Questions

1. Why has fusion been described as a nearly inexhaustible source of energy?
   Solution: Because hydrogen-2 (a.k.a. deuterium) is extremely abundant on earth. The oceans contain trillions of kilograms of the stuff.

2. Explain why nuclear plants are so expensive.
   Solution: Because building one takes an extremely long to time, is a very complex process, and requires a substantial amount of expertise.

3. In the monazite sands region of Kerala, India, adults and children (born and unborn) receive relatively high dose of radioactivity due to naturally occurring sources. The cancer rate is no higher in that region than in other parts of Kerala. How can this be possible?
   Solution: To say that they receive a relatively high dose doesn't mean that over the course of their lifetime they would receive a dose that would result in a noticeable increase in the cancer rate.

4. Why is it so important to model potential failures in nuclear reactors?
   Solution: First and foremost, so you can install redundant systems to try to prevent what failures you can prevent, and have contingency plans for those you can't prevent. Also, by considering the ways in which any system can fail, you may learn something about the system that you don't already know.

Problems

5. Average coal has a heat of combustion of 15 MJ/kg. At what rate (mass/time) must coal be burned to supply a 1000 MW_e utility plant? How much coal is this per day? What mass of uranium-235 would provide the same amount of energy per day? (Assume the energy release from the fission of one atom of uranium-235 to be 200 MeV.)

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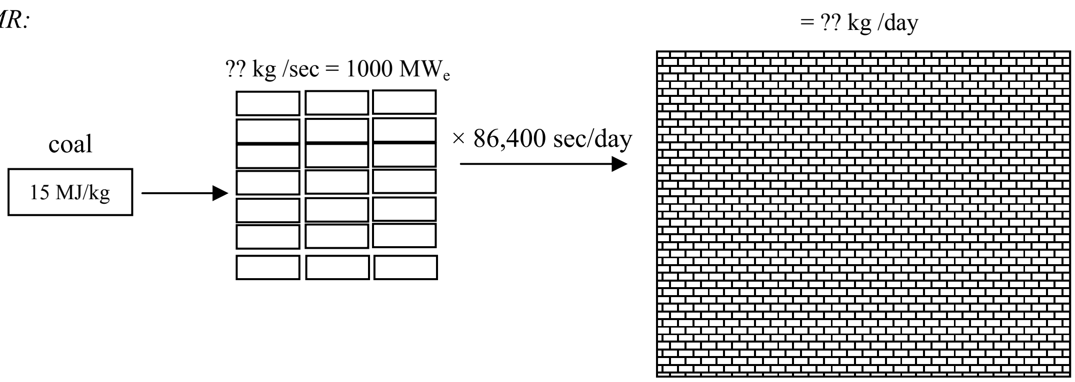

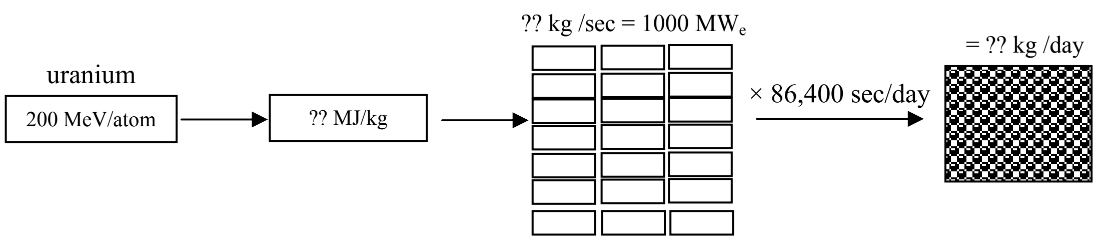

Knowns:	Energy content of coal = 15 MJ/kg Energy released from fission of one U-235 atom = 200 MeV 1 ev = 1.6×10^{-19} J; 1 Mev = 1.6×10^{-13} J 1 u = 1.6×10^{-27} kg the mass of a neutron is 1.009 u the mass of a proton is 1.007 u uranium-235 has 92 protons (periodic table) and 235 - 92 = 143 neutrons
Unknowns:	How much and uranium we need to supply a 1000 MW_e/day
Assumptions:	Rates of energy production from coal and uranium are constant Only 1/3 of the energy produced goes into the production of electricity
SOP:	The amount you use is proportional to the rate at which you consume it and the time over which you consume it
Equations:	Rate = amount/time

Solution: For both cases, since we'll assume only 1/3 of the energy produced actually is converted to electricity, we need…

$$1000MW_e \approx 3000MW = \frac{3000MJ}{\sec}$$

For coal this means…

$$\frac{3000MJ}{\sec}\times\frac{kg}{15MJ}\times\frac{86400\sec}{day} = 1.7\times10^7\,kg/day.$$ That's a lot of coal/day!!

One uranium-235 fission gives off…

$$\frac{200MeV}{atom}\times\frac{1.6\times10^{-13}J}{1MeV}\times\frac{MJ}{10^6J} = 3.2\times10^{-17}MJ/atom$$

One uranium atom has a mass of…

$$\frac{143\text{ neutrons}}{1}\times\frac{1.009u}{\text{neutron}}+\frac{92\text{ protons}}{1}\times\frac{1.007u}{\text{proton}} = 236.9u\times\frac{1.6\times10^{-27}kg}{u} = 3.8\times10^{-25}kg.$$

This means we've got

$$\frac{3.2\times10^{-17}MJ}{\text{atom}}\times\frac{1\,\text{atom}}{3.8\times10^{-25}kg} = 8.4\times10^7 MJ/kg.$$

(Aside: that's $\frac{8.4\times10^7 MJ/kg_{U-235}}{15MJ/kg_{coal}} = 5.6\times10^6$ times more energy/kg than coal!)

So how much uranium do we need in a day?

$$\frac{3000MJ}{\sec}\times\frac{kg}{8.4\times10^7MJ}\times\frac{86400\sec}{day} = 3.1\text{ kg},$$ which is an amount that you could easily hold on your hands. (Although I doubt you'd want to!)

PS If your recall some chemistry, then you could have by-passed some of the calculations for the mass of the uranium using Avogadro's number (number of atoms/mole), either way, your answer should come out the same.

6. What is the average dose of radioactivity absorbed by a person over a lifetime? What is the chance that this person would die of cancer as a result of that life-long dose?

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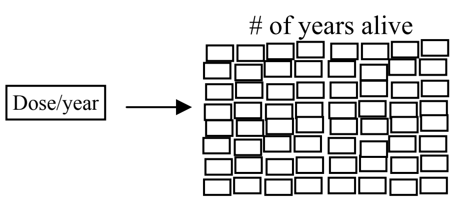

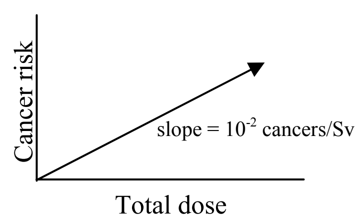

Knowns: *The "Knowns" in this problem are difficult to distinguish from the "Assumptions"*

Unknowns: The health effects of a typical, life-long dose.

Assumptions: Radiation dose is about 3 mSv/yr
Average American lives 76 years
Doses are cumulative and you never recover from a dose
Cancer risk is about 1×10^{-2} cancers/Sv (from table 20.8)

SOP: The amount you receive increases with the rate and the time of the exposure

Equations: Dose = rate × time

Solution: The typical American receives a life-long dose of 3 mSv/yr × 76 years = 228 mSv = 0.23 Sv
The total life-long cancer risk is 1×10^{-2} cancers/Sv × 0.23 Sv = 2.28×10^{-3} cancers/person.

In other words a typical cancer rate is $1/2.28 \times 10^{-3}$ cancers/person, or 1 out of 439 people dies of cancer from this typical life-long exposure.

7. Some residents of Pripyat (next to the Chernobyl reactor) were exposed to 2.5 Sv/hr for 15 hours before they were evacuated. Quantify the health effects that are to be expected in this population.

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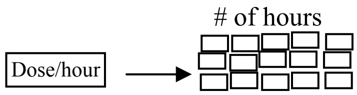

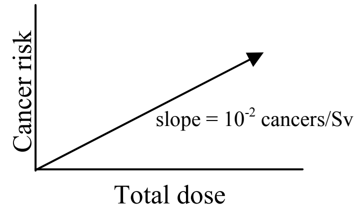

Knowns: Dose rate = 2.5 Sv/hr
Dose time = 15 hours

Unknowns: The health effects of this dose.

Assumptions: Doses are cumulative and you never recover from a dose
Cancer risk is about 1×10^{-2} cancers/Sv (from table 20.8)

SOP: The amount you receive increases with the rate and the time of the exposure

Equations: Dose = rate × time

Solution: The residents received a dose of 2.5 Sv/hr × 15 hours = 37.5 Sv
The cancer risk is 1×10^{-2} cancers/Sv × 37.5 Sv = 0.38 cancers/person.

In this case, the typical cancer rate is 1/0.38 cancers/person, or 1 out of 2.6 people dies of cancer from this accidental exposure.