Introduction

This exercise was meant to develop a class estimate of the amount of radioactive material which was given to Alexander Litvinenko, a Russian dissident living in exile in London. All the required physics has been covered already in class, after which there are two remaining problems

- There are a number of steps involved, and for non-science majors to navigate their way through them is asking a lot.
- Although some quantities are known (principally from the properties of the radioactive isotope) others are not and reasonable assumptions have to be made.

We start with an unrelated example to introduce the idea of estimation before tackling the problem at hand.

Estimation 1

Question: How many babies will be born in the US in the next hour?

Assumptions:

1. The population of the US is constant. If that is true then the number of babies born must equal the number of deaths. Not strictly true but then
   a. the rate of change is small, and this is only an estimation
   b. some of the change is due to a net immigration into the US
2. Population of the US is about 300 million
3. Average human lifespan in the US is about 80 years
4. Birth rate is constant day by day, and hour by hour.

Estimation:

1. Number of deaths per year = 300 million / 80 = 3,750,000 per year
2. Number of deaths per day = 375,000 / 365 days = 10,000 per day
3. Number of deaths per hour = 10,000 / 24 hours = 400 per hour
4. Number of births per hour = 400 per hour

Notes:

1. Actual number of births in 2013 = 3,932,181[(1)]
2. Assuming a constant rate throughout the year this is a rate of 450 per hour.

Estimation 2

Question: How much radioactive material was given to Alexander Litvinenko?

Known:

1. Poison was ^{210}Po.
2. ^{210}Po is an α emitter with an energy of 5.4 MeV (8.6×10^{-13} J).
3. Atomic mass of ^{210}Po = 209.98 amu = 3.5×10^{-25} kg.
4. Half life of ^{210}Po = 138 days = 1.2×10^{7} s. From this the decay constant = ln2/1.2×10^{7} s

1 http://www.cdc.gov/nchs/births.htm

$= 5.8 \times 10^{-8}$ per second.

Assumptions:

1. 100 % of α particle energy was absorbed.
2. Quality factor (rems per rad) for α particles is 25
3. Mass of victim = 100 kg
4. Dose equals LD50 value of 450 rem.

Students were given the flow chart in figure 1, except all boxes were left blank, to be filled in by them. After filling all knowns and assumed values the chart shows a clear path from the last assumption (the dose) to the amount of material given to the victim.

Known quantities are filled in first (shown in red) followed by the assumed quantities (shown in blue). Once these have been entered there is a path leading up the page from the assumed dose (450 rem) to the final answer for the amount of material (1.5 μg)

Discussion

The resulting inquiry found that Mr Litvinenko ingested about 10 μg[(2)] of ^{210}Po, somewhat larger than our estimated value. However, our estimate is within an order of magnitude of the accepted value, a good result given the simplicity of the calculation. Furthermore it is easy to see the principal reason for the difference. We have assumed that he was given the LD50 dose, that is 450 rem, whereas any assassin would surely give a much larger dose than that likely to have a 50% chance of killing his victim. If we increase our assumed dose from 450 rem to about 2500 rem, then our final answer for the amount of ^{210}Po would be in very good agreement with the accepted value.

2 https://en.wikipedia.org/wiki/Poisoning_of_Alexander_Litvinenko#Po-210_content_in_the_body_of_Litvinenko

Figure 1a: Flow diagram outlining variables in each box, and relationships between them.

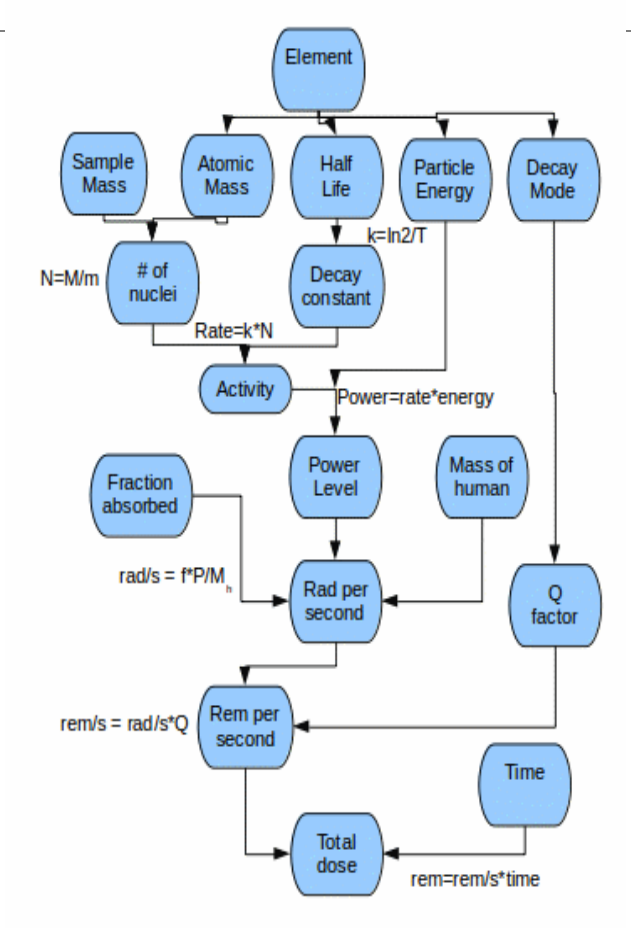

Figure 1b: Assignment of variables. Known variables are in red, assumed variables in blue, and calculated variables in green.