RadWatch Dosimeter/RadLight

RadWatch Dosimeter

Overview :
RadWatch has been designed to assess the deep absorbed dose (cGy) for gamma radiations and the absorbed dose for neutrons. RadWatch has been designed and calibrated expecting it to be worn on the wrist but assess the absorbed dose that is received by the body or torso. This provides the most accurate field dose assessment.

Dosimeter Design:
Primary detectors consist of 3 aluminum oxide optically stimulated luminescence (OSL) discs with each sensor enveloped in a filter assembly:

- Filter 1 assembly indicates photon energy
- Filter 2 assembly assess dose due to photons
- Filter 3 assembly assess dose due to neutrons

RadWatch is comprised of 3 elements, a cover, a base and a slide. The slide fits into a recess in the base. The base and cover have screw-type threads that release after turning the cover. RadWatch contains a radiofrequency identification chip (RFID) on which identification information and sensor calibration data are recorded. The RFID chip is interrogated by the reader that uses the sensor calibration information in the dose calculation. The dose results are stored on the RFID chip so that the dosimeter carries the results of its last analysis.

Technical Specifications:

- Photons with energies greater than 80 keV
- Neutrons with energies greater than 0.1 MeV by assessing recoil protons
- Radiation Detection Range:
    - Photons: 0.01 cGy to more than 30 Gy

- Neutrons: 0.3 cGy tomore than 3,000 cGy with OSL

RadLight Reader

Overview:
The RadLight Reader is a battery operated, field deployable instrument designed to analyze the RadWatch dosimeter.

Dosimeter Analysis:
The reader automatically positions the OSL sensors over a photo-optical engine that guides the stimulation light onto the sensor and then routes the resulting luminescence to a photomultiplier tube (PMT). The dose received by each sensor is calculated from the counts recorded by the PMT using the sensor sensitivity factors stored on the RFID chip and the calibration factor relating normalized counts to dose stored in the reader memory.
The RadWatch is placed on the drawer assembly located on the left side of the reader. When the RadWatch is moved into the read position, the cover is lifted exposing the slide so that it engages with a retraction plate that pulls the slide over the photo-optical engine.

The reader stores all of the analytical data for download into a computer via a miniUSB connection. The analytical results are displayed to the operator via the display screen in the reader.

Features – Benefits

Feature	Benefits	Advantage
1) Non-destructive Readout	- Re-read dosimeters numerous times - Onsite interim analysis with portable RadLight reader - RFID participant and dose tracking	- No delay in dose assessments - Dose data validation - Central processing lab at Redstone provides final NVALP accredited dose of record analysis after Use
2) No Fade	Wear dosimeters for longer wear periods	Less administrative time in managing a dosimetry program with fewer exchange outs
3) Unlimited access to Landauer Certified Health Physicists and Ph.D. physicists	- Technology support - Algorithm support - Abnormal dose investigation support - Regulation interpretations	- Reliable answers and documentation - Credibility
4) Neutron sensitive OSL (OSLN)	- Read onsite	One detector for measuring all types of radiation

5) Equipment Redundancy	Emergency backup throughout the world	- No downtime - 3rd party independent analysis

Technical Approach

3.1 Radiological Requirements

3.1.1 Accident Dosimetry

The casualty dosimetry system shall perform at ±20% response over the following irradiation ranges: 5 to 1,000 rads from Cs-137 and M-150 as defined by ANSI N13.11-2009.

The proposed RadWatch/RadLight dosimetry system exceeds this requirement.

Landauer is NVLAP accredited to produce OSL dosimeters by demonstration of compliance with ANSI N13.11-2009 and ANSI/HPS N13.32 by testing.

The Aluminum oxide OSL sensors used in the RadWatch are extremely sensitive and have a measurement range from 0.01 rads to 5,000 rads for gamma radiation and 0.03 rads to 9,000 rads for neutrons.

3.1.2 Photon Energy Dependence

The casualty dosimetry system shall perform at ±20% response over photon energies ranging from 40 keV to 1.25 MeV. The casualty dosimetry system shall pass the test for the following energy ranges:

NIST Beam Code	Effective Energy (keV)
H50	40
H100	80
H150	120
H200	166
H250	211
H300	252
^{137}Cs	662
^{60}Co	1250

The casualty dosimeter system shall perform at ±20% for photons greater than 70keV and less than 10 MeV.

The proposed RadWatch/RadLight dosimetry system meets this requirement.

A test was conducted at Oak Ridge National Laboratory (ORNL) to determine the energy response of the dosimeters. Three different photon sources were used: X-ray (w/ M30 beam code: 20/21 keV), Cs-137 (661 keV), and Co-60 (1172/1332 keV). Ten dosimeters were used at each energy. Figure 1 is a plot of the observed energy response.

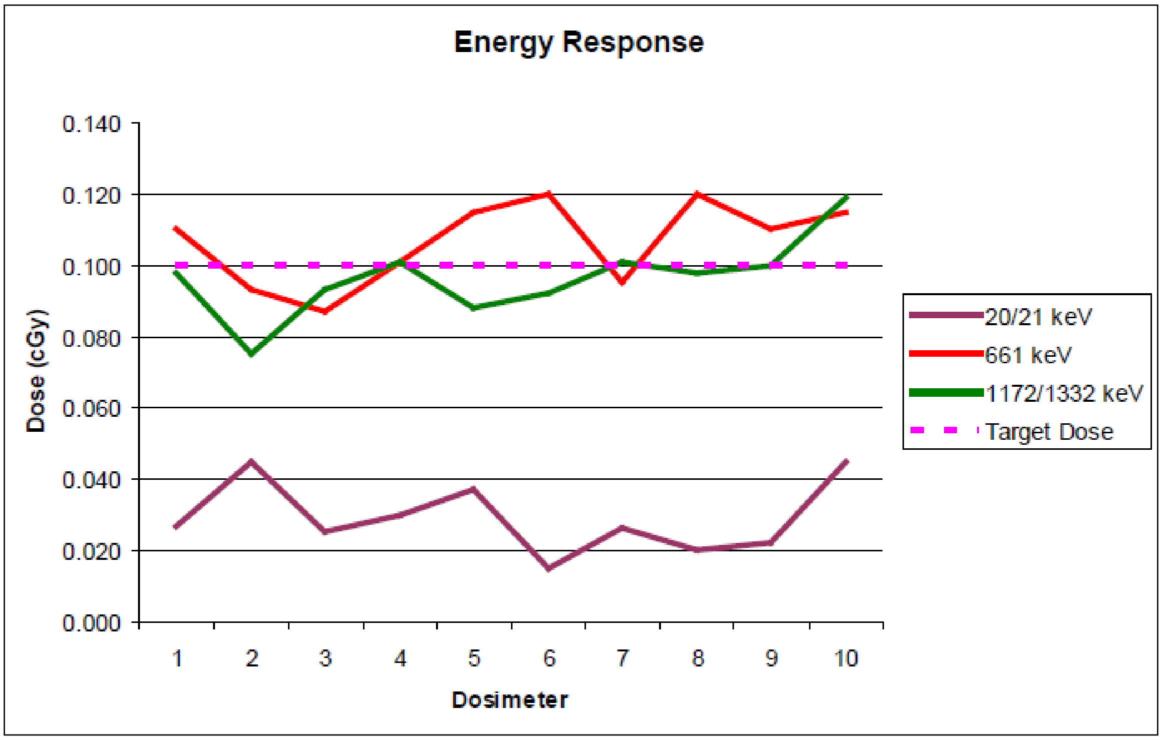

Figure 1 Energy Response of RadWatch dosimeters

For ^{137}Cs and ^{60}Co the recorded dose is within $\pm$20% of the target of 0.100 rad. For the low energy 20 kev X-rays, the response is well below the target. This is expected because a different read-cycle exposure is required to accurately read the very low energy dose.

3.1.3 Neutron Detection

The casualty dosimetry system shall be able to respond to a neutron source (Cf-252) at ±20% of the actual neutron dose.

The proposed RadWatch/RadLight dosimetry system meets this requirement.

Gamma rays deposit their energy or dose by directly ionizing the aluminum oxide atoms of the OSL dosimeter. Neutrons do not interact directly with the aluminum oxide atoms. The dose from neutrons is measured indirectly by the use of a converter consisting of a plastic material with a high concentration of hydrogen. The recoil protons from the elastic scattering of neutrons in the converter directly ionize the aluminum oxide in much the same way as the gamma rays. In the

RadWatch, a thin layer of polyethylene which contains a high concentration of hydrogen atoms is used as the converter.

Neutron dose is determined by subtracting the response of the gamma-only OSL sensor from the polyethylene filtered OSL sensor. Neutron doses are only indicated when the luminescence from the polyethylene sensor is greater than the luminescence from the gamma only sensor.

Preliminary test results indicate that the measured neutron dose is within ±20% of the actual neutron dose for Cf-252 source.

In order for this process to work accurately, it is important that the recorded gamma dose from each sensor be the same. Figure 2 shows the response of the RadWatch dosimeter as a function of photon energy, relative to Cs-137. As the figure illustrates, the response curve is sensibly flat over a large energy range.

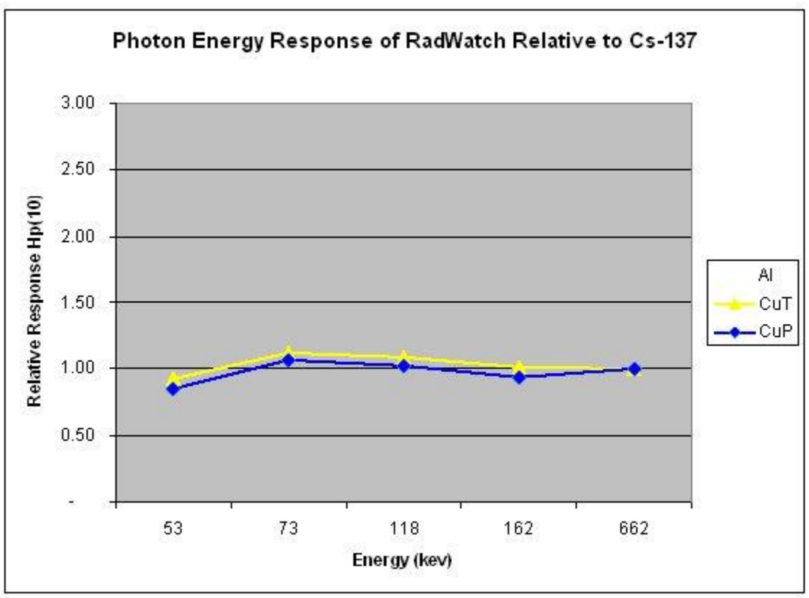

Figure 2 Gamma ray energy response of the gamma ray OSL sensor (CuT) and the neutron plus gamma ray sensor (CuP) showing equal gamma ray response at all energies.

3.1.4 Lower Limit of Detection

The casualty dosimetry system lower limit of detection shall be 5,000 mrad.

The RadWatch/RadLight dosimetry system substantially exceeds this requirement.

Tests were conducted for DTRA by Oak Ridge National Laboratory (ORNL) to determine the limit of statistical significance in the variance of doses measured by the RadWatch dosimeters. Twenty dosimeters were used for this test. Baseline readings were taken, followed by irradiation to100 mrad. The dosimeters were read (5 cycles for each unit) and the measured dose recorded. The standard deviation was calculated for the series of readings from each dosimeter. These values were averaged and the result multiplied by 2 to obtain a 2σ (95% confidence) variability factor. This was found to be 0.015 cGy or 15 mrad.

Additional RadWatch testing was performed by ORNL to determine the lowest statistically significant dose of radiation which can be detected by the OSL sensor in the RadWatch. According to the earlier test results, the Lower Limit of Detection was expected to be approximately 15 mrad. The table below is a summary of the data collected.

Statistical Analysis Data						
Target Dose (cGy):		0.005	0.010	0.015	0.020	0.025
Mean Dose Recorded (cGy):		0.009	0.012	0.013	0.026	0.040
Median Dose Recorded (cGy):		0.008	0.063	0.012	0.081	0.014
Range (cGy):	**(lowest)**	-0.001	-0.014	-0.007	0.021	0.023
	(highest)	0.037	0.030	0.034	0.030	0.095
COV (%):		119.6	94.1	104.4	11.8	53.0

Irradiations at 5, 10, and 15 mrad (0.001 cGy = 1 mrad) showed coefficients of variation (COV) of around 100%. This is as expected since the processes involved at very low doses are exponentially distributed. For target doses of 20 and 25 mrem the COV was substantially smaller as expected as the dose increases. ORNL considered this result to be a validation of the 15 mrad lower limit of detection.

3.1.5 Dose Response and Integration

The dose response/indication shall continue to accumulate while in and following re-entry into a radiation field. Reading the dosimeter shall not remove the accumulated dose nor prevent further response. Accumulated dose shall be capable of being retained, with negligible fading and without human intervention, for a period of ninety (90) days minimum.

The proposed RadWatch/RadLight dosimetry system exceeds this requirement.

The OSL sensors in the RadWatch continue to accumulate dose at all times. The dosimeter can be accurately read within 7 minutes of exposure.

An aluminum oxide crystal accumulates the dose from ionizing radiation by trapping free electrons generated by the ionizing processes associated with the interaction of radiation with matter. As the dose increases more electrons are created and therefore trapped. The electrons remain trapped until stimulated with green light in the RadLight reader. When a trapped electron absorbs the energy from a photon of green light, it is freed from the trap and combines with a luminescence center to create a blue luminescence light. The more trapped electrons, the more luminescence is created; therefore the amount of blue luminescence created by the stimulation green light is directly proportional to the absorbed radiation dose. This process is called optically stimulated luminescence (OSL) dosimetry. The efficiency of the freed electrons to generate the blue luminescence is very high so reading the dosimeter requires only a few electrons to be freed from the traps. Reading the dosimeter does not clear the accumulated dose. The remaining trapped electrons can be stimulated at later times so that the dosimeter can be analyzed repeatedly. This process of stimulating and measuring the resultant luminescence does not affect the sensors ability to continue to accumulate more radiation dose. As a result, an individual's radiation exposure can be checked many times during an exposure event so that the rate of one's accumulation of dose can be monitored.

Unless exposed to very high heat or extremely intense light, the trapped charges in the aluminum oxide sensors are stable for millions of years and OSL is routinely used in the analysis of archeological samples. Therefore, the exposure record retained in the RadWatch will be accurately retained for much longer than the desired 90 days.

Each time the dosimeter is read, some of the trapped charge must be released, consequently reducing the apparent accumulated dose. Because only a few electrons are required to read the dosimeter, this effect is very small. Each reading reduces the dose measurement by no more than 0.5%, which is well within the 20% operating tolerance.

3.2 Physical Requirements

3.2.1 Weight

The weight of the casualty dosimetry reader (if applicable) shall be less than fifteen (15) lbs.

The proposed RadWatch/RadLight dosimetry system exceeds this requirement.

The RadLight reader weighs five (5) pounds with batteries.

The RadLight reader has been made out of high impact plastic that is resistant to scratches, dents, mildew, fungus and chemicals. The internal materials have been chosen so there are no materials that might become radioactive in the case of a significant neutron flux. All of the major repair-by-replacement parts in the RadLight are interchangeable from one unit to the next.

3.2.2 Display

The casualty dosimeter shall have the capability to be processed on site with a small lightweight portable reader.

The proposed RadWatch/RadLight dosimetry system meets this requirement.

The RadLight reader weighs less than five (5) lbs and is about the size of a child's lunchbox (9" x 7" x 7"). The RadLight has an LCD display screen which shows the total absorbed dose and serves to relay operational status and configuration settings to the user.

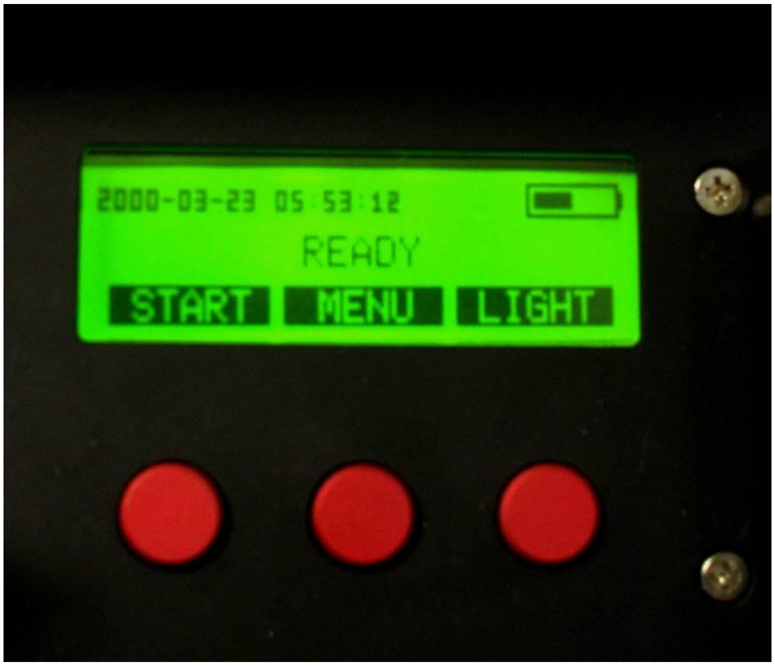

Figure 3 RadLight reader display

Using the main menu, the operator can turn the unit on and off, set time and date, view or transfer stored data and perform configuration, calibration, and maintenance functions.

3.2.3 Anneal (Zeroing)

The casualty dosimetry system shall be capable of being annealed after exposed.

The proposed RadWatch/RadLight dosimetry system meets this requirement.

There is really no operational reason to ever anneal an OSL based dosimeter (see also section 3.1.5). The OSL sensors continuously record absorbed dose and have the capability to operate and be read through wartime nuclear events. Therefore, it is unnecessary to zero them (anneal them) prior to deployment.

The RadWatch dosimeters can be annealed by continuous exposure to very intense light in a specific frequency range. The RadLight reader purposely cannot anneal the dosimeters to ensure that there is no possibility of annealing one inadvertently.

Dosimeters can be returned to the factory to be annealed. Should the Navy wish to anneal its own dosimeters, an annealing system can be purchased separately.

The annealing system uses 8 high output T5 fluorescent lamps to deliver a highly uniform large area annealing surface. The system can remove a dose of a few hundred mrem in a few minutes. Equipped with a lid to prevent eye strain for nearby personnel as well as prevent other “stray” light from influencing the annealing process.

ANNEALING SYSTEM SPECIFICATIONS	
OPERATION	Manual
OVERALL SIZE	750 mm x 750 mm x 150 mm
WEIGHT	15kg
ANNEALING AREA	600mm x 600mm
ANNEALING CAPACITY	576 slides (12 rows of 48 columns)
ANNEALING PERFORMANCE	200 mrem to <10 mrem in 30 minutes

3.2.4 Power

The casualty dosimetry system portable reader (if applicable) shall be capable of operating from commercially available consumable batteries for twenty (20) operational hours (minimum). The reader shall have a low battery indicator. The batteries shall be easily removed without the use of a special tool or method. The vendor shall state the expected continuous operating time using the recommended batteries and the conditions used to determine this time.

The proposed RadWatch/RadLight dosimetry system meets this requirement.

The RadLight portable reader can operate continuously on one set of 4 AA alkaline batteries for 21.5 hours in the temperature range of 18°C to 50°C. At very low temperatures (-10°C to -20°C) the operating time of the reader follows the low temperature performance of the batteries and so the continuous operating time is reduced to about 1/3 of that of normal temperatures. On the other hand, it is easy to keep batteries warm and maintain the operating time of the reader.

The charge state of the batteries is shown in the upper right corner of the LCD display as shown in Figure 3.

In continuous operation the reader processes 2.4 dosimeters/minute or 144 per hour at all temperatures. This is approximately 27 seconds per dosimeter and continuous operation at this rate for 21.5 hours represents the capability of reading 2,900 dosimeters in that time.

Operating time is only an accurate metric for continuous operation. But field use will not be continuous. Other factors such as verifying individual identity and returning the dosimeter to that individual will prevent the operator from inserting and removing dosimeters continuously at the maximum rate for an extended time. The process of removing and replacing the sensor slide represents 95% of the battery consumption, therefore it is more appropriate to gauge the lifetime of the batteries in terms of the number of reads completed. A battery set has the capacity to perform 2,900 reads. If these reads were performed at the rate of 100 per day, one battery set would last nearly a month.

Battery replacement is quite straightforward and requires no tools.

			
Loosen the large captive fastener by turning counter clockwise	Remove the lid	Install new batteries, making sure the orientation is as indicated	Reinstall lid with correct orientation (it will only fit one way) and tighten the captive fastener.

Warranty

4.2 Warranty

A commercial warranty shall be provided with each system. The warranty shall cover repairs and replacement of the system that fails to deliver and maintain the capabilities, performance and physical integrity as specified in this SOW. The warranty period shall begin upon delivery and acceptance of the system(s) to the specific Navy facility.

MELE Associates warrants the RadLight dosimetry reader and the RadWatch dosimeter to be free of manufacturing defects and to operate in accordance with the equipment description in effect at the time of purchase.

4.2.1 Warranty Period

This warranty is in effect for a period of 12 months from the date of acceptance, or one month after delivery, whichever occurs first.

4.2.2 Warranty Coverage

MELE warrants that the Dosimetry Equipment is free of manufacturing defects that materially affect proper operation, and that it operates in accordance with its specifications and operating descriptions. MELE will replace or repair, at its option, any of the Dosimetry Equipment that is found to contain a manufacturing defect or does not operate in accordance with the equipment description in effect at the time of purchase.

4.2.3 Exclusions

All reasons and causes of affected performance except those listed under Warranty Coverage are specifically excluded. Examples of excluded causes include, but are not limited to, mishandling, acts of war or violence, acts of God, operating the equipment outside its rated parameters, attaching other equipment to the Dosimetry Equipment, alteration of the software or parameter settings, and installation of any non-MELE hardware or software on the Covered Equipment.

4.2.4 Type of Warranty

This is a "Return to Factory" warranty.

Delivery Schedule

MELE proposes to deliver the dosimeters and readers within 30 days ACD.

Past Performance

MELE contract CR-214/DAAB07-03-D-B008 was the contract under which MELE and its subcontractor, Landauer Inc. (Landauer), developed, designed, manufactured and tested the miniaturized technologies for the potential replacement of the AN/PDR-75 and the DT-236. The contract ultimately developed 250 prototype and pre-production RadWatches (the potential DT-236 replacement) and 30 pre-production RadLight readers (the potential AN/PDR-75 replacement). Program goals, in addition to miniaturization, and encompassing of the NVLAP and tactical dosimeter requirements allowed MELE to test the equipment in a presumed first article environment at the US test facilities at WSMR NM. The relevance of this, approximately 1.4 million dollar, contract is that the present equipment is ready to proceed to first article test with a high level of confidence in the ability to achieve rapid first article qualification of both the watch and reader. The table below provides detailed information about this contract.