NIST Technical Note 1864

Scaling of Testing Speed for Different Source-to-Detector Distances

B. Norman
A.L. Sallaska
L. Pibida

This publication is available free of charge from:
http://dx.doi.org/10.6028/NIST.TN.1864

National Institute of Standards and Technology
U.S. Department of Commerce

NIST Technical Note 1864

Scaling of Testing Speed for Different Source-to-Detector Distances

B. Norman
A.L. Sallaska
L. Pibida
Radiation Physics Division
Physical Measurement Laboratory

This publication is available free of charge from:
http://dx.doi.org/10.6028/NIST.TN.1864

February 2015

U.S. Department of Commerce
Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie May, Acting Under Secretary of Commerce for Standards and Technology and Acting Director

National Institute of Standards and Technology Technical Note 1864
Natl. Inst. Stand. Technol. Tech. Note 1864, 15 pages (February 2015)
CODEN: NTNOEF

This publication is available free of charge from:
http://dx.doi.org/10.6028/NIST.TN.1864

Scaling of Testing Speed for Different Source-to-Detector Distances

B. Norman, A.L. Sallaska, and L. Pibida

National Institute of Standards and Technology, Gaithersburg, MD 20899-8462

Abstract

Several American National Standard Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) and International Electrotechnical Commission (IEC) standards were developed for radiation detection systems used for homeland security applications and the detection of illicit trafficking of radioactive materials. These standards cover a wide range of tests, some of which require sources to pass by an instrument at a certain speed producing a fixed exposure rate at the distance of closest approach. Some also allow this distance to vary within a specified range. This work investigates the need to apply a scaling factor dependent on distance to the testing speed in order to compensate for the time that the instrument is exposed to the radiation field. It was observed that there is an increase in the instrument response, with factors ranging from 1.5 to 4, when sources are placed at farther distances while maintaining the same testing speed and the same exposure rate at the distance of closest approach between the source and the detector. When the speed is scaled, most of these differences are reduced to values of approximately ±20 %, within the measurement uncertainties. Measurements of alarm verification with speeds both scaled and unscaled were also performed. The alarm probability was observed to decrease significantly if the speed was not scaled.

Key words: *speed scaling; testing of RIDs; moving source, ANSI N42 standards for homeland security; IEC standards*

Introduction

Several American National Standard Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) and International Electrotechnical Commission (IEC) standards were developed for radiation detection systems used for homeland security applications and the detection of illicit trafficking of radioactive materials. Several of these standards are currently being revised or developed. These standards cover a wide range of radiation detection systems from small personal radiation detectors (PRDs), to large radiation portal monitors (RPMs). The main function of these detectors is to measure the magnitude of the radiation field (often expressed as exposure rate or ambient dose equivalent rate), and notify the user by means of an alarm of the presence of radiation and possible identification of the radionuclides present. These systems are not designed to provide a dose record to the user. In fact, some of the instruments only report the radiation field in units of counts per second or some unit-less type display.

These standards cover a wide range of requirements that are verified using well defined test methods. Some of these test methods require sources to pass by an instrument at a fixed speed. The sources are required to produce a fixed radiation field at the distance of closest approach between the instrument and the source (e.g., 50 µR/h, 10 µR/h, 5 µR/h)[1], while allowing for the source-to-detector distance to change within a certain range (e.g., 0.8 m to 1.2 m or 1 m to 3 m). Allowing for such variation in the testing distance creates differences in the radiation fields seen by the instruments. If the instrument is tested with a larger source at a far-away distance, the probability of the instrument to detect such source is larger than testing the same instrument with a smaller source at a closer distance, due to the increased time the source spends in the instrument's field of view. This can cause different results depending on how the test was performed. In order to eliminate such dependence, the speed needs to be adjusted (or scaled), when testing at different distances. This will require the standards to set the requirements not only for a fixed speed, but also for a fixed testing distance. If the standard allows the testing distance to change within a certain range, then the speed needs to be scaled in order to maintain the same radiation field over the time that the instrument is exposed to the source.

During the revision of the ANSI/IEEE N42.34 [1] and IEC 62327 [2] standards for radionuclide identification devices (RIDs), there was concern regarding the necessity to scale the speed when testing the instruments using different sources placed at different distances. Therefore, this paper will summarize the calculations and measurements performed in order to clarify how the scaling of the speed as a function of the testing distance applies to instruments. In particular, the RIDs response is emphasized, as it will provide the information needed for the revision of the standards. Measurements of the effect of scaled and unscaled speeds on alarm response are also discussed.

Scaling calculation for testing speed

Most of the standards test the different types of radiation detection systems by passing a source in front of the instrument at a certain speed and verifying how many times the system alarms for a fixed number of trials. In addition, some standards require that the alarms are produced within a certain time period. This test is usually performed by requiring a radiation field of a certain exposure rate or ambient dose equivalent rate value. Setting up the radiation field based on this rate allows testing laboratories to use existing sources for a long period of time by changing the source-to-detector distance, minimizing the need to replace or purchase sources to perform the tests. In addition, some of the standards permit a range of testing distances, such as 1 m to 3 m or 0.8 m to 1.2 m. Restricting the source-to-detector distances limits the source activities that can be used for the tests.

---

[1] NIST does not endorse the use of non-SI units. This paper uses non-SI units because it addresses the requirements listed in the ANSI/IEEE published standards. The SI unit of exposure rate is C/kg/h where 1 mR/h = 2.58×10^{-7} C/kg/h.

If the testing speed is kept constant and the source-to-detector distances is changed within the suggested range in the standards, while the radiation field is kept unchanged at the reference point of the instrument, then the total exposure or ambient dose equivalent value measured by the instrument will be lower if the source is at the closer distance, see Figure 1. Therefore, the instrument is exposed to a stronger radiation field, above the instrument alarm threshold, for a longer period of time when the source is at a faraway distance. This can lead to differences in test results if testing is performed at different distances at different testing laboratories, where the instruments tested at the largest source-to-detector distances have the advantage.

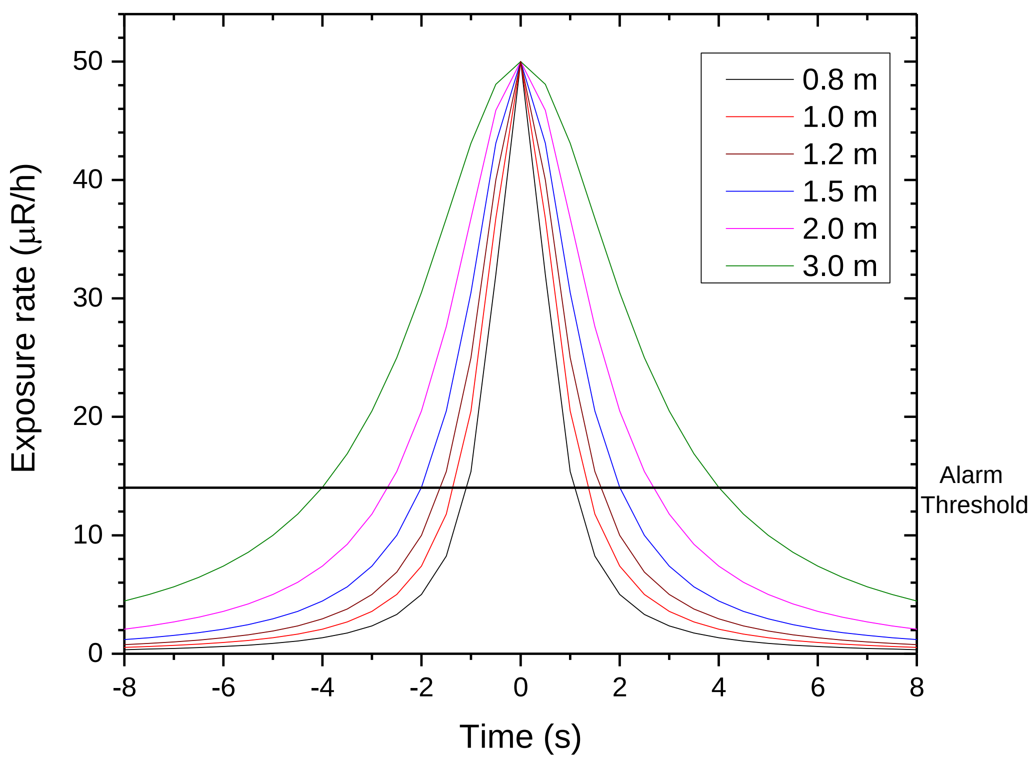

Figure 1: Calculated exposure rate profile as a function of time for a source moving at a speed of 1.2 m/s at different source-to-detector distances

As mentioned in the introduction, in order to address this issue, the standards need to specify the instrument performance requirement at a fixed distance and speed, allowing the source-to-detector distance to change within a range only if the source speed is scaled to cancel this effect. If the standard specifies the requirements at a speed, v_0, and a source-to-detector distance, d_0, and the test is performed at the source-to-detector distance, d, then testing speed shall be adjusted or scaled to a value, v, given by:

$$v = v_0 \times d/d_0 \,. \qquad (1)$$

Therefore, the exposure rate, $\dot{X}$, at the reference point of the instrument, at a distance *r*, is equal to

$$\dot{X} = 50\mu\mathrm{R/h}\,\frac{d^2}{r^2} = 50\mu\mathrm{R/h}\,\frac{d^2}{v^2\,t^2 + d^2}\,, \qquad (2)$$

where *v* is the source speed, *t* is the time, *d* is the distance of closest approach, and 50 µR/h is the exposure rate at the reference point of the instrument when the source is at the distance of closest approach, as shown in Figure 2.

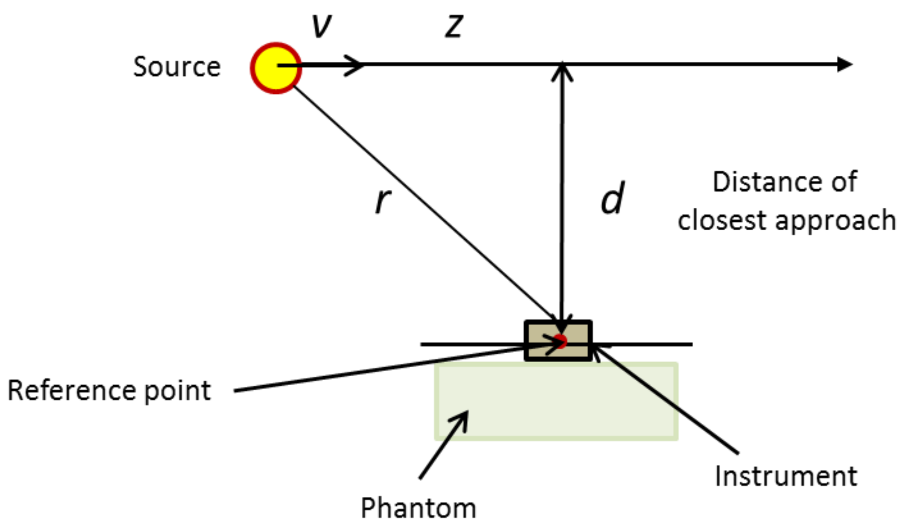

Figure 2: Diagram of source movement with an instrument mounted on a phantom

The total exposure, X, measured by the instrument is given by

$$X = \int_{-T/2}^{T/2} 50\mu\mathrm{R/h}\,\frac{d^2}{v^2\,t^2 + d^2}\,dt = 2\,\times\,50\mu\mathrm{R/h}\,\times\frac{d}{v}\,\left[\mathrm{atan}\left(\frac{Tv}{2d}\right)\right], \qquad (3)$$

where *T* is the integration time. The integration time is determined based on the instruments' requirements; it can be either given by the time it takes the instrument to alarm or the integration time of the instrument.

The following example illustrates the differences in the total radiation field measured by an instrument when exposed to a source that is moving at a speed of 1.2 m/s placed a different distances from the instrument. In general, the standards require the instrument alarms within 2 s from the time of maximum exposure. It is assumed that the source is moving in a direction that is perpendicular to the instrument, so the instrument will see the source approaching and the total radiation field measured will depend on the instrument integration time. For illustration purposes, an integration time is 4 s and an exposure rate at the distance of closest approach is 50 µR/h are assumed. If the standard allows the testing distance to vary between 1 m and 3 m, then the total radiation field measured by the instrument at 3 m will be 72 % larger than at a 1 m. If the standard allows the testing distance to vary between 0.8 m and 1.2 m, then the total integrated exposure measured by the instrument at 1.2 m will be 33 % larger than at a 0.8 m. Clearly, not scaling the speed has a significant effect on the test results.

Experimental setup

In order to illustrate this effect, measurements were performed with a multitude of sources (including the radionuclides, ^{241}Am, ^{133}Ba, ^{137}Cs, and ^{60}Co), at varying distances and speeds. For a given radionuclide and set of distances, *d* (see Figure 2), different source activities were chosen for a pair of sources in order to obtain the same radiation field at the reference point of the instruments at the distance of closest approach.

For all measurements, the figure-of-merit was the ratio of the instrument readings for a given radionuclide for sources placed at a pair of different distances (tested separately) and does not depend on the absolute value of the exposure rates. This quantity was used only to determine which source pairs yielded the same exposure rate at differing distances. Some of these exposure rate values (expressed in units of R/h), $\dot{X}$, were calculated using the point source approximation for a known source activity and encapsulation using [3, 4]:

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

where $\mu_{en}(E_i)$ is the mass energy-absorption in air, 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, A is the source activity, P_i is the probability per disintegration that a photon of energy E_i is emitted, and d is the source-to detector distance at the point of closest approach. The 114.1 value is expressed in units of R·s^2/m^2. The cut-off energy, δ, used for the exposure rate calculations was 40 keV.

Some of the exposure rate values were measured using a pressurised ionization chamber. The pressurized ionization chamber is a 25.4 cm diameter hollow stainless steel sphere with a 0.32 cm wall thickness containing pressurized argon at 25 atmospheres. This chamber is designed to measure exposure rates from background levels up to 100 R/h, with a known energy response for photons between 50 keV and 1.33 MeV.

Two different linear motion systems were used to cover a large range of speeds. For one system, the speed was set from a computer controlled motor. The computer control specifies the revolutions per minute of the motor, and the speed was determined using the measured calibration curve shown in Figure 3. The other linear motion system produces fixed speeds of 1.2 m/s and 2.2 m/s.

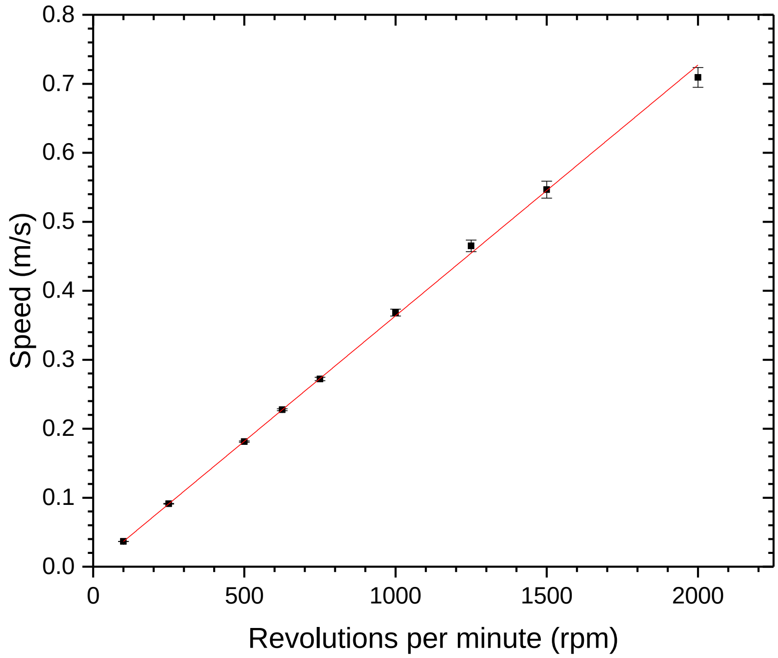

Figure 3: Speed calibration of the linear motion system

Scaling measurements

Several instruments were used to evaluate the response to scaling. The instruments included: one spectroscopic radiation portal monitor (SRPM), one backpack-type radiation detector (BRD), five radionuclide identification devices (RIDs), and one personal radiation detector (PRD). While maintaining the same exposure rate at the distance of closest approach between the source and instrument, several combinations of sources, speeds, and distances were used to assess instrument response when testing at different distances, while for two Cases:

1. Maintaining the same speed at each distance,
2. Scaling the speed for one source at a given distance, using Equation 1.

Different exposure rates values, produced by each of the four radionuclides (^{241}Am, ^{133}Ba, ^{137}Cs, ^{60}Co), were used in order to determine if there were any effects in the instrument response with the radiation field strength.

Table 1 lists the different test configurations used to measure the instrument response for both Case 1 and 2. The ratio of the maximum value of the instruments' readings for the two testing distances is listed and is plotted in Figure 4. Some short distances were chosen as the geometrical effect could be larger, potentially increasing the differences in the instrument response when scaling is applied to the testing speed. From Figure 4, it can be observed that regardless of the type of instrument under test, the measured exposure rate is larger when the source is placed at a faraway distance while maintaining the same exposure rate at the distance of closest approach. These differences varied between approximately a factor 1.5 and 4.

Table 1: List of test configurations used for the measurements and the ratio of exposure rates measured by the instruments at a distance *d* relative to distance d_o. The exposure rate, $\dot{X}_\delta$, produced by each source is determined at the distance of closest approach.

<table>
<tr><th>Instrument</th><th>Source</th><th>Exposure rate, $\dot{X}_\delta$ (μR/h)</th><th>d_0 (m)</th><th>*d* (m)</th><th>*v* (m/s)</th><th colspan="2">Case 1: Ratio without scaling</th></tr>
<tr><td>SRPM</td><td>^{133}Ba</td><td>35</td><td>0.25</td><td>0.65</td><td>2.2</td><td colspan="2">3.37 ± 0.99</td></tr>
<tr><td>SRPM</td><td>^{133}Ba</td><td>35</td><td>0.25</td><td>0.65</td><td>1.2</td><td colspan="2">2.73 ± 0.71</td></tr>
<tr><td>SRPM</td><td>^{137}Cs</td><td>17</td><td>0.50</td><td>1.20</td><td>2.2</td><td colspan="2">2.14 ± 0.57</td></tr>
<tr><td>SRPM</td><td>^{137}Cs</td><td>17</td><td>0.50</td><td>1.20</td><td>1.2</td><td colspan="2">1.66 ± 0.27</td></tr>
<tr><td>SRPM</td><td>^{60}Co (1)</td><td>42</td><td>0.25</td><td>0.95</td><td>2.2</td><td colspan="2">3.85 ± 0.95</td></tr>
<tr><td>SRPM</td><td>^{60}Co (1)</td><td>42</td><td>0.25</td><td>0.95</td><td>1.2</td><td colspan="2">3.59 ± 0.65</td></tr>
<tr><td>SRPM</td><td>^{60}Co (2)</td><td>38</td><td>0.50</td><td>1.00</td><td>2.2</td><td colspan="2">2.01 ± 0.46</td></tr>
<tr><td>SRPM</td><td>^{60}Co (2)</td><td>38</td><td>0.50</td><td>1.00</td><td>1.2</td><td colspan="2">1.57 ± 0.29</td></tr>
<tr><td>BRD</td><td>^{133}Ba</td><td>35</td><td>0.25</td><td>0.65</td><td>2.2</td><td colspan="2">3.53 ± 0.60</td></tr>
<tr><td>BRD</td><td>^{133}Ba</td><td>35</td><td>0.25</td><td>0.65</td><td>1.2</td><td colspan="2">3.26 ± 0.38</td></tr>
<tr><td>BRD</td><td>^{137}Cs</td><td>17</td><td>0.50</td><td>1.20</td><td>2.2</td><td colspan="2">2.53 ± 0.28</td></tr>
<tr><td>BRD</td><td>^{137}Cs</td><td>17</td><td>0.50</td><td>1.20</td><td>1.2</td><td colspan="2">2.41 ± 0.25</td></tr>
<tr><td>BRD</td><td>^{60}Co (1)</td><td>42</td><td>0.25</td><td>0.95</td><td>2.2</td><td colspan="2">4.27 ± 0.60</td></tr>
<tr><td>BRD</td><td>^{60}Co (1)</td><td>42</td><td>0.25</td><td>0.95</td><td>1.2</td><td colspan="2">4.19 ± 0.56</td></tr>
<tr><td>BRD</td><td>^{60}Co (2)</td><td>38</td><td>0.50</td><td>1.00</td><td>2.2</td><td colspan="2">2.24 ± 0.23</td></tr>
<tr><td>BRD</td><td>^{60}Co (2)</td><td>38</td><td>0.50</td><td>1.00</td><td>1.2</td><td colspan="2">2.19 ± 0.21</td></tr>
<tr><td>RID 1</td><td>^{133}Ba</td><td>35</td><td>0.25</td><td>0.65</td><td>2.2</td><td colspan="2">1.68 ± 0.40</td></tr>
<tr><td>RID 1</td><td>^{133}Ba</td><td>35</td><td>0.25</td><td>0.65</td><td>1.2</td><td colspan="2">1.50 ± 0.33</td></tr>
<tr><td>PRD</td><td>^{133}Ba</td><td>35</td><td>0.25</td><td>0.65</td><td>1.2</td><td colspan="2">2.09 ± 0.74</td></tr>
<tr><th>Instrument</th><th>Source</th><th>Exposure rate, $\dot{X}_\delta$ (μR/h))</th><th>d_0 (m)</th><th>*d* (m)</th><th>V_0 (m/s)</th><th>*v* (m/s)</th><th>Case 2: Ratio with scaling</th></tr>
<tr><td>SRPM</td><td>^{60}Co (1)</td><td>45</td><td>0.25</td><td>0.46</td><td>1.2</td><td>2.2</td><td>1.42 ± 0.33</td></tr>
<tr><td>SRPM</td><td>^{60}Co (2)</td><td>42</td><td>0.50</td><td>0.92</td><td>1.2</td><td>2.2</td><td>1.26 ± 0.24</td></tr>
<tr><td>BRD</td><td>^{60}Co (1)</td><td>45</td><td>0.25</td><td>0.46</td><td>1.2</td><td>2.2</td><td>1.29 ± 0.19</td></tr>
<tr><td>BRD</td><td>^{60}Co (2)</td><td>42</td><td>0.50</td><td>0.92</td><td>1.2</td><td>2.2</td><td>1.40 ± 0.14</td></tr>
</table>

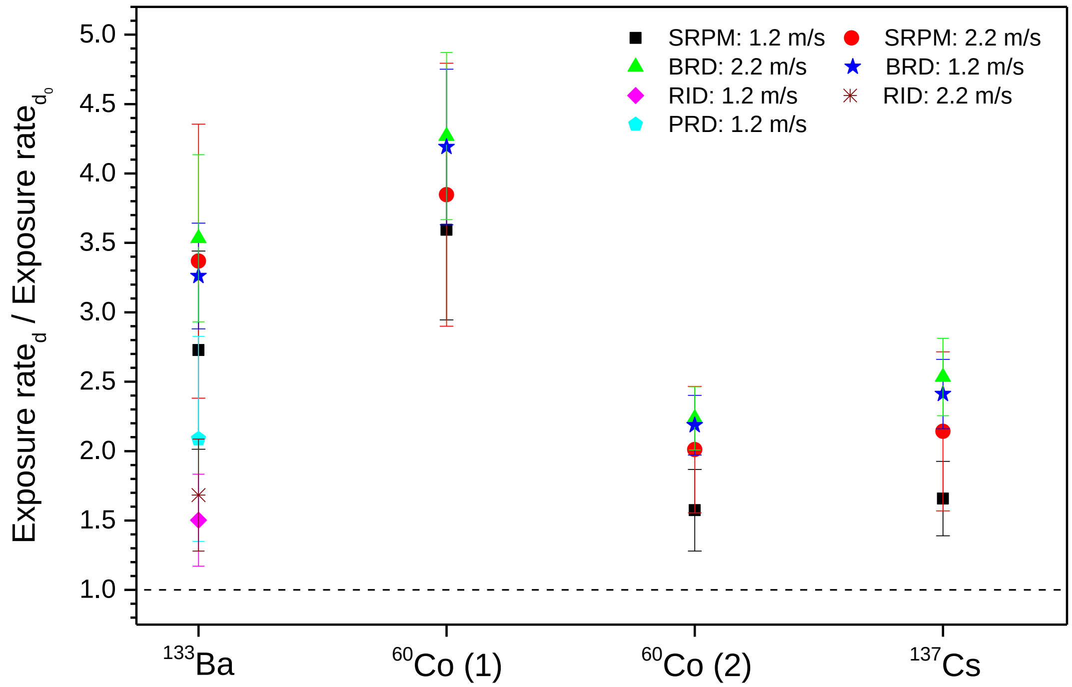

Figure 4: Exposure rate ratio measurements for different sources measured at two speeds and two distances for different types of instruments. Speed values are not scaled for the different testing distances. The exposure rate, $\dot{X}_\delta$, at the distance of closest approach produced by each source is kept constant (within ±20 %).

Additional measurements were performed using the RIDs in order to assess the effects on this particular type of instruments. The test configurations used for these measurements are listed in Table 2. For most cases the determination of the exposure rate was performed by calculation (using Equation 4), for some it was measured using the pressurized ionization chamber (these cases are marked in Table 2). When the speed is scaled using Equation 1, most of the ratios between the measurements at the different distances are approximately within ±20 %, see Figure 5.

Table 2: List of test configurations used for the RIDs measurements and the ratio of the exposure rates measured by the RIDs at a distance *d* relative to distance d_o. The exposure rate, $\dot{X}_\delta$, produced by each source is determined at the distance of closest approach.

Instrument	Source	Exposure rate, $\dot{X}_\delta$ (µR/h)	d_0 (m)	*d* (m)	*v* (m/s)	Case 1: Ratio without scaling	
RID 2	^{133}Ba (1)	35	0.25	0.65	0.5	2.01 ± 0.23	
RID 2	^{137}Cs (2)	17	0.50	1.20	0.5	1.94 ± 0.38	
RID 2	^{60}Co (1)	40	0.50	1.00	0.5	1.80 ± 0.23	
RID 2	^{60}Co (1)	40	0.25	0.95	0.5	2.24 ± 0.48	
Instrument	**Source**	**Exposure rate, $\dot{X}_\delta$ (µR/h)**	**d_0 (m)**	***d* (m)**	**V_0 (m/s)**	***v* (m/s)**	**Case 2: Ratio with scaling**
RID 1*	^{241}Am	55	0.30	0.71	0.21	0.50	0.99 ± 0.11

RID 1	^{133}Ba (1)	35	0.25	0.65	0.50	1.3	1.15 ± 0.16
RID 1*	^{133}Ba (2)	61	0.50	0.92	1.20	2.20	0.92 ± 0.17
RID 1	^{137}Cs (1)	17	0.50	1.20	0.50	1.20	0.73 ± 0.16
RID 1	^{137}Cs (2)	17	0.50	1.20	0.21	0.50	0.92 ± 0.19
RID 1†	^{137}Cs (3)	48	0.80	3.00	0.13	0.50	0.82 ± 0.11
RID 1	^{60}Co (1)	40	0.50	1.00	0.50	1.00	0.96 ± 0.21
RID 1	^{60}Co (2)	40	0.50	1.00	0.25	0.50	0.92 ± 0.16
RID 1	^{60}Co (3)	40	0.25	0.95	0.13	0.50	0.71 ± 0.11
RID 1†	^{60}Co (4)	58	0.80	2.66	0.15	0.50	0.94 ± 0.11
RID 2	^{133}Ba (1)	35	0.25	0.65	0.50	1.3	1.11 ± 0.15
RID 2	^{137}Cs (1)	17	0.50	1.20	0.50	1.20	1.38 ± 0.32
RID 2	^{137}Cs (2)	17	0.50	1.20	0.21	0.50	1.13 ± 0.20
RID 2	^{60}Co (1)	40	0.50	1.00	0.50	1.00	1.10 ± 0.19
RID 2	^{60}Co (2)	40	0.50	1.00	0.25	0.50	1.14 ± 0.14
RID 2	^{60}Co (3)	40	0.25	0.95	0.13	0.50	1.15 ± 0.16
RID 3*	^{241}Am	55	0.30	0.71	0.21	0.50	1.40 ± 0.17
RID 3	^{133}Ba (1)	35	0.25	0.65	0.50	1.3	1.08 ± 0.20
RID 3*	^{133}Ba (2)	61	0.50	0.92	1.20	2.20	1.14 ± 0.27
RID 3	^{137}Cs (1)	17	0.50	1.20	0.50	1.20	0.76 ± 0.15
RID 3	^{137}Cs (2)	17	0.50	1.20	0.21	0.50	1.11 ± 0.15
RID 3†	^{137}Cs (3)	48	0.80	3.00	0.13	0.50	1.00 ± 0.13
RID 3	^{60}Co (1)	40	0.50	1.00	0.50	1.00	1.07 ± 0.20
RID 3	^{60}Co (2)	40	0.50	1.00	0.25	0.50	1.10 ± 0.14
RID 3	^{60}Co (3)	40	0.25	0.95	0.13	0.50	1.12 ± 0.13
RID 3†	^{60}Co (4)	58	0.80	2.66	0.15	0.50	1.01 ± 0.13
RID 4*	^{241}Am	55	0.30	0.71	0.21	0.50	1.31 ± 0.14
RID 4	^{133}Ba (1)	35	0.25	0.65	0.50	1.3	1.15 ±0.11
RID 4*	^{133}Ba (2)	61	0.50	0.92	1.20	2.20	1.11 ± 0.12
RID 4	^{137}Cs (1)	17	0.50	1.20	0.50	1.20	1.43 ± 0.17
RID 4	^{137}Cs (2)	17	0.50	1.20	0.21	0.50	1.09 ± 0.12
RID 4†	^{137}Cs (3)	48	0.80	3.00	0.13	0.50	0.97 ± 0.10
RID 4	^{60}Co (1)	40	0.50	1.00	0.50	1.00	1.05 ± 0.11
RID 4	^{60}Co (2)	40	0.50	1.00	0.25	0.50	1.10 ± 0.12
RID 4	^{60}Co (3)	40	0.25	0.95	0.13	0.50	1.23 ± 0.13
RID 4†	^{60}Co (4)	58	0.80	2.66	0.15	0.50	0.99 ± 0.09
RID 5	^{133}Ba (1)	35	0.25	0.65	0.50	1.3	1.02 ± 0.18
RID 5	^{137}Cs (1)	17	0.50	1.20	0.50	1.20	1.41 ± 0.57
RID 5	^{137}Cs (2)	17	0.50	1.20	0.21	0.50	0.94 ± 0.42
RID 5	^{60}Co (1)	40	0.50	1.00	0.50	1.00	1.06 ± 0.33
RID 5	^{60}Co (2)	40	0.50	1.00	0.25	0.50	1.18 ± 0.25
RID 5	^{60}Co (3)	40	0.25	0.95	0.13	0.50	1.13 ± 0.24

* exposure rates measured at both distances
† exposure rate calculated for close distances and measured for farther distances

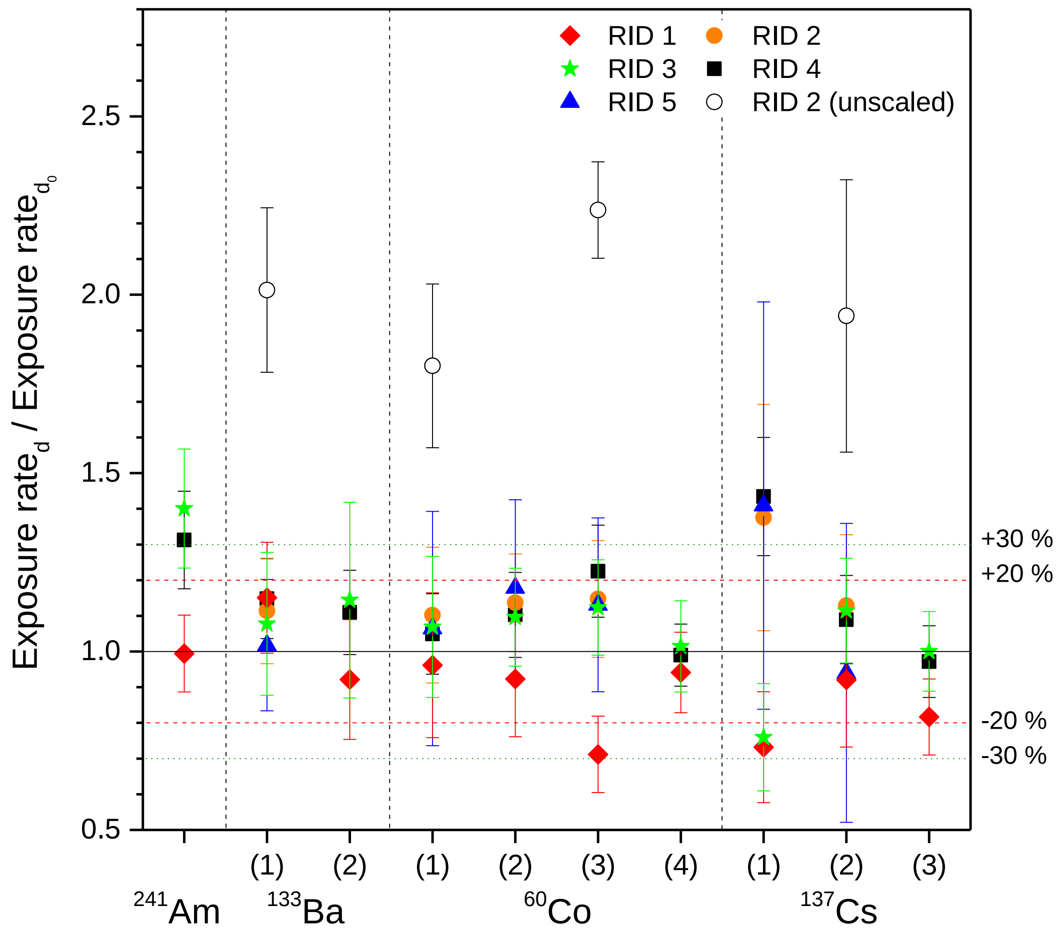

Figure 5: Ratio of exposure rate measurements for scaled and unscaled testing speeds for the different RIDs. Uncertainty bars represent combined uncertainties, as described in the text.

For each source, the background was subtracted, and the statistical uncertainty is the standard deviation of 10 readings for each instrument. Each reading was normalized to its calculated or measured exposure rate value in order to account for small differences in expected exposure rates due to the sources that were available. The absolute value of the exposure rate is eliminated when calculating the ratio. The maximum difference in exposure rates for source pairs was less than 8 % in all cases, with the exception of ^{137}Cs pair number (3) (see Table 2 and Figure 5) in which the difference was 17 %. Uncertainties were added in quadrature to include a ±5 % uncertainty on each source activity (for calculated exposure rates), the exposure rate measurement (if measurements were used), and the uncertainty in the positioning of the instruments. The uncertainty for the exposure rate measurements vary between 3 % and 9 %, depending on the calibration uncertainty for the different photon energies.

For the SRPM and BRD the uncertainty in the distance, *d,* was determined to be 1 cm, as these instruments were quite large and difficult to accurately position. For PRD and the RIDs the uncertainty in the distance was estimated to be 0.5 cm, as the positioning of the smaller instruments can be more precise. These values were used to combine the uncertainty in quadrature for each source and testing distance.

From Figure 4 and Figure 5 it can be observed that the ratio between the instrument readings at two different testing distances can vary between 1.5 and 4.3. These differences were observed for different types of instruments, including PRDs, RIDs, BRDs, and SRPMs. When scaling is applied to the speed, using Equation 1, the ratio between the instrument readings at two different testing distances varies between 0.7 and 1.4 (while maintaining the same radiation field at the distance of closest approach in both cases). These differences suggest the need to use a scaling factor in order to ensure that testing with different source configurations should achieve similar results. Most of the scaled values show ratios that are within ±20 % from the expected value. These variations are expected due to the different uncertainty components that are involved in the setup and measurements using these different types of instruments. There does not seem to be a correlation between the ratios and testing distances. Further testing distances do not reduce the value of the ratios for the instrument readings when the speed is scaled (e.g., for ^{133}Ba measurements were performed between 25 cm and 92 cm and for ^{137}Cs between 50 cm and 300 cm). At closer distances, the ratios of the instruments' readings seem to be larger when the speed is not scaled. Smaller radiation fields lead to larger uncertainty values and larger differences in the scaled ratios.

Alarm response verification

The RID 1 instrument was used to verify the alarm response for the scaled and unscaled speeds, as the exposure rate measurements showed the same type of response for all RIDs. For these measurements the RID dose rate measurements were used to setup the testing fields of ^{133}Ba and ^{137}Cs sources. The test configurations used for these measurements are listed in Table 3. For each source, the measured dose rates for both testing distances are the same within the measured uncertainty. The dose rate was measured by placing (statically) each of the sources in front of the RID 1 at the distance of closest approach, *d*. The source speeds, *v,* used were unscaled and scaled (using Equation 1).

The RID 1 alarm threshold was adjusted based on the maximum dose rate readings measured when the source was moving in front of the RID; values are shown in Table 3. The alarm threshold was adjusted for these measurements because the ANSI standards' testing is performed at radiation fields close to the value of the instruments' threshold. For each test configuration, a total of 50 trials were performed to reduce the uncertainty of the measurements in determining of the probability of alarm, with the associated 95 % lower and upper confidence interval. Results are shown in Table 4. From this table, for the ^{133}Ba source, it can be observed if the dose rate and speed were kept the same and the testing distance was changed (2 different source activities were used), the probability of alarm was reduced from 100 % at the faraway distance to 10 % at the closest distance. If the source speed was scaled using Equation 1 for the closer distance, then the probability of alarm increased back to 100 % as that obtained for the faraway distance. Similar behavior was observed for the ^{137}Cs source. In this case, the alarm probability was reduced from 88 % to 50 % when the speed was not scaled. When the speed was scaled, the alarm probability was equal to 82 %, which is statistically indistinguishable from the original 88 % based on the measured 95 % lower and upper confidence bounds.

Table 3: List of test configurations used for the RIDs alarm verification measurements

Instrument	Source	Dose rate (mrem/h)	*d* (m)	*v* (m/s)	Alarm threshold (mrem/h)	Dose rate moving source (mrem/h)
RID 1	^{133}Ba	0.0795 ± 0.0008	0.65	0.5	0.65	0.073 ± 0.004
RID 1	^{133}Ba	0.0798 ± 0.0007	0.288	0.5	0.65	0.057 ± 0.009
RID 1*	^{133}Ba	0.0798 ± 0.0007	0.288	0.22	0.65	0.071 ± 0.004
RID 1	^{137}Cs	0.0263 ± 0.0007	1.20	0.5	0.20	0.022 ± 0.002
RID 1	^{137}Cs	0.0260 ± 0.0006	0.561	0.5	0.20	0.020 ± 0.003
RID 1*	^{137}Cs	0.0260 ± 0.0006	0.561	0.23	0.20	0.021 ± 0.002
* Scaled speed						

Table 4: List of test configurations used for the RIDs alarm verification measurements and test results

Instrument	Source	*d* (m)	*v* (m/s)	Alarm threshold (mrem/h)	Probability of alarm (%)	95 % Confidence Interval	
						Lower	Upper
RID 1	^{133}Ba	0.65	0.5	0.65	100.00	92.87	100.00
RID 1	^{133}Ba	0.288	0.5	0.65	10.00	4.35	21.36
RID 1*	^{133}Ba	0.288	0.22	0.65	100.00	92.87	100.00
RID 1	^{137}Cs	1.20	0.5	0.20	88.00	76.20	94.38
RID 1	^{137}Cs	0.561	0.5	0.20	50.00	36.64	63.36
RID 1*	^{137}Cs	0.561	0.23	0.20	82.00	69.20	90.23
* Scaled speed							

Conclusions

The measurements performed with the different types of instruments, in particular with the RIDs, show that there is a significant increase in the instrument response (factors ranging from 1.5 to 4) when sources are placed at farther distances while maintaining the same testing speed and the same exposure rate at the distance of closest approach between the source and the detector. When scaling is applied to the speed, most of these differences are reduced to values of approximately ±20 %. From the alarm response measurements, it is clear that the probability of alarm is reduced if different testing distances are used while maintaining the same radiation field and source speed. When the speed is scaled, the probability of alarm at the closer distance matches that of the faraway distance. Per these results, it is recommended to define the requirements in the standards at a fixed distance, speed, and exposure rate at the distance of closest approach, reducing the uncertainty in the measurements and having better reproducibility of the radiation fields between different testing laboratories. The standard can also allow the testing laboratories to use a different testing distance if they do not possess the required source as specified by the standard's requirement and if they have the ability to scale the speed in order to account for the differences in the testing geometry. If the speed is scaled, there seems to be no need to specify a range for the testing distances, as the ratio of the exposure rates seems to be independent of the testing distances for distances between 25 cm and 300 cm.

Acknowledgments

The authors would like to thank the Department of Homeland Security (DHS) Domestic Nuclear Detection Office (DNDO) for funding this work.

References

[1] ANSI/IEEE N42.34-2006, "American National Standard Performance Criteria for Hand-Held Instruments for the Detection and Identification of Radionuclides."

[2] IEC-62327-2006, "Radiation protection instrumentation - Hand-held instruments for the detection and identification of radionuclides and for the indication of ambient dose equivalent rate from photon radiation."

[3] Seltzer S. Air-kerma rate coefficients for selected photon-emitting radionuclide sources. Gaithersburg, MD: National Institute of Standards and Technology; Report No. NISTIR 7092A; 2004.

[4] Johns HE, Cunningham JR. The physics of radiology. Springfield, IL: Charles C. Thomas Publisher; 1983.