War & Peace Cluster, Summit Program
Physics Assignment 5

Unit conversions

You will need the following conversions between the different units

- 1 MeV = 1.6 x 10^{-13} J
- 1 u = 1.66 x 10^{-27} kg
- 1 ton TNT is equivalent to 4.2 x 10^{9} J
- Speed of light (c) = 3 x 10^{8} m/s

Assignment

Let us try to answer the question "When the Hiroshima bomb exploded how much of the uranium was actually used?" It would be unrealistic to assume that all of the ^{235}U underwent fission, once the the chain reaction had gone out of control any remaining uranium (and all of the fission products) would be dispersed by the explosion.

Note: This assignment is an example of estimation, we do not know precisely some of the information, but we can make best guesses which will give a good idea of the answer. We'll never be able to tell if the correct answer is 12.3% as opposed to 12.5%, but we should be able to tell if the answer is all of it, or most of it, or only a small fraction of the total.

1. The estimated energy yield from Fat Man was equivalent to 16 ktons of TNT. What is that in J?

$$16000\,tons\frac{TNT*4.2\text{x}10^{9}\,J}{1\,ton\,TNT}=6.72\,x\,10^{13}\,J$$

2. If the fission of one ^{235}U nucleus yields 150 MeV on average, then how many Joules is released by one fission reaction?

$$150\,MeV*\frac{1.6\text{x}10^{-13}\,J}{MeV}=2.4\,x\,10^{-11}\,J$$

3. How many total fission reactions are required to yield the total energy from question 1?

$$N_{reactions}*\frac{2.4\,x\,10^{-11}\,J}{reaction}=6.72\text{x}10^{13}\,J$$

$$N_{reactions}=\frac{6.72\text{x}10^{13}}{2.4\,x\,10^{-11}}=2.8\text{x}\,10^{24}$$

4. Since the number of fission reactions is also the number of ^{235}U nuclei, what was the mass of uranium that was actually used?
   a. In atomic mass units (amu or just u)
   b. In kg

$$2.8x\,10^{24}\,atoms*\frac{235\,amu}{atom}=6.58x10^{26}\,amu$$

$$6.58x10^{26}\,amu*\frac{1.66x10^{-27}\,kg}{amu}=1.09\,kg$$

5. The amount of uranium used in the bomb was 64 kg[1], but not all of it was ^{235}U. Most was enriched to 89% but some was only 50% ^{235}U, for an average enrichment of 80%. Taking this average enrichment value, what was the amount of ^{235}U in the bomb?

$$80\,\%*64\,kg=51.2\,kg$$

6. What percentage of the ^{235}U in the bomb actually contributed to the explosion?

$$\frac{1.09\,kg}{51.2\,kg}=0.021=2.1\%$$

7. Not all of the mass from question 4 resulted in the explosion. Most of it remained as the mass of the fission products, and a small fraction as the mass of the neutrons which were produced. From the yield estimate the mass that was destroyed to create the energy yield from question 1. (Use $E = mc^2$, with the mass in kg and the energy in J.

$$6.72x10^{13}\,J=m*\left(3x10^{8}\,\frac{m}{s}\right)^{2}$$

$$m=\frac{6.72x10^{13}}{9x10^{16}}=7.4x10^{-4}\,kg=0.74\,grams$$

1 https://en.wikipedia.org/wiki/Little_Boy