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What Does Kirks Radiation Poisoning Tell Us About The *USS Enterprise*?

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Abstract
This paper calculates the power output of Star Treks' *USS Enterprise* warp core if modelled as a uranium powered fission reactor using Captain Kirk's radiation poisoning symptoms as seen in the movie, *Star Trek Into Darkness*. Kirk was said to have received a dose of >30 Gy and through subsequent calculations the power output was determined to be 32 MW.

Introduction
The sci-fi movie, '*Star Trek: Into Darkness*', follows the adventures of the *USS Enterprise*, a spaceship and its crew exploring space [1, 2]. There is a scene where the Enterprise has lost power resulting in its free fall through the Earth's atmosphere due to the propulsion systems (warp core) housing being misaligned. To get the system back online, the captain of the ship, Kirk, enters the heavily irradiated warp core region and climbs up to the warp core housing to manually realign it, hereby exposing himself to the radiation. He successfully manages to restore the warp core and save the ship but in doing so succumbs to the radiation poisoning, dying. This scene is available to view over 2 continuous videos on YouTube [3, 4]. This paper will look at how much radiation Captain Kirk absorbs from his symptoms and consequently calculate the power output of the warp core.

Assumptions
- An inner door stops irradiation of the rest of the ship. Therefore, it will be assumed that Kirk first comes into contact with the radiation once he has opened the inner door. [3, 5]
- Kirks weight is the same as the actor Chris Pine (78 kg) [6].
- Alpha radiation will be discounted due to no alpha-emitters being present in the decay chain of the fission products of Uranium-235 as we assume these to be Xenon-139 and Strontium-95 in 100% of the fission events [7]. Alpha and Beta particles have a neglectable short range and therefore would not affect Kirk until he is adjacent to the housing, which is for a limited time [8].
- Once the warp core is fixed there will be no further radiation emitted to the chambers' surroundings. Due to this we will assume Kirk is only irradiated from his entering of the chamber to the realignment of the housing [4].
- The chambers' surroundings do not absorb any radiation.
- Gamma radiation is homogeneously emitted in every direction during the malfunctioning of the core.

Initial Calculations
The decay chains of the assumed fission products are (all beta decay processes):

$$^{139}Xe \rightarrow {}^{139}Cs \rightarrow {}^{139}Ba \rightarrow {}^{139}La$$
$$^{95}Sr \rightarrow {}^{95}Y \rightarrow {}^{95}Zr \rightarrow {}^{95}Nb$$

In reality, there are more options for fission products and their decay chains. Watching the scene it was estimated that Kirk survived for 368 s once exposed to radiation (see table 1 for a breakdown). Kirk's symptoms included: disorientation, heavy breathing, sweating, slowing movement and multiple organ failure [9, 10]. These symptoms match a radiation dose of at least 30 gray (Gy), or J kg^{-1} body mass [9]. Therefore Kirk's 78 kg body absorbed at least 2340 J in 116 s, which is the time that Kirk spent in the radiation zone of the warp core while it was

malfunctioning. It must be noted that for this dose vomiting is heavily expected. Kirk did not show signs of vomiting however this could have occurred off screen [10].

Time (s)	Description
0	Kirk opens the inner door
75	Kirk reaches the top of the warp core
116	Kirk manages to realign the housing
368	Kirk dies of radiation poisoning.
Total time from first exposure to death=368 s	

Table 1 – A table showing the total time from initial exposure to death from radiation poisoning for Kirk.

We assume that on average, Kirk was irradiated frontally, and that the frontal area of his body was 0.6 m^2 [11]. If Kirk is at a distance R from the source of radiation, the ratio of the area covered by Kirk over the area *not* covered by Kirk at that distance is 0.6 m^2 divided by the surface area of a sphere with radius R. If Kirk is approximated to consist solely of water, for his mass to be 78 kg his volume must be approximately 0.078 m^3 giving the average thickness of his body to be 13 cm. It must be noted that a human body consists of only 60% water however the assumption used was necessary to calculate the amount of radiation Kirk absorbs [12]. Since the half-value thickness of water for gamma radiation is about 5 m, the percentage of incident radiation energy that was absorbed by Kirk can be calculated through [13]:

$$\frac{E_{absorbed}}{E_{incident}} = \left(1 - \frac{1}{2}^{thickness/half-value\ thickness}\right), \qquad (1)$$

Using previous stated values equation (1) produces a value of 2%. An equation for the gamma radiation energy emitted by the source can be constructed:

$$E_{emitted} = \frac{E_{absorbed} 4\pi < R^2 >}{0.02A}, \qquad (2)$$

where $E_{absorbed}$ is the amount of radiation energy absorbed by Kirk, at least 2340 J, $< R^2 >$ is the effective squared distance between Kirk and the source and A is the frontal area exposed. It will be assumed that from entering the door, Kirk was crawling at 1 ms^{-1} for 26 s, then in the following 62 s he cleared 20 m at a constant speed of 0.32 ms^{-1} and then kicked the core for 28 s at a distance of 1 m [3, 4]. Thus it can be calculated that the distance covered is 46 m and that the effective squared distance is 356 m^2. Putting this into equation 2, this gives that the energy of 2340 J that Kirk absorbed was 2.68×10^{-4}% of the total energy produced by the core, which then produces a total energy output of the core to be 8.73×10^8 J.

Discussion

In a typical nuclear reactor, about 7.2% of total power output of the reaction happens due to gamma radiation [14]. That means that the total energy created by the nuclear processes during Kirk's irradiation was 12.1 GJ, equalling a power of 104.5 MW. 92.8% of the total power of a reactor is usable, resulting in the warp core being equivalent to a nuclear power reactor with an effective (electrical) power output of about 32 MW, if corrected for the typical efficiency of a nuclear reactor being 33% [14, 15]. The biggest nuclear powerplant in the USA has a max capacity of around 120 times higher than this value [16].

It is likely that the warp core generates considerably more power than this, with the core using dark matter energy, a high density form of energy and not a regular uranium fission reaction as modelled in this paper [17]. Furthermore, potentially the gamma radiation is not released in every direction, but mostly in one. These explanations would mean that the real total emitted gamma radiation would be much higher than the value calculated from equation 2. It is also possible that Kirk absorbed much more than 30 Gy of radiation, potentially twice as much resulting in the power output of the core being doubled.

Another potential explanation as to why the output power calculated for the warp core is significantly smaller than the expected output, is that the spaceship has some sort of mechanism which significantly decreases the power if the warp core is malfunctioning in order to prevent a nuclear disaster.

Conclusion

From subsequent calculations and assumptions based around Captain Kirks radiation poisoning symptoms as shown in *Star Trek: Into Darkness*, it follows that the warp core of the *USS Enterprise* could be a regular uranium-fission reactor with a net power output of 32 MW. However, this is much lower than the *USS Enterprise* is expected to utilize. From this it can be assumed that the *USS Enterprise* is not powered by a regular uranium-fission core.

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