# PHYS102 - Good Nukes, Bad Nukes - Practice Sheet #3

1. My October electric bill just arrived. It told me that in the 31 days covered by the bill, my wife and I used 1,117 kW-hr of electrical energy. I was charged $124.42 for this energy. a) What would be my cost for keeping a 40 W light on for 8 hours each night at both my front and back doors for a year? b) How much money would I save (just considering the cost of the electricity) if I replaced those 40W bulbs with compact fluorescent bulbs that put out the same amount of light but only consumed electrical energy at a rate of 7 W?

a) a 40W light bulb kept on for 8 hours each night uses $40\text{W} \cdot 8\text{hr} \cdot 365 = 116{,}800\ \text{Wh}$ or 116.8 kWh in one year. If I was charged $\$124.\underline{42}$ for 1,117 kWhr, then I paid $\$124^{72}/1117\ \text{kWh}$ or $0.1114/kWh. So the cost of keeping <u>two</u> lights on for eight hours each night for a year would be

$$2 \cdot 116.8\ \text{kWh} \cdot \$0.1114/\text{kWh} = \boxed{\$26.02}$$

b) If I replaced the 40W incandescent bulbs with 7W compact fluorescent bulbs, the cost per year would be

$$\$26.02 \cdot \left(\frac{7\text{W}}{40\text{W}}\right) = \$4.55$$

So the amount I would save each year would be

$$\$26.^{02} - \$4.55 = \boxed{\$21.^{47}}$$

2. My electric bill also came with an environmental disclosure statement. It says that 14% of my electrical energy came from a nuclear power plant and that for every 1000 kW-hr of energy produced by nuclear power, 0.00951 pounds of high-level radioactive waste (HLW) was created. How much HLW was created by my October electrical energy usage of 1117 kW-hr?

14% of 1117 kWh is 156.38 kWh. If 0.00951 lbs of HLW is generated for every 1000 kWh, then my energy usage for the month created

$$\frac{156.38\text{ kWh}}{1000\text{ kWh}} \cdot 0.00951\text{ lbs} = \boxed{0.001487\text{ lbs}}$$

or about 0.024 ounces of HLW.

3. According to the Energy Information Administration (eia.gov) in 2010 the average residential customer used 958 kWh of electrical energy each month. How many residential customers can be served (on average) by a 1 GWe nuclear reactor?

A 1 $GW_e$ power plant produces

$$1\ GW \cdot 24\ \frac{hrs}{day} \cdot 30\ days = 720\ GWh = 720 \text{ million } kWh$$

of energy each month. (1 GW = 1,000,000 kW)

So this single plant can supply enough energy for

$$\frac{720{,}000{,}000\ kWh}{958\ kWh} = \boxed{752{,}000 \text{ homes}}$$

4. Using the data from my lectures on nuclear weapons design and on nuclear waste, estimate the number of critical masses of plutonium produced each year by a 1 GWe commercial nuclear power plant. (Roughly speaking this would be the number of fission weapons that could be produced each year if the spent fuel was reprocessed for weapons instead of being disposed of.)

From lecture we learned that a 1 GWe nuclear power plant produces about 27 tons = 54,000 lbs of HLW each year. We also learned that for each 1000 lbs of HLW, there were 8 lbs of ${}^{235}U$ and 8.9 lbs of "plutonium isotopes." So a 1 GWe reactor produces about $54 \cdot 8 = 432$ lbs of ${}^{235}U$ and 481 lbs of ${}^{239}Pu$ (assuming all the plutonium isotopes consisted entirely of ${}^{239}Pu$. In lecture we also learned that the bare critical mass of ${}^{235}U$ is 110 lbs and the bare critical mass of ${}^{239}Pu$ is 22 lbs. Putting this together, we see that the HLW from a 1 GWe power plant produces the raw material for 432 lbs/110 lbs = $\boxed{3.9 \text{ bombs}}$ of ${}^{235}U$ and 481 lbs/22 = $\boxed{21.8\ {}^{239}\text{Pu}}$ bombs.

(The question only asked about plutonium, however).

5. According to the Energy Information Administration, the total US energy use during 2010 was 3,884,000,000,000 kWh. The Union of Concerned Scientists estimate that one square meter of solar panels in Arizona would create about 1 kWh per day. What fraction of the state of Arizona would have to be covered in solar panels to provide all the electrical energy for the US (assuming same usage in 2010)? (The area of the state of Arizona is 295,300,000,000 square meters.) How many 1 GWe nuclear power plants would be required? (For comparison there are currently about 104 operating reactors in the US.)

1 kWh each day is 365 kWh every year. Thus to provide the total electrical energy needs of the US would require $3,884,000,000,000 \text{ kWh}/365 \text{ kWh}$ $= 10,641,096,000$ square meters of solar panel. This represent a fraction of $10,641,096,000/295,300,000,000$ $= 0.036$ or $\boxed{3.6\%}$ of the State of Arizona.

From problem 3, a 1 GWe power plant produces 720,000,000 kWh each month, so $12 \cdot 720,000,000 \text{ kWh} = 8,640,000,000 \text{ kWh}$ in a year. So we would need

$$\frac{3,884,000,000,000}{8,640,000,000} = \boxed{449.5}$$ 1 GWe nuclear power plants.

6. The *overpressure* is the increase in pressure over the normal, constant, atmospheric pressure caused by an explosion. The overpressure is a measure of the strength of the effects of blast only, ignoring other weapons effects like thermal radiation or fallout. In my lectures, a given overpressure is associated with different amounts of damage to people and buildings. It is useful to know how the distance from the center of the explosion (symbolized by $R$) for a given overpressure varies with explosive yield (symbolized by $Y$) in two different circumstances (signified by subscripts 1 and 2). That relation is:

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

In my lecture on the effects of nuclear weapons, I noted that the overpressure of a 1 Mt (megaton) nuclear weapon at a distance of 1.7 miles was 12 psi (pounds per square inch) and that resulted in the deaths of virtually all people within that distance from the center of the explosion. Using the relationship above, calculate the distance from the center of the explosion that gives the same overpressure for a 20 kiloton fission bomb (which is approximately equivalent to the explosive yield of the weapon used by the US on Nagasaki at the end of WWII).

This relation gives the distance where the blast effects would be the same for two bombs of two different explosive yields, so the value of the overpressure does not enter into the equation. Let subscript 1 represent the distance we are trying to find for the bomb with a yield of 20 kt, and subscript 2 represent the given result for the 1 Mt = 1000 kt bomb. Then

$$\frac{R_1}{1.7 \text{ miles}} = \left(\frac{20 \text{ kt}}{1000 \text{ kt}}\right)^{1/3} = 0.271$$

Therefore, $R_1 = 0.271 \cdot 1.7 \text{ miles} = \boxed{0.46 \text{ miles}}$

7. A typical radiation dose (one daily dose in a series of doses spread over some weeks) in the treatment of brain cancer is 200 rad. The radiation is in the form of gamma rays. What is the equivalent dose? If this were a whole body dose (which it is not!) what would you expect the acute symptoms of radiation exposure to be?

Since gamma rays have a quality factor of 1, the equivalent dose is $\boxed{\text{200 rem.}}$ From lecture, we learned that a dose of 200 rem = 200,000 mrem gave symptoms somewhere between "hemorrhage" (i.e. bleeding) and death within months.

So medical doses in radiation therapy are really serious doses that go along with explaining the serious side effects patients experience. But these doses are not whole body doses, they are narrowly confined to the region where the tumor occurs. Experience has shown that, on balance, the benefit of killing the tumor cells, outweigh the damage to healthy cells.

8. During 1986-87, 240,000 "liquidators" were used to encapsulate the radioactive material from the Chernobyl accident. Each such worker was exposed to more than 10 rem equivalent dose. If we make the assumption that each such worker received just 10 rem, how many excess cancer deaths would you estimate based on the linear no-threshold model?

In lecture we learned that for every 10,000 people exposed to 1,000 mrem = 1 rem of ionizing radiation, we would expect 5-6 excess deaths from cancer. Using the "linear, no threshold" model, that means we would expect

$$240{,}000 \times 10 \text{ rem} \times \frac{5\text{-}6 \text{ excess death}}{10{,}000 \text{ people}} = \boxed{1200 - 1440}$$

additional cancer deaths due to their work at Chernobyl. If they hadn't worked at Chernobyl, we would expect

$$\frac{240{,}000}{10{,}000} \times 2000 = 48{,}000 \text{ deaths from cancer}$$

among the workers. Thus, their increased risk of cancer death is about $\frac{1200}{48{,}000} = 2.5\%$ to

$$\frac{1440}{48{,}000} = 3\% .$$