Space Radiation Protections Using Water-Shielding for Journey to Mars Inspiring Future Nuclear Engineering: Celebrating Atomic Powered 'Mars 2020' Mission of NASA

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1. Introduction

Another atomic powered space rover for the Martian mission is supposed to launch on July 2020. One of main purposes is to seek the habitable conditions followed by the human journey to the red planet. Fig. 1 shows the position of the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) [1] and Fig. 2 shows its configuration [2]. In this work, it is to analyze the radiation protection to the human as the most important task for the trip. It has been planed to launch the first manned spacecraft to Mars on 2031 for the commercialized civilian purpose [3]. Eventually, it is planed to build cities of one million populations on the Mars in Fig. 3 [4]. The deadly radiation to human is extremely important during the journey. Therefore, the biological substance like human is the critical study topic to reach to Mars or even to any kinds of space travels. In Fig. 4, the simplified spacecraft to Mars is shown in which the living place and landing module are shown.

First of all, the radiation shielding to the crew is the starting stage to radiation management in the space. As one of some materials in the journey, the water is considered as a candidate of the radiation shielding stuff [5]. It is very invaluable to the crews in the drinking and washing. Furthermore, the molecules of water could protect the biological material from the radiation. As the nanoscopic scale, the hydrogen and oxidation will react to the space radiation to protect the humans. Especially, the liquid state of water has advantage to make arbitrary shape in the cabin and to flow to the designed place. For example, the gamma ray has a most dangerous radiation comparing to other ionizing radiations. Considering the physical characteristics, a halving thickness which is the amount of material that will block half of the gamma rays passing through it is higher in water [6], but the halving mass is not. Some examples for the halving thickness are seen in Table I [7]. Radiation needs to be controlled by the material which is carried from the Earth.

For using of water, the drinking is the first stage and then it passes the human body as urine. This circulation is applicable to the radiation shielding material. In addition, the water from sink after washing the dish and bathing is combined. The water is irradiated and it should be treated by the chemical reactions for the biologically safe substance. In the master plan, the launching scenario to Mars is investigated [8] where two cargo vehicles, two habitat vehicles, and two returning vehicles are planned. The time gap between cargo vehicles and others are 2 years. The weight is proposed to be 53,000 kg at launch from Earth and 23,000 kg at landing on Mars from cargo vehicle and the habitat vehicle has 28,800 kg [8]. Currently, about 7 ~ 8 months are needed to reach to Mars. Although, technological performances have been proved as the good results for the trip to Mars, the biological considerations need many problems.

2. Methods

In the modeling of the research, it is considered for the cabin to be the small sized ecological system. Following the water circulation, the radiation shielding is performed against the space hazard radiations. As a recent study, during 210-day journey Mars, the amounts to radiation exposure is 386 +/- 63 mSv [9]. The exposure is compared with some standards as European Space Agency, Russian Space Agency and Canadian Space Agency where the limit is 1,000 mSv. Additionally, NASA has the limits between 600-1,200 mSv, which are variable following sex and age [9]. There are some more data in Table II [3]. It is reported that the upper limit of radiation of 449 mSv during the 210-day trip to Mars is about 3 percent risk for her lifetime [10]. Using, a previous rover, the Curiosity's Radiation Assessment Detector (RAD), it has been observed that during its journey to Mars the Curiosity was exposed to an average of 1.8 mSv of galactic cosmic rays (GCR) radiation per day, which is from outer space caused by high-energy events in other stellar systems, such as supernova explosions and other events outside the solar system where the daily 1.8 mSv of GCR radiation make close to 1 Sv in total as much more than allowed for an astronaut [11].

The water shielding for cosmic radiations is described in Fig. 5. In addition, Fig. 6 shows the water circulation concept where the water changes by the roles as the living of drinking and washing, radiation shielding, and chemical treatment. If the water is irradiated, the water chemistry is changed. In the chemical structure, the free radicals of hydrogen and hydroxyl are produced which could produce gene damage or cancer in human body [12]. That is to say, even though the total weights of the loading material are reduced, the harmful stuffs are produced. The relation between radiation dose and half-value layer (HVL) is obtained as,

$$I = I_o e^{-\mu x} \tag{1}$$

$$HVL = \frac{ln2}{\mu} \tag{2}$$

where, I is the radiation energy after penetrating the material and I_o is the initial energy of radiation. μ is the attenuation coefficient and x is the thickness of material.

So, if there are 2 kinds of material, the formula is modified as,

$$I_1 = I_o e^{-\mu_1 x} = I_o e^{-\frac{ln2}{HVL_1}x}, \quad (3)$$

$$I_2 = I_o e^{-\mu_2 x} = I_o e^{-\frac{ln2}{HVL_2}x} \quad (4)$$

So,

$$\ln\left(\frac{I_1}{I_o}\right) + \ln\left(\frac{I_2}{I_o}\right) = -\left(\frac{ln2}{HVL_1}x_1 + \frac{ln2}{HVL_2}x_2\right) \quad (5)$$

$$\left(-\frac{1}{\frac{ln2}{HVL_1}}\right)\left\{\ln\left(\frac{I_1}{I_o}\right) + \ln\left(\frac{I_2}{I_o}\right) + \left(\frac{ln2}{HVL_2}x_2\right)\right\} = x_1 \quad (6)$$

The values of the above equation are variables by the thickness of shielding material. Equation (6) means the proportional value between water and lead. Once the length of water is longer, that of lead could be shorter. This equation gives that the role of water recycling in the cabin can save the weight of the spacecraft and results to the cost of the total travel to the Mars and other planets.

3. Results

In this work, the optimized thickness for gamma radiation is obtained using the formula. Fig. 7 shows the numeric values of the proposed radiation shielding material comparing to water [7]. The lead is the representative example, because it is a common shielding material for the gamma radiation which is the highest penetrating radiation. There are the proportional values between water and lead in Fig. 8. The optimized value could be obtained as 1 cm of water and 1.9764 cm of lead respectively. Hence, about 50 % of lead length can be obtained for the designed length. By the way, the variation of the water thickness is higher than that of lead. This shows the role of water for the shielding effectiveness is lower than that of lead.

4. Conclusions

Although the radiation control is very important in the space travel due to the hazardous effect to humans, the size of the spacecraft is very limited. For continuing the long trip of 7 months to Mars, it is necessary to make the plan very effectively. The space management of the cabin is very important. Water is designed in this study for multiple purposes, which is very essential matter to live for humans. Therefore, the circulations system of the water including all kinds of phase forms of vapor or ice are good strategy to save the size of habitat as well as the hazard radiation protection. It is proposed that the optimized value following the relation between water and lead can be applied to the other material like the steel and plastic material.

As the results of the simulations, the role of the water for the shielding thickness is lower than that of the lead. Hence, the water could be used for the shielding for the external radiations. However, the effectiveness for the shielding is not quite much. The role of the radiation shielding is important as the aspect of the recycling using the limited resource in the spacecraft. In addition, it is important to be aware that the contribution to radiation material is not very effective. It is concluded that there are some chemical changes of the water contents which could be harmful to humans, which means the irradiated water cannot be used for drinking and other living usages.

The light material in the weight should be developed for the deep space missions which is outer orbit of the Mars. The heavier material need much more fuel to lunch and land. So, the newly made radiation shielding material can save the total weight of the spacecraft. The nanoscopic behavior between shielding molecules and radiation, especially gamma rays, could reduce the weight of the mass. Furthermore, the real time monitoring of the external radiation of GCR and solar cosmic rays could give the necessity of radiation shielding where the thickness and contents of radiation material can be decided. In the data control, the fast computing system can be used for obtaining the required shielding geometry. In addition, the economic travel of less weight and size would be accomplished by the real timing calculations against detected radiations.

As the future work, it is imagined to challenge that the usage of the asteroid during the trip to Mars. Hence, it is easy to meet by chance for the unexpected asteroid where one may arrive there and pick up some soils which is called the regolith. If one would like to arrive to the moving asteroid, it is necessary to make the computer program. So, it is not easy to arrive safely with man controlled system. This study is just one of possible cases that the spaceship could confront an event during the trip. In the analysis, the successful journey could be accomplished after thorough planning and wise adaptation to circumstances.

Acknowledgements

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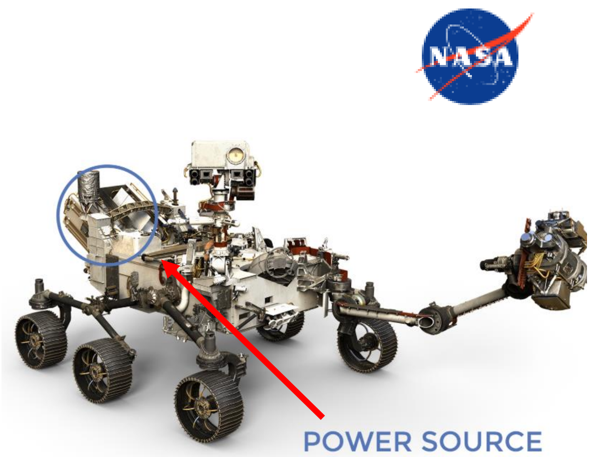

Fig. 1. Rover 'Perseverance' of the Mars 2020 (NASA, 2020a).

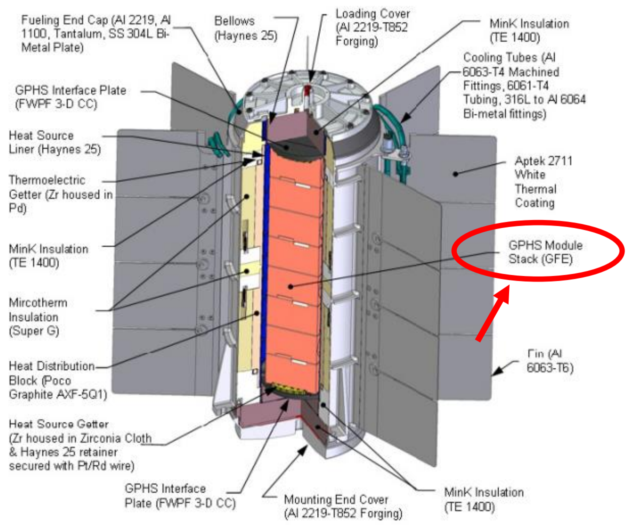

Fig. 2. Configuration of Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) (NASA, 2020b).

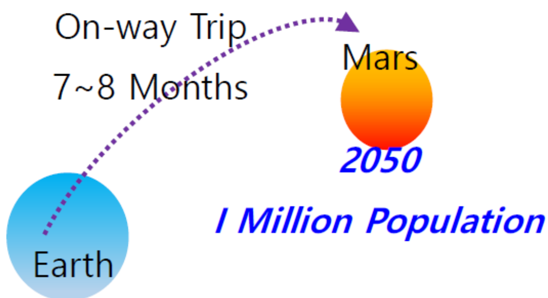

Fig. 3. Configuration of trip to Mars.

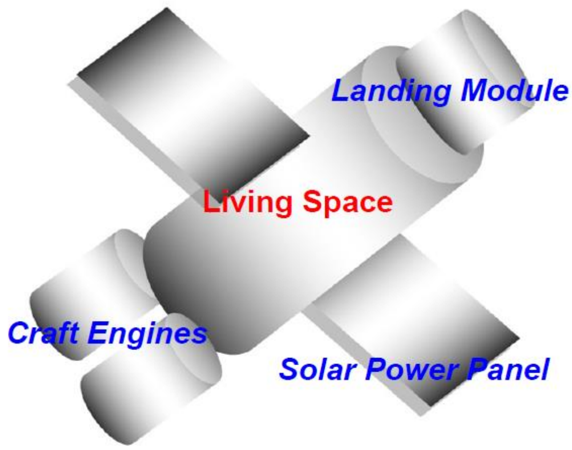

Fig. 4. Simplified manned spacecraft to Mars.

Fig. 5. Water shielding for cosmic radiations.

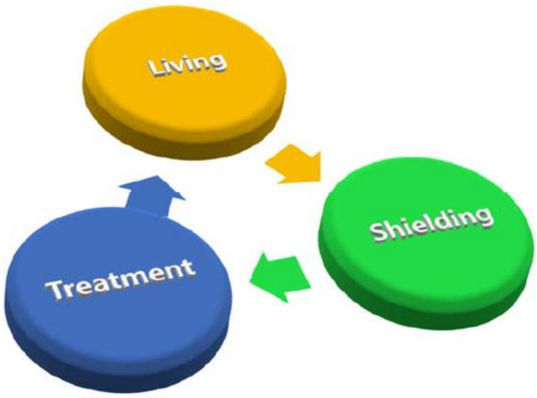

Fig. 6. Water circulation concept.

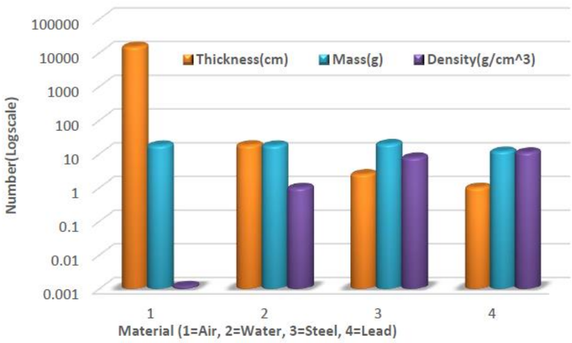

Fig. 7. Physical value of radiation shielding material.

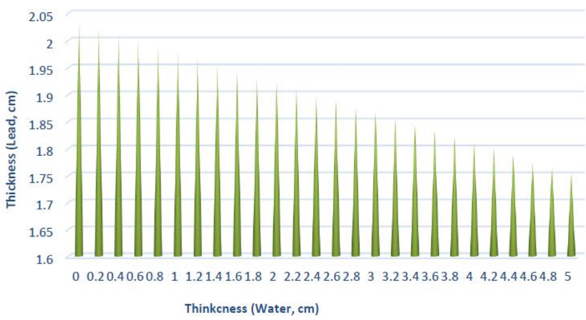

Fig. 8. Optimized thickness of shielding material as water and lead.

Table I: Material for radiation shielding

Material	Density (g/cm^3)	Halving thickness (cm)	Halving mass (g/cm^2)
Air	0.0012	15,240	18
Water	1.00	18.288	18
Packed soil	1.99	9.144	18
Concrete	3.33	6.096	20
Steel	7.86	2.5146	20
Lead	11.3	1.016	12

Table II: Data for Mars One

List	Data
Departure of crew one	2031
Living size of cabin	Below 20 m^3
Period	Around 7 months
Cost for first four persons	$ 6 billion
Cost for every next manned mission	$ 4 billion
Risks during journey	Accident(s) during launch Vital components could malfunction A number of issues entering Mars' atmosphere Problems when landing