Comparison of CLYC vs. CsI in a hand-held detector

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Abstract— **The detection of radioactive and nuclear (RN) material is gaining importance due to the current political situation. Fast and reliable results from on-site measurements require devices to be transportable, quickly ready-for-use, and easily operable. This has driven the development of measurement devices based on materials which enable simultaneous detection of gammas and neutrons. A detector material with these properties is the scintillator Cs_2LiYCl_6:Ce (CLYC). It combines the characteristics of a medium resolution gamma ray detector like Sodium iodide (NaI) or Cesium iodide (CsI) and a ^{3}He proportional counter tube for the detection of neutrons. In this paper the performance of a CLYC based device was compared to one using a traditional scintillator. The exemplary study was carried out on the basis of two RadEYE devices from Thermo: the RadEye SPRD GN with a CLYC crystal and the RadEYE SPRD with a CsI crystal were compared regarding gamma detection. Moreover, the neutron detection capability of the CLYC device was investigated. Dynamic tests were performed using our qualification test system (QuTeSt). This allows repeatable tests with radioactive sources passing the device under test at controlled conditions. Applicable standards and test procedures for Radiation Isotope Identifiers (RIID) from the International Electrotechnical Commission (IEC), from the American National Standards Institute (ANSI), and those released during the ITRAP+10 program were applied. Several tests were performed using radioactive sources covering a wide energy range.**

Keywords —**Dynamic tests, CLYC, CsI, hand-held detector.**

I. INTRODUCTION

A wide variety of handheld systems for detection purpose exists. They can be assigned to different classes like Radiation Isotope Identifiers (RIID), Personal Radiation Detectors (PRD), or Spectroscopic version of PRDs (SPRD) which differ in their external appearance such as weight, size or shape, the measurement task, the measurement result output, which type of radioactivity they can detect, and also in the detector material used. In the present paper a comparison between different detector materials and their influence on the output is investigated. This is done by using handheld devices which should leave constant as many factors as possible. Two devices of the same kind but with different detector materials were chosen. The question to be answered in this paper is in particular: Do the two detector materials behave differently in identification and dynamic tests?

To answer this question, results have been obtained in tests according to International standards like International Electrotechnical Commission (IEC), American National Standards Institute (ANSI) or procedures established during the "Illicit Trafficking Radiation Assessment Program (ITRAP+10)" of the European Union. The Fraunhofer INT facility QuTeSt which had been developed in the framework of ITRAP+10 was used for these tests.

II. QUTEST

Mainly dynamic tests were performed in the framework of the current paper which were done using the dynamic test system part of the QuTeSt system [1].

In Fig. 1 an example of a screenshot of the video observation system during dynamic testing is given. The source is attached to an extension bar to get closer to the devices. The display gives the time prior and after passing the zero position: the point of closest approach at which the source is in front of the detector. The velocity of the source is given as well.

Fig. 1. RadEYE devices during testing. With the blue front the RadEYE SPRD GN with a CLYC crystal and with the black front the RadEYE SPRD equipped with a CsI crystal. The source at the extension bar is moving to the left. Below the source the control display is placed.

III. DYNAMIC TESTS FOR GAMMAS

Dynamic testing is foreseen in the time to alarm tests for gammas and neutrons. The specifications for the gamma testing are listed in Table I. The ITRAP+10 test method for PRDs has a separate dynamic testing part. With a dose rate equivalent of 0.5 µSv/h 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. 30 trials are foreseen and a device will pass the test if an alarm is generated in at least 29 out of 30 trials. The time to alarm is not specified.

TABLE I
TIME TO ALARM SPECIFICATIONS FOR GAMMAS

Device class	ANSI			IEC			ITRAP +10		
	[s]	conditions	trials	[s]	conditions	trials	[s]	conditions	trials
RIID	1	0.5 m/s 0.8-1.2 m	9/10	2	0.5 m/s 1 m	9/10	3	step change	29/30
PRD	2	1.2 m/s 1.5 m	19/20	5	1.2 m/s 1.5 m	8/10	2	step change	29/30
SPRD	2	1.2 m/s 1.5 m	19/20	20	step change	8/10	-	-	

All test to be performed with ^{241}Am, ^{60}Co, and ^{137}Cs with 0.5 µSv/h, except for the ANSI RIID testing with 0.1 µSv/h. In dynamic testing, the source passes the device. The first columns indicate the time within the alarm is to be generated. The conditions are 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.
ANSI values taken from [5], [6] and [7].
IEC values taken from [2], [3] and [4].
ITRAP+10 values taken from [8] and [9].

Only the dynamic tests within the ITRAP+10 do not foresee a specified distance d_0 for the source. In the other cases the distance for the given dose rate varies from 1 m to up to 1.5 m. To fulfill the criteria for tests according to different standards a greater variety of different source activities is necessary.

To achieve the foreseen dose rate equivalent at the point of closest approach with a limited number of sources, the distance d of the radiation source is adjusted. The dose rates are measured in a static measurement with a calibrated device. If the source used does not fulfill the foreseen criterion, the conditions can be changed. The change in the distance has to be compensated in the dynamic tests by changing the velocity v_0 stated in the standard (see Table I) to v using (1).

$$v = v_0 \times d/d_0 \tag{1}$$

IV. TEST DEVICES RADEYE SPRD AND RADEYE SPRD GN

The qualification tests were carried out using two hand-held devices of the same kind but with different detector materials. These are the spectroscopic personal radiation detector RadEYE devices from Thermo [10], [11]. The RadEYE SPRD is equipped with a CsI crystal and the RadEYE SPRD GN with a CLYC crystal. Due to the incorporated nuclear reaction ^{6}Li(n,t)α the latter enables the simultaneous measurement of gammas and neutrons. Table II gives an overview of the crystal related specifications. The Cesium iodide crystal is a bit larger and has a larger surface than the CLYC detector. Fig. 2 shows the relative energy response for the two devices as given in the manufacturer manuals.

TABLE II
SPECIFICATIONS OF RADEYE SPRD AND RADEYE SPRD GN

		RadEYE SPRD	RadEYE SPRD GN
			
crystal	material	CsI	CLYC
	volume [cm^3]	6.8	4.8
	front face	∅: 1.6 cm	1.25 cm x 1.25 cm
	can detect	gamma	gamma und neutron

Information taken from the manuals [10], [11].

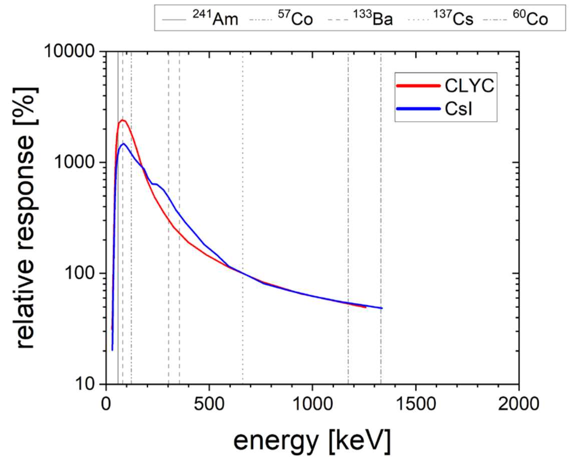

Fig. 2. Energy response for CLYC in red and CsI in blue taken from the instruction manuals of the devices given by Thermo [10], [11]. The response is given relative to the response for ^{137}Cs which is set to 100 % at the corresponding energy line of 661.6 keV. In addition, the positions of the prominent energy lines of the relevant nuclides are added as indicated in the figure.

V. STATIC IDENTIFICATION MEASUREMENTS – SIMULTANEOUS NUCLIDES

In order to evaluate the performance concerning identification, static measurements with ^{137}Cs, ^{60}Co, ^{133}Ba, and ^{152}Eu were carried out. These nuclides were chosen to cover the whole energy region in which the crystals are sensitive. The sources were measured one by one and in combination. In a first set of measurements the sources were placed in a distance in which each lead to a dose rate of 0.5 µSv/h like it is foreseen for the dynamic testing. Unfortunately, except for ^{133}Ba, the dose rates were too low to obtain an identification result. Therefore, the sources were moved closer and showed in the single measurements 1.5 µSv/h ^{60}Co, 0.9 µSv/h ^{137}Cs, 0.7 µSv/h ^{152}Eu, and 0.4 µSv/h ^{133}Ba. Fig. 3 a) and b) show the gamma spectra for the nuclides measured in combination. For comparison purpose a gamma spectrum obtained with a Ge detector is given in a). The one obtained with the CLYC containing RadEYE SPRD GN is given in red in b) and the

RadEYE SPRD with the CsI in blue in b) too. There is a difference in the count height due to the different crystal sizes. The shape of the ^{60}Co peaks is different and worse for the CLYC compared to CsI. The lines for ^{137}Cs are similar. In addition, the lines from ^{133}Ba with lower energies and for ^{152}Eu in the whole energy region are marked.

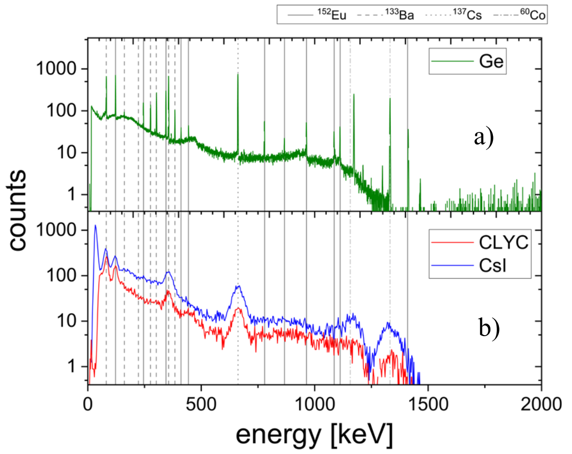

Fig. 3. Simultaneous measurement of 1.5 µSv/h ^{60}Co, 0.9 µSv/h ^{137}Cs, 0.7 µSv/h ^{152}Eu, and 0.4 µSv/h ^{133}Ba. The corresponding energy lines are marked like indicated. a) Spectra obtained with a germanium detector, b) spectra obtained with RadEYE SPRD with CsI in blue and with RadEYE SPRD GN with CLYC in red.

Both devices were used in the ratemeter mode. The identification results from the single source measurements for the RadEYE SPRD with CsI yielded always the correct result. The RadEYE SPRD GN was correct for the ^{133}Ba and the ^{152}Eu. The ^{137}Cs measurements indicated always the correct nuclide, but the result was partly uncertain. On the other hand, the measurement with the ^{60}Co instead never indicated ^{60}Co which reflects the poor quality of the peaks in the spectrum. The combined task was not fulfilled by both devices. Surprisingly, however, the combined measurements with the RadEYE SPRD GN also identified ^{60}Co. All results obtained in 3 respectively 4 measurements are listed in Table III.

TABLE III
COMBINED IDENTIFICATION MEASUREMENTS

nuclide	RadEYE SPRD GN CLYC			RadEYE SPRD CsI			
	70 s	95 s	100 s	50 s	50 s	50 s	50 s
^{60}Co	x	x	x	x	x	x	x
^{137}Cs	x	-	-	x	x	x	x
^{133}Ba	-	-	-	-	x	x	-
^{152}Eu	-	x	x	-	-	-	-
i. a.	^{57}Co	^{57}Co	^{57}Co	u. n.	u. n.	u. n.	u. n.

Measurement results in 3 measurements with RadEYE SPRD GN with CLYC und 4 measurements with RadEYE SPRD with CsI with 4 sources: 1.5 µSv/h ^{60}Co, 0.9 µSv/h ^{137}Cs, 0.7 µSv/h ^{152}Eu, 0.4 µSv/h ^{133}Ba. The noted times are rounded measurement times until the result is displayed in the ratemeter mode. When indicated in the result it is marked with an x if not with -. In the line i.a. results are indicated which are given in addition to the given nuclides. u.n. stands for unknown nuclides.

VI. DYNAMIC TESTS

A. Pass-by alarm tests

The devices' performance regarding alarm generation upon a moving probe was investigated in a series of pass-by tests. These tests were carried out according to RIID ANSI and IEC as well as ITRAP+10 standards. These were carried out for the nuclides ^{241}Am, ^{60}Co, ^{137}Cs, ^{133}Ba, ^{226}Ra, ^{232}Th, and ^{57}Co (only for ITRAP+10) using both RadEYE devices. For all tests the dose rate at the detector position at the position of closest approach was 0.5 µSv/h as prescribed by the standards. Comprehensive results for the dynamic tests are shown in Table IV, where the number of triggered alarms A compared to the number of trials B is listed as A/B.

TABLE IV
DYNAMIC TESTS

nuclide	RIID ANSI and IEC			ITRAP+10	
	velocity [m/s]	RadEYE SPRD GN CLYC	RadEYE SPRD CsI	RadEYE SPRD GN CLYC	RadEYE SPRD CsI
^{241}Am	0.05	10/10	10/10	30/30	30/30
^{60}Co	0.15	6/10	10/10	2/30	30/30
^{137}Cs	0.15	10/10	10/10	8/30	30/30
^{133}Ba	0.16	10/10	10/10	12/30	30/30
^{226}Ra	0.18	10/10	10/10	4/30	30/30
^{232}Th	0.26	2/10	10/10	3/30	30/30
^{57}Co	-	-	-	30/30	30/30

Dose rate at detector position 0.5 µSv/h. The velocity for the RIID ANSI and IEC tests is modified according to the compensation rule for changing the distance to reach 0.5 µSv/h. The tests according to ITRAP+10 were performed with 0.6 m/s. A/B means: an alarm was triggered A times in a total of B trials.

Tests according to ITRAP+10 were carried out at a velocity of 0.6 m/s. It is clear that the CsI detector device detected all tested nuclides reliably, i.e. the alarm set off in every trial. In contrast, the CLYC detector could achieve this only for ^{241}Am and ^{57}Co. For all other nuclides less than 50% of the trials resulted in the alarm setting off.

In the RIID ANSI and IEC case velocities were determined according to the compensation of distance changes to achieve the dose rate of 0.5 µSv/h at the detector position like given in (1). The results are qualitatively similar to the ITRAP+10 results. Again, the CsI detector raised an alarm in all trials. On these conditions with the lower velocity the CLYC crystal performed notably better than before, setting off the alarm on every trial for four out of six tested nuclides. For ^{60}Co and ^{232}Th, however, only few trials (6 out of 10 and 2 out of 10, respectively) set off the alarm.

B. Maximum reading ^{226}Ra

For ^{226}Ra the maximum dose rates displayed by the RadEYE SPRD GN device versus the trial number are presented in Fig. 4. Additionally, the background of 0.06 ± 0.02 µSv/h is shown. The device was used with factory settings, i.e. with an alarm threshold of 0.5 µSv/h. It can be seen, that only a single dose readout within the 30 trials surpassed the threshold, but in total 5 trials resulted in an alarm. This stems from the fact that the device alerts upon detection of artificial radiation regardless of the determined dose rate. In addition, the display does no longer show the dose rate value after alarming, instead a text message is displayed. Therefore, the dose rate values in the alarm cases could be higher, but could not be read from the display. However, it remains unclear why only in a small number of sub-threshold trials an alarm from detection of artificial radiation is set off.

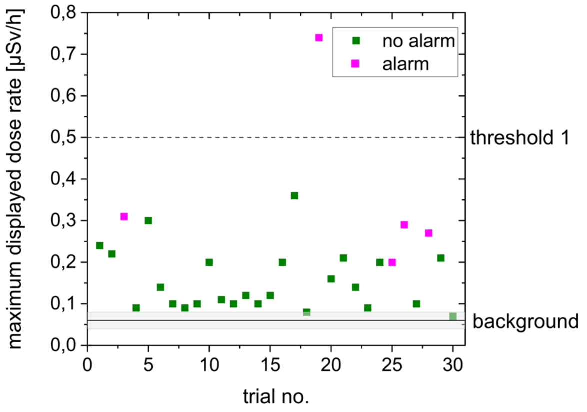

Fig. 4. Maximum displayed dose rate value which could be read at the display of the RadEYE SPRD GN device. ^{226}Ra, 0.5 µSv/h, 0.6 m/s, 30 trials, background 0.06 ± 0.02 µSv/h, device settings according to manufacturer's specification/factory setting, alarm threshold 1: 0.5 µSv/h (dashed line). Alarm is also triggered when artificial radiation is detected.

C. ^{137}Cs – readings at display for ANSI and IEC RIID testing

For ^{137}Cs the measured dose rates of both RadEYE devices were compared during the progress of 10 trials within the ANSI and IEC setting. Dose rates read from the device (SPRD GN with CLYC in red, SPRD with CsI in blue) with respect to measuring time are plotted in Fig. 5. Additionally, the time when the alarm is set off is indicated there with the open symbols. It is clear, that in all cases the CsI device raised the alarm earlier with a time difference in the order of seconds. Moreover, in all cases the CsI device already raised the alarm before the source had passed the detector whereas the CLYC device did not. This can also be seen in Fig. 6 where a sample trial is shown. It can be seen that the CsI device alerts already seconds before the source passes the detector position, whereas the CLYC device alerts slightly after the source has passed. Nevertheless, both devices successfully alerted upon each trial.

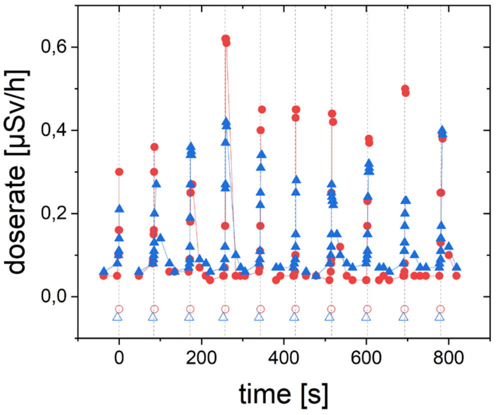

Fig. 5. Maximum displayed dose rate values read from the detector display at different timepoints during a series of trials. ^{137}Cs, 0.5 µSv/h, 0.15 m/s, RIID test ANSI and IEC. Dotted vertical lines mark the timepoints when the source passes in front of the detector. RadEYE SPRD GN with CLYC in red, RadEYE SPRD with CsI in blue. Open symbols indicate the moment when the alarm is triggered.

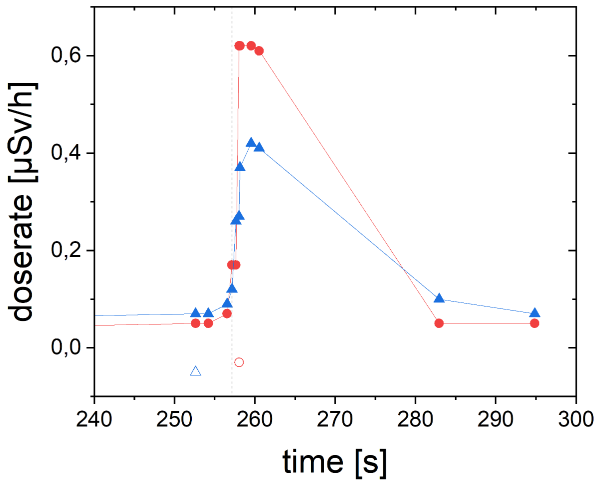

Fig. 6. One trial from the diagram of the previous Fig. 5 enlarged.

VII. ENERGY RESPONSE

To analyze the energy response of both detector materials the gamma spectra of ^{60}Co were recorded both with CsI and CLYC crystals. Resulting spectra showing number of counts versus energy are shown in Fig. 7. Since the CsI crystal employed is larger than the CLYC counterpart, a larger total number of counts was recorded. Also, the gamma spectrum obtained with the CsI crystal is clearly of better quality than the other one recorded with the CLYC crystal. The peaks at 1173.2 keV and 1332.5 keV in the CsI spectrum are much more pronounced and distinguishable from the background than those in the CLYC spectrum. This might also explain the superior performance of CsI compared to CLYC in the dynamic test for ^{60}Co. Similarly, the relatively high number of counts in the low energy region corresponds to a remarkably better performance for ^{241}Am.

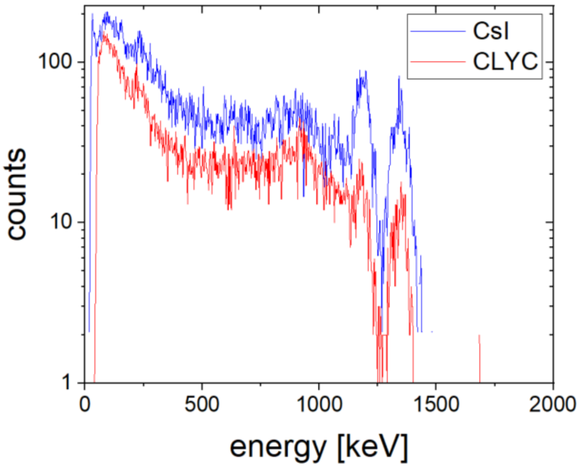

Fig. 7. Energy spectra taken with both RadEYE devices with a ^{60}Co source converted to the same measurement times.

VIII. NEUTRON DETECTION – ^{252}CF

In order to test the detection capability for neutrons, a ^{252}Cf source for both RadEYE devices was used. The SPRD GN with CLYC crystal enables the simultaneous detection of gammas and neutrons. It was mounted on a Polymethylmethacrylate (PMMA) phantom according to the standards in order to simulate a person wearing this device. The SPRD with CsI does not contain any neutron detection capability, but it can detect the accompanying gammas from the ^{252}Cf source and was therefore employed for comparison.

At a probe velocity of 0.6 m/s without any moderator both devices generated only a few alarms (5/30 and 3/30 in the CLYC and CsI cases, respectively). The CLYC detector correctly indicated these as neutron alerts, the CsI detector raised gamma alerts. At a reduced velocity of 0.42 m/s similar results were obtained. The CsI performance was essentially the same, the CLYC detector raised a higher number of alerts with respect to the number of trials, but still only in 4 out of 10 cases.

Significant improvement was achieved when 5 cm of polyethylene were placed between neutron source and detector. In this case the CLYC detector set off neutron alerts in 19 out of 20 trials. Since the CLYC detector material is sensitive for thermal neutrons, a moderator material like polyethylene is essential for successful detection of neutrons.

IX. CONCLUSIONS

The comparative behavior of RadEYE detector devices using either CLYC or CsI detector materials was investigated with respect to identification and dynamic detection.

In the static identification of nuclides both materials performed quite differently. Simultaneously exposed to four radiation sources (^{60}Co, ^{137}Cs, ^{133}Ba, and ^{152}Eu), both detector devices identified ^{60}Co. Which was not the case in the single measurements for the CLYC device. However, the CsI device could also find ^{137}Cs and ^{133}Ba, whereas the CLYC device detected the ^{152}Eu and even indicated the presence of ^{57}Co. None of the detector materials could reliably identify all nuclides if four of them were presented simultaneously.

Substantial differences between both detector materials could also be observed for the sensitivity with respect to the radiation energy. On ITRAP+10 conditions the CsI detector could reliably detect gammas for all tested nuclides, whereas the CLYC device could only achieve this for low energy emitters. Similarly, in the RIID ANSI and IEC tests CsI performed equally flawless, whereas CLYC performed significantly better for several nuclides, only struggling with the high energy emitters ^{60}Co and ^{232}Th. The presence of more pronounced peaks in the ^{60}Co gamma spectrum for CsI compared to CLYC supports this idea. Hence, further tests covering a wide energy region are required.

Finally, the CLYC detector allows for the simultaneous detection of gammas and neutrons. Although the detection rate is poor for unmoderated neutrons, with a moderator present neutron radiation from ^{252}Cf is detected and assigned reliably.

Overall, the RadEYE SPRD GN device with CLYC crystal seems to perform less sensitive in gamma detection and slower in alarm generation than the RadEYE SPRD device with CsI detector crystal, but it includes the possibility to also detect neutrons (moderated). And the answer to the question whether the two detector materials behave differently in identification and dynamic tests or not is yes, they do.

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