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Effects of X-Radiation on the LAMPSHADE Orbital Debris Satellite Shield—II

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Engineering Physics and Mathematics

Effects of X-Radiation on the LAMPSHADE Orbital Debris Satellite Shield — II

M. S. Smith and R. T. Santoro

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ABSTRACT

One-dimensional thermo-hydrodynamic calculations have been performed to estimate the response of the lead (Pb) bumper plate and aluminum (Al) foam liquidator screen of the LAMPSHADE orbital debris satellite shield. Mass fractions in the solid, liquid, and vapor phases as a function of time after irradiation for two incident x-ray spectra, were calculated using the PUFF-TFT code. Material losses due to phase changes did not exceed 3%, but fracture and spallation may seriously reduce the performance of the lead component against incident debris.

1. RESULTS

A previous study[1] using the PUFF-TFT code[2] examined the initial effects of x-radiation on two components of the proposed LAMPSHADE[3] orbital debris satellite shield concept. Material response effects were predicted for a tantalum (Ta) liquidator plate and a lead (Pb) bumper assembly for incident monoenergetic or blackbody x-ray source terms. Recommendations were made in that study to further evaluate the lead response by revising the source term and to consider post-deposition time frames in the analysis. Accordingly, this effort examines the response characteristics of the lead bumper plate assembly subjected to a simulated weapon x-ray source term and to a 1 keV blackbody source term, both utilizing 100 nanosecond log-normal time distributions. In addition, an alternate material, aluminum foam at 25% theoretical density, had been proposed as the liquidator plate. This report also investigates the response characteristics of this candidate material.

The survivability of the LAMPSHADE shield was evaluated by calculating the one-dimensional thermo-mechanical response of the components of the shield to the incident x-ray spectra described above. Two issues were studied: the mechanical integrity of the shield components following exposure to the threat and the amount of material blown off the surfaces of the shield components that have potential for blinding or otherwise reducing the effectiveness of the sensors and windows on the satellite.

To provide insight into the magnitude of these effects, calculations of mass fraction by phase are presented. That is, for each incident radiation source, the fractions of lead or aluminum that exist in the solid, liquid, and vapor states are given as a function of time after irradiation.

The results obtained for the lead bumper plate are summarized in Table 1. Mass fractions by phase are tabulated at 50, 80, 100, 300, and 500 ns after arrival of the incident radiation. These results show that approximately 2% of the material exists in the liquid or vapor states for these source terms, with the hotter weapon spectrum vaporizing and melting a substantially greater fraction of lead than the colder 1 keV blackbody spectrum. Typically, colder spectra are considered more damaging, but in the case of lead, with its low critical enthalpies, the hotter spectrum dominates.

The results in Table 1 show that only small portions of the shield material are lost due to phase changes. The remaining solid material may also suffer mechanical degradation due to spalls or fractures within the medium. Spall/fracture flags in the PUFF-TFT code show considerable degradation throughout the material, and for the weapon source, indicate a fracture plane near the back surface. The mechanical integrity of the shield is clearly suspect for these sources, particularly for the weapon spectrum.

The results obtained for the aluminum foam liquidator are summarized in Table 2. Mass fractions by phase are tabulated at 10, 60, 100, and 500 ns after arrival of the incident radiation. These results indicate that only small amounts of material undergo a phase change to the liquid state and there is no vaporization. In

addition, due to the porous nature of the foam, there are no indications of spallation or fracture within the solid region for either source term. Aside from the minimal surface effects, the aluminum foam appears to be unaffected by the x-radiation.

The time dependence of the impulse loading on the lead shield and aluminum foam liquidator plate is shown in Figures 1-2. These data provide the necessary information for designing the mounting and shock-absorbing assemblies when the shield components are attached to the satellite. For a 1 cal/cm^2 x-ray loading on aluminum foam shown in Figure 1, the impulse peaks at 10 taps for a 1 keV blackbody spectrum and at 13 taps for the weapon spectrum. The impulse to the lead bumper assembly with a loading of 1 cal/cm^2 is plotted in Figure 2. For this case, the loads peak at 93 taps for a 1 keV blackbody spectrum and at 37 taps for the weapon spectrum.

	Bumper Plate	Liquidator
Material	Pb	Ta
Areal Density (g/cm^2)	0.575	0.21

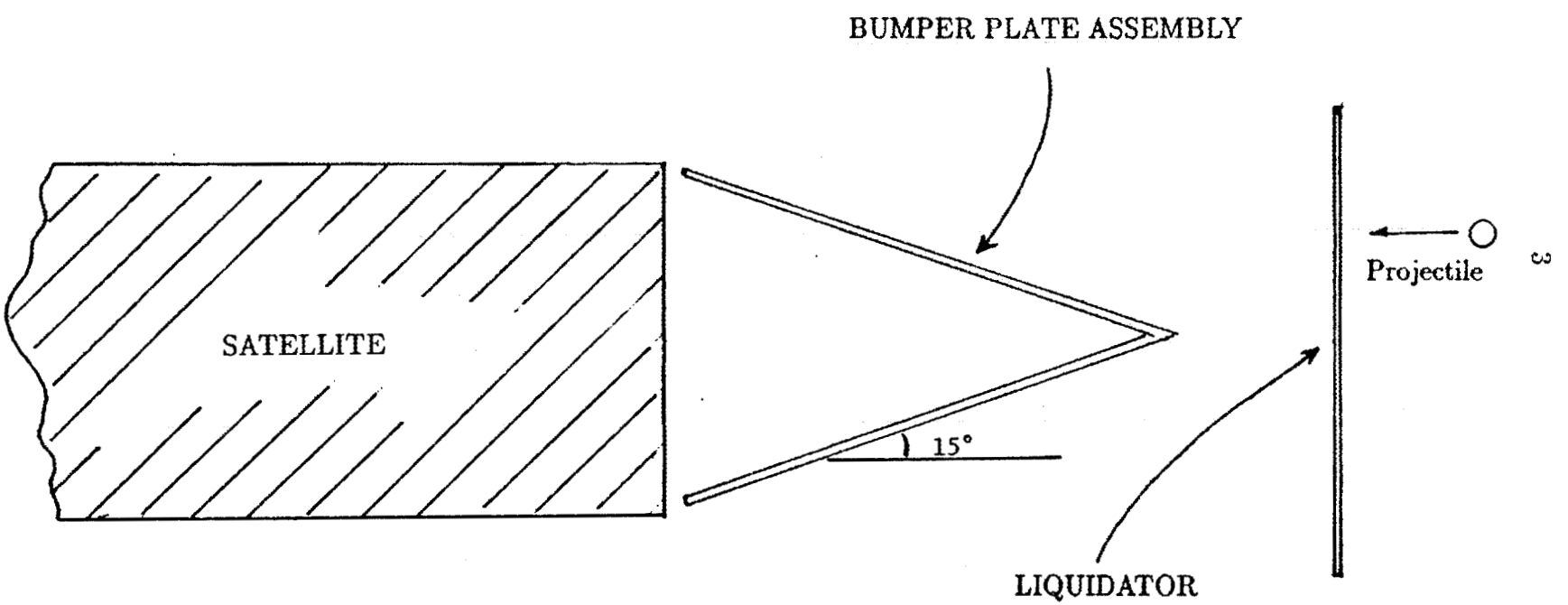

Figure 1. LAMPSHADE Debris Shield Concept (not to scale).

Table 1

Lead
Mass Fraction by Phase

Time (sec)	Solid	Liquid	Vapor
	1 keV Blackbody at 1 cal/cm^2		
5.0–08*	9.918–01	4.069–03	4.089–03
8.0–08	9.910–01	4.179–03	4.849–03
1.0–07	9.910–01	3.959–03	5.068–03
3.0–07	9.883–01	5.899–03	5.812–03
5.0–07	9.870–01	7.478–03	5.549–03
	Weapon Spectrum at 1 cal/cm^2		
5.0–08	9.787–01	1.688–02	4.446–03
8.0–08	9.748–01	1.969–02	5.549–03
1.0–07	9.748–01	1.942–02	5.812–03
3.0–07	9.748–01	1.820–02	7.032–03
5.0–07	9.748–01	1.747–02	7.760–03

*Read as 5.0×10^{-8}

Table 2

Aluminum Foam
Mass Fraction by Phase

Time (sec)	Solid	Liquid	Vapor
	1 keV Blackbody at 1 cal/cm^2		
1.0–08*	1.0		
6.0–08	9.991–01	8.894–04	
1.0–07	9.990–01	9.609–04	
5.0–07	9.991–01	8.894–04	
	Weapon Spectrum at 1 cal/cm^2		
1.0–08	1.0		
6.0–08	9.997–01	2.576–04	
1.0–07	9.998–01	7.572–04	
5.0–07	1.0		

*Read as 1.0×10^{-8}

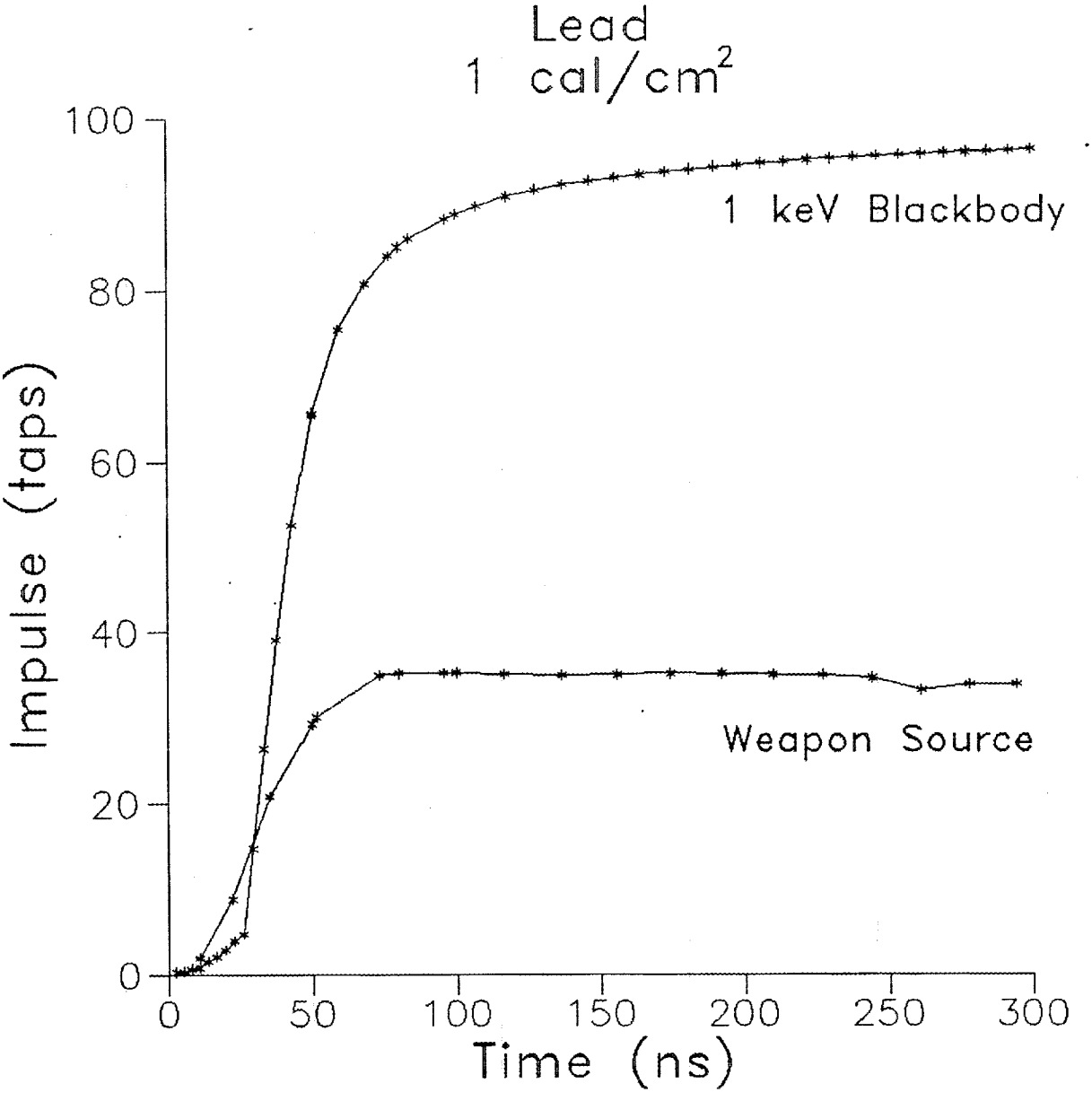

Figure 2. Integrated impulse over time for the lead bumper assembly.

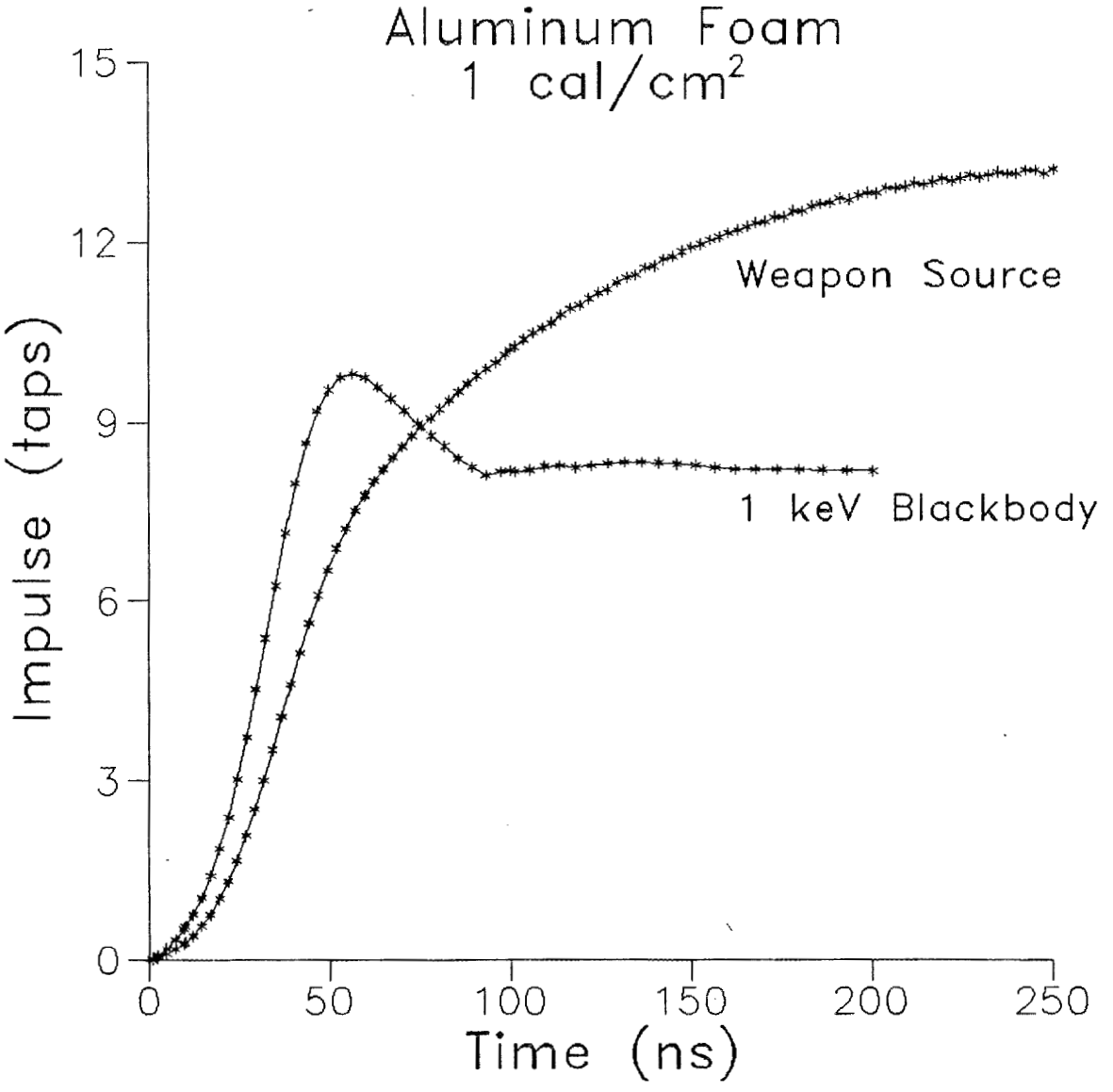

Figure 3. Integrated impulse over time for the aluminum foam liquidator plate.

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