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A1 2 Cooking a Radioactive Cow?

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Abstract

Radioactive nuclei release energy as they decay. We investigate the temperature increase of a cow as the cow consumes contaminated grass near a nuclear accident. We calculate if the cow eats the grass for 1 month, its internal temperature will increase by 2.2×10^{-4} K. Also, we find out the cow would need to eat 2.0×10^{12} kg of grass in one bite to be slow-cooked over a few hours.

Introduction

Nuclear power plant accidents are rare but devastating and can affect large areas. One consequence is that nearby grasslands are contaminated with radioactive substances, and animals can ingest them, which release energy and heat up the animals. We ask, how severe would this heating process be for a cow that eats the contaminated grass? And how much of this grass would it need to consume to be cooked enough to be edible?

Assumptions

- We set the cow's mass m to 900 kg [1].
- The cow eats grass with an activity of 20000 Bq kg^{-1} for 1 month, which was the activity of grass measured 180 km away from the Fukushima incident [2].
- This activity remains constant, as the half-life of $^{137}_{55}$Cs is 30 years [3].
- 80% of the cow's mass is water [4], we assume the entire cow's specific heat capacity is that of water $c = 4200$ J kg^{-1} K^{-1} [5].
- We assume the cow heats up uniformly.

Equations

To calculate the temperature rise of the cow, we first need to determine the number of radioactive decays for $^{137}_{55}$Cs. The equation for radioactive decay is $N = N_0 e^{-\lambda t}$, where N_0 is the initial number of $^{137}_{55}$Cs atoms in a cow, N is the number of atoms remaining after time t (s), λ (s^{-1}) is the decay time constant and $\lambda = \ln(2)/t_{1/2}$, $t_{1/2}$ is the half life of $^{137}_{55}$Cs (=1×10^9 s) [5]. The number of decays dN within a time period t is

$$dN = N_0(1 - e^{-\lambda t}) \tag{1}$$

The amount of $^{137}_{55}$Cs present is often in activity R (decay/s), where $R = \lambda N$ [5]. The energy required to raise the cow's temperature by the amount ΔT is

$$E = mc\Delta T \tag{2}$$

where m is the total mass of the cow (=900 kg), c is the specific heat capacity of water (=4200 J kg^{-1} K^{-1}), and ΔT (K) is the change in temperature [5]. The total energy released from the decay of dN atoms is dNE_{Cs} where E_{Cs} is the energy released by the decay of one $^{137}_{55}$Cs atom (=1 MeV) [3]. Equating the energy released and

(2) gives

$$\Delta T = \frac{dNE_{Cs}}{mc} = \frac{N_0(1-e^{-\lambda t})E_{Cs}}{mc} \quad (3)$$

Result and Discussion

In one month, the cow consumes, on average, 500 kg of grass [6]. This amount of food has a total count rate of 1.0×10^7 Bq, equivalent to 1×10^{16} ${}^{137}_{55}$Cs atoms. We substitute this into equation (3) and set the time to $t = 1 \times 10^9$ seconds. We discover that even after 30 years pass (which is the typical lifespan of a cow [7]), the temperature rise in the cow is only 2.2×10^{-4} K, which is not a significant change in temperature. The cow is safe for its whole life.

But what level of radioactive activity inside the cow would be required to actually cook it, and how much grass does it take to reach this activity (assuming the cow eats it all in one bite)? As beef requires an internal temperature of around 60-70 °C to be safe for consumption, it needs to be heated up by approximately 30 °C [8]. As it has to be slow cooked for hours, we set time $t = 5$ hr $= 18000$ s. We take the temperature change ΔT to be 30K, substitute it and t into Equation (4) to find the activity R:

$$R = \frac{mc\Delta T}{tE_{Cs}} \quad (4)$$

This results in an average activity of 3.9×10^{16} Bq, which means for grass of 20000 Bq kg^{-1}, the cow must eat approximately 2.0×10^{12} kg of grass to be cooked over 5 hours. This is an absurd amount of grass, which is obviously impossible in reality.

Conclusion

To conclude, we can see that a cow eating 500 kg of grass that has a radiation dose of 20000 Bq kg^{-1} would not suffer any complications due to the heat increase. Yet, the cow would still be vulnerable to long-term effects such as acute radiation poisoning [9], and irradiation of its cells, which leads to DNA damage. Based on the cattle that survived the Fukushima disaster [10], it is unlikely this dose of radiation would harm them enough to kill them in a month.

To actually cook the cow, its temperature would need to be around 70 °C, which can be achieved by eating 2 trillion kilograms of grass, which is completely impossible. Needless to say, the meat would still be extremely radioactive, and it should not be consumed!

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