Lecture 2.2 Unclear Points:

The reason for the activity of molybdenum 99 to be slightly greater than that of technetium 99m is due to the branching ratio. Did I understand that correctly?

Yes.

1) What is the reason that you have to isolate the daughter from the parent when the activity of the daughter reaches the maximum?

Otherwise, daughter would be in equilibrium with parent and decay with parent’s half-life. Isolated it decays with daughter’s half-life.

2) Why would you use iridium for removable implant and iodine-125 for permanent implant, but not the other way around? When would you prefer removable implant to permanent implant, and the other way around?

Half-life of $^{192}$Ir is 74 d and avg energy is 0.38 MeV would cause protection problem if implanted permanently. Energy of $^{125}$I is around 35 keV so almost all photons absorbed by patient

Can you explain why the daughter activity increases as parent activity decays in the "trivial case"?

Longer half-life means daughter decays more slowly than parent. Short half-life of parent means more daughter produced.

Also, can you give a conceptual description of the transformation constant?

Fractional decrease in activity per unit time.

How do we separate Radon from Radium?

Radon is a gas.

1) On slide 22, how did you get $1.19 \times 10^{29}$?

Should be $1.19 \times 10^{20}$

2) Can we describe the major differences in equilibrium?

Secular is special case of transient in which half-life of parent is very much longer than that of daughter.

Still not clear as to when and why the parent and daughter appear to have the same half-life (as with radium and radon).

Radon produced as fast as it’s being depleted.
Have we assumed in our statement of the rate of production of a created isotope that daughter products are target atoms? Is there an example where this is not true and the equation \( \frac{dN}{dt} = N_t \cdot \sigma \cdot \phi \) becomes \( \frac{dN}{dt} = (\text{fraction of daughter products which are targets, ie 0.85 for Tc_m}) \cdot N_t \cdot \sigma \cdot \phi \)?

I am not aware of any such examples.

I thought the activity of an element was always a constant and it was almost like a property to each element. I don't understand how they can change. Could you explain that a little more?

The half-life (not activity) is always constant, but in a condition of radiation equilibrium, daughter is produced as well as decay, so the effective half-life is not constant.

Also, what does neutron fluence mean in the process of activating isotopes?

Number of neutrons per unit area, or intensity of neutron beam. Greater intensity of the neutron beam, the more isotope produced.

Why is radon no longer utilized today?

Major reason is that radon is a gas, and can therefore leak out of the radon seed.

Do nuclei have proton absorption resonances like they do for neutrons?

A proton absorption resonance would only occur if the proton were absorbed into the nucleus, e.g., a \((p,n)\) reaction were to take place. Resonance peaks have been observed in this reaction, e.g., Ikeda et al, On resonance peaks in the \((p,n)\) reactions, Physics Letters, 2(4)169-171 (1962). Such reactions are possible and can be used as a source of fast neutrons, but normally we do not consider such interactions when we look at charged-particle interactions.

How did the "barn" get its name? Any truth to the legend it had to do with "the broad side of a barn"?

That story may be correct. It dates from nuclear research during WWII, when such research was secret. 1 barn = \(10^{-28}\) m\(^2\). Other units include the outhouse (10\(^{\text{b}}\)) and the shed (10\(^{24}\) b).

In transient equilibrium, \(A_d > A_p\) by the factor \( \left[ \frac{L_d}{L_d-L_p} \right] \) and the daughter appears to decay with the half-life of the parent. This is from slide 10. If the daughter is decaying at the same rate as it is produced by the parent, why aren't the two activities equal, which is what slide 11 says (isn't it?). Then on slide 12, \(A_d > A_p\) again.

Use equation \( A_d = A_p(t) \left( \frac{\lambda_d}{\lambda_d-\lambda_p} \right) \left[ 1 - e^{-\left(\lambda_d-\lambda_p\right)t} \right] \). We look at long time \(t\), when exponential term can be neglected.
Just for checking my understanding: In radiation equilibrium, the change in activity over time of daughter is equal to the value of parent ( \( \frac{dA_d}{dt} = \frac{dA_p}{dt} \) ), but the actual activities of daughter and parent are different? Again, look at large values of \( t \).

I'm still a little confused over the concept of isotope activation. The cross section area of a neutron or proton is defined as probability of interaction. The cross section of a particle is such a small number. Does that mean that the probability of interaction is very low? Also, shouldn't probability be unitless?

Cross-section is defined as the fractional change in number of nuclei (atoms) interacting per unit incident neutron fluence. Dimensional analysis gives us units of area for cross-section. It is related to probability of interaction, but not exactly equal to probability of interaction.

Is radiation equilibrium the exact point at which the decay rate of the daughter is equal to the rate of production of the daughter?

Equilibrium is point at which rate of production of daughter is equal to rate of decay of daughter. Activity curves of daughter and parent intersect.

Also, I'm still getting used to the lingo of medical physics. Can I use the words 'activity' and 'radioactive decay' interchangeably? I know that Activity is measured in Bq and Ci, so it is the number of disintegrations per second, which is also referred to as Radioactive Decay? Is this correct?

"Radioactive decay" is the process, "activity" is a measure of decay.

Just to make sure I am understanding this correctly: radiation, transient and secular equilibrium are essentially all cases when the half-life of the parent is greater than that of the daughter, just to varying degrees, correct?

Transient and secular equilibrium are both examples of radiation equilibrium.

If we are worried about the protection when we use Iridium-192, why not just use Iodine-125 for all treatments over a longer period of time?

There is a dose-rate effect. The photons emitted by I-125 are emitted at a much lower rate than those emitted by Ir-192. Also, there may be an issue of I-125 seeds being dislodged.

Do we not worry about the photons emitted by the Iridium-192 implant for the few days it remains implanted?

Yes. Ir-192 patient must be isolated during treatment.
Is typically all of the Tc99m able to be chemically separated from the Mo in the generator as the graph seems to indicate? Are there virtually no loses in the extraction process? How long does this process take? What do you mean that neglecting shielding of one atom by another MAY be important when calculating isotope activation? Is there no proof of this being important? Is there proof of it happening though?

When Tc-99m milking is done, is there any concern for the the 15% that simply produces a ground state Tc-99, or does this simply affect the amount necessary for injection to reach a specified dose? You mentioned that the milking is done chemically, so Tc-99m and Tc-99 would be milked together, since they still have the same chemical properties.

When a generator is eluted, the process is very quick. A saline solution is flushed through the column and the Tc-99m comes out in the saline whereas (most of the) Mo-99 stays stuck. Unlike the production of some other radionuclides, the separation process is very simple from a chemical standpoint. I don't know how much of the Tc-99m is removed, but people certainly act as if all of it is (by a reasonable volume of saline, which has probably been determined empirically to be the volume that will wash out most of the Tc-99m while maintaining a usefully high concentration). I think that it would be fair to say that the only “loss” in the extraction process would be Tc that stayed in the column.

I wrote “(most of the) Mo-99” above because a slight amount of the Mo-99 does come out in the elution process. There is a US Pharmacopeia limit of 0.15 uCi of Mo-99 per mCi of Tc-99m. As the Tc-99m decays to Tc-99, the moly to Tc-99m ratio increases until this limit is exceeded, which is one of the reasons why eluted Tc-99m expires after some stated time. Now, one might ask about the Tc-99 as the student did, and I often give this as an exam question. Since A = lambda N, and the decay constant, lambda, of Tc-99 is miniscule ((ln(2))/211,000 years), 30 mCi of Tc-99m decays to just a few Becquerel of Tc-99.

A good reference for these students would be Gopal Saha, Fundamentals of Nuclear Pharmacy. I’ve got the third edition. It is up to the sixth edition now and we’ve got a copy of the sixth edition in the physics library in the CPB. Saha discusses not just the modern generator in some detail but also older chemical extraction methods that aren’t so easy or perhaps so efficient.


Other than critical parameters like the "half-life of a radioactive material" and the "average energy of photons emitted by a radioactive material", are there any, that could significantly impact the decision of using a particular radioactive material as permanent implants?
Not really. Ionizing radiation is ionizing radiation. Long half-life may affect radiation biology; energy considerations also account for radiation safety measured.

Is "activating" an isotope the same thing as creating a radioisotope from a stable element or isotope by bombarding it in a nuclear reactor or cyclotron? If so, why do we call this "activation" of an isotope, a term that implies that we can selectively turn a process on or off?

Can’t argue nomenclature. Many examples of imprecise nomenclature, e.g., Dosimetrist, IMRT, stereotactic, etc.

Is there a more specific name for "radiation equilibrium"?

Other than transient vs secular equilibrium, no.

How did the "barn" get its name? Any truth to the legend it had to do with "the broad side of a barn"?

That story may be correct. It dates from nuclear research during WWII, when such research was secret. 1 barn = 10^{-28} m^2. Other units include the outhouse (10^{-6} b) and the shed (10^{-24} b). See https://en.wikipedia.org/wiki/Barn_(unit)