The ARRT formula sheet

Memorize this page. Write it out on the whiteboard the testing center gives you in the first 15 minutes of the exam.

01 HOW EACH FACTOR CHANGES THE IMAGE

kVp sets beam quality, meaning penetration and contrast, and raises quantity as well. mAs sets quantity alone, meaning receptor exposure and noise. Each row changes only that one factor and holds everything else constant; the few cells that assume you compensated say so.

Factor	Receptor exposure	Contrast	Sharpness	Size	Patient dose
kVp up	Up, sharply	Down (longer scale)	No change	No change	Up at the same mAs
mAs up	Up 1:1 (less quantum noise)	No change	No change	No change	Up, one for one
SID up	Down (inverse square)	No change	Up	Less magnification	Down at the same mAs
OID up	Down	Up (air gap sheds scatter)	Down	More magnification	Up (~10% more mAs per cm of gap)
Focal spot up	No change	No change	Down (more blur)	No change	No change
Grid ratio up	Down, so raise mAs	Up	No change	No change	Up (from the required mAs increase)
Filtration up	Down	Down slightly	No change	No change	Down (skin)
Tighter collimation	Down, so raise mAs	Up (less scatter)	No change	No change	Down
Part thickness up	Down	Down (more scatter)	Down (anatomy farther off receptor)	More magnification	Up
Motion	No change	No change	Down (motion unsharpness)	No change	No change
Anode heel effect	Lower at the anode end	No change	No change	No change	No change
Angle (tube/part/IR)	No change	No change	Down	Elongation or foreshortening	No change

02 THE FORMULAS

MILLIAMPERE-SECONDS
mAs = mA × time (s)

INVERSE SQUARE LAW
$I_1 / I_2 = D_2^2 / D_1^2$

DIRECT SQUARE LAW
$mAs_2 = mAs_1 \times (SID_2^2 / SID_1^2)$

THE 15% RULE
+15% kVp ≈ 2× mAs (same exposure)

MAGNIFICATION FACTOR
M = SID / SOD

GEOMETRIC UNSHARPNESS
P = FSS × OID / SOD

GRID CONVERSION
$mAs_2 = mAs_1 \times (GCF_2 / GCF_1)$

GRID RATIO
ratio = h / D

TRANSFORMER LAW
$V_S / V_P = N_S / N_P$

EQUIVALENT AND EFFECTIVE DOSE
H = D × wR · E = Σ(wT × HT)

CONTRAST MEDIA DOSE
mL = (lb ÷ 2.2) × mL/kg

PIXEL SIZE
pixel size = FOV ÷ matrix

BIT DEPTH
gray shades = 2^n

HALF-VALUE LAYER
HVL = thickness that halves beam intensity

Grid conversion factors: No grid = **1** · 5:1 = **2** · 6:1 = **3** · 8:1 = **4** · 12:1 = **5** · 16:1 = **6**

Watch the hidden step: SOD is rarely given. Stems hand you SID and OID, and expect you to work out SOD = SID − OID.

03 NUMBERS WITH NO LOGIC, ONLY MEMORY

Dose limits

- Occupational effective dose: **50 mSv/yr** (5 rem)
- Cumulative lifetime: **10 mSv × age** in years
- Public: **1 mSv/yr**
- Thyroid, skin, hands, feet: **500 mSv/yr** equivalent dose
- Embryo or fetus: **0.5 mSv/month**, **5 mSv** across the pregnancy
- Student under 18: **1 mSv/yr**

Unit conversions

- 1 Gy = **100 rad** · 1 Sv = **100 rem**
- 1 rad = **10 mGy** · 1 rem = **10 mSv**
- Exposure, the quantity measured in air: C/kg in SI, or the roentgen (R)

Equipment and regulatory

- Total filtration: **2.5 mm Al** or more above 70 kVp
- Protective apparel: **0.25 mm Pb** minimum, 0.5 mm typical for fluoroscopy
- Fluoroscopy timer alarm: **5 minutes** cumulative
- Min **fluoroscopic** source-to-skin: **38 cm** stationary, **30 cm** mobile
- Fluoroscopy tabletop limit: **100 mGy/min**, or **200 mGy/min** with high-level control
- Standard SIDs: **40 in (100 cm)** routine, **72 in (180 cm)** chest, **60–72 in** lateral C-spine
- The control booth is a **secondary** barrier: the useful beam never points at it

04 PHYSICS, POSITIONING AND EQUIPMENT

Physics in one line

- **Photoelectric effect.** Total absorption. Proportional to Z^3 (atomic number) and $1/E^3$ (photon energy). This is what makes contrast.
- **Compton scatter.** Deflected photon. Ignores atomic number. Dominant at high kVp by proportion, not by count. Source of your occupational exposure and image fog.
- **Coherent scatter.** Low energy, no ionization.
- **X-ray production.** About 99% heat, 1% x-rays. Bremsstrahlung dominates. Characteristic radiation needs ~70 kVp (tungsten K-shell 69.5 keV).
- **Anode heel effect.** The beam runs stronger on the cathode side. Put the thick end of the part toward the cathode.
- **Automatic exposure control.** Controls time only. You still set kVp, mA, receptor and grid.
- **Quantum mottle.** Grainy image from too few photons. Raise mAs.
- **ALARA.** As low as reasonably achievable: less time, more distance, shielding.

Positioning numbers

- **AP axial clavicle:** 15–30° cephalad. Thin (asthenic) 25–30°, thick-chested (hypersthenic) 15–20°
- **Towne (AP axial skull):** 30° caudad to the orbitomeatal line (OML), 37° to the infraorbitomeatal line (IOML)
- **Caldwell (PA axial skull):** 15° caudad, exits at nasion
- **AP axial C-spine:** 15–20° cephalad
- **AP axial sacrum:** 15° cephalad · coccyx 10° caudad
- **AP knee (ASIS to tabletop):** <19 cm: 5° caudad · 19–24 cm: 0° · >24 cm: 5° cephalad
- **AP oblique foot, medial:** Rotate 30–40°
- **Cervical obliques:** Rotate 45°. Posterior (RPO/LPO) + 15–20° cephalad = upside foramina. Anterior (RAO/LAO) + 15–20° caudad = downside
- **Lumbar obliques:** Rotate 45° for the Scottie dog. Posterior (RPO/LPO) = downside joints, anterior = upside. Rotate 50° at L1–L2, 30° at L5–S1
- **SI joints:** Rotate 25–30° posterior oblique, side of interest elevated (LPO opens the right joint)
- **Sternum:** 15–20° RAO

Digital display

- **Window level** sets brightness. Direct: level up, image brighter
- **Window width** sets contrast. Inverse: wide = long gray scale, low contrast. Narrow = high contrast
- **Look-up table** reshapes brightness and gray scale after the histogram is read
- **mAs no longer sets brightness.** The computer does. Underexposure produces quantum noise, not a dark image

Radiobiology

- **Bergonié and Tribondeau:** radiosensitivity rises with immaturity, youth, high metabolic activity, and a high rate of proliferation
- Stem cells sensitive, mature cells resistant
- Most sensitive: **lymphocytes and spermatogonia** (the two most radiosensitive cells), then erythroblasts and intestinal crypt cells
- Most resistant: **nerve and muscle** cells

Equipment

- **OSL:** aluminum oxide, read by laser light
- **TLD:** lithium fluoride, read by heat
- **Line focus:** smaller anode angle = smaller effective spot (detail), large actual spot (heat)
- **Image intensifier:** input phosphor (CsI) → photocathode → electrostatic lenses → output phosphor (ZnCdS)

The explanations behind the sheet

A memorized sheet you do not understand falls apart under exam pressure. Read this once, slowly, until every line on page one stops feeling arbitrary.

Why each factor behaves this way

kVp

kVp, or kilovoltage peak, sets the peak energy of the x-ray photons the tube produces. That energy is what radiography calls beam quality, and higher-energy photons penetrate more tissue: as kVp increases, beam penetrability increases. Be precise about the mechanism, because the exam builds distractors from it. kVp does not make photons travel faster, since all x-ray photons travel at the speed of light. It raises their energy. More of a higher-energy beam reaches the image receptor, and those photons are attenuated more uniformly by bone and soft tissue, so the difference in attenuation between the two narrows. The result is a longer scale of contrast, which means lower radiographic contrast. Higher kVp also increases the proportion of Compton scatter, which reduces contrast further.

mAs

mAs, or milliampere-seconds, sets the quantity of x-ray photons the tube produces, and the relationship is directly proportional. Doubling the mAs doubles both the receptor exposure and the patient's absorbed dose. mAs affects only the quantity of the beam and has no effect on its quality, so radiographic contrast is unchanged. In digital imaging, mAs governs quantum noise, because too few photons reaching the receptor leave insufficient signal to render a smooth image.

SID

SID, or source-to-image-receptor distance, governs beam intensity and image geometry at the same time. Increasing the SID decreases x-ray beam intensity at the receptor, which is why the mAs must be increased to compensate. Hold those two facts apart, because the table and this paragraph can look contradictory otherwise. At a fixed mAs, moving the tube back lowers the dose at the patient's skin, which is what the table's dose cell reports. Once you raise the mAs to restore receptor exposure, that saving is largely given back, so a longer SID is chosen for geometry rather than as a dose-reduction tactic. The geometry improves because the photons reaching the part travel along more nearly parallel paths, which reduces size distortion and improves spatial resolution. Chest radiography uses 72 inches for this reason, since the heart is measured on those images and magnification would produce a false impression of cardiomegaly.

OID

OID, or object-to-image-receptor distance, is the separation between the anatomy of interest and the receptor. Increasing the OID increases magnification and decreases spatial resolution, which is why placing the part in contact with the receptor answers so many positioning questions. One exception is worth knowing. A deliberate increase in OID allows a portion of the scattered radiation to travel past the receptor rather than reach it, which improves contrast. This is the air-gap technique, and it substitutes for a grid at the cost of magnification and of patient dose, because the mAs must rise roughly 10% for every centimeter of gap, which is about the same technique an 8:1 grid demands.

Focal spot

The focal spot is the area of the anode from which the beam originates, and its size determines geometric unsharpness. A larger focal spot records every edge over a wider area of the receptor, which reduces spatial resolution. It affects nothing else, changing neither receptor exposure, nor contrast, nor patient dose, and exam questions are written specifically to test whether you know that. A small focal spot improves recorded detail, and the cost is reduced heat-loading capacity.

Grids

A grid is a device of thin lead strips separated by radiolucent interspaces, placed between the patient and the receptor. Photons traveling along the divergence of the primary beam pass between the strips, while scattered photons arriving at other angles are absorbed. Less scatter reaching the receptor means improved radiographic contrast, which is the purpose of the device. The grid also attenuates a portion of the transmitted primary beam, so the mAs must be increased to maintain receptor exposure, and that increase is what raises the patient's dose. A higher grid ratio removes more scatter and demands a larger mAs increase.

Filtration

Aluminum filtration at the tube port absorbs the low-energy photons that would be attenuated by the patient before reaching the receptor. Those photons contribute nothing to the image and would otherwise deposit their entire energy in superficial tissue. Filtration therefore reduces entrance skin exposure while having only a small effect on the image. It hardens the beam, raising the average photon energy while reducing the total quantity of photons, and that hardening is why radiographic contrast falls slightly as filtration increases.

Collimation

Restricting the field size irradiates a smaller volume of tissue, which lowers patient dose, and it leaves less tissue available to produce scattered radiation, which raises radiographic contrast. Because fewer photons reach the receptor overall, close collimation may require a modest increase in mAs. Collimation is one of the few adjustments that improves image quality and patient dose at the same time, which is why collimating to the anatomy of interest is almost never the wrong answer.

Part thickness

Thicker anatomy attenuates a greater portion of the beam and generates more scattered radiation. Every 4 to 5 cm change in part thickness requires the mAs to be adjusted by a factor of 2. This relationship underlies technique charts, automatic exposure control, and every question that asks how the technique should change for a larger patient.

Every formula, letter by letter

Knowing what a symbol stands for is half the work. Knowing what it looks like when a question hides it behind different words is the other half.

Milliampere-seconds

mAs = mA × time (s)

What the letters mean. mA is tube current, the number of electrons crossing the tube each second. Time is the exposure time in seconds, although stems frequently state it in milliseconds to test whether you convert, since 50 ms equals 0.05 s. Their product is proportional to the total quantity of photons produced.

How it sounds in a question. "Which set of exposure factors produces the greatest receptor exposure?" or "What exposure time at 400 mA produces 20 mAs?"

This is the foundation that every other exposure calculation rests on. A technique of 200 mA at 0.05 s and one of 400 mA at 0.025 s both produce 10 mAs and therefore the same receptor exposure, and this equivalence is called reciprocity. When your patient may move during the exposure, select the higher mA and the shorter time.

Inverse square law

$I_1 / I_2 = D_2^2 / D_1^2$

What the letters mean. I is intensity, but a stem almost never says that word. Look instead for an exposure rate in mR/hr, a dose rate in mGy/hr, air kerma, or "the exposure at the tabletop." D is your distance from the source: the tube for a primary beam, the patient during fluoroscopy, since the patient is what scatters. Any unit works as long as both distances match. Notice the subscripts cross over, because intensity and distance move in opposite directions.

How it sounds in a question. "The exposure rate 1 m from the patient is 40 mR/hr. What is it at 2 m?" or "Doubling your distance reduces your exposure by a factor of ___."

Intensity falls off with the square of the distance, because the same number of photons spreads across a wider area. When you double your distance, you receive one quarter of the radiation. When you halve it, you receive four times as much. Stepping back during a mobile exposure therefore reduces your exposure more than almost any other single action, because the reduction is squared.

Worked through: 40 mGy/hr at 1 m becomes 40 ÷ 4 = 10 mGy/hr at 2 m.

Direct square law

$mAs_2 = mAs_1 \times (SID_2^2 / SID_1^2)$

What the letters mean. This one calculation goes by three names, so learn all three: the direct square law, the exposure maintenance formula, and the mAs/distance compensation formula. mAs_1 and SID_1 are the technique and distance that produced an acceptable image. SID_2 is the new distance and mAs_2 is the technique you must now calculate. Unlike the inverse square law, these subscripts do not cross, because the mAs must increase along with the distance rather than against it.

How it sounds in a question. "A satisfactory radiograph is produced at 10 mAs and 40 inches. The projection is repeated at 72 inches. What mAs maintains receptor exposure?" The trigger words are "maintain," "same receptor exposure," or "compensate." The stem may also name the direct square law outright.

This formula is the practical application of the inverse square law. Moving the tube farther away weakens the beam at the receptor, so you must produce more radiation to compensate. When the distance increases, the mAs increases with it.

Worked through: Going from 40 to 72 inches needs $(72 \div 40)^2 = 3.24$ times the mAs.

The 15% rule

+15% kVp ≈ 2× mAs (same exposure)

What the letters mean. kVp is kilovoltage peak, the peak energy of the beam. Increasing it by 15% means multiplying by 1.15, so 80 becomes 92 and 86 becomes 99. The mAs adjustment is always the companion move, because a 15% increase in kVp is paired with halving the mAs.

How it sounds in a question. “kVp is increased from 80 to 92. What mAs change maintains receptor exposure?” or “Which change lowers patient dose while maintaining receptor exposure?” The second phrasing describes this substitution.

Increasing the kVp by 15% doubles receptor exposure, producing the same result as doubling the mAs. Reaching that exposure through kVp rather than mAs also increases penetrability, lowers radiographic contrast, and delivers less dose to the patient. Note that this is the one place where raising kVp lowers dose: the table's kVp row holds mAs constant, while this rule halves it. Applied in reverse, the rule maintains receptor exposure, because you increase the kVp by 15% and reduce the mAs by half. One limit is worth carrying: the rule is most reliable in the middle of the diagnostic range. Below about 70 kVp a smaller change produces the effect, and at 90 kVp and above a larger one is needed.

Worked through: 80 kVp at 20 mAs becomes 92 kVp at 10 mAs, same exposure, lower dose.

Magnification factor

M = SID / SOD

What the letters mean. M is the magnification factor and carries no units, so a value of 1.11 means the image is recorded 11% larger than the object. SID is the source-to-image-receptor distance. SOD is the source-to-object distance, and this is where questions become difficult, because stems rarely provide the SOD directly. They provide the SID and the OID, which is the object-to-image-receptor distance, and expect you to calculate SOD = SID − OID yourself.

How it sounds in a question. “A structure is imaged at 40 inches SID with the part 4 inches from the receptor. It measures 5.5 cm on the image. What is its actual size?” Calculate the SOD first, then divide.

The magnification factor tells you how much larger the image is than the object itself. True object size equals image size divided by M. The only ways to bring M closer to 1 are a longer SID or a smaller OID, which are the same two adjustments listed in the direction-of-change table in section 01.

Worked through: SID 40 in, OID 4 in, so SOD is 36 in and M = 40 ÷ 36 = 1.11.

Geometric unsharpness

P = FSS × OID / SOD

What the letters mean. P stands for penumbra, the width of the unsharp margin at the edge of the recorded image. Stems also call it geometric unsharpness, edge unsharpness, focal-spot blur, or loss of recorded detail, and the terms are interchangeable. FSS is the effective focal spot size in millimeters, meaning the spot as projected toward the patient rather than the larger actual area struck by the electrons, so a stem will contrast a 0.6 mm spot with a 1.2 mm one. OID appears in the numerator because a greater separation increases unsharpness, and SOD appears in the denominator because greater distance from the source reduces it.

How it sounds in a question. This is rarely calculated. Expect instead “Which combination of factors produces the least geometric unsharpness?” with four sets of values to compare. The correct answer combines the smallest focal spot, the longest SID, and the smallest OID.

The size of the focal spot determines how sharply each edge is recorded, because a larger source spreads the edge over a wider area of the receptor. This is the same geometric principle that governs magnification. Every geometry question on the exam reduces to three habits: keep the part close to the receptor, keep the tube far from it, and select the smallest focal spot the exposure allows.

Grid conversion

$mAs_2 = mAs_1 \times (GCF_2 / GCF_1)$

What the letters mean. GCF is the grid conversion factor, also called the Bucky factor. Stems use both names for the same value, which is the multiplier applied to the mAs when a grid is added or changed. Grid ratio is a separate specification, expressed as strip height over interspace width.

How it sounds in a question. "A radiograph is produced at 8 mAs without a grid. What mAs is required with a 12:1 grid?" or "The Bucky factor for a 12:1 grid is approximately ___."

A grid consists of thin lead strips separated by radiolucent interspaces. Photons traveling in a straight line pass between the strips, while scattered photons arriving at an angle are absorbed. Less scatter reaches the receptor, so contrast improves, which is the reason grids exist. The grid also absorbs some useful photons, so you must raise the mAs to compensate, and the patient receives that additional exposure. Note carefully where the dose increase originates, because the exam tests this distinction: the grid itself only attenuates the beam, and the added dose results from the mAs increase you make.

Worked through: 10 mAs with no grid becomes 10 × 5 = 50 mAs behind a 12:1 grid.

Grid ratio

$ratio = h / D$

What the letters mean. h is the height of the lead strips and D here is the width of the interspace between them, not the distance used in the inverse square law. The ratio describes how selectively the grid removes scatter. The grid conversion factor on the previous card describes the mAs increase that selectivity requires.

How it sounds in a question. "A grid with 3 mm strips and 0.25 mm interspaces has a ratio of ___," or a conceptual item asking which ratio removes the most scattered radiation.

Taller strips separated by narrower interspaces accept a narrower range of transmission angles, so a greater proportion of scattered radiation is absorbed. A higher ratio therefore improves radiographic contrast and increases patient dose through the mAs it demands.

Transformer law

$V_s / V_p = N_s / N_p$

What the letters mean. V is voltage and N is the number of turns of wire in a coil. The subscript p denotes the primary, or input, side and s denotes the secondary, or output, side. A stem provides the turns ratio and the incoming line voltage. Current varies inversely with voltage, so a transformer that steps voltage up steps current down.

How it sounds in a question. "A transformer has 100 primary turns and 50,000 secondary turns. With an input of 220 V, what is the output voltage?"

Voltage varies in direct proportion to the turns ratio. The step-up transformer carries more turns on the secondary side and raises the incoming line voltage to the kilovoltage the tube requires. The filament circuit uses a step-down transformer, which lowers voltage and raises current.

Worked through: A turns ratio of 500 with an input of 220 V produces 110,000 V, or 110 kV.

Equivalent and effective dose

$H = D \times wR \cdot E = \Sigma(wT \times HT)$

What the letters mean. D is absorbed dose in grays. wR is the radiation weighting factor, which is 1 for x-rays and gamma rays, so for everything you do H equals D numerically. H is equivalent dose in sieverts. wT is the tissue weighting factor, which reflects how radiosensitive an organ is, and HT is the equivalent dose that organ received. E is effective dose, also in sieverts, and it is the sum across every irradiated tissue.

How it sounds in a question. "Which quantity accounts for the type of radiation and the sensitivity of the tissue irradiated?" or a stem giving an absorbed dose in mGy and asking for the equivalent dose in mSv.

These two formulas are why radiation has three different dose quantities rather than one. Absorbed dose measures energy deposited. Equivalent dose adjusts it for how damaging that radiation type is. Effective dose adjusts further for which organs absorbed it, so a dose to the gonads counts for more than the same dose to the skin. Because the weighting factor for x-rays is 1, converting absorbed dose to equivalent dose in diagnostic imaging is arithmetic you can do in your head.

Worked through: 3 mGy from an x-ray beam gives H = 3 × 1 = 3 mSv.

Contrast media dose

mL = (lb ÷ 2.2) × mL/kg

What the letters mean. Divide the patient's weight in pounds by 2.2 to get kilograms, then multiply by the prescribed dose per kilogram. If the stem gives a concentration rather than a volume, finish with volume = total dose ÷ concentration.

How it sounds in a question. “A 154 lb patient is prescribed 2 mL/kg of contrast. What volume is administered?” This is the only arithmetic in the patient care section.

Contrast is prescribed per kilogram, and stems give weight in pounds, so the conversion is the whole test. Work in the order the formula is written and the rest is multiplication.

Worked through: 154 lb ÷ 2.2 = 70 kg, and 70 × 2 mL/kg = 140 mL.

Pixel size

pixel size = FOV ÷ matrix

What the letters mean. FOV is the field of view, the physical area the image covers. Matrix is the number of pixels along one side of the image. The result is the size of a single pixel, and smaller pixels record finer detail.

How it sounds in a question. “A 512 matrix is changed to 1024 over the same field of view. What happens to spatial resolution?” Expect the relationship far more often than the calculation.

Hold the field of view constant and enlarge the matrix, and each pixel gets smaller, which improves spatial resolution. Students invert this constantly, because a bigger number for the matrix feels like it should mean bigger pixels. It means the opposite.

Worked through: A 25 cm field over a 512 matrix gives 250 mm ÷ 512 = 0.49 mm pixels.

Bit depth

gray shades = 2^n

What the letters mean. n is the bit depth. The result is how many shades of gray the system can record and display, which is its contrast resolution.

How it sounds in a question. “How many shades of gray can a 12-bit system display?”

Each additional bit doubles the number of available shades. Greater bit depth means finer contrast resolution, at the cost of a larger file.

Worked through: A 12-bit system gives 2^{12} = 4,096 shades of gray.

Half-value layer

HVL = thickness that halves beam intensity

What the letters mean. The half-value layer is expressed as a thickness in millimeters of aluminum for diagnostic beams. It functions like a formula although it is a definition, because each successive layer halves the remaining intensity, so two layers transmit one quarter and three transmit one eighth.

How it sounds in a question. “A 400 mR beam passes through 2 HVLs. What is the remaining intensity?” or the conceptual form, “HVL is a measure of ___,” for which the answer is beam quality.

The half-value layer is the quantitative measure of beam quality. Adding filtration or raising the kVp increases the HVL, which indicates that the beam has been hardened and its average photon energy raised.

Worked through: 400 mR through 2 HVLs leaves 100 mR.

The physics, three sentences at a time

Photoelectric effect

An inner-shell electron absorbs the photon completely. This is why bone appears white on the image, because differences in absorption are what produce contrast. The interaction favors materials with a high atomic number, which is why barium and iodine work as contrast media, and its probability falls rapidly as photon energy rises. It produces dose and contrast, and because the photon is absorbed outright rather than deflected, it adds no scatter fog to the image.

Compton scatter

The photon displaces a loosely bound outer-shell electron and continues in a new direction. That deflected photon fogs the image and delivers your occupational exposure during fluoroscopy. Read the wording of these questions carefully, because the exam constructs a distractor from it. Raising the kVp does not increase the number of Compton interactions. Compton interactions decrease slowly as energy rises, while photoelectric interactions decrease far more rapidly, so Compton accounts for a larger share of the interactions at higher energies even though its own count is falling. It dominates by proportion, not by count. When a question asks where your occupational exposure originates, the answer is Compton scatter.

Coherent scatter

The photon changes direction without transferring energy to the atom, so no ionization occurs. It takes place at the low-energy end of the diagnostic range and contributes little to the radiographic image.

X-ray production

Almost all of the kinetic energy of the incident electrons is converted to heat, which is why anodes rotate and why heat-unit calculations exist. The majority of the beam consists of bremsstrahlung, or braking radiation, which forms a continuous spectrum. Characteristic radiation contributes discrete peaks, but only once the kVp exceeds the K-shell binding energy of tungsten at 69.5 keV, and even above that threshold it accounts for roughly 15% of the beam.

Anode heel effect

The angled face of the anode absorbs a portion of the beam emitted toward the anode side, so beam intensity is greater at the cathode end of the field. Femur and AP thoracic spine questions both depend on this principle.

Automatic exposure control

The ionization chamber terminates the exposure once a predetermined quantity of radiation has reached it. Your selected kVp still governs radiographic contrast. Selecting the wrong chamber beneath a dense structure prolongs the exposure, which increases patient dose.

Quantum mottle

Quantum mottle is the noise that appears when too few photons reach the receptor to produce a uniform signal. It is the consequence of reducing mAs too far in digital imaging, where the computer corrects the brightness but cannot restore the missing signal.

ALARA

ALARA is the governing principle behind every radiation-protection question, and its three practical measures are time, distance, and shielding. Distance produces the greatest reduction for the least effort, because the inverse square law reduces intensity by the square of the change in distance.

Digital imaging, radiobiology and the equipment questions

The digital display traps

The exam is written to catch students applying film logic to a digital receptor, so learn these four facts as a set. Window level controls brightness, and the relationship is direct, which means that raising the level makes the image brighter. That direction is worth stating explicitly, because many students assume the opposite. Window width controls contrast, and the relationship is inverse, which means that a wide window distributes the anatomy across many shades to produce a long gray scale and low contrast, while a narrow window compresses it toward black and white to produce high contrast. The look-up table reshapes brightness and gray scale after the histogram is analyzed, which is why raw digital data appears flat until it is processed. The final fact catches the most students, because mAs no longer controls brightness in digital imaging. The computer sets the brightness, so an underexposed image still displays at an acceptable brightness, but it contains substantial quantum noise.

The law of Bergonié and Tribondeau

You do not need to memorize a sensitivity ranking for every tissue, because one law generates the entire ranking. The law of Bergonié and Tribondeau states four things. Stem cells are radiosensitive while mature cells are radioresistant. Younger tissues and organs are radiosensitive. Tissues with high metabolic activity are radiosensitive. And a high proliferation rate for cells, together with a high growth rate for tissues, increases radiosensitivity. Apply those four tests to any cell and the answer follows. Lymphocytes and spermatogonia are the two most radiosensitive cells in the body, with erythroblasts and intestinal crypt cells alongside them at the sensitive end. On the female side, the most radiosensitive cell during germ cell development is the oocyte in the mature follicle. Nerve and muscle cells are mature, highly specialized, and no longer dividing, so they are the most radioresistant. The same law explains why the exam repeatedly emphasizes that fetuses and children are more sensitive than adults.

The two dosimeters

Expect a question that asks you to distinguish between these two, and the detector material together with the readout method is all you need. The optically stimulated luminescence dosimeter uses aluminum oxide and is read with laser light, which its own name indicates, because optical stimulation means it is read by light. The thermoluminescent dosimeter uses lithium fluoride and is read with heat, which its name also indicates, because thermo refers to heat.

The line-focus principle

There are two focal spots, and each one serves a different purpose. The actual focal spot is the physical area of the anode that the electrons strike, and it should be large so that the heat spreads across a wider area rather than melting the target. The effective focal spot is the area projected downward toward the patient and the receptor, and it should be small in order to record sharp detail. Angling the face of the anode achieves both objectives at once, because the smaller the anode target angle, the smaller the projected effective focal spot compared with the actual area of electron interaction. Target angles typically run 5° to 20°.

Inside the image intensifier

Fluoroscopy questions almost always test the order of the energy conversions, so learn the sequence rather than the individual parts. X-rays strike the input phosphor, which is made of cesium iodide, and are converted into visible light. That light strikes the photocathode, which releases electrons through a process called photoemission. A potential difference of roughly 25,000 volts between the photocathode and the anode then accelerates those electrons down the tube, while electrostatic focusing lenses keep the electron pattern precise as the image is minified. Note the division of labor, because the exam tests it: the lenses focus, and the anode potential accelerates. The electrons strike the much smaller output phosphor, which is made of zinc cadmium sulfide, and are converted back into a far greater quantity of visible light. The increase in brightness comes from two quantities multiplied together. Flux gain is the ratio of light photons leaving the output phosphor to the x-rays that struck the input phosphor, and it results from that acceleration. Minification gain results from concentrating a large input image onto a small output screen.

Why the angles are what they are

Every angle exists to move one structure out from behind another. Knowing what each one dodges is what makes it stay in your head.

Towne, 30° caudad

The angle is about the sella. It projects the dorsum sellae and posterior clinoid processes into the shadow of the foramen magnum rather than above it. Angle too little and the dorsum sellae rides above the foramen. Angle too much and the posterior arch of C1 crowds in. Symmetrical petrous ridges tell you the skull was not rotated.

Clavicle and sternum angles depend on body habitus

The clavicle angle projects most of the bone above the scapula and the upper ribs. The range runs opposite to what most students expect, because thin patients require more angulation at 25 to 30° while thick-chested patients require less at 15 to 20°. The sternum reverses that pattern, because a large, deep-chested thorax requires less rotation than a thin-chested one.

The sacrum angles cephalad and the coccyx angles caudad

The two angles point in opposite directions because each one compensates for the curvature of its own bone. When you angle correctly, the sacrum appears without foreshortening and the pubis is projected clear of the sacral foramina, while the coccyx appears above the pubis without superimposition.

The AP knee angle depends on your measurement

Measure from the ASIS to the tabletop before you set the angle. Under 19 cm, angle 5° caudad. Between 19 and 24 cm, which covers the average patient, use no angle at all. Over 24 cm, angle 5° cephalad. The goal never changes, which is to direct the central ray parallel to the tibial plateau.

Oblique laterality follows opposite rules in the cervical and lumbar spine

These are the highest-yield facts in this section, and the exam tests the contrast between them. Cervical posterior obliques, meaning the RPO and LPO, use a cephalad angle and demonstrate the upside intervertebral foramina, which are the ones farthest from the receptor. Cervical anterior obliques, meaning the RAO and LAO, use a caudad angle and demonstrate the downside foramina. One mnemonic covers both positions, because the LPO and the RAO each demonstrate the right foramina. The lumbar spine reverses this convention, because posterior obliques demonstrate the downside zygapophyseal joints, so the RPO produces the right Scottie dogs. For the sacroiliac joints, the side of interest is elevated, so the LPO opens the right joint. Do not extend the 45° habit too far, because the thoracic zygapophyseal joints require 70°.