivalent
C. 10 mm lead equivalent
D. 20 mm standard-density concrete
E. 40 mm low-density concrete

Answer: The correct answer is A. The typical barrier of a CT-sim suite wall is at least 1/16th inches of lead equivalent material, which is approximately 1.6 mm of lead-equivalent material.

An HDR vault is being planned in a single-story outpatient facility, with a very simple floorplan shown below. The RAM License allows up to 15 curies of Ir-192. Other relevant factors and constants are as follows:

Γ = 4.6 R cm^2/mCi hr.	f-factor = 0.964 cGy/R
$T_{outdoor}$ = 1/40	$T_{waiting}$ = 1/20
$T_{control}$ = 1	$T_{CT\text{-}Sim}$ = 1/2



32. Calculate the weekly dose at a protection point 6 m away, assuming that the newly installed 15 curie source is unshielded at the center of the vault for a total of 20 h per week, inclusive of patient treatment time and quality control. For simplicity, assume that the activity remains constant for the week being considered:

    A. 37 mGy/week
    B. 22 Gy/week
    C. 16 mGy/week
    D. 8 mGy/week
    E. 4 mGy/week

    Answer: The correct answer is A. The workload can be calculated from:
    Dweek = $A \times \Gamma \times t \times f \div r^2$
    Dweek = (15,000 mCi) × (4.62 R·cm^2/mCi·h) × (20 h/week) × (9.64 mGy/R) ÷ (600 cm)^2
    Dweek = 37 mGy/week

33. What is the barrier protection factor for the control booth?

    A. 0.263
    B. 0.125
    C. 0.062
    D. 0.045
    E. 0.027

    Answer: The correct answer is *E*. $B = P \cdot d^2 / W \cdot U \cdot T$ = 1 mGy/week. ÷ 37 mGy/week = 0.027.

34. How many TVLs of standard-density concrete would be needed for the wall to the control booth?

    A. 1.6
    B. 1.3
    C. 1.2
    D. 0.9
    E. 0.6

    Answer: The correct answer is A. $n = -\log(B) = -\log(0.027)$.

35. What is the barrier protection factor for the outdoor parking lot?

    A. 1.8×10^{-2}
    B. 2.2×10^{-2}
    C. 2.7×10^{-3}
    D. 6.2×10^{-3}
    E. 5.4×10^{-4}

    Answer: The correct answer is *B*. $B = P \cdot d^2 / W \cdot U \cdot T$ = 0.02 mGy/week ÷ (37 mGy/week × 1/40) = 0.022.

36. How many TVLs of high-density concrete would be needed for the exterior wall to the parking lot?

    A. 1.2
    B. 1.7
    C. 2.2
    D. 2.6
    E. 3.3

    Answer: The correct answer is B. $n = -\log(B) = -\log(0.022)$.

37. According to TG 203, which of the following statement is correct?

    A. Use of a lead shield would reduce the dose to the pacemaker for a VMAT plan whose field border is 10 cm inferior to the implantable device.
    B. A lead shield is recommended to reduce the internally scattered radiation.
    C. A lead shield would completely attenuate the photons leaking from the accelerator head.
    D. None of the above statements are true.

    Answer: The correct answer is D. Task Group 203 does not recommend the use of a lead shield for treatment. Treatment planning should utilize beam angles to increase the distance between the field device [18].

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