CONF-900216--2

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DE89 016219

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* This work was sponsored by the Air Force Weapons Laboratory.

† Operated by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400, U.S. Department of Energy

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INTRODUCTION

Monte Carlo radiation transport calculations have been performed to estimate the effects of natural (protons and electrons) and weapon enhanced (electron) Van Allen Belt (VAB) radiation on a space deployed weapon platform. (The satellite configuration adopted for this study represents the authors' concept of such a system.) The purpose of this study was to evaluate the long term and transient effects of these radiation modes on the components of a satellite deployed in a circular orbit at an altitude of 500 km and inclination angle of 0–deg. These kinds of satellites must survive long–term (up to 10 years) exposure to the natural radiation environment and the effects of enhanced radiation introduced when nuclear weapons are detonated in space.

This paper describes the platform/weapon system and its components, the Van Allen Belt spectra, the methods of calculation, and summarizes the radiation damage to platform components from VAB protons and electrons and enhanced electron belt radiation.

DETAILS OF THE WEAPON SATELLITE

The weapon satellite, shown in Figure 1a is a cylindrical assembly comprised of two weapon–fuel tank modules connected by a central command, control, and communications (C^3) components bay. The satellite has an overall length of 4.27 m and a diameter of 1.63 m. Each weapon–fuel tank module accommodates five kinetic–kill vehicles in 1.98 m–long by 0.21 m–inner–radius launch tubes and four 1.97 m–long by 0.203 m–diameter fuel tanks arranged symmetrically about the cylindrical axis. The fuel supply (chosen to be hydrazene with volume density of 1 g/cc) is for maneuvering the satellite to avoid collisions with space debris, evading enemy projectiles, and maneuvering the platform during engagement.

The central C^3 bay houses the electronic systems in two concentric, thin–walled, ring shaped containers. In the center is a box for housing the most–critical or sensitive electronics. The rationale for designing the C^3 bay in this manner is that the components that are least sensitive to radiation can be located in the outer ring while the more sensitive components can be located in the inner ring or the central box. The sensitive components in the inner locations are thereby shielded by the outer components. Allowance was made for the addition of shielding between the ring assemblies although this was not included in these calculations.

Power is supplied to the electrical and electronic systems by two 3.41 m–long by 1.71 m–wide by 0.05 m–thick solar panels, one on each side of the satellite. During conflict, the panels, shown in the deployed position in Figure 1a, are folded onto the "top" of the platform to reduce the cross–section of the satellite to attack by enemy weapons. A 0.01 m–thick carbon shield is mounted on the earth facing surface of the satellite to protect it against harassment and interdiction from ground based laser radiation. A single antenna assembly, mounted on the top surface provides communication with other sensor and battle management satellites. The total weight of the platform including fuel and ten kinetic kill weapons is 2722 kg.

The kinetic kill vehicles (KKV) are each 1.90 m–long and consist of a warhead, sensor assembly, fuel tank, and rocket motor. Each KKV weighs 69.16 kg.

The SBI satellite and its components were modelled for the calculations using the Combinatorial Geometry package that is available at the Oak Ridge National Laboratory for use with various Monte Carlo radiation transport codes.

VAN ALLEN BELT SPECTRA AND METHODS OF CALCULATION

The differential natural VAB proton and electron spectra and the enhanced electron fluence spectrum arising from a nuclear weapon detonation (Starfish–type) in space are plotted in Figure 1b. The spectra were calculated for an altitude of 500 km and 0–deg orbit angle.

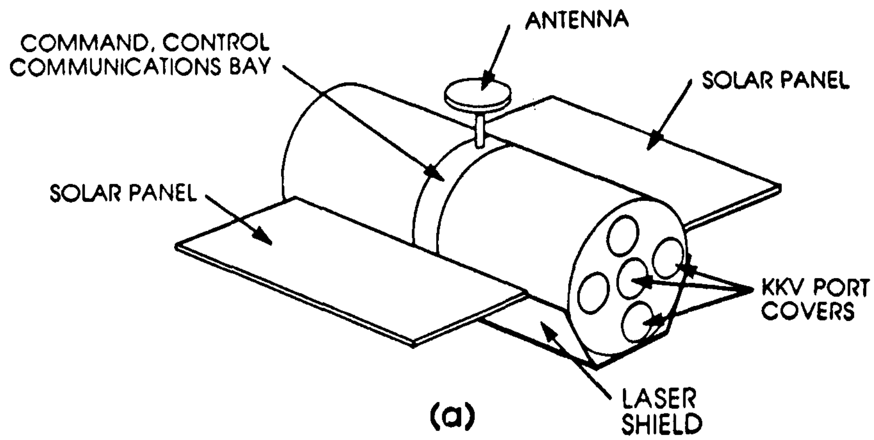
The proton spectrum is cut off at 30 MeV. Since the outer skin of the SBI platform will stop most of the protons with energies below 30 MeV and since they would not contribute significantly to the total dose, the low energy portion of the analysis is cut off at 30 MeV to reduce code running time. The assumption is also made that the proton flux above 1000 MeV is zero since there are very few, if any, trapped protons at these high energies. In contrast to the proton spectrum, the electron energies are much lower, on the order of a few MeV. Since the range of these energy electrons is small, they will not contribute to the damage to components that are protected by the platform skin. The majority of the damage to these components, particularly the electronics, arises from bremsstrahlung gamma rays produced by electron interactions.

Note that the enhanced electron spectrum extends to higher energies than the natural electron spectrum and that the enhanced spectrum is also much harder. Also, it does not decay as rapidly after the burst. Because they have higher energies, these electrons have greater penetrating capability and may damage electronic components located inside the platform. To determine the total damage sustained from the combined effects of natural and enhanced VAB radiation requires summing the dose accumulated during orbits through the natural radiation environment with the dose received as a function of time after enhancement.

The radiation transport calculations to estimate the effects of VAB proton radiation were carried out using the Monte Carlo code HETC. The calculations to estimate the effects of natural electrons and enhanced electrons were performed using the Monte Carlo code EGS4. Complete descriptions of these codes are given in Reference 1 and the references contained therein.

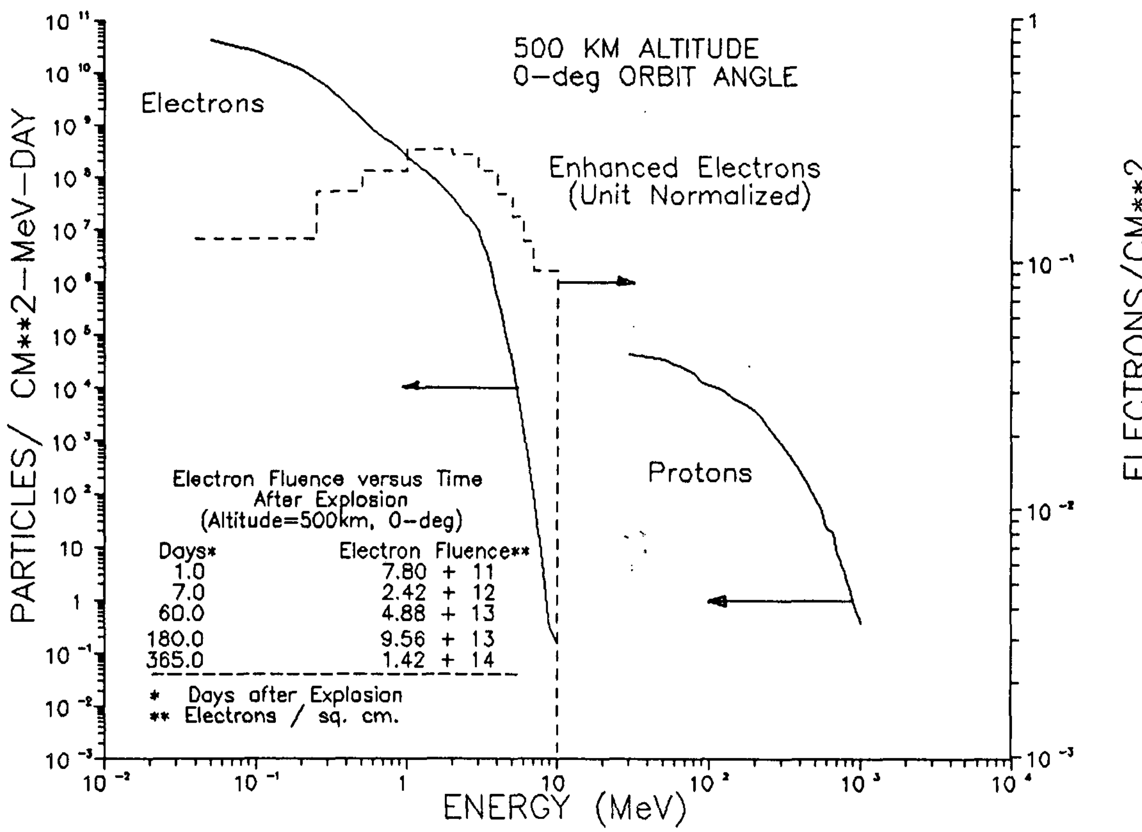
The radiation damage in the SBI and the KKVs was estimated at 68 locations that were considered to be potentially most sensitive to the incident radiation. A detector refers to a region in the combinatorial geometry representation of the satellite and the KKVs in which an estimate of the radiation damage is desired. For example, the C^3 bay, contains fifteen detector regions; the central critical electronics component box, six angular segments in the inner ring, and eight segments in the outer ring. Separate detector regions were adopted for the fuel tanks, antenna, solar panels, and the KKV fuel tanks, computers, and sensors.

To improve the statistical fluctuations in the dose distributions in the sensitive areas, the source particle energies and directions were sampled from biased distributions. These biased distributions were constructed so that those source-particle energies and directions that resulted in relatively large dose contributions



(a)

Figure 1a. Calculational Model of the Space Based Interceptor Weapon Platform



(b)

Figure 1b. Proton and Electron Van Allen Belt Spectra were sampled more frequently. Statistical weighting fractions to account for the biasing were then applied to each source particle so that the original incident source spectral shape and normalization were preserved.

RESULTS

The radiation damage in several components of the satellite and KKVs from VAB proton radiation for the source spectrum given in Figure 1b is summarized in Table 1. The column labeled "Primary" gives the dose due to the incident proton radiation only. The column labeled "Primary Plus Secondary" is the dose from the incident protons plus the dose from secondary particles produced by the reactions of the incident radiation in the materials of the system.

The dose/day from VAB protons in all 68 detector regions is low. Even after ten years exposure to this radiation, the cumulative doses range from approximately 200 rads in the C^3 bay to 1500 rads in the inner layers of the solar panel. These doses are well below the total dose levels (10^6 rad) at which silicon based electronics and solar cells will fail.

The damage from VAB electrons and enhanced electron belt radiation in the SBI platform and KKVs at an altitude of 500 km is given in Table 2. The damage from natural radiation is normalized to rads/day whereas the enhanced damage is in units of rads/electron.

The enhanced electron spectra showed small (less than 5%) spectral differences with respect to orbital height, orbital inclination, and time after nuclear detonation (6 hours to 1 year). Therefore, the spectrum was averaged and the total electron fluence as a function of time after the nuclear detonation was used to determine the dose due to the nuclear enhanced electron radiation environment. Multiplying the normalized enhanced electron doses given in Table 2 by the total electron fluences given in Figure 1b yields the cumulative doses due to the nuclear enhanced electron environment as a function of time after nuclear detonation.

The low energy natural electron spectrum results predominately in a surface dose in the components. The dose then falls off rapidly with depth. Any damage to components inside of the platform can result only from secondary bremsstrahlung photons produced from primary electron interactions. The enhanced electron spectrum also leads to a large surface dose. However, since the electrons are somewhat more energetic and the spectrum is harder, the dose profile in these components is much flatter and the dose in the interior layers is significantly higher than the dose due to the natural electron environment. Comparing the dose averaged through the solar panel reveals that the dose rate from the natural environment is 2.29×10^{-3} rad/day whereas the enhanced electron dose rate at six hours after weapon detonation is 1.1×10^{3} rads/day. The slow decay of the enhanced spectrum indicates that the dose accumulated in the outer layers of the solar panels and antenna is sufficiently large to cause material damage and bit upset, degradation, and failure in near surface mounted electronic components.

To determine the combined dose from both environments, the dose rate from the natural environment must be multiplied by the time that the platform resided in the environment and added to the cumulative dose from enhancement. For example, if the platform was in orbit for one year prior to the detonation of a weapon in space, the dose average with depth in the solar panels would be 0.84 rads from natural electrons and 67.5 rads from protons. Six hours after the explosion, the dose from enhanced electrons would be 279 rads.

Table 1. Dose Due to Van Allen Belt Protons

Detector Region	Primary[a] (rads/day)	Primary & Secondary[b] (rads/day)
C^3 Bay Central Instrument Box	4.74−02 ± 10%	4.89−02[c] ± 16%
C^3 Bay Inner Instrument Ring	4.90−02 ± 3%	4.34−02 ± 4%
C^3 Bay Outer Instrument Ring	6.89−02 ± 3%	6.26−02 ± 3%
Average for the Kinetic Kill Vehicle Computers	6.28−02 ± 4%	6.61−02 ± 5%
Average for the Kinetic Kill Vehicle Sensors	7.63−02 ± 3%	7.07−02 ± 4%
Outer 0.5 cm Thickness of the Solar Panels	1.05−01 ± 3%	1.17−01 ± 4%
Average for the Solar Panels	1.85−01 ± 1%	2.13−01 ± 1%
Average for the Antenna	1.96−01 ± 4%	1.64−01 ± 5%
Average for the Kinetic Kill Vehicle Rocket Fuel	7.94−02 ± 2%	7.31−02 ± 3%
Average for the SBI Weapon Platform Rocket Fuel	6.85−02 ± 2%	6.42−02 ± 2%

[a] Dose due to unattenuated primary protons only.
[b] Dose due to primary and secondary collisions and full proton transport.
[c] Read as 4.89×10^{-2}.

Table 2. Dose Due to Natural and Enhanced Van Allen Belt Electrons

Detector Region	Natural Background Dose (rads/day)	Enhanced Electron Dose (rads-cm^2/electron)
C^3 Bay Central Instrument Box	3.23−05[a] ± 30%	1.13−12 ± 26%
C^3 Bay Inner Instrument Ring	5.19−05 ± 15%	3.79−12 ± 11%
C^3 Bay Outer Instrument Ring	1.49−04 ± 12%	6.85−12 ± 6%
Average for the Kinetic Kill Vehicle Computers	7.39−05 ± 15%	4.12−12 ± 9%
Average for the Kinetic Kill Vehicle Sensors	1.20−04 ± 11%	6.42−12 ± 7%
Outer 0.5 cm Thickness of the Solar Panels	8.78+00 ± 2%	9.79−09 ± 1%
Average for the Solar Panels	2.29−03 ± 3%	3.58−10 ± 1%
Average for the Antenna	5.83−04 ± 2%	8.64−11 ± 6%
Average for the Kinetic Kill Vehicle Rocket Fuel	1.02−04 ± 11%	5.22−12 ± 5%
Average for the SBI Weapon Platform Rocket Fuel	3.51−04 ± 7%	1.52−11 ± 4%

[a] Read as 3.23×10^{-5}.

REFERENCES

1. R. T. Santoro and T. A. Gabriel, *Shield Optimization Program, Part I: Executive Summary*, ORNL/TM-11143, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, June 1989.