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Shielding design considering commercial parts for LEO mission satellite using SPENVIS software

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HIGHLIGHTS

- Effects of radiation damage on satellite parts and subsystems in the presence of various types of radiation in space.
- Use of commercial parts in satellites, taking into account economic considerations.
- Reducing the effects of radiation damage through radiation shielding.
- Using SPENVIS, SHIELDOSE, and MULASSIS software for shielding design in LEO orbit mission.
- Almost the same result simulation using all three software, SPENVIS, SHIELDOSE and MULASSIS.

ABSTRACT

The space radiation environment includes trapped protons and electrons, solar protons, galactic cosmic radiation, and neutrons, which can lead to electronic satellite malfunctions. Radiation damage has destructive effects on the electronic components of satellites. As a result of economic reasons and the presence of various limitations, the utilization of commercial components has become common in short-term and low-altitude missions. The most efficient method of protection against radiation is the use of shields. The purpose of this study is to investigate the optimal shielding in a 3-year mission in LEO orbit by considering the radiation resistance of commercial parts using SPENVIS software, SHIELDOSE code, and MULASSIS software. The result of SHIELDOSE, MULASSIS calculations is that the amount of thickness of different materials for the radiation tolerance of commercial parts does not vary significantly in condensation thickness. Furthermore, there is no need for complex protection and you can utilize the usual protections. A comparison of the calculations obtained from MULASSIS and SHILEDOSE to deliver the dose into the silicon target indicates that the values are very similar and if there is a limitation in each of the capabilities of either MULASSIS and SHILEDOSE, another can be utilized as a substitute software.

KEYWORDS
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Radiation damage
Commercial components
Shielding

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1 Introduction

The space radiation environment consists of trapped protons and electrons, solar protons, galactic cosmic radiation, and neutrons, which can lead to the disappointment of electronic satellites (ASTRIUM, 2001; Maurer et al., 2008). The environmental effects of space radiation are categorized into three general categories, total ionizing dose effects (TID), single-event effects (SEE), and displacement damage effects (DD) (NASA, 1999). Radiation has devastating effects on electronic components in satellites, so the selection of components has particular importance. In general, there are three classifications of component categories for space systems. Rad Hard, Rad Tolerant, and COTS. Rad-Hard Designed for the long term, these devices are constructed to endure high levels of radiation over prolonged periods. These devices are heavyweights, designed to handle exceptionally high levels of radiation. Their structure and materials are selected and improved to withstand the most severe radiation environments. Every possible avenue is explored when qualifying rad-hard devices. Every wafer lot undergoes thorough testing, ensuring that each component meets the highest radiation resistance standards. Rad-

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Tolerant: Customized for shorter durations, rad-tolerant electronics are ideal for missions or applications with a lifecycle of typically five years or less. They're more like sprinters, designed to perform optimally in short, intense bursts. Rad-Tolerant: Suited for less harsh radiation environments, these devices can usually handle radiation exposure ranging from 10 to 30 krad (Si). In certain situations, they may be adjusted to withstand slightly higher doses, but they won't match the resilience of rad-hard devices.These devices undergo a more efficient, automotive-like approval process, with one-time radiation characterization. Although they are tested to ensure radiation tolerance, the process is less exhaustive than with rad-hard devices, reflecting their shorter operational expectancy and less demanding radiation requirements (Center, 1996; Poivey, 2017).

COTS products, which are also known as commercially available off-the-shelf products, refer to pre-packaged hardware or software that are modified after purchase to meet the specific requirements of the buying organization. Some spacecraft manufacturers have no choice but to utilize Commercial Off-The-Shelf (COTS) components in order to fulfill the requirements for the performance and cost of a mission. Numerous COTS devices are currently functioning effectively in outer space. To ensure mission reliability, the location of COTS parts and sub-systems within the entire construction is crucial and spacecraft simulation software like TRAD's FASTRAD can help identify areas of the satellite structure that can offer improved levels of shielding from radiation (Rojdev et al., 2015).

Most COTS components are resistant to radiation up to 5 krad. Some of them fail before 1 krad. By the COTS method, commercial components and subsystems are purchased and they can be used in the satellite provided they meet other environmental requirements (vibration, temperature, etc.)

The advantages of using COTS instead of space-class components are time efficient, up-to-date, and cost-effective, and they cannot access, on the other hand, it is increased using these components in smaller satellites in LEO orbit. Most of the important components utilized in radiation systems have silicon bases and are fabricated on VLSI semiconductor technology, therefore the most studied radiation damage is focused on silicon. The most effective way to protect against radiation is to use the shield. The shielding effect of various materials can be studied using particle transport codes. For shielding, as well as investigating the protective effect of different materials, it can be optimized on the layout and structure of the shield. Traditionally, aluminum has been the standard material utilized in space applications to fulfill radiation shielding and structural-functional requirements. But other materials are also used in this field, including polyethylene, thallium, etc. In this study, various types of materials have been used for shielding calculations (Rahman et al., 2017; ASTRIUM, 2001; Wrobel, 1987).

Space radiation researchers have developed different models to simulate the elements of the radiation environment. These models are based on data sets of different space missions launched in different orbits.The protective effectiveness of different materials can be evaluated using particulate transport codes. HZETRN, MCNP, GEANT4, and SHIELDOSE-2 CODES are available independently or in software packages such as OMERE and SPENVIS.In this work, SPENVIS is used. The SPENVIS system is developed by a group led by the Royal Belgian Institute for Space Aeronomy (BIRA-IASB) for ESA's Space Environments and Effects Section through its General Support Technology Programme (GSTP). The development team at BIRA-IASB maintains the system (Truscott et al., 2004).

The Space Environment Information System (SPENVIS) is a web application that provides models and tools to space engineers and scientists to simulate the space environment around Mercury, Earth, Mars, and Jupiter but also in the interplanetary medium. Furthermore, it allows the users to merge and chain results between different models enabling them to calculate the potential effects of the environments specific to their (planned) mission. The effects are categorized into the following groups: ionizing dose, non-ionizing energy loss, radiation damage in solar cells, single event upsets, spacecraft charging, atomic oxygen erosion, and meteoroid and debris models (The ESP models, d.d. `https://www.spenvis.oma.be/help/background/flare/flare.html#ESP`).

SHIELDOSE and MULASSIS are implemented in SPENVIS software. It is used this capability in this work. SHIELDOSE is a computer code for space-shielding radiation dose calculations. It determines the absorbed dose as a function of depth in shielding materials of spacecraft, given the electron and proton fluences encountered while in orbit (Truscott et al., 2004). MULASSIS enables the definition of a multi-layered, one-dimensional shield and incident particle source, and using the Geant4 toolkit simulates radiation transport through the geometry, treating electromagnetic and nuclear interactions. It started working in the field of space radiation as the country's attention to the design and construction of satellites. Most activity in this field is performed using the OMERE software for determination and shielding calculations. This study aims to investigate the best shielding in LEO missions by considering the radiation resistance of COTS components using SPENVIS software.

Table 1: Mission Orbit Specifications.

Parameter	Value
Perigee altitude	500 km
Apogee altitude	500 km
Inclination	55°
Mission start	01/01/2023
Mission end	31/12/2025

2 Research theories

As mentioned in the introduction, shielding is significant for utilizing COTS parts, so to discover a suitable shield, first, it is necessary to calculate and simulate different and appropriate materials. To consider the impact of TID

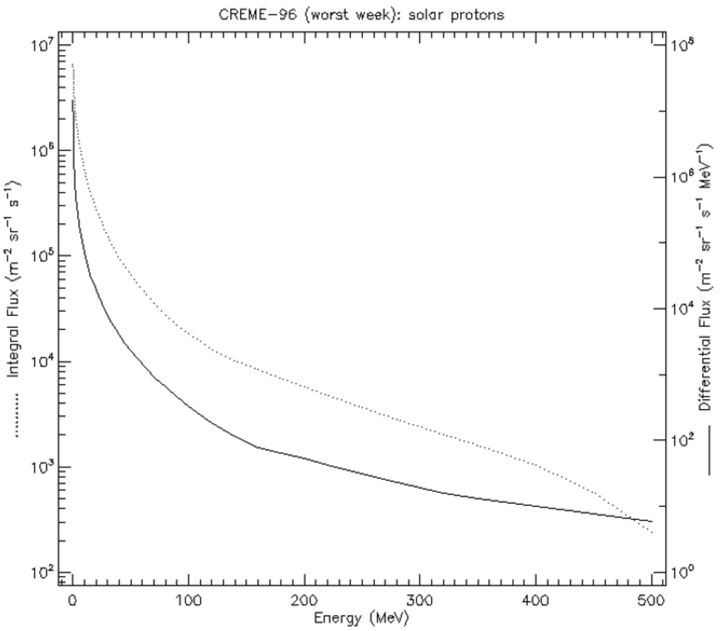


Figure 1: Differential and integral flux of solar protons vs energy.

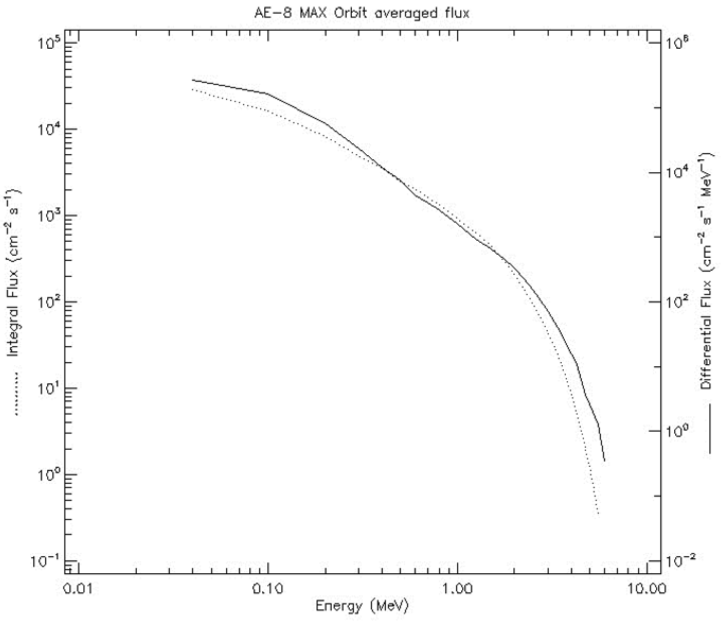


Figure 2: Differential and integral flux of trapped electrons vs energy.

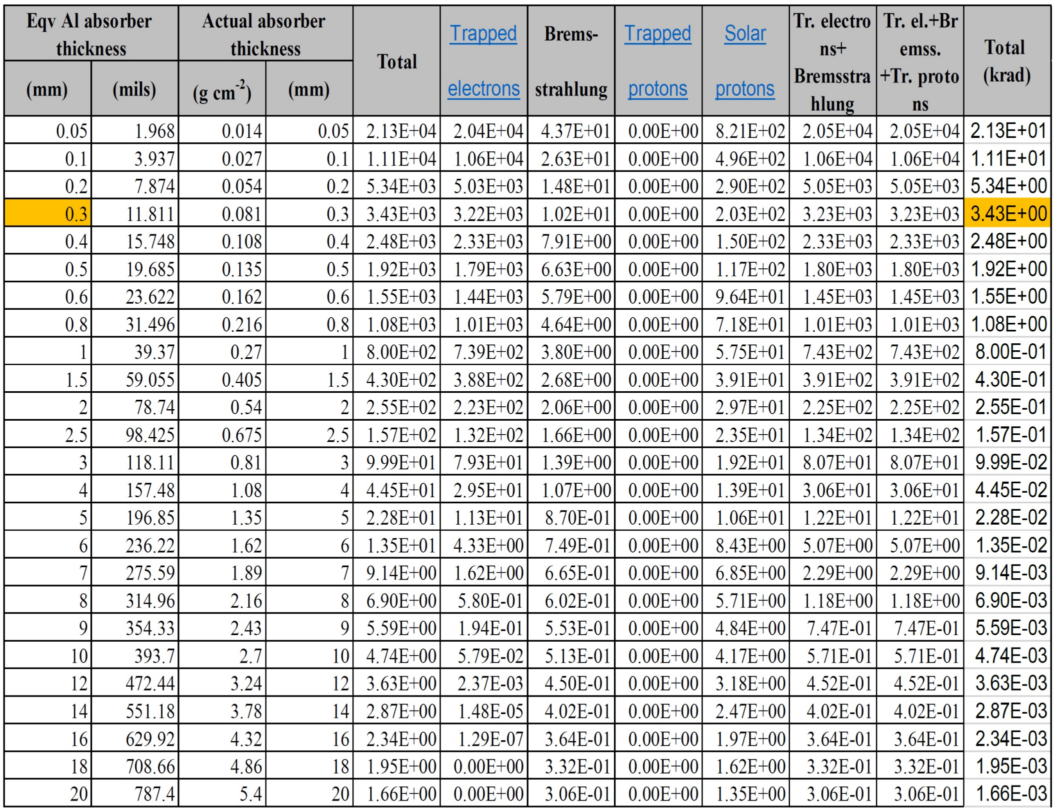
against the shield, different shields such as aluminum, titanium, tantalum, iron, copper-tungsten alloy, and a bilayer shielding sample (consisting of aluminum and tantalum) have been studied and the amount of TID absorbed into silicon has been calculated for different thicknesses.

3 Results

Protons and solar ions, trapped particles including electrons, protons, and galactic cosmic rays are considered the radiation sources of this orbit. The results of calculations using SPENVIS computer program are presented in this section. In Figs. 1 and 2, the flux of some radiation sources is displayed.

As shown in Fig. 1, the energy range of solar protons extends up to approximately 500 MeV. The flux of these particles decreases with increasing energy.

As shown in Fig. 2, the energy range of trapped electrons extends up to approximately 10 MeV. The flux of these particles also decreases with increasing energy. According to the characteristics of the orbit and the radiation sources, the dose curve is drawn vs thickness. Figure 3 shows an example of calculations performed with this software The target material is silicone and the shield is intended to be flat. The obtained dose of trapped electrons, trapped protons, and solar protons and the total dose in



Eqv Al absorber thickness		Actual absorber thickness		Total	Trapped electrons	Bremsstrahlung	Trapped protons	Solar protons	Tr. electrons+ Bremsstrahlung	Tr. el.+Bremss. +Tr. protons	Total (krad)
(mm)	(mils)	(g cm^{-2})	(mm)								
0.05	1.968	0.014	0.05	2.13E+04	2.04E+04	4.37E+01	0.00E+00	8.21E+02	2.05E+04	2.05E+04	2.13E+01
0.1	3.937	0.027	0.1	1.11E+04	1.06E+04	2.63E+01	0.00E+00	4.96E+02	1.06E+04	1.06E+04	1.11E+01
0.2	7.874	0.054	0.2	5.34E+03	5.03E+03	1.48E+01	0.00E+00	2.90E+02	5.05E+03	5.05E+03	5.34E+00
0.3	11.811	0.081	0.3	3.43E+03	3.22E+03	1.02E+01	0.00E+00	2.03E+02	3.23E+03	3.23E+03	3.43E+00
0.4	15.748	0.108	0.4	2.48E+03	2.33E+03	7.91E+00	0.00E+00	1.50E+02	2.33E+03	2.33E+03	2.48E+00
0.5	19.685	0.135	0.5	1.92E+03	1.79E+03	6.63E+00	0.00E+00	1.17E+02	1.80E+03	1.80E+03	1.92E+00
0.6	23.622	0.162	0.6	1.55E+03	1.44E+03	5.79E+00	0.00E+00	9.64E+01	1.45E+03	1.45E+03	1.55E+00
0.8	31.496	0.216	0.8	1.08E+03	1.01E+03	4.64E+00	0.00E+00	7.18E+01	1.01E+03	1.01E+03	1.08E+00
1	39.37	0.27	1	8.00E+02	7.39E+02	3.80E+00	0.00E+00	5.75E+01	7.43E+02	7.43E+02	8.00E-01
1.5	59.055	0.405	1.5	4.30E+02	3.88E+02	2.68E+00	0.00E+00	3.91E+01	3.91E+02	3.91E+02	4.30E-01
2	78.74	0.54	2	2.55E+02	2.23E+02	2.06E+00	0.00E+00	2.97E+01	2.25E+02	2.25E+02	2.55E-01
2.5	98.425	0.675	2.5	1.57E+02	1.32E+02	1.66E+00	0.00E+00	2.35E+01	1.34E+02	1.34E+02	1.57E-01
3	118.11	0.81	3	9.99E+01	7.93E+01	1.39E+00	0.00E+00	1.92E+01	8.07E+01	8.07E+01	9.99E-02
4	157.48	1.08	4	4.45E+01	2.95E+01	1.07E+00	0.00E+00	1.39E+01	3.06E+01	3.06E+01	4.45E-02
5	196.85	1.35	5	2.28E+01	1.13E+01	8.70E-01	0.00E+00	1.06E+01	1.22E+01	1.22E+01	2.28E-02
6	236.22	1.62	6	1.35E+01	4.33E+00	7.49E-01	0.00E+00	8.43E+00	5.07E+00	5.07E+00	1.35E-02
7	275.59	1.89	7	9.14E+00	1.62E+00	6.65E-01	0.00E+00	6.85E+00	2.29E+00	2.29E+00	9.14E-03
8	314.96	2.16	8	6.90E+00	5.80E-01	6.02E-01	0.00E+00	5.71E+00	1.18E+00	1.18E+00	6.90E-03
9	354.33	2.43	9	5.59E+00	1.94E-01	5.53E-01	0.00E+00	4.84E+00	7.47E-01	7.47E-01	5.59E-03
10	393.7	2.7	10	4.74E+00	5.79E-02	5.13E-01	0.00E+00	4.17E+00	5.71E-01	5.71E-01	4.74E-03
12	472.44	3.24	12	3.63E+00	2.37E-03	4.50E-01	0.00E+00	3.18E+00	4.52E-01	4.52E-01	3.63E-03
14	551.18	3.78	14	2.87E+00	1.48E-05	4.02E-01	0.00E+00	2.47E+00	4.02E-01	4.02E-01	2.87E-03
16	629.92	4.32	16	2.34E+00	1.29E-07	3.64E-01	0.00E+00	1.97E+00	3.64E-01	3.64E-01	2.34E-03
18	708.66	4.86	18	1.95E+00	0.00E+00	3.32E-01	0.00E+00	1.62E+00	3.32E-01	3.32E-01	1.95E-03
20	787.4	5.4	20	1.66E+00	0.00E+00	3.06E-01	0.00E+00	1.35E+00	3.06E-01	3.06E-01	1.66E-03

Figure 3: An example of calculation of dose determination vs thickness in SHIELDOSE software.

silicon were calculated based on thickness. The output from these tables is the dose curve regarding condensation thickness (g.cm^{-2}). The red horizontal line represents the radiation tolerance of COTS components. The minimum amount of thickness is obtained from the intersection of two graphs. In Fig. 4, the dose curve is displayed in terms of thickness for aluminum shielding.

This work has also been applied for Titanium, Tantalum, Iron, Al + Ta bi-layer, and CW80 Copper-Tungsten Alloy, and the results are summarized in Table 2. In this table, the minimum amount of condensation thickness (g.cm^{-2}) for the radiation tolerance of COTSs for different materials in this mission is obtained.

The minimum condensation thickness values for the radiation tolerance of commercial parts in different materials are presented in Fig. 5. As shown in Table 2 and Fig. 5, the amount of thickness of different materials for the radiation tolerance of COTS components does not differ much in terms of condensation thickness in this mission. The lowest and highest thickness is related to Tantalum and Ta+Al (1 mm) combined shields.

To assessment dose quality, two capabilities of SPENVIS, MULASSIS and SHILDOSE have been used. To validate the two software, the dose values are calculated in the same conditions. The results of this comparison are shown in Fig. 6. As shown in this figure, the values obtained for the dose are almost close to each other in thicknesses of 2 to 8 mm and follow the same order of magnitude, therefore, it can be concluded that if there is a limitation in any of the capabilities of MULASSIS and SHILEDOSE, another can be used as an alternative software.

Table 2: Minimum condensing thickness (g.cm^{-2}) for radiation tolerance of COTS components for different materials.

Shield material	Thickness (mm)	Condensation thickness (g.cm^{-2})
Titanium	0.1798	0.0873
Tantalum	0.0485	0.0799
Iron	0.1029	0.0858
Al + Ta bi-layer	0.5000	0.1400
Aluminium	0.3000	0.0932
CW80 Copper-Tungsten Alloy	0.0520	0.0852

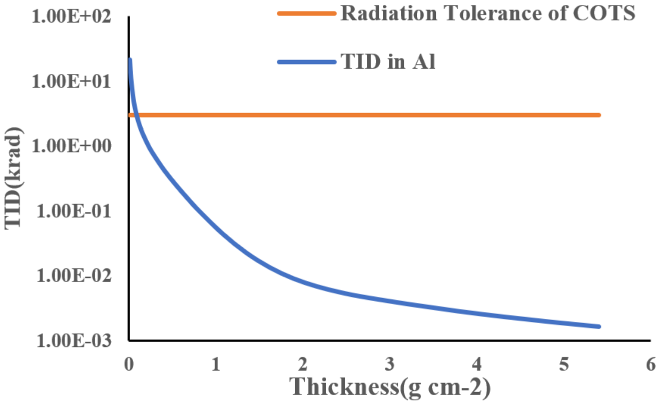


Figure 4: Total ionizing dose curve in terms of thickness for aluminum.

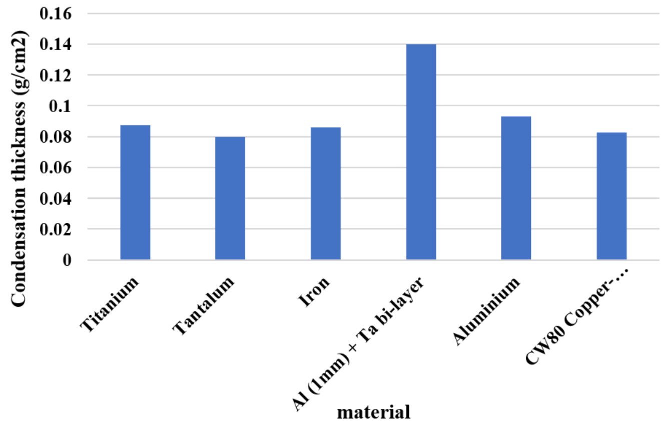


Figure 5: Xomparison of the minimum amount of condensing thickness (g.cm^{-2}) for radiation tolerance of different materials.

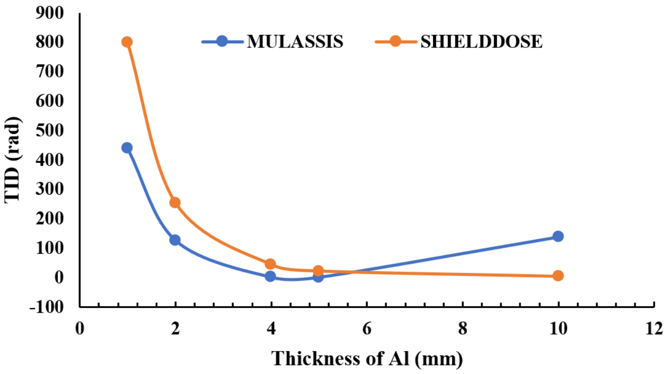


Figure 6: Comparison of total ionizing dose curve obtained from MULASSIS and SHIELDOSE calculations in terms of thickness for aluminum shielding in silicon.

4 Conclusions

It is important to have a good understanding of these effects on the satellite to provide the required shielding for mission planning and design. Radiation damage has devastating effects on electronic components in satellites, and the selection of components has a particular importance. The most effective way to protect against radiation is to use a shield. The use of shields appears to be the only practical tool to reduce the impact of radiation on astronauts and satellite cargo. There are two transport radiation codes used in this study. This work aims to investigate the optimal shielding in LEO missions by considering the radiation resistance of COTS components using SPENVIS software. It will be a three-year mission for a low-altitude orbit satellite (LEO).

The results of SHIELDOSE2 calculations show that the amount of thickness of different materials, for the radiation tolerance of commercial parts, does not differ much in terms of condensation thickness in this mission. In other words, if the basis of calculation is the condensation thickness of the different materials, then the amount of different materials for radiation protection in this mission is the same. The lowest and highest thickness is related to Tantalum and Ta+Al (1 mm) combined shields. A comparison of the calculations obtained from MULASSIS and SHILEDOSE to achieve the dose into the silicon target indicates that the values are very similar and if there is a limitation in each of the capabilities of MULASSIS and SHILEDOSE, another can be used as an alternative software. The general conclusion of the conservation design topics in this mission is that there is no need to use complex shielding and can also be used for this purpose.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

References

ASTRIUM, S. (2001). Circumventing radiations effects by logic design, executive summary report.

Center, J. S. (1996). Space Radiation Effects on Electronic Components in Low-Earth Orbit. *Preferred Reliability Practices.*

Maurer, R. H., Fraeman, M. E., Martin, M. N., et al. (2008). Harsh environments: space radiation. *Johns Hopkins APL Technical Digest*, 28(1):17.

NASA (1999). Jet Propulsion Laboratory, Radiation Design Margin Requirement. Yn NASA Lesson (Rhifyn PD-ED-1260). NASA. Gwelwyd gan `http://llis.nasa.gov/lesson/792`.

Poivey, C. (2017). Total Ionizing and Non-Ionizing Dose Radiation Hardness Assurance. *Short Course of NSREC*, 17.

Rahman, M. M., Shankar, D., and Santra, S. (2017). Analysis of radiation environment and its effect on spacecraft in different orbits. In *Conference: international Astronautical Congress (IAC2017)*, pages 8073–8079.

Rojdev, K., Tylka, A. J., and Atwell, W. (2015). Preliminary radiation analysis of the total ionizing dose for the resource prospector mission. In *AIAA SPACE 2015 Conference and Exposition*, page 4504.

Truscott, P., Lei, F., Dyer, C., et al. (2004). Mulassis-Monte Carlo radiation shielding simulation tool for space applications made easy. In *Radiation and its Effects on Components and Systems, RADECS 2003, Proceedings of the 7th European Conference, held 15-19 September 2003 in Noordwijk, The Netherlands. Edited by K. Fletcher. ESA SP-536, ESA/ESTEC, 2004., p. 191*, volume 536, page 191.

Wrobel, T. F. (1987). On heavy ion induced hard-errors in dielectric structures. *IEEE Transactions on Nuclear Science*, 34(6):1262–1268.

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