Dynamic qualification tests of radiation measurement equipment – Using the D3S as an example of a wearable RIID for homeland security

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1 ABSTRACT

Radiation measuring instruments find a wide range of applications in the field of nuclear material management. They are used in areas ranging from nuclear safeguards and nuclear security as well as the field of homeland security, up to the growing contributions of nuclear techniques to sustainable development around the world. These systems are needed to fulfill different tasks such as monitoring, detecting, identifying and qualifying. One common element independent from the task is the need to gain reliable results. In order not to rely only on information given by the manufacturer concerning the performance and reliability of the device, tests results gained by third parties are necessary.

Qualification tests can be performed against consensus standards for reproducibility independent of the testing location. Fraunhofer INT has conceived and built the QuTeSt test environment (**Qu**alification **Te**st **S**ys**t**em for radiation detection devices) to perform the corresponding dynamic and static test measurements using neutron and gamma sources.

In the previous years the static part of QuTeSt was introduced and results gained during testing of radionuclide identification devices (RIID) as well as personal radiation dosimeters (PRD) were presented. The displayed readings are required to assess the situation also when approaching a measurement situation. Identification results produced while moving to or through a scene sometimes are very confusing and may not be correct, so that a closer examination of the influence of dynamic effects on identification results is necessary. However, these measurements are not static but of course dynamic which shows the need for dynamic qualification tests also for handheld devices like RIIDs and PRDs and not only for radiation portal monitors (RPM).

This paper deals with the dynamic part of the Fraunhofer INT QuTeSt. A battery powered automated trolley runs on a rail system and moves radioactive sources by the device to be tested. The system was recently upgraded to perform tests for vehicle RPMs. Experiences gained with the dynamic system as well as first investigations with handheld devices like the D3S from Kromek are presented.

Key words: test procedure for nuclear and radioactive measurement devices, illicit trafficking, qualification tests, dynamic test, gamma sources, D3S, RIID, PRD, SPRD

2 INTRODUCTION

In [1] and [2] accuracy tests obtained with the D3S were presented. These tests were performed using a static test system. The normal use of a handheld device is not static but in motion which indicates the need for dynamic tests. For reasons of practicability, the sources are moved during testing instead of the measurement devices. The common test methods specify dynamic tests mainly for time to alarm tests (see section 4). Some results according to the test methods as well as further test results that provide a more comprehensive view of the performance of the device and the limitations of the test procedures are presented in the paper.

3 Dynamic Test System

The dynamic test system is shown in Figure 1. It consists of a battery powered automated trolley which runs on a rail system mounted on oriented strand boards. According to the given standards the velocity can be chosen like needed from 0.02 m/s to at least 2.2 m/s. The source can be positioned vertically up to a height of 4.5 m.

Figure 1: Dynamic test system with neutron source behind HPDE shielding, see arrow.

For testing RIIDs or PRDs the horizontal position of the source has to be changed in order to set the dose rate. For these tests, the source is mounted on an extension bar and can be moved horizontally and thus the dose rate can be easily adjusted. The dynamic system is completed with a video system for observation and documentation of the measurement results and with the control system of the trolley (see Figure 2).

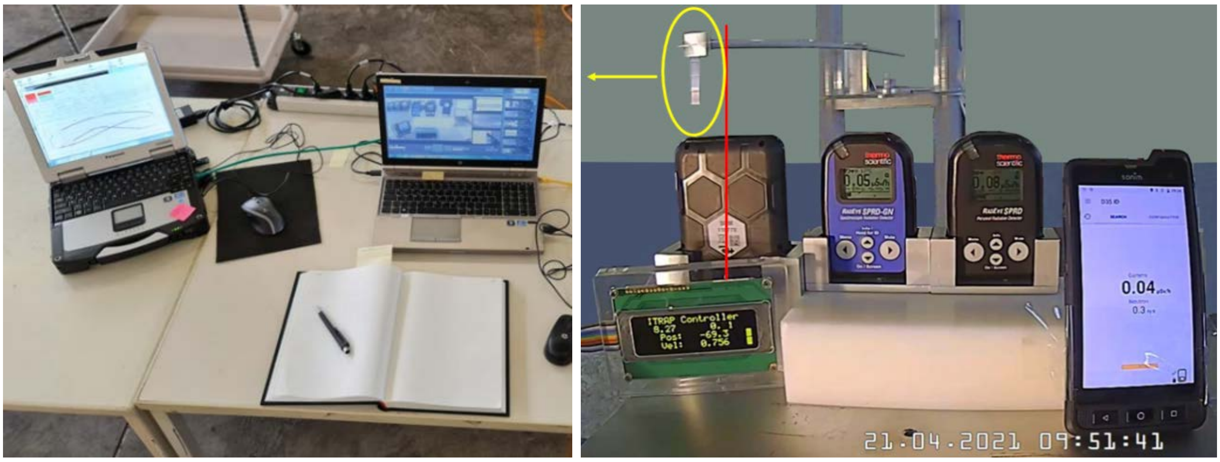

Figure 2: <u>Left</u>: Laptop for operation of the source trolley and laptop with video system. <u>Right:</u> Screenshot of the video observation of handheld devices placed for performing dynamic tests. The source (yellow ellipse), is moving to the left. The red line indicates the zero position. The control display is below the source.

In the right part of Figure 2 an example of a screenshot from a test with handheld devices is given. The source is moving as indicated by the direction of the yellow arrow. The display gives the time prior and after passing the zero position which is marked with the red line. The velocity is given as well. Three handheld devices are placed for tests, in the middle two RadEYE devices and the D3S consisting of the display part on the right and the detector part on the left at zero position.

4 TEST METHODS - STANDARD SPECIFICATIONS FOR HANDHELD DEVICES

Several test methods for qualification tests exists. The common test procedures are from the American National Standards Institute (ANSI), the International Electrotechnical Commission (IEC) or from the Illicit Trafficking Radiation Assessment Program initiated by the European Commission (ITRAP+10). An overview of the existing standards for Radionuclide Identification Devices (RIID), Personal Radiation Dosimeters (PRD) and Spectroscopic Personal Radiation Detectors (SPRD) is given in Table 1.

	ANSI	IEC	ITRAP+10
RIID	N42.34-2015 [3]	62327 [4]	[5]
PRD	N42.32-2016 [6]	62401 [7]	[8]
SPRD	N42.48-2018 [9]	62618 [10]	-

Table 1: Summary of standards and test methods for testing of handheld devices.

One of the tests which shall be performed is time to alarm testing. The following sections are dealing with the criteria given for neutron and gamma testing.

4.1 Time to Alarm Tests for Neutrons

All standards foresee ^{252}Cf sources for testing. The source strength shall be N_R = 20 000 n/s and the source shall be placed in a distance of d_0 = 25 cm. If the source does not have the count rate N_R the distance can be changed according to (1) to perform the test anyway.

$$d = \mathrm{d}_0 \times \sqrt{N_T/\mathrm{N}_\mathrm{R}} \quad (1)$$

The neutron source shall be surrounded by 4 cm of high-density polyethylene (HDPE). For all tests the device to be tested shall be placed on a phantom made of a polymethyl methacrylate (PMMA) to represent the situation of a measuring device worn on the body. Table 2 summarizes the specifications for the time to alarm tests for the different standards. For the different device classes the allowed time to alarm time and the number of trials which have to be fulfilled for passing the tests are given as well as the conditions for the tests. Partly the tests shall be performed with a step change, partly with a moving source using a dynamic test system.

In the RIID tests for ANSI and IEC, the source must pass the device to be tested; in the other tests with the dynamic system the source must move at a given velocity towards the position of closest approach and then stop. If the distance has to be changed, the stated velocity v_0 has to be changed within certain limits to v according to (2).

$$v = \mathrm{v}_0 \times d/\mathrm{d}_0 \quad (2)$$

Device class	ANSI			IEC			ITRAP +10		
	time [s]	conditions	trials	time [s]	conditions	trials	time [s]	conditions	trials
RIID	1	0.5 m/s source passes	9/10	2	0.5 m/s source passes	9/10	5	step change	29/30
PRD	5	1.2 m/s source stops at point of closest approach	19/20	5	1.2 m/s source stops at point of closest approach	8/10	5	step change	29/30
SPRD	5	1.2 m/s source stops at point of closest approach	19/20	20	step change	8/10	-	-	-

Table 2: Time to alarm specifications for neutron tests. The trials column gives the criterion for passing as well as the number of trials to be performed. All test to be performed with ^{252}Cf, 20 000 n/s, surrounded by 4 cm HDPE, in 25 cm distance. The device shall be on a PMMA phantom. Related standards see Table 1.

4.2 Time to Alarm Tests for Photons

The specifications for the time to alarm tests for photons are summarized in Table 3. All tests will use ^{241}Am, ^{137}Cs and ^{60}Co in nearly all cases with a dose rate of 0.5 µSv/h in the given distance d_0. Similar to the time to alarm tests for neutrons, only the ITRAP+10 and the IEC method of tests for photons for SPRDs foresee a step change. But in contrast to the neutron tests the dynamic tests all foresee a passing source.
The distance d_0 as well as the velocity v_0 for the dynamic tests are given. If the foreseen dose rate is not reached with the used sources the velocity has to be adjusted using (2) within certain limits.

Device class	ANSI			IEC			ITRAP +10		
	time [s]	conditions	trials	time [s]	conditions	trials	time [s]	conditions	trials
RIID	1	0.5 m/s 0.8 m -1.2 m	9/10	1	0.5 m/s 1 m	9/10	3	step change	29/30
PRD	2	1.2 m/s 1.5 m	19/20	2	1.2 m/s 1.5 m	19/20	2	step change	29/30
SPRD	2	1.2 m/s 1.5 m	19/20	3	step change	8/10	-	-	

Table 3: Time to alarm specifications for gamma tests. Tests to be performed with ^{241}Am, ^{137}Cs and ^{60}Co with 0.5 µSv/h except for ANSI RIID testing with 0.1 µSv/h. The conditions column gives v_0 and d_0 for dynamic tests or states a step change test. The trials column gives the criterion for passing as well as the number of trials to be performed. Related standards see Table 1.

4.3 Dynamic sensitivity to gamma and neutron radiation

The ITRAP+10 test method for PRDs has a separate dynamic testing part. With a dose rate equivalent of 0.5 µSv/h on the surface of the instrument at the distance of closest approach a source shall be passing by with a speed of 0.6 m/s. The sources ^{241}Am, ^{137}Cs and ^{60}Co shall be used. In addition, a 20 000 n/s ^{252}Cf source enclosed in 4 cm HDPE shall be passing by in 25 cm distance. 30 trials are foreseen and a device will pass the test if an alarm is generated in 29 out of 30 trials. The time to alarm is not specified.

5 TESTED DEVICE D3S

The D3S from Kromek [11] consist of two parts. The detection unit which can be worn on a belt and a smartphone for data collection and display. The D3S in the measurement situation is shown in Figure 2. Both are connected via Bluetooth. The detection unit has two detectors, a CsI crystal for gamma detection and a Lithium based one for neutron detection. The D3S can either function as a PRD device or as a RIID. Therefore, the different criteria for the different device classes have to be considered when testing.

6 TEST RESULTS

6.1 Dynamic sensitivity gamma and neutron

For all tests concerning the ITRAP+10 PRD dynamic sensitivity test (see section 4.3) the distance of the available sources was adjusted to generate 0.5 µSv/h. The source had a velocity of 0.6 m/s. In addition to the tests with the foreseen sources the available nuclides ^{133}Ba, ^{57}Co, ^{226}Ra and ^{232}Th were used to gain a more complete picture of the detector's performance. The number of the 30 trials in which an alarm was generated are given in Table 4 as well as the evaluation of whether the test was successful or not.

The tests for the gamma sources foreseen in ITRAP+10 were all successful. However, the test with ^{232}Th was not successful. In contrast to the specification from ITRAP+10 the test with the ^{252}Cf source had to be performed without HDPE surrounding the source. Therefore, the unsuccessful test would have to be taken as a need for further tests with HDPE in order to investigate the influence like observed for the tests shown in section 6.2.

Source kind	Nuclide	Alarm generated	Test successful
gamma	^{241}Am	29/30	yes
	^{133}Ba	30/30	yes
	^{57}Co	30/30	yes
	^{60}Co	30/30	yes
	^{137}Cs	30/30	yes
	^{226}Ra	30/30	yes
	^{232}Th	13/30	no
neutron	^{252}Cf	11/30	no

Table 4: Result of the dynamic sensitivity testing. The dose rate for the gamma sources was 0.5 µSv/h. The distance of the ^{252}Cf source was adjusted according to (1) and the device was mounted on a PMMA phantom. In all cases the velocity was 0.6 m/s.

6.2 Neutron tests

Only the ANSI and IEC tests for RIIDs foresee passing dynamic tests with a ^{252}Cf neutron source (see Table 2) for the time to alarm tests. According to (1) the distance of the neutron source was adapted to the given count rate of 13 800 n/s to 20.8 cm. The velocity was adapted according to (2) to 0.42 m/s. The detector part was fixed to the phantom and the display part placed next to the display in order to observe the temporal correlation. It was not possible to place the given 4 cm

HDPE around the source. Nevertheless, in order to carry out tests with HDPE, bricks of 5 cm thickness were placed in front of the D3S (see Figure 3).

The obtained results are given in Table 5. Without HDPE an alarm was generated only in 3 out of 20 trials. With 5 cm HDPE in front of the device an alarm was generated in all trials. This shows the great influence of the moderating HDPE. However, the tests cannot be rated as passed, as neither the time of 1 s to alarm foreseen by ANSI nor the time of 2 s foreseen by IEC are met in the required 9 out of 10 cases.

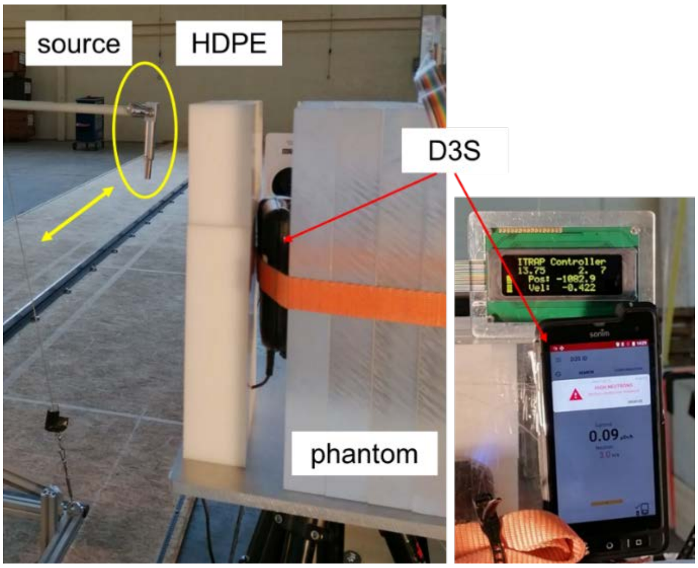

Figure 3: Setup for the neutron tests with HDPE. <u>Left:</u> D3S detector part mounted on the phantom. The source is moved along the yellow arrow. <u>Right:</u> Display part of the D3S and timer giving the time prior and after passing zero position, the reference point of the D3S.

HDPE	Alarm generated	Alarm < 2 s	Alarm < 1 s	Test successful	
				ANSI	IEC
no	3/10	1/10	0/10	no	no
5 cm	20/20	7/10	4/20	no	no

Table 5: Results obtained with ^{252}Cf at a distance of 20.8 cm and velocity of 0.42 m/s. Setup see Figure 3.

6.3 Gamma tests

The time to alarm tests for photons with a passing source foresee 0.5 µSv/h in 1.5 m distance with 1.2 m/s or in 1 m distance with 0.5 m/s (see Table 3). All available sources produce less than 0.5µSv/h at a distance of 1 m, so the speed must be adjusted with the changed distance according to (2). Therefore, the condition 1 m distance with 0.5 m/s, which is the condition of IEC and ANSI for RIIDs, was chosen. The results are listed in Table 6. The device passed the tests for the foreseen nuclides ^{241}Am, ^{60}Co and ^{137}Cs. The additional used nuclides ^{133}Ba and ^{226}Ra lead to a successful result too. Only in the case of ^{232}Th the alarm was only generated in 1 out of 10 cases within the specified 1 s. ^{232}Th is the only nuclide which belongs to the natural occurring decay chain. A possible explanation for the behavior could be that the source is initially identified as natural, which explains the time delay and demonstrates the need to expand testing to include more nuclides.

Nuclide	Alarm generated	Alarm < 1 s	Test successful
^{241}Am	10/10	10/10	yes
^{133}Ba	10/10	10/10	yes
^{60}Co	10/10	10/10	yes
^{137}Cs	10/10	10/10	yes
^{226}Ra	10/10	10/10	yes
^{232}Th	10/10	1/10	no

Table 6: Results obtained with gamma sources. Using (2) the individual velocities were adjusted to the distance in which 0.5 µSv/h is reached.

7 CONCLUSIONS AND FURTHER RECOMMENDATIONS

The specifications differ for different qualification tests and it is necessary to know exactly according to which standard you are testing in advance. In order to comply with the different specifications, you need a variety of sources. As the sources decay with a certain half-life it is not possible to have always all necessary sources for each test. This complicates the performance of qualification tests in general. As starting point to solve the problem for the neutron tests the ^{252}Cf with a half-life of only 2.6 years will be substituted in some test procedures with ^{244}Cm or ^{248}Cm with a half-life of 18.1 years or $3.4 \cdot 10^5$ years.

The neutron tests have shown the sensitivity of the device for thermal neutrons and therefore the need for a moderator for devices with neutron components that also have their sensitivity in the thermal range. Due to the heavy weight the HDPE cannot be placed around the source in our system which shows a necessity for modification and to study the influence of the position of the source.

The D3S passed most tests successfully except the neutron tests and the tests with ^{232}Th. The latter nuclide is not part of the test procedures. However, extending the tests for a more comprehensive evaluation of the tested device by including more nuclides makes the tests more complex and expensive. Nevertheless, every user should be aware that the test results reflect only a selection of measurement tasks and nuclides.

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