IM-276/PD Next Generation Navy Battlefield Dosimeter – System Overview and Test Summary

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Naval Surface Warfare Center – Carderock Division

Outline

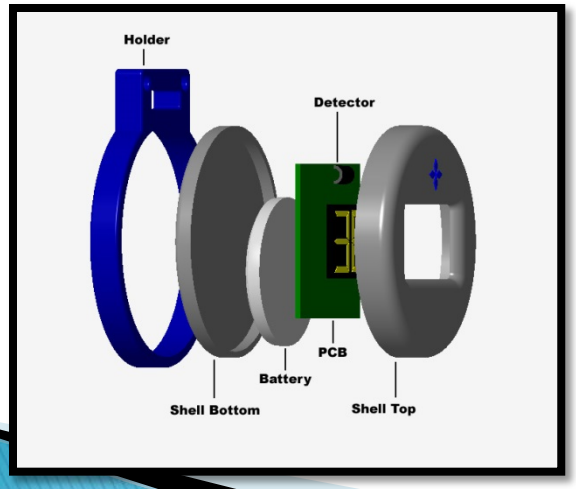
- Overview of current Battlefield Dosimeter – IM-270/PD
- Overview of next generation Battlefield Dosimeter – IM-276/PD
- IM-276/PD Test Results

Navy's Current Battlefield Dosimeter IM-270/PD

- Radiation Health Protection Manual NAVMED P-5055 description of the IM-270/PD.
  - "The IM-270/PD dosimeter is a personnel accident dosimeter that uses metal oxide semiconductor field effect transistor (MOSFET) technology. It is designed to detect x-ray and gamma rays. It has a dynamic range of 10-1000 rad (0.1 – 10 Gy) in 1 rad (0.01 Gy) increments which will initiate after an initial exposure of 10 rads (0.1 Gy). **The IM-270/PD has a battery life expectancy of 10 years.**"

IM-270/PD – General Characteristics

- MOSFET Technology.
- Photon Only sensitive dosimeter.
- One-time use device.
- Dosimeter Range: 10-1000 rads (0.1 – 10 Gy)
- 10 year battery life.
- Final batch delivered in 2009.

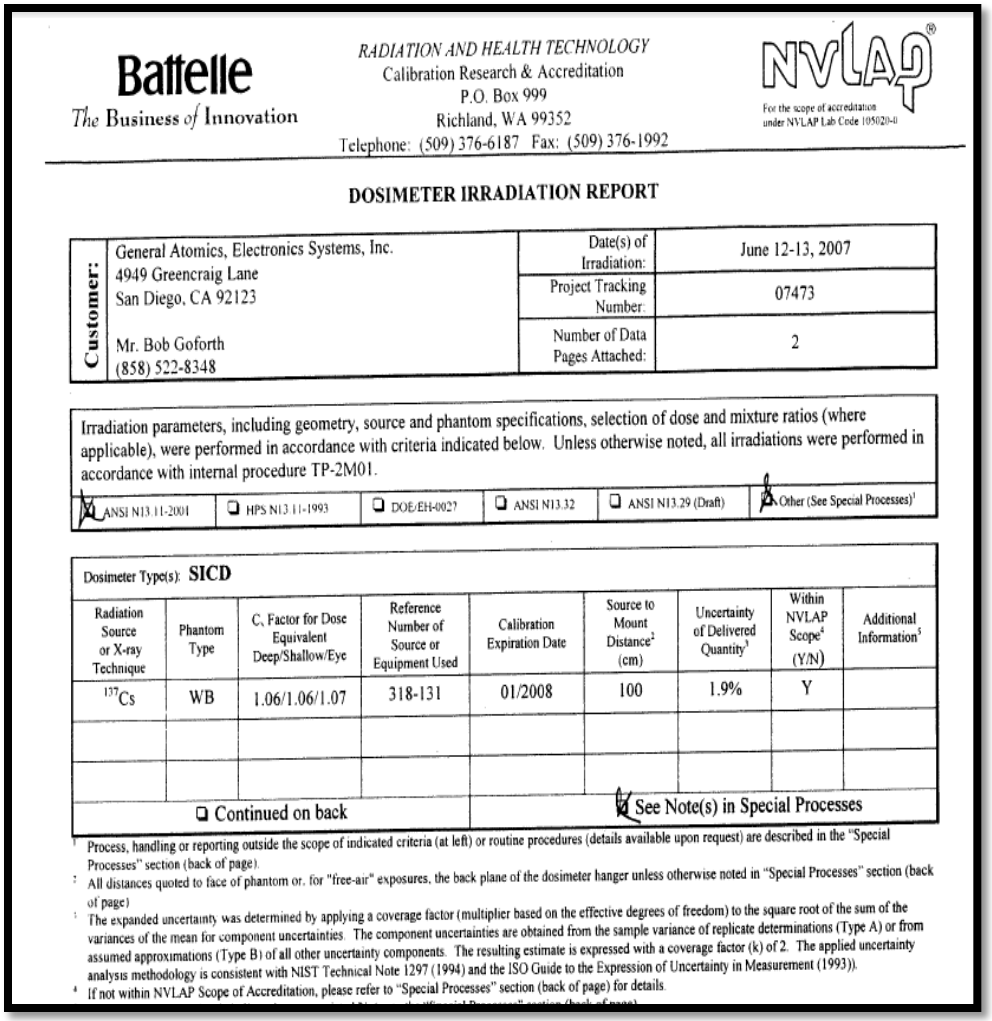


IM-270/PD – Navy Application

- The IM-270/PD is issued when the threat level is raised to Mission Oriented Protective Postures (MOPP) Level 2.
  - Indicates the threat of a nuclear attack.
  - All sailors facing the threat are issued an IM-270/PD.

IM-270/PD – Acceptance Tests

- The IM-270/PD were Radiologically Tested at NSWCCD and at Battelle.
- Environmentally Tested by:
  - Multiple Contractors
    - Electromagnetic Interference (EMI)
    - Immersion
    - Operating Temperature (High and Low)



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DOSIMETER IRRADIATION REPORT

Customer:	General Atomics, Electronics Systems, Inc. 4949 Greencraig Lane San Diego, CA 92123 Mr. Bob Goforth (858) 522-8348	Date(s) of Irradiation:	June 12-13, 2007
		Project Tracking Number:	07473
		Number of Data Pages Attached:	2

Irradiation parameters, including geometry, source and phantom specifications, selection of dose and mixture ratios (where applicable), were performed in accordance with criteria indicated below. Unless otherwise noted, all irradiations were performed in accordance with internal procedure TP-2M01.

☒ ANSI N13.11-2001 | ☐ HPS N13.11-1993 | ☐ DOE/EH-0027 | ☐ ANSI N13.32 | ☐ ANSI N13.29 (Draft) | ☒ Other (See Special Processes)[1]

Dosimeter Type(s): **SICD**

Radiation Source or X-ray Technique	Phantom Type	C_x Factor for Dose Equivalent Deep/Shallow/Eye	Reference Number of Source or Equipment Used	Calibration Expiration Date	Source to Mount Distance[2] (cm)	Uncertainty of Delivered Quantity[3]	Within NVLAP Scope[4] (Y/N)	Additional Information[5]
^{137}Cs	WB	1.06/1.06/1.07	318-131	01/2008	100	1.9%	Y	

☐ Continued on back ☒ See Note(s) in Special Processes

[1] Process, handling or reporting outside the scope of indicated criteria (at left) or routine procedures (details available upon request) are described in the "Special Processes" section (back of page).
[2] All distances quoted to face of phantom or, for "free-air" exposures, the back plane of the dosimeter hanger unless otherwise noted in "Special Processes" section (back of page)
[3] The expanded uncertainty was determined by applying a coverage factor (multiplier based on the effective degrees of freedom) to the square root of the sum of the variances of the mean for component uncertainties. The component uncertainties are obtained from the sample variance of replicate determinations (Type A) or from assumed approximations (Type B) of all other uncertainty components. The resulting estimate is expressed with a coverage factor (k) of 2. The applied uncertainty analysis methodology is consistent with NIST Technical Note 1297 (1994) and the ISO Guide to the Expression of Uncertainty in Measurement (1993)).
[4] If not within NVLAP Scope of Accreditation, please refer to "Special Processes" section (back of page) for details.

Why is the Navy replacing the IM-270/PD?

- Battery Limitations
  - Nearing the end of useful battery life.
  - Completely sealed dosimeter does not allow battery to be replaced.

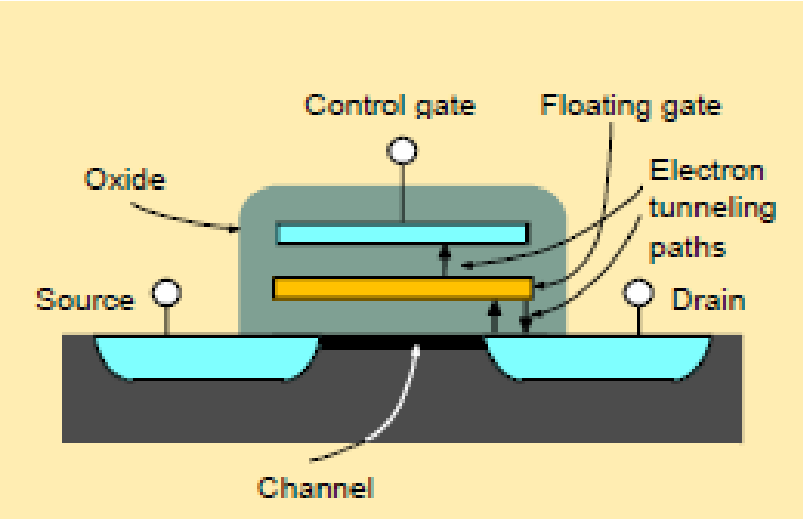
- Capability Gap – Identified after Operation Tomadachi
  - Neutron insensitive
  - Lower Limit of Detection for Operations Other Than War (OOTW)

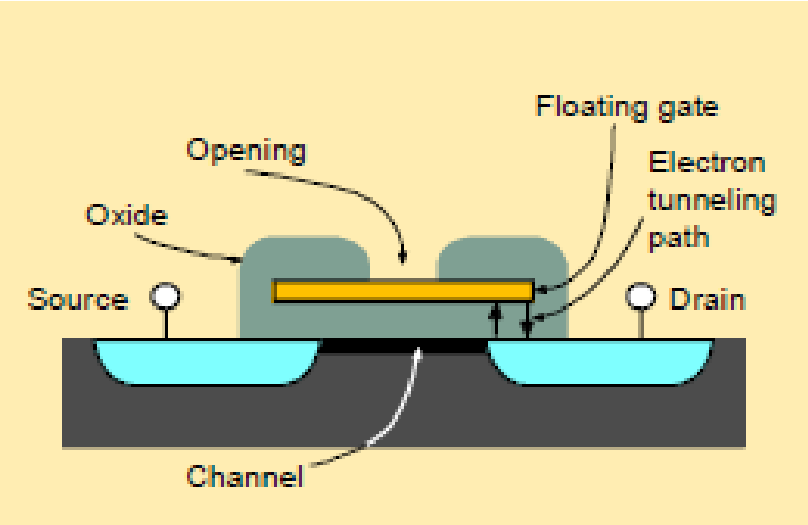
IM-276/PD – General Characteristics

- Hybrid device (active/passive): stores and accumulates signal of dose without main battery.
- Gamma & Neutron Direct Ion Storage (DIS chambers).
- Active LCD display.
- Legal Dose (NVLAP) capable.
- Resistance to RF, EMI, EMP.
- Field replaceable battery > 700 hours.

Direct Ion Storage (DIS): Evolution

- Non-volatile memory cell developed in early 90's
  - Information is stored in the form of an electronic charge trapped on the floating gate of a MOSFET transistor.
  - DIS: if oxide layer has an opening to air, charge from ions can be transferred and stored

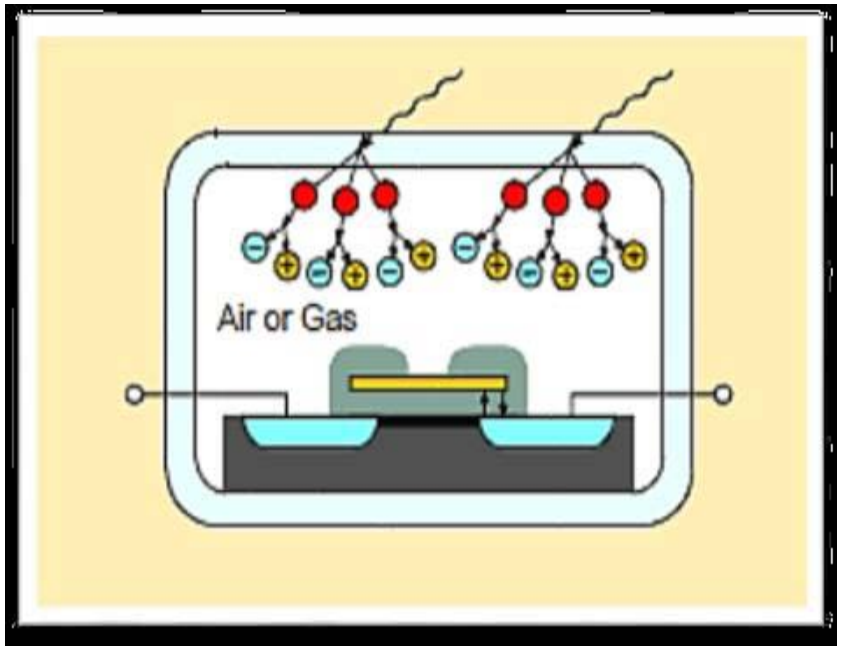




Direct Ion Storage (DIS): Evolution

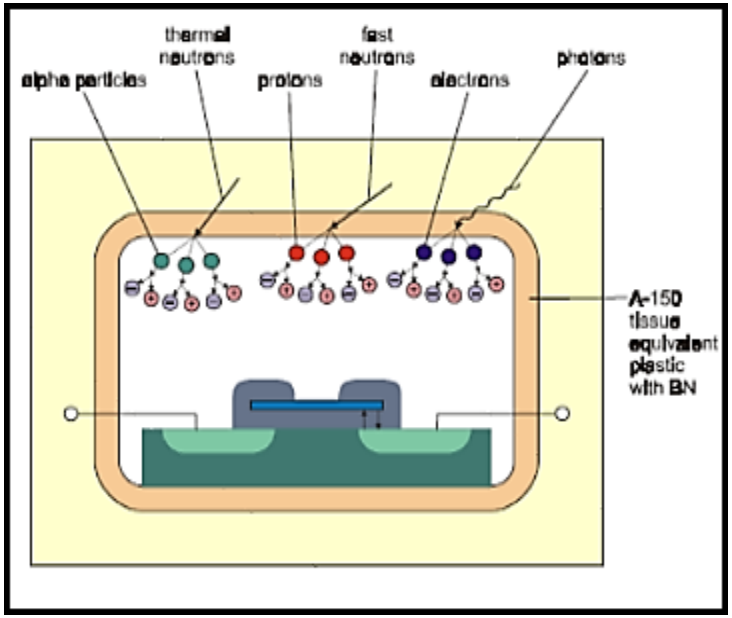
- By surrounding the memory element with a conductive wall, an ion chamber is effectively formed.
- Photon radiation interacting with the wall produces secondary electrons which ionize the gas.
- Providing an electric field within the chamber allows for charge collection at the gate.
- Reading the stored charge is performed by measuring the channel conductivity and does not disturb the charge.

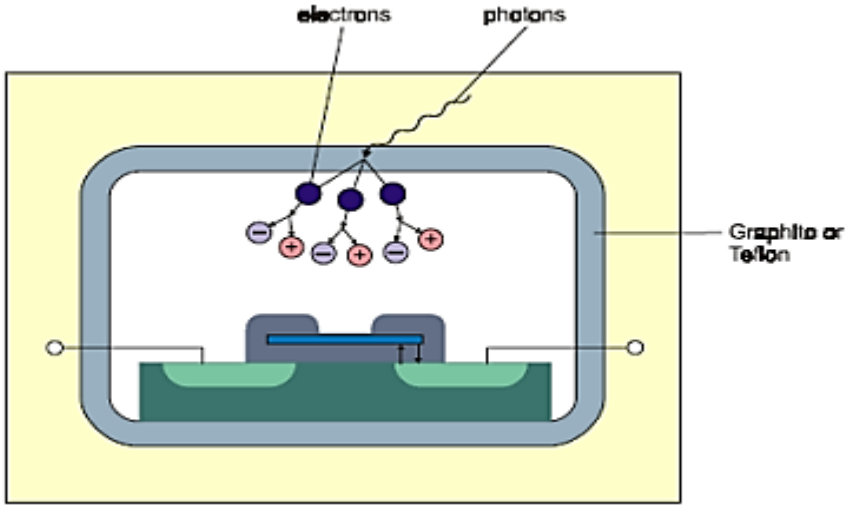
Gamma Elements



Direct Ion Storage (DIS): Neutron Dosimetry

- Different wall materials allow for neutron dosimetry measurements.
- Wall materials tested
  - Fast neutrons: A-150 and polyethylene (PE) for detection of recoil protons.
  - Thermal neutrons: A-150 containing different contents of boron nitride (BN).
  - Current design: A-320 & ~2% BN





- Neutron Chamber sensitive to photons
  - Provide a second chamber with neutron insensitive material for use in subtraction.

IM-276/PD Specifications

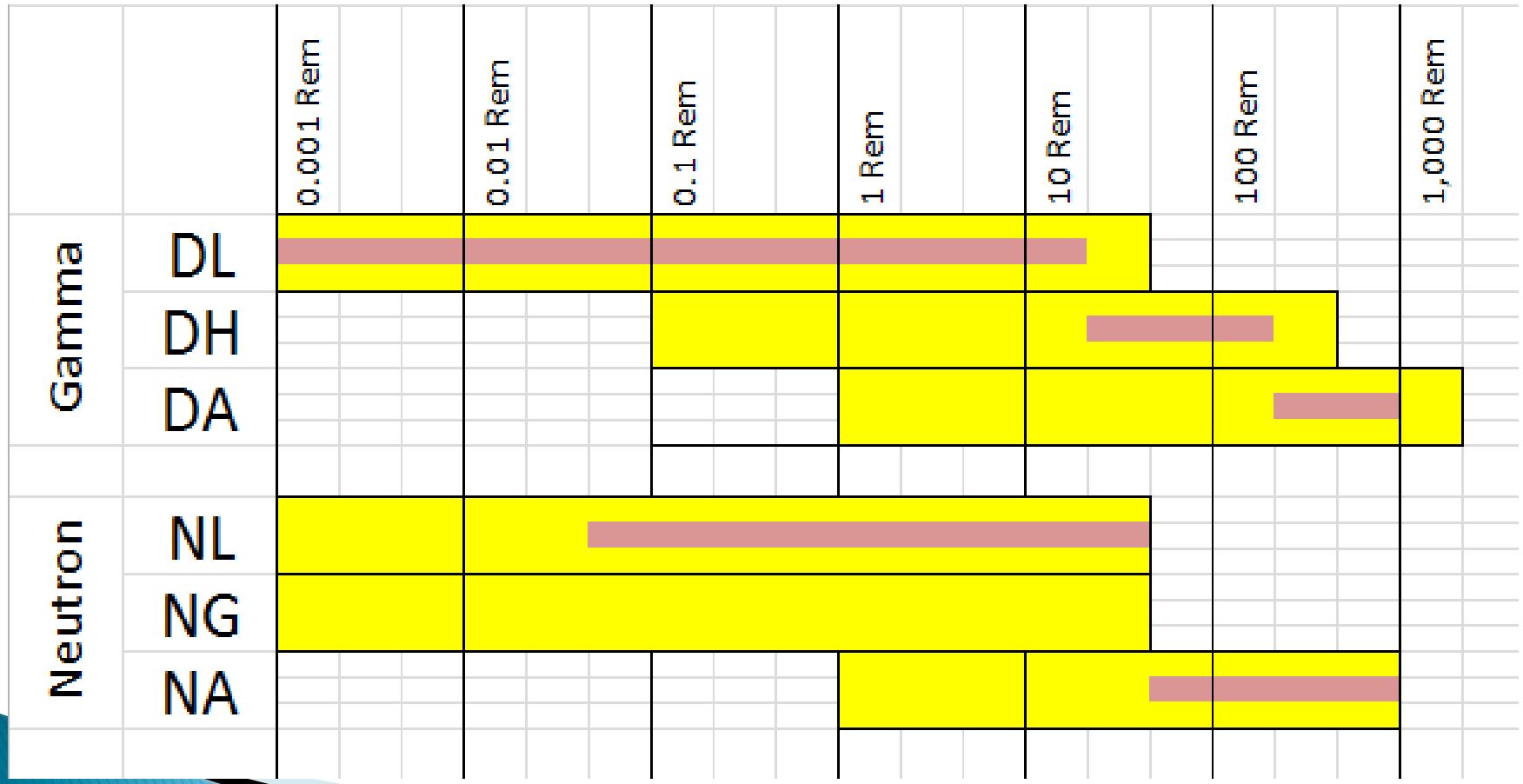
Radiological Characteristics	Radiation Detected: Energy Range:	Photon, 80 keV – 1.25 MeV Neutron, 0.6 – 2.1MeV
Physical Characteristics	Dimensions: Weight:	2” x 2.2” x 0.86” 1.07 oz. with batteries
Environmental Characteristics	Operating Temperature Range: Storage Temperature Range: Humidity: Water Resistance: Drop Test: RF-EMI Emissions: Vibration/Sand/Dust/Salt Fog/Fungus	-32°C to 52°C -54°C to 71°C RH of 95% at 60°C IP-67 1m height on hard surface RS101,RS103, RS105, RE102 IAW MIL STD 167,810G
Electrical Characteristics	Main Battery (Field Replaceable)	Renata CR2430, > 700 hrs.

IM-276/PD Detectors

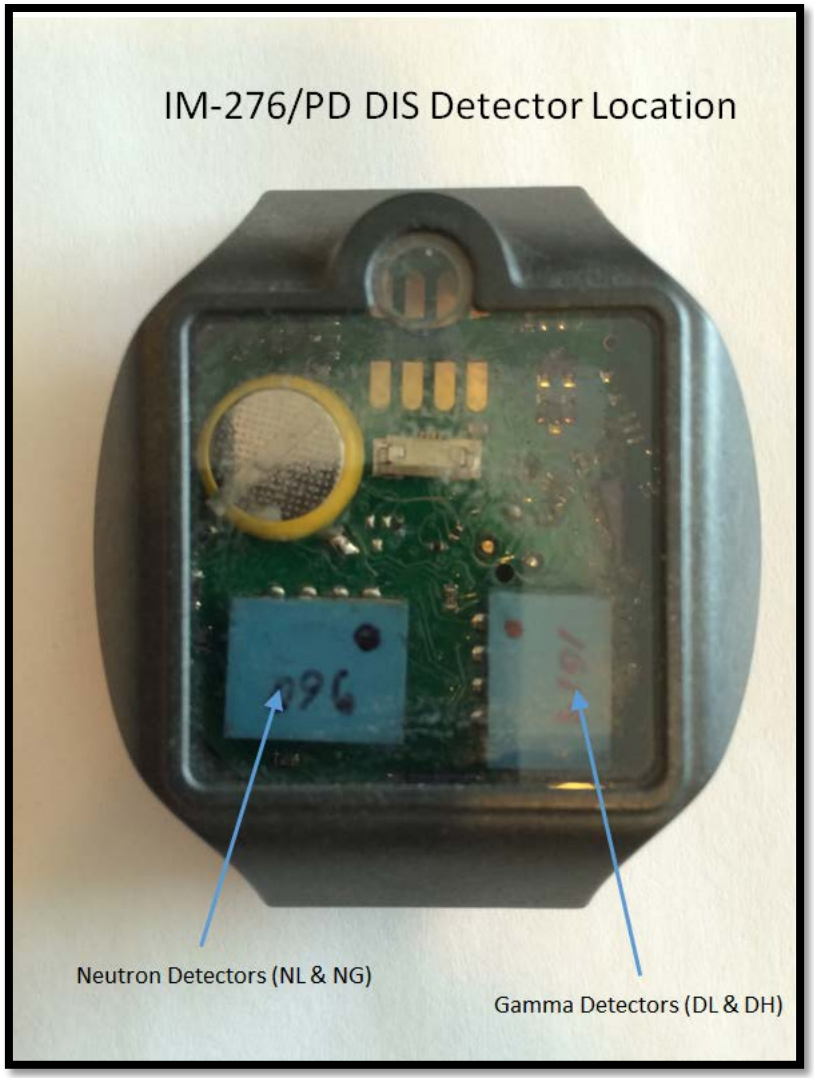
Detector		Code	LLD	Upper Range	Comments
Deep Gamma	DIS Low Range	DL	10 mrem (0.1 mSv)	60 rem (0.6 Sv)	Detector used on other commercial DIS dosimeter
	DIS High Range	DH	100 mrem (1 mSv)	600 rem (6 Sv)	Detector used on other commercial DIS dosimeter
	MOSFET	DA	1 rem (0.01 Sv)	2,000 rem (20 Sv)	MOSFET Detector
Deep Neutron	ϒ + n DIS	NL	10 mrem (0.1 mSv)	60 rem (0.6 Sv)	Sn shield covering NL and NG for low E gamma compensation
	ϒ DIS	NG	10 mrem (0.1 Sv)	600 rem (6 Sv)	Value subtracted to obtain net neutron dose
	PIN Diode	NA	1 rad (0.01 Gy)	1,000 rad (10 Gy)	Detector used on other commercial dosimeter

IM-276/PD Detectors

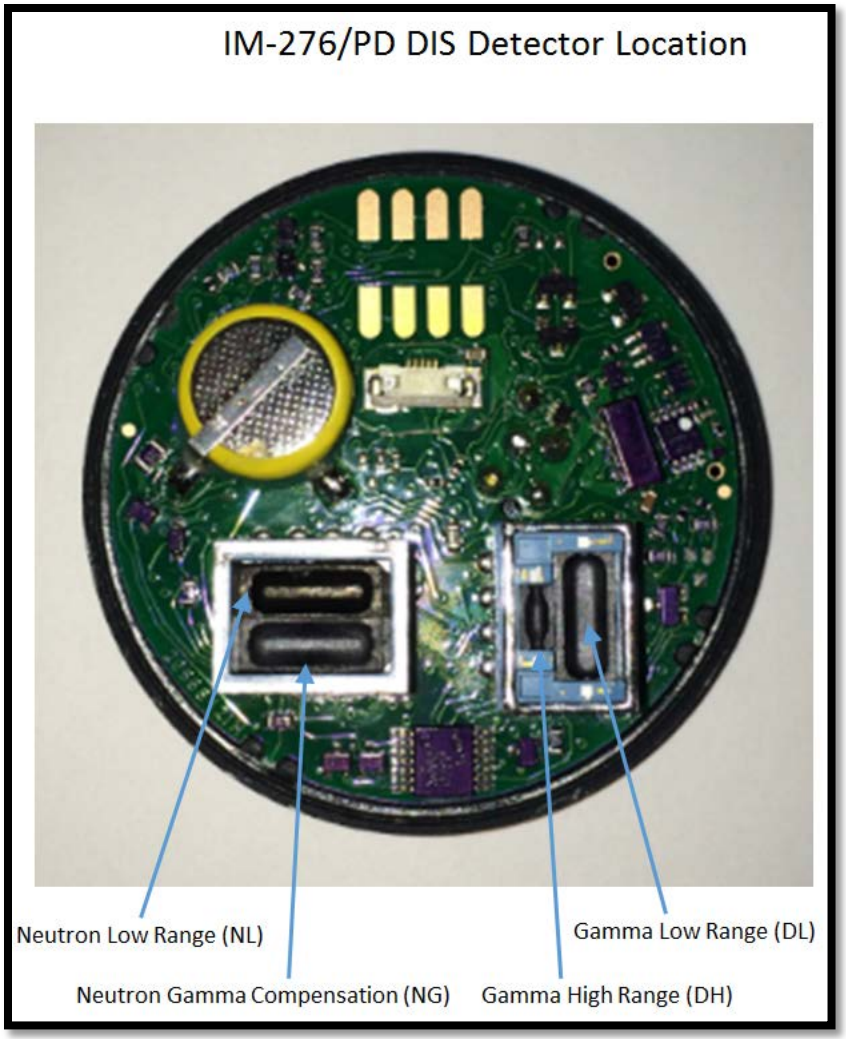
- Detector Range vs Display



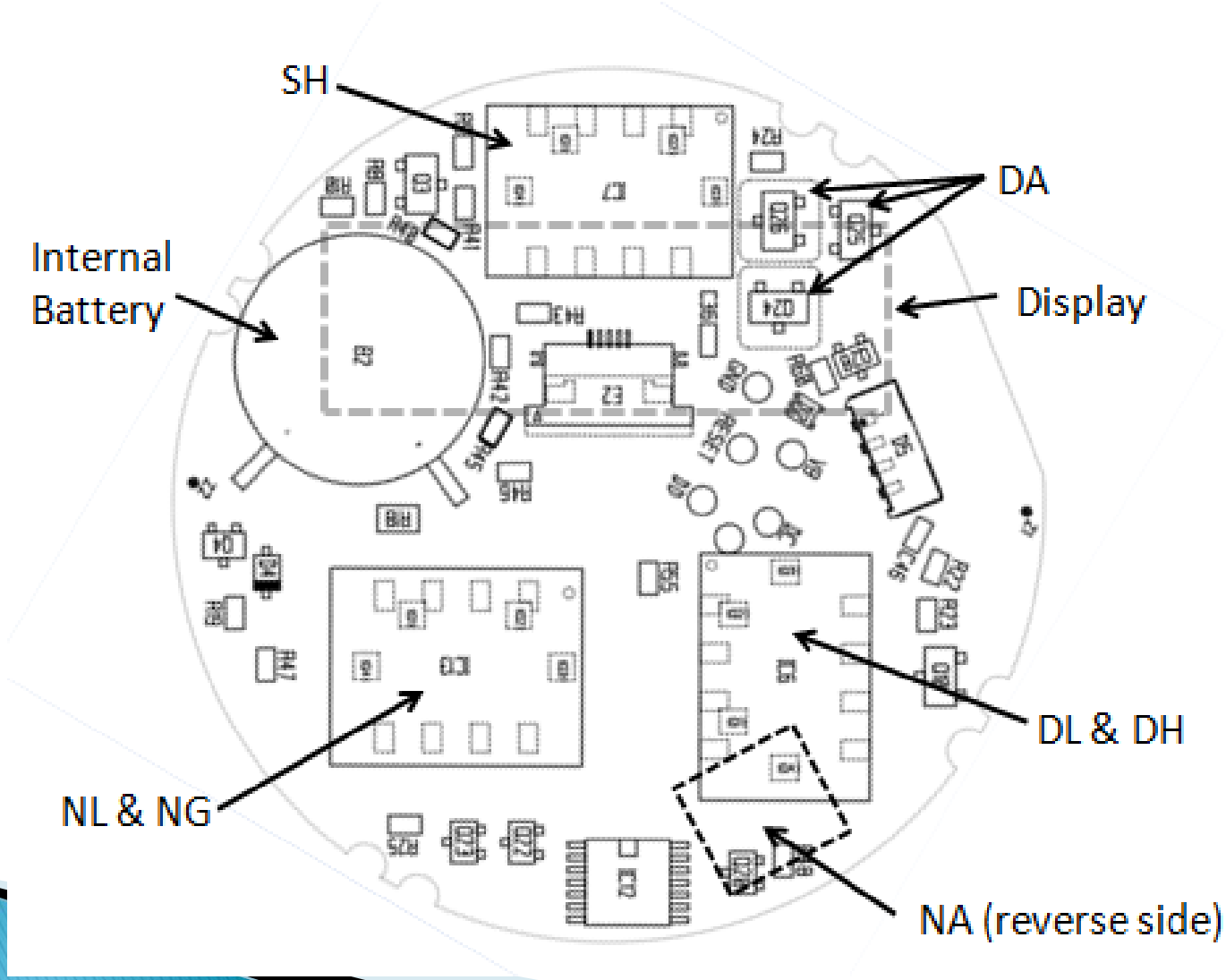
IM-276/PD Detectors



IM-276/PD Detectors



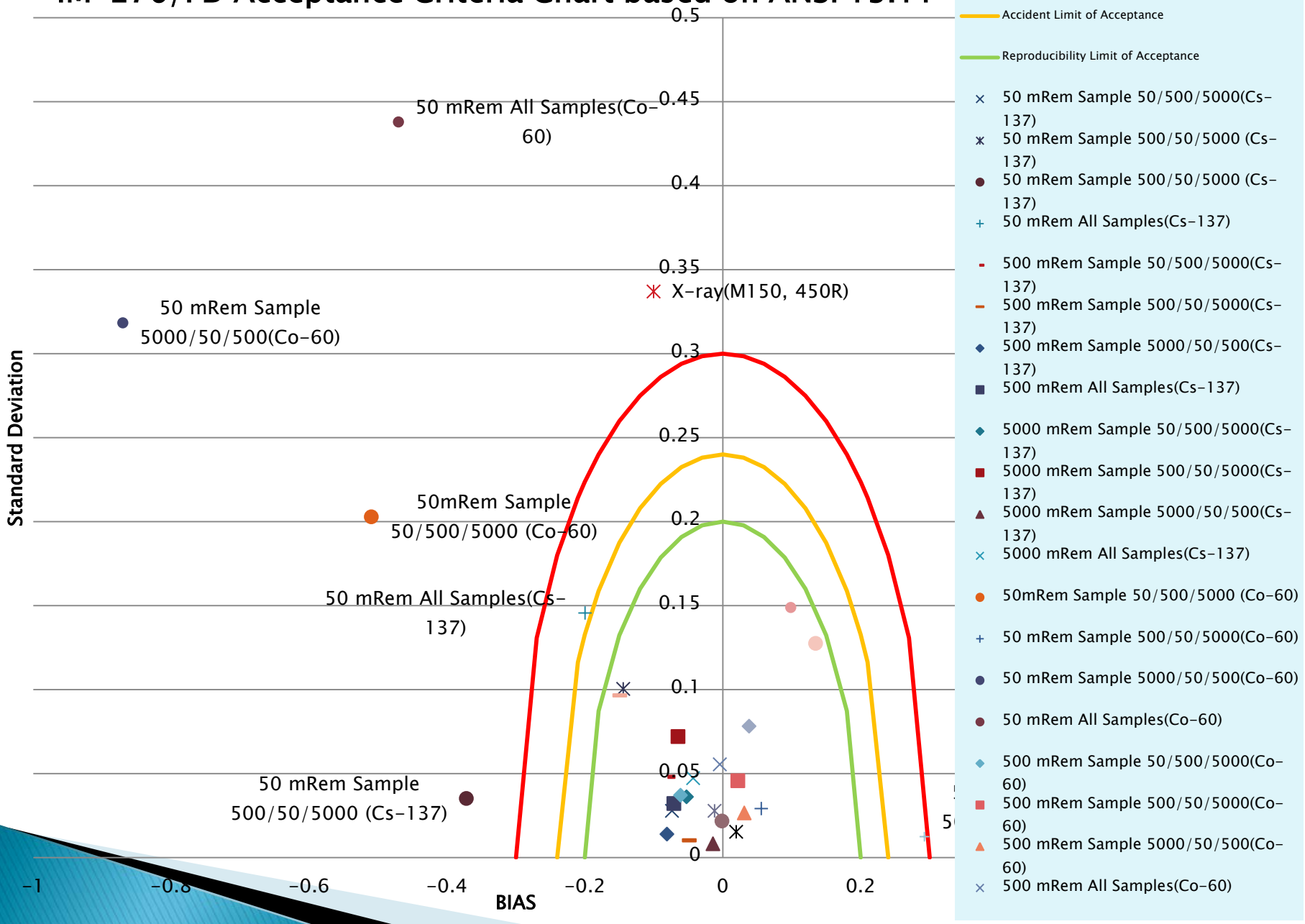
IM-276/PD Detectors



IM-276/PD Initial Test Data

Data	Bias	Stdev	PerfQuot	Limit	Test
50 mRem Sample 50/500/5000(Cs-137)	-0.07335	0.027742	0.00615	0.2	Pass
50 mRem Sample 500/50/5000 (Cs-137)	-0.14434	0.100262	0.030887	0.2	Pass
50 mRem Sample 500/50/5000 (Cs-137)	-0.37176	0.035091	0.139439	0.2	Fail
50 mRem All Samples(Cs-137)	-0.19955	0.14555	0.061006	0.2	Fail
500 mRem Sample 50/500/5000(Cs-137)	-0.07925	0.048009	0.008585	0.2	Pass
500 mRem Sample 500/50/5000(Cs-137)	-0.0486	0.010184	0.002465	0.2	Pass
500 mRem Sample 5000/50/500(Cs-137)	-0.08089	0.013833	0.006734	0.2	Pass
500 mRem All Samples(Cs-137)	-0.07081	0.032015	0.006039	0.2	Pass
5000 mRem Sample 50/500/5000(Cs-137)	-0.05252	0.036041	0.004058	0.2	Pass
5000 mRem Sample 500/50/5000(Cs-137)	-0.06496	0.071976	0.0094	0.2	Pass
5000 mRem Sample 5000/50/500(Cs-137)	-0.01423	0.008053	0.000267	0.2	Pass
5000 mRem All Samples(Cs-137)	-0.04267	0.047077	0.004037	0.2	Pass
NIST Neutron 150 mRem(Cs-137)	-0.3314	0.122068	0.124728	0.3	Fail
50mRem Sample 50/500/5000 (Co-60)	-0.50946	0.202718	0.300649	0.2	Fail
50 mRem Sample 500/50/5000(Co-60)	0.056048	0.028989	0.003982	0.2	Pass
50 mRem Sample 5000/50/500(Co-60)	-0.87006	0.318294	0.85831	0.2	Fail
50 mRem All Samples(Co-60)	-0.47041	0.437938	0.413071	0.2	Fail
500 mRem Sample 50/500/5000(Co-60)	-0.06108	0.037024	0.005102	0.2	Pass
500 mRem Sample 500/50/5000(Co-60)	0.021862	0.045615	0.002559	0.2	Pass
500 mRem Sample 5000/50/500(Co-60)	0.031423	0.026423	0.001686	0.2	Pass
500 mRem All Samples(Co-60)	-0.00404	0.055392	0.003085	0.2	Pass
5000 mRem Sample 50/500/5000(Co-60)	-0.01159	0.027663	0.0009	0.2	Pass
5000 mRem Sample 500/50/5000(Co-60)	-0.00102	0.021586	0.000467	0.2	Pass
5000 mRem Sample 5000/50/500(Co-60)	0.292479	0.012318	0.085696	0.2	Fail
5000 mRem All Samples(Co-60)	0.098839	0.148839	0.031922	0.2	Pass
Neutron/Gamma(Cs-137) (150 mRem / 50 mRem)	-0.3649	0.08783	0.140869	0.2	Fail
Neutron/Gamma(Cs-137) (150 mRem / 150 mRem)	-0.29714	0.066482	0.092712	0.2	Fail
Neutron/Gamma(Cs-137) (150 mRem / 450 mRem)	-0.18487	0.046273	0.036319	0.2	Pass
Neutron/Gamma(Cs-137) (All, 3:1,1:1,1:3)	-0.27766	0.098459	0.086789	0.3	Pass
Neutron/Gamma(Cs-137)(150mrem,500mR)	0.997958	0.393671	1.150897	0.3	Fail
Gamma (Cs-137, 50mR)	0.134597	0.12741	0.03435	0.2	Pass
X-ray(M150, 450R)	-0.10001	0.336927	0.123522	0.2	Fail
Batch 3 - M150(300R)	-0.15	0.10	0.031599	0.24	Pass
Batch 3 - M150(10R)	0.04	0.08	0.007574	0.24	Pass
Batch 3 - Cs-137, 500/50/5000	0.01951	0.015263	0.000614	0.3	Pass

IM-276/PD Acceptance Criteria Chart based on ANSI 13.11



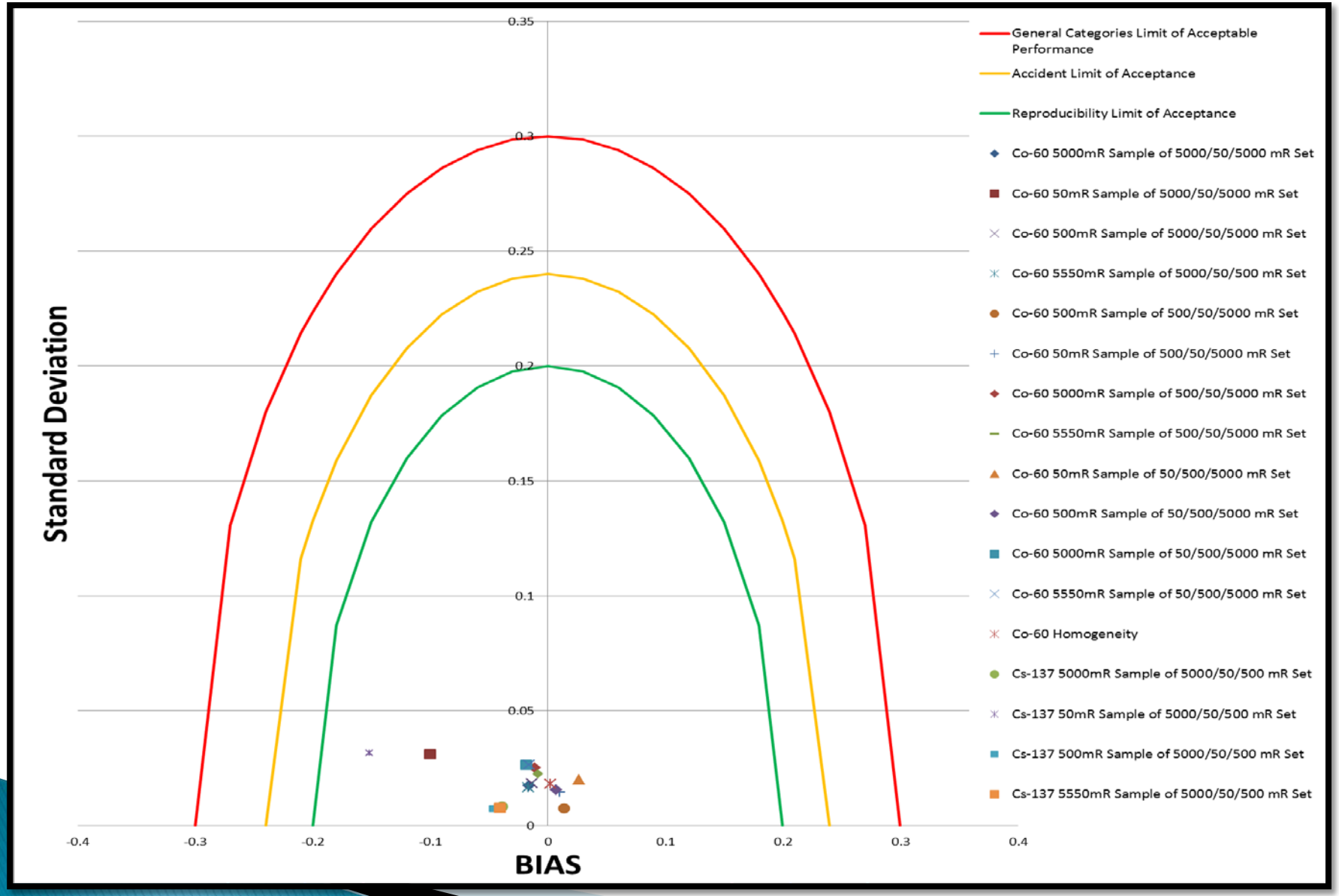
IM-276/PD Acceptance Test Results

- Due to acceptance test failures, Batches 001 – 004 were sent back to the IM-276/PD manufacturer. Using in-house testing and NSWCCD's data, the following were changes performed on the device:
  - Firmware modification
  - Calibration adjustments
  - Quality Assurance/Control on manufactured detectors
- Once these were implemented, the IM-276/PD significantly improved its performance.

Acceptance Test Data – Post Batch 005 (Cs-137 & Co-60)

Data	Bias	Stdev	PerfQuot	Limit	Test
Co-60 5000mR Sample of 5000/50/5000 mR Set	-0.01581	0.017363	0.000551	0.2	Pass
Co-60 50mR Sample of 5000/50/5000 mR Set	-0.10014	0.031227	0.011004	0.2	Pass
Co-60 500mR Sample of 5000/50/5000 mR Set	-0.01341	0.018385	0.000518	0.2	Pass
Co-60 5550mR Sample of 5000/50/500 mR Set	-0.01635	0.016676	0.000546	0.3	Pass
Co-60 500mR Sample of 500/50/5000 mR Set	0.013881	0.007641	0.000251	0.2	Pass
Co-60 50mR Sample of 500/50/5000 mR Set	0.010308	0.014673	0.000322	0.2	Pass
Co-60 5000mR Sample of 500/50/5000 mR Set	-0.011	0.025243	0.000758	0.2	Pass
Co-60 5550mR Sample of 500/50/5000 mR Set	-0.00857	0.022627	0.000585	0.3	Pass
Co-60 50mR Sample of 50/500/5000 mR Set	0.026551	0.020131	0.00111	0.2	Pass
Co-60 500mR Sample of 50/500/5000 mR Set	0.007059	0.015674	0.000296	0.2	Pass
Co-60 5000mR Sample of 50/500/5000 mR Set	-0.01825	0.026527	0.001037	0.2	Pass
Co-60 5550mR Sample of 50/500/5000 mR Set	-0.01556	0.026527	0.000946	0.3	Pass
Co-60 Homogeneity	0.002511	0.018199	0.000338	0.3	Pass
Cs-137 5000mR Sample of 5000/50/500 mR Set	-0.03905	0.00825	0.001593	0.2	Pass
Cs-137 50mR Sample of 5000/50/500 mR Set	-0.15188	0.031537	0.024062	0.2	Pass
Cs-137 500mR Sample of 5000/50/500 mR Set	-0.04634	0.007251	0.0022	0.2	Pass
Cs-137 5550mR Sample of 5000/50/500 mR Set	-0.04072	0.007846	0.00172	0.3	Pass

Acceptance Test Data – Post Batch 005 (Cs-137 & Co-60)



IM-276/PD Acceptance Test H300 Results

BeamCode:	H300			**BeamCode:**		H300			
Exposure:	50	mR		**Exposure:**		500	mR		
Dose rate:	1.6	R/hr		**Dose rate:**		8	R/hr		
kV	300			**kV**		300			
mA	2.45			**mA**		12.18			
Time	112.5	sec		**Time**		2250	sec		
Expected Dose (mRem):	62.267	mRem		**Expected Dose (mRem):**		622.67	mRem		
S/N:	**Dose (mrem)**	**Expected (mrem)**	**ResponseTime (min)**	**Bias**		**Dose (mrem)**	**Expected (mrem)**	**ResponseTime (min)**	**Bias**
A0015772	63	62.267	5.83	0.011771886		631	622.67	6.92	0.013377873
A0015840	59	62.267	4.67	-0.052467599		597	622.67	10.75	-0.041225689
A0015883	62	62.267	10.20	-0.004287986		608	622.67	4.22	-0.023559831
A0015885	64	62.267	6.83	0.027831757		620	622.67	3.75	-0.004287986
A0015894	58	62.267	6.45	-0.06852747		574	622.67	6.33	-0.078163393
A0016161	59	62.267	6.33	-0.052467599		582	622.67	6.39	-0.065315496
Mean			6.72	-0.023024502			622.67	6.39	-0.033195754
Stdev			1.86	0.039881115			0.00	2.78	0.035258642

IM-276/PD Acceptance Test H100 Results

Beam Code:	H100				**Beam Code:**	H100			
Exposure:	50	mR			**Exposure:**	500	mR		
Dose rate:	1.5	R/hr			**Dose rate:**	5	R/hr		
kV	100				**kV**	100			
mA	8.13				**mA**	26.98			
Time	120	sec			**Time**	360	sec		
Expected Dose (mRem):	81.9995	mRem			**Expected Dose (mRem):**	819.995	mRem		
S/N:	**Dose (mrem)**	**Expected (mrem)**	**ResponseTime (min)**	**Bias**		**Dose (mrem)**	**Expected (mrem)**	**ResponseTime (min)**	**Bias**
A0014959	71	81.9995	6.38	-0.134141062		709	819.995	6.37	-0.135360581
A0015842	89	81.9995	11.08	0.085372472		909	819.995	6.33	0.108543345
A0015961	80	81.9995	6.40	-0.024384295		792	819.995	6.40	-0.034140452
A0015983	84	81.9995	10.55	0.02439649		862	819.995	10.55	0.051225922
A0016036	76	81.9995	6.38	-0.07316508		775	819.995	6.38	-0.054872286
A0016056	78	81.9995	6.28	-0.048774688		780	819.995	8.92	-0.048774688
Mean	79.66666667		7.85	-0.02844936		804.5	820.00	7.49	-0.018896457
Stdev	6.282250128		2.31	0.076613274		70.67319152	0.00	1.87	0.086187344

IM-276/PD Acceptance Test H250 Results

5000/50/500 mR			
Beam Code:	H250		
Exposure:	5550	mR	
Dose rate:	Various	R/hr	
kV	250		
mA	Various		
Time	Various	sec	
Distance:	100	cm	
Expected Dose (mRem):	7203.678	mrem	
S/N:	**Dose (mrem)**	**Expected (mrem)**	**Bias**
A0015331	6706	7203.678	-0.069086653
A0015838	6939	7203.678	-0.036742064
A0015881	7004	7203.678	-0.027718896
A0016058	6588	7203.678	-0.085467174
A0016088	6494	7203.678	-0.098516064
A0016105	6930	7203.678	-0.037991426
Mean	6776.83		-0.059253713
Stdev	210.73		0.029252926

IM-276/PD Acceptance Testing – Electromagnetic & Environmental Effects (E3) and Prompt Radiation Tests

UNCLASSIFIED/FOUO

ATEC Project No.
2016-DT-WSMR-NVSPT-G6306.
DETAILED TEST REPORT (DTR) FOR THE
IM-276/PD BATTLEFIELD DOSIMETER

FRANK ANDREWS

SURVIVABILITY, VULNERABILITY AND ASSESSMENT DIRECTORATE (SVAD)
WHITE SANDS TEST CENTER (WSTC)
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WSMR, NEW MEXICO 88002

March 2017

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IM-276/PD Acceptance Test Results Summary

Requirement	Status	Results	Comments
3.3.3 Temperature Shock Requirement	Performed	Specs Met	None.
3.3.5 Salt Fog Requirement	Performed	Specs Met	None.
3.3.7 Immersion/Submersion Requirement	Performed	Specs Met	None.
3.3.10 Vibration Requirement	Performed	Specs Met	None.
3.3.12 Non-Ionizing Radiation Interfering Response Requirement	Performed	Specs Met	None.
3.3.13 Electromagnetic Interference Requirement – RS101	Performed	Specs Met	None.
3.3.13 Electromagnetic Interference Requirement – RS103	Performed	Specs Met	None.
3.3.13 Electromagnetic Interference Requirement – RE102	Performed	Specs Met	None.
3.3.14 Electromagnetic Pulse Requirement	Performed	Specs Met	None.
3.1.10 Prompt Nuclear Radiation (Gamma)	Performed	Specs Met	None.
3.1.10 Prompt Nuclear Radiation (Neutron)	Performed	Specs Met	None.

IM-276/PD Acceptance Test Results Summary

Requirement	Status	Results	Comments
3.1.1.3 Photon Performance Criteria – Cat IIB (Cs-137)	Performed	Specs Met	None.
3.1.1.3 Photon Performance Criteria – Cat IIB (Co-60)	Performed	Specs Met	None.
3.1.1.3 Photon Performance Criteria - Cat IIC	Performed	Specs Met	None.
3.1.2.2 Accident Photon Performance Criteria – Cat IA (Cs-137)	Performed	Specs Met	None.
3.1.2.2 Accident Photon Performance Criteria – Cat IA (M150)	Performed	Specs Met	None
3.1.4 Accuracy (Cs-137)	Performed	Specs Met	None.
3.1.4 Accuracy (Co-60)	Performed	Specs Met	None.
3.1.4 Accuracy (H100 – H300)	Performed	Specs Met	None.
3.1.6 Batch Homogeneity	Performed	Specs Met	None.
3.1.3.3 Neutron/Photon Performance Criteria – Cat VA ($Cf\text{-}252_{mod}$ + Cs-137)	Ongoing	Specs Partially Met	Navy Energy Correction Factor needs to be established for IM-276/PD.

Battlefield Dosimeter, IM-276/PD (MBD-1)

- IM-276/PD Neutron Response needs Navy Energy Correction Factor (NECF) to improve acceptance criteria evaluation.

- Differences in neutron spectra between Pacific Northwest National Laboratory and National Institutes of Standards and Technology are playing a part.
  - For example, DT-702/PD (Navy Primary Dosimeter) has a 25% difference.

- Path forward , once NECF is established, reevaluate neutron response against standard. Based on current data, high-confidence, response will improve.

Conclusion

- Robust acceptance testing protocol is needed to ensure a quality product is delivered to the end users.
- IM-276/PD expected to be fully delivered by October 2017.
  - 21,400 units and 214 cases expected
- Navy will receive a significant upgrade in Battlefield Dosimetry capabilities.

Questions

If you have any questions please contact:

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