Radiation Protection & Associated Regulations

Bushberg – Chapter 23
RSNA & AAPM Physics Curriculum: Module 9

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a copy of this lecture may be found at:
http://courses.washington.edu/radxphys/PhysicsCourse.html

Module 9: Radiation Protection & Assoicated Regulations Fundamental Knowledge

- Indentify the sources of background radiation, and describe the magnitude of each source.
- State the radiation limits to the public and radiation workers (Max Permissible Dose Equivalent limits).
- Understand the differences among advisory boards, accrediting organizations, and regulatory organizations for radioactive materials and radiation-generating equipment, and recognize their respective roles.
- Define the principles of time, distance, and shielding in radiation protection.
- Define ALARA and its application to radiation protection.
- Identify methods used to monitor occupational exposure.
- Discuss appropriate equipment used to monitor radiation areas or areas of possible exposure or contamination.
- Describe the fundamental methods used to determine patient and fetal doses…. ***Described in detail in 4/15/2010 lecture***
- Explain the basic principles for designing radiation shielding.
- List the steps in managing radiological emergencies.

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Module 9: Radiation Protection & Assoicated Regulations Clinical Applications

- Understand safety considerations for patients and staff, including pregnant staff, in mobile radiography ("portables").
- Use your knowledge of radiation effects in planning for and reacting to an emergency that includes the exposure of personnel to radiation.
- Discuss the contributions of medical sources to the collective effective dose.
- Define the responsibilities and qualifications of an authorized user (all categories) and the radiation safety officier.
- Describe the training and experience requirements for using sealed and unsealed sources of radioactive material.
- Describe the use of personnel radiation protection equipment.
- Describe the appropriate equipment for wipe tests and contamination surveys.
- Provide information to the public concerning radon.
- Provide clinical examples that demonstrate ALARA principles.
- Discriminate between workers in a public area who are occupationally exposed and those who are treated as members of the general public.

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Module 9: Radiation Protection & Assoicated Regulations Clinical Problem-Solving

- Discuss the factors that determine dose to a pregnant person seated next to a patient injected with a radionuclide for a diagnostic or therapeutic procedure.
- Describe steps used in applying appropriateness criteria.
- Describe what must be done before administering a radioactive material to a patient.
- Describe what is required to have a person listed on a facility's Nuclear Materials License as an Authorized User.

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Key Points for Radiation Protection

- Sources of exposure to ionizing radiation
  - Naturally occurring
  - Man-made (technologically) based
- Personnel dosimetry
- Radiation protection and exposure control
  - Time, distance and shielding
- Regulatory agencies and radiation dose limits
  - Occupational limits
  - Non-occupational limits
  - ALARA

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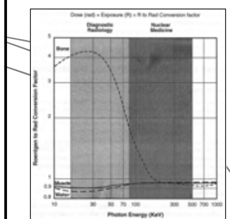
Review – Radiation Units
Exposure, Dose, and Effective Dose

- **What is exposure??**
  - Measurement that describes an x-ray machine output intensity (mR/mAs, mR/min)
  - Only a measure of photon intensity IN AIR
  - Formal definition: the amount of electrical charge (ΔQ) produced by ionizing radiation per mass of air (Δm) [C-kg^{-1}]
  - Traditional units: Roentgen (R) = 2.58x10^{-4} C/kg (note: R is still a commonly used unit)



- **What is dose??**
  - Measurement of energy deposited in tissue
  - Measures ALL types of radiation that deposit energy in tissue
  - Formal definition: the amount of energy (ΔE) deposited by ionizing radiation per unit mass (Δm) [J/kg]
  - Traditional units: rad (acronym for radiation absorbed dose)
  - 1 Gy = 1 J per kg = 100 rad
- **What is effective dose??**
  - (Equivalent dose accounts for radiation type incident on tissue – radiation weighting factors (w_R))
  - Effective dose accounts for tissue sensitivity – tissue weighting factors (w_T) defined in ICRP report no. 60)
  - Traditional units: rem (acronym for Roentgen equivalent man)
  - 1 Sievert (Sv) = 100 rem

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p.55.

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Review – Radiation Units (Chapter 3)

TABLE 3-6. RADIOLOGICAL QUANTITIES, SYSTEM INTERNATIONAL (SI) UNITS, AND TRADITIONAL UNITS

Quantity	Description of Quantity	SI Units (Abbreviations) and Definitions	Traditional Units (Abbreviations) and Definitions	Symbol	Definitions and Conversion Factors
Exposure	Amount of ionization per mass of air due to x- and gamma rays	C kg^{-1}	Roentgen (R)	X	1R = 2.58 × 10^{-4} C kg^{-1} 1R = 8.708 mGy air kerma @ 30 kVp 1R = 8.767 mGy air kerma @ 60 kVp 1R = 8.883 mGy air kerma @ 100 kVp
Absorbed dose	Amount of energy imparted by radiation per mass	Gray (Gy) 1 Gy = J kg^{-1}	rad 1 rad = 0.01 J kg^{-1}	D	1 rad = 10 mGy 100 rad = 1 Gy
Kerma	Kinetic energy transferred to charged particles per unit mass	Gray (Gy) 1 Gy = J kg^{-1}	—	K	—
Air kerma	Kinetic energy transferred to charged particles per unit mass of air	Gray (Gy) 1 Gy = J kg^{-1}	—	K_{air}	1 mGy = 0.115 R @ 30 kVp 1 mGy = 0.114 R @ 60 kVp 1 mGy = 0.113 R @ 100 kVp 1 mGy ≅ 0.014 rad (dose to skin) 1 mGy ≅ 1.4 mGy (dose to skin)
Imparted energy	Total radiation energy imparted to matter	Joule (J)	—	D_I	Dose (J kg^{-1}) × mass (kg) = J
Equivalent dose (defined by ICRP in 1990 to replace dose equivalent)	A measure of radiation specific biologic damage in humans	Sievert (Sv)	rem	H	$H = w_R D$ 1 rem = 10 mSv 100 rem = 1 Sv
Dose equivalent (defined by ICRP in 1977)	A measure of radiation specific biologic damage in humans	Sievert (Sv)	rem	H	$H = Q D$ 1 rem = 10 mSv 100 rem = 1 Sv
Effective dose (defined by ICRP in 1990 to replace effective dose equivalent)	A measure of radiation and organ system specific damage in humans	Sievert (Sv)	rem	E	$E = \Sigma_T w_T H_T$
Effective dose equivalent (defined by ICRP in 1977)	A measure of radiation and organ system specific damage in humans	Sievert (Sv)	rem	H_E	$H_E = \Sigma_T w_T H_T$

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p.59.

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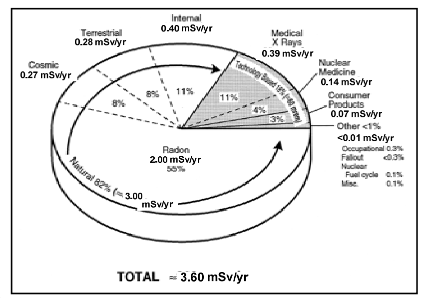
Sources of Exposure to Ionizing Radiation
NCRP Report 93 (published in 1987)



- ***NCRP Report 93*** – annual exposure to radiation is 3.6 mSv per year – according to NCRP report #160 (published 2009), the medical radiation exposure to US population has increased by nearly 6 times compared to the previous NCRP publication (#93)
  - Medical radiation totaled about 0.53 mSv per year
  - About 3.0 mSv per year from background radiation

c.f. NCRP Report #93

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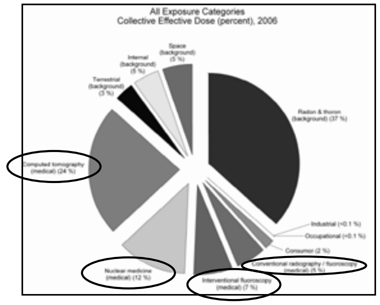
Sources of Exposure to Ionizing Radiation
NCRP Report 160 (published in 2009)



- ***NCRP Report 160 – 6.2 mSv per year***
  - <u>Medical radiation</u> totals about 3.0 mSv per year – largest contribution is from CT (increased nearly 10-11% annually in the past two decades) & nuclear medicine
  - About 3.1 mSv per year from <u>background radiation</u>

c.f. NCRP Press Report. *Medical Radiation Exposures of the U.S. Population Greatly Increased Since the Early 1980s. 3 March 2009.*

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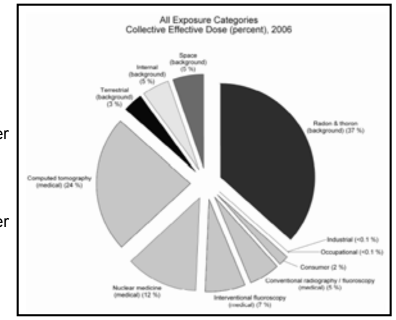
Sources of Ionizing Radiation:
Naturally Occurring Radiation Sources

Annual average total effective dose from exposure to ionizing radiation in USA is approximately 6.2 mSv (National Council on Radiation Protection and Measurement – NCRP)

3.1 mSv (~50%) is from **<u>naturally occurring sources</u>**

- Radon/Thoron – 2.3 mSv per year
- Internal radiation – 0.28 mSv per year
- Terrestrial radioactivity – 0.19 mSv per year
- Cosmic radiation – 0.34 mSv per year



c.f. NCRP Press Report. *Medical Radiation Exposures of the U.S. Population Greatly Increased Since the Early 1980s. 3 March 2009.*

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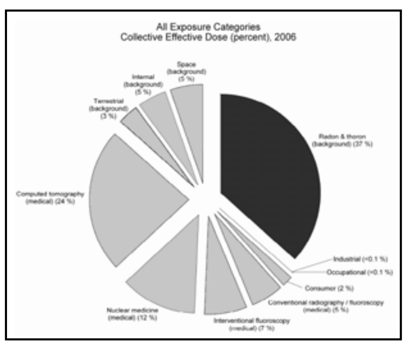
Sources of Ionizing Radiation:
Naturally Occurring Radiation Sources

As the largest contributor to natural background (2.3 mSv/year), Radon (Rn-222) is a radioactive gas formed during the decay of radium

- Radium (Ra-226) is a decay product of U-238 found in the soil and has a half-life ($T_{½}$) of 1620 years
- Radon is an alpha emitter with a $T_{½}$ of approx. 4 days
- Thoron gas – is also a radioactive isotope of radon
  - $T_{½}$ = 55 seconds



c.f. NCRP Press Report. *Medical Radiation Exposures of the U.S. Population Greatly Increased Since the Early 1980s. 3 March 2009.*

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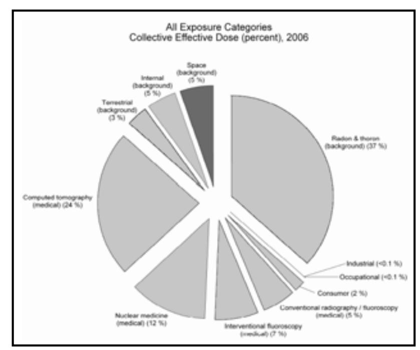
Sources of Ionizing Radiation:
Naturally Occurring Radiation Sources

Cosmic rays: energetic p^+ and α particles (particulate radiation) originate in stars (11% of natural radiation, or roughly 0.34 mSv/year)

- Exposures increase with altitude approx. doubling every 1500 m as there is less atmosphere to attenuate the cosmic radiation
  - Leadville, Colorado (3200 m): 1.25 mSv/year
  - More at poles than equator
  - Airline crews and frequent fliers receive an additional ~ 1 mSv/yr
  - 5 hour transcontinental flight will result in an equivalent dose of ~ 25 μSv
  - Apollo astronauts – 2.75 mSv during the lunar missions



c.f. NCRP Press Report. *Medical Radiation Exposures of the U.S. Population Greatly Increased Since the Early 1980s. 3 March 2009.*

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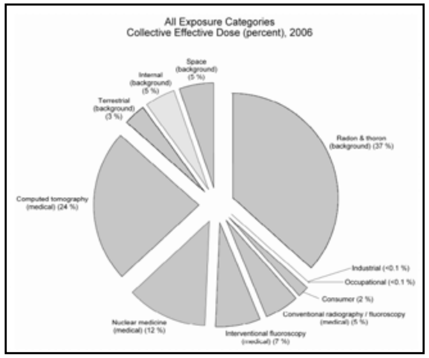
Sources of Ionizing Radiation:
Naturally Occurring Radiation Sources

Internal radiation is the exposure from radionuclides in the body (9% of natural radiation, or roughly 0.28 mSv/year)

- Ingestion of food and water containing primordial radionuclides
- K-40 is most significant
  - $T_{1/2}$ = 1.3x10^9 yrs
  - 1.33 MeV e^-/1.46 MeV γ
  - 0.01% abundance
- Skeletal muscle has the highest concentration of potassium in the body



c.f. NCRP Press Report. *Medical Radiation Exposures of the U.S. Population Greatly Increased Since the Early 1980s. 3 March 2009.*

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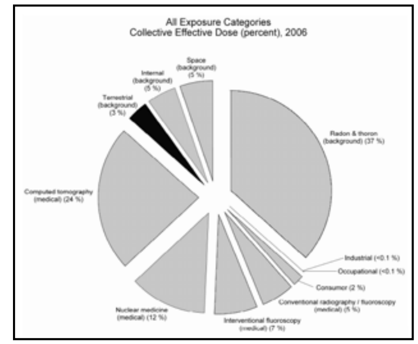
Sources of Ionizing Radiation:
Naturally Occurring Radiation Sources

Terrestrial radioactive materials that have been present on earth since its formation are called *primordial radionuclides* (7% of natural radiation, or roughly 0.19 mSv/year)

- High Z decay chains
  - U-238 – isotope of uranium
  - Th-232 – thorium – at least 3-4x more abundant than uranium in the earth's crust
- K-40 – potassium – naturally occurring radionuclide; typically ~0.1 µCi in the body (about 200,000 decays per minute)
- Varies by location



c.f. NCRP Press Report. *Medical Radiation Exposures of the U.S. Population Greatly Increased Since the Early 1980s. 3 March 2009.*

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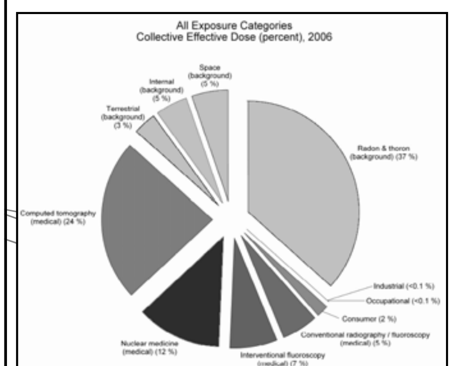
Sources of Ionizing Radiation:
Technology-Based Radiation Sources



- ***Medical radiation*** totals about 3.0 mSv per year
- Approximately 50% of all annual exposures… compared to the previously reported one-third in NCRP report #93

c.f. Mahadevappa Mahesh, PhD. *Magnitude of Radiation Exposure to US Population with focus on CT.* 51st Annual AAPM Meeting. Presented July 2009.

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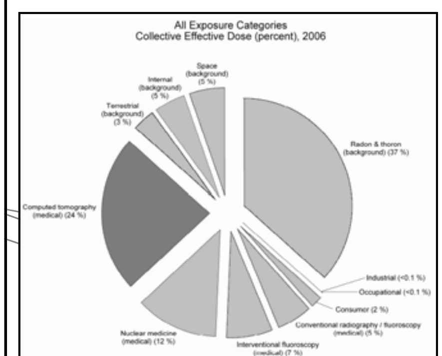
Sources of Ionizing Radiation:
Technology-Based Radiation Sources



- ***Medical radiation*** totals about 3.0 mSv per year
- **Computed Tomography** increased nearly 10-11% annually in the past two decades
  - NCRP 100 (pub. 1989): 3,700 person Sv
  - Current Estimations: ~440,000 person Sv (Eff Dose per capita ~1.5 mSv)

c.f. Mahadevappa Mahesh, PhD. *Magnitude of Radiation Exposure to US Population with focus on CT.* 51st Annual AAPM Meeting. Presented July 2009.

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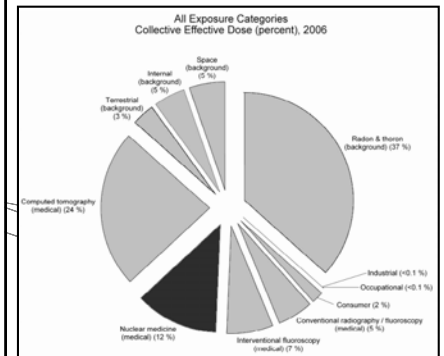
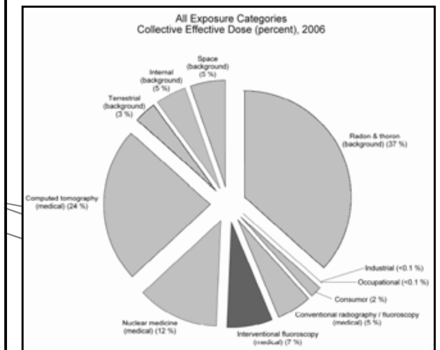
Sources of Ionizing Radiation:
Technology-Based Radiation Sources



- ***Medical radiation*** totals about 3.0 mSv per year
- **Nuclear medicine** increased about 5% annually in the past two decades
  - NCRP 100: 32,000 person Sv
  - Current Estimations: ~231,000 person Sv (Eff Dose per capita ~0.80 mSv)

c.f. Mahadevappa Mahesh, PhD. *Magnitude of Radiation Exposure to US Population with focus on CT.* 51st Annual AAPM Meeting. Presented July 2009.

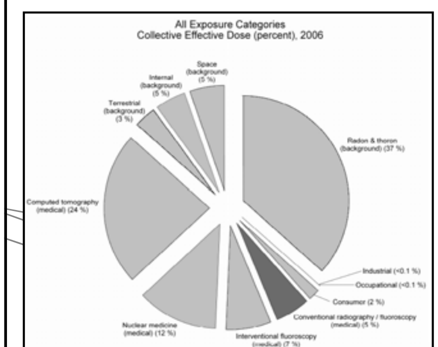
Sources of Ionizing Radiation:
Technology-Based Radiation Sources



- ***Medical radiation*** totals about 3.0 mSv per year
- **Interventional Fluoroscopy**
  - *Diagnostic* – 12,120 person Sv; 2.0 million per year
  - *Therapeutic* – 25,840 person Sv; 1.4 million per year
  - *Cardiac* – 68,226 person Sv; 4.6 million per year
  - Other procedure types (e.g. ERCP, Urology, etc)
  - Current Estimations: Eff Dose per capita ~0.43 mSv

c.f. Mahadevappa Mahesh, PhD. *Magnitude of Radiation Exposure to US Population with focus on CT.* 51st Annual AAPM Meeting. Presented July 2009.

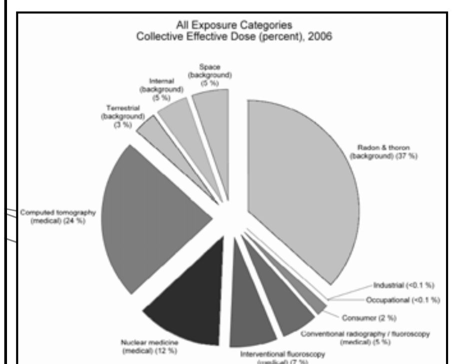
Sources of Ionizing Radiation:
Technology-Based Radiation Sources



- ***Medical radiation*** totals about 3.0 mSv per year
- **Conventional Radiography** including Mammo, dental, chiropractic radiography, bone densitometry, and some fluoro
  - NCRP 100 (pub. 1989): 84,000 person Sv
  - Current Estimations: ~100,000 person Sv (Eff Dose per capita ~0.33 mSv)

c.f. Mahadevappa Mahesh, PhD. *Magnitude of Radiation Exposure to US Population with focus on CT.* 51st Annual AAPM Meeting. Presented July 2009.

Sources of Ionizing Radiation:
Technology-Based Radiation Sources



- ***Medical radiation*** totals about 3.0 mSv per year
- **Other sources of medical radiation to consider:**
  - Sealed source radioactive materials (nuc med)
  - Therapeutic external radiation

c.f. Mahadevappa Mahesh, PhD. *Magnitude of Radiation Exposure to US Population with focus on CT.* 51st Annual AAPM Meeting. Presented July 2009.

Sources of Ionizing Radiation:
Technology-Based Radiation Sources

Medical radiation totals about 3.0 mSv per year

Modalities	# Procedures (millions)	%	Collective Dose (Person-Sv)	%	Per Capita (mSv)
Computed Tomography	67[a]	17	440,000	49	1.50
Nuclear Medicine	18	5	231,000	26	0.80
Radiography & Fluoroscopy[b]	293	74	100,000	11	0.30
Interventional	17	4	128,000	14	0.40
Total	**~395**		**899,000**		**~3.0**

[a] Number of CT scans
[b] excludes dental bitewing & full mouth procedures, but includes 2500 person-Sv for collective dose

c.f. NCRP Report #160. March 2009.

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Regulatory Agencies and Advisory Bodies

Radiation Dose Limits
U.S. Nuclear Regulatory Commission

ALARA

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Regulatory Agencies

- **U.S. Nuclear Regulatory Commission (NRC)** regulates special nuclear material, source material, by-product material of nuclear fission, regulates the maximum permissible dose equivalent limits
  - Agreement states arrange with the NRC to self-regulate medically related licensing and inspection requirements of radioactive materials
  - 10 CFR Parts 20 (standards for protection against radiation)
  - 10 CFR Parts 19, 30, 32, 35, 110
- **Food and Drug Administration (FDA)** regulates radiopharmaceutical development, manufacturing, performance and radiation safety requirements associated with the production of commercial x-ray equipment

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Advisory Bodies

- **NCRP – National Council on Radiation Protection and Measurements**
  - Collect, analyze, develop and disseminate, in the public interest, information and recommendations about radiation protection, radiation measurements, quantities and units
- **ICRP – International Commission on Radiological Protection**
  - Similar to NCRP, however its international membership brings to bear a variety of perspectives on radiation health issues
- The NCRP and ICRP have published over 200 monographs containing recommendations on a wide variety of radiation health issues that serve as the reference documents from which many regulations are crafted
- **IAEA – International Atomic Energy Agency**
- **JCAHO – Joint Commission on Accreditation of Healthcare Organizations**
- **ACR – American College of Radiology**

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Radiation Dose Limits

Bushberg Table 23-18. Nuclear Regulatory Commission (NRC) Regulatory Requirements: Maximum Permissible Dose Equivalent Limits[a]

	Maximum Possible Annual Dose Limit	
Limits	**mSv**	**rem**
Occupational Limits		
Total effective dose equivalent (ED)	50	5
Total dose equivalent to any individual organ (except lens of eye)	500	50
Dose equivalent to the lens of the eye	150	15
Dose equivalent to the skin or any extremity	500	50
Minor (< 18 years old)	10% of adult limit	10% of adult limit
Dose to an embryo/fetus[b]	5 in 9 months	0.5 in 9 months
Non-occupational (Public) Limits		
Individual members of the public	1.0 per yr	0.1 per yr
Unrestricted area	0.02 in any 1 hr[c]	0.002 in any 1 hr[c]

[a] These limits are exclusive of natural background and any dose the individual has received for medical purposes; inclusive of internal committed dose equivalent & external effective dose equivalent (i.e., total effective dose equivalent).
[b] Applies only to conceptus of a worker who declares her pregnancy. If the limit exceeds 4.5 mSv (450 mrem) at declaration, conceptus dose for remainder of gestation is not to exceed 0.5 mSv (50 mrem).
[c] This means the dose to an area (irrespective of occupancy) shall not exceed 0.02 mSv (2 mrem) in any 1 hour. This is not a restriction of instantaneous dose rate to 0.02 mSv per hour (2 mrem per hour).

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p791.

Occupational Exposures

TABLE 23-3. AVERAGE ANNUAL OCCUPATIONAL EFFECTIVE DOSE EQUIVALENT IN THE UNITED STATES

	Average annual total effective dose equivalent	
Occupational category	mSv	mrem
Uranium miners[a]	12.0	1,200
Nuclear power operations[b]	6.0	600
Airline crews	1.7	170
Diagnostic radiology and nuclear medicine techs	1.0	100
Radiologists	0.7	70

- 1 mSv per year for diagnostic radiology is lower than expected because it includes personnel who receive very small occupational exposures
- 15 mSv per year or more are typical of special procedures utilizing fluoroscopy and cineangiography
- Again, occupational exposure limit is 50 mSv per year

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p745.

Persons at Risk

- To determine appropriate dose limits and/or appropriate imaging protocols, distinguish between:
  - Radiation workers
    - Pregnancy identified
    - Pregnancy status-unknown
  - Staff not designated as radiation workers (i.e. schedulers, reception workers, volunteers, etc)
  - Members of the public
  - Fetus
  - Patients
    - Adult
      - Pregnancy identified
      - Pregnancy status-unknown
    - Child

As Low As Reasonably Achievable
ALARA

- Dose limits to workers and the public are regarded as upper limits rather than as acceptable doses or thresholds of safety
- In addition to the dose limits, all licenses are required to employ good health physics practices and implement radiation safety programs to ensure that radiation exposures are kept as low as reasonably achievable (ALARA), taking societal and economic factors into consideration
- The ALARA doctrine is the driving force for many of the policies, procedures, and practices in radiation laboratories, and represents a commitment by both employee and employer to minimize radiation exposure to staff, the public, and the environment to the greatest extent possible

Radiation Detection Equipment

Personnel Dosimetry

Radiation Safety

Radiation Safety Officer (RSO)

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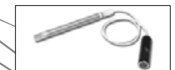
Radiation Detection Equipment:
Ionization Chambers and Survey Meters

- Characteristics of equipment are optimized for specific applications
  - Sensitivity
  - Energy resolution
- Calibrated annually (required by state/federal agencies) – NIST traceable
- Ionization chambers – physics testing




www.radcal.com
www.flukebiomedical.com

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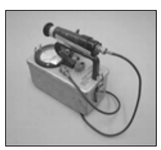
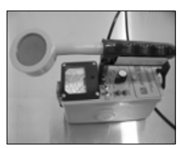
Radiation Detection Equipment:
Ionization Chambers and Survey Meters

- Survey meters – radioactive contamination, 'source search'
  - US NRC definition: Any portable radiation detection instrument especially adapted for inspecting an area or individual to establish the existence and amount of radioactive material present.

http://www.uos.harvard.edu/ehs/radiation/how_surveymeter.shtml

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Personnel Dosimetry:
General Information

- Required for personnel expected to get more than 10% of the occupational dose.
- The dosimetry report lists the "shallow" equivalent dose, corresponding to the skin dose, and the "deep" equivalent dose, corresponding to penetrating radiation
- Generally placed at waist level or shirt-pocket level
- For fluoroscopy, placed at collar level outside the lead apron to measure radiation dose to thyroid and lens of eye
- Pregnant radiation workers typically wear a second badge at waist level (behind the lead apron, if used) to assess the fetal dose

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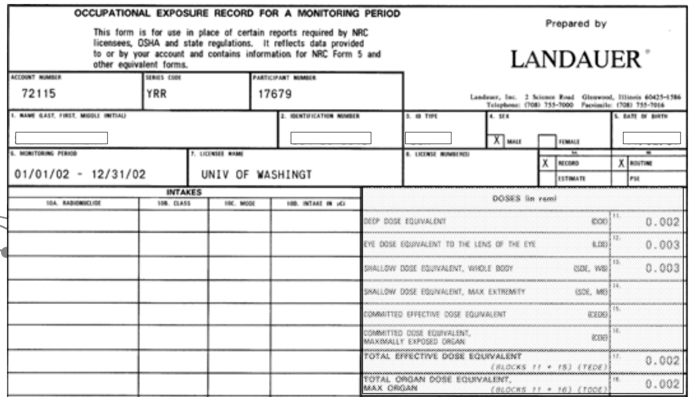
Personnel Dosimetry:
General Information



OCCUPATIONAL EXPOSURE RECORD FOR A MONITORING PERIOD

This form is for use in place of certain reports required by NRC licensees, OSHA and state regulations. It reflects data provided to or by your account and contains information for NRC Form 5 and other equivalent forms.

Prepared by LANDAUER

Landauer, Inc. 2 Science Road Glenwood, Illinois 60425-1586 Telephone: (708) 755-7000 Facsimile: (708) 755-7016

ACCOUNT NUMBER	SERIES CODE	PARTICIPANT NUMBER
72115	YRR	17679

1. NAME (LAST, FIRST, MIDDLE INITIAL) — 2. IDENTIFICATION NUMBER — 3. ID TYPE — 4. SEX: X MALE / FEMALE — 5. DATE OF BIRTH

6. MONITORING PERIOD: 01/01/02 - 12/31/02 — 7. LICENSEE NAME: UNIV OF WASHINGT — 8. LICENSE NUMBER(S) — X RECORD / ESTIMATE — X ROUTINE / PSE

INTAKES			
10A. RADIONUCLIDE	10B. CLASS	10C. MODE	10D. INTAKE IN µCi

DOSES (in rem)		
DEEP DOSE EQUIVALENT (DDE)	11.	0.002
EYE DOSE EQUIVALENT TO THE LENS OF THE EYE (LDE)	12.	0.003
SHALLOW DOSE EQUIVALENT, WHOLE BODY (SDE, WB)	13.	0.003
SHALLOW DOSE EQUIVALENT, MAX EXTREMITY (SDE, ME)	14.	
COMMITTED EFFECTIVE DOSE EQUIVALENT (CEDE)	15.	
COMMITTED DOSE EQUIVALENT, MAXIMALLY EXPOSED ORGAN (CDE)	16.	
TOTAL EFFECTIVE DOSE EQUIVALENT (BLOCKS 11 + 15) (TEDE)	17.	0.002
TOTAL ORGAN DOSE EQUIVALENT, MAX ORGAN (BLOCKS 11 + 16) (TODE)	18.	0.002

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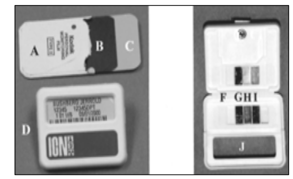
Personnel Dosimetry:
Film Badge

- A pack containing film is placed inside a special plastic film holder
- Using metal filters (typically lead, copper, and aluminum) the relative optical densities of the film underneath the filters can be used to identify the general energy range of the radiation and allow for the conversion of the film dose to tissue dose
- Open window (J) where film is not covered by a filter or plastic and is used to detect medium and high-energy beta radiation
- Most film badges can record doses from about 100 mGy to 15 Gy for photons and from 500 mGy to 10 Gy for beta radiation
- Excessive moisture or heat will damage film inside badge



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p749.

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Personnel Dosimetry:
Thermoluminescent Dosimeters (TLD)

- TLD is a dosimeter in which consists of a scintillator in which electrons become trapped in excited states after interactions with ionizing radiation
- If the scintillator is later heated, the electrons can then fall to their ground state with the emission of light
- Thermoluminescent means emitting light when heated
- The amount of light emitted by the TLD is proportional to the amount of energy absorbed by the TLD
- After TLD has been read, it may be baked in an oven and reused

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Personnel Dosimetry:
Thermoluminescent Dosimeters (TLD)

- Lithium Fluoride (LiF) is one of the most useful TLD materials
- LiF TLDs have a wide dose response range of 10 µSv to 10^3 mSv
- Used in nuclear medicine to record extremity exposures

- Landauer ring
  - Lithium fluoride (LiF) crystal structure
  - Measures x-ray, gamma-rays, and beta radiation

http://www.landauerinc.com/

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Personnel Dosimetry:
Optically Simulated Luminescent Dosimeters (OSL)

- OSL is similar to TLDs except that the light emission is stimulated by a laser light instead of heat
- Crystalline aluminum oxide activated with carbon (Al_2O_3:C) is commonly used
- Broad dose response range like TLDs
- They can be reread several times

- Landauer Luxel ® Badge
  - Measures x-ray, gamma-rays, and beta radiation with optional neutron detection (CR-39 incorporated into plastic film pack)

http://www.landauerinc.com/

Personnel Dosimetry:
Summary

TABLE 23-7. SUMMARY OF PERSONNEL MONITORING METHODS

Method	Measures	Useful range	Permanent record	Uses and comments
Film badge	Beta; gamma and x-ray	(x and gamma) 0.1–15,000 mSv[a] (beta) 0.5–10,000 mSv[a]	Yes	Routine personnel monitoring; most common in diagnostic radiology and nuclear medicine
TLD	Beta; gamma and x-ray	0.01–10^6 mSv[a]	No	Becoming more common but still more expensive than film; used for phantom and patient dosimetry
OSL	Beta; gamma and x-ray	0.01–10^6 mSv[a]	No[b]	Advantage over TLD includes the ability to reread the dosimeters and distinguish between dynamic and static exposures
Pocket dosimeter	Gamma and x-ray	*Analog* 0 to 0.2 R, 0 to 0.5 R, 0 to 5 R; *Digital* 0–100 mSv[a]	No	Special monitoring (e.g., cardiac cath); permits direct (i.e., real-time) reading of exposure

[a]Multiply mSv by 100 to obtain mrem.
[b]OSL dosimeters are typically retained and can be reread by the manufacturer for approximately 1 year.
OSL, optically stimulated luminance; TLD, thermoluminescent dosimeter.

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p753.

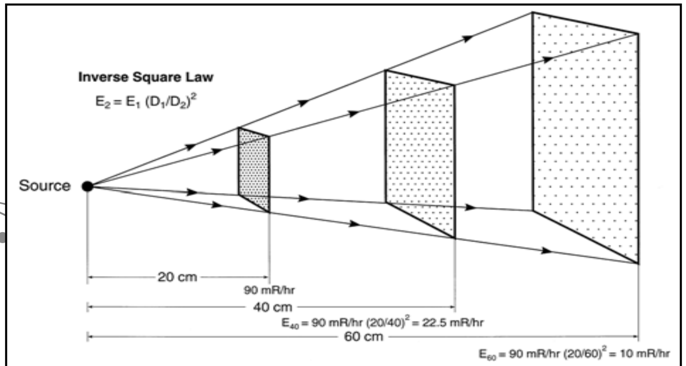
Radiation Protection & Exposure Control

Time
Distance
Shielding

Radiation Protection & Exposure Control
Time

- Reduce the time spent near a radiation source
  - Direct relationship between time and exposure
- Exposure rates – constant radiation sources (radionuclides) vs. "on/off" radiation
  - Diagnostic x-ray equipment usually produces high exposure rates in brief intervals
  - Radionuclides – generally low exposure rates over extended periods
- Use time efficiently and wisely
  - Understand task to perform
  - Utilized appropriate equipment
  - Example: Injection of FDG (F-18; 511 keV) – practice with non-radioactive source first, injections should be done in lead shielded syringe

Radiation Protection & Exposure Control
Distance – Inverse Square Relationship



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p757.

Radiation Protection & Exposure Control
Distance – Inverse Square Relationship

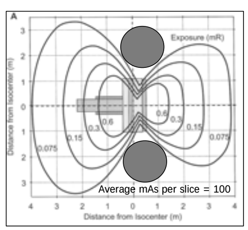
- Rule of thumb (diagnostic energy range):
  - At 1 m from a patient at 90 degrees to the incident beam, the radiation intensity is 1/1000th the intensity of the beam incident at the patient
- More precisely: 0.1% - 0.15% (0.001 to 0.0015) of the intensity of the beam incident upon the patient for a 400 cm^2 area field area
- The NCRP recommends that personnel should stand at least 2 m from the x-ray tube and the patient and behind a shielded barrier or out of the room, whenever possible

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p757.

Radiation Protection & Exposure Control
Shielding

- Shielding is used to reduce exposure to patients, staff and the public
  - Radiation suite walls and windows
  - Moveable shields – important in fluoroscopy suites
  - Scatter plots – utilize room layout (i.e. CT angio)
- Shielding calculations determine the thickness of an attenuating material required to reduce radiation exposure to acceptable levels
  - For shielding design purposes:
    - Maximum allowable exposure: 1 mSv/yr (0.02 mSv/week) for non-occupational personnel (members of public and non-radiation workers)
    - 5 mSv/yr (0.1 mSv/week) for controlled areas where occupational workers are allowed

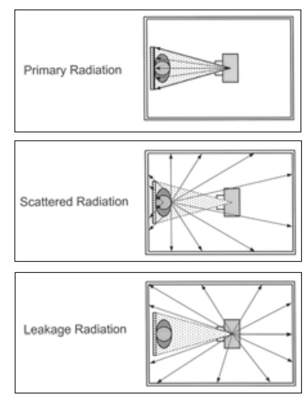
Note: shielding methodology recommends 10 times less than annual occupational radiation limit (i.e. 5 mSv/year as opposed to 50 mSv/year, therefore, 0.1 mSv/wk)



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p770.

Radiation Protection & Exposure Control
Shielding – Room Designs

- Typical shielding
  - Mammo:
    - gypsum wallboard (usually 2 sheets, 1.6 cm thick)
  - Gen Rad/Fluoro:
    - lead (1/32" to 1/16")
    - Fluoro – II absorbs primary beam
  - CT:
    - Walls – lead (1/16" to 1/8")
    - Ceiling/floors – concrete (standard thickness with some lead, or thicker concrete slab)
- Shielding against
  - Primary (focal spot)
  - Scattered (patient)
  - Leakage (x-ray tube housing, <100 mR/hr @ 1 m from housing)



c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p760.

Radiation Protection & Exposure Control
Shielding – Room Designs

- NCRP Report #147 – *Structural Shielding Design for Medical X-ray Imaging Facilities*
- Estimated workload (W) – depends on techniques and patient load
  - Estimate of total x-rays produced per week
  - Fluoroscopy – W = (mA • min/week)
  - General Radiography – W = (mGy/week); this is based on average # patients per week and average mGy per patient
  - Estimated total of x-rays incident on any given wall depends on whether it is a primary or secondary barrier
- Distance (d) – measured from source of radiation to the area to be protected (inverse square principle)
  - Room sizes affect amount of additional shielding in walls

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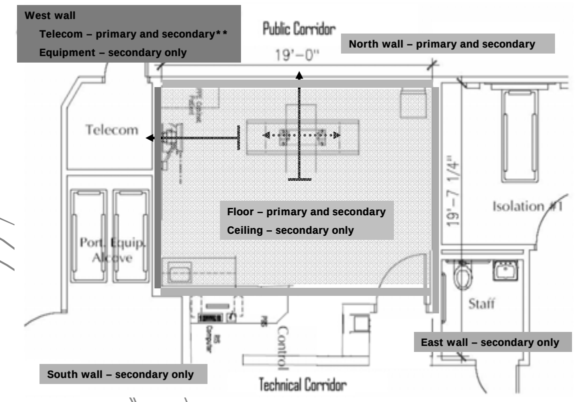
Radiation Protection & Exposure Control
Shielding – Room Designs (Primary or Secondary)



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Radiation Protection & Exposure Control
Shielding – Room Designs

- Use factor (U) – indicates the fraction of time during which the radiation under consideration is directed at a particular barrier
  - U ranges between 0 and 1 for primary barriers
    - Accounts for rooms with wall/table bucky verses wall only or table only rooms
  - U = 1 for secondary barriers (ALWAYS)

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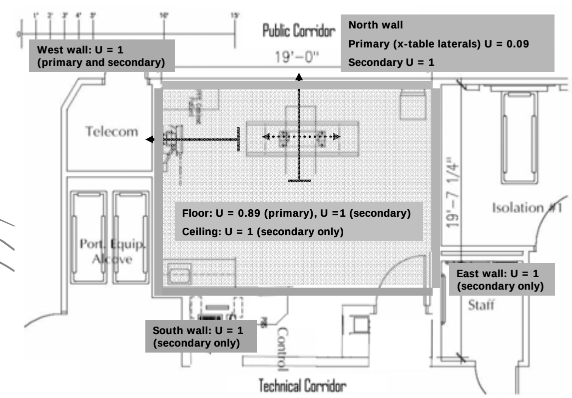
Radiation Protection & Exposure Control
Shielding – Room Designs



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Radiation Protection & Exposure Control
Shielding – Room Designs

- Occupancy factor, T, indicates the fraction of time during a week that a single individual might spend in an adjacent area
  - T = 1 for full occupancy (work areas, offices etc.)
  - T = 1/2 for exam rooms and treatment areas
  - T = 1/5 for partial occupancy (corridors, staff rest rooms and lounges, etc.)
  - T = 1/8 for doors
  - T = 1/20 for occasional occupancy (waiting rooms, public rest rooms, storage rooms etc.)
  - T = 1/40 for rare occupancy (outdoor areas w/transient pedestrian/vehicle traffic, unattended parking garages, etc)

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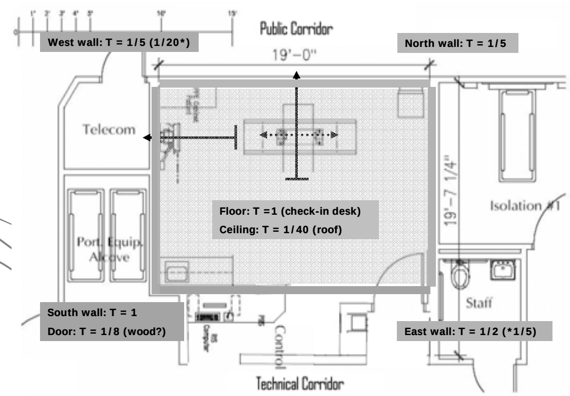
Radiation Protection & Exposure Control
Shielding – Room Designs



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Radiation Protection & Exposure Control
Shielding – Room Designs

- Lead usually used for shielding and specified as weight per square foot (lb/ft^2)
  - Typically 2 lb/ft^2 (1/32th inch) or 4 lb/ft^2 (1/16th inch) is sufficient for diagnostic radiology
- Calculated using HVL and tenth value layer (TVL) of the material
  - $(1/2)^n$ – reduction in beam intensity, n is HVL
- Shielding material used from base of floor to a height of 7 feet**
  - Gen. rad. – same thickness of lead for entire wall (or even more simple, one thickness for all walls)
  - CT – more complex designs (concrete slab directly beneath scanner, different lead thickness on each wall depending on distance from gantry isocenter to walls)
- Acrylic, leaded glass, gypsum drywall, steel are other materials used besides lead for shielding

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Radiation Protection & Exposure Control
Protection of Patient in Medical X-ray Imaging

- Miscellaneous Considerations
  - Careful identification of patients (ID bracelets/Q-A)
  - Determination of pregnancy status (very important!)
  - Eliminate screening exams that only rarely detect pathology
  - "Yearly" dental exams may not be appropriate for all patients
  - Use of high speed dental film reduces dose
  - "Yearly" screening mammography exams not appropriate for women younger than 40 years old (perhaps 50 years old)
  - Technique errors and high repeat rates can be avoided by posting technique charts and using phototiming
  - Good quality control program to eliminate equipment and processor problems

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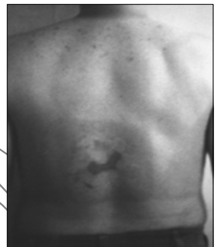
Radiation Protection & Exposure Control
Protection of Patient in Medical X-ray Imaging

- Fluoroscopy
  - Use high dose techniques judiciously – maximum 10 R/min in standard mode vs. 20 R/min in 'boost' mode (WAC246-225-050(3)); also new technology of '3-D spin'



Area of injury – 6 to 8 weeks

Progressive necrosis (estimated >20 Gy skin dose)

c.f. Bushberg, et al. The Essential Physics of Medical Imaging, 2nd ed., p777.

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Example Board Question

The annual recommended dose to the lens of the eye of a radiation worker is:

A. 500 mSv
B. 150 mSv
C. 50 mSv
D. 5 mSv
E. 1 mSv

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Example Board Question

The recommended weekly effective dose equivalent permitted for radiologists under current regulations is:

A. 10 mSv
B. 50 mSv
C. 100 mSv
D. 0.5 mSv
E. 1.0 mSv

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Example Board Question

Regulations limit the dose equivalent to the embryo/fetus of a declared pregnant radiation worker to ______ mSv/month.

A. 50
B. 10
C. 5
D. 0.5
E. 0.1

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Example Board Question

According to NCRP Report No. 116, the recommended maximum annual dose equivalent for radiation workers' whole body is _____ mSv and for the hands is _____ mSv.

A. 5 5
B. 5 50
C. 10 100
D. 50 50
E. 50 500

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Example Board Question

Film badges:

A. Can measure only the total dose of radiation, but cannot distinguish between low and high energy x-rays.
B. Can measure dose of 0.01 mSv.
C. Are insensitive to heat.
D. Use the optical density of the film to measure dose.

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Example Board Question

A shielding design for a diagnostic or therapy installation, when there is no restriction on the beam direction, must:

A. Consider all walls as primary barriers.
B. Assign all walls a use factor (U) of 1.
C. Assign all areas adjacent to the installation an occupancy factor (T) of 1.
D. Shield all areas to a radiation level of 1.0 mSv per week.
E. Shield such that adjacent areas will *not* receive instantaneous exposure rates greater than 2 mR/hr.

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Example Board Question

The occupancy factor (T) is changed from 1/16 to 1/2 and the activity factor (A) is doubled for a radiation source whose HVL is 0.3 mm Pb. In order to maintain the same level of protection, _____ mm Pb must be added to the shielding.

A. 0.3
B. 0.6
C. 0.9
D. 1.2
E. 1.5

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