

# Power from radioactivity

## Introduction

Having investigated the physics of radioactivity, it is now time to ask the question “Can I make a viable power plant for the production of energy from a radioactive sample?” To answer this question you need to have a clear idea of the relationship between half life and activity, and of the concept that energy is carried away by the radioactive emission ( $\alpha$ ,  $\beta$ ,  $\gamma$ ).

## Assumptions

To try to answer this question we need to make some assumptions.

- Which isotope are we using. For the moment let us assume that it is  $^{238}\text{U}$ , which in the end will be the isotope we use in nuclear power stations. Later we can discuss what would be the result of selecting a different isotope.
- Of the energy emitted, how much is actually turned into electrical energy. Let us assume 100 %, although the actual figure is likely to be only around 30 %.
- The amount of material available to us. Assume 1000 kg (about a ton), which is a lot of  $^{238}\text{U}$ .

## Data

Now that we have selected the isotope we can look up the following data

- half life =  $4.5 \times 10^9$  years
- energy released = 4.270 MeV (as an  $\alpha$  particle)

## Calculation

First we need to do some conversions

- Convert the time to seconds (we need to this because the unit of power is the Watt, which is equivalent to J/s)
  - There are  $60 \times 60 \times 24 \times 365 = 3.15 \times 10^7$  s in a year, and so
  - $4.5 \times 10^9$  years =  $4.5 \times 10^9 \times 3.15 \times 10^7$  s =  $1.4 \times 10^{17}$  s
- Convert the energy to Joules (same reason)
  - 1 MeV =  $1.6 \times 10^{-13}$  J, and so
  - $4.270$  MeV =  $4.270 \times 1.6 \times 10^{-13}$  J =  $6.8 \times 10^{-13}$  J

Now find the decay constant

$$k = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{1.4 \times 10^{17}} = 4.9 \times 10^{-18}$$

and the number of nuclei. (One nucleus has a mass of 238 amu =  $238 \times 1.66 \times 10^{-27}$  kg)

$$\text{number of nuclei} = \frac{1000 \text{ kg}}{238 * 1.66 \times 10^{-27} \text{ kg}} = 2.6 \times 10^{27}$$

We can now find the activity

$$\text{activity} = \text{decay constant} * \text{number of nuclei} = 4.9 \times 10^{-18} * 2.6 \times 10^{27} = 1.3 \times 10^{10} \text{ s}^{-1}$$

That might seem to be a lot (13 billion disintegrations per second). But remember that each disintegration results in only one  $\alpha$  particle, with a very small energy ( $6.8 \times 10^{-13}$  J). The rate at which we get energy (the power) is only

$$\text{Power} = \text{activity} * \text{energy per particle} = 1.3 \times 10^{10} * 6.8 \times 10^{-13} = 0.0085 \text{ W}$$

That's not even enough to light one flashlight! And that is if we can convert energy of the particles to electrical energy with 100% efficiency.

### Other choices

So what could we do? Certainly one choice would be to choose a more radioactive isotope, but that brings other problems

- Choosing  $^{137}\text{Cs}$  with a half life of 30 years would help a lot, but not enough. If you re-run the calculation above with the new half life then 1000 kg of  $^{137}\text{Cs}$  would generate about 1 MW, still 100 -1000 times less than we need for a viable power station.
- Choosing  $^{25}\text{Al}$ , with a half life of only 7 seconds, would make the numbers above work out favorably, but after only one minute (equivalent to about 8.5 half lives) all the  $^{25}\text{Al}$  would have decayed away, and you would have to refuel with another 1000 kg of aluminum.
- Isotopes with short half lives don't occur naturally, they have to be made, and only in limited quantities, and the shorter the half life, the less there is. Where on Earth are you going to get 1000 kg of  $^{25}\text{Al}$  from? (Answer: you're not. There hasn't been that much  $^{25}\text{Al}$  on Earth, ever.)

### Conclusion

For the most part, we cannot use radioactivity as the basis of a power station. The radioactive processes are simply too slow. It has been done for very limited use, such as powering a single piece of equipment in a remote location where electricity is not available. But as for supplying San Francisco, or even Turlock – forget about it!

We have to find some other way, a means by which we can induce a “radioactivity-like” process, rather than passively waiting for it to happen. And that means nuclear reactions.