C1-Radiation Protection and Patient Safety

Time, distance and shielding; workload, use and occupancy factors; shielding design for primary, scattered and leakage radiation; barrier calculation; report preparation; air concentrations of radioactivity; department design; radiation standards and units; radiation protection principles; radiation regulations and requirements; responsibilities of the radiation protection office; radiation surveys in diagnostic radiology, nuclear medicine and radiation therapy; characteristics of survey equipment; evaluation of radiation hazards; personnel monitoring; and related subjects.

ALARA Principle:

Distance
Time
Shielding

Think answers toward these 3 directions!!

Dose definition

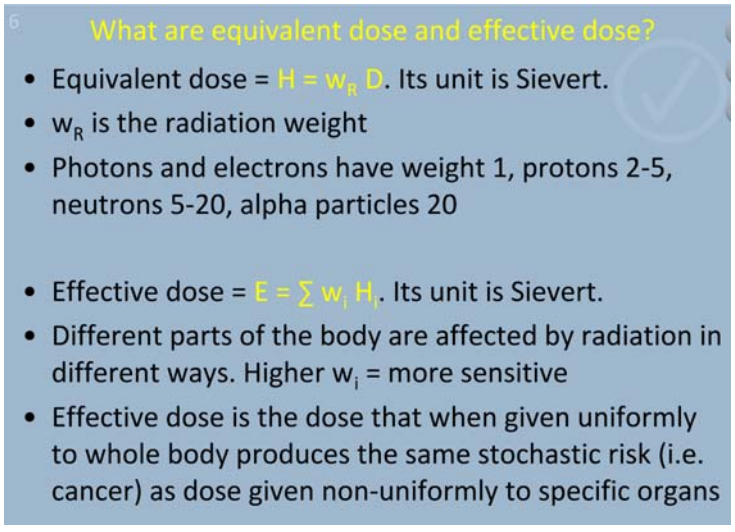
- (2008) Explain the difference between absorbed dose, dose equivalent and effective dose equivalent? Explain the beam quality factors for various beams? Explain the weighting factors of gonads, breast, lung and skin? Why don't we calculate the effective dose equivalent in most of the treatment we gave to patients, for example, pelvis?

(Hall p225 – 227)

Absorbed dose: The quantity used to measure the amount of ionizing radiation is the absorbed dose, which is defined as the energy absorbed per unit mass in J/kg.

Equivalent dose: In radiologic protection, the equivalent dose is the product of the absorbed dose averaged over the tissue or organ & the radiation weighting factor selected for the type and energy of radiation involved. This is the dose we used for shielding design.

Effective dose: If the body is uniformly irradiated, the probability of the occurrence of stochastic effects (cancer & hereditary effects) is assumed to be proportional to the equivalent dose. So effective dose is …This is the dose we used for annual permissible dose.



So, the effective dose is the whole body dose quantifying the probability of cancer induction. However, when we do the planning, we are interested in the dose deposited to OAR or target volume, and we are especially interested in the normal tissue complication which is a different purpose than the effective dose.

- Define with equation mean dose equivalent

$$H_T = \sum W_R D \text{ (Sv)}$$

(Hall p226)

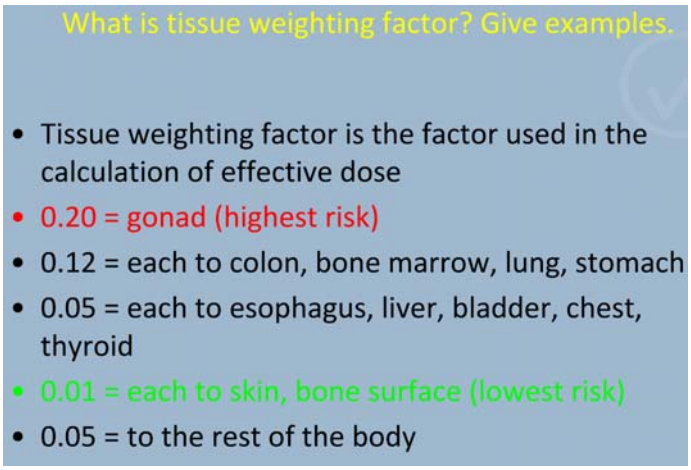
The radiation weighting factor represents the relative biologic effectiveness (RBE) contributed by the different type of the radiation beam. **Note: W_R is determined by ICRP based on RBE but not 1 to 1 corresponds to RBE.**

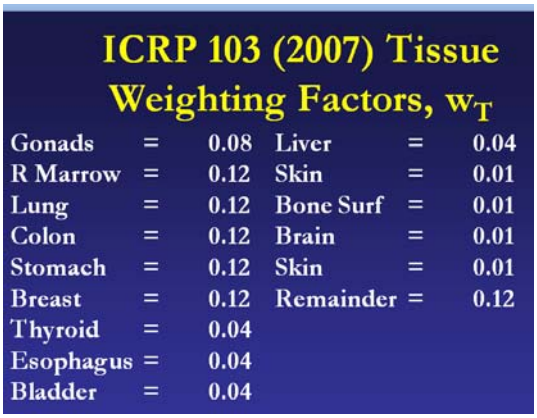
Quality Factor W_R:	Xrays, electrons	$W_R = 1$
	protons	$W_R = 2$
	Thermal neutrons	$W_R = 5$
(rough estimates)	Fast Neutrons	$W_R = 20$
	Ions, Pions	$W_R = 2$
Older Unit:	H[rem] = D[rad] • Q	

- Define with equation effective dose equivalent

NCRP 151 used the "dose equivalent" as the shielding design goal units

o What is the weighting factor for gonads (0.08), skin (0.01), breast, bone marrow (0.12) ICRP 103 number?





o **From ICRP60 (1991)**

C1-A (Neutron Shielding)

- Neutron shielding (no pictures): In what way neutrons present radiological hazard for linear accelerators? How are neutrons produced – what's the energy threshold and when does it become a serious problem?

(E Hall p227)

The radiation weighting factor (or quality factor) W_R for **fast neutron** is 20 folder higher than photon.

Quality Factor W_R:	**Xrays, electrons**	**$W_R = 1$**
	protons	**$W_R = 2$**
	Thermal neutrons	**$W_R = 5$**
(rough estimates)	**Fast Neutrons**	**$W_R = 20$**
	Ions, Pions	**$W_R = 2$**
Older Unit:	**H[rem] = D[rad] • Q**	

H_T (tissue equivalent dose) = $\sum W_R$ D,

W_R = 20 for the most effective neutron energy 1 MeV
W_R = 1 for photon and electron
W_R = 2 for proton

Does the dose equivalent quality factor for neutron depend on its energy?

- Yes. The quality factor is a continuous function of energy, but for practical purposes, you can use these from ICRP recommendation:

Energy	< 10 keV	10-100 keV	100 keV – 2 MeV	2-20 MeV	> 20 MeV
Q	5	10	20	10	5

(Podgorsak)
The neutron contamination is produced by high-energy photons and electrons incident on the target, primary collimator, beam flattening filter, collimator jaws, beam accessories 'accelerator head', air and the patient (by photon-neutron (x,n) {$^{A}X + r \rightarrow n + {}^{A-1}X$} and electron-neutron (e,n) reactions). The neutron yield from electron reaction is several orders lower than the photon reaction so it will be ignored.

Thermal: $\bar{E}_n = 0.025$ eV at 20 °C; typically $E_n \leq 0.5$ eV (cadmium resonance)
Intermediate: $0.5 \text{ eV} < E_n \leq 10$ keV
Fast: $E_n > 10$ keV

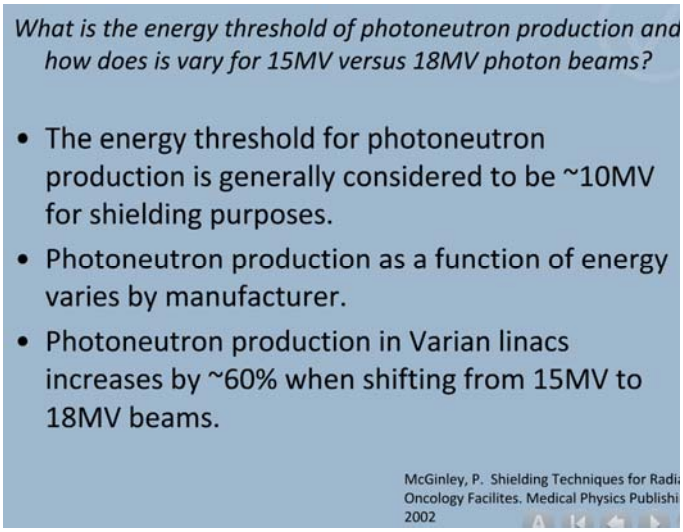
(McKinley p64)
An additional complication caused by photon-neutron reactions from high-energy linac is that a number of materials found in the linac head become radioactive. Technicians who enter the room after linac has been terminated can have the exposure to gamma radiation from the induced material.

The energy threshold for neutron

(This number is from McGinley p58)

The neutron threshold energy is generally believed as 8 MeV.
(NCRP151, p21) The neutron yield for most linac materials does not become significant for photon energy < 10 MeV. Most machine used Pb and W (tungsten) as the linac material.

(Peter Biggs summer school) By 15 MV, the neutron production increases by a factor of **10**, and by 18 MV increases by a factor of **20**



*(PART2) Using photon mode in the linear accelerator, which one from the following materials have the highest cross section for

Besides being produced in the linac head, photoneutrons are also produced in the patient and in the bunker walls, floor and ceiling. The production in the linac head is particularly important because of the presence of a large amount of high-Z materials and their large photoneutron production cross sections. Furthermore, these high-Z materials have low neutron capture cross sections and the generated photoneutrons will escape from the linac head.

Since this question asks the material, I therefore put possible choice as reference : 1. Tungsten W(□), 74, 2. Lead Pb 82, 3. Copper, Cu 29, 4. Aluminium, Al 13.

- What locations and room designs, is it a problem – laminated vs. all concrete rooms

(NCRP151 p32 & 40); the photoneutron + neutron capture gamma ray dominating in the room shielding is in the door area or HVAC conduits (those with thin barrier).

Neutrons interaction is basically by 2 processes (1). Recoiling protons from H and recoiling heavy nuclei from other elements & (2) nuclear disintegrations. For the 1st process, the energy transfer is very efficient if the colliding particles have the same mass, ex: H nucleus, so the paraffin wax or polyethylene are good material for shielding neutron. Lead is transparent to neutron (Kahn 3rd p75)

Concrete has high hydrogen content so it is a good material for photon-neutron shielding. The TVL for primary x-ray is about 37 cm (6x) & 45 cm(15x), & for photon-neutron is 21 cm. Therefore, the concrete shielding the x-ray is thick enough to shielding the neutron.

Laminated Barriers (NCRP151 p27): When we have space limit, the primary barrier may not just composited by the concrete. The ordinary concrete can be used conjunction with lead or steel. The concern for laminated barrier is for high energy beam > 10 MV, the photon-neutron interaction in the high z material and the neutron capture gamma ray produced in the concrete wall.

From NCRP151 or AAPM 2011 review course (p25), from inside, it suggested lead and then concrete, because photoneutron can be produced in the lead itself, so concrete can then absorb neutron. (KW) As we put in our penn shielding. So we can have lead attenuating the photon first and use the concrete to attenuate the photon as well as absorb the neutron produced from the linac and the lead.

- (Door shielding): How do you design a linac door? Shown a picture of a door and had me draw the cross-section of a door without a maze for a high energy linac room. Talk about what materials (lead, borated-polyethelene) and why and what order they should be in?

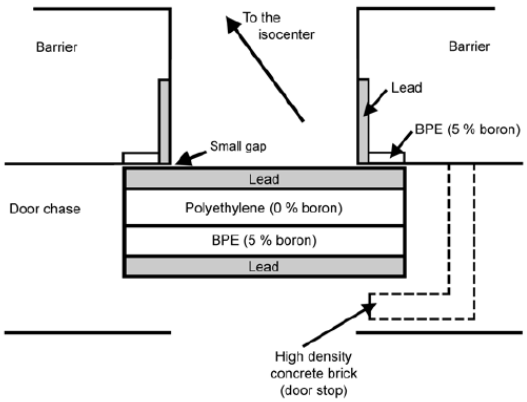
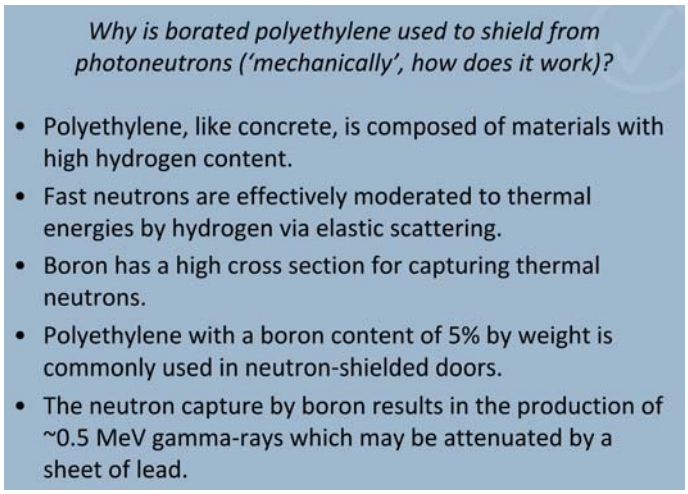
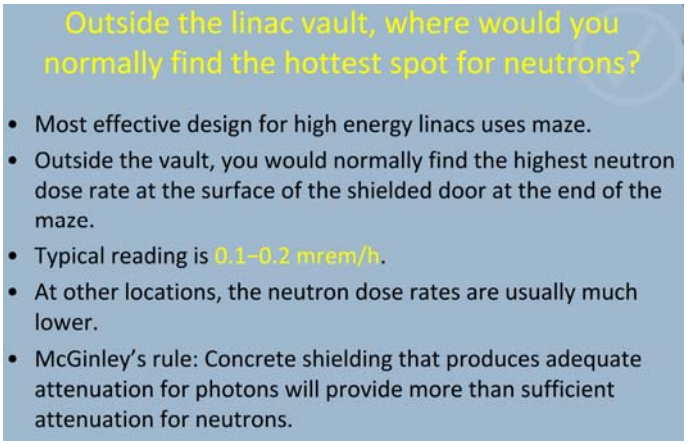


Fig. 2.11. Alternative to large overlap at door.

The lead on the inner side of the BPE reduces neutron energy by inelastic scattering, hence making the BPE more effective. The lead on the outside of the BPE will serve to attenuate the neutron capture gamma rays (0.5 MeV) emanating from the BPE itself.

- (2006) Neutron questions. Why do you moderate them? What so special about BPE that makes them a good moderator? (Hydrogen/Boron content)





Lead (reducing photon)→Polyethylene (fast neutron) → Boron (thermal neutron) → lead (neutron capture gamma ray by boron (photon) **0.5 MeV**)

The average of neutron capture gamma ray in concrete is **3.6 MeV**.

- What are the energies of neutrons at door and BPE TVL? Why use Boron in BPE? Why not just use Boron alone then?

NCRP(151 p 46): The average neutron energy at the maze entrance is reported to be **0.1 MeV**, with a *TVL* in BPE of 4.5 cm (NCRP, 1984). The neutron energy inside the room is 1 – 2 MeV and outside room is < 0.5 MeV (NCRP151 p177 – 176).

Borated polyethylene (BPE) (5 % by weight) is only a little less effective in fast neutron shielding, but is **much more effective for thermal neutrons** compared with polyethylene without boron. The *TVL* for BPE is 3.8 cm for 2 MeV neutrons, and 1.2 cm for thermal neutrons. For purposes of maze door shielding, a conservatively safe recommendation is that a ***TVL* of 4.5 cm** be used in calculating the BPE thickness requirement.

- What's the door thickness of **your** linac room?
  Penn: We use 2 doors, the inner door thickness is **1.3 cm lead + 5 cm BPE** mainly used for neutron shielding and we have maze, the concrete for maze is 84 cm, and we have an outer door with 0.6 cm lead. Our maze distance is 6 m from the edge of the inner door to the maze entrance, and total maze length is 8 m. We have 1 turn at the door entrance, so the total maze distance used for Kersey's formula is 6 + 1 = 7 m. Our Maze is used to shield everything, but our PCAM maze shield photon primarily because neutron is well shielded in the inner door.

You are designing a high energy linac door. What materials would you use, in what order do you place them and why?

- A typical high energy linac door (at the end of a maze) would consist of ~0.5cm steel case containing ~10cm of borated polyethylene (neutron moderation and attenuation) and 1.5cm of lead (gamma-ray attenuation).
- Traditionally the lead is placed after the borated polyethylene (from the perspective of standing inside the vault looking out) to attenuate gammas produced by capture of the neutrons.
- *Authors note: Designs placing the lead BEFORE the borated polyethylene have been proposed to be more efficient (see McCall 1997), however the traditional design may be more appropriate for the purposes of the examination.

McGinley, P. Shielding Techniques for Radiation Oncology Facilites. Medical Physics Publishing. 2002

McCall, R.C. Shielding for Thermal Neutrons. Med. Phys. 24:135-136, 1997

- How would you calculate the maze wall thickness?
  The standard maze wall is about 0.9meter. I will initially give about this thickness and do the calculation for dose at the maze entrance see what much leakage transmitted dose at the door → decide on the maze thickness.

- How do you shield for neutrons? What is the equation?
  High hydrogen material such as concrete
  Wall: lead - concrete
  Door shielding: lead – BPE – lead

In Kersey's formula, d_0 is actually 1.41 m from target (NCRP151, p44 eq.2-18, KW)

$$H_{n,D} = (H_0)\left(\frac{S_0}{S_1}\right)\left(\frac{d_0}{d_1}\right)^2 10^{-\left(\frac{d_2}{5}\right)} \quad (2.18)$$

In this application of Kersey's method, H_0 is the total (direct plus room-scattered plus thermal) neutron dose equivalent at a distance d_0 (1.41 m) from the target per unit absorbed dose of x rays at the isocenter (mSv Gy^{-1}) (see Table B.9 in Appendix B for measured values of H_0). The ratio S_0/S_1 is the ratio of the inner maze entrance cross-sectional area to the cross-sectional area along the maze (Figure 2.8). These are usually different primarily because of their different widths, though the height may change also due to the use of lintels above the inner maze entrance. Distance d_1, which is shown in Figure 2.8, is the distance from the isocenter to the point on the maze centerline from which the isocenter is just visible (A). For a maze with one bend as illustrated, d_2 is the distance in meters from A to B. In the case of a maze with two bends, d_2 is the distance from A to C plus length C to D. Note that for this method the maze has a *TVD* of 5 m for the attenuation of neutrons in the maze.

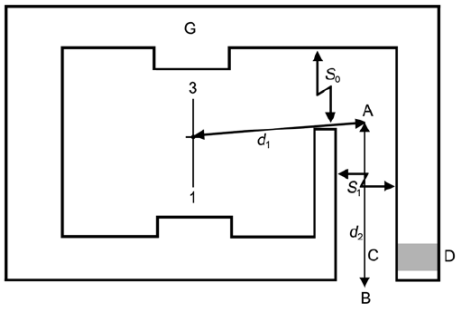


Fig. 2.8. Room layout for calculating neutron capture gamma-ray and neutron dose equivalents at the maze door.

$H_{n,D}$ is neutron dose equivalent in mSv/Gy, the d_0 is the 1.41 distance from target not the SAD!!

What can you do to lower the neutron dose rate at the maze entrance?

- Increase the length of the maze. The TVD ≈ 5 m along the maze for neutrons. Thus each 5 m of maze reduces neutron dose by a factor of 10.
- Decrease the inner cross section (width x height) of the maze.
- Increase the number of turns in the maze. This number is the minimum number of scatter a neutron takes to go from the linac head to the outer maze entry. Each turn will reduce the neutron dose by a factor of about 3.
- Make the turns sharper.

- These factors are implicit in the Kersey's formula for neutron dose.

- Shielding door. Contribution to the door from different components for a low energy and high energy beam. Picture of a linac vault door. What materials do you use and why?

(NCRP151, p 38, 39): **Low energy** we have $H_G = fH_{prim\_s} + H_{ps} + H_{Ls} + H_{LT}$
f is accounted for the primary beam transmission through the pt. H_G = at 1 GA.

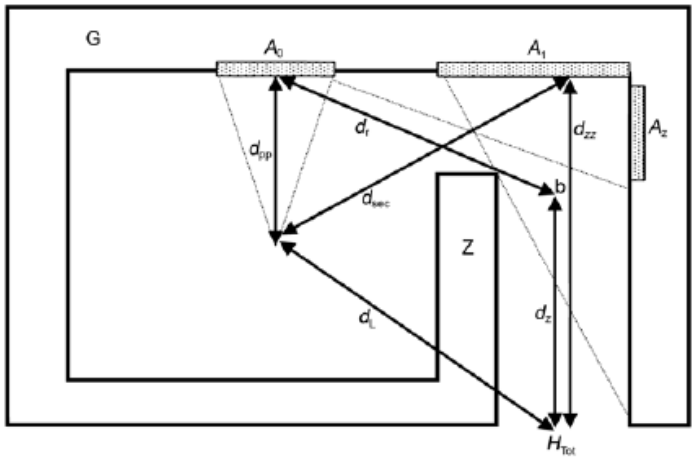


Fig. 2.7. General room layout for definition of parameters used in maze door shielding (see Figure 7.1 for more detail).

$$H_S = \frac{W\ U_G\ \alpha_0\ A_0\ \alpha_z\ A_z}{(d_h\ d_r\ d_z)^2}$$

U_G = use factor for the Wall G
α_0 = reflection coefficient at the first scattering surface A_0
A_0 = beam area at the first scattering surface (m^2)
α_Z = reflection coefficient for second reflection from the maze surface A_z (an energy of 0.5 MeV is usually assumed)
A_Z = cross-sectional area of maze inner entry projected onto the maze wall from the perspective of the irradiated primary barrier A_0 (m^2)
d_h = perpendicular distance from the target to the first reflection surface [equal to d_{pp} (perpendicular distance from isocenter to the wall, see Figure 2.7) plus 1 m] (meters)
d_r = distance from beam center at the first reflection, past the edge of the inner maze wall, to Point b on the midline of the maze (meters)
d_z = centerline distance along the maze from Point b to the maze door (meters)

This area reflects the largest field size 40 x 40 projected to the wall.

$$H_{LS} = \frac{L_f\, W_L\, U_G\, \alpha_1\, A_1}{(d_{sec}\, d_{zz})^2} \qquad H_{ps} = \frac{a(\Theta)\, W\, U_G \left(\frac{F}{400}\right) \alpha_1\, A_1}{(d_{sca}\, d_{sec}\, d_{zz})^2} \qquad H_{LT} = \frac{L_f\, W_L\, U_G\, B}{d_L^2}$$

4 angle : H_{tot} = 2.6 x H_G rather than 4 x H_G (for low energy <= 10 MV), but the

High energy: beside the H_G, we have photon-neutron H_n and neutron capture gamma ray H_{cg} contribution.
$H_w = H_{TOT} + H_{cg} + H_n$
$H_{cg} = W_L h$ (x-ray)
$H_n = W_L H_{n,D}$ (neutron)

Important: W_L is the weekly leakage workload produced inside the linac head and produce the most neutron dose!

$$h_\varphi = K\, \varphi_A\, 10^{-\left(\frac{d_2}{TVD}\right)}$$

h is the dose equivalent from the neutron capture gamma rays at the outside maze entrance per unit x-ray absorbed dose at iso.

$H_{n,D}$, Kersey's formula, is the total neutron dose equivalent at the outside maze entrance per unit x-ray absorbed dose at iso.

- How are neutron measured? What methods? Explain the functioning of instruments used in measuring neutron doses.

Fig. C.2. Thermo Electron Corporation ASP/2e NRD neutron survey meter.

Fig. C.1. Victoreen neutron survey meter Model 190N.

How does neutron detector work? (1)

- Neutrons have no charge so cannot easily be collected directly.
- Use nuclear reactions to convert neutrons to charged particles.
- Boron is very effective at capturing neutrons and creating charged particles from the reaction (in technical terms, boron has a large cross section for reacting with neutrons).
- The reaction is: $^{10}B + n \rightarrow {}^{7}Li + \alpha + 2790$ keV
- Note that this is a nuclear reaction, involving only the nucleus. This discussion on HPS may help if you get confused.
- Both of the products on the r.h.s. (^{7}Li and α particle) are born as energetic positive ions. Their total KE can be up to 2790 keV.
- These positive ions, and the negative electrons left behind, can now be collected. You then convert charge to dose.
- Neutron cross section for ^{11}B (more common isotope, about 80% of all boron) is orders of magnitude lower than that for ^{10}B, so you cannot use it for this measurement. You want ^{10}B.

How does neutron detector work? (2)

- Neutron detectors use boron in the form of BF_3. This is a pungent colorless toxic gas which is very corrosive. This is why neutron detector housing is usually moisture proof.
- In addition to ^{10}B, Helium-3 is also commonly used in gas-filled neutron detectors.
- The reaction is: $^{3}He + n \rightarrow {}^{3}H + {}^{1}H + 765$ keV
- The reaction products on the r.h.s. are tritium and proton, with a total kinetic energy of 765 keV.
- The Canberra NP100 neutron detector shown here, for example, comes in 2 models. Model NP100B is filled with BF_3 and model NP100H is filled with ^{3}He. Helium is more sensitive.

B & He are 2 materials used to absorb neutron, n, so not to mix them!!

How does neutron detector work? (3)

- For both ^{10}B and ^{3}He, the cross section is roughly proportional to the inverse square root of neutron energy: $\sigma \approx 1/\sqrt{E}$
- Or, since these particles are not at relativistic speed, the cross section is inversely proportional to the neutron speed: $\sigma \approx 1/v$
- This means to get more reaction in the detector you want to slow down the neutrons → use neutron moderator

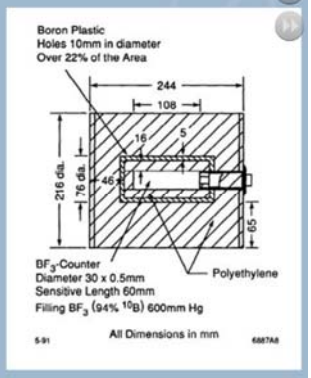
If we slow down the neutron first using polyethylene (fast -> thermal), and boron will react with "more" neutron and our detection efficiency will be increased!

What kind of bias voltage is used in neutron detectors?

- Neutron meters typically operate with bias ≈ 1000–2000 V.
- They operate in the proportionality region → neutron detectors are proportional counters.
- Proportional region → Large bias gives primary ions enough energy to cause secondary ionizations. The collected charge can be amplified to about 10,000 times this way.
- Due to this large amount of charge, neutron detectors use pulsed bias, instead of continuous bias used in the Farmer chamber for example.
- By analyzing the pulse shape, the detector can distinguish neutron contribution from photon contribution and reject the photon part. Photon contributions are always present but unwanted in neutron measurement.

How do you slow down neutrons?

- Most commonly used material to moderate neutrons is polyethylene.
- By combining appropriate amount of polyethylene (attenuator) and boron sleeve with holes (absorber) around the BF3-filled proportional counter, you get the classic design of Anderson-Braun (AB) rem-meter.
- The main point of this design is that its response is proportional to the absorbed dose AND the neutron quality factor for all neutron energy. So the reading from the rem-meter is directly in rem (or Sv) and not in rad (or Gy).
- You can use this rem-meter without having to worry about the spectrum.



Liu et al. (1991)
Neutron dosimetry at SLAC

Neutron detector is ION CHAMBER working in proportional counter region!!!
Therefore, Rem meter is one kind of ion chamber which detects charge

- Know that inside the room we measure the neutrons with activation foil. Give the formula. Outside the room we use Rem ball counter and gave the Boron formula ($^{10}B+n \rightarrow {}^{7}Li + \alpha + e^-$).

  - You are in a reactor and are give two detectors contained within polyethylene spheres of 10 cm diameter. One is coated with 1 mm of cadmium. Describe the neutron response of the two detectors?
    - Polyethylene sphere moderates the fast neutron to thermal neutron and get the reading from thermal neutron
    - Cd (like boron) cover is to absorb the thermal neutron from the environment and let the fast neutron passing, and we only measure the fast neutron fluence (mainly from the linac head). (NCRP151 p 187)
    - My guess for this one is, cadmium is like boron has large cross section of reacting with thermal neutron. so the detector in poly sphere with cadmium coating will only have readings for fast neutron.
    - *Passive monitoring refers to the use of activation foils, TLDs, solid state nuclear track detectors, and bubble detectors.*

      Active monitoring relies on slowing down fast neutrons or moderating them until they reach thermal energies. A thermal detector is then used to detect the thermal neutrons. Depending on the geometry and configuration of the moderator, the instrument is designed to measure either dose equivalent (rem meter) or fluence (fluence meter).

(Kahn p416 & NCRP151 p186) Neutron measurements in or near the primary x-ray beam can be made with **passive detectors** such as activation detectors (foil), without being adversely affected by pulsed radiation.

Because the **strong photon fluence** from the pulsed radiation will interference active detection system (the active detector sys needs to analyze the pulse shape and distinguish if it's photon or neutron signal) and passive systems are insensitive to photon fluence.

So, the passive neutron devices such as cadmium (*KAD-mee-əm*) **Cd** and phosphorus activation foils can be used both inside and outside treatment rooms.

Other materials for activation foil is
Gold, Indium (for thermal neutron); phosporus (for thermal and fast)

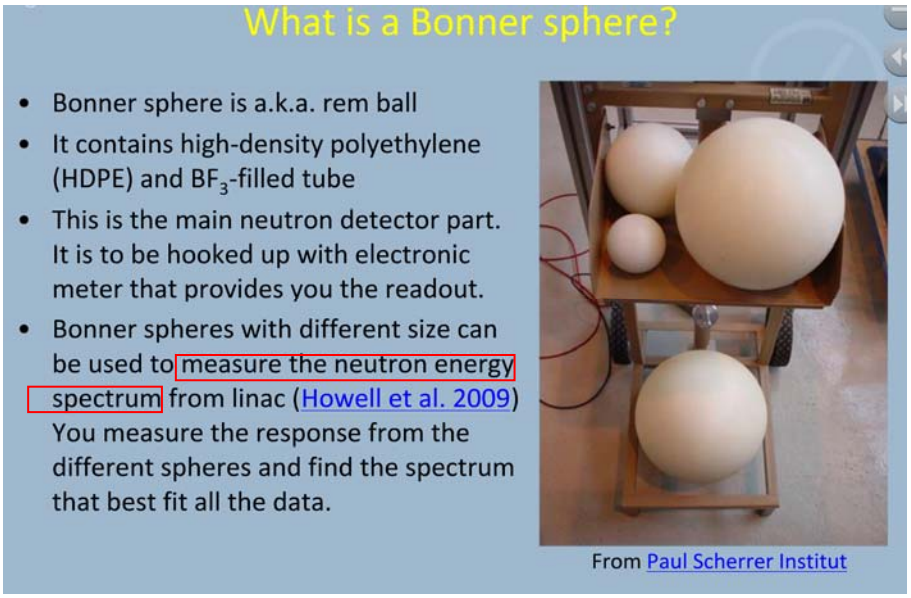
(NCRP151 P195) Due to the pulsed nature of the accelerator beam and the high-intensity photon field, **active detectors should only be used outside the shielded treatment room**, and possibly in the outer maze area.

Pulsed radiation -- passive detectors, and
continuous radiation such as Co-60 -- active or passive detectors.

On outside the treatment room the effect of pulses from linac head is washed out so both detectors can be employed.

Passive detector working principle:
1. neutron absorption by foil results in production of radioactive nucleus.
2. Radioactivity can be correlated with incident neutron fluence
3. they are stable and reproducible.

- Neutron energy spectra, in front of door, how to measure the spectra?
- How to Measure neutron spectrum?



Thermal-neutron detectors can be used inside a series of hydrogenous spheres (bonner sphere)of varying diameters to determine the neutron spectrum (Bramblett *et al.*, 1960). Since the amount of moderation varies in each of these spheres, it is possible to calculate the total spectrum by taking all the responses and folding them into a series of equations. Since this usually requires a computer program, a large number of spheres and long measurement times, the process is fairly laborious. This method is referred to as the Multi-Sphere or Bonner-Sphere method. (Don't mix this one with rem meter!!)

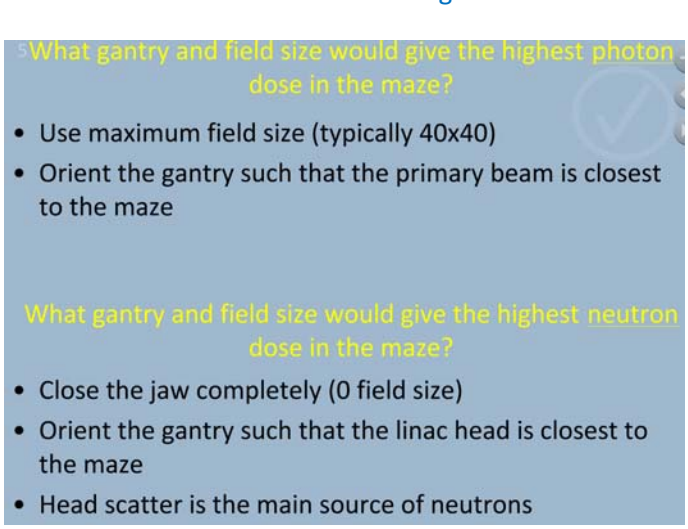
- Talked about the neutron energy spectra similar to the fission spectra

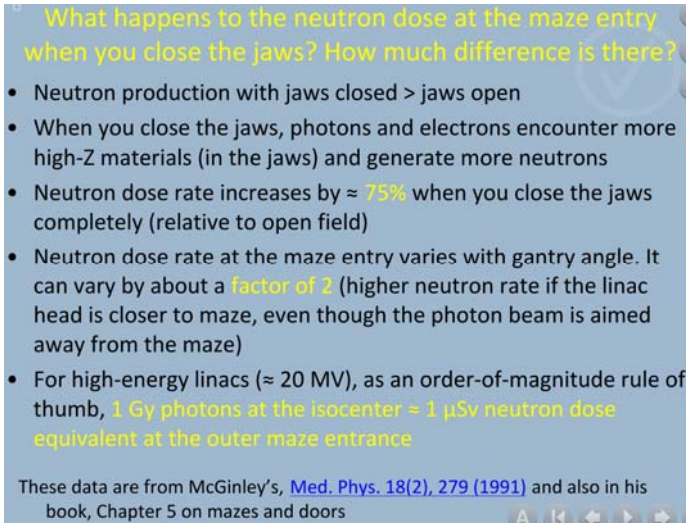
(NCRP151 appendix c) The neutron detector needs to transfer from neutron fluence to dose equivalent, and it is energy dependent. So some neutron detector is calibrated against 252CF (known neutron fission spectrum) because it has similar spectrum as the photoneutron from linac.

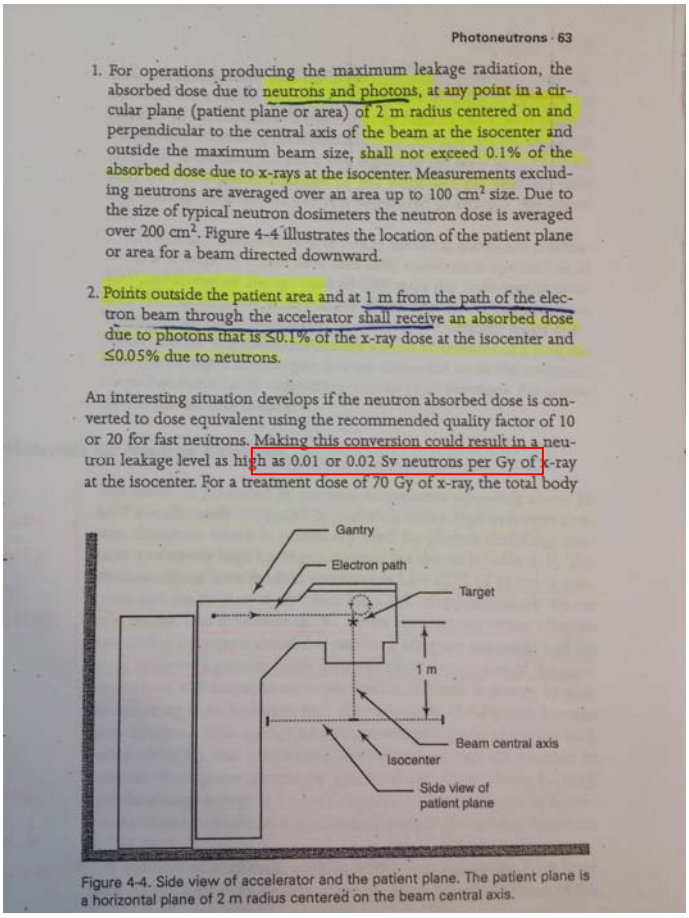
- Leakage of photon beams how to measure, how do you compare scatter? how about neutrons? Discuss linear no threshold method.
    - Films are pasted on the linac head, identify the hot spot and put ion chamber close to it and measure the leakage.
    - Leakage energy is higher than the scattered energy, and it is more penetrated.
    - The radiation fraction of leakage is 10^{-3} which is 1 order higher than the scatter fraction at 90 degree
    - If the machine is equipped with IMRT ability, the leakage workload will be higher than the workload used to calculate scattered dose.
    - In most case, leakage is dominated than the scatter component.
    - At some case, if we consider small angle scattering, and no IMRT component, the leakage can be comparable to the scatter part.
    - (NCRP151) In most high-energy accelerator facilities, a secondary barrier that is adequately designed for the leakage radiation component will be more than adequate for the scattered radiation with the possible exception of zones adjacent to the primary barrier intercepted by small angle scatter.

E (MeV)/scat. Frac.	20 degree	40 degree	90 degree
6x	1.2 (7×10^{-3})	0.7	0.2 (4×10^{-4})
18x	2.1 (5×10^{-3})	0.9	0.3 (2×10^{-4})

    - The neutron dose will be an issue if our machine energy >= 10 MeV. The neutron dose is related to the leakage workload.
    - Thermal neutron also generated from wall as well.







Photoneutrons · 63

1. For operations producing the maximum leakage radiation, the absorbed dose due to neutrons and photons, at any point in a circular plane (patient plane or area) of 2 m radius centered on and perpendicular to the central axis of the beam at the isocenter and outside the maximum beam size, shall not exceed 0.1% of the absorbed dose due to x-rays at the isocenter. Measurements excluding neutrons are averaged over an area up to 100 cm^2 size. Due to the size of typical neutron dosimeters the neutron dose is averaged over 200 cm^2. Figure 4-4 illustrates the location of the patient plane or area for a beam directed downward.

2. Points outside the patient area and at 1 m from the path of the electron beam through the accelerator shall receive an absorbed dose due to photons that is ≤0.1% of the x-ray dose at the isocenter and ≤0.05% due to neutrons.

An interesting situation develops if the neutron absorbed dose is converted to dose equivalent using the recommended quality factor of 10 or 20 for fast neutrons. Making this conversion could result in a neutron leakage level as high as 0.01 or 0.02 Sv neutrons per Gy of x-ray at the isocenter. For a treatment dose of 70 Gy of x-ray, the total body

Figure 4-4. Side view of accelerator and the patient plane. The patient plane is a horizontal plane of 2 m radius centered on the beam central axis.

- Question on Neutron Shielding. Drew the diagram of swinging door and composition and a pocket door with its composition.
- Discuss **gaps** at door. Discuss **vents/ducting at door (HVAC** entering above the door).

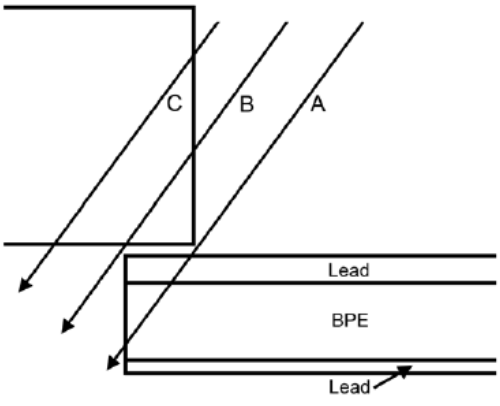


Fig. 2.10. Incomplete shielding at door.

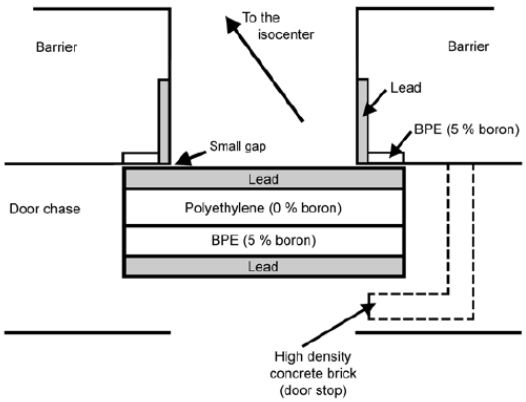


Fig. 2.11. Alternative to large overlap at door.

(NCRP P50) There are two ways to solve this problem:

1. One is to make the door overlap with the wall much larger; Making the door wider adds significantly to the weight and mechanical drive concerns as well as to the opening time and expense so it is a less desirable alternative.

2. the other is to make a shielded doorstop as shown in Figure 2.11. the lead is placed in the linac room side for photon and the BPE is outside for neutron. The lead on the inside reduces the energy of the neutrons by inelastic scattering and this makes the BPE more effective.

(Venting and HVAC) NCRP, p77 – 80

HVAC is the largest ducts.

The duct should be placed

(1). the least amount of concrete is removed by the duct in the direction of the radiation beam (Fig. 4.3)

(2). the direct radiation passing through the duct aperture is minimized.

The ducts may exit the room at an angle to the wall to maintain this short path or they may be staggered through the wall (Fig. 4.2).

(3). Ducts *should* never be placed in the primary barriers, no matter how small.

(4). The duct should be placed as high as possible to reduce the amount of downward scattered radiation, & hence, to minimize the exposure to personnel outside the room.

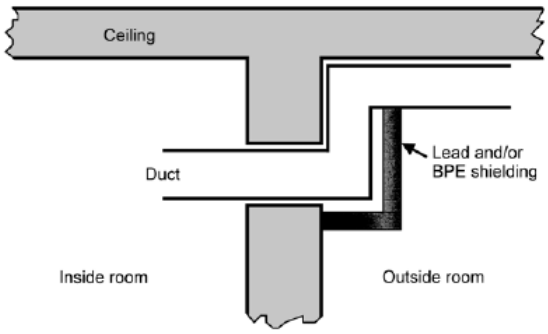


Fig. 4.2. Bend in duct to avoid radiation streaming.

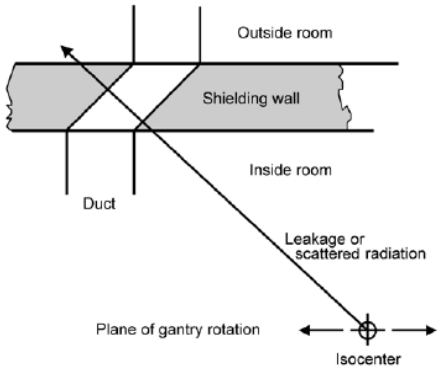


Fig. 4.3. Duct penetration with least amount of concrete removed along path of primary radiation.

(1). *Rooms with Mazes*

For rooms that incorporate a maze, the logical place for the duct penetrations is directly through the shielding above the door, where the photon and neutron fluencies are lowest.

For low-energy machines (<10 MV), no additional shielding around the duct is generally required.
For high-energy machines, the need for additional shielding depends strongly on the length of the maze.

Maze 5.2 m in length, the total dose equivalent at the duct was found to be on the order 0.07 mSv/wk, so no additional shielding was required. For a 2.2 m maze, the total dose equivalent was ~0.75 mSv/wk,

In this case, added shielding is needed and the preferred arrangement is to

(1) bend the ducts immediately after they have exited the maze (Figure 4.2).
(2) or the ducts *should* be wrapped with lead and BPE, as shown in Figure 4.4.

(3) use the concrete shielding as a baffle, as shown in Figure 4.5. Here two parallel, overlapping sections of concrete provide a vertical "mini-maze." For this arrangement to be successful, the degree of overlap *should* be as large as possible.

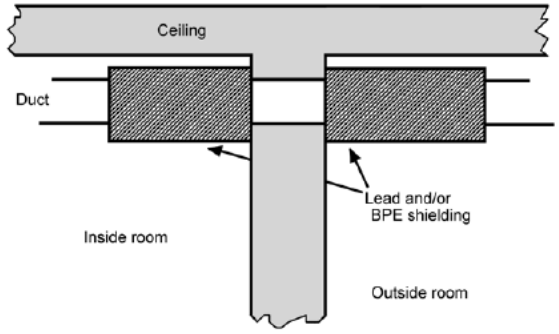


Fig. 4.4. Duct wrapped with shielding material on both sides of barrier

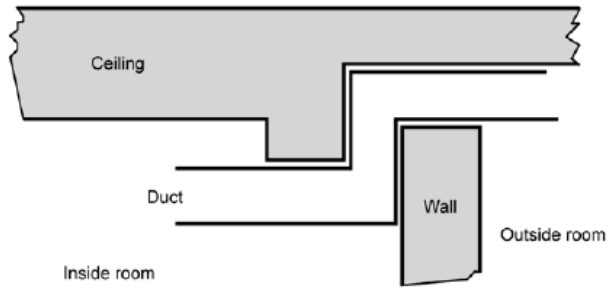


Fig. 4.5. Concrete baffle used to accommodate duct.

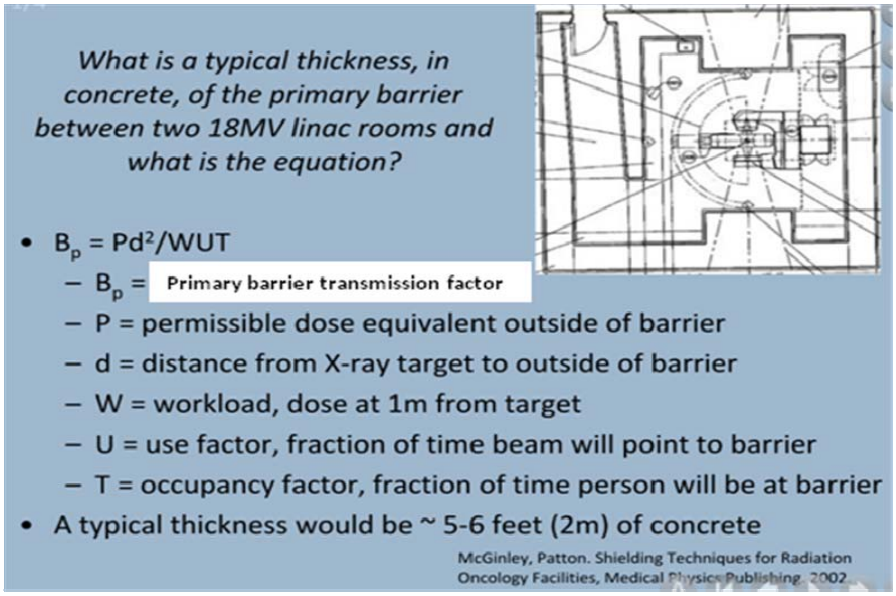
(2). *Rooms without Mazes*

the walls parallel to the gantry rotation plane are best suited for duct penetrations, because the radiation shielding requirements are lower for these walls than for those in the gantry rotation plane.

C1-C (Shielding Design)

- One LINAC room.
  Write all Shielding equations for facility layout shown above, Bp, Bs, & Bl (primary, secondary & leakage). What is the difference between primary and secondary and leakage radiation, etc. Explain each item. Calculate Workload, how do you define Unit factor, Occupancy factor, P. What numbers would you use for each? What permissible doses would you use and why? Where do these numbers come from, what report? (NCRP151)

- (2010-2011)Q4: Generic question on linac shielding. What are the considerations (shielding for primary beam, scatter, & leagake , W U T, energy, barrier thickness)? What are the usual thicknesses of primary/secondary barriers (**200 cm of concrete, 90 cm of concrete for primary & secondary**)? What is the greatest contributor to dose through the secondary barriers (leakage)?



Concrete TVL for 18 MV is about 45 cm, and for MV, lead TVL is 5.7 cm for all the energy.
without lead it's about 200 cm/45 cm = 4.4 TVL. Our place has 106 cm concrete + 10 cm lead (106 /45 + 10/5.7) = 4.2 TVL for primary & 80 cm concentrate as secondary 80/45 = 1.8 TVL.

Primary barrier are designed to attenuate the primary photon beam directed from treatment unit that is directly incident on the primary barrier. The primary barrier is also expected to adequately attenuate the secondary product from the primary photon beam, such as neutron, neutron capture gamma ray, scattering and leakage radiation.

*$B_p = Pd^2/WUT$

In NCRP151, the primary barrier thickness is calculated by $TVL_1 + (n-1)TVL_e$

	Concrete (cm)	Lead (cm)	Earth (cm)
6x	37 (33)	5.7	57
18x	45 (43)	5.7	

Equilibrium tenth-value layer (*TVLe*): The thickness of a specific material that attenuates a specified radiation by a factor of 10, under broad-beam conditions, in that penetration region in which the directional and spectral distributions of the radiation are practically independent of thickness.

Secondary barrier: to protect (1). Scattering radiation from patient and wall (2). Leakage radiation from linac (3). The neutron dose generated from the linac head and neutron capture gamma ray generated from the wall.

Since leakage and scattered radiation are of different energy, in the shielding calculation, we compute these 2 components separately and compared to come out with the final recommended thickness.

Patient scatter:

The barrier transmission needed for radiation scattered by the patient (B_{ps}) is given by Equation 2.7.

$$B_{ps} = \frac{P}{aWT} d_{sca}^2 \; d_{sec}^2 \; \frac{400}{F} \qquad (2.7)$$

In Equation 2.7, the symbols P, W and T are as defined earlier (Section 2.2.1) and:

d_{sca} = distance from the x-ray target to the patient or scattering surface (meters)
d_{sec} = distance from the scattering object to the point protected (meters)
a = scatter fraction or fraction of the primary-beam absorbed dose that scatters from the patient at a particular angle (see Table B.4 in Appendix B)
F = field area at mid-depth of the patient at 1 m (cm^2)

and the value 400 assumes the scatter fractions are normalized to those measured for a 20 cm × 20 cm field size. The distances d_{sca} and d_{sec}, and the Area F are shown in Figure 2.6.

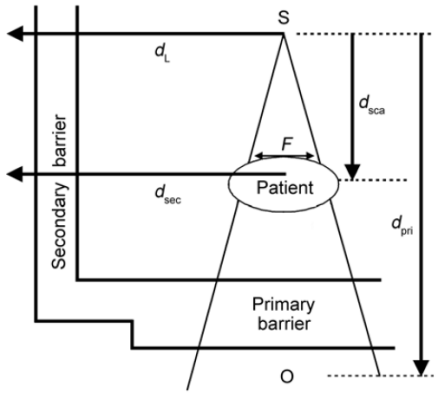


Fig. 2.6. Room layout showing distances associated with patient-scattered (d_{sca}, d_{sec}) and leakage radiations (d_L).

Note: NCRP151 consider 90 degree scattering from pt. and the use factor is 1 no matter where the gantry angle is. Penn calculation used use factor at particular angle and consider small scattering angle < 90 degree at different reference points beyond the barrier.

Leakage radiation:

$$B_L = \frac{Pd_L^2}{10^{-3}WT}$$

The factor 10^{-3} arises from the assumption that leakage radiation from the accelerator head is 0.1 % of the useful beam. The use factor again is taken as 1, and d_L is measured from the iso if it can be assumed that the accelerator GA used are, on average, symmetric.
If this is not the situation, then the distance to the individual barriers *should* be taken from the closest approach of the accelerator head to each barrier and actual use factors *should* be employed in the denominator of Equation 2.8. Table B.7 can be used to find measured *TVL*s for leakage radiation for ordinary concrete. If the clinical practice includes IMRT, then the workload for leakage radiation (W_L) *shall* be modified.

Secondary shielding rule:
If the thickness of the required barrier is about the same for each secondary component, **1 *HVL*** is added to the larger of the two barrier thicknesses.

If the two thicknesses differ by a *TVL* or more, the larger barrier thickness is used. This is often referred to as the **2-source rule**.

In most high-energy accelerator facilities, a secondary barrier that is adequately designed for the leakage radiation component will be more than adequate for the scattered radiation with the possible exception of zones adjacent to the primary barrier intercepted by small angle scatter.

(NCRP151 ch1): **W**: Workload is the time integral of the absorbed dose rate determined at the d_{max}, 1 m from source. The common time period for W is a "week". The value for W is specified as the absorbed dose from photons delivered to the iso in a week. The workload is usually estimated from the average #

of patient treated per wk and the dose delivered per patient. The workload also includes the dose delivered during QA, calibration or other physics measurements. The typical workload for conventional machine (no IMRT) is **450 Gy/wk** NCRP 151 example value (Penn is 360 – 600 Gy/wk) . Our IMRT factor is **5** estimated by MU/dose for each machine. If 40 pts/day x 5 days x 2.5 Gy/fx = 500 Gy. If 60% of patient go to IMRT, it will be 300 x 5 = 1500, so total leakage workload will be 1500 + 200 = 1700 Gy

U (Use factor): the fraction of a primary beam workload that is directed toward a given primary barrier.

TABLE 3.1—*High-energy (dual x-ray mode) use-factor distribution at 90 and 45 degree gantry angle intervals.*[a]

Angle Interval Center	*U* (%)
90 degree interval	
0 degree (down)	31.0
90 and 270 degrees	21.3 (each)
180 degrees (up)	26.3
45 degree interval	
0 degree (down)	25.6
45 and 315 degrees	5.8 (each)
90 and 270 degrees	15.9 (each)
135 and 225 degrees	4.0 (each)
180 degrees (up)	23

[a]Rodgers, J.E. (2001). Personal communication (Georgetown University, Washington). Unpublished reanalysis of the survey data in Kleck and Elsalim (1994).

We use (0.4 at 0 & 180 degree) and (0.25 at 90 and 270 degree) which is a conservative choice, because the maximum use factor among the 4 linacs is 0.38 at 0 degree.

T (Occupancy factor): Average fraction of time that the maximally exposed individual is present while the beam is on. The T for an area is not the fraction of time that it is occupied by any persons, but rather it is the fraction of the time it is occupied by the single person who spends the most time there.

TABLE B.1—*Suggested occupancy factors*[a] *(for use as a guide in planning shielding when other sources of occupancy data are not available).*

Location	Occupancy Factor (T)
Full occupancy areas (areas occupied full-time by an individual), *e.g.*, administrative or clerical offices; treatment planning areas, treatment control rooms, nurse stations, receptionist areas, attended waiting rooms, occupied space in nearby building	1
Adjacent treatment room, patient examination room adjacent to shielded vault	1/2
Corridors, employee lounges, staff rest rooms	1/5
Treatment vault doors[b]	1/8
Public toilets, unattended vending rooms, storage areas, outdoor areas with seating, unattended waiting rooms, patient holding areas, attics, janitors' closets	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), stairways, unattended elevators	1/40

[a]When using a low occupancy factor for a room immediately adjacent to a therapy treatment vault, care *shall* be taken to also consider the areas further removed from the treatment room. The adjacent room may have a significantly higher occupancy factor and may therefore be more important in shielding design despite the larger distances involved.

[b]The occupancy factor for the area just outside a treatment vault door can often be assumed to be lower than the occupancy factor for the work space from which it opens.

P (Shielding design goal): the maximum permissible "dose equivalent" at the reference point beyond a protective barrier, usually in a weekly format. During shielding design, we need to use this P value to evaluate if our shielding is sufficient enough to meet the NCRP recommendations.

Annual Maximum Permissible Dose Equivalents

A. Occupational exposures	
1. Effective dose limits	
a) Annual	**50 mSv**
b) Cumulative	**10 mSv x age**
2. Equivalent dose annual limits for tissues and organs	
a) lens of eye	**150 mSv**
b) skin, hands and feet	**500 mSv**
B. Public exposures (annual)	
1. Continuous or frequent	**1 mSv**
2. Infrequent	**5 mSv**
3. For tissues and organs	
a) lens of eye	**15 mSv**
b) skin, hands and feet	**50 mSv**
C. Embryo-fetus (monthly)	**0.5 mSv**

NCRP116

Controlled area: The employees who work in controlled areas have significant potential for exposure to radiation in the course of their assignments, or are directly responsible for or involved with the use and control of radiation. Generally, these employees have training in radiation management and are subject to routine personal monitoring.

NCRP recommends an annual limit for ***E (effective dose)*****(not TEDE)** for these individuals of 50 mSv/y with the cumulative *E* not to exceed the product of 10 mSv and the worker's age in years (exclusive of medical and natural background radiation).
Another consideration is that a pregnant radiation worker *should not* be exposed to levels that result in greater than the monthly equivalent-dose (H_T) limit of 0.5 mSv to the worker's embryo or fetus (NCRP, 1993).

To achieve both recommendations, this Report recommends 50/10 = 5 mSv/y, and a weekly shielding design goal (*P*) of 0.1 mSv dose equivalent (*H*) for controlled areas.

The *P* value adopted in this Report would allow pregnant radiation workers continued access to their work areas.
Recommendation for Controlled Areas:
Shielding design goal (*P*) (in dose equivalent): 0.1 mSv/week or **(5 mSv/y)**

Uncontrolled areas are those occupied by individuals such as patients, visitors to the facility, and employees who do not work routinely with or around radiation sources. Areas adjacent to, but not parts of, the radiotherapy facility are also uncontrolled areas.

Recommendation for Uncontrolled Areas:
Shielding design goal (*P*) (in dose equivalent): 0.02 mSv/week, (1 mSv/y)

The instantaneous dose rate limit is 0.02 mSv/hr in any unrestricted area
10 CFR20.1301
(2) The dose in any unrestricted area from external sources, exclusive of the dose contributions from patients administered radioactive material and released in accordance with § 35.75, does not exceed 0.002 rem (0.02 millisievert) in any one hour.

Note:
From health physicist: I assume you are not looking at the back side of the safe which, because the area outside the hot lab often is an unrestricted area, often does need to meet the 0.02 mSv/hr limit (and much lower if the area is constantly occupied).

I do not think 0.02 mSv/hr is becoming a general dose limit. I suspect it is just that it happens to be in the right ball park. Within some restricted areas you will often have an absolute design limit of 0.025 mSv/hr for reasons that will be obvious shortly. The only regulatory limits, though, is 0.05 mSv/hr to avoid posting the area as a "Radiation Area." Now if you remember that all workers work exactly 40 hours per week and take exactly two weeks off per year in vacation and sick time (What? You do not think that is true?) you get a work year of 2000 hours. Since the annual dose limit for workers with monitoring is 50 mSv, that gets you to 0.025 mSv/hr if the workers' function puts them constantly in the radiation field and they receives no other dose (for example, workers welding sealed sources in a hot cell all day long). In a more practical example, say you are designing a safe and you have a dose goal for the contribution of the safe to the total dose of 5 mSv/year. If the hot lab workers are assumed to about one eighth of their time next to the safe, that also gets you to 0.02 mrem/hr dose rate. I will assert that if you set any reasonable combination of dose goal and occupancy you will come up with a does rate that is within a factor of ten to either side of 0.02 mSv/hr in order to meet the dose goal.

For all the shielding design, we use 0.1 mSv/wk & 0.02 mSv/wk!!! But hourly rate is strict for unrestricted area, and the hourly rate can also be used as a ball-park limit for controlled area as well.
Normally, if we satify the 0.1 mSv/wk design goal, the hourly goal is automatically satisfied, since it's 5 mSv/2000 = 0.0025 mSv/hr compared to 50 mSv/2000 = 0.025 mSv/hr ~ 0.02 mSv/hr.

- Picture of linac room. How do you shield? Where do you find guidelines?
  NCRP 151

- Shielding calc with maze. Dose at the maze door and talk about neutron shielding. and the different occupancy factors based on the definition of the rooms

- Layout of Linac Room shown below: Calculate workload for shielding this facility? What effect does IMRT have on Workload?
  (NCRP151 p15): The MU of IMRT can be 3 – 10 times higher than conventional plan. Therefore, the leakage dose impact on the secondary barrier can be as much as 10 times higher than the conventional treatment.

  - Why does the primary barrier extend by 30cm on either side?
    To account for the high energy scatter with small scattering angle.

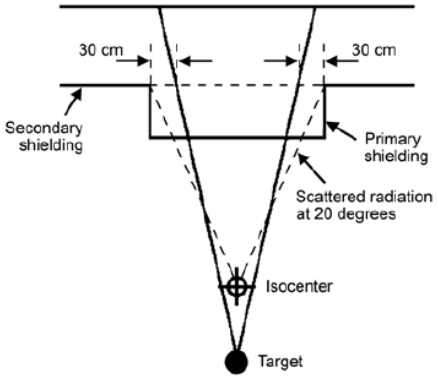
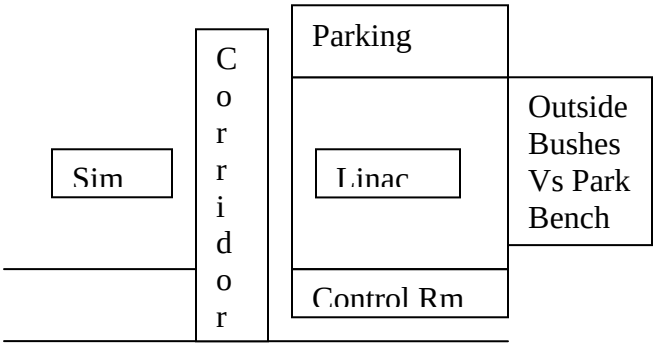


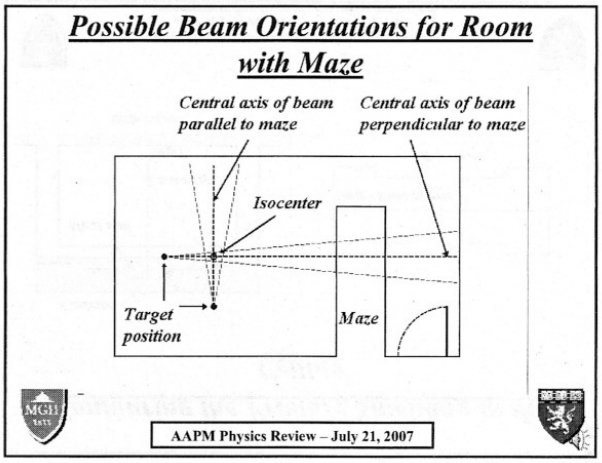
Fig. 2.4a. Width of primary barrier protruding into the room.



- *The vault was originally constructed in the early 1980's. With the new linac, the facility plans to heavily implement IMRT. How does that effect the primary shielding?*
  - The multiple small fields associated with IMRT treatments result in significantly more MUs, 2-10 times more depending upon method and equipment.
  - Due to the small field sizes and often greater number of gantry angles employed, effect upon the primary barriers is often not significant.
- *How does it effect the secondary shielding barriers?*
  - Secondary barrier thickness is primarily associated with head leakage which will increase proportionally with the number of MUs.
  - Neutron and capture gamma radiation at the maze door will also be significantly increased although a reduction in the use of high energy beams with the implementation of IMRT may partially offset the effect.

Upgrade the machine to IMRT, the secondary barrier is a concern!!!

- Image of a vault with a secretary on the room to the left, and in the rooms to the right, a hallway below, and nothing on the upper wall. Which way should the machine be installed and why**,** Discuss use factor, occupancy factor, dose limits.
  (Summer school peter biggs, p19 & 20)



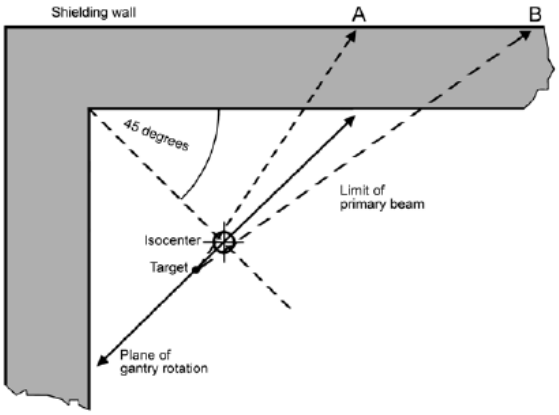


Fig. 2.4d. Sketch showing angulation of the plane of gantry rotation at 45 degrees to the walls. Note the asymmetry of the extremities of the primary beam on the outside of the wall (A, B) compared with the central axis of the beam.

If the gantry rotation plan is parallel, we only need to consider the scattering and leakage dose to the maze wall. If the rotation plan is orthogonal to the maze wall, we will need to consider the primary, so the calculation will be more complicated and requires the thicker door at the end of the maze.

Secretary office: T = 1, dose limit is 0.02 mSv/wk (uncontrolled area), general public 1 mSv/yr
Hallway: T = 1/5, dose limit is 0.02 mSv/wk (uncontrolled area), general public 1 mSv/yr
T = 1 everywhere when we calculate the dose limit/hr

TABLE B.1—*Suggested occupancy factors*[a] *(for use as a guide in planning shielding when other sources of occupancy data are not available).*

Location	Occupancy Factor (T)
Full occupancy areas (areas occupied full-time by an individual), *e.g.*, administrative or clerical offices; treatment planning areas, treatment control rooms, nurse stations, receptionist areas, attended waiting rooms, occupied space in nearby building	1
Adjacent treatment room, patient examination room adjacent to shielded vault	1/2
Corridors, employee lounges, staff rest rooms	1/5
Treatment vault doors[b]	1/8
Public toilets, unattended vending rooms, storage areas, outdoor areas with seating, unattended waiting rooms, patient holding areas, attics, janitors' closets	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas (unattended), stairways, unattended elevators	1/40

[a]When using a low occupancy factor for a room immediately adjacent to a therapy treatment vault, care *shall* be taken to also consider the areas further removed from the treatment room. The adjacent room may have a significantly higher occupancy factor and may therefore be more important in shielding design despite the larger distances involved.

[b]The occupancy factor for the area just outside a treatment vault door can often be assumed to be lower than the occupancy factor for the work space from which it opens.

- Picture of a treatment room with secretary offices on either side, a maze hallways on the other sides and a control area. What the limits are for those areas for occupational workers and the public. Where would you put the linac in the room?
  Secretary office: T = 1, dose limit is 0.02 mSv/wk (uncontrolled area), general public 1 mSv/yr
  Hallway: T = 1/5, dose limit is 0.02 mSv/wk (uncontrolled area), general public 1 mSv/yr
  Console: T = 1, dose limit is 1 mSv/wk (controlled area), occupational worker 50 mSv/yr
  T = 1 everywhere when we calculate the dose limit/hr

- **(2008)** Describe of characteristics of broad beam and narrow beam? How do they affect our shielding design (i.e. HVL values)? Which should be used for shielding

How do you measure attenuation or TVL in material?

- Measure 1' away from the distal side of the barrier
- This is also the same rule as in shielding survey: When you measure dose at the shielding wall, e.g., you measure it at 30 cm (one foot) away from it.
- Typical concrete TVL for 6X ≈ 35 cm

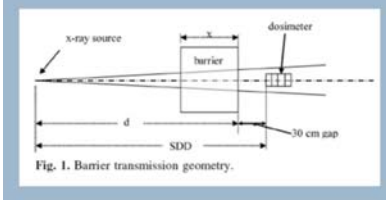


Fig. 1. Barrier transmission geometry.

From JE Rodgers, Analysis of Tenth-Value-Layers for Common Shielding Materials, Health Physics, 92(4), 379 (2007)

What is the difference between narrow and broad beams?

- Ideal narrow beam geometry = NO scattered or secondary particles strike the detector
- Broad beam geometry = Anything other than the narrow beam geometry! You get scattered and secondary particles in detector.

- Detector gets more particles in broad beam → measured attenuation coefficient always: μ(narrow beam) > μ(broad beam)
- In other words: TVL(narrow beam) < TVL(broad beam). This means if you plot TVL as a function of field size, the curve always increases with field size.
- Broad beam is more realistic assumption and also more conservative (higher TVL) → use broad beam TVL for shielding calculation.

(2008) Shown a plot of LINAC room design with surrounding area, office, waiting area…What is the permissible dose for each area and how do you calculate the shielding required for each area?
Read NCRP 151 ex7

(2008) Read NCRP 151 and practice doing shielding calculations for linacs, HDR vaults, diagnostic room. Know the different equations and typical values and the impact on these values of specialized techniques. Know how to plan a cancer center so as to limit costs. Know different solutions to limit space requirements.

(NCRP151 P16) For example, a corridor can be used to separate offices and support rooms from the treatment rooms rather than leaving these rooms adjacent to one another. This strategy will often reduce the amount of required shielding to protect the office occupants. The corridor is a low occupancy area and the occupied spaces (offices and lounges) are at least 2.5 m further from the source of radiation, though they may still be the determining factor for the barrier thickness. The same strategy applies for spaces above and below; locating a treatment room below a corridor or mechanical room rather than an occupied office is an effective strategy for reducing shielding requirements.

- If we use lead and concrete as the shielding material for the primary barrier, we can tapper the lead so we need less lead for the scattering part to reduce the cost.

- We can use laminated barrier lead + concrete to reduce the space for concrete only
- Using direct door shielding instead of maze

Wut else?

- Shown a Linac room with maze and isocenter location. Minimal dimensions required for 6x machine? For dual energy machine? How to put machine, console, AC duct, physics duct, HV cable? Shielding against what sources? How? Typical thickness?
  (AAPM Summer school Peter biggs) normal treatment room is 22 x 20 ft (6.7 x 6.1 m^2) and minimum **3 m** height to accommodate the machine & the entire duct work and conduits, overhead laser necessary for the room.

Varian 600 C/D (4 & **6 MV**) minimum room size (L x W x h) = **6.7** x 6.1 x 3.2 m (22 x 20 x 10.5 ft).
Treatment head (L X W X h) **2.7** x 1.2 x 2.7 m

Varian Cinic IX (6 - **23 MV**) minimum room size (L x W x h) = **7.8** x 6.1 x 3.1 m (25.6 x 20 x 10 ft)
Treatment head (L X W X h) **3.7** x 1.2 x 2.6 m

The difference is really the length of the room which is coming from the waveguide length difference of high and low energy machine.

our PCAM room is 23 x 25 ft (7.6 x 7 m^2) and 10ft (3 m) for 15 and 6x linac
so for dual energy room (6 – 23 MV) size is about **8 x 6 x 3 m**

"The Modern Technology in Radiation Oncology" book:

"The length of the accelerating waveguide depends on the final electron kinetic energy and ranges from **~30cm at 4MeV to ~150 cm at 25 MeV**.

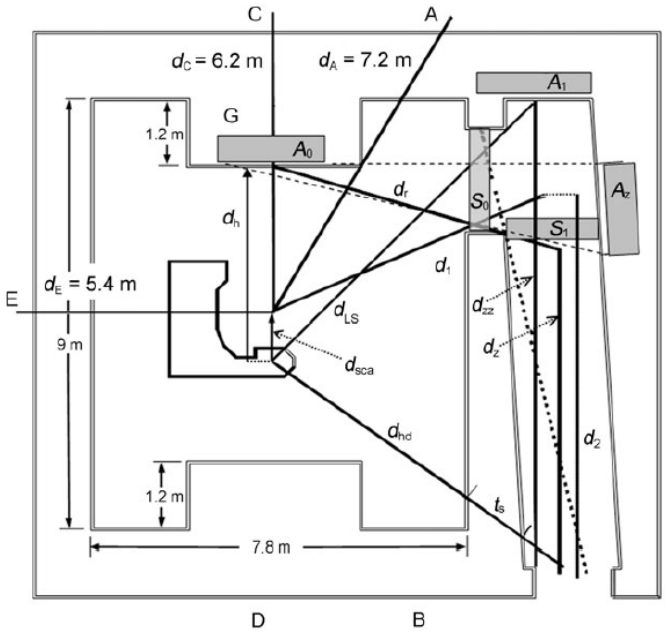


Fig. 7.1. Example for a dual-energy linear accelerator room with maze barrier.

- (2008) Diagram showing the lay out of an 18 MV Linac with maze wall
  - Follow Up:
    - Linac primary beam orientation facing the maze? Which direction would you have the primary beam facing (Not suggest to face the maze)
    - Talk about Neutron shielding
    - Energy of the capture gamma rays at the door. 0.5 MeV
    - Where will you have the air ducts placed in the room? - Maze area (Door)
    - How much margin you give for the patient scatter at the primary beam thickness?-A foot (NCRP151)

As a general rule, the barrier width for the primary beam is determined by calculating the size of the diagonal of the largest beam and adding at least **30 cm** to each side

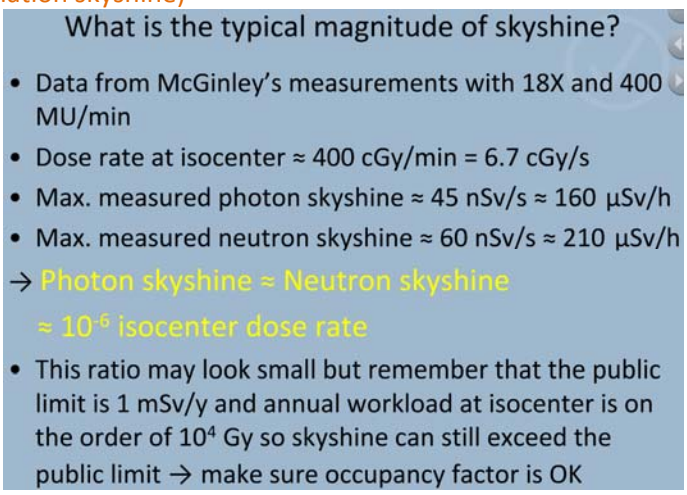
- (2010-2011) If Given picture of linac vault (with maze)designed for 6MV accelerator. What do you need to consider and what are the potential problems if you want to upgrade it to a High Energy accelerator? Discuss maze design, door design, primary shielding, neutron production, different shielding materials, etc.
  Due to the energy increase: 1. Check if primary thickness still enough. 2. Leakage energy is also increase, and I will also check the secondary barrier. 3. Neutron will be a consideration.

  Since the average energy of neutron capture gamma rays from **concrete** **is 3.6 MeV** (Tochilin and LaRiviere, 1979), a maze and door that provide sufficient shielding for the neutron capture gamma rays will also be adequate for the scattered photons.
  For mazes in high-energy accelerator rooms, the photon field is dominated by neutron capture gamma rays and the scattered photon component can be ignored.

  In fact, the photon dose equivalent outside the maze door changes only slightly when the collimator of the accelerator is adjusted from maximum size to the closed position or when the scattering phantom is removed from the beam.

  Therefore door shielding in high-energy rooms is usually dominated by the neutron capture gamma ray and photoneutron requirements.

- (2010-2011) Discuss consideration in designing a vault. What is "skyshine" What considerations would be taken in building renovations (room additions) around a vault?
  (use wepassed radiation skyshine)



- (2010-2011) Can you use an LDR room for HDR? (No, the workload for HDR can be much higher compared to LDR even the LDR is designed for Cs137 having higher energy than Ir-192) Can you use the Sim room for HDR? (No, the energy for sim is about 120 keV which is a lot lower than Ir-192 400 keV, and the dose rate from HDR is much higher compared to simulator), Limits for radiation exposure

- (2010-2011) How is ALARA implemented for Brachytherapy? What are the concerns for permanent implants and low dose rate patients?

  (LDR-137)
  1. Restrict visitor and nurse time with pt. (time)

2. Put lead shielding (shielding)
3. Draw a 2 mR/h line on the floor (distance)

Prostate pt:

1. No pregnant wife and kid close to pt. in a month or 2 (keep 3 feet away)
2. Avoid public transpiration
3. Sleeping arrangement

(Clam shell)

- **(2010 - 2011)** Testicle clam shell for radiation protection. Why would you use it? Patient instruction after the treatment.
- Showing a pic of a ball-shaped shielding device in the man's testis area. Discuss how shielding works, dose fall-off outside the tx field, what information need to estimate dose outside field
  - To protect the testicle and prevent radiation inducing sterility
  - Clam shell is about 1.3 cm thick in lead
  - We do the in vivo dosimetry using, diode, OSLD or Mosfet inside the cell (TG36):

In summary, the dose outside a beam is a function of

1. Distance from the beam edge
2. Field size
3. Energy
4. Depth within the patient.

Out-of-beam dose

< 10 cm of the beam edge

Scatter off the collimator & patient scatter dominate.

10 ~ 20 cm

Patient scatter dominate

At about 30 cm,

Pt. scatter & head leakage are approximately equal and dominate,

> 30 cm, head leakage predominates.

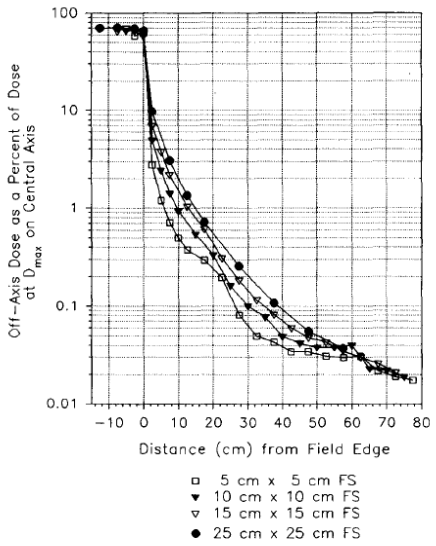
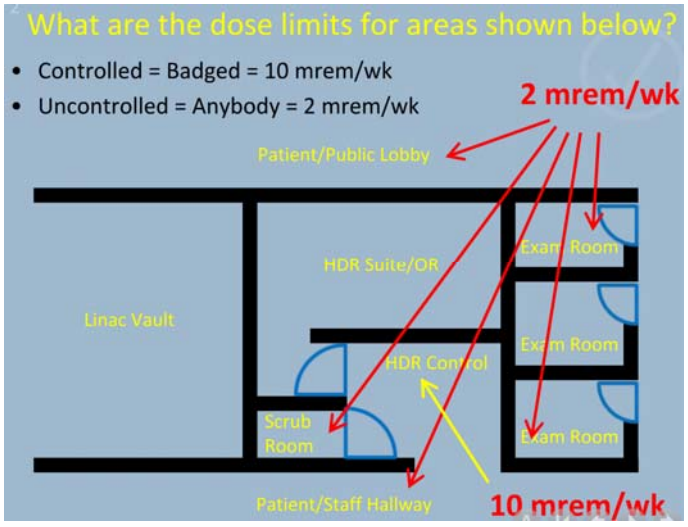


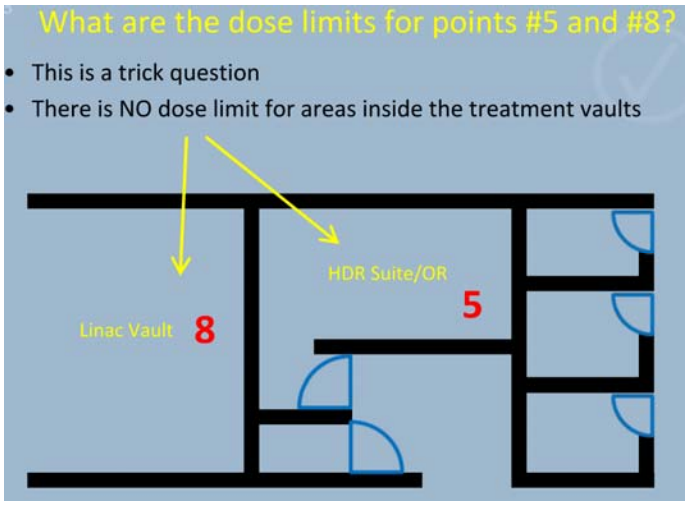
FIG. 21. Total absorbed dose in phantom from 6-MV photons for field sizes of 5×5, 10×10, 15×15, and 25×25 cm^2 at 10-cm depth, normalized to 100% on the central axis at depth of maximum dose.

10X10 field 10 cm deep (TG36, data	2 cm	5 cm	10-20 cm
6x	5 – 7 %	3 %	2- 0.6 %
15x	5 %	2 %	0.4 – 0.1 %

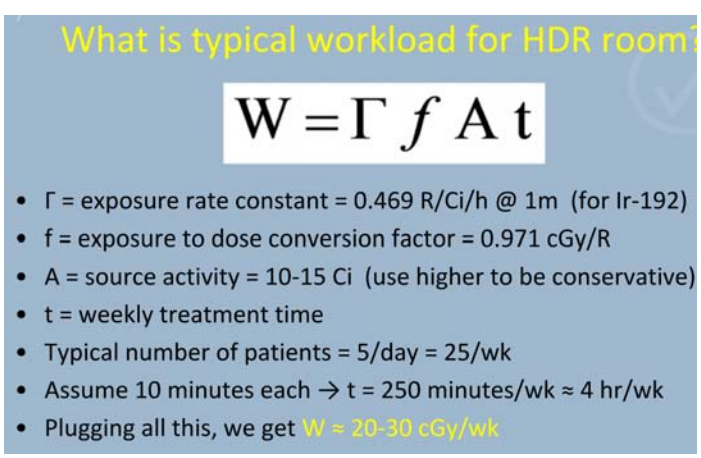
- **(HDR Shielding)** Picture of an HDR room with nearby rooms labeled as control room, janitorial closet, nearby exam room, corridor, physician's office and modulator room. How do you do shielding for HDR, write equation.

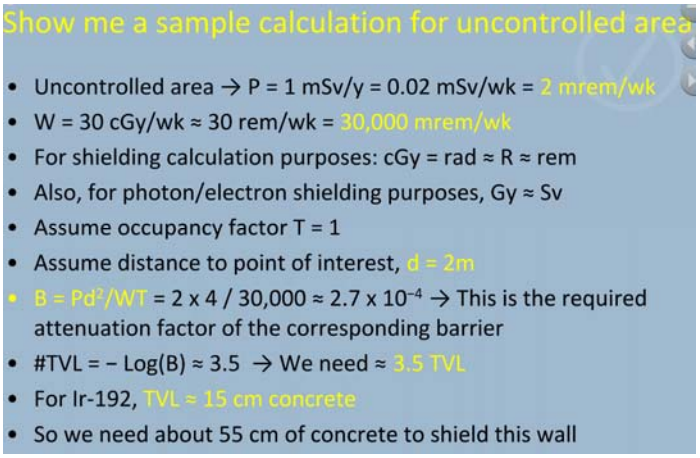
o What's defined as controlled and non-controlled areas? What rooms are controlled and what rooms are not? If physicist is the RSO for the department and he wears a badge – would you use controlled area limit for his office? (YES) How about a modulator room?



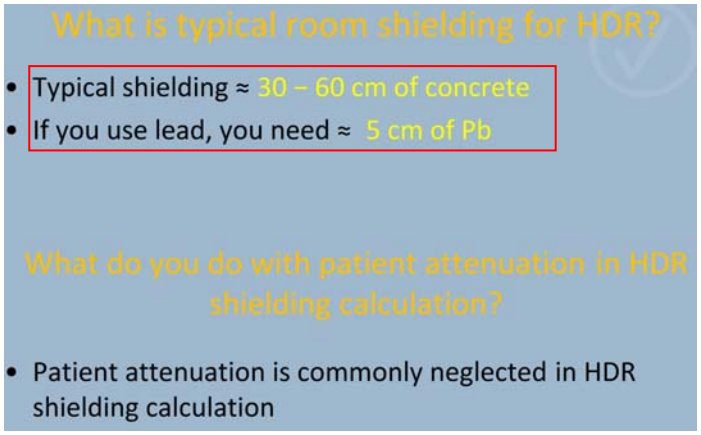


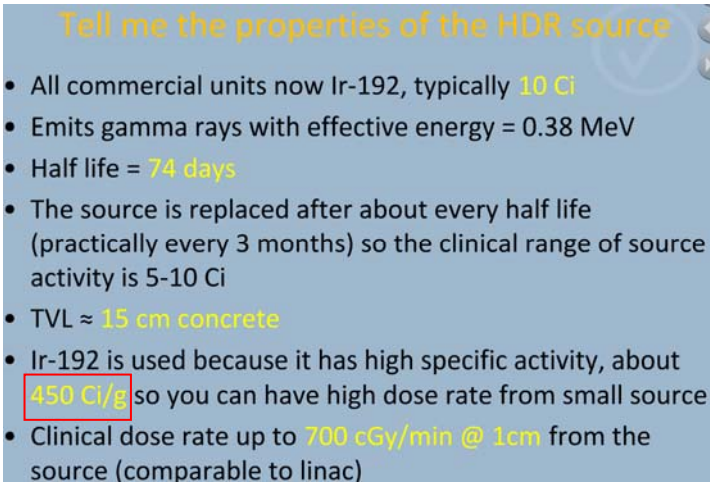
- Write down how you calculate workload for HDR





- What is HVL/TVL thicknesses for Iridium (lead and concrete)





- What are the corresponding occupational and non-occupational limits.

What are the recommended radiation dose limits?

- NCRP 116 (1993) Limitations of exposure to ionizing radiation
- Radiation workers = 50 mSv/y and cumulative < 10 mSv x age
- Public = 1 mSv/y and should not exceed 0.02 mSv in ANY one hour

What are the recommended shielding goals?

- NCRP 151 (2005) Structural shielding design for MV X-ray
- Controlled areas = 5 mSv/y = 0.1 mSv/wk = 10 mrem/wk
- Uncontrolled areas = 1 mSv/y = 0.02 mSv/wk = 2 mrem/wk
- Note that the shielding goal for controlled areas is much lower than the dose limit for radiation workers. This is to limit the dose to pregnant worker to 0.5 mSv/month

How is HDR room different from a linac vault?

- Technically, an HDR room is a surgery room therefore it needs to follow the regulations for a surgery facility (maintaining sterile conditions)
- Often the HDR room is also used as simulator room or operating room for intra-op procedures. This affects the design of the room

What do you do with the door? Anything special?

- The door needs to have the same radiation protection as the wall it is replacing
- Last-man-out button: Install this INSIDE the treatment room, next to the door. The last person verifies that no one in the treatment room except the patient. After the button is pressed, the operator has a predefined time to leave the room and close the door.

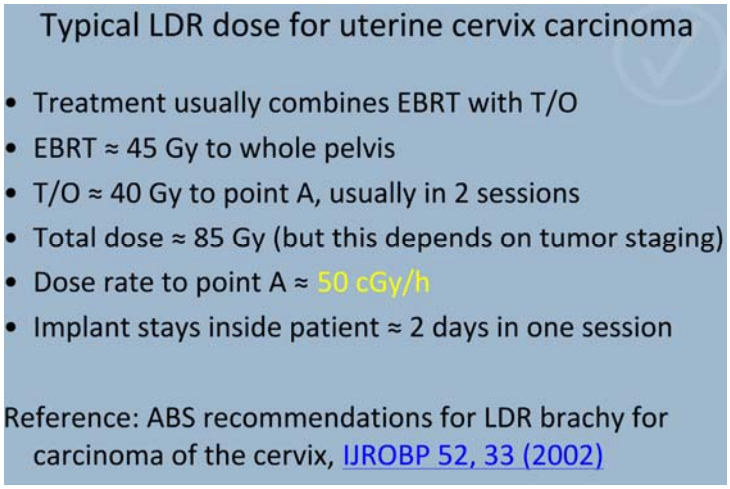
- (2010-2011) Discuss the HDR Unit. What are your concerns to implement it in your facility? All concerns (Shielding, personnel, license).
    - **Licensee application** (Regulations)
    - **Radiation safety/Shielding**: Shielding design, emergency plan, film badgering, survey equipment, team member safety training
    - Facility requirements: door interlock sys, AV, HDR chain locked to the unmovable structure, independent dosimetry system.
    - **Staff requirements/training**
    - Clinical procedure and equipment procedure establishment
    - QA system
    - **Licensed activity should be able to keep two sources**
    - Commission system
- (2010-2011) Shown a HDR vault. Many questions on this. Asked me to calculate taking some random numbers for workload. I wrote down the equation for workload and gave a on the fly calculation to arrive at some 2 ft of concrete for the HDR shielding

- (2010-2011) Picture of HDR vault and surrounding rooms. What are shielding considerations? How do you calculate workload? He wanted to hear that you should **add 1 TVL to your shielding for ALARA**. He also asked what would be most likely to determine the shielding for low workloads, the dose per week calc, or the dose in any one hour calc ? He wanted to hear dose in any one hour.
  If we compare radiation worker

- **(LDR Shielding)** Picture of a patient room (similar to shown below) What brachy treatments require extended stay? Mention LDR Ir and Cs but also I-125 (eye-plaques)…

  (1). Cs 137 In a LDR sessions, Rx: 20 – 30 Gy at point A over 72 hrs (3days) x 2 fxs separated by 2 wks. (50 – 80 cGy/h). For 1 fx, pt stay in the hospital for 3 days. (DABR 196)

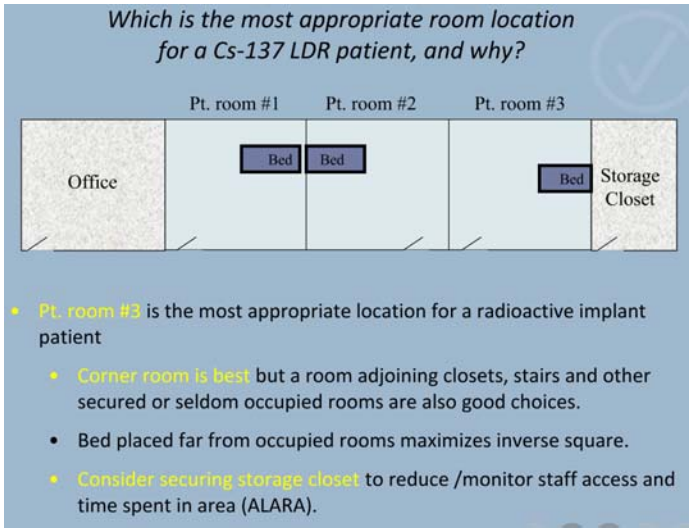
  T&O LDR procedure Cs137 (662keV, 30 yr half life), 15 - 20 Gy x 2 fx, dose rate at point A is around 50 cGy/hr, so pt. stay in hospital **2 days** (DABR p158 + Handbook p509) for 1 fx, and the 2nd fx is about 1 - 2 wks after.

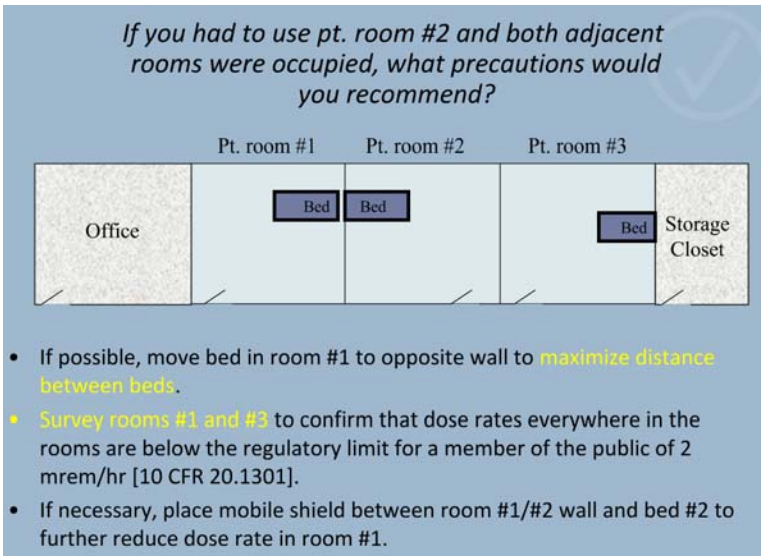


So LDR CS-137 for cervical cancer, pt stays in hospital for 2- 3 days.

(2). LDR Ir-192 ribbon for sarcoma, pt staying in hospital for 2 days.
(3). LDR-Ir 192 for H&N, pt stayed in hospital for 3 days
(4). From handbook of evidence-based radiation oncology (p83), it mentioned that Eye-plaque pt. with I125 is also discharged in 24 hrs, and come back for the plaque remove in4 – 7 days. (At MSK, eye-plaque patient was prescribed to 85Gy to tumor depth +1mm. the I125 seed we used is about 7 - 8 mCi apparent activity, and plaque will stay in for about 3 days.)

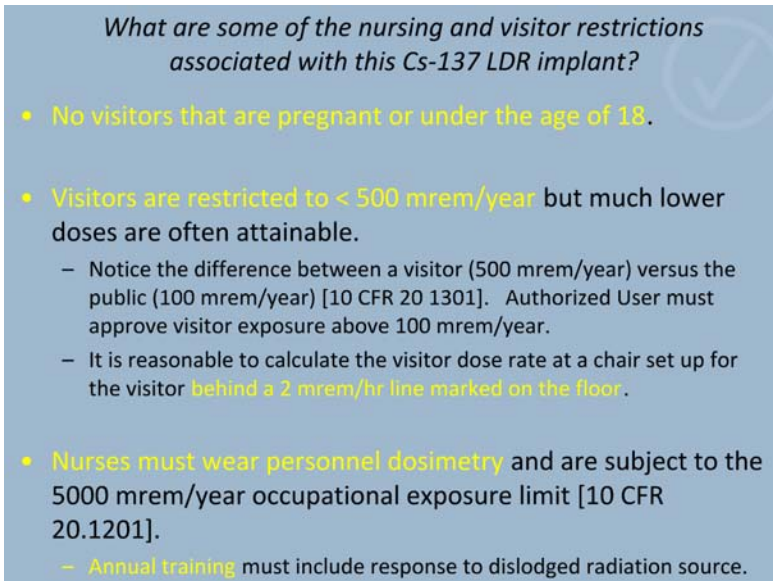
- Which room would you put a brachy patient? What are your concerns and how would you design a patient room? how do you apply ALARA principles to a brachy treatment room? What are the maximum hourly dose rates





2 mrem/hr = 0.02 mSv/hr

- What is dose limit to member of the public? (1 mSv/yr) & (0.02mSv/h)acceptable in adjacent rooms? How about corridor? The same
- LDR: How do you determine time limits for visitors and nursing staff (using dose limit 0.02 mSv/h for general public, and 1 mSv/wk for nurse)? What are dose limits for public and workers? Would you consider a nurse a radiation worker in this case and why (yes, 50 mSv/y, because the radiation from the pt.)
- Rooms with mR/hr readings. LDR room/instructions, nurse instructions. Badging, ALARA, limits at different rooms, basic assumptions
- (2010-2011) For temporary implant, how long can you let the nurse make the bed (15 mins/day), what is the dose rate in the next room (need to < 2 mR/h), what shielding should be used (mobile lead)

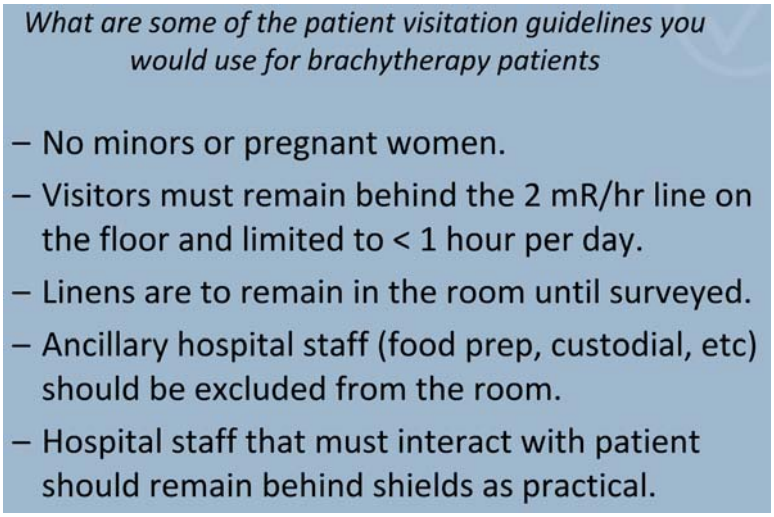


(General rule not just for Cs-137)

10CFR 20 1301:

A licensee may permit visitors to an individual who cannot be released, under § 35.75, to receive a radiation dose > 1 mSv if (1) The radiation dose received does not exceed 5 mSv

500 mrem/yr = **5 mSv/yr** is increased from 1 mSv/yr
100 mrem/yr = 1 mSv/yr as public
5000 mrem/yr = 50 mSv/yr ~ as radiation worker



- **The implant pt. can not share the room with non-implement pt.**
- **Nurse should know when there is an emergency, whom they should call, and they are not supposed to handle the seed.**

dislodged seeds (from friend):
Always call the people on the emergency list first and apply ALARA principle. Nurses are not supposed to handle sources. There is a survey meter and lead pig available in the ward. When any of the people on the emergency list makes to the room, he/she will remove all applicators off the patient, put them in the pig, take the patient out of the room, and survey the patient.

Nurse Instructions

Visitor Restrictions:
- No visitors under 18 or pregnant.
- __0__ minutes each day maximum for each visitor.
- Visitors must stay behind line on floor at all times.

Nursing Restrictions:
- Patient is restricted to room.
- Patient is restricted to bed.
- No nurses who are pregnant may render care.
- __15__ minutes each day per nurse in room. (calculation based in following 1 mSv/wk radiation worker dose limit, nurse working 5 days a wk, and directly contact with pt.)

Patient Care:
- Wear your radiation monitor when caring for the patient. Leave at nursing station at the end of your shift. You may use the same monitor on your next shift. Do not share. Call RSO for additional monitors if needed.
- If a source appears dislodged, call the attending physician and the RSO immediately.
- Omit bed bath.
- No perineal care. Pad may be changed as necessary.
- Save surgical dressings for disposal by attending physician or RSO.
- See special oral hygiene care instructions.
- _____

In case of emergency, or if you have a question, call:

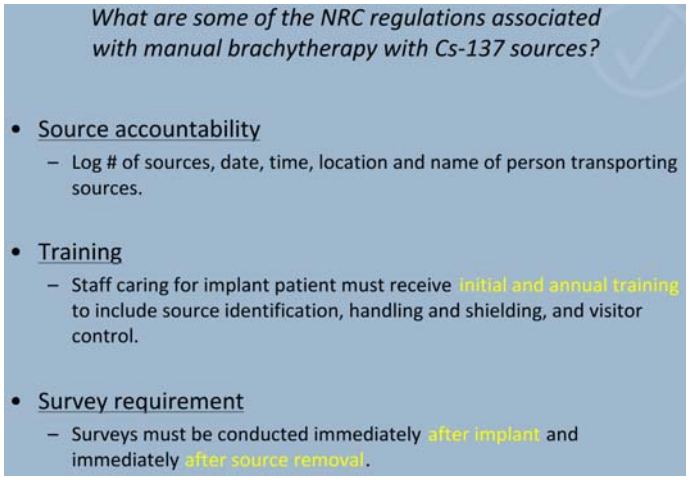
RSO: ****	Work: **	Home/Cell _____	Pager: _____
Resident: ****	Work: ***	Home/Cell	Pager:
Physicist: ****	Work: ***	Home/Cell:	Pager: _____
Health Physicist: ***	Work: ***	Home/Cell: Pager	

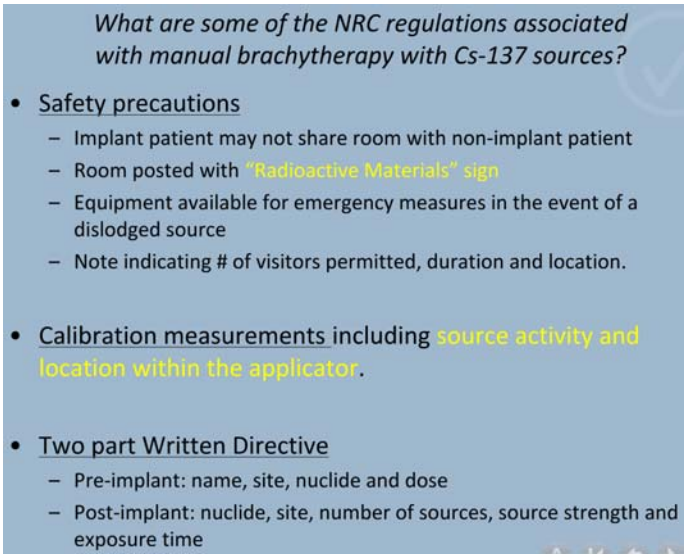
- (2010-2011) Discuss basic LDR. Typical loading (3 source in tandem 15 10 10, ovid 15 mg-Ra-eq for each), source (Cs-137), patient bed dose (~40 mR/h 1 m from pt. midline), what areas need to be surveyed

(Bed, and surrounding area?)? What devices need to be left in pt LDR room (emergency container & the survey meter)? What information should be in patient's chart (prescription dose, survey information, source activity, treatment time)?

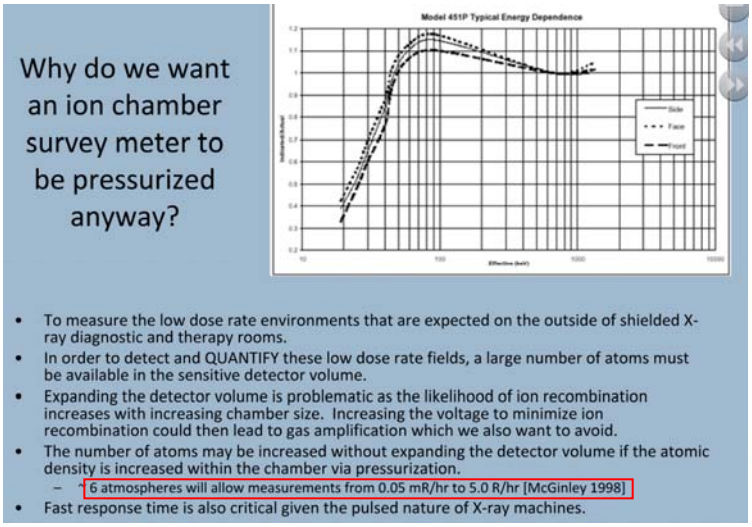
(LDR room, TG56)

1. A **"CAUTION: RADIATION AREA"** sign shall be posted on the door to the patient's room as well as a description of the radioactive material (number of ribbons, seeds, tubes, etc.) and strength, and the means to contact the RSO and physician in an emergency.
2. Emergency container & survey meter is in place
3. 2 mR/h line and portable lead shield





- How do you measure dose in adjacent rooms (assuming it's for Cs137)?
  We can use the ionization chamber. Preferably, the pressurized ionization chamber is a better choice for low energy and low dose situation.



Model 451P & 451P-DE-SI Ion Chamber Survey Meter

1.4 Specifications

Radiation Detected	Beta above 1 MeV & gamma above 25 KeV
Operating Ranges	0 to 500 µR/hr (0 to 5 µSv/h), 0 to 5 mR/h (0 to 50 µSv/h) 0 to 50 mR/h (0 to 500 µSv/h), 0 to 500 mR/h (0 to 5 mSv/h) 0 to 5 R/h (0 to 50 mSv/h)
Accuracy	± 10% of reading between 10% and 100% of full-scale indication on any range, exclusive of energy response (calibration source is ^{137}Cs)
Detector	230 cc volume air ionization chamber, pressurized to 6 atmospheres Plastic chamber wall 200 mg/cm2 thick

Pressurized ion chamber can only detect the radiation energy > 25 keV so it's not a good one for I125 & Pd103

- Why you cant use your calibration chamber for area survey? – low sensitivity?
  Survey meter has much large air volume and usually is compressed for higher sensitivity

Most facilities have two different survey meters:

Ludlum Model 9 Ion Chamber
Ludlum Model 14-C Geiger-Mueller Survey Meter

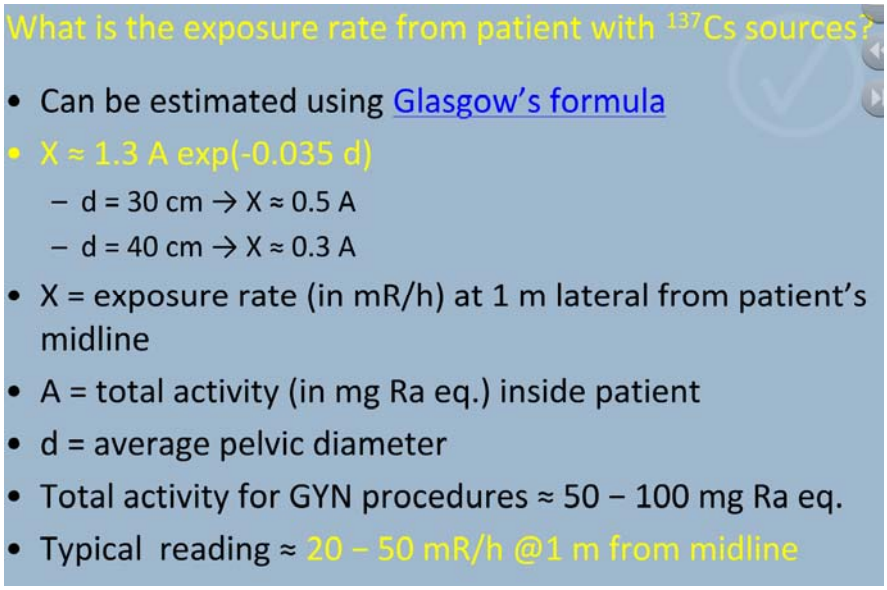
Ludlum Model 9 Ion Chamber Radiation Monitor:

The Ludlum Model 9 Ion Chamber Radiation Monitor is used for general purpose surveying. Specs include:

Ludlum Model 14C Survey Meter:

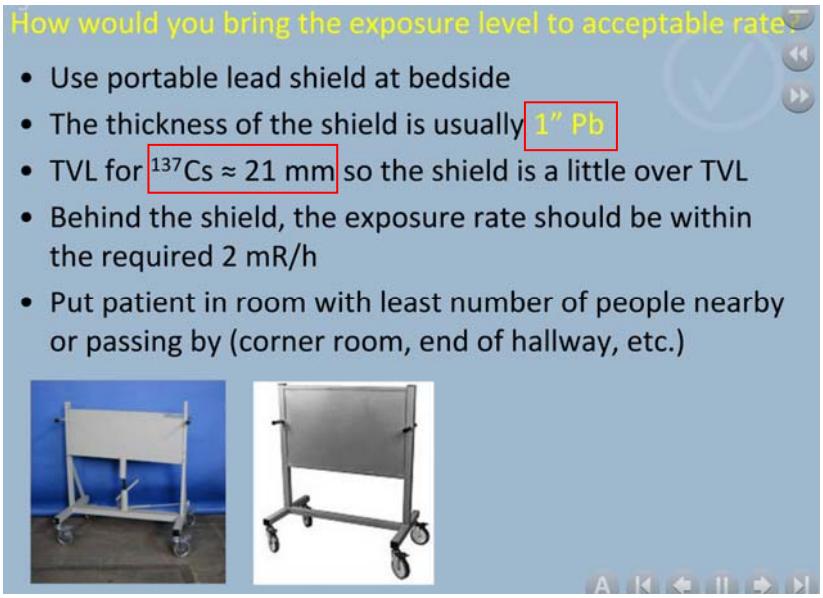
The Ludlum Model 14C survey can be used with one or more external probes, e.g. a GM or scintillation detectors for alpha, beta, or gamma detection up to 0 – 200 mR/hr. An additional internal detector creates a fifth response range of 0 – 2000 mR/hr in addition to the four ranges covered by the external probe. It is used in hospitals, universities, power plants, and regulatory facilities. Standard scale is 0 – 2 mR/hr with five counting ranges: x0.1, x1, x10, x100, and x1000. Specs include:

- A question about expected dose rates near a LDR **CS137** patient



USE X = 0.4A = 0.4 x 100 = **40 mR/h @ 1 m from midline** = **0.4 mSv/h**

- What if dose is larger than what's acceptable, what do you do? What to do if you determine patient in next room is getting more than limit? Where do you put shields (show on graph) – why do you put there?



Orthovoltage shielding

- (2006) orthovoltage/ superficial? Workload/permissible dose?
- Describe the shielding requirements for a 250 kVp orthovoltage unit?
- Given picture of an orthovoltage treatment room. Questions regarding shielding including W, U, and T. (Bushberg p762)

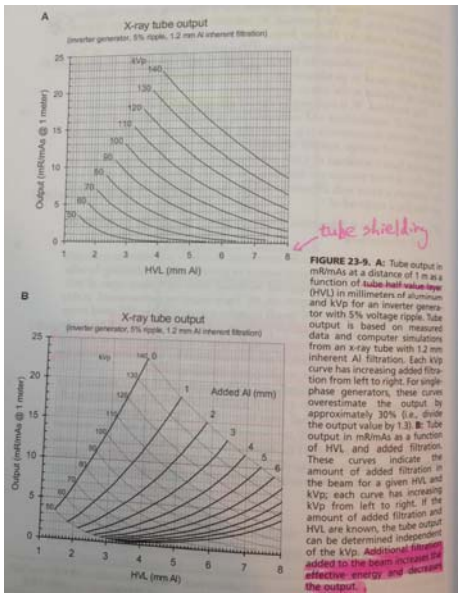


FIGURE 23-9. A: Tube output in mR/mAs at a distance of 1 m as a function of tube half-value layer (HVL) in millimeters of aluminum and kVp for an inverter generator with 5% voltage ripple. Tube output is based on measured data and computer simulations from an x-ray tube with 1.2 mm inherent Al filtration. Each kVp curve has increasing added filtration from left to right. For single-phase generators, these curves overestimate the output by approximately 30% (i.e., divide the output value by 1.3). B: Tube output in mR/mAs as a function of HVL and added filtration. These curves indicate the amount of added filtration in the beam for a given HVL and kVp; each curve has increasing kVp from left to right. If the amount of added filtration and HVL are known, the tube output can be determined independent of the kVp. Additional filtration added to the beam increases the effective energy and decreases the output.

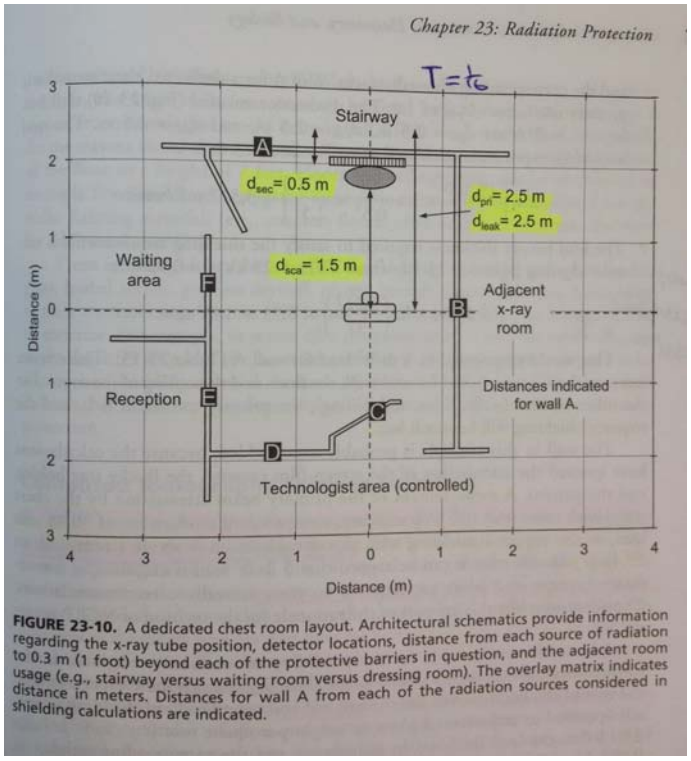


FIGURE 23-10. A dedicated chest room layout. Architectural schematics provide information regarding the x-ray tube position, detector locations, distance from each source of radiation to 0.3 m (1 foot) beyond each of the protective barriers in question, and the adjacent room usage (e.g., stairway versus waiting room versus dressing room). The overlay matrix indicates distance in meters. Distances for wall A from each of the radiation sources considered in shielding calculations are indicated.

Orthovoltage the workload is defined as the (mA min)/wk & then we can calculate the exposure based on the tube output (lookup table or figure) in mR/(mA min) @ 1 m.

The permissible dose is same as other shielding calculation; 2 mR/wk & 2 mR/hr for uncontrolled & 10 mR/wk for controlled area.

Workload = 30pts/day x 2 films/pt x 5 mAs/film x 1/60 x 5 days/wk = 25 (mA min/wk)

Primary (X_p) = workload (mA min/wk) * tube output (mR/mA min)←decided by beam energy and filtration

Scatter (X_s) = $X_p/(d_{sca}^2)$ * scatter factor * (field size/400)

Leakage (X_l) = 1.67 mR/(mA_{MAX} min) * workload

Exposure due to the leakage radiation cannot > 100 mR/h at 1 m from the x-ray tube for the max continuous allowable current ex: 3 - 5 mA, at max kVp (ex: 150 kVp). The max leakage is therefore 100 mR/(mA_{MAX} hr) at 1 m = 1.67 mR/(mA_{MAX} min)

X (behind the wall in the primary beam direction)
= $X_p/d_{pri}^2 * U * T + X_s/d_{sec}^2 * T + X_l/d_l^2 * T$

C1-B (Regulations and Guidelines)

- (2008) AAPM's virtual library on 10CFR20, 10CFR35... Know limits established by the NRC. Know the rules and regulations. When to report to the NRC?
- Definition of a medical event. A lot of follow-up questions and discussion for this question.
- 14% overall dose inaccuracy found, thought process --- need to know the daily, weekly and whole-process action level for Medical event and medical reportable event. The policy for reporting, and the authority (state environmental health department & NRC for non linac case, and state only for linac) to report to.

The U.S. Nuclear Regulatory Commission (NRC) is the Federal agency responsible protecting the health and safety of the public and the environment by licensing and regulating civilian uses of the following radioactive materials in medical, academic, research, and industrial applications (including the generation of nuclear power):

- Source material (uranium and thorium)
- Special nuclear material (enriched uranium and plutonium)
- Byproduct material (material that is made radioactive in a reactor, and residue from the milling of uranium and thorium)

Of more than 20,000 active source, byproduct, and special nuclear materials licenses in place in the United States, about a quarter are administered by the NRC, while the rest are administered by 34 Agreement States.

Medical reportable event for radiation-producing machine therapy—(219.3)
PA Linac medical event: **(States is only for LINAC from Penn RSO)**

- Accelerator only (otherwise, it is an ME)
- Dose in treatment area differs from prescribed by > 20% over the course of treatment or
  > 30% during one week
- Dose outside the treatment area that is greater than the expected to that region by 20% of the prescribed dose to the treatment volume
- Treatment of wrong individual

US.NRC Medical event 10CFR.35.3045 (for everything except the linac such as brachytherapy)

USNRC medical event is much more precise and accurate compared to state regulation.

1. It use total effective dose, ex: > 50 mSv dose to the whole body annual effective dose as one of the condition, so it our PTV hot spot > 50 mSv, it does not count, because total effective dose is the dose to induce cancer, and hot spot in PTV will not induce cancer.
2. It use dose equivalent to the organ.

Review friend's the reportable event note

According to PA code, if the deviation is still harm to pt, we still need to report it to state within 30 days.

- Explain about medical event. Who gets notified?

What constitutes a Byproduct Material Misadministration?

- A dose that differs from the prescribed dose by more than 5 rem effective dose equivalent, 50 rem to an organ or tissue, or 50 rem shallow dose equivalent to the skin; and
  - (i) The total dose delivered differs from the prescribed dose by 20 percent or more;
  - (ii) The total dosage delivered differs from the prescribed dosage by 20 percent or more or falls outside the prescribed dosage range; or
  - (iii) The fractionated dose delivered differs from the prescribed dose, for a single fraction, by 50 percent or more.

What constitutes a Byproduct Material Misadministration?

- A dose that exceeds 5 rem effective dose equivalent, 50 rem to an organ or tissue, or 50 rem shallow dose equivalent to the skin from any of the following—
  - (i) An administration of a wrong radioactive drug containing byproduct material;
  - (ii) An administration of a radioactive drug containing byproduct material by the wrong route of administration;
  - (iii) An administration of a dose or dosage to the wrong individual or human research subject;
  - (iv) An administration of a dose or dosage delivered by the wrong mode of treatment; or
  - (v) A leaking sealed source.

5rem = 50 mSv effective dose equivalent = annual occupational dose limit
50rem = 500 mSv to organ / skin = annual occupational dose limit

What constitutes an a linac-based external beam misadministration?

- Regulatory responsibility over linear accelerator based external beam radiation therapy is with the individual States.
- Regulations of what constitutes a misadministration and the required reporting requirements vary from State to State.

What actions are required in the event of a HDR Misadministration?

- Telephone NRC within 24 hours
- Generate a written report within 15 days to include:
  - Materials license identification
  - Responsible physician
  - Description of event
  - Anticipated patient effects from event
  - Actions taken to minimize likelihood of reoccurrence
  - Confirmation that referring physician and patient were notified within 24 hours and a report of the event was provided to them within 15 days
- The term "medical event" has replaced "misadministration" in NRC but some States continue to use the "misadministration" term.

- What's the model used in regulations, what are occupational and non-occupational dose limits – why are they different? Know about dose imitations for workers and pregnant worker in specific

Annual Maximum Permissible Dose Equivalents

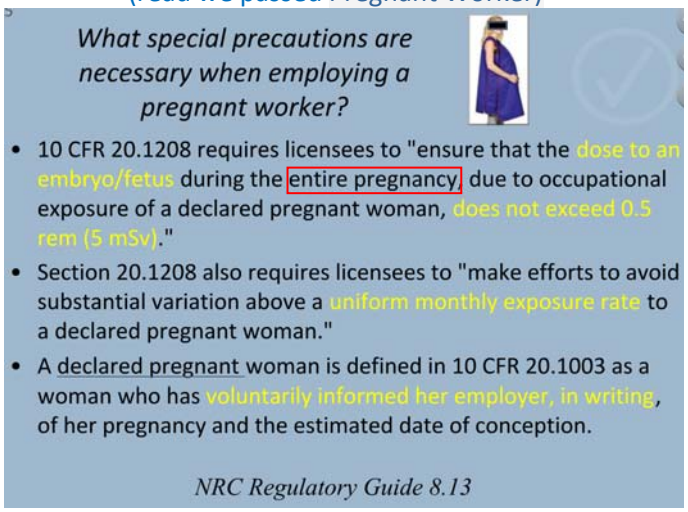
A. Occupational exposures	
1. Effective dose limits	
a) Annual	**50 mSv**
b) Cumulative	**10 mSv x age**
2. Equivalent dose annual limits for tissues and organs	
a) lens of eye	**150 mSv**
b) skin, hands and feet	**500 mSv**
B. Public exposures (annual)	
1. Continuous or frequent	**1 mSv**
2. Infrequent	**5 mSv**
3. For tissues and organs	
a) lens of eye	**15 mSv**
b) skin, hands and feet	**50 mSv**
C. Embryo-fetus (monthly)	**0.5 mSv**

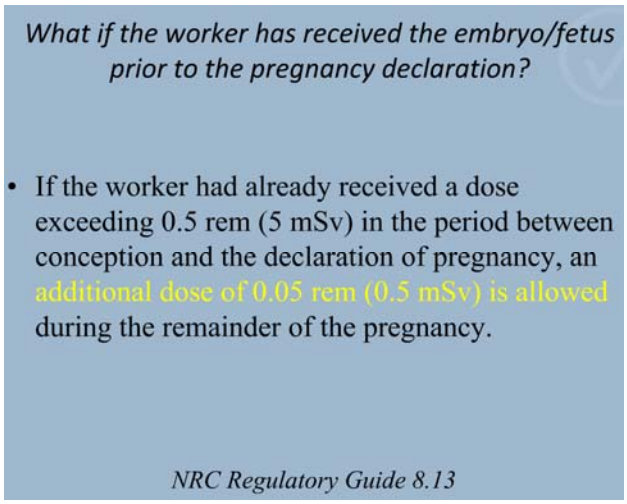
LNT model

Because the chance of radiation worker exposed to radiation is higher than the general public, following the **ALARA** (as low as reasonable achievable), we have different dose limit for occupational and non-occupational dose limit.

Occupational (職業)

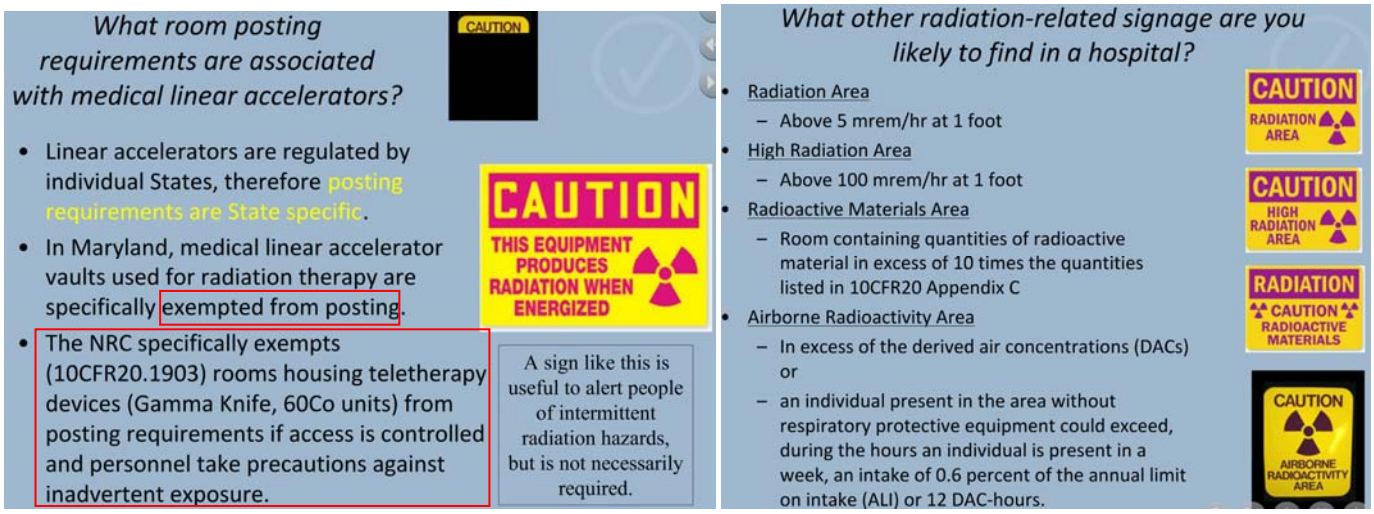
(read we passed Pregnant Worker)





For the pregnant worker, the total dose limit is 5 mSv, and 0.5 mSv/month. Additional 0.5 mSv is allowed.

- Posting signs. What posting required on your Linac door, HDR door, source room door, LDR door? What are the regulations?



Ex: NRC for Cs-137, it list as 10 µCi so 10 times more will be 100 uCi for sign posting.

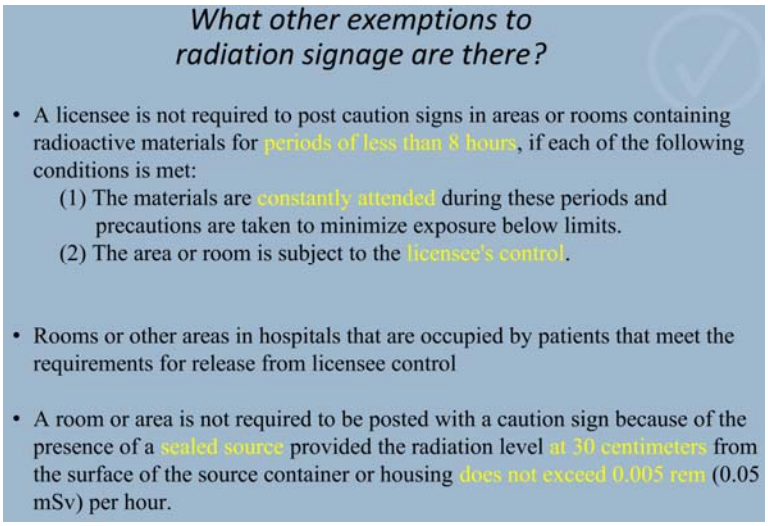
PA code: 219.159. Posting of radiation-producing machines.

The registrant or licensee shall ensure that each radiation producing machine is labeled in a conspicuous manner which cautions individuals that radiation is produced when it is energized. EX:

PA code: 219.160. Exceptions to posting requirements. (so we don't have sign on our linac room door)

In addition to incorporation by reference of 10 CFR Part 20 (relating to standards for protection against radiation), a room or area is not required to be posted with a caution sign because of the presence of radiation machines used solely for diagnosis in the healing arts.

So PA does not require linac room posting but require it on the machine. Most of state requirements does follow NRC requirement.



So we don't have the posting on our HDR room door due to the exposure is too low.

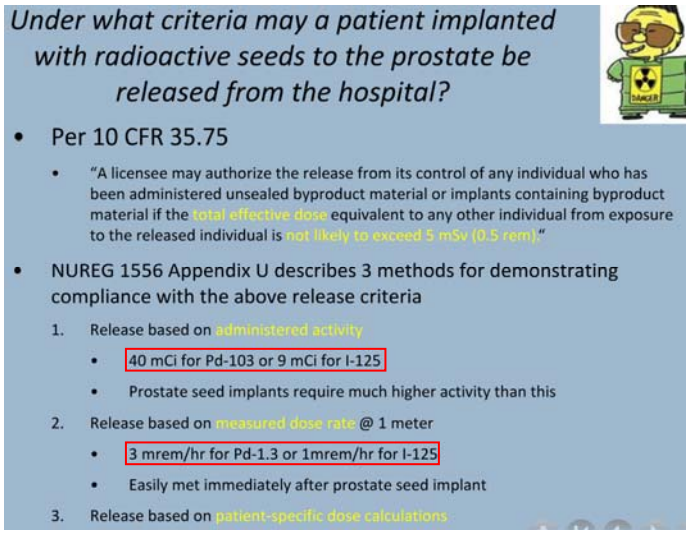
(Hot lab: TG56): All radioactive sources shall be stored in a lead source safe of sufficient thickness to reduce the exposure rate to acceptable levels. This source safe and a working area shall be in a secured room (hotlab). There shall be a ''**CAUTION: RADIOACTIVE MATERIALS**'' sign posted on the door to this area.

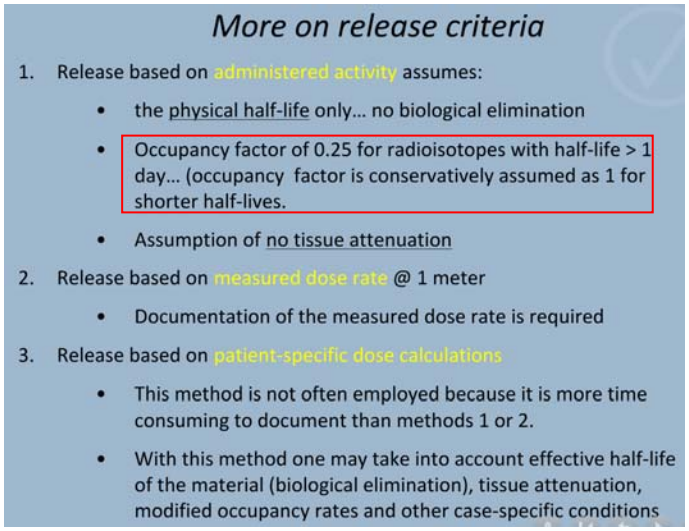
Emergency instructions (including a call list of names and phone numbers) and a source inventory shall be posted inside the room.

Remote afterloader units shall be kept in a secure location when the unit is not use. The treatment unit shall be posted with ''CAUTION: RADIOACTIVE MATERIALS,'' as well as the type and maximum strength of the source.

(LDR room, TG56) A **''CAUTION: RADIATION AREA''** sign shall be posted on the door to the patient's room as well as a description of the radioactive material (number of ribbons, seeds, tubes, etc.) and strength, and the means to contact the RSO and physician in an emergency.

- **(Pt. release criteria):** What are the releasing criteria for I-125 prostate seed implant patient? He was looking for a measurement type data that a physicist has to do before he/she can release the patient.



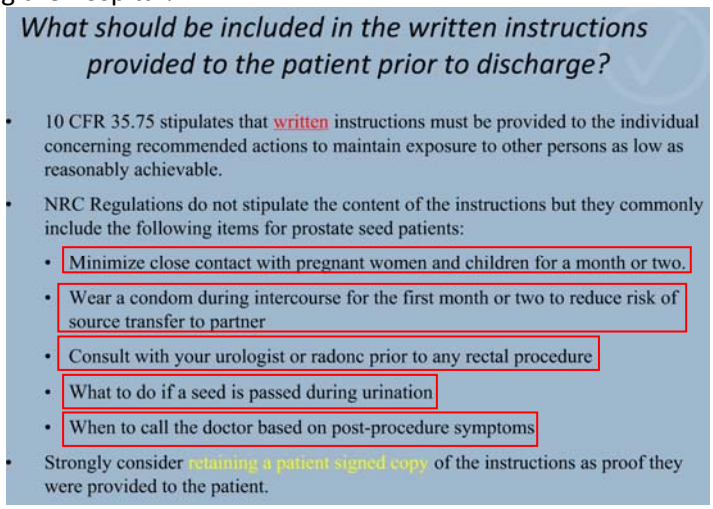


The release criteria can be
(1). The dose at 1 m away from pt. < 5 mSv. Therefore, the initial activity needs to be less a certain value or
(2). If the initial activity is > a criteria, normally for the prostate implant case, measured dose rate needs to be less a certain value.

For **Pd-103**, we can use ion chamber to measure the exposure rate as 0.03 mSv/h or 3 mrem/h @ 1 m away from the implant site.

For **I-125**, we can use IC to measure the exposure rate as 0.01 mSv/h or 1 mrem/h @ 1 m away from the implant site.

- Explain the **release instruction** of prostate implant patients. - What instructions do you give the patient upon leaving the hospital?



2.3.2 Instructions Regarding Permanent Implants

For patients who have received permanent implants, additional instructions may include the following.

A small radioactive source has been placed (implanted) inside your body. The source is actually many small metallic pellets or seeds, which are each about 1/3 to 1/4 of an inch long, similar in size and shape to a grain of rice. To minimize exposure to radiation to others from the source inside your body, you should do the following for _____ days.

- Stay at a distance of _____ feet from _____.
- Maintain separate sleeping arrangements.
- Minimize time with children and pregnant women.
- Do not hold or cuddle children.
- Avoid public transportation.
- Examine any bandages or linens that come into contact with the implant site for any pellets or seeds that may have come out of the implant site.
- If you find a seed or pellet that falls out:
  - Do not handle it with your fingers. Use something like a spoon or tweezers to place it in a jar or other container that you can close with a lid.
  - Place the container with the seed or pellet in a location away from people,
  - Notify one of the persons listed in this instruction.

USNRC 8.39

- Know about discharge instructions for an I-125 prostate seed patient with a pregnant wife. What are limitations for time spent with wife or small children? (Be specific- how long do limitations, if any, need to be in place?)

  (from Arthur)

  - Children and pets should not sit on the patient's lap for the first two (2) months after the implant.
  - Pregnant (or possibly pregnant) women should avoid prolonged, close contact with the patient for the first two (2) months after the implant.
  - A distance of 1 m is acceptable.
  - At a distance of three 1m , there is no limit to the length of time anyone can be with the patient.

- What device would you take to an I-125 implant? What if an Ir-192 implant?

  Scintillation (NaI) detector (we used NaI probe in Penn) for I-125;

Scintillation (NaI) Probe w/ Survey Meter:

A scintillation probe is based on the light emission by substances (e.g. a crystalline sodium-iodide salt called NaI) that emits light or "scintillates" when struck by ionizing radiation). These light flashes are collected by a photomultiplier tube, which also amplifies the signal. These sensitive components are all encased in a magnetically shielded, light tight aluminum shell. This type of probe is used primarily to detect low energy photons (I-125) and low energy x-rays.

Which Instrument(s) should I use?

Radionuclide	Emission	Energy (MeV)	Detector	Probe
3H	beta	0.0186	LSC	N/A
14C	beta	0.156	Survey Meter	Pancake GM Probe
			LSC	N/A
32P	beta	1.709	Survey Meter	Pancake GM Probe
33P	beta	0.249	Survey Meter	Pancake GM Probe
			LSC	N/A
35S	beta	0.167	Survey Meter	Pancake GM Probe
45Ca	beta	0.257	Survey Meter	Pancake GM Probe
51Cr	gamma	0.320	Survey Meter	Pancake GM Probe
60Co	gamma	1.17, 1.33	Survey Meter	Pancake GM Probe
125I	gamma	0.035	Survey Meter	NaI
131I	gamma, beta	0.364	Survey Meter	Pancake GM Probe, NaI

In general, for betas, choose a pancake probe (preferable) or at least a Thin Window GM detector

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

Please see this Harvard website about the survey meter used for which radioactive material, where DABR copied from. The scintillation detector is designed particular for low energy photon < 40 keV. **Therefore, it is good to use it for I-125, but for Ir-192, GM is a better choice.**

(Arthur and Rob) I used both NaI and GM meters to find missing I-125 seeds. GM counter works good but only if it is in close proximity to the seed, therefore one has to put the probe very close to all areas in order to detect the source. NaI probe on the other hand will detect the source in the room even if the detector itself is not in the close proximity to the source.

The only problem with NaI detector is that if the patient is still in the OR and you are looking for the seed outside the patient, the signal from the sources implanted in the patient will be picked up by NaI and so you will have meter going off making it impossible to look for the seed outside, (too much background from the patient).

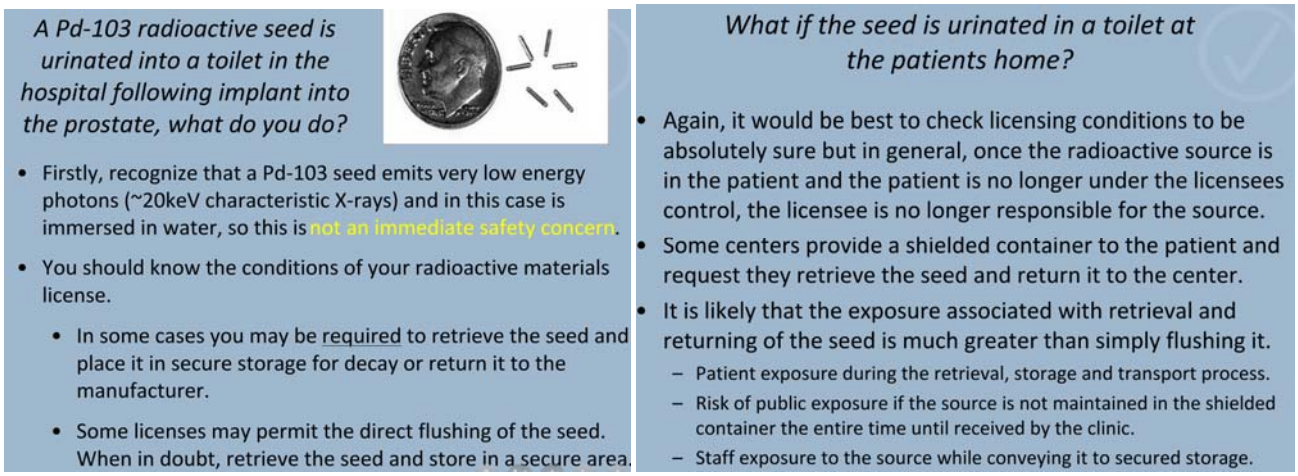
GM on the other hand will only go off if it is pointed in the direction of patient abdomen. If the detector is pointed away it will not go off unless there is another source present.

Therefore I routinely had 2 meters in OR, GM and Scintillator, and used one or the other depending on the circumstance.

Conclusion: GM and NaI are both used for I-125. GM is good to find the approximate location of the seed, and then NaI (with the directional probe) can accurately locate the seed. For example, if the seed is in the landfill, GM can give you an idea where the seed can be, and NaI can give you more accurate location.

- How to find seeds lost on the way to an implant – GM+ Scintillation counter.

- One I-125 seed flushed out in toilet. What would you do?
- What if the seed is in a hospital toilet? What about at the patient's home?



Retrieve or not is based on the license.

Once the radioactive material has been put into pt. body, it becomes unlicensed, so the regulation stops applied. However, if pt. is in the hospital, it's hard to prove if the loosen seed is from pt. or from hospital incorrectly placed by staffs.

I will retrieve the seed in the hospital toilet. If the seed has been flushed, and not sure where to go, I will give up since the seed activity is very low (1seed: 0.4 mCi (I-125) or 1.4 mCi (Pd-103)) won't harm general public. Exposure at 1 feet away: 1.4 x 1.5 (R cm^2/(mCi h)) / (1000) = 0.2 mR/h < 2 mR/h not even consider occupancy factor.

If the seed is in the patient home, depending on the license, I will decide to ask patient retrieve the seed or not. If we are not clear on the license, we should retrieve the seed.

- 20 I-125 seeds (0.5 mCi each) on the way to land-fill (拉機掩埋場). What would you do? Instrumentation – why?
- What if 10 seeds are lost in trash?
- if 20 0.5 mCi seeds get lost in hospital trash what would you do

Again before implanted the source to the patient, based on NRC regulation, we need to retrieve the seed.

(Penn radiation safety seminar)

10. CFR. 20.1801 Security of stored material.
The licensee shall secure from unauthorized removal or access licensed materials that are stored in controlled or unrestricted areas.

10. CFR. 20.1802 Control of material not in storage.
The licensee shall control and maintain constant surveillance of licensed material that is in a controlled or unrestricted area and that is not in storage.

We should **retrieve the source** from the trash or landfill. Use scintillation (NaI) detector to get the I-125 seeds because the scintillation detector is **suitable for low energy x-ray and low radiation level.** It has shorter resolving time (the time required by the detector to regain its normal state after registering a pulse) compared to GM, so it can be used in high radiation level (it is not easily saturated by the high radiation level compared to GM)

From TG64, it suggested GM counter and scintillation detector
TG56 (page1583), it specifically mentioned scintillation detector
2 websites say GM counter won't be able to detect I125 < 0.05 uCi
http://web.princeton.edu/sites/ehs/radmanual/radman_app_b.htm#i125
http://researchcompliance.uc.edu/radsafety/isotope/isds-i125.html

If we should report NRC of lost/stolen seed, it is based on the NRC regulation activity (chk friend's note)

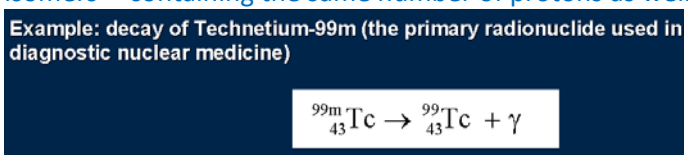
- What are isotone, isotope and isobar? Usage of them respectively
  ${}^{A}_{Z}X$
  Isotone - same neutron since it has an n there,

  Isotope - same proton or z since has p there ${}^{131}_{53}I, {}^{125}_{53}I$

  Isobar is with the same number of nucleons but different number of protons; (Kahn p22): Positron emission:
  A specific example of positron emission is the decay of ${}^{22}_{11}Na$:

  $$^{22}_{11}\mathrm{Na} \xrightarrow[2.60\ \text{years}]{T_{1/2}} {}^{22}_{10}\mathrm{Ne} + {}^{0}_{+1}\beta + \upsilon + 1.82\ \mathrm{MeV}$$

  Isomers -- containing the same number of protons as well as neutrons, but different excited state



(Personal dose monitor)
(2010-2011)Know about film badges and radiation safety program. Who do you badge? Pregnant workers? Limits to fetus?
(read we passed: Personnel-Dosimetry-Program, personnel badge, high badge reading)

When is a person required to participate in a personnel dosimetry program?

- If there is a reasonable potential for the person to receive 10% or more of the applicable dose limit (including the more restrictive limits associated with minors and pregnant women).
- If they will be entering a high or very high radiation area

What are some typical annual dose equivalent readings associated with hospital workers?

- Radiation therapist < 10 mrem (0.1mSv)
- Physicist involved in brachy < 100 mrem (1mSv)
- Nuclear med. tech. = 200-500 mrem (2-5mSv)
- Special procedure Radiologist ~1000 mrem (10mSv)
- Cardiologists = 2000 to 3000 mrem (20-30mSv)

How accurate is your personnel dosimetry?

- The Luxel+ optically stimulated luminescence badge is accurate to within +/- 15% photons above 20 keV for both deep and shallow dose.

Some radiation badges have a grid on top of the filter pack, why would that be?

- The purpose of the grid is to help determine if the badge was stationary during the entire exposure.
- A distinct grid pattern indicates that the badge was static during the entire exposure, indicating that the badge was likely not being worn at the time.
- A blurred pattern would imply that the badge was is motion during the exposure

- How do you know if the readings are correct?
  1. Compare the reading with other work who have the similar daily schedule
  2. Do calculation based on the occupancy factor, source activity, shielding
  3. Perform area survey to compare the personal dosimeter level to see if the reading within reasonable range
  4. Ask vendor check the grid to see if the badge was static during the entire exposure

- How would you choose a vendor?

Sensitivity

- The film and TLD badges: 0.1 mSv - 10 Sv;
- OSL : 10-30 μSv – 10 Sv.

Energy dependence

- film exhibits a strong energy dependence
- LiF TLD & OSL dosimeters have good energy independence
- EPDs containing energy-compensated detectors, energy dependence is within ±20% over the energy range from 30 keV to 1.3 MeV.

Uncertainties in personal monitoring measurements

Directional dependence

- According to the ICRU, the individual dosimeter must be iso-directional

Discrimination between different types of radiation

- Film dosimeters can identify and estimate the doses of x rays, gamma rays, beta particles and thermal neutrons.
- TLD, OSL and RPL dosimeters generally identify and estimate doses of x rays, gamma and beta radiation.

Rigid enough (water resistant blister pack & grid)

- I was also asked to describe different personnel dose monitors and how they were used. (Podgorsak, Handbook p95)

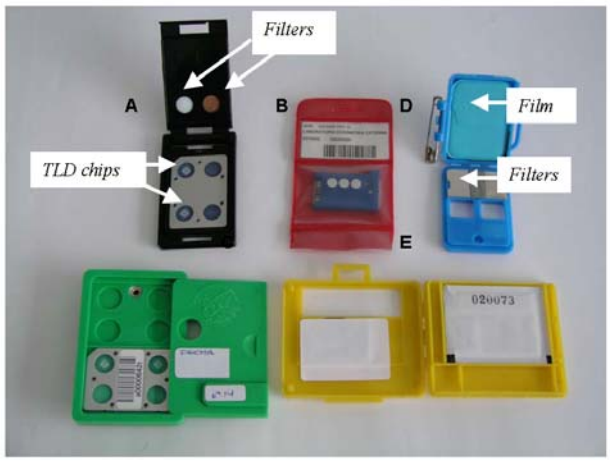


FIG. 4.5. Personal dosimeters: Examples of TLD badges (A, B, C) and film badges (D, E).

1. **Film badge**
   - A special photographic film in a light-tight wrapper enclosed in a case or holder with windows, with appropriate filters, is known as a film badge.
   - As the film is non-tissue equivalent, a filter system has to be used to flatten the energy response, especially at lower photon beam qualities, to approximate the response of a tissue-equivalent material.
   - Cumulative doses from beta, x, gamma, and thermal neutron radiation are evaluated by measuring the film optical densities under different filters, and then comparing the results with calibration films that have been exposed to known doses of well defined radiation of different types.
   - Films are adversely affected by many external agents, such as heat, liquids, excessive humidity, etc. The latent image on undeveloped film fades with time, limiting possible wearing periods to 3 months in ideal conditions.

TLD

- A TLD badge consists of a set of TLD chips enclosed in a plastic holder with filters. The most frequently used TLD materials (also referred to as phosphors) are LiF:Ti,Mg.
- The TLD badges that use high atomic number Z TLD materials are not tissue equivalent and, like film, they too require filters to match their energy response to that of tissue. TLD badges using low Z phosphors do not require such complex filter systems.
- The TLD signal exhibits fading, but the problem is less significant than that for films.
- TLDs are convenient for monitoring doses to parts of the body (e.g., eyes, arm or wrist, or fingers) using special type of dosimeters, including extremity dosimeters (like TLD ring).
- Various techniques have been used for neutron monitoring such as using the body as a moderator to thermalize neutrons or using LiF enriched with Li-6 for enhanced thermal neutron sensitivity due to the (n,α) reaction of thermal neutrons in lithium-6.

- **OSLD(**10 µSv – 10 Sv, 5 keV to 40 MeV, accuracy >20 keV 15%)
- OSL dosimeters contain a thin layer of aluminum oxide (Al_2O_3:C). During analysis the aluminum oxide is stimulated with selected frequencies of laser light producing luminescence proportional to radiation exposure.
- OSLD badge come preloaded, incorporating an Al_2O_3 strip sandwiched within a filter pack that is heat-sealed. Special filter patterns (grid) provide qualitative information about conditions during exposure.
- OSL dosimeters are highly sensitive
- OSL dosimeters can be reanalyzed several times without loosing the sensitivity and may be used for up to one year.
- We use OSLD for body dose monitoring.

Direct reading personal dosimeters fall into two categories: (1) Self-reading pocket dosimeters and (2) Electronic personal dosimeters (EPD).

- Self-reading pocket dosimeter resembles a pen and consists of an ionisation chamber that acts as a capacitor. The capacitor is fully charged and reads zero before use. On exposure to radiation for an interval of time the ionisation produced in the chamber discharges the capacitor and the exposure (or air-kerma) is directly proportional to the discharge that can be directly read against light through a built-in eyepiece. However, the use of pocket dosimeters has declined in recent years because of their poor useful range, charge leakage problems, and poor sensitivity compared to electronic personal dosimeters.

- Electronic personal dosimeters (EPD)
  - based on miniature GM counters or silicon detectors are available with the measurement range down to 30 keV photon energy.
  - EPD provides instantaneous display of accumulated dose equivalent at any time.
  - EPDs have auto-ranging facilities and give visual and audio indication (flashing or chirping frequency proportional to dose equivalent rate), so that the changes in radiation field can be recognized immediately.
  - EPDs are very useful at the emergency situations for immediate readout of the doses received.

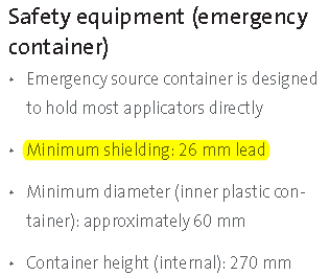
C1-F (HDR and Emergency)

- Picture of an HDR treatment to neck area. How do you enter the room? (with survey meter, and survey around the door area make sure the exposure level is at the background level) Emergency procedures for HDR if the source stays out. How would you know that it is still out? What do you do if the source is not retracted into the safe? What to do in the case of HDR emergency? Wanted to know about actions taken outside the room, i.e. pushing stop and emergency stop buttons. What do you do inside?

(Penn emergency procedure + GammaMedPlus manual)

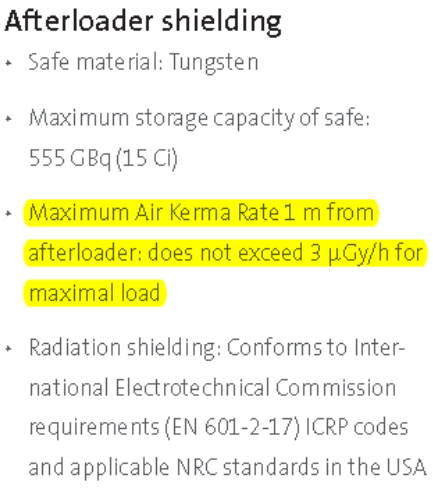
1. If after treatment, the source is still out. The primalert/radiation monitor at the wall should flush, so we know the source is out. We use Varian GammaMedPlus. If the source is out, it will also give us the warning sign on the screen.
2. Press Interrupt button on control console (normal speed), then the emergency off button on the wall (max speed). (One of them is already enough to retract source. We use both in case the interrupt button fail)

3. Enter the room with survey meter (we used pressurized ion-chamber). If the Interrupt and the Emergency button do not work, opening the door should retract the source as well.
4. Measure the exposure at the door location. If the reading is high, meaning the source is still out.
5. Press the Emergency off button on HDR unit (it will shut down all the external power of the RAU such as the GM detector in the unit, and use the battery power only to retract the source to the shield).
6. If it fails again, we will need to use hand-crank on the RAU to retract the source.
7. If it still fails, we use the forcep to remove the whole applicator into the emergency container.
8. If the source is not able to be removed, emergency surgical recovery of the source is necessary. (24-hour Trauma and Surgical Critical Care Division at HUP will be notified of the medical emergency)
9. After source recovered, survey patient, and RAU or emergency container to make sure the radiation level is low from the patient, and source is in the RAU or the emergency container.
10. Removal of pt from treatment room, and perform redundant survey of the room and pt.
11. Exit the room, close the door, and restrict access. Post "CAUTION Radiation Area Do Not Enter" sign on door. A designated individual shall stand at the door entrance to prevent individuals from entering to the room until survey & analysis is performed by RSO.
12. Notify RSO



10 Ci x 0.469 $Rm^2/(hCi)$ x $10^{-26/20}$ = 230 mR/h @ 1m

Lead container is only 26 mm lead, so the radiation level can still be high close to the container → we want to close the door and restrict the area and let RSO take care of it.



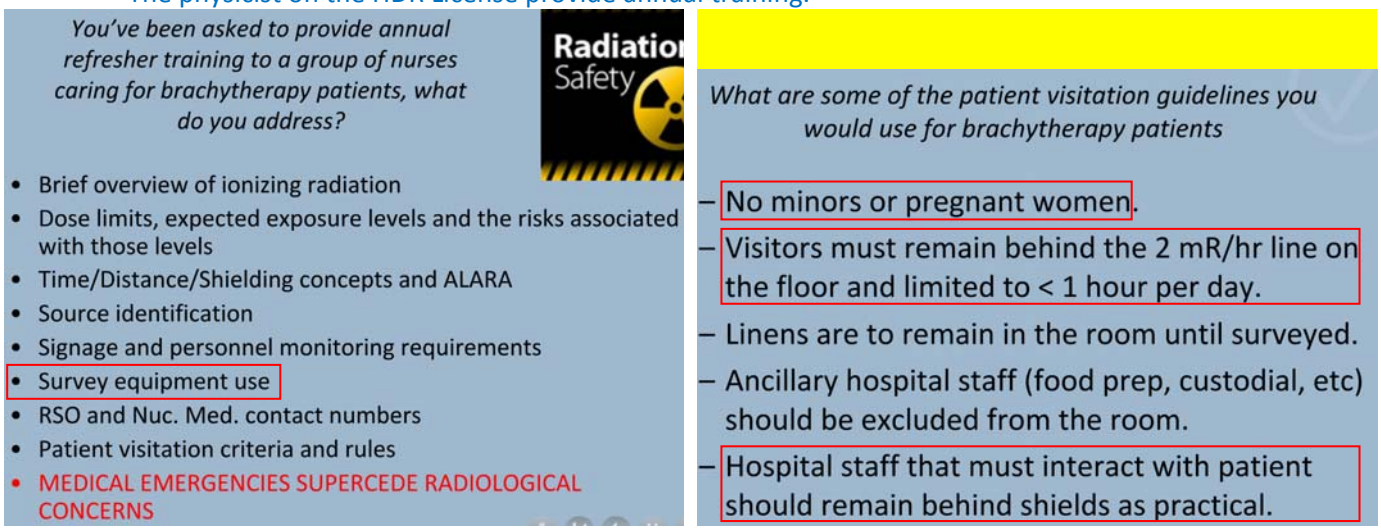
Varian GammaMed Plus spec~ 0.7 mR/h (15 Ci)at 5 cm close to the surface & 10 Ci will be ~ 0.4 (we have about ~ 0.25 mR/h reading in the daily survey)

- How do you calculate the dose/time? What do you do for a second check? (we have excel sheet to calculate the dose at a point using inverse square law and exposure rate constant, the treatment location

for HDR is about 2 cm from the source, so it is in good range for inverse square law (1 – 5 cm away from the source)) What about a second check for a planar implant (Prostate nomogram)?
Both physician and physicist should present during the emergency procedure. A person should be responsible for note taking and time keeping during emergency. In each treatment, we have one person using **stop watch** to record the source-out time beside the timer used in GammaMedPlus as a backup timer if emergency event happens.

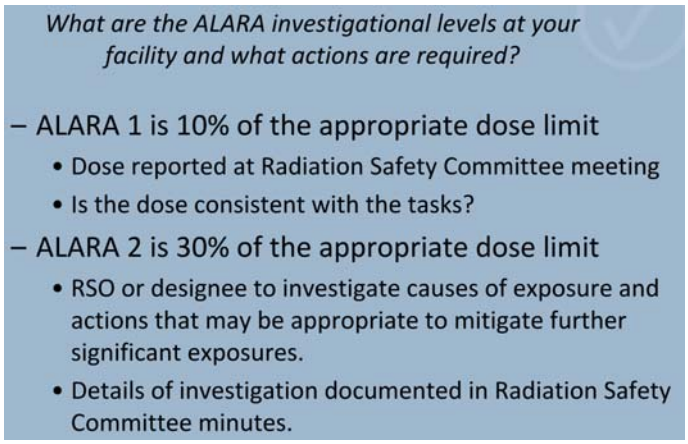
(Nomogram as 2nd check)

- Who provides training for staff? Why do you train the staff? Basic stuff.
  The physicist on the HDR License provide annual training.



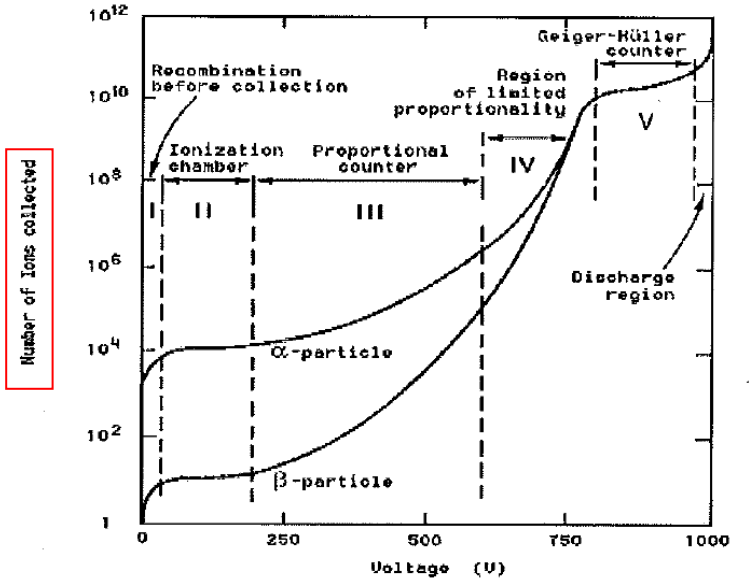
Ancillary (附屬物)

dislodged seeds (from friend):
Always call the people on the emergency list first and apply ALARA principle. Nurses are not supposed to handle sources. There is a survey meter and lead pig available in the ward. When any of the people on the emergency list makes to the room, he/she will remove all applicators off the patient, put them in the pig, take the patient out of the room, and survey the patient.



- Picture of HDR. What type of detector do you need?
  Pressurized ion chamber to measure correct dose/exposure for patient survey. GM meter is used to locate the seed.

- How does a GM meter work? Compare scintillator vs GM meter.
  http://www.uos.harvard.edu/ehs/radiation/how_surveymeter.shtml



DABR p109 the explanation for 5 regions

The screen protects the thin-film window from breakage, scratches, or puncture. Inside the chamber, there is a "target" shaped electrode called an anode. This electrode collects the charge created by the ionization from the incident radiation. The electric circuit is completed by using the chamber wall as the cathode. The chamber is filled with a special gas that amplifies the signal after the ionization. The amplification means that an interaction is counted but does not directly relate to the radiation dose. Looking

(anode 陽極)

300 V is to let the chamber in the saturation zone (100 – 400). If we have too high bias voltage (400-800), we are getting into the proportional zone, the ion itself gains enough energy, and starts to produce secondary ion, and at this region, the larger bias voltage you provided the more secondary ion generated, so it calls proportional region; (the limit proportional zone is simply the voltage is non-linear to the number of ion collected). When V > 800, ion avalanche happened, (one photon ionizing event generates an avalanche of charge). In this case, the # of ion collected does not reflect the energy deposited by the photon.

(Pordogaks p90 - 93)

In the GM region the discharge spreads throughout the volume of the detector and the pulse height becomes independent of the primary ionization or the energy of the interacting particles. In the GM counter detector the gas multiplication spreads along the entire length of the anode. Gas-filled detectors cannot be operated at voltages beyond the GM region because they continuously discharge.

Because of the large charge amplification (9 to 10 orders of magnitude), GM survey meters are widely used at very low radiation levels (e.g., in areas of public occupancy around the radiotherapy treatment rooms).

Scintillation (NaI) Probe w/ Survey Meter:

A scintillation probe is based on the light emission by substances (e.g. a crystalline sodium-iodide salt called NaI) that emits light or "scintillates" when struck by ionizing radiation). These light flashes are collected by a photomultiplier tube, which also amplifies the signal. These sensitive components are all encased in a magnetically shielded, light tight aluminum shell. This type of probe is used primarily to detect low energy photons (I-125) and low energy x-rays.

1. Because of finite resolving time, GM-based systems would saturate beyond a few thousand counts per second. Low dead time counters or dead time correction circuits enable these detectors to operate at higher intensity radiation fields.

- Scintillation-based systems are generally used for survey at very low radiation levels (e.g., contamination monitoring, lost source detection survey, etc.). However, they can also be used at higher radiation levels, since their resolving time is quite low (a few μsec or lower) compared to GM counters.

2. **Scintillation-based systems are more sensitive than GM counters** because of higher gamma conversion efficiency and the dynode amplification.

3. GM counters **exhibit strong energy dependence** for low energy photons (<80 keV).

4. GM survey meters are **not suitable for use in pulsed fields** due to the possible overload effect and ionization chamber-based survey meters should be used instead.

(source transport & receive)

- (2010-2011) Transport index and if some package is delivered to you and sits next to a secretary at child bearing age. Picture of 3 labels White I, Yellow II, Yellow III.
  (use wepassed Transport index)

(TG56)
Receiving source:
1. Source should be received by trained personeel (RSO or physicist) in a controlled & secured area.
2. Chk the # of source & source strength indicated on the shipping label is consistent with what we ordered
3. Check integrity for any damage?
4. Leak test and measure the TI (mrem/h) at 1 m away from the surface
5. Update log: measurement result, source strength
6. Source location should be documented anytime. (If we move source, it should be documented where it go)

C1-D (hotlab)

- (2006) Design of a hot lab with Cs-137. How do you design a Cs safe? about a hot lab or other storage facility for the safe. Signage for hot lab and other safety concerns.

In order to meet these requirements, a licensee must have an isotope laboratory for storage, source preparation, source transportation and leak testing.

(Space & Door): A radioactive isotope laboratory consists of a lockable room with enough space and solid concrete wall performing the above procedure.

(Safe & Area): A source preparation area should be surfaced with stainless steel and should contain lead safes for the storage of brachytherapy source.

An **L-block** with **lead glad viewing window (to handling the source)** should be located conveniently near the safes. The area with good lighting so we can see the source clearly.

(Equipment) 1. Well chamber and electrometer nearby for source calibration; and a GM area monitor or other survey meter to monitor radiation levels while the sources are being handled. Pressurized ion chamber can only detect the radiation energy > 25 keV so it's not a good one for I125 & Pd103

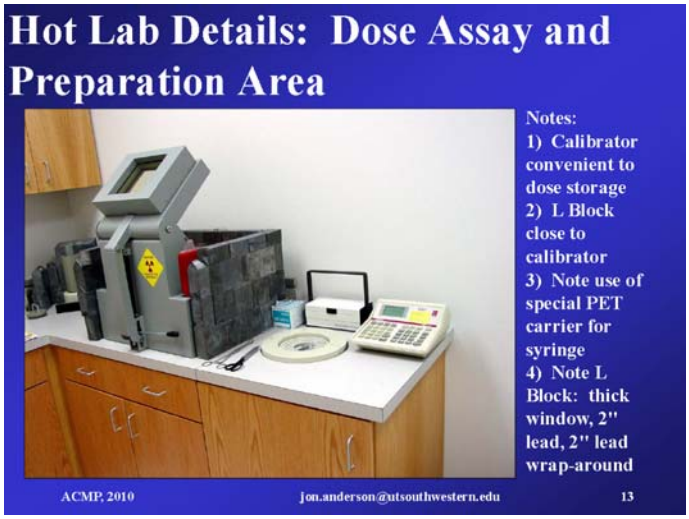
2. Need to equipped with a wheeled pig for transporting the sources to the OR and back.
3. Devices for handling source, especially forceps should be available.

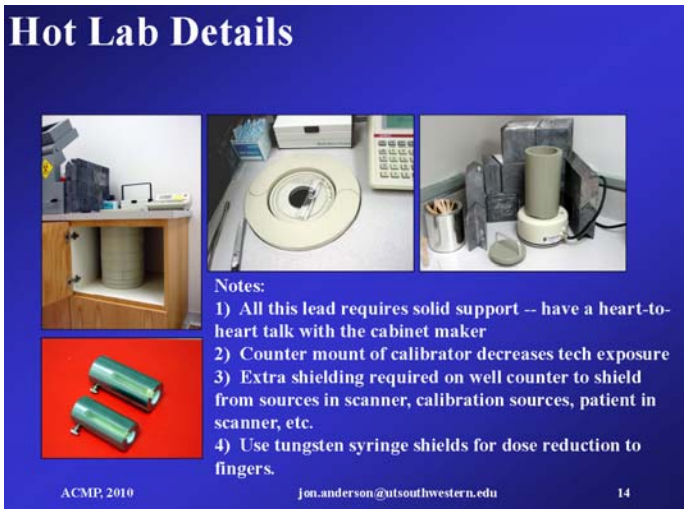
(Room) If radium(Ra) is to be used, the room must be ventilated by direct filtered exhaust, to avoid Radon gas.

Sink must be fitted with a trap to prevent accidentally washing a source into a public sewer system.

(Posting sign): (TG56): **1.** All radioactive sources shall be stored in a lead source safe of sufficient thickness to reduce the exposure rate to acceptable levels. This source safe and a working area shall be in a secured room (hotlab). There shall be a ''**CAUTION: RADIOACTIVE MATERIALS**'' sign posted on the door to this area.

2. Emergency instructions (including a call list of names and phone numbers) and a source inventory shall be posted inside the room.





Summary:

-Restricted area
-2" (5 cm) Lead Safe
-L-block
-Well chamber and electrometer; GM area monitor; Wheeled pig; forceps
-Ventilate by a direct filtered exhaust
-Sink with trap
-posting sign
-emergency instruction & contact

- FU: what's the TVL for Cesium? (2.1cm for lead) how do you identify the C_s sources? "What if I'm colorblind and I can't see the colors?" (ex: 2 methods should be available, color code and bar pattern)

  Source must be stored within a secured room (generally within the safe, check license). Sources should be identified by two methods (ex: color code, source marking (bar), etc.).

o Frequency of leak test? Inventory?
o

An inventory check is required 6 months (10 CFR 35.67).

The main guide for leak test is NRC 10 CFR 35.67.

1. **Do measurements in low background area**.
2. Preferably using a NaI(Tl) **well counter** for photons and liquid scintillation or gas-flow proportional counter for beta or alpha emitting source.
3. Instrumentation must be sensitive down to 0.005 uCi.
4. Leak tests are required every 6 months, but are not required if half-life < 30 days, it is not being used (leak test required before use) & the Ir-192 ribbon

If sealed sources fail the leak test, immediately stop using it; store, dispose, or have it repaired; file a report within 5 days of the leak test. The report should be sent to appropriate NRC regional office. Also send a copy to the Federal/State Materials and Enviromental Management Programs. This is covered in 10 CFR 35.3067. If you are in Agreement State, follow your state regulations.

Sr-90 is a low energy beta emitter (average energy including those from its Y-90 daughter ~ 0.7 Mev). Has a very long life (29 years) and commonly used in eye-plaque therapy for pterygium. A liquid scintillation counter would be ideal instrument since the close contact of the scintillation cocktail with the radionuclide permits highly efficient counting.

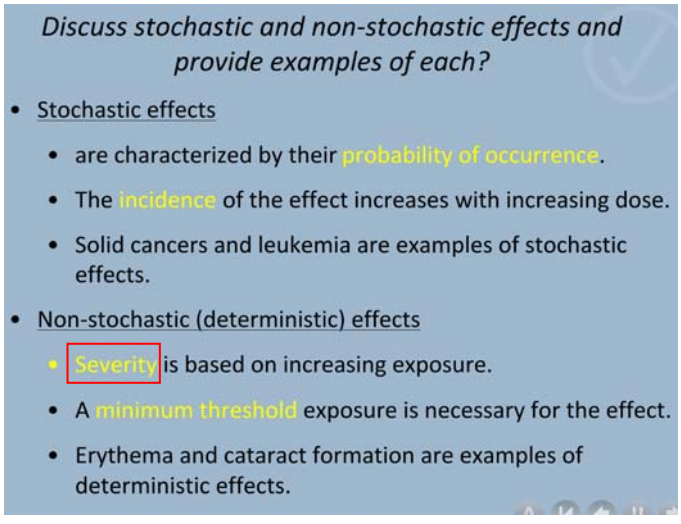
- Cs hot lab. How would you design the shielding? What if it's not enough? (add more lead)
- Picture of an L-shield. How do you control access (we gave door passcode for authorized users), how do you account for sources, what instrumentation, etc (well chamber and electrometer to check the source activity, NaI well counter for leak test)?
- Design of 200 mCi Cs-137 safe. Permissible doses? (2 mR/h)Typical thickness (2 inch).
  0.2 Ci x 326 mR m^2/Ci h x B = 2 mR/h, B = 0.03, if we have 2" of lead, we will have 2.5 TVL, so the dose @ 1 m will be 0.2 mR/h
  @30 cm will be 2.2 mR/h

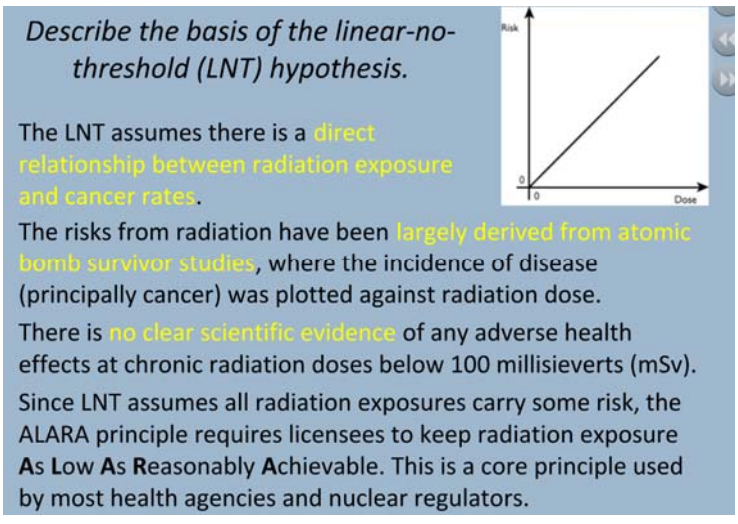
- Any difference if safe in hospital rather than in Department of radiation oncology? What would be different if we picked up the Cs safe and put it in another room?
  My thought is in the department of radiation oncology; the personnel is considered as radiation worker so the dose limit is 1 mSv/wk = 100 mrem/wk = 20 mrem/day. If we consider one person working 8 hours in the hotlab, the dose is 2.5 mrem/hr > 2 mrem/h dose limit. Using 2 mrem/h seems more conservative and realistic criteria, but if we move the safe to outside the dept. of radonc, it will stay in general public, we will also need to consider the dose limit of 0.02 mSv/wk received by a public individual.

- Q: if u design a hot lab and the room given to u is with a window outside the window is a public space. What will do with that window?
  A: you can put fence to prevent someone get into the room through the window.

C1-G (Radiobilogy)

- Talk about stochastic and non-stochastic effects of radiation, Definitions, where do these models come from? Give examples for both of these effects.
- Stochastic and non-stochastic definitions. Discuss radiation safety, and whole body dose. Example, if person gets 10 Gy whole body dose, what effects? Will this cause death? (yes,) Why/why not?





Erythema (紅斑)

Discuss these curves

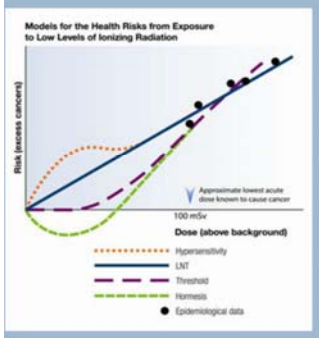


Image from Canadian Nuclear Safety Commission (CNSC) website

- They are different models for health risks from radiation exposure
- Pertinent to low level of radiation, not applicable to high dose in RT
- They provide the bases for radiation safety recommendations and regulatory limits (e.g., how much dose is acceptable within ALARA)
- Calculates the risk from radiation exposure that an individual would face over lifespan
- Latest analysis (BEIR VII) concludes that the Linear No Threshold (LNT) model is most appropriate model
- Lifetime cancer risk = 0.1 / Sv
- Risk for developing cancer over lifespan due to 100 mSv is 1%
- Risk for cancer over lifespan due from other causes is 42%

Where did the data for these curves come from?

- The data are mostly from the atomic bomb survivors (especially on the long-term effects of radiation)

Mushroom cloud from the second atomic bomb attack on 11 AM, August 9, 1945 in Nagasaki, Japan.

Define the terms describing external exposure limits.

- *Total Effective Dose Equivalent* (TEDE) means the sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).
- *Effective dose equivalent* (H_E) is the sum of the products of the dose equivalent to the organ or tissue (H_T) and the weighting factors (W_T) applicable to each of the body organs or tissues that are irradiated ($H_E = \Sigma W_T H_T$).
- *Committed effective dose equivalent* ($H_{E,50}$) is the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues ($H_{E,50} = \Sigma W_T H_{T,50}$).

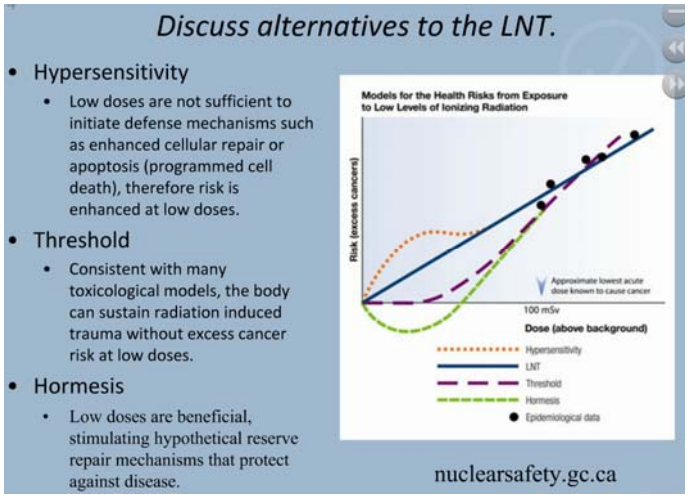
Define the terms describing external exposure limits.

- *Derived air concentration-hour* (DAC-hour) is the product of the concentration of radioactive material in air (expressed as a fraction or multiple of the derived air concentration for each radionuclide) and the time of exposure to that radionuclide, in hours. A licensee may take 2,000 DAC-hours to represent one ALI, equivalent to a committed effective dose equivalent of 5 rem (0.05 Sv).
- *Annual limit on intake* (ALI) means the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a committed effective dose equivalent of 5 rem (0.05 Sv) or a committed dose equivalent of 50 rem (0.5 Sv) to any individual organ or tissue. (ALI values for intake by ingestion and by inhalation of selected radionuclides are given in Table 1, Columns 1 and 2, of appendix B to §§ 20.1001-20.2401).

TEDE is used in medical event but not in the annual permissible dose

LNT **"conservatively"** suggests that any increase in dose, no matter how small, results in an incremental increase in risk. Therefore, this risks associated w low level radiation are **conservatively calculated in proportion to** those observed w high level exposure.

- (2010-2011)Discuss ALARA principle implementation in permanent and temporary implant. What biological model is used to derive ALARA principle? (Linear-nonthreshold model). What model is more conservative (hypersensitivity)?



Hormesis (毒物兴奋效应)

Examples of Non-stochastic or Deterministic Effects:

Acute "whole-body" reactions:

Hematopoietic Syndrome:	*2 Gy*
White cell count falls immediately	
Red cell count falls in a few months	
Gastrointestinal Syndrome:	*10 Gy*
Destruction of intestinal epithelium	
Ablation of marrow	
Nervous Syndrome:	*20 – 40 Gy*
Ataxia	
Shock	

Acute "local" reactions:

Cataract	*2 – 5 Gy*
Epilation	*> 3 Gy*
Permanent Sterility	*3 – 6 Gy (0.3 Gy for temporary sterility)*
Erythema	*3 – 10 Gy*

Hematopoietic Syndrome: die several weeks : bone marrow beak down
Gastrointestinal Syndrome: die a few days destruction of GI mucosa
Nervous syndrome: die 1 -2 days: neurologic and cardiovascular breakdown

- For non-stochastic asks the dose limits for cataract formation, sterility (不育症) thresholds in males and females

(Eric Hall) p185
Mini dose for Cataract: 2 Gy in single exposure
Fractionated (dose spread over 3 wks to 3 months): 4Gy
More than 3 months: 5.5 Gy

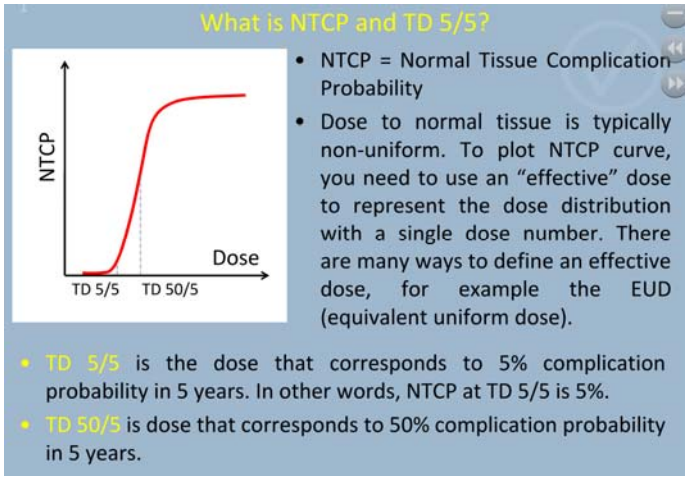
Sterility:

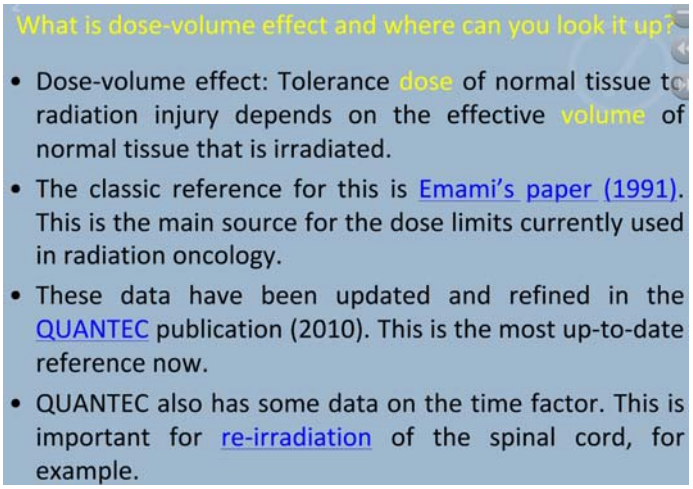
Male: 0.1 Gy (temporary reduction of sperm number), 0.15 Gy leads tempoary sterility, 2 Gy leads no sperm production for several years; 6 Gy in single exposure or 6 – 8 Gy in 2 Gy fractions lead to permanent sterility. (Hall p341)
Female: temporary: 0.6 Gy

permanent sterility: 12 Gy Prepuberty (青春期)

2 Gy premenopausal (絕經前) (Hall p157)

- Dose limit for kidney, lung, spinal cord, lens, cornea





Quantec summary
Kidney: V20 < 30%
Lung: Mean lung < 20 Gy, V20 < 30%,
Cord: max < 45 Gy (or 50)
Lens: max < 10 Gy (Emami)

(Practical radiotherapy planning p49)
Cornea max< 48Gy
Retina < 45 – 50 Gy

- Spine belong to which category? (serial organ)

- Discuss the Cell Survival Curve from Eric Hall's book. (Curve A – no shoulder, Curve B –with shoulder, and n) What is D_0, surviving fraction, quasi-threshold? Which is high LET? Explain factors in the multi target theory.

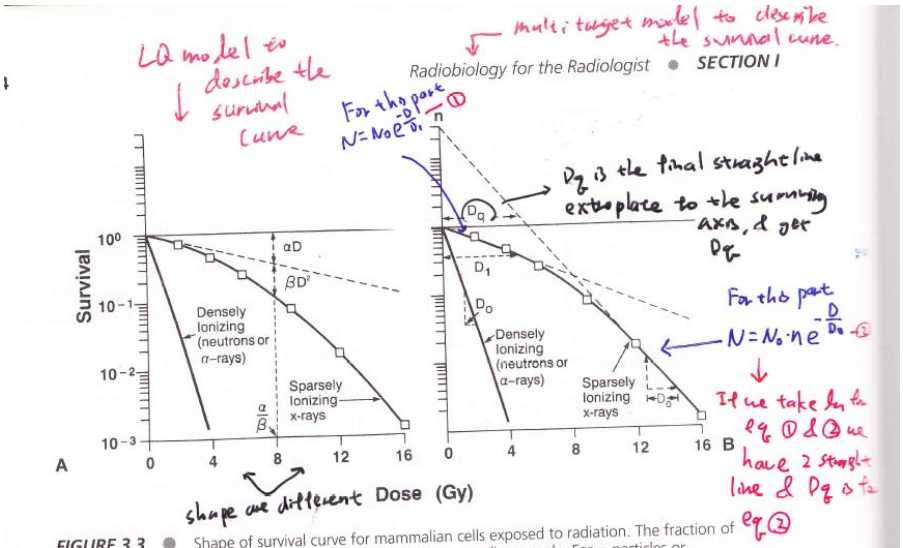


FIGURE 3.3 ● Shape of survival curve for mammalian cells exposed to radiation. The fraction of cells surviving is plotted on a logarithmic scale against dose on a linear scale. For α-particles or low-energy neutrons (said to be densely ionizing), the dose–response curve is a straight line from the origin (i.e., survival is an exponential function of dose). The survival curve can be described by just one parameter, the slope. For x- or γ-rays (said to be sparsely ionizing), the dose–response curve has an initial linear slope, followed by a shoulder; at higher doses, the curve tends to become straight again. **A:** The linear quadratic model. The experimental data are fitted to a linear-quadratic function. There are two components of cell killing: One is proportional to dose (αD); the other is proportional to the square of the dose (βD^2). The dose at which the linear and quadratic components are equal is the ratio α/β. The linear-quadratic curve bends continuously but is a good fit to experimental data for the first few decades of survival. **B:** The multitarget model. The curve is described by the initial slope (D_1), the final slope (D_0), and a parameter that represents the width of the shoulder, either n or D_q.

Fig. 3.3 B shows the **multitarget model (2 exp model describe the cell survival curve, $N = N_0e^{-D/D1}$, & $N = N_0ne^{-D/Dq}$**. The survival curve is described by the

Initial slope (D_1) resulted from single cell killing event, describing the dose required to reduce the fraction of surviving to 0.37 on the initial straight portion.

Final slope (D_0) resulted from multiple-cell killing event; & it is the dose required to reduce the survival fraction further to 37% (0.1 to 0.037) on the final straight porition.

n (extrapolation number) measure the width of the shoulder. If n is large, we have broader shoulder, vice versa. Broader shoulder means we have slow cell-killing; need higher dose to achieve the same cell killing compared to small n value.

D_q (quasi-threshold dose): It is defined as the dose at which the straight portion of the survival curve, extrapolated backward, cuts the dose axis drawn through a survival fraction of unity. It is related to the capacity of the cell to recover from sub-lethal damage.

$Ln(n) = D_q/D_0$, calculated as, $ln(N) = ln(n) – D/D_0$, & y = 0, $ln(n) = D/D_0$ where D = Dq

- Cell survival curve (explain the terms, n, D_q, D_0) talk about RBE and calculate RBE based on two different curves. One is high LET and the other one is low LET

Linear energy transfer (LET): LET is the energy transferred per unit length of the track dE/dl

TABLE 7.1

Typical Linear Energy Transfer Values Higher energy ⇒ w/ lower LET → relative less effective biological damage

Radiation	Linear Energy Transfer, keV/μm	
Cobalt-60 γ-rays (=1.1 MeV photon)	0.2	
250-kV x-rays	2.0	
10-MeV protons	4.7	
150-MeV proton	0.5	
	Track Avg.	Energy Avg.
14-MeV neutrons	12	100
2.5-MeV α-particles	166	
2-GeV Fe ions (space radiation)	1,000	

Equal doses of different types of radiation do not produce equal biologic effects. To compare different radiations, it is customary to use x-rays as the standard. RBE is defined as

Relative Biologic effectiveness (RBE): Dose of a reference radiation 250 keV x-ray to produce a given biological effect / **Dose** of a test radiation required to give the same effect

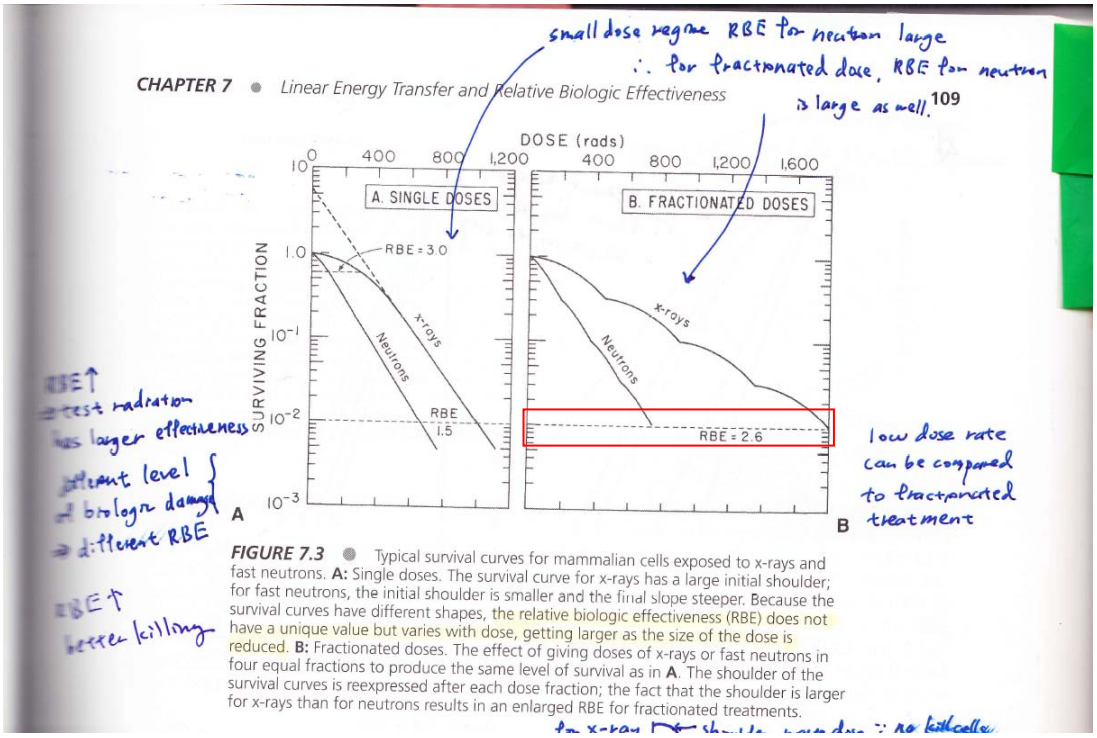
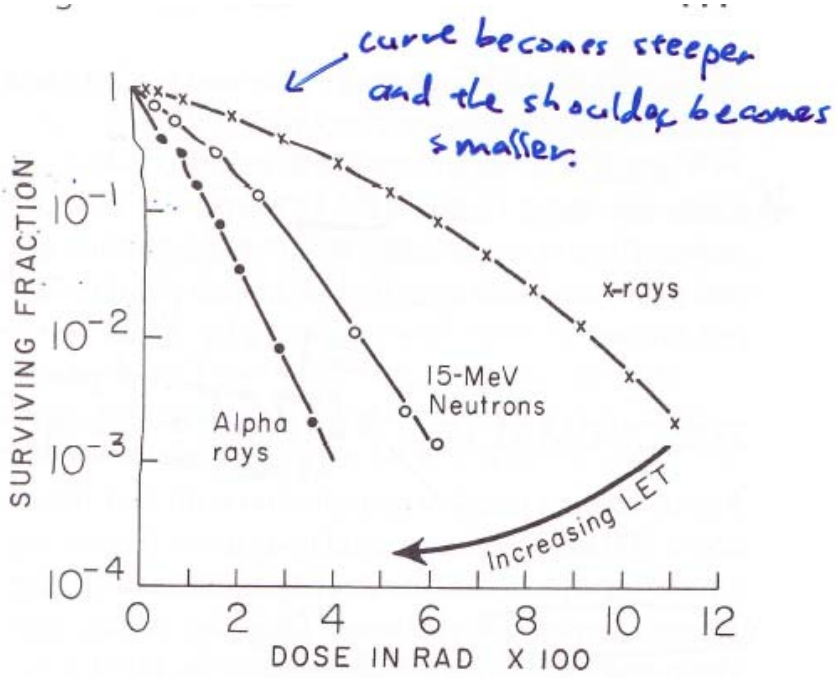


FIGURE 7.3 • Typical survival curves for mammalian cells exposed to x-rays and fast neutrons. **A:** Single doses. The survival curve for x-rays has a large initial shoulder; for fast neutrons, the initial shoulder is smaller and the final slope steeper. Because the survival curves have different shapes, the relative biologic effectiveness (RBE) does not have a unique value but varies with dose, getting larger as the size of the dose is reduced. **B:** Fractionated doses. The effect of giving doses of x-rays or fast neutrons in four equal fractions to produce the same level of survival as in **A**. The shoulder of the survival curves is reexpressed after each dose fraction; the fact that the shoulder is larger for x-rays than for neutrons results in an enlarged RBE for fractionated treatments.



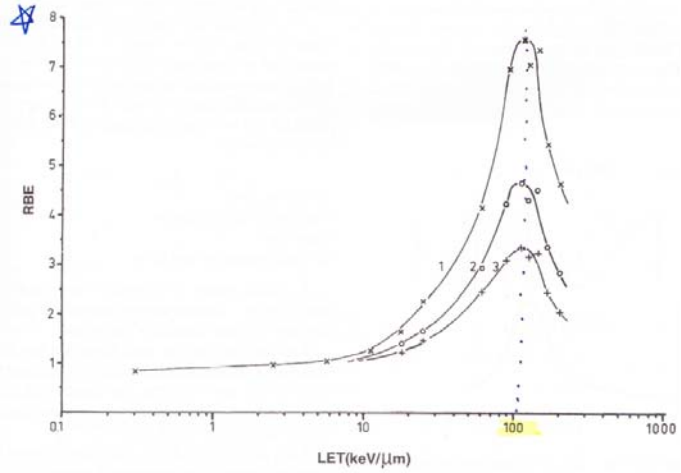


FIGURE 7.6 ● Variation of relative biologic effectiveness (RBE) with linear energy transfer (LET) for survival of mammalian cells of human origin. The RBE rises to a maximum at an LET of about 100 keV/μm and subsequently falls for higher values of LET. Curves 1, 2, and 3 refer to cell survival levels of 0.8, 0.1, and 0.01, respectively, illustrating that the absolute value of the RBE is not unique but depends on the level of biologic damage and, therefore, on the dose level. (From Barendsen GW: Responses of cultured cells, tumors, and normal tissues to radiation of different linear energy transfer. *Curr Top Radiat Res Q* 4:293–356, 1968, with permission.)

- Dose rate and cell survival question, for the dose rate we used clinically, could we obtain increased cell killing by increasing the dose rate?
  For dose rate larger than 1Gy/min, change dose rate won't affect radiobiology effect.