Testing and Evaluation Protocol for Backpack- Based Radiation Detection Systems Used for Homeland Security

T&E Protocol N42.53, 2013

Table of Content

Testing and Evaluation Protocol for Backpack- Based Radiation Detection Systems Used for Homeland Security

1. Scope

This document establishes the protocol for testing alarming personal radiation detectors based on the performance requirements established in ANSI N42.53, "American National Standard Performance Criteria for Backpack- Based Radiation-Detection Systems Used for Homeland Security."

2. References

This protocol shall be used in conjunction with the following documents:

[R1] ANSI N42.53, "American National Standard Performance Criteria for Backpack-Based Radiation-Detection Systems Used for Homeland Security."

[R2] ANSI/IEEE N42.42, "Data Format Standard for Radiation Detectors Used for Homeland Security."

[R3] NIST Handbook 150, NVLAP Procedures and General Requirements

[R4] NIST Handbook 150-23, NVLAP Radiation Detection Instruments

3. Compliance Level Information

Instrument under test might meet all the requirements listed in the ANSI/IEEE N42.53 standard. Therefore, different agencies developed documents describing the compliance levels required for particular applications of the instruments under test. An example of such compliance level requirements is those required by the Graduated Rad/Nuc Detector Evaluation and Reporting (GRaDER®) program. For this program, information can be found in the "Compliance Level for GRaDER® Instrument Performance" document located at http://www.dhs.gov/GRaDER .

4. Test and evaluation steps

It is recommended that testing laboratories perform the tests listed in this protocol in the following order:

- Check all items listed in the general requirements
- Perform the radiological tests
- Perform the temperature and humidity tests
- Perform the entire electrical and electromagnetic test except the Electrostatic Discharge (ESD) test
- Perform the impact and the vibration tests
- Perform the moisture and dust test
- Perform the ESD test
- Perform the drop test, as required

Excel template sheets are provided by NIST to the testing laboratory to guarantee that all data required is being provided in the test report. The excel template sheet are available for download at http://www.nist.gov/pml/div682/grp04/ansieeen42.cfm.

5. Recording test results

The excel template data sheets shall be used to record and report all test results. Each data sheet is associated with a specific section(s) of the referenced ANSI standard, N42.53. Instrument status shall be recorded on the "Test Summary" sheet as testing is performed. The comment section in each data sheet shall be used to record changes to the test requirements and methods listed in the ANSI standard. The comment section shall also include the rational of the changes.

6. Test report

A test report summarizing the results of the test shall include the following sections:

a. Laboratory equipment information:
   1. Identify all participating laboratory facilities. Include points of contact names, mailing address, telephone number, and electronic mail addresses.
   2. Identify the tests performed in the different facilities.
   3. List all supporting equipment name, model number and last day of calibration used for each test.

b. Test equipment information :
   1. Include manufacturer name, instrument model, instrument serial number, software and firmware version identification, and last day of calibration.
   2. List the operating modes and parameter setting of the instrument and accessory kit(s) used in each test.

c. Data sheets:
   1. The excel template data sheets shall be completed and provided as part of the report.
   2. Include any changes made to the ANSI standard test requirements or methods and rational to the changes, if changes were made during testing.

7. Guidance for testing ANSI N42.42 data format requirements

The standard associated with this Test and Evaluation Protocol requires verification that an output data file is created that complies with ANSI/IEEE N42.42 standard requirements. The range of complexity of the N42.42 compliant instrument output file is extremely broad. Data output files from these instruments are simple files that can be checked manually using a text editor such as Notepad or WordPad. These files can also be verified using additional tools. In principle, all data output files that meet ANSI N42.42 can be verified manually using a text editor as these files are XML files. File reading software, such as Altova XMLSpy® or Oxygen XML1 can also be used for manual viewing and validating of structure and content.

N42.42 schemas can be used to validate the file format as specified in the ANSI/IEEE N42.42 standard. These schemas are available at the NIST web site http://www.nist.gov/pml/div682/grp04/n42.cfm..

There are several XML validators that can be used to verify the XML structure of the N42.42 compliant instrument output file. Examples of these validators can be found at https://secwww.jhuapl.edu/n42/Account/LogOn, http://www.xmlvalidation.com/ or http://validator.w3.org/.

---

[1] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

8. Considerations

The standard establishes exposure rates for test in Roentgen per hour (R/h). When testing instruments that read in rem per hour, the test field shall be in rem/h instead of R/h. Refer to the "Units and Uncertainties" section in the standard for additional information.

9. "Source data" entry in data sheets

The standard requires testing with different radionuclides to establish the instrument's capability to correctly identify those radionuclides. The ANSI/IEEE N42.53 standard specified that these tests should be performed by placing the different radioactive sources in front the instrument to produce an exposure rate of 5 µR/h above background at the reference point of the instrument. Based on these requirements, the "Source Data" entry in the data sheets should contain the following information:

- Source ID number
- Activity at reference time
- Reference time
- Activity at time of test
- Time of test
- Source to detector distance
- Calculated exposure rate

The exposure rate values used for testing are very low; this will require using calculated values to determine the radiation field used for the test. If point sources are used for these measurements the following calculation shall be used to determine the radiation field used for the tests.

In order to have a consistent way to determine exposure rate, $\dot{X}$, among all users of this standard, the following method shall be used. There might be different and perhaps slightly better methods to perform these determinations, but the most critical issue to address in this standard is the reproducibility and consistency across all the testing laboratories in how the determination of the radiation fields are made. Due to the low exposure rates (*i.e.*, 5 µR/h or 10 µR/h above background) required to perform some of the tests, it would not be possible to make accurate measurements with the uncertainty required by the standard of ±20 % (k = 1).

The proposed method assumes a point source in air, and it does not account for buildup in air. The cut-off energy, δ, used for the calculations shall be 40 keV, and for practical purposes all photon emissions with a probability larger than 0.5 % shall be included in the calculation.

For the point source in vacuum, the fluence rate $\dot{\Phi}_i$ of photons with energy E_i at a radial distance r is simply $AP_i/(4\pi r^2)$, where A is the source activity, and P_i is the probability per disintegration that a photon of energy E_i is emitted. Assuming charged-particle equilibrium, the air-kerma rate $\dot{K}_i$ from photons of energy E_i is then $\dot{K}_i = \dot{\Phi}_i E_i \frac{\mu_{tr}(E_i)}{\rho_{air}}$, where $\frac{\mu_{tr}(E_i)}{\rho_{air}}$ is the mass energy-transfer coefficient for air [1]. In general, for a point source in vacuum, emitting more than one energy photon the air kerma rate is obtained by summing over all photon energies as follows:

$$\dot{K}_\delta = \sum_i \frac{A\,P_i\,E_i}{4\pi r^2}\frac{\mu_{tr}(E_i)}{\rho_{air}}, \qquad (1)$$

where δ denotes the minimum photon energy included.

Now consider the point source surrounded by spherical shell(s) of encapsulating material in an infinite air medium. Each encapsulation material surrounding the source will have a thickness z_j and a density ρ_j. The attenuation of the photon beam from any material surrounding he source and the column of air between the source and the point of detection can be accounted for by using the following estimate of the air-kerma rate at a radial distance *r*:

$$\dot{K}_\delta = \frac{A}{4\pi r^2}\sum_i P_i\, E_i\, \frac{\mu_{tr}(E_i)}{\rho_{air}}\ \exp\left[-\sum_j \frac{\mu_j(E_i)}{\rho_j}\,\rho_j\ z_j\right]\exp\left[-\frac{\mu_{air}(E_i)}{\rho_{air}}\,\rho_{air}\ r\right], \qquad (2)$$

where μ_j/ρ_j the mass attenuation coefficient for the encapsulating-layer material of thickness z_j and a density ρ_j, and μ_{air}/ρ_{air} is that for air. Note that in Equation 2 there are two exponentials. The first one accounts for the attenuation of all the materials surrounding the source while the second exponential accounts for the attenuation of the air column.

The relationship between the radiation quantities of exposure *X* (units of R) and air-kerma *K* (units of Gy) is given by

$$K = X\ \ (2.58\times 10^{-4})\left(\frac{W}{e}\right)\left(\frac{1}{1-g}\right), \qquad (3)$$

where *W/e* is the mean energy expended in dry air by electrons per ion pair formed (equal to 33.97 J/C) [5], and *g* is the mean fraction of the initial kinetic energy of secondary electrons liberated by photons that are lost through radioactive processes in air. The SI unit of exposure is the coulomb per kilogram (C/kg); the special unit of exposure, the roentgen (R), is equal to exactly 2.58×10^{-4} C/kg.

$$\mu_{en}(E_i) = (1-g)\mu_{tr}(E_i) \qquad (4)$$

where $\mu_{en}(E_i)$ is the mass energy-absorption in air; the values are listed in Table 1.

From Equations 2, 3 and 4 an expression for the exposure rate, $\dot{X}$, can be easily derived for the practical case of an encapsulated source in air as

$$\dot{X}_\delta = \frac{114.1\,A}{4\pi r^2}\sum_i P_i\ E_i\ \frac{\mu_{en}(E_i)}{\rho_{air}}\ \exp\left[-\sum_j \frac{\mu_j(E_i)}{\rho_j}\,z_j\ \rho_j\right]\exp\left[-\frac{\mu_{air}(E_i)}{\rho_{air}}\,r\ \rho_{air}\right], (5)$$

In order to ensure that all testing laboratories obtain a consistent calculated value of the ambient dose equivalent rate, the different coefficients and values for the different quantities used in the equations above shall only be taken from the following references:

- μ_j/ρ_j and ρ_j shall be obtained from the XCOM database, see reference [2].
- Pi shall be obtained from reference [3]; if a given radionuclide is not listed [3], then reference [4] shall be used. For convenience, due to the long decay chain, the values for the probabilities per disintegration (P) for ^{232}Th and ^{226}Ra (in equilibrium) are listed here in Table 1.
- The μ_{en}/ρ_{air} and μ_{air}/ρ_{air} values are given in Table 2.
- The density of air shall be ρ_{air} = 0.0012 g/cm3.
- The cut-off energy, δ, used for the calculations shall be 40 keV.
- All photon emissions with a probability larger than 0.5 % shall be included in the calculation.

This method assumes that the sources used have small or negligible self-attenuation. This means that the dimensions and/or density of the source active material are such that the attenuation within the source is negligible. Appropriate corrections to Equation 5 shall be applied to account for source self-attenuation for the case of large and/or dense sources.

Table 1: Probabilities per disintegration for ^{232}Th and ^{226}Ra (in equilibrium) as a function of photon energy

^{232}Th (in equilibrium)		^{226}Ra (in equilibrium)	
Photon energy keV	*P*	Photon energy keV	*P*
72.805	7.51E-03	46.539	4.312E-02
74.815	1.04E-01	53.228	1.060E-02
74.969	1.26E-02	74.816	6.26E-02
77.107	1.75E-01	77.109	1.047E-01
84.373	1.22E-02	79.293	7.12E-03
86.83	2.09E-02	87.344	3.59E-02
87.349	4.01E-02	89.784	6.70E-03
89.784	1.46E-02	90.074	1.10E-02
89.957	1.96E-02	186.211	3.555E-02
93.35	3.19E-02	241.997	7.268E-02
99.509	1.26E-02	258.87	5.24E-03
105.604	7.40E-03	295.224	1.8414E-01
115.183	5.92E-03	351.932	3.56E-01
129.065	2.42E-02	609.312	4.549E-01
153.977	7.22E-03	665.453	1.53E-02
209.253	3.89E-02	768.356	4.892E-02
238.632	4.33E-01	785.96	1.064E-02
240.986	4.10E-02	806.174	1.262E-02
270.245	3.46E-02	839.04	5.87E-03
277.351	2.27E-02	934.061	3.10E-02
300.087	3.28E-02	1120.287	1.491E-01
328	2.95E-02	1155.19	1.635E-02
338.32	1.13E-01	1238.111	5.831E-02
409.462	1.92E-02	1280.96	1.435E-02
463.004	4.40E-02	1377.669	3.968E-02
510.77	8.12E-02	1385.31	7.95E-03
562.5	8.70E-03	1401.5	1.33E-02
583.191	3.04E-01	1407.98	2.389E-02
726.863	6.20E-03	1509.228	2.128E-02
727.33	6.58E-02	1583.22	7.07E-03
755.315	1.00E-02	1661.28	1.048E-02

763.13	6.52E-03	1729.595	2.844E-02
772.291	1.49E-02	1764.494	1.531E-01
794.947	4.25E-02	1847.42	2.025E-02
830.486	5.40E-03	2118.55	1.158E-02
835.71	1.61E-02	2204.21	4.913E-02
840.377	9.10E-03	2447.86	1.548E-02
860.564	4.46E-02		
904.19	7.70E-03		
911.204	2.58E-01		
964.766	4.99E-02		
968.971	1.58E-01		
1078.62	5.64E-03		
1247.08	5.00E-03		
1459.138	8.30E-03		
1495.93	8.60E-03		
1580.53	6.00E-03		
1588.19	3.22E-02		
1620.5	1.49E-02		
1630.627	1.51E-02		
2614.453	3.56E-01		

Table 2: Values of the mass energy-transfer, mass energy-absorption, and mass attenuation coefficients for air

	Photon Energy MeV	μ_{tr}/ρ (cm^2/g)	μ_{en}/ρ (cm^2/g)	μ/ρ (cm^2/g)
	1.000E-03	3.599E+03	3.599E+03	3.606E+03
	1.500E-03	1.188E+03	1.188E+03	1.191E+03
	2.000E-03	5.263E+02	5.262E+02	5.279E+02
	3.000E-03	1.615E+02	1.614E+02	1.625E+02
	3.203E-03	1.330E+02	1.330E+02	1.340E+02
18 K	3.203E-03	1.460E+02	1.460E+02	1.485E+02
	4.000E-03	7.637E+01	7.636E+01	7.788E+01
	5.000E-03	3.932E+01	3.931E+01	4.027E+01
	6.000E-03	2.271E+01	2.270E+01	2.341E+01
	8.000E-03	9.448E+00	9.446E+00	9.921E+00
	1.000E-02	4.743E+00	4.742E+00	5.120E+00
	1.500E-02	1.334E+00	1.334E+00	1.614E+00
	2.000E-02	5.391E-01	5.389E-01	7.779E-01
	3.000E-02	1.538E-01	1.537E-01	3.538E-01

4.000E-02	6.836E-02	6.833E-02	2.485E-01
5.000E-02	4.100E-02	4.098E-02	2.080E-01
6.000E-02	3.042E-02	3.041E-02	1.875E-01
8.000E-02	2.408E-02	2.407E-02	1.662E-01
1.000E-01	2.326E-02	2.325E-02	1.541E-01
1.500E-01	2.497E-02	2.496E-02	1.356E-01
2.000E-01	2.674E-02	2.672E-02	1.233E-01
3.000E-01	2.875E-02	2.872E-02	1.067E-01
4.000E-01	2.953E-02	2.949E-02	9.549E-02
5.000E-01	2.971E-02	2.966E-02	8.712E-02
6.000E-01	2.958E-02	2.953E-02	8.055E-02
8.000E-01	2.889E-02	2.882E-02	7.074E-02
1.000E+00	2.797E-02	2.789E-02	6.358E-02
1.250E+00	2.675E-02	2.666E-02	5.687E-02
1.500E+00	2.557E-02	2.547E-02	5.175E-02
2.000E+00	2.359E-02	2.345E-02	4.447E-02
3.000E+00	2.076E-02	2.057E-02	3.581E-02
4.000E+00	1.894E-02	1.870E-02	3.079E-02
5.000E+00	1.770E-02	1.740E-02	2.751E-02
6.000E+00	1.683E-02	1.647E-02	2.522E-02
8.000E+00	1.571E-02	1.525E-02	2.225E-02
1.000E+01	1.506E-02	1.450E-02	2.045E-02
1.500E+01	1.434E-02	1.353E-02	1.810E-02
2.000E+01	1.415E-02	1.311E-02	1.705E-02

References

[1] Seltzer, S.M., *Air-Kerma-Rate Coefficients for Selected Photon-Emitting Radionuclide Sources*, National Institute of Standards and Technology publication NISTIR 7092A (2004).

[2] National Institute of Standards and Technology (NIST), 2012, *XCOM: Photon Cross Sections Database*, available online at http://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html.

[3] LNE-LNHB, Le Laboratoire National Henri Becquerel, Table of Radionuclides, http://www.nucleide.org/DDEP_WG/DDEPdata.htm.

[4] ENSDF, Evaluated Nuclear Structure Data File, National Nuclear Data Center, Chart of Nuclides, http://www.nndc.bnl.gov/.

[5] Boutillon M, Perroche-Roux AM. Re-evaluation of the W value for electrons in dry air. Phys. Med. Biol. 32, No 2: 213-219, 1987.

[6] Tables of x-ray mass attenuation coefficients and mass energy-absorption coefficients 1 keV to 20 MeV for elements Z = 1 to 92 and 48 additional substances of dosimetric interest, NISTIR 5632, J.H. Hubbell and S.M. Seltzer, May 2005, http://www,nist,gov/pml/data/xraycoef/.

[7] The physics of radiology, 4th Edition, Publisher Charles C. Thomas, Authors: Harold Elford Johns and John Robert Cunningham (1983).