Challenges in the Conformal Testing of Dosimeters against Prompt Neutron and Gamma Exposures
• All information in this presentation are from open and public sources
• This presentation is very general and does NOT address any test results
• If you are DOD (or US Govt) and would like more information, please contact us

Set of 5 Soviet personal radiation dosimeters DP-24
Focus of Talk

The Army needs to be able to measure the radiation dose to the soldiers on the battlefield, to include the nuclear battlefield. Ensuring our dosimeters have this capability present challenges:

- Mission is somewhat limited to the military
- Specialized equipment
- Lack of clear traceability to standards
- Operational realities

Team

Joint Project Leader for Radiological and Nuclear Defense
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- Dr. Paul Blake, CHP, DTRA

Outline

- Motivation
- Dose Range
- Neutron / Gamma Ratio
- Spectrum
- Sampling
- Measurements
- Standards
- Traceability
- Pertinence to the Field
- Risks
- Path Forward

PDR-75 and DT-236
Image from:
http://www.globalsecurity.org/military/systems/ground/images/pdr75.jpg
Motivation

- Why bother measuring prompt? Isn’t the mushroom cloud the end of the battle?

Hiroshima City, 6 August 1945
Motivation

- For weapons under 20 kT, radiation is one of the primary drivers for casualties.

Comparison of Weapons Effects (Radii of Effects in Kilometers for Airburst) FM 8-10-7, Health Service Support in a Nuclear, Biological, and Chemical Environment, 22 April 1993.

<table>
<thead>
<tr>
<th></th>
<th>1 KT</th>
<th>20 KT</th>
<th>100 KT</th>
<th>1 MT</th>
<th>10 MT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NUCLEAR RADIATION (1,000 cGy)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.71</td>
<td>1.3</td>
<td>1.6</td>
<td>2.3</td>
<td>3.7</td>
<td></td>
</tr>
</tbody>
</table>

| **BLAST (50% INCIDENCE OF TRANSLATION WITH SUBSEQUENT IMPACT WITH A NON-YIELDING SURFACE)** |      |       |        |      |       |
| 0.28       | 1.0  | 1.4   | 3.8    | 11.7 |       |

| **THERMAL (50% INCIDENCE OF 2ND-DEGREE BURNS TO BARE SKIN, 10 KM VISIBILITY)** |      |       |        |      |       |
| 0.77       | 1.8  | 3.2   | 4.8    | 14.5 |       |
Motivation

- **Enhanced Radiation Weapons (Neutron Bomb)**

  - **Effects of Detonation:**
    - Standard nuclear weapon
    - **Residual Radiation:** 10%
    - **Instant Radiation:** 5%
    - **Thermal Energy:** 35%
    - **Blast:** 50%

  - **Effects of Detonation:** Enhance nuclear weapon
    - **Residual Radiation:** 5%
    - **Thermal Energy:** 25%
    - **Instant Radiation:** 30%
    - **Blast:** 40%

Dose Range

• Detection range – PDR-75A
  – Gamma from 0.01 to 3000 cGy
  – Neutron from 0.3 to 3000 cGy

Expected Response to Radiation for Physically Demanding Tasks
**Neutron / Gamma Ratio**

- **Neutron/Gamma Ratio**
  - Any

<table>
<thead>
<tr>
<th>Yield (Kt)</th>
<th>n/g</th>
<th>n/n + g</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>4.6</td>
<td>0.82</td>
<td>360 meters</td>
</tr>
<tr>
<td>1.0</td>
<td>3.0</td>
<td>0.75</td>
<td>650 meters</td>
</tr>
<tr>
<td>10.0</td>
<td>1.6</td>
<td>0.62</td>
<td>1040 meters</td>
</tr>
<tr>
<td>100.0</td>
<td>0.47</td>
<td>0.32</td>
<td>1500 meters</td>
</tr>
<tr>
<td>1000.0</td>
<td>0.042</td>
<td>0.04</td>
<td>2280 meters</td>
</tr>
</tbody>
</table>

*Assumptions: HOB = 60W^{1/3} meters, where W = yield in kilotons; air density is equal to 0.9, relative to sea level; fission only device; total dose is equal to 2600 cGy.*

Typical Neutron-to-Gamma and Neutron Dose-to-Total Dose Rates

• **Gamma**

Figure 8.106. Spectrum of initial gamma radiation 2,000 yards from a 20-kiloton explosion.

• **Neutron**

Figure 8.116a. Neutron spectrum for a fission weapon per kiloton total energy yield.

### Spectrum

- DTRA provides updated spectrum information

<table>
<thead>
<tr>
<th>Type of Spectrum</th>
<th>Neutron Source</th>
<th>Photon Source</th>
</tr>
</thead>
</table>

Measurements - FBR

- **White Sands Missile Range**
  - **Fast Burst Reactor (FBR)**
    - Unmoderated and unreflected cylindrical assembly of uranium and molybdenum alloy
    - Produces high-yield pulses of microsecond width, as well as long-term, steady state radiation
    - Closely simulate the neutron radiation environment produced by a fission weapon
    - Similar to "Unshielded Device Spectrum" [Gritzner et al. 1976 (EM-1 Fission)]

Fast Burst Reactor
Survivability, Vulnerability and Assessment Directorate (SVAD)
Nuclear / DEW / E3/ Environmental Facilities and Capabilities.
29 July 2009.
Approved for Public Release.
Measurements - FBR

Fast Burst Reactor (FBR) Technical Data
Survivability, Vulnerability and Assessment Directorate (SVAD)
Nuclear / DEW / E3/ Environmental Facilities and Capabilities.
29 July 2009.
Approved for Public Release.

- System / Piece-part Level
- Burst and Steady-State (Power) Modes
- Burst Mode: Up to 6.5E13 n/cm² of 45µs width
- Steady state Mode: Up to 8 kW
- Gamma enhanced environment uses Cd loaded poly to produce gamma dose rates up to 10⁸ RAD(Si) during pulse
Measurements - Neutrons

Neutron Spectrum of the WSMR FBR
Measurements - Gamma

- **WSMR Gamma Sources**
  - Physics International - 538 (PI-538) Flash X-ray machine
  - Gamma Radiation Facility (GRF)
- **Army Primary Standards Lab**
  - Beam codes
  - Co-60
  - Cs-137

 Gamma Radiation Facility (GRF)
Survivability, Vulnerability and Assessment Directorate (SVAD)
Nuclear / DEW / E3/ Environmental Facilities and Capabilities.
29 July 2009.
Approved for Public Release.
Sampling

- Test each lot delivered using the DCMA (Defense Contract Management Agency) tables

**ZERO-BASED ACCEPTANCE SAMPLING PLAN**

"A Indicates that the Entire Lot Must be Inspected"

<table>
<thead>
<tr>
<th>LOT SIZE</th>
<th>0.1%</th>
<th>0.15%</th>
<th>0.25%</th>
<th>0.4%</th>
<th>0.65%</th>
<th>1%</th>
<th>1.5%</th>
<th>2.5%</th>
<th>4%</th>
<th>6.5%</th>
<th>10%</th>
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<td>A</td>
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<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
<td></td>
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<tr>
<td>9-15</td>
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<td>A</td>
<td>A</td>
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<td>A</td>
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<td>13</td>
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<td>13</td>
<td>8</td>
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<td>91-150</td>
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<td>A</td>
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<td>8</td>
<td>5</td>
<td>3</td>
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<tr>
<td>151-280</td>
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<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>20</td>
<td>13</td>
<td>8</td>
<td>7</td>
<td>6</td>
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<td>A</td>
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<td>20</td>
<td>13</td>
<td>8</td>
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<td>6</td>
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<tr>
<td>501-1200</td>
<td>A</td>
<td>800</td>
<td>500</td>
<td>315</td>
<td>200</td>
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<td>200</td>
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<td>315</td>
<td>200</td>
<td>125</td>
<td>50</td>
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<td>47</td>
<td>29</td>
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<tr>
<td>10,001-35,000</td>
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<td>500</td>
<td>315</td>
<td>300</td>
<td>294</td>
<td>189</td>
<td>135</td>
<td>108</td>
<td>77</td>
<td>60</td>
<td>46</td>
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<tr>
<td>35,001-150,000</td>
<td>800</td>
<td>500</td>
<td>490</td>
<td>476</td>
<td>294</td>
<td>218</td>
<td>170</td>
<td>123</td>
<td>96</td>
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<tr>
<td>150,001-500,000</td>
<td>800</td>
<td>750</td>
<td>715</td>
<td>476</td>
<td>345</td>
<td>270</td>
<td>200</td>
<td>156</td>
<td>119</td>
<td>90</td>
<td>64</td>
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<tr>
<td>500,001 &amp; Over</td>
<td>1200</td>
<td>1112</td>
<td>715</td>
<td>556</td>
<td>435</td>
<td>303</td>
<td>244</td>
<td>189</td>
<td>143</td>
<td>102</td>
<td>64</td>
</tr>
</tbody>
</table>

DCMA Sampling Table.

Image from: jacks.jpeocbd.army.mil/Public/FactSheetProvider.ashx
Standards – ANSI N13.11

• **Category 1 - Gamma**
  - Same units (absorbed dose)
  - Good overlap for dose range
  - Good overlap for energy range
  - Does not address pulse duration

• **Category 2 – Neutron**
  - Different units
  - Poor overlap for dose range
  - Good overlap for energy range
  - Does not address pulse duration

---

**Table 1a. Test categories, test irradiation ranges, and tolerance levels**

<table>
<thead>
<tr>
<th>I. Accidents, photons</th>
<th>Test irradiation range</th>
<th>Tolerance level (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. General (B and C, random)</td>
<td>0.05 to 5 Gy (5 to 500 rad)</td>
<td>Deep: 0.24, Shallow: No test</td>
</tr>
<tr>
<td>B. $^{137}$Cs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. M150</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

II. Photons/photon mixtures

| A. General ($\bar{E} \geq 20$ keV, $\gamma \leq 70$ keV) | 0.5 to 50 mSv (0.05 to 5 rem) | 0.30 |
| B. High E ($^{137}$Cs, $^{89}$Sr, $^{60}$Co, $\alpha \leq 60^\circ$) |  |
| C. Medium E ($\bar{E} \geq 70$ keV, $\alpha \leq 60^\circ$) |  |
| D. Plutonium specific (see Appendix A, Section A2) |  |

III. Betas

| A. General (B and C, random) | 2.5 to 250 mSv (0.25 to 25 rem) | No test |
| B. High E ($^{85}$Rb, $^{89}$Sr, $^{85}$Y) |  |
| C. Low E ($^{85}$Kr) |  |
| D. Uranium slab |  |

IV. Photon/beta $^b$ mixtures

| Shallow | 3.0 to 300 mSv (0.30 to 30 rem) | ... |
| Deep | 0.5 to 50 mSv (0.05 to 5 rem) | 0.30 |

V. Neutron/photon mixtures $^c$

| A. General (B and C, random) | 1.5 to 50 mSv (0.15 to 5 rem) | 0.30 |
| B. $^{252}$Cf + II |  |
| C. $^{252}$Cf($^{2}$H$_2$O) + II |  |

ANSI/HPS N13.11-2009
Standards – ANSI N13.3

- Uses absorbed dose
- Not as detailed as N13.11
- Leaves field characteristics to the user
  - Energy range
  - Duration
  - Neutron / Gamma ratio
- Not a focus of dosimetry companies and test organizations
- Seems to lack enough participants to justify a separate program for accreditation (i.e., separate from NVLAP)

Table 1. Performance testing criteria of criticality accident dosimeter systems

<table>
<thead>
<tr>
<th>Total absorbed dose range</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 to 1 Gy (10 to 100 rad)</td>
<td>±50%</td>
</tr>
<tr>
<td>1 to 10 Gy (100 to 1000 rad)</td>
<td>±25%</td>
</tr>
<tr>
<td>&gt;10 Gy (1000 rad)</td>
<td>Must give positive indication of &gt;10 Gy (1000 rad)</td>
</tr>
</tbody>
</table>

ANSI/HPS N13.3
**Traceability**

- **Traceability of Gamma**
  - Energy range - Good
  - Dose range - Good
  - Pulse - Limited

- **Traceability of Neutron**
  - Energy range – Good
  - Dose range – Limited
  - Pulse - Limited

- **Issues facing WSMR**
  - Uses calibrated sulfur pellets to measure the output of the WSTC MoLLY-G Fast Burst Reactor (FBR)
  - For traceability and calibration of high dose neutron detectors, need fast fission spectrum neutrons with an emission rate near $1 \times 10^{10}$ neutrons per second (n/s)
  - NIST $^{252}$Cf source with the highest neutron emission rate is below $1 \times 10^{8}$ n/s
  - Even using the source with the highest emission rate, routine irradiations are becoming prohibitively long, tying up the facility for durations of weeks to as long as several months.
Pertinence to the Field

- Life is not lived on an infinite plan
- Gamma and neutron spectrum changes
- Neutron / gamma ratio changes
- Most exposures will likely be partial body exposures with combined injuries
- Dosimeters likely stored at unit for long time before use

Color footage of atomic bomb tests in Nevada
Pertinence to the Field

- Working with DTRA to better understand the radiation incident on the warfighter

Urban horizontal neutron absorbed dose. Figure 5-3 of DTRA-TR-13-045, *Monte Carlo Modeling of the Initial Radiation Emitted by a Nuclear Device in the National Capital Region*, July 2013.

Photon-to-neutron dose for urban and open field. Figure 5-13 of DTRA-TR-13-045, *Monte Carlo Modeling of the Initial Radiation Emitted by a Nuclear Device in the National Capital Region, Revision 1*, August 2016.
• Dosimeters likely stored at unit for long time before use
• Maintenance and surveillance are key
• Work with Army Dosimetry Center to ensure tactical dosimeters remain accurate
Risks

- For neutron, tied to one reactor right now
- Losing traceability for high dose neutrons
- Test sources may not reflect radiation on the battlefield at blast survivable distances

Image from: Google Images
Path Forward

- Continue with rigorous testing
- Continue interaction with industry
- Don’t let ANSI forget about us
  - Inclusion in applicable standards
  - Push for more input on ANSI N13.3 or separate standard focused on prompt
- Push NIST for traceability

Image from: http://fsd.trekships.org/operations/images/tricorder-6.gif
Summary

The Army needs to be able to measure the radiation dose to the soldiers on the battlefield, to include the nuclear battlefield.

Challenges exist ensuring our dosimeters have this capability:

- Mission is somewhat limited to the military
- Specialized equipment
- Lack of clear traceability to standards
- Operational realities