The influence of shielding - measurements of nuclear material

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1 ABSTRACT

If suspicious objects are found and suspected to be improvised nuclear devices (IND) or radioactive dispersal devices (RDD) radioactive or nuclear material may be involved. In this case it is necessary to gain information about the composition of those materials. Fast and reliable measurements have to be performed and the material has to be identified especially in the case of nuclear material. This will be done by analysis of high resolution gamma spectra.

A number of portable high energy resolution detection systems using electrical cooling and implemented automatic analysis routines are nowadays available. The obtained spectra and therefore the analysis results are strongly influenced by the geometry of the measurement setup. In the aforementioned scenario the radioactive or nuclear material would be surrounded by other components of the IND or RDD like steel or explosives. If the radiation is intended to be reduced lead might be present as well.

In previous campaigns measurements using various sources of nuclear material were performed and the results obtained by the automatic analysis routines were analyzed. In the present paper similar measurements are presented also investigating the quality of the outcome of automatic analysis routines. The main focus of the present measurements is the influence of different shielding on the measurement results.

Measurements were obtained with four different detectors. Those are three out of the Detective series (Detective EX, Micro-Detective and Detective 200) from ORTEC and the Falcon 5000 from Canberra. The Detectives differ in the crystal size, electronic components, and the firmware version. Therefore the comparison of the three different Detectives is meaningful. For shielding we used 1.5 cm of stainless steel, a 2 mm lead sheet, and 5 cm of explosive simulate; both in combination and by itself.

The measurements were performed using in total eight uranium and plutonium sources with different enrichment respectively isotopic composition. They took place at the Institute for Transuranium Elements (ITU) at the Joint Research Center (JRC) in Karlsruhe, Germany.

Keywords: identification, radiological material, nuclear material, gamma detection, electrical cooled Ge-Detector, Detective 200, Micro-Detective, Detective EX, Falcon 5000, shielding

2 INTRODUCTION

Identification measurements of special nuclear material (SNM) play a major role in the field of nuclear security. This is in particular because of the large impact on the public. Often measurements are carried out by non-experts, therefore it is especially important to have measurement systems with reliable automatic analysis routines. Several previous measurements have shown that the outcome of such systems is not always correct [1], [2]. Test measurements obtained with SNM are necessary for the evaluation. Due to the fact of restrictions for the possession of SNM it is difficult to perform test measurements with this kind of material and in

particular gain experience in this area. We had the opportunity to use the extensive possibilities at the Institute for Transuranium Elements (ITU) at the Joint Research Center (JRC) in Karlsruhe, Germany and performed measurements with different SNM.

3 EXPERIMENTAL SETUP

Altogether 8 different SNM sources were used for the measurements, mainly oxides. Those were four different uranium sources with enrichments from depleted uranium (DU, ^{235}U: 0.3 %), natural uranium (nat. U, 0.7 %), to low enriched uranium (U1: 4.5 %) up to high enriched uranium (U2: 91 % (metal)). In the case of plutonium there were four sources: fuel grade plutonium (Pu1: ^{239}Pu: 9 %, Pu2: 63 %) and weapon grade plutonium (Pu3: 93 %, Pu4: 92 % (metal)). The sources have been measured separatly and in combination in case of U2 and Pu2.

Measurements were obtained with four different detectors. Those are three out of the Detective series (Detective EX, Micro-Detective and Detective 200) from ORTEC and the Falcon 5000 from Canberra. The left hand side of Figure 1 shows a typical experimental setup. The detectors were located on the floor. Height compensation was done in order to have the centers of the crystals and the source at the same height. All measurements were done with a distance of 20 cm from the center of the source towards the endcap of the detector. The sources are axially symmetric and were measured simultaneously with all four detectors.

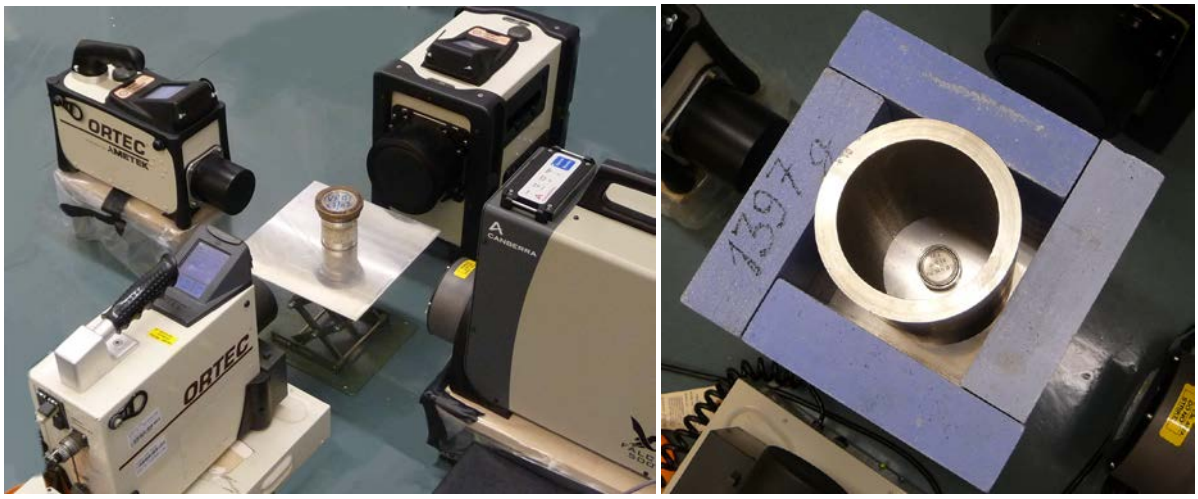

Figure 1: **<u>Left:</u> Experimental setup with the detectors surrounding the plutonium source Pu4. The detectors are (clockwise starting on the bottom left): Detective EX, Micro-Detective, Detective 200 and Falcon 5000. <u>Right:</u> Setup with steel and explosive simulate (blue) surrounding the plutonium source Pu2.**

In the present paper the main focus of attention was drawn to more realistic measurement situations in terms of source shielding. Several materials were used for surrounding the sources in order to represent sources for example inside a suspicious object. We used steel, lead and explosive simulate material with characteristics similar to explosive material concerning shielding effects but not being explosive. The explosive simulate had a thickness of 5 cm, the steel 1.5 cm and the lead 2 mm. Lead and explosive simulate were used separately as well as in combination. Steel was always accompanied by explosive simulate (see right hand side of Figure 1).

During each measurement the chronological changes of the results have been achieved by observing the display. In particular attention was drawn on the point of the first appearance of a hint for the existence of uranium or plutonium. In addition we obtained measurements during

midday or night with accordingly longer measurement times. We performed all measurements simultaneously and tried to use the available time in an optimal way. Therefore life times of the measurements varied over a wide range from 7 s to 57400 s

4 MEASUREMENT SYSTEMS

Four High purity Germanium detectors (HPGe) with electrical cooling were used. The main characteristic values are given in Table 1, as well as the outer dimensions of the systems. Three Detectors are out of the Detective series from ORTEC; in addition the Falcon 5000 from Canberra was investigated. The three Detectives (Detective EX, Micro-Detective and Detective 200) differ from each other in respect of the Germanium crystal and the firmware. Detective EX and Micro-Detective are comparable concerning the crystal (see Table 1) but differ in the firmware. Detective 200 and Micro-Detective both have the newer firmware V3 but the Detective 200 has a larger crystal. As we are investigating the whole system to the point of the identification result we gain three different results out of those three Detective systems.

Detector, Manufacturer	Weight of device [kg]	Size of Device [cm]	Crystal Size [cm] Ø/Length	Energy Resolution [keV]		Relative Efficiency [%] for ^{60}Co	Battery Life [h]
				at 186 keV	at 662 keV		
Detective EX, ORTEC	12	37 x 18 x 34	5 / 3	1.3	1.7	16	> 3
Micro-Detective ORTEC	7	37 x 15 x 28	5 / 4	1.3	1.7	11	5
Detective 200, ORTEC	21	43 x 24 x 39	8.5 / 3	1.1	1.5	52	3
Falcon 5000, Canberra	15	40 x 35 x 16	6 / 3	1.1	1.4	18.5	6-8

Table 1: Overview of the detection systems and their specifications. The weight and the size for the Falcon 5000 do not include a necessary PC. Weight and size for all systems include batteries. The Battery Life in the case of the Falcon 5000 does not consider Battery Life for the necessary PC. The relative efficiencies are obtained using the standard measurement procedure in which a ^{60}Co source is placed 25 cm away from the end-cap of the detector.

In all cases the spectra can be stored and the spectrum files can be exported and transferred to a specialist. The systems feature automatic identification and in particular special SNM Modes. The latter have been specially considered for this uranium and plutonium measurements. In order to gain additional information concerning uranium enrichment and plutonium composition the data were analyzed with the Isotopic Analysis Software PC/FRAM 5.1 (ORTEC version) [3]. Thereby we used the existing parameter file for uranium (u_cx_120-1010) and plutonium (pu_cx_120-460) after adapting the energy calibration but without any further optimization.

Compared to the firmware used from the Detective EX, the firmware of the Detective 200 and Micro-Detective has limited information output especially in the standard non-expert modus (see chapter 4.1.2). To have a better comparability we therefore have not strictly used the recommended settings for the subsequent measurements although we want to evaluate the results which non-expert users would gain.

The identification mode displays of the Detective devices continuously update the results and run until they are manually stopped by the user. The Falcon 5000 can be operated with a

preselected time or without a preset. However the result of the SNM Mode will be only displayed after the end of the measurement. The chronological development of the measurement results were specially observed for all detectors. In the case of the Micro-Detective for example the time for the identification of plutonium “unshielded or shielded by up to 5 mm steel or 10 mm lead shall be less than 13 s for all types of Pu (with Cd filter if higher Am content)” [4]. Whenever possible, spectra with longer measurement times were obtained for example during midday or night.

The Detective EX and the Micro-Detective were equipped with small ^{3}He tubes for neutron detection which were not used for these experiments.

4.1 The Detective Series

The SNM mode of the Detectives is a display in which a bar graph for ^{239}Pu-region, ^{235}U-region and – when included – Neutron is shown. When a certain measurement parameter exceeds its limits indication information is displayed: “Possible SNM. Position Detective to maximize reading, then press Identify to confirm”. The further identification Mode (ID-Mode) differs between the two different existing firmware versions and is therefore considered separately. In the classify mode the instrument runs without preset and classifies found and suspect nuclides according to the scheme: medical, industrial, natural occurring material (NORM), Bremsstrahlung, other, nuclear uranium, nuclear plutonium and nuclear neptunium.

4.1.1 Detective EX

After the analysis routine in the ID-mode leads to a first hint for the identification of nuclides, the nuclides are listed as “suspected”; when led to a credible result, nuclides are listed as “found” (confidence level 99.9 % according to the manual). In the case of nuclear material the following relevant result categories for the degrees of enrichment or isotopic composition are possible [5]:

- Pu, including ^{241}Am: major lines of Pu and high energy lines of ^{241}Am are detected.
- Weapon Grade Pu: major lines of Pu are detected and indication for ^{239}Pu > 90 %.
- Reactor Grade Pu: major lines of Pu are detected and ^{239}Pu < 90 %.
- Highly enriched uranium: major lines of U are detected and indication for ^{235}U > 70 %.
- Depleted uranium: major lines of U are detected and indication for ^{235}U < 0.6 %.
- Natural uranium: major lines of U are detected and indication for ^{235}U ≈ 0.7 %.
- Low enriched uranium: major lines of U are detected and indication for 0.8 % < ^{235}U < 70 %.
- Elevated uranium concentration: peak count rates for major lines of U are significantly higher than background. Can be any enrichment.

It has to be mentioned that for all Detective devices the limit between low enriched uranium and high enriched uranium is set to 70 % in contrast to the generally accepted value according to IAEA regulations of 20 %.

4.1.2 Micro-Detective and Detective 200

With the new firmware V3 less information is gained. Unfortunately it no longer categorizes the degree of enrichment or isotopic composition in general. Only high enriched uranium (HEU) is indicated with the same unconventional definition of HEU as for the Detective EX. The possible relevant results are [6], [7]:

- ^{241}Am (unshielded) (in the industrial category): 59 keV peak is located.
- enriched uranium: ^{235}U and ^{238}U are present, estimated enrichment 0.7 % < ^{235}U < 70 %.

- HEU: major lines of uranium are detected and indication for ^{235}U > 70 %.
- ^{235}U: ^{235}U is present with considerations to possible interfering isotopes
- ^{238}U: ^{238}U is present with considerations to possible interfering isotopes
- 186 keV peak present: suspect ID only shown in the LCX mode, count longer
- ^{239}Pu: ^{239}Pu is present, Pu isotopic composition (WGPu or RGPu) is not calculated
- ^{238}Pu: ^{238}Pu is present, possibly in significant quantity
- ^{241}Am (shielded) (in the nuclear plutonium category): ^{241}Am is present with heavy shielding (both external and internal). Gamma signature similar to ^{241}Am from a Pu source

The Detective instruments with the V3 can operate in two modes: “Classifiy” and “ANSI”. The Classify Mode displays in the ID-Mode a classification message such as “found nuclear uranium 2” which means that two nuclear nuclides classified as nuclear uranium are found. In the ANSI mode the classification is no longer indicated and the present nuclides are named directly, both suspect and found. The presented measurements were carried out in the Classify mode because of the comparability to the Detective EX measurements which only has the Classify mode.

Another innovation compared to the Detective EX is the Low Confidence Expert (LCX) ID Mode. This LCX mode displays suspected threat alarms and identifications at lower confidence level than the normal mode. Tests carried out previous to presented measurement campaign have shown the advantage of this mode and lead to the decision to perform the measurements in the LCX mode although it is not the standard mode.

4.2 Falcon 5000

In the nuclide identification view (NID view) the results are displayed continuously in a table. The real-time identification of individual isotopes and their calculated activity are included here. The certainty of the identification of a nuclide is indicated by the confidence level (% Conf. in the result table). The values for the confidence level are given in percentage. The results for a confidence level between 10 % and 50 % are indicated as “suspected” and above 50 % the confidence values are displayed in numbers.

If after completion of the measurement the nuclide identification analysis indicates any kind of SNM, i.e. Plutonium or Uranium, the Falcon 5000 automatically performs a SNM classification. The following relevant results for the characterization of uranium or plutonium are possible for the SNM classification [8]:

- “SNM: Weapons Grade Plutonium identified”: ~6% ^{240}Pu
- “SNM: Reactor Grade Plutonium identified”: ~25% ^{240}Pu
- “SNM: Low enriched Uranium identified”: > ~0.7% ^{235}U, < ~20% ^{235}U
- “SNM: High enriched Uranium identified”: > ~20% ^{235}U
- “SNM: Natural Uranium identified”: ~0.7% ^{235}U
- “SNM: Depleted Uranium identified”: < ~0.7% ^{235}U

In every case of SNM detection, one or more of these classifications are presented.

5 RESULTS

5.1 Uranium Measurements

The results obtained for all four uranium sources without additional material surrounding the sources are listed in Table 2. For the Detective devices all given results are achieved by the instantaneously performed analysis. The given measurement times are the times when the

displayed result appeared for the first time and did not change any more during the whole observation time, the times are determined by using a separate stop watch. For the Falcon 5000 measurements the results of the SNM analysis with the respective measurement times are given as well as the first appearance of ^{235}U and ^{239}Pu. The times for appearance in general are the average out of three measurements. The given results are color coded as follows: in green: correctly identified; *blue*: uranium identified but with wrong enrichment or not indicated enrichment; in red: false results. Naturally occurring nuclides are not listed.

Detector	**DU**	**nat. U**	**U1**	**U2**
^{235}U abundance	0.3 % depleted uranium	0.71 % natural uranium	4.46 % low enriched uranium	91.42 % high enriched uranium
Detective EX	21 s: ▪ DU	5 s: ▪ *nuclear uranium* ▪ elevated uranium conc.	3 s: ▪ low enriched uranium ▪ elevated uranium conc.	1 s: ▪ *nuclear uranium* ▪ *low enriched uranium*
Micro-Detective	12 s: ▪ *U-238* 41 s: ▪ *U-235*	24 s: ▪ *U-238* ▪ *U-235*	3 s: ▪ *U-235* 8 s: ▪ *U-238*	13 s: ▪ HEU
Detective 200	3 s: ▪ *U-238* 11 s: ▪ *U-235*	4 s: ▪ *U-238* ▪ *U-235*	2 s: ▪ *U-235* 4 s: ▪ *U-238*	2 s: ▪ *U-235* 9 s: ▪ HEU
Falcon 5000	▪ depleted uranium (U-235: 17 s)	▪ *depleted uranium* (U-235: 8 s)	▪ low enriched uranium ▪ WGPu (U-235: 3 s Pu-239: 30 s)	▪ *low enriched uranium* ▪ WGPu (U-235: 3 s Pu-239: 15 s)

Table 2: Overview of the measurement results obtained with the different uranium sources without shielding. The results are displayed as given by the detector (see chapter 4.1 and 4.1.2). For the Falcon 5000 the results of the SNM mode at the end of the measurement are given as well as the first appearance of U-235 and Pu-239. The other measurement times in the cells are first time of appearance of the final result and obtained also with a separate stop watch. The results are highlighted as follows: in green: correctly identified; *blue:* wrong enrichment or not indicated; in red: false results.

A first result of the measurement with the unshielded sources is the identification of nuclear uranium however given within seconds. The enrichment though was correctly given only in the minority of cases. This is based on the fact that the V3 firmware of the Micro-Detective and the Detective 200 only indicates high enriched uranium (HEU). The analysis of the Detective 200 data using FRAM lead to excellent results in respect of the categorization depleted uranium, natural uranium, low and high enriched uranium. Thereby all sources were identified correct. In the case of the Micro-Detective the classifications are also correct except for the natural uranium in that case the result is depleted uranium.

A second eye-catching result is the indication of Weapon Grade Plutonium (WGPu) for two measurements with the Falcon 5000 (U1 and U2). Suchlike wrong results were also observed in previous measurements [2].

In order to evaluate the measurements results obtained with shielded sources we focused on the high enriched uranium source due to the fact that only for this source all four devices will give an enrichment result. Table 3 gives an overview of the results with no additional shielding, with steel and explosive simulate and with lead. The data are displayed like aforementioned; in addition the blue color code now also includes identification results for uranium which are uncertain. In the cases where no uranium was observed the whole measurement time is given as well as for a long time measurement with the Detective EX. The results for the measurements without additional shielding are transferred from Table 2.

Detector	**91 % ^{235}U (HEU) obtained with**		
	no additional shielding	1.5 cm steel and 5 cm explosive simulate	2 mm lead
Detective EX	1 s: ▪ *nuclear uranium* ▪ *low enriched uranium*	900 s: ▪ no uranium	250 s: ▪ no uranium 6000 s: ▪ *elevated uranium conc.* ▪ *natural uranium*
Micro-Detective	2 s: ▪ *nuclear uranium* 13 s: ▪ HEU	27 s: ▪ *nuclear uranium* 54 s up to 900 s: ▪ *enriched uranium* 900 s (suspect): ▪ *HEU*	37 s: ▪ *U-235* 720 s: ▪ *enriched uranium* 1800 s: ▪ HEU
Detective 200	2 s: ▪ *U-235* 9 s: ▪ HEU	8 s: ▪ *U-235* 480 s: ▪ *enriched uranium* 600 s: ▪ HEU	14 s: ▪ *U-235* 420 s: ▪ *enriched uranium* 1080 s: ▪ HEU
Falcon 5000	900 s: ▪ *low enriched uranium* ▪ WGPu (U-235: 5 s)	900 s: ▪ *low enriched uranium* (U-235: 18 s)	360 s: ▪ *low enriched uranium* 58000 s: ▪ HEU ▪ WGPu (U-235: 23 s)

Table 3: Overview of the measurement results obtained with HEU source U2 without additional shielding and surrounding material as given. The results are displayed as given by the detector (see chapter 4.1 and 4.1.2). For the Falcon 5000 the results of the SNM mode at the end of the measurement are given as well as the first appearance of U-235. Measurement times for the Detective devices in the cells are first time of appearance of the final result and obtained also with a separate stop watch. Exception: Detective EX with shielding, whole measurement time is given and in the lead case we have two separate measurements. The results are highlighted as follows: in green: correctly identified; *blue:* uncertain result or wrong enrichment or not indicated; in red: false results.

The first result out of the displayed measurements is that higher measurement times required for measurements with additional shielding. The Detective 200 for example gave the correct result HEU in all three cases after 9 s, 600 s respectively 1080 s. The Micro-Detective indicated HEU also in all three cases but with steel and explosive simulate only uncertain as suspected result. This might change to a found result after longer measurement time but was not tested. In some cases the Falcon 5000 indicated again weapon grade plutonium although definitely there was no plutonium at all. The uranium enrichment was given as low enriched uranium instead of high

enriched except for the long time measurement with lead shielding. In that case however weapon grade plutonium was indicated in addition.

The Detective EX lead to the worst result and indicated both measurements with shielding no uranium at all except for the lead shielded case with a long time measurement during night. This is especially interesting as one can clearly see the 186 keV peak when examining the spectra. Maybe the problems arise out of the fact, that the energy calibration of the Detective EX was unfortunately not very well. This was only noticed afterwards. As there is no possibility to rerun an identification with a changed spectra this cannot be checked.

As was expected the time to get a result corresponds with the efficiency of the detector. In the case of the devices which are comparable except for the crystal size the time needed by the Micro-Detective is at least 40 % larger than for the Detective 200 to get the result.

5.2 Combined Uranium and Plutonium Measurements

In reality there might be a mixture of sources. For example sources with lower dose might be masked with other sources. However, we considered this fact in doing a combined measurement with the U2 source placed on top of the Pu2 source. The plutonium source has thereby a much higher dose rate than the uranium source and exceeds it almost by a factor of 100. The results obtained without and with additional shielding material are displayed in table 5. The results at the end of the measurement are given and color coded like previous mentioned. The times given in the table are the measurement life time and in brackets: the time of the first appearance of a suspicion for uranium, the time of the first appearance of a found plutonium result both measured using a stop watch and the real time of the measurement.

Eye-catching are the partly extreme discrepancies between life and real times due to high dead times. For example the Detective 200 without additional shielding has a measurement life time of 10 s, whereas the real time was 214 s which leads to a dead time of 95 %. Taking this into account the identification result is excellent and even the HEU is identified correct.

The Detective EX led to the best result concerning the plutonium, in all cases reactor grade plutonium was correct identified in reasonably times. The Micro-Detective and the Detective 200 also identify plutonium in all cases rather fast but do not give information about the isotopic composition like mentioned earlier. While examine the displayed times it is also interesting, that all Detective devices identify plutonium much faster (mainly within seconds) than uranium. For the Falcon 5000 the result is vice versa. In the case of steel and explosive simulate the time for detection of plutonium is extremely long, above 15 minutes. For the lead case no plutonium is indicated at all which might change with longer measurement times.

Compared to this the results for the weaker uranium component are considerable worse. The best result is obtained by the Falcon 5000 although in no case the uranium with the correct enrichment was identified. Yet uranium was identified in all cases and except in the lead case in decent times. The Detective EX has a very poor performance concerning the identification of uranium only in one case elevated uranium concentration was found. The spectra however show energy lines at 186 keV. Again it cannot be excluded that the worse energy calibration can have an effect on the output. Detective 200 and Micro-Detective perform well in the unshielded case and identify HEU after about 10 s. With shielding only in one case ^{235}U and ^{238}U are identified and in the other cases only nuclear uranium is suspect: 186 keV peak present. Even wrong isotopes are identified: ^{232}U and the medical isotope ^{67}Ga.

	HEU on top of RGPu obtained with			
	no additional shielding	1.5 cm steel and 5 cm explosive simulate	2 mm lead	5 cm explosive simulate
Detective EX	373 s: (-, 29 s, 662 s) ▪ Nucl. Pu: RGPu ▪ no uranium	826 s: (-, 31 s, 901 s) ▪ Nucl. Pu: RGPu ▪ no uranium	840 s: (-, 10 s, 912 s) ▪ Nucl. Pu: RGPu ▪ no uranium	791 s: (100 s, 10 s, 1025 s) ▪ Nucl. Pu: RGPu ▪ *elevated uranium conc.*
Micro-Detective	250 s: (13 s, 10 s, 660 s) ▪ Am -241 ▪ *Nucl. Pu: Pu-239* ▪ Nucl. Uranium: HEU ▪ U-232	524 s: (120 s, 22 s, 580 s) ▪ Am-241 ▪ *Nucl. Pu: Pu-239* ▪ U-232 ▪ Ga-67 (med) ▪ *Suspect nucl. U, 186 keV peak present*	645 s: (146 s, 6 s, 670 s) ▪ Am-241 ▪ *Nucl. Pu: Pu-239* ▪ U-232 ▪ *Suspect nucl U, 186 keV peak present*	419 s: (15 s, 8 s, 707 s) ▪ Am-241 ▪ *Nucl. Pu: Pu-239* ▪ U-232 ▪ Ga-67 (med) ▪ *Suspect nucl. Uranium, 186 keV peak present*
Detective 200	10 s: (25 s, 13 s, 214 s) ▪ Am-241 ▪ *Nucl. Pu: Pu-239* ▪ *Nucl. Uranium: U-235* ▪ HEU	344 s: (150 s, 6 s, 739 s) ▪ Am-241 (shielded) ▪ *Nucl. Pu: Pu-239* ▪ *Nucl. Uranium:* U-232 *U-235* *U-238*	400 s: (26 s, 4 s, 853 s) ▪ *Nucl. Pu: Pu-239* ▪ Am-241 ▪ Nucl. Np.: Np-237 ▪ Ga-67 (med) ▪ *Suspect nucl.U, 186 keV peak present*	64 s: (25 s, 10 s, 494 s) ▪ Am-241 ▪ *Nucl. Pu: Pu-239* ▪ Ga-67 (med) ▪ Nucl. Uranium: U-232 ▪ *Suspect nucl. Uranium, 186 keV peak present*
Falcon 5000	90 s: (5 s, 12 s, 145 s) ▪ *LEU* ▪ RGPu	339 s: (35 s, 1070 s, 1154 s) ▪ *LEU* ▪ RGPu	719 s: (160 s, - , 801 s) ▪ *natural uranium* ▪ no plutonium	95 s: (7 s, 50 s, 130 s) ▪ *LEU* ▪ RGPu

Table 4: Results of measurements with HEU (U2) on top of RGPu (Pu2) with additional surrounding material in a distance of 20 cm. The results are displayed as given by the detector (see chapter 4.1 and 4.1.2) after the end of the measurement. The live times are given in the cells, the times in brackets are: (time of first appearance of a suspicion for uranium, time of the first appearance of a found plutonium result, real time). The results are highlighted as follows: in green: correctly identified; *blue:* uncertain result or wrong enrichment or isotopic composition not indicated; red: false results.

Again we have analyzed the data using FRAM. In the case without additional shielding the isotopic composition of the plutonium component was correctly classified as reactor grade plutonium for all four detectors.. The uranium would be classified using the FRAM result as low enriched uranium for the Detective EX and the Micro-Detective and correct as high enriched uranium for the Detective 200 and the Falcon 5000. Although the output of the Detective EX leads to no identification of uranium at all the FRAM analysis proves that the obtained spectrum is of good enough quality to identify uranium. The FRAM result of the Micro-Detective is at first sight worse than the indicated result of the device by itself. The device identified HEU, FRAM lead to LEU. Unfortunately the data file analyzed by FRAM has a shorter measurement time compared to the time after which the HEU result appeared on the Micro-Detective Display. It happens sometimes that one clicks accidentally two times on the display and leaves unintended the mode and deletes the spectrum as there is no query on all Detective devices.

6 CONCLUSIONS

The general results for the unshielded sources are reasonable whereas the results obtained with additional shielding are partly disappointing referring to the combined measurement. Especially if one takes into account that in reality the thickness of the material might even be larger. Even with this thin lead shielding the results have been disappointing. Of course in the case of the single HEU source the results have been partly very promising. The Detective 200 performed well and identified HEU in all cases correct.

Wrong results lead to incorrect risk estimations and will therefore lead to inapplicable activities. The combined measurement of SNM with lead shielding with the Falcon 5000 has an unsuspicious output: natural uranium, no plutonium. Also the identification of WGPu without the existence of plutonium in the case of the Falcon 5000 measurements are misleading.

The fact that no information concerning the degree of enrichment (except HEU) or isotopic composition is displayed by the devices in case they run with the new V3 Firmware version (Micro-Detective and Detective 2000) proved to be a drawback. The measurement analysis results obtained by FRAM yielded reasonable results, at least in part. This leads to the conclusion, that this composition information would be rather helpful.

Especially the results with the shielded sources have shown that extensive practical experiences with realistic situations are necessary in order to be prepared for real events.

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8 REFERENCES

[1] Risse, M.; Berky, W.; Friedrich, H.; Köble, T.; Rosenstock, W.; Rennhofer, H.; Pedersen, B.: **Identification of Nuclear Material with Hand-Held Gamma and Neutron Measuring Devices,** INMM 51st Annual Meeting, Madison, Wisconsin: Omnipress, 2010, 10 S. - URN nbn:de:0011-n-1460856

[2] Risse, M.; Berky, W.; Friedrich, H.; Köble, T.; Rosenstock, W.; Schumann; O. Berndt, R.: **Identification Measurements of nuclear material – Detective EX versus Falcon 5000,** INMM 53rd Annual Meeting, Madison, Wisconsin: Omnipress, 2012, 10 S. - URN nbn:de: 0011-n-2194422

[3] Advanced Measurement Technology, **http://www.ortec-online.com/download/PC-FRAM.pdf**, downloaded on the 6th of July 2013

[4] Advanced Measurement Technology, **http://www.ortec-online.com/download /MICRO-DETECTIVE.pdf** , downloaded on the 6th of July 2013

[5] Micro-Detective® Portable Neutron and Gamma Nuclide Identifiers Operator's Manual, Part No. 931046 Manual Revision B, ORTEC®, a subsidiary of AMETEC ®, Inc, 2008

[6] Micro-Detective® Detective® -200 Portable Neutron and Gamma Nuclide Identifiers User's Manual, Software Version 3.1, Part. No. 931046 Manual Revision F, ORTEC®, a subsidiary of AMETEC ®, Inc, 2012

[7] personal communication with ORTEC, July 2013

[8] F5K SNM Classification engine. Canberra GmbH, Rüsselsheim, Germany