Temporary Personal Radioactivity

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As part of a bone scan procedure to look for the spread of prostate cancer, I was injected with radioactive technetium. In an effort to occupy/distract my mind, I used a Geiger counter to determine if the radioactive count obeyed the inverse-square law as a sensor was moved away from my bladder by incremental distances.

Within a few weeks after being diagnosed with prostate cancer and before surgery (radical prostatectomy), my urologist ordered a full body bone scan to help ascertain if cancer cells had already left my prostate and settled in their most likely place, bones. I reported to a hospital early one morning where I received an injection that included 27 microcuries of radioactive technetium-99m (^{99m}Tc). One curie (Ci) is defined to be 3.7×10^{10} dis/s, so 27 μCi is approximately 1.0×10^6 dis/s.[1]

The isotope of technetium chosen by doctors for this procedure has a half-life of 6.01 hours, which translates to 94% of it decaying within a day. The metastable nuclei decay by emitting 140 keV gamma ray photons,[2] which can then be detected by the hospital's scanning camera/machine. Prior to injection into the body, the ^{99m}Tc atoms are tagged (bound to) a pharmaceutical. The combination is unusually sensitive to bone rebuilding activities associated with fractures and tumors, and collects around these areas.[3]

After the technetium is injected into the human body, it circulates via the bloodstream through the body. Some of it ends up building up around fractures or tumors, and some of it remains in the bloodstream. Most of the technetium that remains in the bloodstream eventually finds its way to the bladder and is then eliminated from the body by urination.

Fig. 1. Front and rear full body bone scan images of my body obtained about five hours after being injected with 27 microcuries of ^{99m}Tc.

It is the technetium that builds up around scar tissue and/or tumors that is of interest to doctors. When the full body bone scan is conducted, the concentrations of the technetium are detected by their gamma emissions and show up on the image produced by the sensors of the scanning machine. See Fig. 1.

Of course, it takes time for a human's blood to circulate the technetium throughout the body. Much to my surprise, immediately after the 8 a.m. injection I was told by the technician that I could leave the hospital and return in the early afternoon for the full body bone scan. Knowing that I must be emitting gamma rays, I asked if it was acceptable for me to be with other people. He advised me that it was okay, but I should not be "within an arm's length of anyone for the rest of the day for more than a few seconds." When I asked if it would be okay for me to sleep in the same bed with my wife that night, he said something like: "No problem. Most of the radioactive materials will go to your bladder, and almost all will be gone from your body by then."

Having been a physics teacher for 33 years and now serving as an administrator (director of science), all sorts of questions came to my mind as I drove away from the hospital and toward my relatively isolated school office. For example:

1. If I shouldn't be within arm's length of anyone for more than a few seconds, what about all the other parts of my body?! Aren't they all within just about an arm's length of my bladder? They will be irradiated all day!
2. What about the occasional person who does come close to me? Should I warn him or her?
3. It has been decades since radioactive materials have been permitted in my school. Should I be there at all?
4. How do I know that it will be OK to share a bed with my wife tonight?

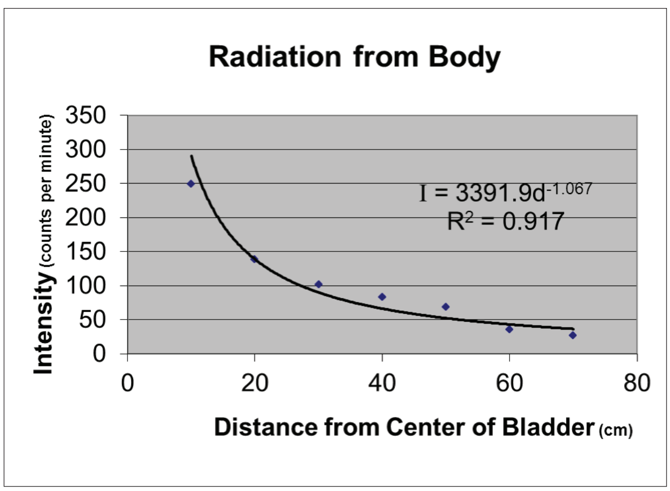


Fig. 2. Best-fit function graph obtained by using Excel showing an inverse relation of intensity with distance.

While driving to my office, I recalled that an old Geiger counter had been given to me months earlier and was still on a shelf in my office. I wondered if I would be able to detect the radiation I was emitting. It was at this point that an idea for an investigation came to me: If significant radiation could be detected and if the technetium mostly gathers in my bladder, then perhaps I could determine if there was an inverse-square relationship as the sensor is moved away from my bladder. Would the technetium located in the bladder simulate a "point source" of the radioactive emissions?

Shortly after arriving in my office, I found that the Geiger counter worked, and I quickly determined that the readings being obtained when I was standing close to the sensor were very different from the readings when I was a few meters away. When I held the sensor on my chest, the Geiger counter clicked away at what I found to be an alarming rate. It behaved in a similar way when the sensor was held near my bladder.

I made the decision to wait to take measurements to check about the inverse-square law relationship. The background radiation rate was established by letting the counter count while I left the office for periods of time. Before testing how the radioactive count was affected by the distance of the sensor from my bladder, I wanted to wait until my bladder was filled to the extent of being uncomfortable to provide the greatest concentration of technetium in that area. Approximately three hours after the initial injection, I began taking readings by first placing the Geiger counter sensor against the skin of my lower abdomen and recording the radioactive counts for two minutes. I estimated the distance from the sensor to the center of my bladder to be 10 cm.

The remaining measurements were taken by placing the sensor at increasing increments of distance from my bladder. For example, the next measurement was taken by placing the sensor 10 cm from my skin, which then was recorded as 20 cm from the center of my bladder. Measurements were taken in 10-cm increments up to 70 cm. I was unable to repeat the measurements for two reasons: 1) My bladder had become somewhat painful, and I needed to take care of that; 2) It was time for me to go back to the hospital for the full body scan.

The radiation measurements taken during the investigation are shown in Table I. When Excel was used to plot the data, I was intrigued to find that the $1/d^2$ did not seem to yield the most accurate function for the data. Instead, the graph that seemed to match the data best was the inverse of distance, not the inverse square of the distance (see Fig. 2).

Table I. Data showing the intensity of radiation as the sensor distance from the bladder is increased.

d (cm)	*I** (counts/min)
10	249
20	139
30	102
40	83
50	69
60	36
70	27

* Intensity data listed has been corrected for background

Radioactivity detected

The inverse relationship of the data indicates that my body was acting more like a line source of radioactivity rather than a point source of radioactivity. An analogy for this is the electric field strength as a function of distance from charged objects. If the object can be considered a point charge (e.g., small sphere), the field strength is dependent on the inverse square of the distance. However, if the object is a line of charge (instead of a point charge), the field strength is simply dependent on the inverse of the distance—just as I found in the investigation of my body.

Perhaps a more parallel analogy is that of light intensity. The intensity of light from a point source (e.g., tungsten lamp) drops off with the square of the distance. If the intensity of light is measured near a line source of light (e.g., long fluorescent tube), the light intensity is dependent on the inverse of the distance: $I \sim 1/d$.

It seems safe to conclude that the majority of the radioactive technetium had not become gathered in my bladder at the time of the measurements. Instead, the radioactive technetium was distributed throughout my body. Since I am a lot taller than I am wide, the Geiger counter was sensing me more as a line of radiation than a point source of radiation.

Another possible interpretation is that two sources of radiation were influencing the results. The concentration in the bladder could have caused a d^{-2} effect. Additionally the technetium spread throughout the rest of my body could have enabled the sensor to sense a *surface* of radiating material, causing no distance effect (d^0). These two factors may have been able to combine to cause a distance function exponent to be somewhere between zero and -2, depending on which was more dominant. Thus, it may have been coincidental that it ended up being so close to -1.0.

It should be noted that natural radioactive sources cause an average annual effective dose equivalent for people in the United States to be about 3 milliSievert (mSv). One Sv is the same biological effect as one joule of gamma rays absorbed in one kilogram of tissue.[4]

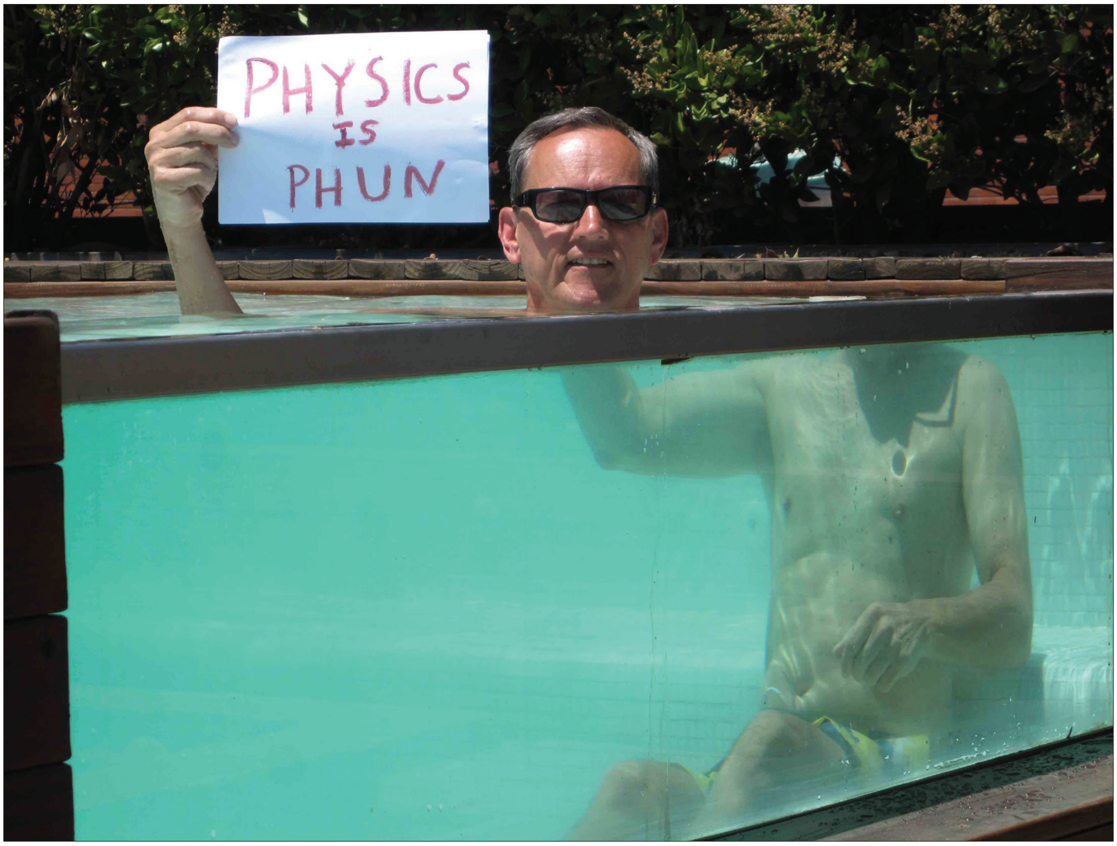
My rough calculations showed that the effective dose of radiation I received from this procedure was approximately 50 μSv, equivalent to about five days' worth of extra background radiation.

Not fully trusting the technician, I took the Geiger counter home that evening and checked the radiation being emitted by my body. By 10 p.m. I was unable to discern any radiation beyond that of background radiation. Since the time elapsed was only about 2½ half-lives later, it was apparent that most of the technetium had been eliminated from my body through urination. It appeared that the technician was correct, and it was safe to sleep in the same bed with my wife!

References

1. "Technetium-99m," en.wikipedia.org/wiki/Technetium-99m, accessed Jan. 3, 2012.
2. Walter R. Steiger, "A radioactive tracer in medicine," *Phys. Teach.* **37**, 408-409 (Oct. 1999).
3. "Technetium," Human Health Fact Sheet (Argonne National Laboratory, 2005), www.evs.anl.gov/pub/doc/technetium.pdf.
4. "Guidance for Radiation Accident Management," Radiation Emergency Assistance Center, orise.orau.gov/reacts/guide/measure.htm, accessed April 23, 2012.

Photo of the Month



While vacationing in Buenos Aires, we encountered this glass-sided pool and immediately realized we had a terrific physics moment. The location of the swimmer below water appears to dramatically shift due to the refraction of light passing from water to glass to air.

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