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Mr. Jeff Stein  
President and CEO of Bar-Ray Products  
Littlestown, PA

Dear Mr. Stein,

I conducted a series of tests of Bar-Ray radiation protection materials using production samples spanning the range of current products used in radiation protective garments. Materials were taken from the Cost Cruncher, Prestige, Starlite and Truelite product lines. All tests were done at the Bar-Ray quality control station under my direction and using x-ray protocols designed by me. At least 3 samples of each material were tested and in multiple layer tests this included a minimum of 3 different layer sets.

**Test Conditions:**

Tests were done under narrow-beam conditions using a tandem detector arrangement combined with a simultaneous noninvasive kV monitor, all components supplied by RadCal Inc. and calibrated at the factory within 12 months of the tests. The tandem arrangement uses a DDX6-W dose diode beam monitor in the entrance beam and a 10x6-6 ion chamber for measuring transmission and kV was monitored with a 40X12-W Accu-kV. All detectors were coupled to the Accu-Pro 9096 multi purpose dosimeter system. The tandem arrangement provides much tighter measurement precision than a sequential method and is more suitable for production testing. A 0.15 mm copper filter was used in all x-ray beams and tests were done at 80, 90, 100 and 120 kV. Half value layers of those beams are listed in the second column of Table 1.

**Table 1:** Half-Value Layers (mm Al) using 2 mm Aluminum and 0.15 mm Cu filters for Bar-Ray QC testing (only second column settings were used in this report)

| kV  | 2 mm Al | .15 mm Cu |
|-----|---------|-----------|
| 50  | 2.3     | 3.5       |
| 60  | 2.8     | 4.5       |
| 70  | 3.2     | 5.4       |
| 80  | 3.7     | 6.2       |
| 90  | 4.2     | 6.8       |
| 100 | 4.6     | 7.4       |

|     |     |     |
|-----|-----|-----|
| 110 | 5.1 | 7.9 |
| 120 | 5.4 | 8.4 |

All materials were rated by Bar-Ray for lead equivalence at 90 kV so testing was done to evaluate that specification but was also extended to lower (80) and higher 100 and 120 settings for a more complete evaluation.

Percent attenuation values are listed in Table 2.1-2.6 at each of the kV settings for each material at a nominal thickness of 0.125, 0.167, 0.175, 0.25, 0.35 and 0.5 mm Pb equivalent, respectively. Also shown in each table is the attenuation of a pure lead sample with a thickness equivalent to the nominal specification.

**Table 2.1:** Measured attenuation of 0.125 mm Pb and nominal 0.125 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV.

| Material      | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|---------------|-----------|-------|------|-------|------|--------|------|--------|------|
|               |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| 0.125 mm Pb   |           | 67%   |      | 62%   |      | 60%    |      | 55%    |      |
| Starlite      | 1 x 0.125 | 68%   | 1.1% | 64%   | 1.1% | 59%    | 1.2% | 51%    | 1.5% |
| Cost Cruncher | 1 x 0.125 | 70%   | 0.9% | 66%   | 1.2% | 63%    | 1.4% | 60%    | 1.5% |
| TrueLite      | 1 x 0.125 | 69%   | 2.0% | 65%   | 2.1% | 61%    | 2.3% | 56%    | 2.7% |
| Prestige      | 1 x 0.125 | 67%   | 1.1% | 62%   | 1.3% | 58%    | 1.3% | 51%    | 0.8% |

**Table 2.2:** Measured attenuation of 0.167 mm Pb and nominal 0.167mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV..

| Material      | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|---------------|-----------|-------|------|-------|------|--------|------|--------|------|
|               |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| 0.167 mm Pb   |           | 75%   |      | 72%   |      | 67%    |      | 62%    |      |
| Starlite      | 1 x 0.167 | 75%   | 0.6% | 73%   | 0.7% | 66%    | 0.8% | 57%    | 0.9% |
| Cost Cruncher | 1 x 0.167 | 76%   | 1.3% | 71%   | 1.5% | 67%    | 1.6% | 64%    | 1.7% |
| TrueLite      | 1 x 0.167 | 76%   | 1.1% | 71%   | 1.3% | 68%    | 1.5% | 64%    | 1.4% |
| Prestige      | 1 x 0.167 | 75%   | 0.9% | 71%   | 0.9% | 66%    | 1.1% | 59%    | 1.2% |

**Table 2.3:** Measured attenuation of 0.175 mm Pb and nominal 0.175 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV..

| Material    | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|-------------|-----------|-------|------|-------|------|--------|------|--------|------|
|             |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| 0.175 mm Pb |           | 75%   |      | 72%   |      | 68%    |      | 65%    |      |
| Starlite    | 1 x 0.175 | 87%   | 0.2% | 75%   | 1.2% | 70%    | 1.4% | 61%    | 1.5% |
| TrueLite    | 1 x 0.175 | 78%   | 0.8% | 74%   | 0.9% | 71%    | 1.0% | 66%    | 1.2% |

|                 |           |     |      |     |      |     |      |     |      |
|-----------------|-----------|-----|------|-----|------|-----|------|-----|------|
| <i>Prestige</i> | 1 x 0.175 | 77% | 0.3% | 73% | 0.3% | 68% | 0.3% | 61% | 0.3% |
|-----------------|-----------|-----|------|-----|------|-----|------|-----|------|

**Table 2.4:** Measured attenuation of 0.25 mm Pb and nominal 0.25 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV..

| <b>Material</b> | <b>Layers</b> | <b>80 kV</b> |             | <b>90 kV</b> |             | <b>100 kV</b> |             | <b>120 kV</b> |             |
|-----------------|---------------|--------------|-------------|--------------|-------------|---------------|-------------|---------------|-------------|
|                 |               | <b>Mean</b>  | <b>% CV</b> | <b>Mean</b>  | <b>% CV</b> | <b>Mean</b>   | <b>% CV</b> | <b>Mean</b>   | <b>% CV</b> |
| 0.25 mm Pb      |               | 85%          |             | 81%          |             | 79%           |             | 76%           |             |
| Starlite        | 2 x 0.125     | 86%          | 0.6%        | 83%          | 0.7%        | 79%           | 0.7%        | 71%           | 0.9%        |
| Starlite        | 1 x 0.25      | 87%          | 0.2%        | 83%          | 0.2%        | 80%           | 0.2%        | 72%           | 0.2%        |
| Cost Cruncher   | 2 x 0.125     | 87%          | 0.5%        | 83%          | 0.6%        | 82%           | 0.6%        | 80%           | 0.7%        |
| Cost Cruncher   | 1 x 0.25      | 85%          | 0.5%        | 81%          | 0.6%        | 79%           | 0.6%        | 76%           | 0.7%        |
| TrueLite        | 2 x 0.125     | 87%          | 1.0%        | 83%          | 1.2%        | 80%           | 1.4%        | 76%           | 1.6%        |
| TrueLite        | 1 x 0.25      | 86%          | 0.7%        | 82%          | 0.8%        | 79%           | 0.9%        | 76%           | 1.0%        |
| Prestige        | 2 x 0.125     | 85%          | 0.7%        | 82%          | 0.8%        | 78%           | 0.9%        | 71%           | 1.0%        |

**Table 2.5:** Measured attenuation of 0.35 mm Pb and nominal 0.35 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV..

| Material        | Layers    | 80 kV |      | 90 kV |       | 100 kV |      | 120 kV |      |
|-----------------|-----------|-------|------|-------|-------|--------|------|--------|------|
|                 |           | Mean  | % CV | Mean  | % CV  | Mean   | % CV | Mean   | % CV |
| 0.35 mm Pb      |           | 91%   |      | 88%   |       | 86%    |      | 84%    |      |
| <i>Starlite</i> | 2 x 0.175 | 93%   | 0.0% | 90%   | 0.02% | 86%    | 0.0% | 79%    | 0.1% |
| <i>TrueLite</i> | 2 x 0.175 | 93%   | 0.0% | 89%   | 0.2%  | 86%    | 0.0% | 79%    | 0.1% |
| <i>Prestige</i> | 2 x 0.175 | 92%   | 0.1% | 91%   | 0.6%  | 87%    | 0.2% | 80%    | 0.2% |

**Table 2.6:** Measured attenuation of 0.5 mm Pb and nominal 0.5 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV..

| Material             | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|----------------------|-----------|-------|------|-------|------|--------|------|--------|------|
|                      |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| 0.5 mm Pb            |           | 95%   |      | 93%   |      | 92%    |      | 91%    |      |
| <i>Starlite</i>      | 3 x 0.167 | 96%   | 0.1% | 94%   | 0.1% | 91%    | 0.1% | 85%    | 0.2% |
| <i>Starlite</i>      | 2 x 0.25  | 96%   | 0.2% | 94%   | 0.0% | 93%    | 0.3% | 87%    | 0.2% |
| <i>Cost Cruncher</i> | 3 x 0.167 | 95%   | 0.3% | 93%   | 0.5% | 92%    | 0.5% | 92%    | 0.6% |
| <i>Cost Cruncher</i> | 2 x 0.25  | 96%   | 0.2% | 93%   | 0.2% | 92%    | 0.3% | 92%    | 0.3% |
| <i>TrueLite</i>      | 3 x 0.167 | 96%   | 0.1% | 94%   | 0.1% | 92%    | 0.1% | 91%    | 0.2% |
| <i>TrueLite</i>      | 2 x 0.25  | 96%   | 0.2% | 94%   | 0.3% | 93%    | 0.3% | 91%    | 0.4% |
| <i>Prestige</i>      | 3 x 0.167 | 96%   | 0.2% | 95%   | 0.4% | 92%    | 0.5% | 87%    | 0.8% |

**Table 3.1:** Measured lead equivalence of nominal 0.125 mm lead equivalent materials specified at 90 kV.

| Material             | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|----------------------|-----------|-------|------|-------|------|--------|------|--------|------|
|                      |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| <i>Starlite</i>      | 1 x 0.125 | 0.129 | 2.7% | 0.130 | 2.6% | 0.123  | 2.5% | 0.112  | 2.5% |
| <i>Cost Cruncher</i> | 1 x 0.125 | 0.131 | 2.2% | 0.133 | 2.7% | 0.133  | 3.1% | 0.133  | 3.2% |
| <i>TrueLite</i>      | 1 x 0.125 | 0.131 | 4.7% | 0.131 | 4.8% | 0.129  | 4.9% | 0.123  | 4.7% |
| <i>Prestige</i>      | 1 x 0.125 | 0.121 | 2.6% | 0.124 | 2.8% | 0.121  | 2.3% | 0.110  | 1.2% |

**Table 3.2:** Measured lead equivalence of nominal 0.167 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV.

| Material             | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|----------------------|-----------|-------|------|-------|------|--------|------|--------|------|
|                      |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| <i>Starlite</i>      | 1 x 0.167 | 0.172 | 2.1% | 0.172 | 2.1% | 0.160  | 2.2% | 0.141  | 1.6% |
| <i>Cost Cruncher</i> | 1 x 0.167 | 0.161 | 4.6% | 0.160 | 4.6% | 0.162  | 3.7% | 0.164  | 4.5% |
| <i>TrueLite</i>      | 1 x 0.167 | 0.169 | 3.7% | 0.171 | 3.5% | 0.167  | 4.4% | 0.156  | 3.7% |

*Prestige*            1 x 0.167      0.165    2.9%    0.169    2.8%    0.157    3.0%    0.140    2.5%

**Table 3.3:** Measured lead equivalence of nominal 0.175 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV.

| <b>Material</b> | <b>Layers</b> | <b>80 kV</b> |             | <b>90 kV</b> |             | <b>100 kV</b> |             | <b>120 kV</b> |             |
|-----------------|---------------|--------------|-------------|--------------|-------------|---------------|-------------|---------------|-------------|
|                 |               | <b>Mean</b>  | <b>% CV</b> | <b>Mean</b>  | <b>% CV</b> | <b>Mean</b>   | <b>% CV</b> | <b>Mean</b>   | <b>% CV</b> |
| <i>Starlite</i> | 1 x 0.175     | 0.201        | 3.8%        | 0.199        | 4.0%        | 0.186         | 3.8%        | 0.155         | 3.5%        |
| <i>TrueLite</i> | 1 x 0.175     | 0.190        | 2.7%        | 0.189        | 2.6%        | 0.185         | 2.8%        | 0.176         | 2.8%        |
| <i>Prestige</i> | 1 x 0.175     | 0.181        | 1.0%        | 0.187        | 1.2%        | 0.171         | 0.9%        | 0.147         | 0.7%        |

**Table 3.4:** Measured lead equivalence of nominal 0.25 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV.

| Material      | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|---------------|-----------|-------|------|-------|------|--------|------|--------|------|
|               |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| Starlite      | 2 x 0.125 | 0.267 | 2.1% | 0.267 | 2.0% | 0.252  | 1.9% | 0.208  | 2.1% |
| Starlite      | 1 x 0.25  | 0.276 | 0.8% | 0.274 | 0.7% | 0.257  | 0.5% | 0.214  | 0.5% |
| Cost Cruncher | 2 x 0.125 | 0.270 | 1.7% | 0.273 | 1.8% | 0.271  | 1.8% | 0.272  | 1.7% |
| Cost Cruncher | 1 x 0.25  | 0.259 | 1.5% | 0.259 | 1.7% | 0.261  | 1.5% | 0.261  | 1.5% |
| TrueLite      | 2 x 0.125 | 0.267 | 3.6% | 0.269 | 3.8% | 0.265  | 3.7% | 0.252  | 3.7% |
| TrueLite      | 1 x 0.25  | 0.261 | 2.5% | 0.260 | 2.2% | 0.257  | 2.4% | 0.248  | 2.2% |
| Prestige      | 2 x 0.125 | 0.256 | 2.2% | 0.260 | 2.5% | 0.247  | 2.4% | 0.206  | 2.5% |

**Table 3.5:** Measured lead equivalence of nominal 0.35 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV.

| Material | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|----------|-----------|-------|------|-------|------|--------|------|--------|------|
|          |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| Starlite | 2 x 0.175 | 0.397 | 0.1% | 0.397 | 0.1% | 0.360  | 0.2% | 0.291  | 0.5% |
| TrueLite | 2 x 0.175 | 0.397 | 0.1% | 0.377 | 0.9% | 0.360  | 0.2% | 0.291  | 0.5% |
| Prestige | 2 x 0.175 | 0.369 | 0.5% | 0.391 | 3.6% | 0.370  | 1.0% | 0.287  | 0.6% |

**Table 3.6:** Measured lead equivalence of nominal 0.5 mm lead equivalent materials specified at 90 kV, but measured at 80, 90, 100 and 120 kV.

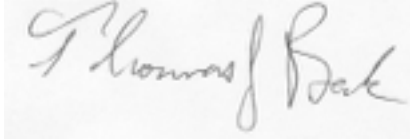
| Material      | Layers    | 80 kV |      | 90 kV |      | 100 kV |      | 120 kV |      |
|---------------|-----------|-------|------|-------|------|--------|------|--------|------|
|               |           | Mean  | % CV | Mean  | % CV | Mean   | % CV | Mean   | % CV |
| Starlite      | 3 x 0.167 | 0.527 | 0.6% | 0.519 | 0.7% | 0.469  | 0.6% | 0.372  | 0.7% |
| Starlite      | 2 x 0.25  | 0.523 | 2.2% | 0.553 | 0.2% | 0.514  | 2.4% | 0.391  | 0.8% |
| Cost Cruncher | 3 x 0.167 | 0.499 | 3.4% | 0.497 | 3.5% | 0.499  | 3.8% | 0.501  | 3.8% |
| Cost Cruncher | 2 x 0.25  | 0.518 | 2.0% | 0.519 | 1.8% | 0.520  | 2.0% | 0.521  | 2.0% |
| TrueLite      | 3 x 0.167 | 0.512 | 0.9% | 0.512 | 0.8% | 0.504  | 0.9% | 0.475  | 1.0% |
| TrueLite      | 2 x 0.25  | 0.523 | 2.2% | 0.522 | 2.3% | 0.514  | 2.4% | 0.488  | 2.5% |
| Prestige      | 3 x 0.167 | 0.522 | 2.5% | 0.528 | 3.2% | 0.484  | 3.4% | 0.386  | 3.4% |

### Conclusions:

Essentially all materials in all tested combinations met the design specification of nominal lead equivalence at 90 kV. As expected the lead equivalence of materials except all-lead Cost-Cruncher declines at higher kVs. The reduction in lead equivalence is greatest with Starlite, and least with Truelite. These findings are entirely consistent with theoretical effects and with prior reports. One comment is that the beam filtration of 0.15 mm Cu is somewhat heavy for

radiographic beams commonly used in the US, and is consistent with IEC 1331-1 European standards at 80 and 90 kV. The practical effect is that with the typical 2-3 mm Al beams used in the US will produce greater attenuation than shown here. On the other hand, IEC 1331-1 specifies 0.25 mm Cu filtration for 100 and 120 kV so that somewhat lower attenuation would be observed than in these tables. Future testing will be done with a sampling of Bar-Ray materials using lighter aluminum filters and 0.25 mm Cu filters at 100 and 120 kV.

Sincerely Yours,

A handwritten signature in cursive script that reads "Thomas J. Beck". The signature is written in dark ink on a light-colored background.

Thomas J. Beck, Sc.D.