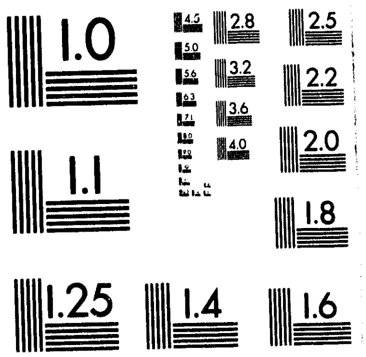
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VULNERABILITY ASSESSMENT OF A SPACE BASED WEAPON PLATFORM ELECTRONIC SYSTEM EXPOSED TO A THERMONUCLEAR WEAPON DETONATION*

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ABSTRACT

Rapidly changing world events, the increased number of nations with inter-continental ballistic missile capability, and the proliferation of nuclear weapon technology will increase the number of nuclear threats facing the world today. Monitoring these nation's activities and providing an early warning and/or intercept system via reconnaissance and surveillance satellites and space based weapon platforms is a viable deterrent against a surprise nuclear attack. However, the deployment of satellite and weapon platform assets in space will subject the sensitive electronic equipment to a variety of natural and man-made radiation environments. These include Van Allen Belt protons and electrons; galactic and solar flare protons; and, neutrons, gamma rays, and X-rays from intentionally detonated fission and fusion weapons. In this paper, the MASH v1.0 code system is used to estimate the dose to the critical electronics components of an idealized space based weapon platform from neutron and gamma-ray radiation emitted from a thermonuclear weapon detonation in space. Fluence and dose assessments were performed for the platform fully loaded, and in several stages representing limited engagement scenarios. The results indicate vulnerabilities to the Command, Control, and Communication (C^3) bay instruments from radiation damage for a nuclear weapon detonation for certain source/platform orientations. The distance at which damage occurs will depend on the weapon yield (n,γ/kiloton) and size (kilotons).

I. INTRODUCTION

Rapidly changing world events, the increased number of nations with inter-continental ballistic missile capability, and the proliferation of nuclear weapon technology will increase the number of nuclear threats facing the world today. Many of these nations are run by unstable governments hostile to the United States and her allies. Consequently, monitoring these nation's activities and providing an early warning and/or intercept system via reconnaissance and surveillance satellites and space based weapon platforms is a deterrent against a surprise nuclear attack.

Electronic equipment, including modern integrated circuits, may undergo permanent or transient changes of the electrical properties of the active components when exposed to radiation. The deployment of satellite and weapon platform assets in space will subject the sensitive electronic equipment to a variety of natural and man-made radiation environments. These include Van Allen Belt protons and electrons; galactic and solar flare protons; and, neutrons, gamma rays, and X-rays from intentionally detonated fission and fusion weapons. Furthermore, in a pulsed radiation environment, radiation induced photo currents can lead to transient circuit upsets. The changes in the electrical characteristics can result in degradation of circuit performance or device failure. In this paper, the Monte Carlo Adjoint Shielding code system - MASH v1.0[1] is used to estimate the dose to the critical electronics components of an idealized space based weapon platform from neutron and gamma-ray radiation emitted from a thermonuclear weapon detonated at various distances and directions relative to the platform.[2] The purpose of this study is to demonstrate the merits of the MASH code system in estimating dose and shielding tactors for a space based asset.

II. COMPUTATIONAL METHODOLOGY

A typical MASH problem involves analyzing a target (armored vehicle, building, etc.) in a prompt radiation field. MASH employs a forward discrete ordinates calculation to determine the neutron and gamma-ray fluence on a coupling surface surrounding the armored vehicle or shielded structure, and an adjoint Monte Carlo calculation to determine the dose importance of the surface fluence. MASH then utilizes a processing code to fold the fluence with the dose importance to yield the desired detector response(s) (dose, radiation damage, latchup, etc.). The general structure of a typical MASH calculation is given in Figure 1.

The MASH code system was developed at the Oak Ridge National Laboratory (ORNL) for the Department of Defense to estimate nuclear weapon and reactor radiation environments along with the protection offered by shielded assemblies (armored vehicles, shelters, etc.) to the neutron and gamma radiation from these sources. The code system consists of several sub-codes that, in combination, yield the spectra, dose, and dose reduction and protection factors of the assembly under study. The definitions of the reduction factors and protection factors are given in Tables 1 and 2. For initial radiation environments(on the ground), MASH has been extensively benchmarked through comprehensive comparisons with measured data obtained at the Army Pulsed Radiation Facility (APRF) at Aberdeen Proving Ground, Maryland. Several experimental configurations have been studied including, the Soviet Armored Infantry Fighting Vehicle (BMP-1), the U.S. Abrams Tank (Version XM-1 and M1A1), and two steel-shielded assemblies: the Radiological Test Configuration (RTK)[3] and the Two-Meter Box Test-Bed Assembly.[4-6] Additionally, MASH has been used to calculate crew protection factors for the U. S. M60A1[7] and crew and electronic component protection factors for the U. S. M1A1 and M1A2 Abrams Main Battle Tanks. MASH has been adopted by the NATO Panel VII Ad Hoc Group of Shielding Experts as the reference code for <u>all</u> (NATO and non-NATO) armored vehicle prompt radiation nuclear vulnerability calculations.

III. THE ORNL SPACE BASED INTERCEPTOR (SBI) PLATFORM

The weapon platform model used in this study was used previously in the ORNL Shield Optimization Program[8] of the Strategic Defense Initiative (SDI) and is not proposed for deployment. The platform, shown in Figure 2, was "designed" on the basis of space weapon system requirements eluded to in documentation on SDI space weapon-sensor architecture requirements. The ORNL weapon platform is a cylindrical shell comprised of two interceptor-fuel tank modules connected by a Command, Control, and Communications (C^3) bay. Each module contains five interceptor-launch tube assemblies and four fuel tanks. Power is supplied to the platform by solar panels, and a single antenna is shown, but it is recognized that other antennae and sensors may also exist on an actual platform design. A laser shield covers the earth-exposed surfaces for protection against illumination by ground based laser weapons. The electronic circuits are housed in two concentric rings assemblies of the C^3 bay. At the center of the C^3 module is a "critical components" box. The cylindrical ring assemblies and the box are thin walled hollow assemblies that can be filled with detailed models of electronic circuitry or homogenized materials representative of those comprising the electronic packages. The electronics bay is also designed for additional shielding should it be necessary to further minimize the effects of nuclear radiation. Ten identical interceptors are modeled in their appropriate locations inside the platform. Each interceptor includes a warhead, sensors, fuel tank, rocket motor and nozzle. The body of the interceptor will contain appropriate shielding to protect the interceptor guidance system from exposure to weapon radiation outside the platform during engagement.

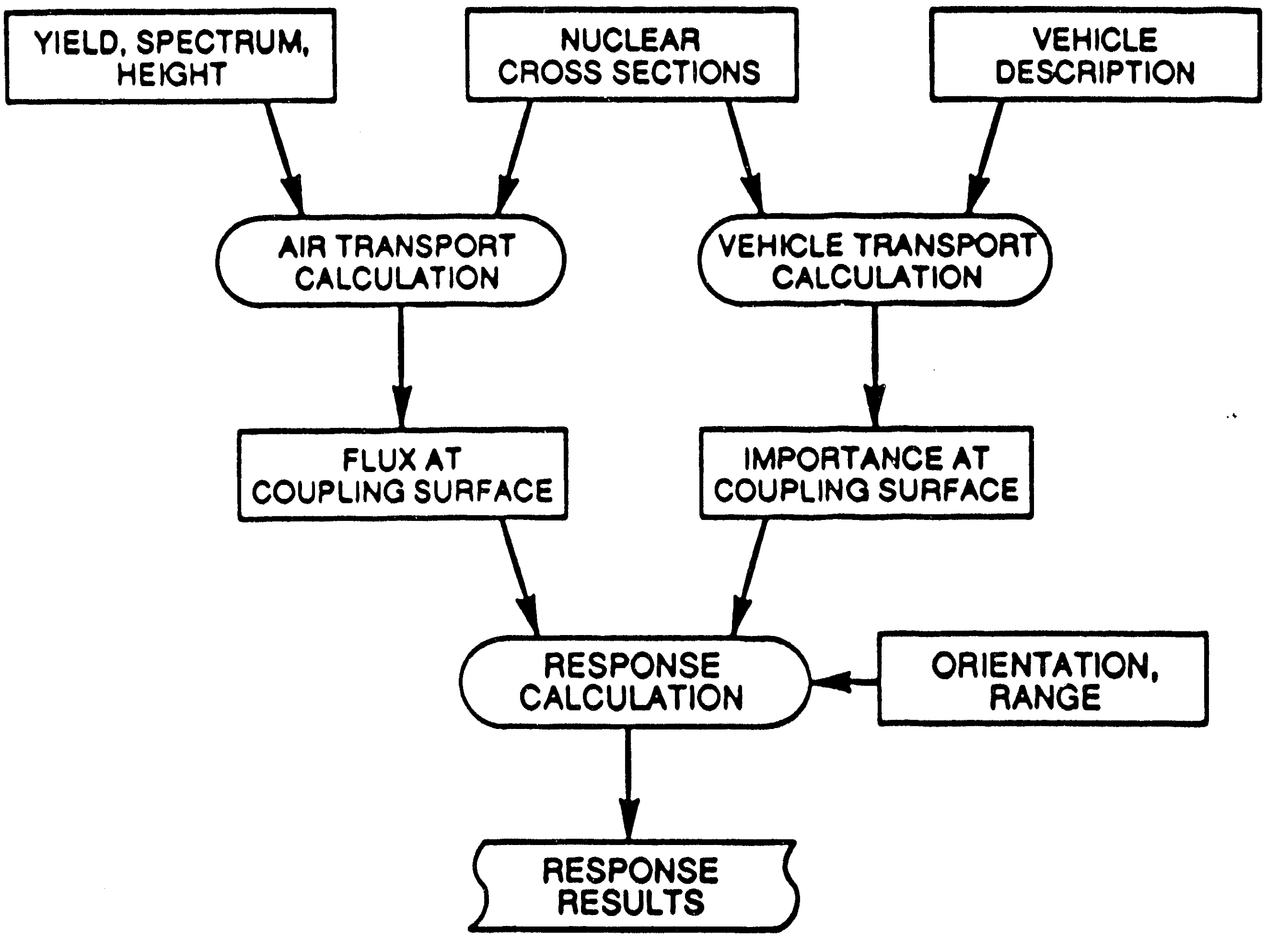

Figure 1. General Structure of a Typical Application of the MASH Code System.

Table 1. Detector Response Definitions in the DRC Program of the MASH v1.0 Code System.

Detector	Response Definition
1	Direct neutron - a neutron entering the vehicie and contributing a neutron dose.
2	Capture gamma rays from vehicle - gamma ray resulting from a neutron entering the vehicle and contributing a secondary gamma-ray dose.
3	Capture gamma rays from ground - a gamma ray resulting from a neutron entering the ground without passing through the vehicle and generating a secondary gamma-ray dose from a ground interaction. (This dose is already included in the upward-directed gamma rays that enter the vehicle. This generally is negligible.
4	Direct gamma rays - a gamma ray entering the vehicle and contributing a gamma-ray dose. This source of gamma rays includes both gamma rays originating from the source, and capture gamma rays from the air.
5	Total gamma-ray dose - Sum of detectors 2, 3, and 4.
6	Gamma-ray dose from gamma rays entering the vehicle (usually dominated by direct gamma rays) - Sum of detectors 3 and 4.
7	Neutron and gamma-ray dose from neutrons incident on the vehicle - Sum of detectors 1 and 2.

Table 2. Definitions of Parameters and Protection Factors used to Characterize the Effectiveness of Shields.

Parameter	Response Definition
FFN	Free-Field Neutron Response
FFG	Free-Field Gamma Response
NPF	Neutron Protection Factor NPF = FFN / Detector 7
GPF	Gamma Protection Factor GPF = FFG / Detector 6
TPF	Total Protection Factor TPF = (FFN+FFG)/(Detector 7 + Detector 6)
NRF	Neutron Reduction Factor NRF = FFN / Detector 1
GRF	Gamma Reduction Factor GRF - FFG / Detector 5
TRF	Total Reduction Factor TRF = (FFN+FFG)/ (Detector 1 + Detector 5)

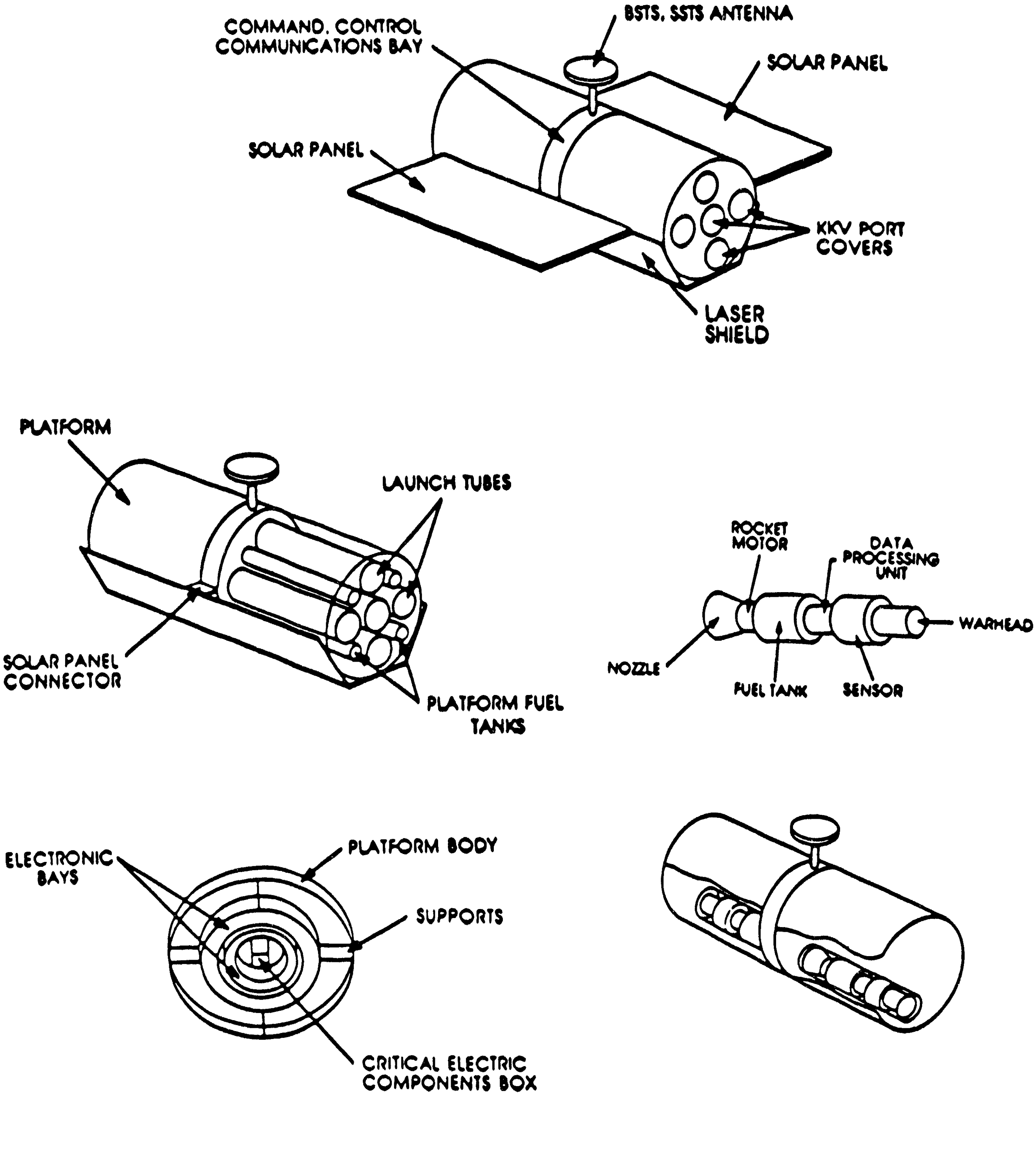

Figure 2. Calculational Model of the Space Based Interceptor Platform.

IV. APPLICATION OF MASH TO THE SBI PLATFORM

To demonstrate the applicability of MASH for analyzing space based assets exposed to nuclear weapon radiation, calculations have been completed for a thermonuclear weapon detonation in space. Fluence and dose assessments were performed for the platform fully loaded, center interceptors launched, and multiple side interceptors launched. The results were obtained for the C^3 bay critical components box; for the platform at 1 km and 10 km; and with the weapon detonation above the platform, facing an end of the platform, and at an approximate 45 degree angle to the platform. Each MASH case initiated 500,000 source particles which yielded integral data statistics within 10% for the three geometries considered. The statistics on the spectral data were typically within 20%.

The silicon dose and protection factor results are presented in Table 3 for the various source orientations and geometry configurations. The protection factor definitions are presented in Table 2 with the definitions of the components defining the protection factors presented in Table 1. The results indicate varying degrees of radiation protection for the different source/platform cases analyzed. With respect to dose, the results indicate a $1/R^2$ dependence as seen in the comparison of the 1 km and 10 km cases for the weapon detonation directly above the SBI platform. Similar results were seen in the dose results for the weapon source in front of the platform and at a 45 degree angle to the front and top sides of the platform. The protection factors for these two cases, however, are constant since both the free-field and in-platform doses are falling off by approximately the same factor.

The effects of limited engagement are also seen when comparing the fully loaded and center launched interceptor cases where the protection factors decrease by approximately a factor of four for the source in front of the weapon platform. It is interesting to note that the neutron protection factor is less than one for this case. This is due to the secondary gamma-ray production in the platform components contributing to the dose in the critical components box (see the definition of NPF given in Table 2). Finally it should be noted that for the last case (source 1 km above and 1 km in front), the source has a direct line-of-sight to the critical components box regardless of the number of interceptors present. This indicates a need for localized shielding or additional hardening requirements for this area of the platform.

V. CONCLUSIONS

MASH was used to estimate the dose to the critical electronics components of an idealized space based weapon platform from neutron and gamma-ray radiation emitted from a thermonuclear weapon detonation in space. Fluence and dose assessments were performed for the platform fully loaded, and in several stages representing limited engagement scenarios (some of the interceptors launched). The results indicate vulnerabilities to the C^3 bay instruments from radiation damage for a nuclear weapon detonation for certain source/platform orientations. The distance at which damage occurs will depend on the weapon yield ($n,\gamma/kT$) and size (kilotons).

The geometry configuration studied here is greatly simplified compared to an actual design. The MASH code system is capable of estimating the dose in much more complicated geometries and should prove to be an invaluable tool for assessing the radiation effects of both on-spacecraft and external radiation sources to electronic equipment. Combining the MASH code system with other codes that estimate natural radiation effects will provide satellite and weapon platform designers with a full complement of analytic tools.

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Table 3. Calculated Neutron and Gamma-Ray Dose and Protection Factors for the Space Based Weapon Platform C^3 Bay Critical Components Box Due to the Detonation of a Thermonuclear Weapon.

Radiation Parameter	Platform Fully Loaded	Platform Center Interceptors Launched	Platform Multiple Side Interceptors Launched
	Detonation 1 km Above the Weapon Platform		
n Dose[a]	1.70-22[b]	1.52-22	1.63-22
γ Dose	1.02-21	1.01-21	9.80-22
NPF	1.47	1.71	1.78
GPF	8.68	6.87	6.81
TPF	3.65	3.73	3.79
	Detonation 10 km Above the Weapon Platform		
n Dose	1.57-24	1.41-24	1.51-24
γ Dose	9.28-24	9.23-24	8.96-24
NPF	1.45	1.69	1.75
GPF	8.38	6.68	6.62
TPF	3.57	3.64	3.70
	Detonation 1 km in Front of the Weapon Platform		
n Dose	1.70-22	1.26-21	1.23-22
γ Dose	7.73-22	3.31-21	6.29-22
NPF	3.20	0.76	3.43
GPF	6.77	1.26	9.88
TPF	5.15	1.06	6.47
	Detonation 1 km Above and 1 km in Front of the Weapon Platform		
n Dose	4.98-22	4.65-22	4.49-22
γ Dose	1.53-21	1.35-21	1.47-21
NPF	0.65	0.75	0.77
GPG	1.55	1.66	1.48
TPF	1.12	1.24	1.18

[a]Neutron and Gamma-Ray Dose in Units of cGy/source n,γ.
[b]Read as 1.70×10^{-22}