Presentation to:
Council on Ionizing Radiation Measurements and Standards

Challenges in the Conformal Testing of Dosimeters against Prompt Neutron and Gamma Exposures

Dr. Chad McKee and Dr. Chad Weaver
Physicists
Joint Project Leader,
Radiological and Nuclear Defense

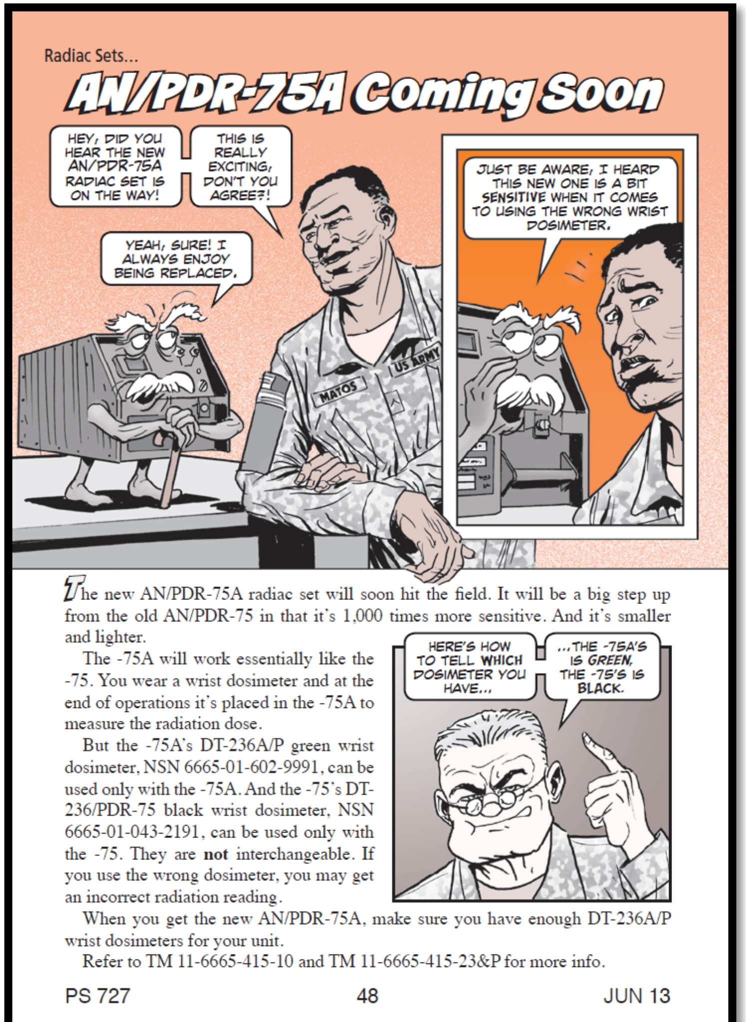
27 March 2017

Releasability

- **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
Image from: http://www.soviet-power.com/detail.php?pid=45138

Focus of Talk



The new AN/PDR-75A radiac set will soon hit the field. It will be a big step up from the old AN/PDR-75 in that it's 1,000 times more sensitive. And it's smaller and lighter.

The -75A will work essentially like the -75. You wear a wrist dosimeter and at the end of operations it's placed in the -75A to measure the radiation dose.

But the -75A's DT-236A/P green wrist dosimeter, NSN 6665-01-602-9991, can be used only with the -75A. And the -75's DT-236/PDR-75 black wrist dosimeter, NSN 6665-01-043-2191, can be used only with the -75. They are **not** interchangeable. If you use the wrong dosimeter, you may get an incorrect radiation reading.

When you get the new AN/PDR-75A, make sure you have enough DT-236A/P wrist dosimeters for your unit.

Refer to TM 11-6665-415-10 and TM 11-6665-415-23&P for more info.

PS 727 48 JUN 13

"AN/PDR-75A Coming Soon." *The Preventive Maintenance Monthly*, Issue 727, June 2013.

Focus

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

- Dr. Chad McKee
- Dr. Chad Weaver

With input from:

- Frank Andrews, WSMR
- Dr. T. Mike Flanders, WSMR
- Bill Harris, CHP, Army Dosimetry Center
- Gabe Lockwood, Army Dosimetry Center
- 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
I456742mage from: http://apjjf.org/2011/9/43/Yuki-Tanaka/3623/article.html

Motivation

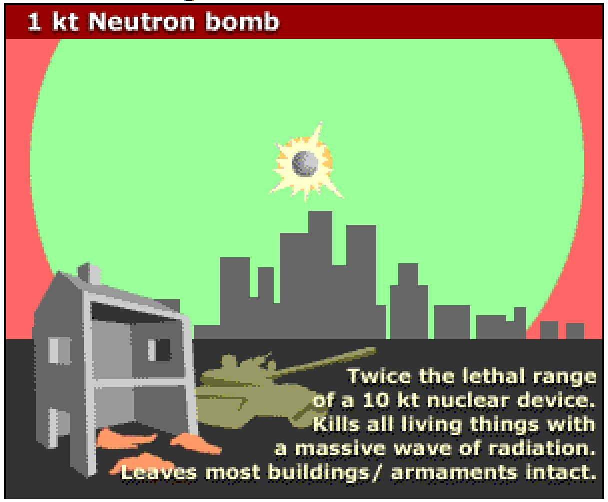
- **For weapons under 20 kT, radiation is one of the primary drivers for casualties.**

	1 KT	20 KT	100 KT	1 MT	10 MT
NUCLEAR RADIATION (1,000 cGy)	0.71	1.3	1.6	2.3	3.7
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

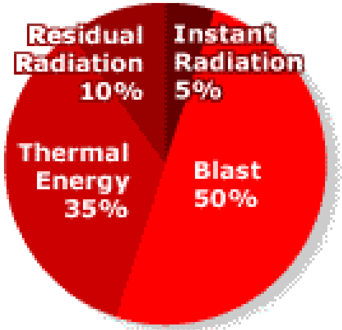
Comparison of Weapons Effects (Radii of Effects in Kilometers for Airburst) FM 8-10-7, Health Service Support in a Nuclear, Biological, and Chemical Environment, 22 April 1993.

Motivation

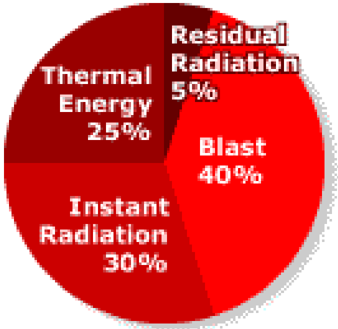
- **Enhanced Radiation Weapons (Neutron Bomb)**



Effects of Detonation:
Standard nuclear weapon



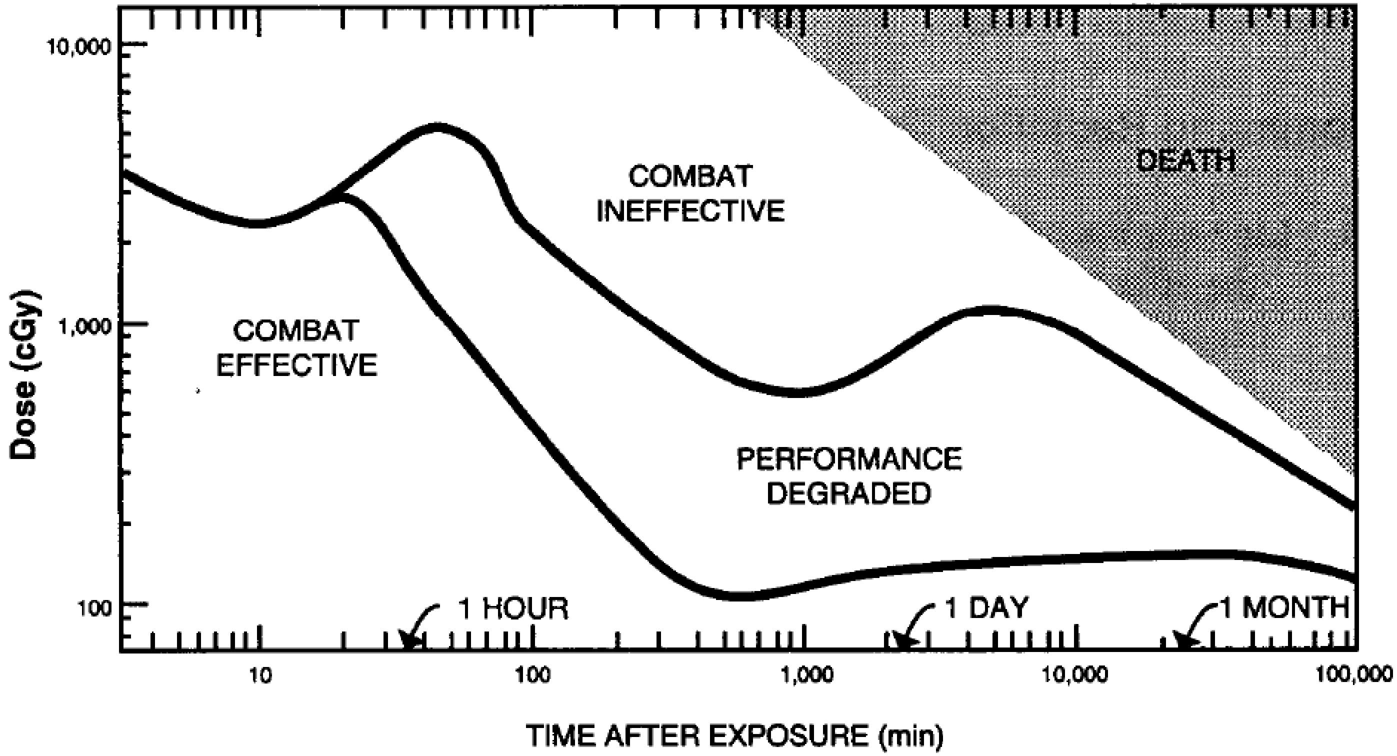
Effects of Detonation:
Enhanced nuclear weapon



http://news.bbc.co.uk/2/hi/science/nature/395689.stm

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
USACHPPM Tech Guide 244, *The Medical NBC Battlebook*, May 2000.

Neutron / Gamma Ratio

- **Neutron/Gamma Ratio**
  - Any

Yield (Kt)	n/g	n/n + g	Range
0.1	4.6	0.82	360 meters
1.0	3.0	0.75	650 meters
10.0	1.6	0.62	1040 meters
100.0	0.47	0.32	1500 meters
1000.0	0.042	0.04	2280 meters

* 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
USACHPPM Tech Guide 244, *The Medical NBC Battlebook*, May 2000.

Spectrum

- **Gamma**

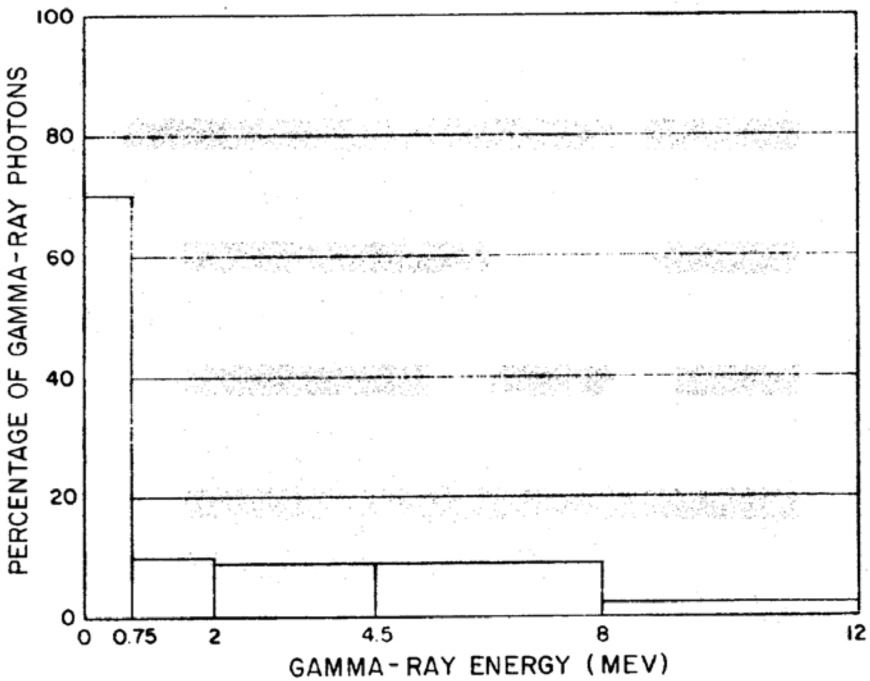


Figure 8.106. Spectrum of initial gamma radiation 2,000 yards from a 20–kiloton explosion.

- **Neutron**

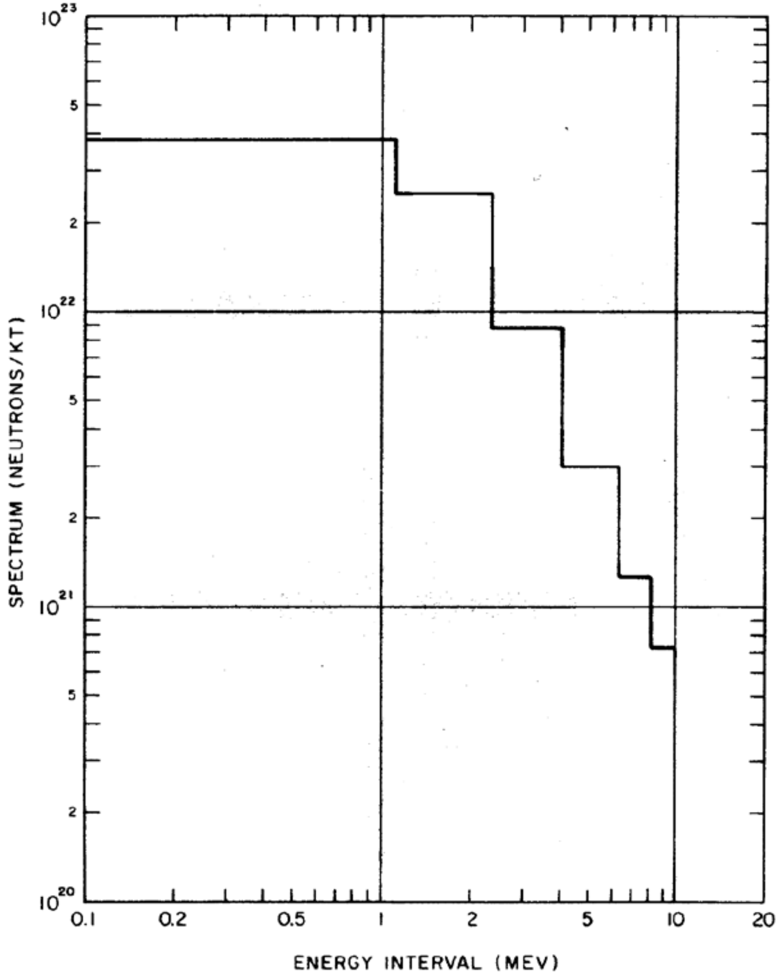


Figure 8.116a. Neutron spectrum for a fission weapon per kiloton total energy yield.

Glasstone and Dolan, *The Effect of Nuclear Weapons*, 1977.

Spectrum

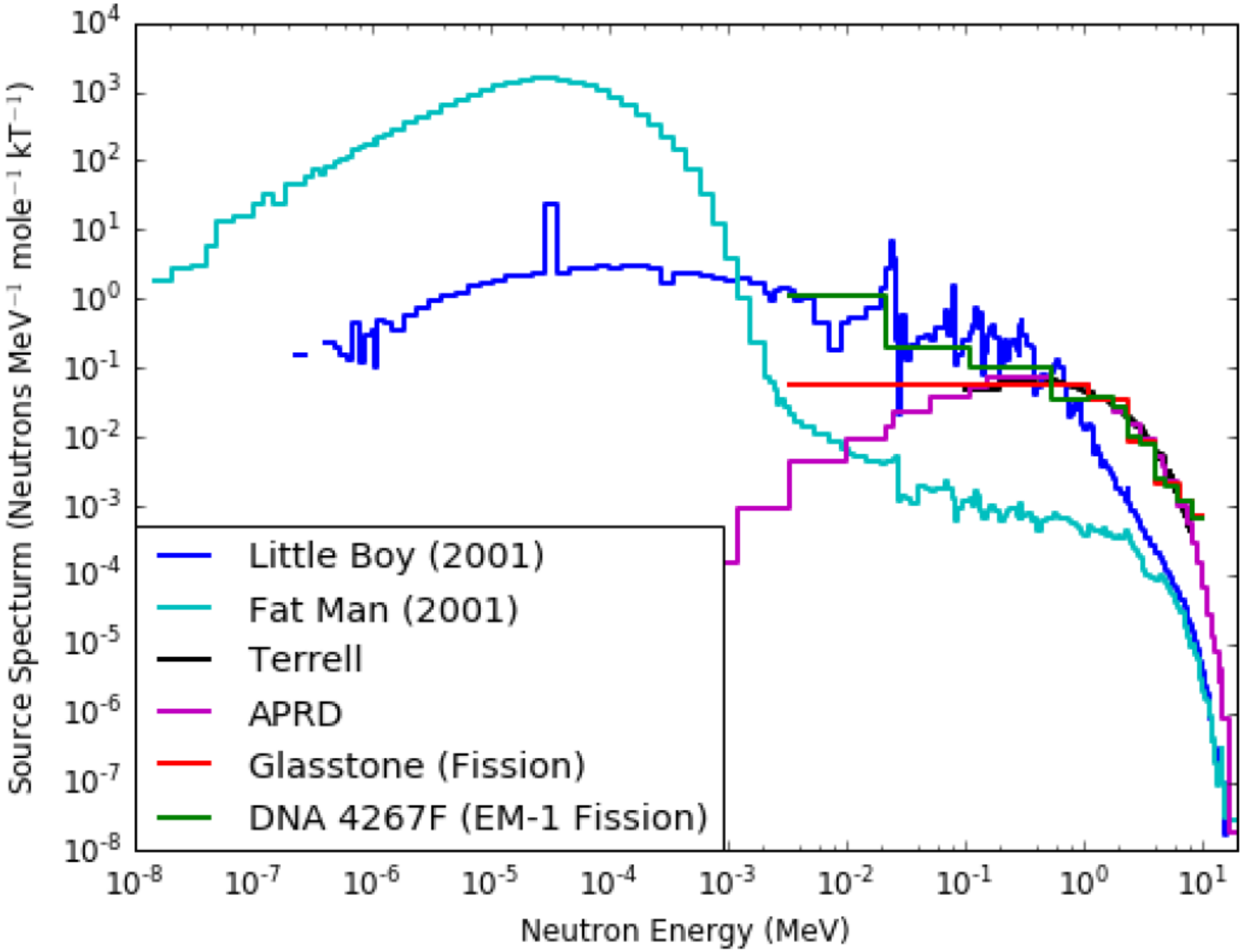
- **DTRA provides updated spectrum information**

Type of Spectrum	Neutron Source	Photon Source
"Little Boy"-type spectrum	White, Whalen & Heath 2001	White, Whalen & Heath 2001
"Fat Man"-type spectrum	White, Whalen & Heath 2001	White, Whalen & Heath 2001
Unshielded device spectrum	Gritzner, et al. 1976 (EM-1 Fission)	Gritzner, et al. 1976 (EM-1 Fission)
Thermonuclear spectrum	Gritzner, et al. 1976 (Low Yield Thermonuclear)	Gritzner, et al. 1976 (Low Yield Thermonuclear)

Suggested spectra for simulation of leakage radiation for a nuclear device.
DTRA-TR-17-026, *Publicly Released Prompt Radiation Spectra Suitable for Nuclear Detonation Simulations.* March 2017.

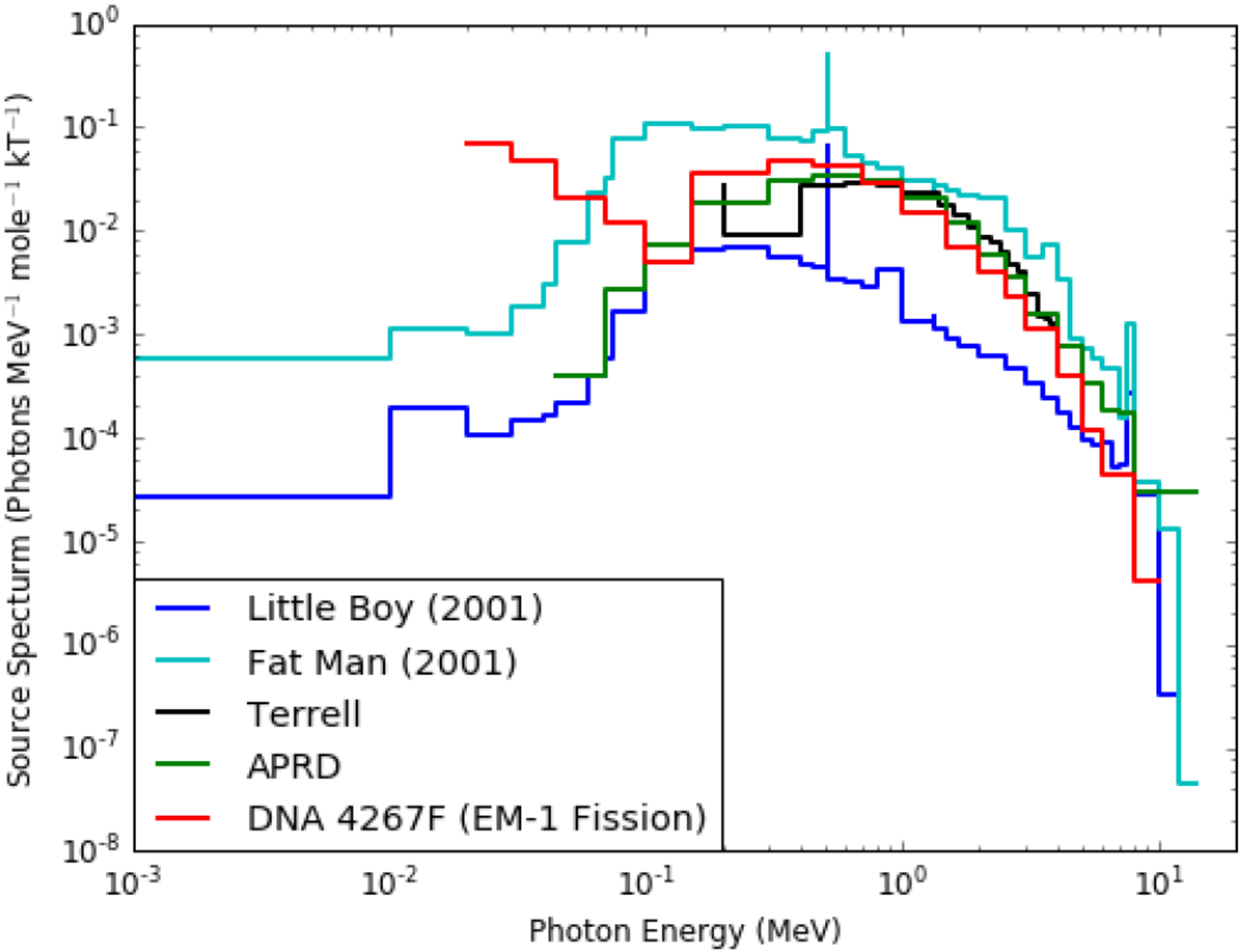
Spectrum - Neutron

Neutron spectra for from fission sources. DTRA-TR-17-026, *Publicly Released Prompt Radiation Spectra Suitable for Nuclear Detonation Simulations.* March 2017.



Spectrum - Photon

Photon spectra for from fission sources. DTRA-TR-17-026, *Publicly Released Prompt Radiation Spectra Suitable for Nuclear Detonation Simulations.* March 2017.

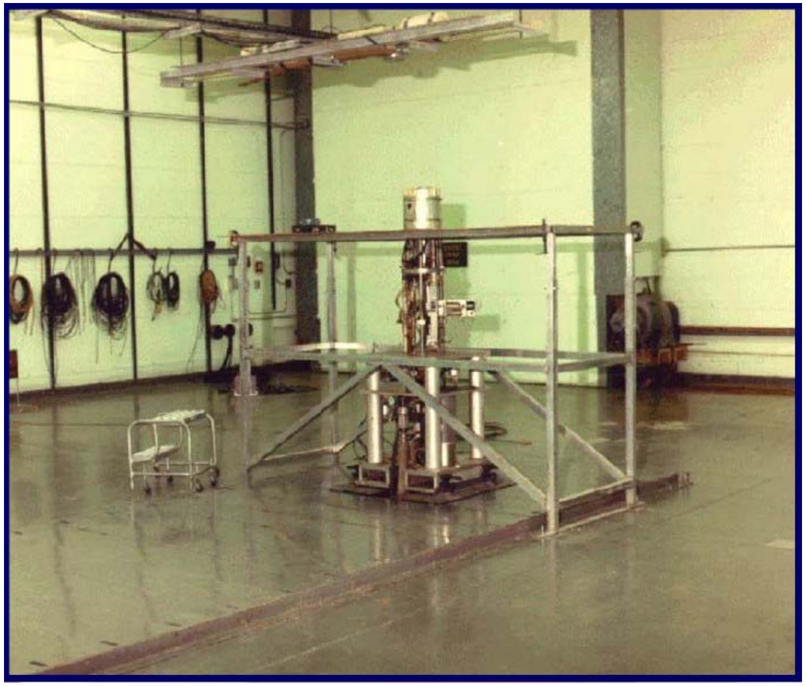


Measurements - FBR

- **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

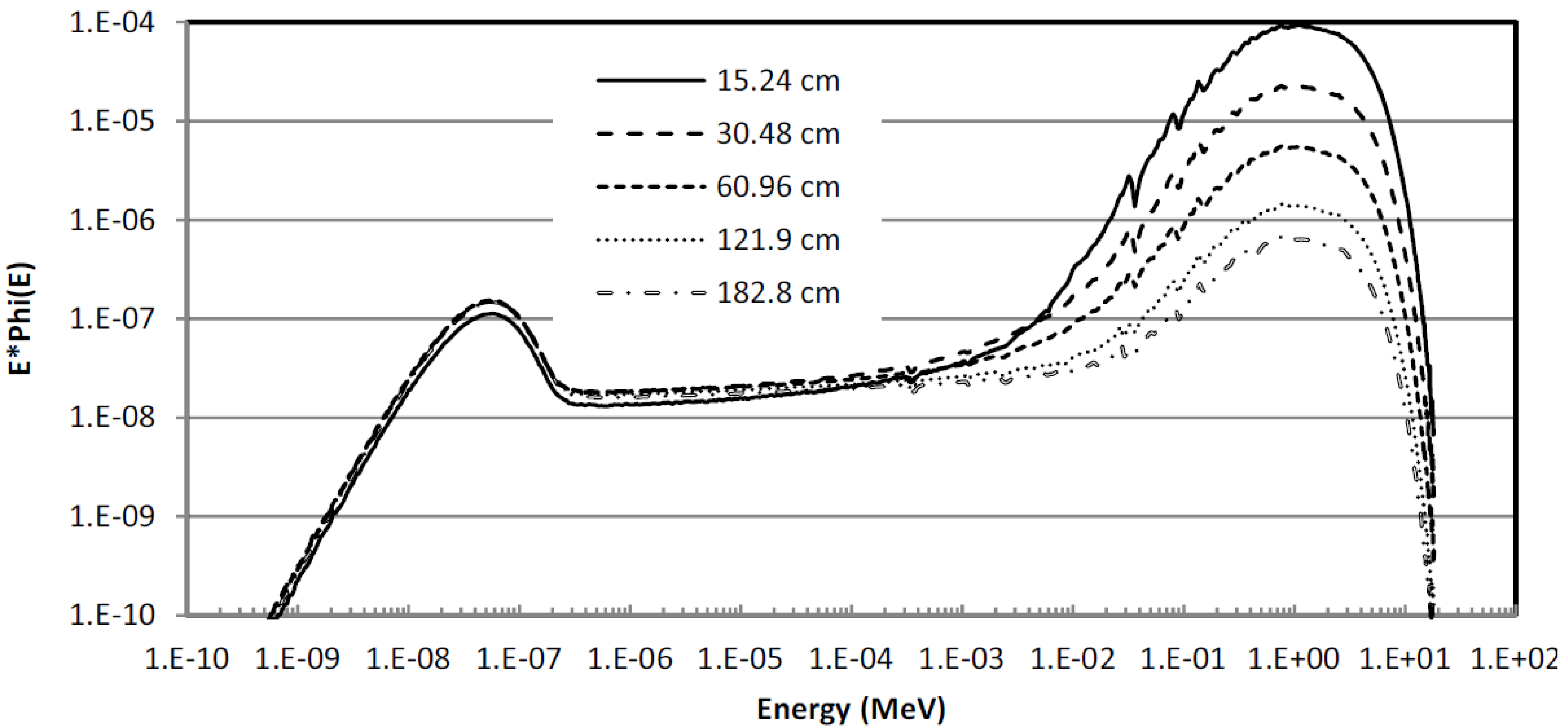


Fast Burst Reactor (FBR)
Survivability, Vulnerability and Assessment Directorate(SVAD)
Nuclear / DEW / E3/ Environmental Facilities and Capabilities.
29 July 2009.
Approved for Public Release.

- System / Piece-part Level
- Burst and Steady-State (Power) Modes
- Burst Mode: Up to 6.5E13 n/cm^2 of 45μs width
- Steady state Mode: Up to 8 kW
- Gamma enhanced environment uses Cd loaded poly to produce gamma dose rates up to 10^8 RAD(Si) during pulse

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.

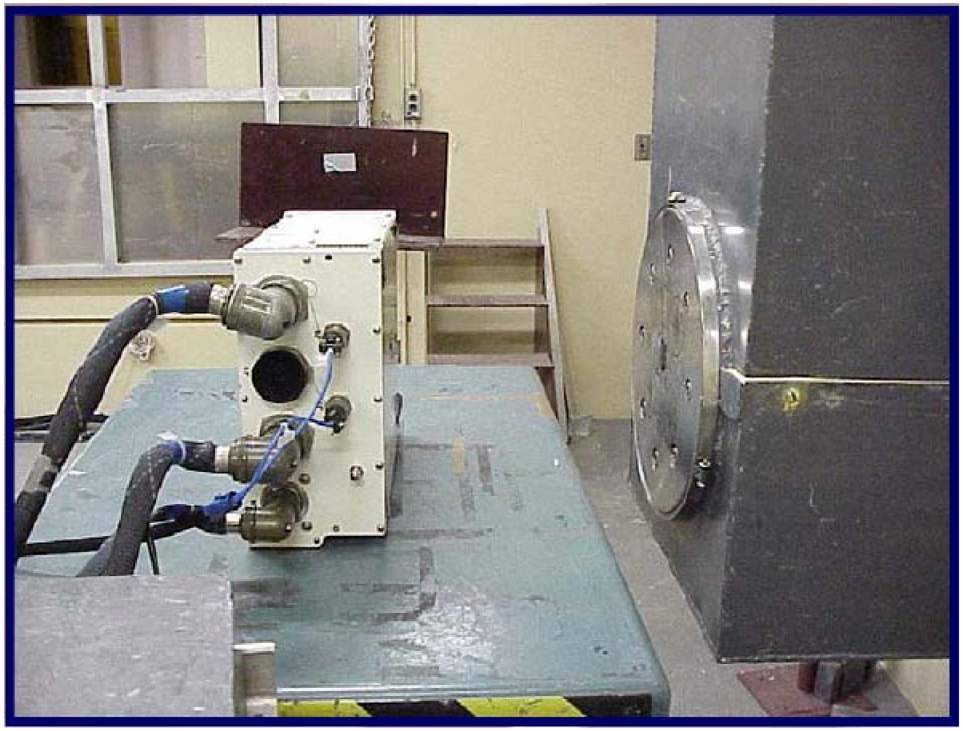
Measurements - Neutrons



Neutron Spectrum of the WSMR FBR
Sparks, Mary Helen and T. Micheal Flanders, *A Re-Evaluation of the Reference Environment at the WSMR Fast Burst Reactor*. EPJ Web of Conferences 106, 01006 (2016).

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"

Acceptable Quality Level (AQL)

LOT SIZE	.010%	.015%	.025%	.040%	.065%	.10%	.15%	.25%	.40%	.65%	1.0%	1.5%	2.5%	4.0%	6.5%	10.0%
1-8	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	5	3	2	2
9-15	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	13	8	5	3	2	2
16-25	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	20	13	8	5	3	3	2
26-50	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	32	20	13	8	5	5	5	2
51-90	*A*	*A*	*A*	*A*	*A*	*A*	80	50	32	20	13	8	7	6	5	4
91-150	*A*	*A*	*A*	*A*	*A*	125	80	50	32	20	13	12	11	7	6	5
151-280	*A*	*A*	*A*	*A*	200	125	80	50	32	20	20	19	13	10	7	6
281-500	*A*	*A*	*A*	315	200	125	80	50	48	47	29	21	16	11	9	7
501-1200	*A*	800	500	315	200	125	80	75	73	47	34	27	19	15	11	8
1201-3200	1250	800	500	315	200	125	120	116	73	53	42	35	23	18	13	9
3201-10,000	1250	800	500	315	200	192	189	116	86	68	50	38	29	22	15	9
10,001-35,000	1250	800	500	315	300	294	189	135	108	77	60	46	35	29	15	9
35,001-150,000	1250	800	500	490	476	294	218	170	123	96	74	56	40	29	15	9
150,001-500,000	1250	800	750	715	476	345	270	200	156	119	90	64	40	29	15	9
500,001 & Over	1250	1200	1112	715	556	435	303	244	189	143	102	64	40	29	15	9

DCMA Sampling Table.

AN/PRD-75A
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

		Test irradiation range	Tolerance level (L)	
			Deep	Shallow
I. Accidents, photons A. General (B and C, random) B. ^{137}Cs C. M150		0.05 to 5 Gy (5 to 500 rad)	0.24	No test
II. Photons/photon mixtures A. General[a] ($\bar{E} \geq 20$ keV; $\perp$ if ≤ 70 keV) B. High E (^{137}Cs, ^{60}Co; $\alpha \leq 60^{\circ}$) C. Medium E[1] ($\bar{E} > 70$ keV, $\alpha \leq 60^{\circ}$) D. Plutonium specific[a] (see Appendix A, Section A2)		0.5 to 50 mSv (0.05 to 5 rem)	0.30	0.30
III. Betas A. General (B and C, random) B. High E (^{90}Sr/^{90}Y) C. Low E (^{85}Kr) D. Uranium slab		2.5 to 250 mSv (0.25 to 25 rem)	No test	0.30
IV. Photon/beta[b] mixtures	Shallow	3.0 to 300 mSv (0.30 to 30 rem)	...	0.30
	Deep	0.5 to 50 mSv (0.05 to 5 rem)	0.30	...
V. Neutron/photon mixtures[c] A. General (B and C, random) B. ^{252}Cf + II C. ^{252}Cf(D_2O) + II		1.5 to 50 mSv (0.15 to 5 rem)	0.30	No test

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)**

A recreation of the criticality experiment that Slotin conducted.
Image from http://nerdist.com/tickling-the-dragons-tail-the-story-of-the-demon-core/

Table 1. Performance testing criteria of criticality accident dosimeter systems

Total absorbed dose range	B
0.1 to 1 Gy (10 to 100 rad)	±50%
1 to 10 Gy (100 to 1000 rad)	±25%
>10 Gy (1000 rad)	Must give positive indication of >10 Gy (1000 rad)

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 1×10^{10} neutrons per second (n/s)
  - NIST ^{252}Cf source with the highest neutron emission rate is below 1×10^{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.

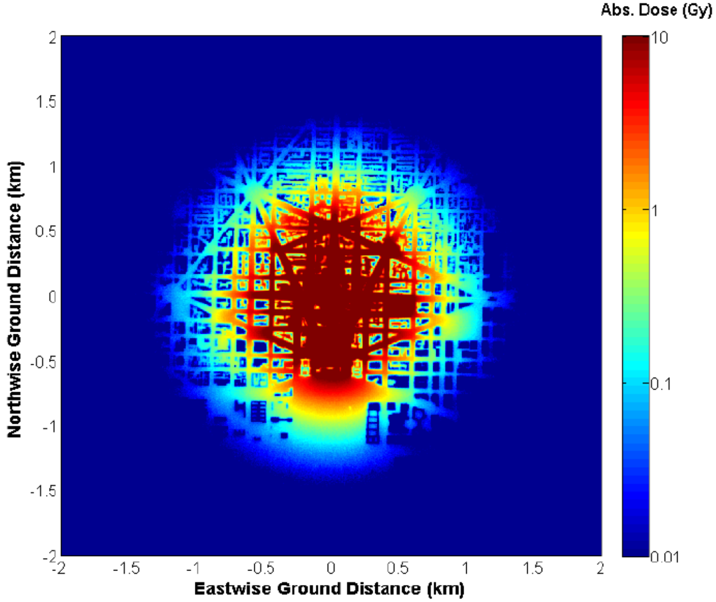
Pertinence to the Field

Color footage of atomic bomb tests in Nevada
Image from
https://nevadastatepersonnelwatch.wordpress.com/2015/11/07/atomic-soldiers-and-the-nuclear-battlefield/

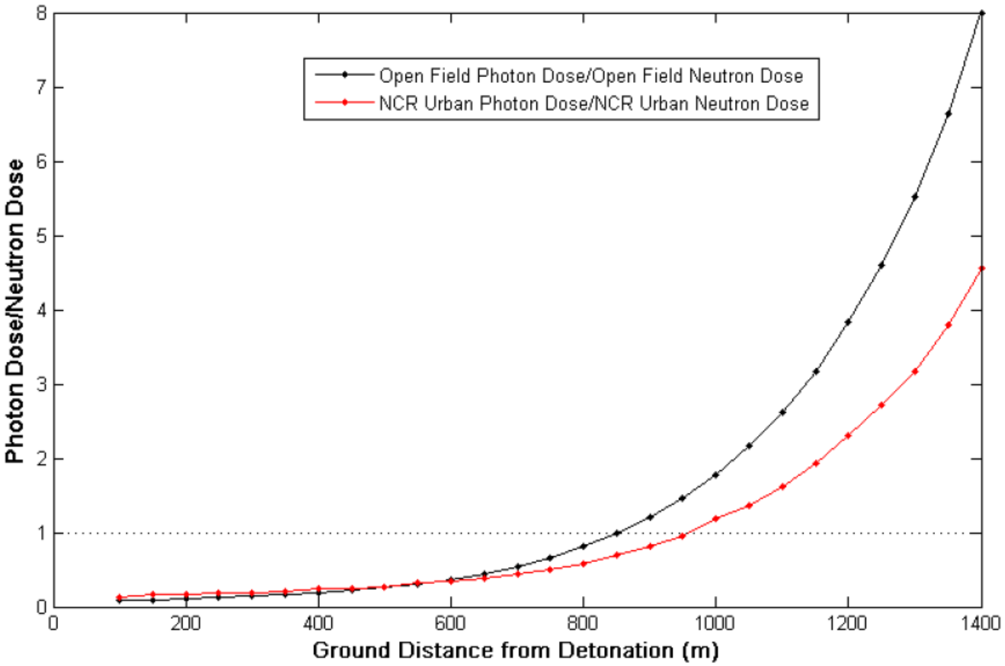
- **Life is not lived on an infinite plan**
- **Gamma and neutron spectrum changes**
- **Neutron / gamma ratio changes**
- **Most exposures will likely be partial body exposures with combined injuries**
- **Dosimeters likely stored at unit for long time before use**

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.

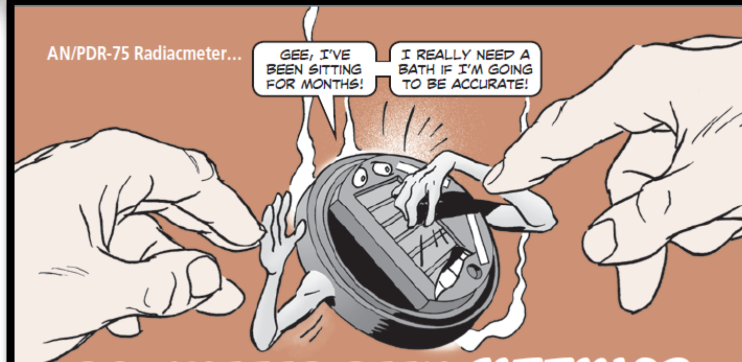


Photon-to-neutron dose for urban and open field. Figure 5-13 of DTRA-TR-13-045, *Monte Carlo Modeling of the Initial Radiation Emitted by a Nuclear Device in the National Capital Region, Revision 1*, August 2016.

Pertinence to the Field

- 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

ARMY PRIMARY STANDARDS LABORATORY
REDSTONE ARSENAL



DOSIMETER BEEN SITTING? IT MAY NEED A BATH!

If the DT-236 dosimeters, NSN 6665-01-043-2191, for the AN/PDR-75 radiacmeter have been sitting for a long time, they may have lost their accuracy. If that's the case, the dosimeters will give readings on the CP-696/PDR-75 computer indicator that are out of tolerance on the low side.

If your dosimeters have been sitting, they may need a simple cleaning to correct the problem. CBRN specialists, to check if a dosimeter needs cleaning, open it following the procedure in Para 2.6 of TM 11-6665-236-12. With the cover removed, see if the phosphate glass is clear. If the glass is clear, the dosimeter doesn't need cleaning. Put it back together.

But a milky white coating on the surface of the glass means the dosimeter base needs cleaning. Place the dosimeter base in a solution of warm water and liquid dishwashing detergent and let it soak for 5-10 minutes. Rinse the dosimeter base in plain water and let it dry completely. If the glass is now clear, reassemble the dosimeter. If it's not clear, repeat the cleaning process until it is clear.

To make sure your dosimeter keeps working correctly, remember to check it annually like the TM says.

PS 694 51 SEP 10

"Dosimeter Been Sitting? It May Need a Bath." *The Preventive Maintenance Monthly*, Issue 694, Sep 2010.

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**

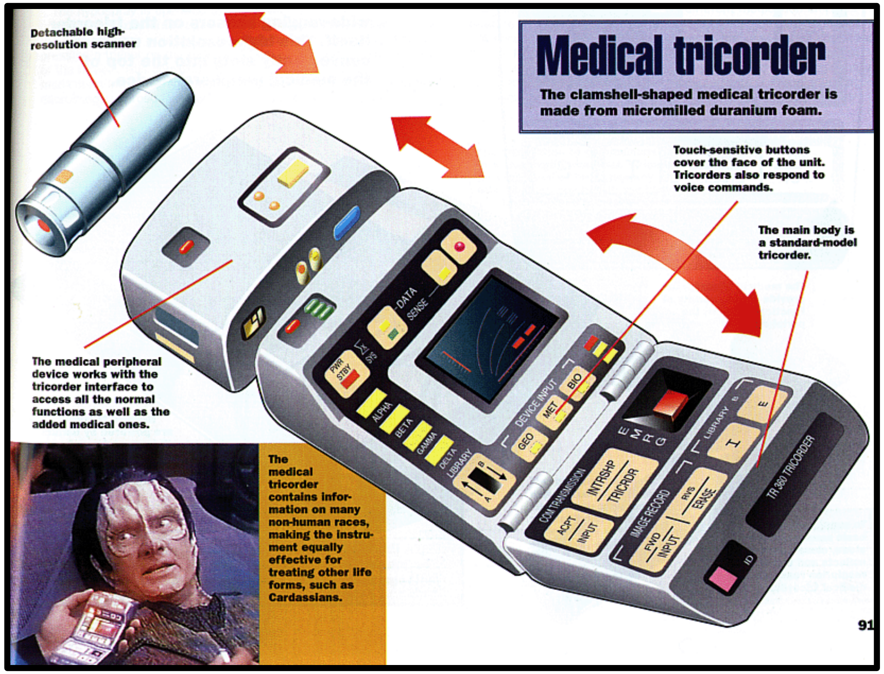


Image from: http://fsd.trekships.org/operations/images/tricorder-6.gif

Summary

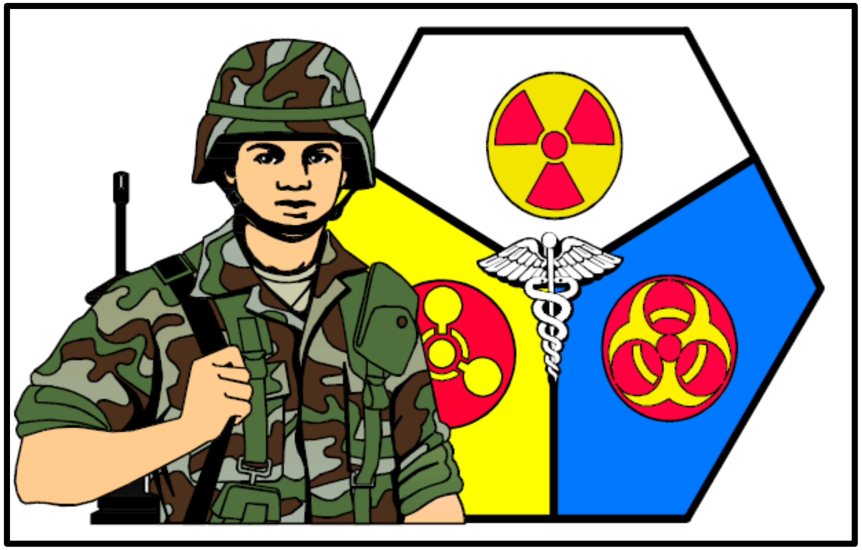


Image from USACHPPM Tech Guide 244, *The Medical NBC Battlebook*, May 2000.

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**