Radiation Characterization of AlBeMet® 162 Material

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A Report Prepared for the Brush-Wellman Company

The shielding properties of the aluminum-beryllium alloy (38% Al, 62% Be) AlBeMet® 162 material (referred to hereafter as AlBeMet®) has been characterized for a wide range of photon and electron energies. The 'figures of merit' in evaluating these shielding properties are the absorbed dose to silicon and gold. The same characterization has also been performed on a standard aluminum alloy, Al6061, to provide a comparison of radiation shielding effectiveness.

1.0 Introduction

This report documents the radiation transport analysis conducted to evaluate the AlBeMet® in certain photon and electron environments in lieu of performing much more costly testing at a variety of nuclear radiation simulators. The analysis consists of computing dose to silicon and gold for various photon and electron energies, and comparing these results against computed dose(Si) and dose(Au) for Al6061.

Appendix A contains all the graphs of dose(Si) and dose(Au) vs. energy for the two materials for the various radiation environments.

1.1 Description of AlBeMet®

AlBeMet® is an aluminum-beryllium alloy consisting of 62% Be, and 38% Al, with a density of 2.10 g/cm³. This alloy is significantly less absorbing than the Al6061, as would be expected from the high percentage of x-ray transparent Be.

1.2 Description of Al6061

The Al6061 aluminum alloy is commonly used for the electronic package housing material in missile and space applications. It consists of 97.8% Al, 1% Mg, 0.25% Cr,
Analysis Approach

0.7% Fe, and 0.25% Cu, with a density of 2.68 g/cm³. Even though this material is a better x-ray attenuator than AlBeMet®, other much higher atomic number materials are necessary for shielding electronic components to reasonable dose levels, at least in most military applications. This will tend to equalize Al6061 and AlBeMet®, since the high Z materials would provide the bulk of the shielding.

1.3 Photon and Electron Environments

The photon characterization is divided into two parts: a characterization over the energy range of 5 keV to 200 keV to cover the x-ray environments from a nuclear burst; and a characterization over the energy range of 1 MeV to 9 MeV that covers the γ-ray environments from nuclear bursts, as well as some natural space environments.

The energy range over which the absorbed dose from β-ray (electron) radiation is computed is 500 keV to 5 MeV, again covering typical energies from nuclear and natural radiation sources.

1.4 Neutron Environment

The results of a brief study into neutron shielding are presented in the results section. While Be is much better at slowing down neutrons than Al, the thicknesses required to attenuate the neutron fluence significantly would be impractical in space and military electronic packaging. Most components used in these types of applications are relatively insensitive to the damage caused by neutrons, at least for the reasonable neutron fluences accompanying survivable x- and γ-ray environments.

2.0 Analysis Approach

Most weapon or natural source radiation models are described using specific spectra. In order to provide results that are useful for a variety of radiation models, the 'delta function' response has been calculated at various source particle energies. These results are then be multiplied by a particular model's spectra (expressed in cal/MeV) to obtain the absorbed dose(Si or Au) for that model. However, when this approach was used to compute dose(Si) for a particular weapon model, the computed dose was ~25% lower than when using the actual spectra. This could be improved by taking smaller ∆E steps, but would result in more computational costs. These results provide a quick way to assess the shielding effectiveness of AlBeMet®, final dose values used to determine actual package thicknesses or thicknesses of additional shielding materials should be obtained by re-running the transport code using the actual spectrum of interest.

Dose(Si) and dose(Au) for the two materials are computed for a range of thicknesses depending on the energy range of the particular source. For x-rays, the thickness range is 0.010 inches to 0.200 inches. For γ- and β-rays, the thickness range is 0.050 inches to 0.500 inches.
The energy range for x-rays is shown in Table 1. For γ-rays, the energy range is 1 MeV to 9 MeV by 2 MeV steps, while for b-rays, the range is 500 keV to 5 MeV by 500 keV steps.

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 19 keV</td>
<td>2 keV</td>
</tr>
<tr>
<td>22 to 49 keV</td>
<td>3 keV</td>
</tr>
<tr>
<td>55 to 100 keV</td>
<td>5 keV</td>
</tr>
<tr>
<td>110 keV to 200 keV</td>
<td>10 keV</td>
</tr>
</tbody>
</table>

2.1 The CEPXS/ONELD Transport Code

The CEPXS/ONELD (Coupled Electron-Photon Cross Section/One-Dimensional Discrete Ordinates) transport code was developed by Sandia National Laboratories. It is essentially the deterministic equivalent to Sandia's ITS (Integrated Tiger Series) stochastic transport code. Since CEPXS/ONELD is an analytic solution to Boltzmann's transport equation, it is considerably faster than its Monte Carlo counterpart, the TigerP portion of ITS. CEPXS/ONELD models the same physical interactions as ITS 2.1, however, for electron transport, modifications are made to the electron cross sections so that the more amenable Boltzmann-CSD transport equation can be solved. The reason for this lies in the description of the collisional cross section for electrons. The inelastic cross section rapidly increases as energy losses become small, which would necessitate an excessive number of narrow-width groups to be used. This would make the cost of a discrete ordinates solution exorbitant. The continuous slowing-down (CSD) approximation (or operator) is introduced into the calculation of the electron collision cross-sections, effectively transforming the ONELD code into a Boltzmann-CSD equation solver for electrons [1].

3.0 Analysis Results

Graphs of dose vs. energy for the two materials over the thickness ranges stated in Section 2 are in Appendix A.

3.1 Using the Results

The actual units of the absorbed energy are cal/g/cal of incident fluence. When trying to determine the absorbed dose for a particular spectrum, the dose for a specific energy must be multiplied by the integrated fluence of the spectrum at that energy. This requires the incident spectrum to be initially expressed in units of cal/keV/cal/cm² (or cal/MeV/cal/cm²). The integrated values are then in units of cal/cal/cm². Either the spectrum or the dose information is then interpolated onto the same energy values, the two quantities are multiplied, and the absorbed dose for that spectrum is obtained (in...
units of cal/cal/cm² of the incident spectrum). As mentioned previously, the dose obtained in this manner is low by approximately 25%.

A commonly used procedure is to generate the spectrum (or digitize some facility-provided curve). The spectrum is integrated using the trapezoidal rule, with the energy (x-axis) value set to the average of the energy values used in the integration, i.e.,

\[
S_j = \frac{1}{2} (F_i + F_{i-1}) (E_i - E_{i-1})
\]

\[
E_j = \frac{1}{2} (E_i + E_{i-1})
\] (EQ 1)

where \( F_i \) is the fluence at \( E_i \), and \( S_j \) is the integrated fluence at \( E_j \). The \( S_j \)'s are then interpolated (if needed) onto the energy values for the absorbed dose data. The total absorbed dose is then

\[
D_T = \sum_j S_j \cdot D_j
\] (EQ 2)

where \( D_T \) is the total absorbed dose, and \( D_j \) is the absorbed dose at energy \( E_j \).

3.2 Neutrons

Neutrons, since they possess no charge, are only slowed by collisions with other particles. The more closely the mass of these other particles matches that of a neutron, the better the energy transfer, and hence shielding properties. However, when neutrons are scattered, secondary radiation in the form of γ-rays are generated, which a shielded best by higher atomic number materials. So, a typical neutron shielding design involves the use of low atomic number materials to provide efficient neutron scattering, a material that absorbs the slowed down, i.e., thermalized to room temperature (most materials have fairly large thermal neutron absorption cross sections), along with higher atomic number materials to absorb the secondary radiation [2]. However, reasonable thicknesses of the scattering material are necessary (about 10 cm for water for a 10% reduction in neutron fluence). For thicknesses that would be used in electronic packaging applications, the advantage of AlBeMet® 162 over Al6061 is small.

4.0 Conclusions

Due to its high beryllium content, AlBeMet® 162 material is a relatively poor radiation shield when compared to Al6061. However, neither material would be expected to provide the bulk of the radiation shielding, especially in military applications. This would be accomplished by using denser, higher atomic number materials like tungsten.

Also, any surface treatments, such as anodizing or coating with alodine or nickel, would provide essentially no increase shielding effectiveness for the thicknesses usually employed.
5.0 References


Appendix A

Radiation Characterization of
AlBeMet® 162 Material

This Appendix contains the graphical results of the radiation characterization of the AlBeMet® 162 material. Each graph contains dose (Si or Au) vs. energy for AlBeMet® and Al6061.
1.0 X-ray Characterization (5 keV to 200 keV)

**FIGURE 1.**
Dose(Si) vs. energy for 10 mils thick AlBeMet® and Al6061.

**FIGURE 2.**
Dose(Si) vs. energy for 20 mils thick AlBeMet® and Al6061.
**FIGURE 3.** Dose(Si) vs. energy for 30 mils thick AlBeMet® and Al6061.

**FIGURE 4.** Dose(Si) vs. energy for 40 mils thick AlBeMet® and Al6061.
FIGURE 5.
Dose(Si) vs. energy for 50 mils thick AlBeMet® and Al6061.

FIGURE 6.
Dose(Si) vs. energy for 60 mils thick AlBeMet® and Al6061.
X-ray Characterization (5 keV to 200 keV)

FIGURE 7.
Dose(Si) vs. energy for 70 mils thick AlBeMet® and Al6061.

FIGURE 8.
Dose(Si) vs. energy for 80 mils thick AlBeMet® and Al6061.
FIGURE 9.
Dose(Si) vs. energy for 90 mils thick AlBeMet\textsuperscript{®} and Al6061.

FIGURE 10.
Dose(Si) vs. energy for 100 mils thick AlBeMet\textsuperscript{®} and Al6061.
FIGURE 11. Dose(Si) vs. energy for 110 mils thick AlBeMet® and Al6061.

FIGURE 12. Dose(Si) vs. energy for 120 mils thick AlBeMet® and Al6061.
FIGURE 13. Dose(Si) vs. energy for 130 mils thick AlBeMet® and Al6061.

FIGURE 14. Dose(Si) vs. energy for 140 mils thick AlBeMet® and Al6061.
FIGURE 15.
Dose(Si) vs. energy for 150 mils thick AlBeMet® and Al6061.

FIGURE 16.
Dose(Si) vs. energy for 160 mils thick AlBeMet® and Al6061.
FIGURE 17. Dose(Si) vs. energy for 170 mils thick AlBeMet® and Al6061.

FIGURE 18. Dose(Si) vs. energy for 180 mils thick AlBeMet® and Al6061.
FIGURE 19.
Dose(Si) vs. energy for 190 mils thick AlBeMet® and Al6061.

FIGURE 20.
Dose(Si) vs. energy for 200 mils thick AlBeMet® and Al6061.

Appendix A
LOCKHEED MARTIN MISSILES & SPACE
FIGURE 21. Dose(Au) vs. energy for 10 mils thick AlBeMet® and Al6061.

FIGURE 22. Dose(Au) vs. energy for 20 mils thick AlBeMet® and Al6061.
FIGURE 23. Dose(Au) vs. energy for 30 mils thick AlBeMet® and Al6061.

FIGURE 24. Dose(Au) vs. energy for 40 mils thick AlBeMet® and Al6061.
FIGURE 25.
Dose(Au) vs. energy for 50 mils thick AlBeMet® and Al6061.

FIGURE 26.
Dose(Au) vs. energy for 60 mils thick AlBeMet® and Al6061.
FIGURE 27.  Dose(Au) vs. energy for 70 mils thick AlBeMet® and Al6061.

FIGURE 28.  Dose(Au) vs. energy for 80 mils thick AlBeMet® and Al6061.
FIGURE 29. Dose(Au) vs. energy for 90 mils thick AlBeMet® and Al6061.

FIGURE 30. Dose(Au) vs. energy for 100 mils thick AlBeMet® and Al6061.
FIGURE 31.
Dose (Au) vs. energy for 110 mils thick AlBeMet® and Al6061.

FIGURE 32.
Dose (Au) vs. energy for 120 mils thick AlBeMet® and Al6061.
FIGURE 33.
Dose (Au) vs. energy for 130 mils thick AlBeMet® and Al6061.

FIGURE 34.
Dose (Au) vs. energy for 140 mils thick AlBeMet® and Al6061.
X-ray Characterization (5 keV to 200 keV)

**FIGURE 35.**
Dose(Au) vs. energy for 150 mils thick AlBeMet\(^\circledR\) and Al6061.

**FIGURE 36.**
Dose(Au) vs. energy for 160 mils thick AlBeMet\(^\circledR\) and Al6061.

Appendix A
LOCKHEED MARTIN MISSILES & SPACE
FIGURE 37. Dose(Au) vs. energy for 170 mils thick AlBeMet® and Al6061.

FIGURE 38. Dose(Au) vs. energy for 180 mils thick AlBeMet® and Al6061.
X-ray Characterization (5 keV to 200 keV)

**FIGURE 39.** Dose(Au) vs. energy for 190 mils thick AlBeMet® and Al6061.

**FIGURE 40.** Dose(Au) vs. energy for 200 mils thick AlBeMet® and Al6061.

Appendix A

LOCKHEED MARTIN MISSILES & SPACE
2.0 \( \gamma \)-ray Characterization (1 MeV to 9 MeV)

FIGURE 41.
Dose(Si) vs. energy for 50 mils thick AlBeMet\textsuperscript{®} and Al6061.

FIGURE 42.
Dose(Si) vs. energy for 100 mils thick AlBeMet\textsuperscript{®} and Al6061.
FIGURE 43. Dose(Si) vs. energy for 150 mils thick AlBeMet® and Al6061.

FIGURE 44. Dose(Si) vs. energy for 200 mils thick AlBeMet® and Al6061.
FIGURE 45.

Dose(Si) vs. energy for 250 mils thick AlBeMet® and Al6061.

FIGURE 46.

Dose(Si) vs. energy for 300 mils thick AlBeMet® and Al6061.

A-24

LOCKHEED MARTIN MISSILES & SPACE
FIGURE 47.  Dose(Si) vs. energy for 350 mils thick AlBeMet® and Al6061.

FIGURE 48.  Dose(Si) vs. energy for 400 mils thick AlBeMet® and Al6061.
FIGURE 49. Dose(Si) vs. energy for 450 mils thick AlBeMet® and Al6061.

FIGURE 50. Dose(Si) vs. energy for 500 mils thick AlBeMet® and Al6061.
FIGURE 51.
Dose (Au) vs. energy for 50 mils thick AlBeMet® and Al6061.

FIGURE 52.
Dose (Au) vs. energy for 100 mils thick AlBeMet® and Al6061.
FIGURE 53.
Dose(Au) vs. energy for 150 mils thick AlBeMet® and Al5061.

FIGURE 54.
Dose(Au) vs. energy for 200 mils thick AlBeMet® and Al5061.
FIGURE 55.
Dose (Au) vs. energy for 250 mils thick AlBeMet® and Al6061.

FIGURE 56.
Dose (Au) vs. energy for 300 mils thick AlBeMet® and Al6061.
FIGURE 57. Dose (Au) vs. energy for 350 mils thick AIBeMet and AI6061.

FIGURE 58. Dose (Au) vs. energy for 400 mils thick AIBeMet and AI6061.
FIGURE 59. Dose (Au) vs. energy for 450 mils thick AlBeMet® and Al6061.

FIGURE 60. Dose (Au) vs. energy for 500 mils thick AlBeMet® and Al6061.
3.0 \( \beta \)-ray Characterization (500 keV to 5 MeV)

**FIGURE 61.**  Dose(Si) vs. energy for 50 mils thick AlBeMet\(^\text{®}\) and Al6061.

**FIGURE 62.**  Dose(Si) vs. energy for 100 mils thick AlBeMet\(^\text{®}\) and Al6061.

A-32

LOCKHEED MARTIN MISSILES & SPACE
FIGURE 63. Dose(Si) vs. energy for 150 mils thick AlBeMet® and Al6061.

FIGURE 64. Dose(Si) vs. energy for 200 mils thick AlBeMet® and Al6061.
FIGURE 65.
Dose(Si) vs. energy for 250 mils thick AlBeMet® and Al6061.

FIGURE 66.
Dose(Si) vs. energy for 300 mils thick AlBeMet® and Al6061.
FIGURE 67. Dose(Si) vs. energy for 350 mils thick AlBeMet® and Al6061.

FIGURE 68. Dose(Si) vs. energy for 400 mils thick AlBeMet® and Al6061.
FIGURE 59.  
Dose(Si) vs. energy for 450 mils thick AlBeMet® and Al6061.

FIGURE 70.  
Dose(Si) vs. energy for 500 mils thick AlBeMet® and Al6061.
FIGURE 71. Dose(Au) vs. energy for 50 mils thick AlBeMet® and Al6061.

FIGURE 72. Dose(Au) vs. energy for 100 mils thick AlBeMet® and Al6061.
FIGURE 73.
Dose (Au) vs. energy for 150 mils thick AlBeMet® and Al6061.

FIGURE 74.
Dose (Au) vs. energy for 200 mils thick AlBeMet® and Al6061.
FIGURE 75.  Dose(Au) vs. energy for 250 mils thick AlBeMet® and Al6061.

FIGURE 76.  Dose(Au) vs. energy for 300 mils thick AlBeMet® and Al6061.