Journal of Physics Special Topics
An undergraduate physics journal

S4_6 Fallout: Put Another Quarter In The Nuke-Box

M. J. Duggan, J. T. Best, S. M. B. Croxford

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

November 21, 2017

Abstract

In Fallout 4, Mini Nukes can be slung at enemies. We found a nuke to have 2.99 times the explosive energy of a standard issue US Military grenade, and thus determined the mass of Plutonium-239 required to achieve this energy to be 1.06×10^{-8} kg.

Introduction

In the American post-apocalyptic wasteland game "Fallout 4", the player can acquire a "Mini Nuke", fired from a slingshot device. This paper will determine how much nuclear material is required to power this bomb.

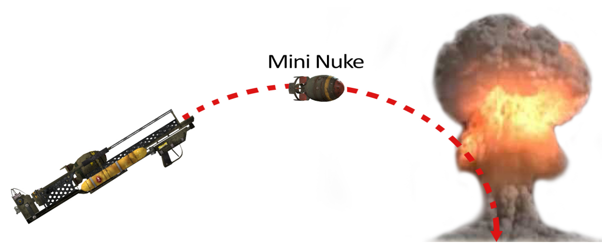

Figure 1: Illustration of a Mini Nuke detonation.

Theory

In the game, the damage statistic of the nuke was found to be 450 [1]. We compared this to a fragmentation grenade within the Fallout universe, which has a damage rating of 151 [2]. Extrapolating from this, assuming damage scale is linear, we can see that a Mini Nuke is 2.99 times more damaging than a frag grenade. We assume that the Mini Nuke is modelled on the "Fat Man" nuclear bomb. Fat Man contained 6.19 kg of Plutonium-239 (^{239}Pu) core, but fissioned only 1 kg making the process 16.1% efficient [3].

The mass defect determines the energy released during the fission of a nuclei, from Einstein's famous equation $E = mc^2$ where E is the energy, m is the mass and c is the speed of light in a vacuum; this energy is known as the binding energy. A more thorough equation for the binding energy of a nuclide with a atomic number Z and a mass number A is

$$B = mc^2 = m_{\mathrm{A}}c^2 - Zm_{\mathrm{e}}c^2 + B_{\mathrm{e}}, \tag{1}$$

where $m_{\mathrm{A}}c^2$ is the atomic mass energy, $Zm_{\mathrm{e}}c^2$ is the mass energy of electrons, and B_{e} is the electronic binding energy [4]. Z is the number of protons, which is also equal to the number of electrons resulting in a neutrally charged nulcei. The electronic binding energy, B_{e}, is typically 1×10^{-6} of B, hence it can be ignored for the purposes of this paper. The binding energy for a nuclide ${}^{A}_{Z}X$ is the difference between its mass energy and its constituent nucleons [4] giving

$$B = [Zm_{\mathrm{p}} + Nm_{\mathrm{n}} - \{m(^{\mathrm{A}}X) - Zm_{\mathrm{e}}\}]c^2. \tag{2}$$

Where $[Zm_{\text{p}} + Nm_{\text{n}}]c^2$ is the nucleons, $[\{m(^{\text{A}}X) - Zm_{\text{e}}\}]c^2$ is the mass energy of nuclide, and $m_{\text{A}} = m(^{\text{A}}X)$. Additionally m_{p}, m_{n}, and m_{e} are the mass of a proton, neutron and electron, respectively.

Results

We compared the Mini Nuke to a standard US Military M67 grenade. It has a mass of 0.397 kg and is comprised of Composition B [5]; ingredients are 59.5% Research Department Explosive (RDX), 39.4% Trinitrotoluene (TNT) and 1% Paraffin Wax [6]. RDX and TNT have mass 0.236 kg and 0.156 kg, respectively. RCX was designed to be 1.5 times the explosive energy of TNT per unit mass, and 1 kg of TNT is equivalent to 4.18 $\times 10^6$ J. Thus, the energy of TNT and RDX are 6.52×10^5 J and 1.48×10^6 J, respectively and the resultant explosive energy of the grenade is $E = 2.13$ MJ. Since the energy of the Mini Nuke is 2.99 more damaging, it therefore has an initial detonation energy of $E = 6.37$ MJ.

Plutonium-239 (^{239}Pu) has a nucleon count of 94 protons, Z, and 145 neutrons, N [9]. The isotope mass of ^{239}Pu is 239.0521634 u, where u is the unified atomic mass unit (UAMU), which is equivalent to 1.660539040 $\times 10^{-27}$ kg [10]; we will use up to 3 significant figures. Substituting these values into equation (2) we get the binding energy of ^{239}Pu to be 1.48×10^{-9} J or 9.22 GeV. In order to find the mass of the ^{239}Pu required, we now find the number of fissions for it to meet the energy needed. This can be found using Equation (3):

$$\frac{E}{B} = \frac{6.37 \times 10^6}{1.48 \times 10^{-9}} = 4.30 \times 10^{15}, \qquad (3)$$

therefore 4.30×10^{15} nuclei fissions occurred in order to produce the required energy of the bomb.

This can now be converted into mass required for fission by multiplying the number of fissioned nuclei, isotope mass, and the UAMU 1 kg mass equivalent together. Substituting the relevant values gives $m_{\text{f}} = (4.30\times10^{15})(239)(1.66\times10^{-27})$ resulting in $m_{\text{f}} = 1.71 \times 10^{-9}$ kg. As mentioned in the Theory section, Fat Man was only 16.1% efficient at fission, therefore the total mass of the Mini Nuke is

$$m_{\text{total}} = \frac{m_{\text{f}}}{0.161} = 1.06 \times 10^{-8} \text{ kg}. \qquad (4)$$

Conclusion

We found that the amount of nuclear material required to produce the destructive capabilities of a Mini Nuke to be 1.06×10^{-8} kg. This means that a Mini Nuke would be easily portable.

References

[1] `https://goo.gl/bA3Fyf` [Accessed 21 November 2017]

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[3] `https://goo.gl/brr96m` [Accessed 21 November 2017]

[4] I. Hutchinson, “PA322 Atoms and Nuclei Unit 3 Lecture 12”, University of Leicester, Department of Physics and Astrophysics, 2017.

[5] `https://goo.gl/KJw6Ka` [Accessed 21 November 2017]

[6] `https://goo.gl/AjaFX5` [Accessed 21 November 2017]

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[10] `https://goo.gl/adrf4o` [Accessed 21 November 2017]