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P1_1 Could Bruce Willis Save the World?

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Abstract

The film Armageddon (1998) puts forward the possibility of using a nuclear weapon buried deep within an Earth-bound asteroid to split the asteroid in two, each half clearing opposite sides of the Earth with only relatively minor damage. This article investigates the feasibility of such a plan and shows that even using the largest nuclear weapon made to date, the bomb comes over 9 orders of magnitude short of the yield required.

Between a Rock and a Nuclear Weapon

In the film "Armageddon", Bruce Willis portrays an oil drilling platform engineer who is charged with landing on the surface of an Earth-bound extinction-level asteroid, drilling to the centre and detonating a high-yield nuclear weapon, splitting the asteroid in half. This way the asteroid passes either side of the Earth with minimal fallout onto the surface [1].

Certain information can be gleaned from the movie itself on the size, composition and trajectory of the asteroid and so an investigation into whether this is feasible can be attempted.

A series of assumptions must be made due to limited information in the film. First, the asteroid is approximated as a spherical object 1000km in diameter (the asteroid is quoted as being the size of Texas [1]) that splits into two equal sized hemispheres. The asteroid in the film reaches a clearance either side of the Earth of 400 miles (640km) [1] which is the assumed value for our calculation. In addition we will be ignoring any binding energy (gravitational or otherwise) of the asteroid and gravitational effects from the Earth are ignored (in other words nothing is holding the asteroid together and nothing will attempt to pull it back upon splitting).

The distance of the cut-off point (the point referred to as the zero barrier in the movie beyond which splitting the asteroid would still result in an impact) was derived using certain timed events in the movie, most notably the slingshot manoeuvre around the moon to land on the asteroid, and the asteroids velocity of 22,000 mph (10 kms^{-1}). The distance from the Earth at which the bomb is detonated is taken as 63,000 miles (101000km) [2].

Using a simple energy analysis, the two halves must each have enough kinetic energy perpendicular to the direction of the asteroid's original motion to pass the Earth before crashing into it. That is, the time for it to travel the 63,000 miles to the Earth's surface must be greater than the time it takes for each hemisphere to reach the safe clearance distance either side of the Earth.

Considering one hemisphere and taking the critical perpendicular velocity (where both times are equal and the hemisphere just clears the Earth):-

$$\frac{D}{v_1} = \frac{R}{v_2}\ , \qquad (1)$$

where R is the clearance radius (Radius of Earth plus 400 miles), D is the distance to detonation from the Earth, $v_1$is the asteroids pre-detonation velocity and v_2 is the hemispheres post detonation perpendicular velocity. Rearranging for v_2 and substituting into the kinetic energy equation:-

$$KE = \frac{1}{2}mv^2, \qquad (2)$$

and using the fact that there are two hemispheres of density ρ and volume $\frac{2}{3}\pi r^3$, where r is the radius of the asteroid (ie. half a spheres volume), that each require the kinetic energy to clear the Earth, the resulting total kinetic energy required is:-

$$E = \frac{2}{3}\pi r^3 \rho \left(\frac{Rv_1}{D}\right)^2. \quad (3)$$

From the film, the substance of which the asteroid is composed is 'Iron Ferrite', assumed to be a mixture of Iron based minerals. This gives an upper bound on the density of the asteroid as pure iron is much denser than the majority of minerals it can produce. An approximate density of 7,000 kgm^{-3} was used for our calculation. Using the data provided above, the energy required was calculated to be $8 \times 10^{26} J$.

A really Big Bang

The bomb used in the film is referred to simply as an H bomb [1]. No specific information is given on the yield. However we will make the fairly obvious assumption that all the effort possible would be put into saving Earth and so that the largest bomb made to date would be used. The bomb in question is known as Big Ivan or the Tsar Bomba, effectively King of Bombs, made by the Soviet military and tested on October 30th 1961. It had an overall yield of 50 megatons [3], though it was designed to allow for 100 megatons. A simple conversion may be made between yield and the energy of the explosion, namely 1 megaton = 4.18 petajoules [4]. Thus the total energy output of the bomb at maximum yield is approximately $4.18 \times 10^{17} J$.

Sorry Bruce…

It can clearly be seen that this number comes up well short (by over 9 orders of magnitude) of the required kinetic energy, and this is based on a number of assumptions, the majority of which work in the bomb's favour.

The energy of the bomb is assumed to be completely converted into the kinetic energy of the asteroid with no losses through friction, the binding energy (gravitational, intermolecular or otherwise) of the asteroid, the gravitational influence of the Earth, losses through light, sound and heat production in the explosion or any other losses associated with the situation.

Although it is admitted that our estimation of the density and size of the asteroid may have been overestimated, those changes are unlikely to reduce the result by more than 2 orders of magnitude, most likely a little over 1 order, whereas the removal of a binding energy calculation may result in an increase in the required energy of many more orders of magnitude.

As a point of interest, the distance that the bomb would have had to have been detonated in order to allow for the vastly insufficient magnitude of the bombs output was calculated as approximately $1.3 \times 10^{13} m$ which is approximately 10^{-3} lightyears, or $88 AU$. This would place the asteroid somewhere on the outer edge of the Kuiper Belt, a place generally rich in icy bodies like comets and Pluto-like dwarf planets, but very poor in high-iron content asteroids, meaning such a body is very unlikely to have originated so far away. Interestingly, this distance is remarkably similar to the current distance of the Voyager 1 and 2 probes, launched in 1977, 2 decades before the film is set.

The conclusion is very simple. Our current level of technology is simply nowhere near sufficient to protect Earth from such an asteroid by this specific means of asteroid defence, though other possible methods have been suggested that may be more feasible.

References

[1] "Armageddon", 1998, Michael Bay (Director), Jerry Bruckheimer Films

[2] Lehane, J, "Armageddon (1998): Geological Critique", www.dinojim.com, 2011, accessed 17/10/11

[3] "The Soviet Weapons Program - The Tsar Bomba", www.nuclearweaponarchive.org, 2007, accessed 17/10/11

[4] "Joules to Megatons conversion calculator", www.unitconversion.org, 2011, accessed 17/10/11