ARRT Radiography Registry: X-Ray Math & Dosimetry Practice Bank

30 Comprehensive Practice Problems with Step-by-Step Solutions • Radiation Units, Exposure, Technique, Geometry & Protection

Registry Exam Scope Note: Per ARRT Radiography Content Specifications, standalone CT physics (such as helical pitch, $CTDI_{vol}$, and DLP) is tested on the post-primary CT certification exam rather than the primary Radiography registry. However, **dose comparisons** between radiography and CT, plus **SI vs. conventional unit conversions** (Gy/rad, Sv/rem, C/kg/R), are actively tested and included below.

Quick Reference Constants & Grid Factors	Value / Conversion	Quick Reference Tissue Weighting (W_T)	Factor
1 Gy = 100 rad | 1 Sv = 100 rem	1 mGy = 0.1 rad | 1 mSv = 0.1 rem	Red Bone Marrow, Colon, Lung, Stomach, Breast	0.12 each
1 C/kg = 3,876 R | 1 R = 2.58 × 10^{-4} C/kg	X-ray W_R = 1 (1 mGy ≈ 1 mSv)	Gonads (Ovaries / Testes)	0.08
Grid Bucky Factors (GCF): Non-grid = 1	5:1 = 2 • 6:1 = 3 • 8:1 = 4 • 12:1 = 5 • 16:1 = 6	Bladder, Esophagus, Liver, Thyroid	0.04 each
Anode Heat Unit (HU) Generator Factors	1-Phase = 1.0 • 3-Phase (6p) = 1.35 • 3-Phase (12p) / HF = 1.41	Bone Surface, Brain, Salivary Glands, Skin	0.01 each

Section 1: Radiation Units & Conversions (Questions 1–5)

Q1 **Absorbed Dose Unit Conversion (rad to mGy)**

A fluoroscopy procedure results in a peak skin absorbed dose of **45 rad**. What is this absorbed dose in **milligray (mGy)** and **Gray (Gy)**?

Answer: 450 mGy (or 0.45 Gy)

Step-by-Step: Since 1 Gy = 100 rad, divide rad by 100 to find Gray: 45 rad ÷ 100 = **0.45 Gy**. Multiply Gy by 1,000 to convert to milligray: 0.45 Gy × 1,000 = **450 mGy** (Shortcut: 1 rad = 10 mGy).

Q2 **Effective Dose Conversion (mSv to mrem)**

A radiologic technologist's quarterly dosimeter report shows an occupational effective dose of **1.8 mSv**. Express this exposure in **millirem (mrem)**.

Answer: 180 mrem

Step-by-Step: Since 1 Sv = 100 rem, it also follows that 1 mSv = 100 mrem. Multiply 1.8 mSv × 100 = **180 mrem**.

Q3 Air Exposure Conversion (Roentgen to C/kg)

An ionization chamber measures an X-ray beam air exposure of **250 mR** (0.25 R). What is this exposure in SI units of **Coulombs per kilogram (C/kg)**?

Answer: 6.45 × 10^{-5} C/kg

Step-by-Step: Use the conversion factor `1 R = 2.58 × 10^-4 C/kg`. First convert 250 mR to Roentgens: 250 mR ÷ 1,000 = 0.25 R. Then multiply: 0.25 × (2.58 × 10^{-4}) = **6.45 × 10^{-5} C/kg**.

Q4 Equivalent Dose for Mixed Radiation Fields

A worker is accidentally exposed to **4 mGy of diagnostic X-rays** (W_R = 1) and **0.5 mGy of alpha particles** (W_R = 20) from a laboratory source. What is the total **Equivalent Dose (H_T)** in mSv?

Answer: 14 mSv

Step-by-Step: Apply $H_T = \Sigma(D \times W_R)$. For X-rays: 4 mGy × 1 = 4 mSv. For alpha particles: 0.5 mGy × 20 = 10 mSv. Total Equivalent Dose = 4 mSv + 10 mSv = **14 mSv**.

Q5 Effective Dose Calculation Using Tissue Weighting Factors

During a specialized thoracic procedure, a patient receives an absorbed X-ray dose of **15 mGy to the lungs** (W_T = 0.12), **10 mGy to the breast tissue** (W_T = 0.12), and **5 mGy to the esophagus** (W_T = 0.04). Calculate the whole-body **Effective Dose (E)** in mSv.

Answer: 3.2 mSv

Step-by-Step: Since X-rays have W_R = 1, mGy equals mSv for each organ. Apply $E = \Sigma(H_T \times W_T)$:

• Lungs: 15 mSv × 0.12 = 1.80 mSv | Breast: 10 mSv × 0.12 = 1.20 mSv | Esophagus: 5 mSv × 0.04 = 0.20 mSv

• Total Effective Dose: 1.80 + 1.20 + 0.20 = **3.2 mSv**.

Section 2: mA, Exposure Time, mAs & Output Linearity (Questions 6–10)

Q6 Basic mAs Calculation

A portable chest radiograph is taken using **200 mA** at an exposure time of **0.04 seconds (40 ms)**. What is the total **mAs** used?

Answer: 8 mAs

Step-by-Step: Use `mAs = mA × Time (s)`. Multiply 200 mA × 0.04 s = **8 mAs**.

Q7 Solving for Exposure Time

An abdomen radiograph requires **32 mAs**. If the technologist selects the **400 mA** focal spot station, what exposure time in seconds and milliseconds is required?

Answer: 0.08 seconds (80 ms)

Step-by-Step: Rearrange to `Time = mAs ÷ mA`. Divide 32 mAs ÷ 400 mA = **0.08 s**. Multiply by 1,000 to convert to milliseconds: 0.08 × 1,000 = **80 ms**.

Q8 Reciprocity Law (Maintaining mAs to Stop Motion)

A pediatric KUB is originally planned at **100 mA and 0.15 s**, but the child is moving. To maintain the exact same receptor exposure while reducing exposure time to **0.03 s**, what mA station must be selected?

Answer: 500 mA

Step-by-Step: Original mAs = 100 mA × 0.15 s = 15 mAs. To keep 15 mAs at 0.03 s: `mA = mAs ÷ Time` = 15 mAs ÷ 0.03 s = **500 mA**.

Q9 Direct Proportionality of mAs and Air Kerma

At 75 kVp and 40 inches SID, an exposure of **12 mAs** produces an entrance skin air kerma of **1.5 mGy**. If the technique is adjusted to **30 mAs** (with kVp and SID unchanged), what is the new air kerma?

Answer: 3.75 mGy

Step-by-Step: Radiation output is directly proportional to mAs ($\text{Dose}_1 / \text{Dose}_2 = \text{mAs}_1 / \text{mAs}_2$). Set up the proportion: 1.5 / Dose_2 = 12 / 30. Solve: Dose_2 = (1.5 × 30) ÷ 12 = 45 ÷ 12 = **3.75 mGy**.

Q10 mA Linearity Check (Quality Control)

During QC testing at 80 kVp, **100 mA for 0.10 s** yields **0.82 mGy**, while **200 mA for 0.05 s** yields **0.86 mGy**. Calculate the mR/mAs (mGy/mAs) output for each station to determine if they are linear (must be within 10%).

Answer: 0.082 mGy/mAs and 0.086 mGy/mAs (4.8% difference — Passes QC)

Step-by-Step: Both exposures equal 10 mAs. Station 1: 0.82 mGy ÷ 10 mAs = **0.082 mGy/mAs**. Station 2: 0.86 mGy ÷ 10 mAs = **0.086 mGy/mAs**. Linearity variance = (0.086 - 0.082) ÷ 0.084 = 0.0476 (**4.8%**), well within the ±10% ARRT/FDA limit.

Section 3: Distance Laws — Inverse Square & Direct Square (Questions 11–15)

Q11 Inverse Square Law (Intensity Decrease with Distance)

A mobile X-ray exposure produces an intensity of **3.6 mGy** at a distance of **40 inches** from the tube target. What is the beam intensity at **72 inches** if technical factors remain constant?

Answer: 1.11 mGy

Step-by-Step: Use $I_1 \times d_1^2 = I_2 \times d_2^2$. Plug in values: 3.6 × 40^2 = I_2 × 72^2 → 3.6 × 1,600 = I_2 × 5,184 → 5,760 = 5,184 × I_2 → I_2 = 5,760 ÷ 5,184 = **1.11 mGy**.

Q12 Inverse Square Law (Occupational Radiation Safety)

During portable fluoroscopy, a technologist stands **2 feet** from the patient and receives an exposure rate of **48 mR/hr**. What will the exposure rate be if the technologist steps back to **6 feet**?

Answer: 5.33 mR/hr

Step-by-Step: Distance tripled (from 2 ft to 6 ft), so intensity drops by 3^2 (factor of 9). Using $I_2 = I_1 \times (d_1 / d_2)^2$: I_2 = 48 × $(2 / 6)^2$ = 48 × (1 / 9) = **5.33 mR/hr**.

Q13 **Direct Square Law (SID Increase Compensation)**

A satisfactory lateral lumbar spine radiograph is obtained at **40 inches SID** using **40 mAs**. If the SID must be increased to **60 inches** due to equipment constraints, what new mAs is required to maintain image receptor exposure?

Answer: 90 mAs

Step-by-Step: Use the Density Maintenance (Direct Square) formula $mAs_2 = mAs_1 \times (d_2 / d_1)^2$. Calculate: $mAs_2 = 40 \times (60 / 40)^2 = 40 \times (1.5)^2 = 40 \times 2.25 =$ **90 mAs**.

Q14 **Direct Square Law (SID Decrease Compensation)**

An upright chest radiograph normally requires **6 mAs at 72 inches SID**. For a trauma patient on a stretcher, the maximum achievable SID is **48 inches**. What mAs should be set to maintain proper receptor exposure?

Answer: 2.67 mAs

Step-by-Step: Apply $mAs_2 = mAs_1 \times (d_2 / d_1)^2$. Calculate: $mAs_2 = 6 \times (48 / 72)^2 = 6 \times (0.667)^2 = 6 \times 0.444 =$ **2.67 mAs**.

Q15 **Finding Required Safe Distance**

The radiation exposure rate **1 meter** from a mobile C-arm is **100 µSv/hr**. How far from the source must personnel stand to reduce the exposure rate to **6.25 µSv/hr**?

Answer: 4 meters

Step-by-Step: Rearrange the Inverse Square Law to solve for d_2: $d_2 = d_1 \times \sqrt{(I_1 / I_2)}$. Calculate: $d_2 = 1$ m $\times \sqrt{(100 / 6.25)} = 1 \times \sqrt{16} =$ **4 meters**.

Section 4: The 15% kVp Rule & Grid Conversions (Questions 16–20)

Q16 **15% kVp Rule (Increasing Penetration While Maintaining Exposure)**

A knee radiograph taken at **60 kVp and 12 mAs** shows inadequate penetration. To increase penetration using the 15% rule while keeping the receptor exposure constant, what new kVp and mAs should be used?

Answer: 69 kVp and 6 mAs

Step-by-Step: Increase kVp by 15%: 60 kVp × 1.15 = **69 kVp**. Because a 15% increase in kVp doubles receptor exposure, cut the mAs in half to compensate: 12 mAs ÷ 2 = **6 mAs**.

Q17 **15% kVp Rule (Increasing Contrast / Decreasing kVp)**

An image acquired at **80 kVp and 15 mAs** exhibits excessive scatter and low subject contrast. If the technologist decreases kVp by 15% to improve contrast, what new kVp and mAs are needed to maintain receptor exposure?

Answer: 68 kVp and 30 mAs

Step-by-Step: Decrease kVp by 15%: 80 kVp × 0.85 = **68 kVp**. Because a 15% drop in kVp cuts receptor exposure in half, double the mAs: 15 mAs × 2 = **30 mAs**.

Q18 **15% kVp Rule (Doubling Exposure Without Changing mAs)**

A hand radiograph using **52 kVp and 2 mAs** is underexposed by half, and the console is already at its lowest mAs setting. What kVp should be selected to double the receptor exposure without changing mAs?

Answer: 60 kVp (59.8 kVp)
Step-by-Step: Increasing kVp by 15% doubles the radiation reaching the image receptor. Calculate: 52 kVp × 1.15 = 59.8 kVp, rounded to **60 kVp**.

Q19 **Grid Conversion (Adding a Grid to a Tabletop Technique)**

A tabletop shoulder exam is performed without a grid using **5 mAs**. If the exam is repeated using a **12:1 grid** (Bucky Factor = 5), what new mAs is required to maintain image receptor exposure?

Answer: 25 mAs
Step-by-Step: Use $mAs_2 = mAs_1 \times (GCF_2 / GCF_1)$. Non-grid GCF = 1; 12:1 grid GCF = 5. Calculate: mAs_2 = 5 mAs × (5 / 1) = **25 mAs**.

Q20 **Grid Conversion (Switching Between Two Different Grids)**

A lumbar spine image is taken with an **8:1 grid** (GCF = 4) at **32 mAs**. If the patient is moved to a room equipped with a **16:1 grid** (GCF = 6), what new mAs is needed?

Answer: 48 mAs
Step-by-Step: Apply $mAs_2 = mAs_1 \times (GCF_2 / GCF_1)$. Calculate: mAs_2 = 32 mAs × (6 / 4) = 32 × 1.5 = **48 mAs**.

Section 5: Image Geometry — Magnification, SOD & Unsharpness (Questions 21–25)

Q21 **Source-to-Object Distance (SOD) & Magnification Factor (MF)**

An AP thoracic spine is imaged at **40 inches SID** with an Object-to-Image Distance (OID) of **8 inches**. Calculate the **SOD** and the **Magnification Factor (MF)**.

Answer: SOD = 32 inches; MF = 1.25 (25% magnification)
Step-by-Step: First find SOD: `SOD = SID - OID` = 40 in - 8 in = **32 inches**. Next find MF: `MF = SID ÷ SOD` = 40 ÷ 32 = **1.25**.

Q22 **Calculating True Object Size from Image Size**

A kidney stone measures **1.5 cm** on a radiograph taken at **40 inches SID** and **10 inches OID**. What is the actual anatomical diameter of the stone?

Answer: 1.125 cm (11.25 mm)
Step-by-Step: First find SOD = 40 - 10 = 30 inches. Find MF = 40 ÷ 30 = 1.333. Use `Object Size = Image Size ÷ MF` = 1.5 cm ÷ 1.333 = **1.125 cm**.

Q23 **Geometric Unsharpness (Penumbra)**

Calculate the **geometric unsharpness (Ug)** when using a **1.2 mm** focal spot at **40 inches SID** and **5 inches OID**.

Answer: 0.17 mm
Step-by-Step: Find SOD = 40 - 5 = 35 inches. Apply `Ug = (Focal Spot × OID) ÷ SOD`. Calculate: Ug = (1.2 mm × 5 in) ÷ 35 in = 6.0 ÷ 35 = **0.171 mm**.

Q24 **Percentage of Magnification**

A cross-table lateral hip radiograph is performed at **44 inches SID** with an OID of **11 inches**. By what **percentage** is the femoral neck magnified?

Answer: 33.3% magnification

Step-by-Step: SOD = 44 - 11 = 33 inches. MF = 44 ÷ 33 = 1.333. Convert MF to percentage magnification: `% Mag = (MF - 1) × 100` = (1.333 - 1) × 100 = **33.3%**.

Q25 **Spatial Resolution (Line Pairs per Millimeter)**

A digital imaging detector has a pixel pitch of **0.10 mm (100 µm)**. What is its theoretical limiting spatial resolution (Nyquist frequency) in **line pairs per millimeter (lp/mm)**?

Answer: 5.0 lp/mm

Step-by-Step: One line pair requires 2 pixels (one dark line, one bright space). Use `Spatial Resolution = 1 ÷ (2 × Pixel Pitch)` . Calculate: 1 ÷ (2 × 0.10 mm) = 1 ÷ 0.20 = **5.0 lp/mm**.

Section 6: Shielding (HVL), Tube Heat & Radiation Physics (Questions 26–30)

Q26 **Half-Value Layer (HVL) Beam Attenuation**

An X-ray beam has an initial intensity of **6.4 mGy**. If the Half-Value Layer (HVL) of lead at this kVp is **0.25 mm**, what is the transmitted intensity after passing through a **0.75 mm** lead apron?

Answer: 0.80 mGy

Step-by-Step: Find the number of HVLs (n): 0.75 mm ÷ 0.25 mm = 3 HVLs. Apply $I = I_0 \times (0.5)^n$. Calculate: I = 6.4 × $(0.5)^3$ = 6.4 × 0.125 = **0.80 mGy** (12.5% transmitted; 87.5% attenuated).

Q27 **Determining Required Shielding Thickness**

A primary beam intensity of **32 mGy/hr** must be reduced to **2 mGy/hr**. If 1 HVL of concrete is **2.4 cm**, what thickness of concrete is needed?

Answer: 9.6 cm (4 HVLs)

Step-by-Step: Count how many times 32 must be halved to reach 2: 32 → 16 (1) → 8 (2) → 4 (3) → 2 (4 HVLs). Multiply number of HVLs by HVL thickness: 4 × 2.4 cm = **9.6 cm**.

Q28 **Anode Heat Units (HU) for Single Exposure**

Calculate the **Heat Units (HU)** generated by a single exposure on a **three-phase, 12-pulse generator** (factor = 1.41) using **90 kVp, 400 mA, and 0.25 seconds**.

Answer: 12,690 HU

Step-by-Step: Apply `HU = kVp × mA × Time (s) × Generator Factor`. Calculate: 90 × 400 × 0.25 × 1.41 = 9,000 × 1.41 = **12,690 HU**.

Q29 Cumulative Anode Heat Units (Serial Radiography)

A rapid sequence of **6 exposures** is taken on a **high-frequency generator** (factor = 1.41) at **80 kVp, 300 mA, and 0.10 seconds** per exposure. What is the total heat load delivered to the anode?

Answer: 20,304 HU

Step-by-Step: Heat per exposure = 80 × 300 × 0.10 × 1.41 = 3,384 HU. Multiply by 6 exposures: 3,384 HU × 6 = **20,304 HU**.

Q30 Minimum Wavelength (λ_{min}) & Maximum Photon Energy

An X-ray tube operates at **100 kVp**. What is the maximum kinetic energy of the projectile electrons (in keV), and what is the **minimum wavelength (λ_{min})** of the resulting bremsstrahlung X-ray photons (in Angstroms, Å)?

Answer: 100 keV max energy; 0.124 Å minimum wavelength

Step-by-Step: Peak kilovoltage (100 kVp) directly equals peak electron energy (**100 keV**). Use the Duane-Hunt formula λ_{min} `(Å) = 12.4 ÷ kVp`: 12.4 ÷ 100 = **0.124 Å** (or 0.0124 nm).

This is for informational purposes only. For medical advice or diagnosis, consult a professional. AI responses may include mistakes.