Fruit, Flights, and Fleas
Radiation Risk Communication
Marco Kaltofen   April 10, 2014

Radiation levels are measured with a large variety of units, including, (as abbreviated), Bq, Sv, uSv, Gy, pCi/g, rads, rem, J/kg, and others. These units are confusing to the general public. Instead of trying to use the standard units, general publications often use one of three possible physical units of radiation exposure. These are bananas, an airplane flight from New York to San Francisco, and a tiny but highly radioactive speck of plutonium, also called a fuel flea. During the Fukushima accidents in 2011, all three units were frequently used by news organizations.

It would be useful to have some quantitative and qualitative description of these three units of radiation exposure, and see if they can be related to more standard units of absorbed dose. The first step is to see how the media use these units. Step two is to look at peer-reviewed publications that have quantified the activities of these items, and find references that accurately describe the quality of the radiation from each.

Bananas: Forbes Magazine, (circulation 2 million), compared the risk of eating a meal of tuna contaminated by Fukushima to eating $1/20^{th}$ of a banana, (Forbes, 11/16/2013). According to a peer-reviewed reference cited by the Forbes article, (1), a "standard" banana was assumed to have a mass of 200 grams. Scientific publications are not above using bananas. The AAAS journal, Science, cited only equivalent exposures from cosmic rays and bananas in their description of annual background dose to residents around Yucca Mountain. (7) Wikipedia goes so far as to list a bananas equivalent dose, BAD, as a farcical standard unit of radiation dose. Converting to Sieverts, 1 BAD = 15 Bq. The USEPA notes that this is equivalent to a committed dose of 0.078 uSv. (6) (1 Bq = 1 Becquerel, 1 disintegration per second; 1 Sv = 1 Sievert = 1 J/kg).

Bananas turn out to be a poor unit of equivalent dose because there is no net dose. The human body maintains rigid homeostatic control over potassium levels. Any excess consumption of potassium, (and ^{40}K), would result in rapid excretion of the unnecessary potassium. (6) The committed effective dose, (CED), assumes a 50-year exposure, so 1 BAD may be in fact derived from 15 Bq per banana, but it does not truly yield a CED of 0.078 uSv. (6) A BAD is more accurately defined simply as 15 Bq per banana. This is a poor candidate for a physical approximation of radiation exposure, because it has no physical significance for net dose.

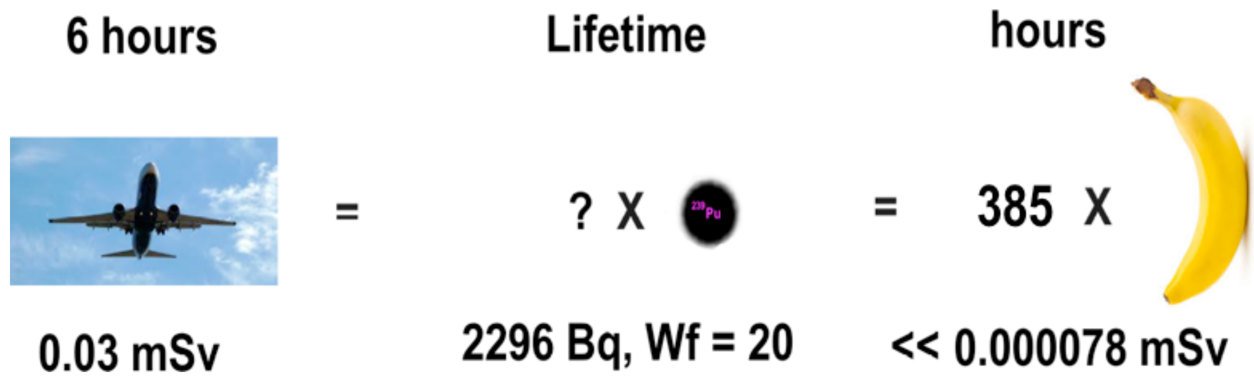
<u>Flights</u>: The Military Times, a Gannett Company publication, quantified the risk to US military ground personnel responding to the Japanese Tsunami as $1/3^{rd}$ of a cross-country airline flight, (Military Times, 1/14/2014). On 3/14/2011, two days after the initial meltdowns began at Fukushima, NBC news provided some specifics, reporting that a cross-country airline trip would generate an exposure of 0.005 milliSieverts per hour, (based on ICRP 1991). Unlike the banana, this does represent a net dose. The radiation absorbed on an airplane flight comes from cosmic radiation. This is primarily due to energetic charged particles and neutrons, as well as secondary particles ejected from targets in Earth's atmosphere. The secondary particles are mostly neutrons. Comparing the ICRP value for flights and the US EPA value for ^{40}K in bananas, a six-hour flight has a value equivalent to 385 BADs. A weighting factor of 10 is also added for these particles, due to their greater relative biological effectiveness compared to gamma photons from ^{40}K in bananas. The comparison is partially a fair one, because in both cases, actual exposures are transitory and measured in hours. Nevertheless, the BAD dose assumes lifetime exposure, which is false.

<u>Fuel fleas</u>: The University of California at Berkeley's Nuclear Engineering Dept. hosted a forum on radiation risk and measurement. (Disclaimer: The forum did not necessarily represent the views of the university or the department.) In the forum a plutonium fuel flea with a mass of 1 microgram was described as sufficient to cause cancer. (2) Evidently, a flea must be perceived as a much larger measure of risk than the dose from a banana or an airplane flight. Blogs and other media outlets picked up this unit, which was originally a quote from a presenter at a symposium at the New York Academy of Medicine on March 11, 2013. (3)

Many blogs, some with colorful names like, "Nuclear Doom", conflated the plutonium fuel flea with other more generic hot particles. Similarly sized radioactively hot particles of natural uranium, depleted uranium or ^{137}Cs would be expected to be less hazardous than ^{239}Pu. These would have lower specific activities or lower weighting factors than "fleas" of ^{239}Pu. This plutonium isotope emits a 5.24 MeV alpha particle, leaving behind a ^{235}U daughter. A weighting factor relates the relative biological effectiveness, (RBE), of different qualities of radiation. For example, alpha particles have a weighting factor of 20 compared to photons, meaning that the level of biological effect is assumed to be 20 greater. Generic radioactively-hot particles need not contain ^{239}Pu or any other alpha particle emitter, and would not have the same predicted effects. As much as these physical units make sense, it is reasonable to standardize our BAD, (amount of ^{40}K or 78 nSv); our flight, (charged particles and neutrons or 5 uSv); and our fuel flea, (1 ug of ^{239}Pu emitting 5.24 MeV alphas).

One fuel flea, a.k.a. one microgram of ^{239}Pu, is 1/239,000,000 moles or 62 nCi or 2296 Bq or 153 BADs. It is very important to note that the quality factor for ^{239}Pu is 20 times that of a BAD, since ^{239}Pu decays via alpha emission rather than by beta decay, gamma photon emission and EC as with ^{40}K. All other things being equal, the biologically equivalent absorbed dose from a flea is 20X larger than the same number of Bq from a BAD. This would mean that the absorbed dose from a flea is 3060X the absorbed dose from a BAD. Exposure to the flea's alpha particles is potentially a lifetime exposure, so unlike a BAD or a flight, a flea can reasonably be expressed as a lifetime committed effective dose.

This is what we have so far. The flight and bananas are equated based on the equivalent absorbed dose in mSv. These doses in Sieverts include the respective quality factors and are from 1991 ICRP Publication 60 recommendations.



The reality of the absorbed doses pictured is actually not even so simple as the graphic implies. Keep in mind that the true net absorbed dose for a banana is zero. The flight is over in a matter of hours. The fuel flea committed effective dose is actually quite complicated, as many biological processes can move plutonium among various tissues and organs in the body. The great length of the exposure period to the flea also means that decay products such as ^{241}Am may be in play, and that various excretion pathways will reduce exposure each year.

^{239}Pu has a 5.24 MeV alpha emission. This is equal to 0.84 E -12 Joules. On a per kilogram basis, this would be 0.84 E -10 rads per alpha emission. Since our flea is 2296 Bq, this is 1.93 E -7 rads per sec./kg or 6.1 rads per kg annually. The target organ and lifespan of the fuel flea exposure varies depending on whether it is inhaled or ingested. Rather than trying to track the hot particle across various tissues, one can assume a whole body dose or just a dose to the lungs. For a 70 kg adult, the whole body absorbed dose is 6.1 rads / 70 kg or 0.09 rads. For lungs only, the NIH gives a mean male adult mass of 0.88 kg, converting to a 6.9 rad organ dose. (Important: This ignores the normal tissue weighting factor of 0.12, because we simply assumed the entire dose went to the lung). For a 50 year (lifetime) whole body exposure, this is 4.5 rads or 0.045 Sv. Using the ICRP 60 value of 0.10 low rate low dose cancer risk per Sv, one gets a cancer risk of 0.23 %. (9) This is not the certain cancer described in the NY School of Medicine symposium. (3) Of course, the lung cancer risk is much higher if the flea is assumed to only expose the lung, instead of the whole body.

Some authors have described certain superlinear effects from low levels of hot particle exposure, which may create additional risks above and beyond that described by the linear no threshold (LNT) risk model. Pattison (5) suggests that high-z particles such as plutonium create recoil electrons when the particle is struck by background X-ray or gamma photons. This effect, however, is small, on the order of 10X background. It is also limited to the tiny target area of the particle compared to the target area presented by the body as a whole.

Having converted all three colloquial physical units into an absorbed dose that includes the impact of the actual linear energy transfer on biological effects, we get:

1 X 

= 1,500 X  = 5.8 E 5 X 

45 mSv 0.03 mSv << 0.000078 mSv

Of course some simplifying assumptions were made for the fuel flea, and the banana example has proven an inappropriate example from the start. The utility of a standard unit, the Sievert couldn't be more clear. Using Sieverts, these ad hoc physical analogies can at least be put on a relative scale.

But bananas aren't going away as a unit of radiation. Just picking a media reference from the date this paper is authored, April 10, 2014, in the Columbus, Ohio Dispatch, (10), "Industry officials say radiation isn't a problem. 'We are talking about naturally occurring radioactive materials,' said Tom Stewart, vice president of the Ohio Oil and Gas Association. 'It's the very same thing that you encounter on your granite desktop, or when you eat a banana.' "

References

1 Evaluation of radiation doses and associated risk from the Fukushima nuclear accident to marine biota and human consumers of seafood, Nicholas S. Fisher, et al, 2013, Proc. Nat. Acad. Sci., 110 (26) 10670-10675, www.pnas.org/cgi/doi/10.1073/pnas.1221834110

2 University of California at Berkeley, Dept. of Nuclear Engineering, nonpeer-reviewed forum, http://www.nuc.berkeley.edu/forum/218/1-millioninth-gram-inhaled-plutonium-will-give-you-cancer.2012-06-13

3 Symposium: The Medical and Ecological Consequences of the Fukushima Nuclear Accident, March 11-12, 2013, The New York Academy of Medicine, New York City, NY

4 Blog, nonpeer-reviewed, "Nuclear Doom", http://drsircus.com/medicine/nuclear-doom

5 Enhancement of natural background gamma-radiation dose around uranium microparticles in the human body, John E. Pattison, Richard P. Hugtenburg and Stuart Green, J. R. Soc. Interface 2010 **7**, doi: 10.1098/rsif.2009.0300 first published online 23 September, 2009

6 US EPA Report on Radiation Risk 402r-99-001 p. 16, (in whole and also as cited by en.wikipedia.org/wiki/Banana_equivalent_dose)

7 Science and Policy Clash at Yucca Mountain, Richard A. Kerr, *Science*, New Series, Vol. 288, No. 5466 (Apr. 28, 2000), p. 602

8 Am J Forensic Med Pathol. 2012 Dec;33(4):368-72. doi: 10.1097 / PAF.0b013e31823d29ad., Normal organ weights in men: part II-the brain, lungs, liver, spleen, and kidneys., Molina DK1, DiMaio VJ.

9 ICRP, 1991. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP 21 (1-3).

10 Columbus, Ohio Dispatch, April 10, 2014, Officials Dismiss Radioactive Threat from Fracking, http://www.dispatch.com/content/stories/local/2014/01/27/radioactive-threat.html