Name Solution Set

PHYS102 - Fall '16 - Good Nukes, Bad Nukes - Quiz #3

This quiz is open notes, but you must work without assistance from others. It is not enough to just give the answers, but you **must** explain your reasoning in words about how you got your answers. All questions are equally weighted. Questions start on the next page. Here is some potentially useful data.

Potentially useful data

The bare critical mass of plutonium-239 is 22 lbs. The bare critical mass of uranium-235 is 110 lbs.

The relative biological effectiveness (RBE) of X, γ, and β radiation is 1, of protons is 5, and of α particles is 20.

The half-life of $^{99}_{43}Tc$ is 6.0 hours. The half-life of $^{14}_{6}C$ is 5730 years. The half-life of $^{238}_{92}U$ is 4.47 billion years. The half-life of tritium ($^{3}_{1}H$) is 12.32 years. The energy equivalent of 1 amu is 931.5 MeV.

A 1 g sample of carbon taken from something living today has an activity of 14 decays per minute (dpm).

For every 10,000 people exposed to 10 rem of excess radiation, one would expect between 5 and 6 excess deaths due to cancer (in the linear, no-threshold, approximation). Of those 10,000 people, one expects 2000 to die of cancer without exposure to radiation above the radiation background.

1. In a 2011 study, the National Resources Defense Council noted that TV set-top boxes were becoming among the top energy users in residences. In many cases, the set-top boxes exceeded the energy usage for more traditional appliances such as refrigerators.

A typical HD-DVR box in use today averages 35 W and is powered on "24/7" (*i.e.,* all the time) even when no one is watching TV. How much would you spend for the electricity to run this one set-top box for a year if your utility were charging you $0.13/kWh?

If the set-top box uses energy at a rate of 35 W for one hour, it would use 35 Wh of electrical energy. There are 24 hr × 365 days/yr = 8,760 hours in a year. Therefore, the set-top box uses 8760 × 35 Wh = 306,600 Wh or 306.6 kWh each year. At a cost of $0.13 per kWh, that would represent a yearly cost of 0.13 × 306.6 =

$39.86

2. Recall that the overpressure of the blast due to a 1 Mt nuclear weapon dropped to 12 psi at a distance of 1.7 miles from ground zero. Also recall that 98% of the people exposed to a blast overpressure of at least 12 psi (and hence within a distance of 1.7 miles of ground zero for a 1 Mt bomb) died.

At what distance from ground zero would the overpressure from a 300 kt nuclear weapon (typical of a US strategic nuclear weapon) be 12 psi?

The equation that relates equivalent distances for equivalent blast effects (like overpressure) is:

$$\frac{R_1}{R_2} = \left(\frac{Y_1}{Y_2}\right)^{1/3}.$$

Let subscript 2 represent the distance at which there is an overpressure of 12 psi from the 1 Mt (= 1000 kt) nuclear weapon. Then we can find the distance at which there will be an overpressure of 12 psi from a 300 kt weapon using:

$$\frac{R_1}{1.7\ \text{mi}} = \left(\frac{300\ \text{kt}}{1000\ \text{kt}}\right)^{1/3} = 0.6694$$

$$\Rightarrow \quad R_1 = (0.6694)(1.7\ \text{mi}) = \boxed{1.14\ \text{mi}}$$

3. Recall that a 1 GW nuclear reactor produces 27 tons of high-level waste (HLW) each year and, for each 1000 lbs of that HLW, there are 8.9 lbs of plutonium isotopes.

The North Korean government operates a 5 MW nuclear reactor to produce plutonium for nuclear weapons. Estimate the number of plutonium bombs this reactor can produce each year.

If a 1 GW (= 1000 MW) nuclear reactor produces 27 tons of HLW, then a 5 MW reactor will produce $\left(\frac{5\ MW}{1000\ MW}\right) \cdot 27$ tons $= 0.135$ tons $= 270$ lbs of HLW. If 1000 lbs of HLW contains 8.9 lbs of plutonium, then 270 lbs will contain $270/1000 \times 8.9 = 2.4$ lbs of plutonium. Since the bare critical mass of plutonium is 22 lbs, this reactor can only produce $2.4/22 = 0.11$ plutonium bombs each year.

(This sounds reassuring but appears to be an underestimate for some reason. Also, the North Koreans have developed uranium enrichment technology and have the ability to create weapons using $^{235}_{92}U$. Estimates of how many weapons the North Koreans have range from 6 to 48.)

4. In the United States, a worker in a nuclear industry can legally receive radiation doses of up to 5000 mrem each year as part of their jobs. Assume that 1000 workers have 30 year careers and they receive the maximum dose each year. (Note: there are separate regulations that guarantee that this never, in fact, happens for any of them!) How many excess cancer deaths among these 1000 workers would you expect? How many would you expect to die of cancer without this occupational exposure?

If 10,000 people are exposed to 1000 mrem of radiation, we expect 5-6 excess cancer deaths according to the linear, no-threshold model (over the lifetimes of those exposed.)

So, if 1000 workers were exposed to 5000 mrem for one year, we would expect

$$\frac{5000 \text{ mrem}}{1000 \text{ mrem}} \times \frac{1000}{10,000} \times (5 \to 6) = (2.5 \to 3) \text{ excess}$$

cancer deaths just from that one year of exposure. If we then multiply by a 30 year career of exposure, we get $30 \times (2.5 \to 3) = \boxed{(75 \to 90) \text{ excess cancer}}$ deaths.

Without exposure a group of 10,000 people would expect about 2000 to die of cancer.* So the chances of dying of cancer among the workers increases from (taking the midpoint of 82.5 excess deaths) $\frac{282.5}{1000} = 28.3\%$ from 20%.

* So for 1,000 people expect $\boxed{200}$ to die without exposure.

But, as noted, no workers in real world get these kinds of exposures.