Problem Set 1
Nuclear Physics 2005, by Armin Reichold
This draws on lectures 1, 2 and 3, discussing the SEMF and decays

Q1. [About the SEMF]
Describe the semi-empirical mass formula for nuclei in your own words. Pay particular attention to the following points.

1. Which physical models are underlying the formula?
2. Which observations motivate these models?
3. Which predictions can the formula make?
4. What can the formula tell us about beta decay of nuclei?
5. Which limitations and shortcomings does the formula have?
6. To which nuclei (size) does the model apply and why?
7. Anything else that you think sheds light on the SEMF

Q2. [SEMF, finals 1978 Q5]
The radius R of a nucleus with mass umber A is given by the formula $R_0 = r_0 A^{\frac{1}{3}}$ with $r_0 \approx 1.2 fm$. Using the Fermi-gas model show that the energy ϵ_F of the Fermi level in a nucleus with equal numbers of protons and neutrons is given by:

$$\epsilon_F = \frac{\hbar^2}{2M_P r_0^2}(9\pi/8)^{\frac{2}{3}} \tag{1}$$

Estimate the total kinetic energy of the nucleons in an ^{16}O nucleus. For a nucleus with neutron number N and proton number Z the asymmetry term in the semi-empirical mass formula is $\gamma\frac{(N-Z)^2}{A}$. Assuming that $|N-Z| << A$ use the Fermi-gas model to justify this form and estimate the value of γ.

Q3. [The Oklo natural reactor]

1. The SEMF for the mass of a nucleus characterised by atomic number Z and mass number A should be well known to you. Write it down and give a brief account of the physics underlying the terms in it. (Note: use the from which has Z^2 in the Coulomb term, not $Z(Z+1)$. What would the latter form try to describe?). The values of the coefficients should be taken as:

Volume term	$= 15.56$
Surface term	$= 17.23$
Asymmetry term	$= 23.285$
Coulomb term	$= 0.697$
Pairing term	$=$ has an amplitude of 12

   All in unit of MeV ($c^2 = 1$)

2. The fission of $U(235, 92)$ by thermal neutrons is asymmetric, the most probable mass numbers of fission fragments being 93 and 140. Estimate the energy released in fission of $U(235, 92)$ and hence the mass of $U(235, 92)$ consumed each second in a 1 GW reactor.

3. In almost all uranium ores, the proportion of $U(235)$ to $U(238)$ is 0.0072. However, in certain samples from Oklo in the Gabon, the proportion is 0.004. Assuming that a natural fission reactor operated in the Gabon 2×10^9 years ago, estimate the total energy released from 1 Kg of the then naturally occurring uranium.

4. How might the hypothesis that U(235) was depleted by fission be tested?

Data on half lives: $t_{1/2}(U(238)) = 4.5 \times 10^9$ years, $t_{1/2}(U(235)) = 7.0 \times 10^8$ years