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NOVE: Novel neutron detection methods for nuclear security – Dynamic testing

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Abstract

A large number of novel and conventional neutron detectors were tested under the same experimental conditions. This report presents both the different techniques used as well as measurement results. The measurements were performed at the Metrology laboratory of the Finnish Radiation and Nuclear Safety Authority using a Cf-252 source moving on an automated track. The project was a natural continuation of the stationary measurements performed in 2013. The following organizations participated in the project:

- Radiation and Nuclear Safety Authority, STUK, Finland
- University of Lund, Sweden
- Norwegian Radiation Protection Authority, NRPA
- GE Reuter-Stokes
- Symetrica Security Ltd.
- Environics Oy
- Thermo Fisher

The results were presented and discussed in a seminar in Oslo, Norway. Certain problems in intercomparison testing where identified, such as the effect of neutron scattering in the measurement hall and the false positive alarm rate. IEC standards where used as a reference for the test. While standards provide a minimum performance level, standard tests are not necessarily designed to facilitate a comparison between different detectors. The majority of the detectors did not have problems passing the detection requirement set by the standards.

Key words

Neutron detection

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Final Report from the NKS-B NOVE activity (Contract: AFT/B(14)6)

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1. Introduction

Society can be threatened in various ways by nuclear materials. Growing international crime enhances the possibility of illicit trafficking and terrorism relying on the use of uranium or plutonium. Therefore efficient border control and detection of these materials is of utmost importance.

The detection of neutrons is based on either direct or indirect methods or their combination. Conventionally thermal neutron counting has been based on He-3 counters. The required He-3 gas is a side product of nuclear weapons fabrication. Due to the reduced weapons production and the increased need of neutron detectors for security applications He-3 counters are nowadays expensive. This has triggered a development of novel ways to detect neutrons.

In 2013, different detection methods were presented and tested in the NKS NOVE project. The tests consisted of stationary measurements at the Metrology Laboratory of the Finnish Radiation and Nuclear Safety Authority (STUK). Cf-252 and AmBe neutron sources were used as such and with different neutron shields.

In the present project, detectors were tested in dynamic conditions at STUK. An automated track was used to move a neutron source which passed the detectors several times. The alarm performance of the detectors were documented. The test thus simulates the conditions of a neutron source passing a portal monitor or a backpack detector user walking past a neutron source.

The following organizations participated in the project:

- University of Lund/Swedish Radiation Safety Authority
- Norwegian Radiation Protection Authority, NRPA
- Finnish Radiation and Nuclear Safety Authority, STUK
- Symetrica Security Ltd.
- GE Reuter-Stokes
- Environics Oy
- Thermo Fisher

All organizations tested their own detectors except NRPA, who organized the seminar. The measurement results are presented together with descriptions of the tested detectors. A seminar was held in Oslo, Norway, after the measurement sessions. The seminar minutes are in Appendix A.

2. Experimental

2.1 Source measurement set-up

IEC standards 62484 and 62694 were the basis for planning the measurement set-up[1]. A 165 kBq Cf-252 neutron source emitting about 19 000 neutrons per second was used (the measurements were performed over a period of about two months). The source was shielded with 1 cm of iron and 0.5 cm of lead at all times. In addition, moderators were used surrounding the source with either 4 cm or 8 cm of HDPE. The track is shown in Figure 1. The tests were performed in a large, empty hall in STUK.

The source was moved at walking speed (1.2 m/s) using an automated track. In the case of portal monitors, the source passed the detector 50 times bare and 50 times moderated with 8 cm HDPE. The closest source-detector distance was 1 m from the centre of the detector, and the detector was placed so that the centre of the detector and the source were at the same height from ground (ca 120 cm). The standard requirement for number of alarms is 49 times out of 50 passes. In some cases, other track-detector distances were also tested and/or the 4 cm HDPE was used.

When backpack-sized detectors were tested, the backpack or detectors were attached to an Alderson torso phantom. The source passed the detector 10 times in different angles in 45° increments over a 180° range both horizontally and vertically. In the vertical measurements, the neck of the phantom was turned towards the track, simulating the user walking past and under a source. The backpack standard specifies a detector-track-distance of 1.5 m. Measurements were performed at a distance of 1.5 m and 1 m, to get results comparable with the portal monitor measurements. The standard requires that an alarm is given in 96 out 100 trials.

Figure 1. The testing track moving the source past STUKs BLASTER detector.

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[1] IEC 62484: *Radiation protection instrumentation – Spectroscopy-based portal monitors used for the detection and identification of illicit trafficking of radioactive material*) and 62694 Ed. 1: *Radiation protection instrumentation – Backpack-type radiation detector (BRD) for detection of illicit trafficking of radioactive material*.

2.2 False alarm rates

The amount of correct alarms in the test is, of course, dependent on the used alarm threshold level of the signal. The lower this threshold is, the more false positive alarms one can expect. The IEC standards require the false positive alarm rate to be not more than 1 alarm in 2 h for portal monitors and less than 1 alarm in 1 h for backpack detectors. The alarm threshold level depends on the background count rate, which was measured.

The standard thus allows for quite a few false alarms, and in some cases, the alarm threshold of the detector set-up was not lowered, while in others, the threshold was set to at least theoretically be on the level of the standard.

3. Detector system descriptions and results

3.1 Detectors tested by STUK and results

RanidPORT–N portal monitor

The RanidPort–N portal monitor (Figure 2) is a radiation detector system manufactured by Environics Oy. The detector contains a 4 l NaI(Tl) detector (4”x4”x16”) surrounded on three sides with polyethylene (PE) and PVC. The energy range is up to 8 MeV, enabling neutron source detection by high-energy (>3.5 MeV) photons (Holm et al, 2012). The MCA uses 2048 channels and thus the wide energy range does not prevent normal gamma spectrometry. The PE and PVC acts as neutron moderators. The chlorine in the PVC also emits high-energy photons in neutron capture reactions ($\sigma(n,\gamma)$ for ^{35}Cl is 44 b at E=0.025 eV (ENDF/B-VII.1)). The detector system measures and analyses the data in real-time with an integration times of 1 s, 10 s and 100 s. The data is stored in a local LINSSI database and can also be transferred to a remote database. The operational alarm level is set to obtain a very low false positive alarm rate (theoretically 10^{-6}).

Figure 2. RanidPort portal monitor.

Table 1 presents the detection performance in the dynamic tests. The alarms are from 1 second measurements.

Table 1. Alarms/source passes for the RanidPORT –N portal monitor with a detector-track distance of 1 m. The values in the rightmost column represents the number of alarms that would have been obtained with an alarm limit that theoretically is within the standard requirements for false positive alarm rates.

	STUK alarm limits	Lower alarm limit
Bare Cf-252	36/50	49/50
Cf-252 and 4 cm HDPE	39/50	50/50
Cf-252 and 8 cm HDPE	32/50	50/50

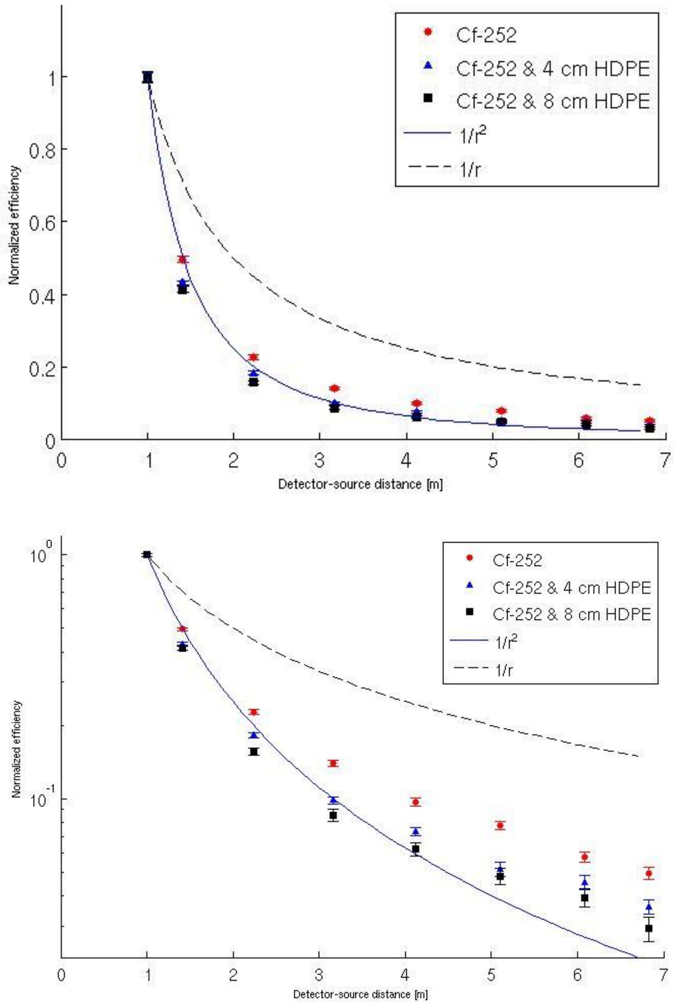


Figure 3. Normalized neutron count rate of the RanidPORT-N. The figure can be compared to figure 14.

BLASTER

The BLASTER (Boron-Loaded Attenuated SpectromeTER, see Figure 1) is a fast-neutron detector build by STUK and it consists of a boron-loaded plastic scintillator coupled to a photomultiplier tube and a Canberra Osprey MCA (Holm et al, 2014). The MCA is operated in list-mode, and coincidence pulses are looked for. The coincidence pulses are caused by fast neutrons that thermalize by scattering with hydrogen (first pulse) and then get captured by the boron (second pulse). The scintillator is shielded with lead to minimize the amount of random coincidences caused by gamma radiation. In addition to the fast neutron coincidence signal, the detector also uses the high-energy (3.5 MeV – 5 MeV) singles spectrum and the neutron capture peak to detect neutron sources. The operational alarm level is set to obtain a very low false positive alarm rate (theoretically 10^{-6}).

The detector was only tested with its operational configuration (5 second integration time and very low false positive alarm rate). No alarms were obtained with this configuration. The detector has a good signal-to-noise ratio, but low efficiency. Therefore, the detector is useful in neutron detection only when long counting time is operationally possible (>> 100 s).

3.2 University of Lund neutron detectors

Alarm algorithm

Assuming the detector has a relatively flat angular response, the response in the detector when a radioactive source is moving past at a fixed speed is mostly a factor of the distance between the source and the detector (There may be a significant angular response due to detector geometry, as in the backpack neutron detector presented in section 3.5). The theoretical response of the detector can thus be modelled as a function of time. Most detector systems measuring a dynamic radiation field perform a train of integrations of fixed length. The theoretical response of a detector and a train of integrations of 1 second length each is illustrated in Figure 4.

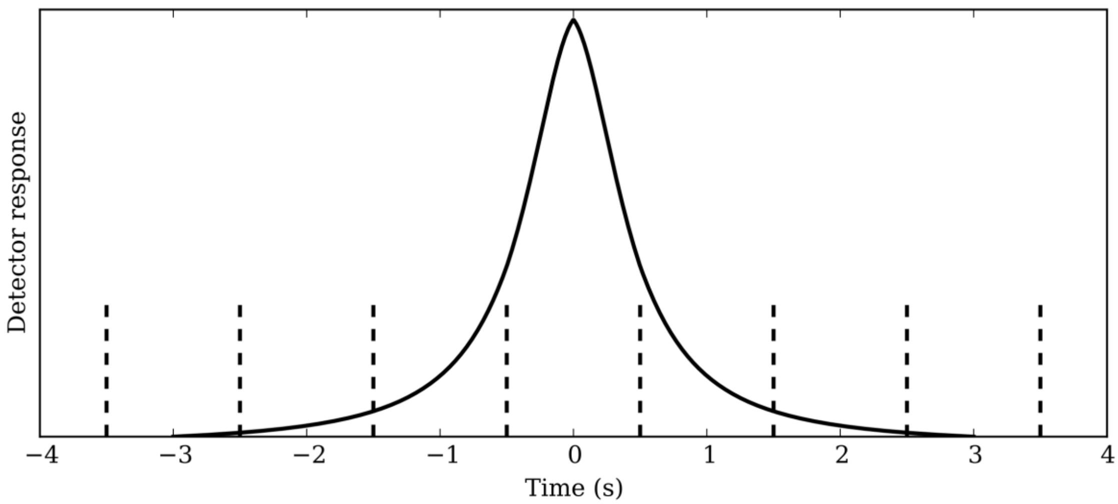


Figure 4. Theoretical response of a detector and a train of 1 second integrations.

Figure 4 has one integration period which is done from the time -0.5 to 0.5 seconds. As the peak of the response curve is located at 0 seconds, it is clear that this specific integration period is the one which integrates the largest area of the response curve and thus statistically should receive the most number of pulses from the source. However, when performing integrations with a fixed integration time, the alignment of the integration times can usually not be controlled. The worst case scenario is instead that the integration starts (or ends) when the source is at its closest point to the detector. In this case, a smaller area of the response curve is integrated in comparison to the case when the middle of the integration period is located at the time of the peak. Figure 5 shows the area of the response curve integrated for both of these cases.

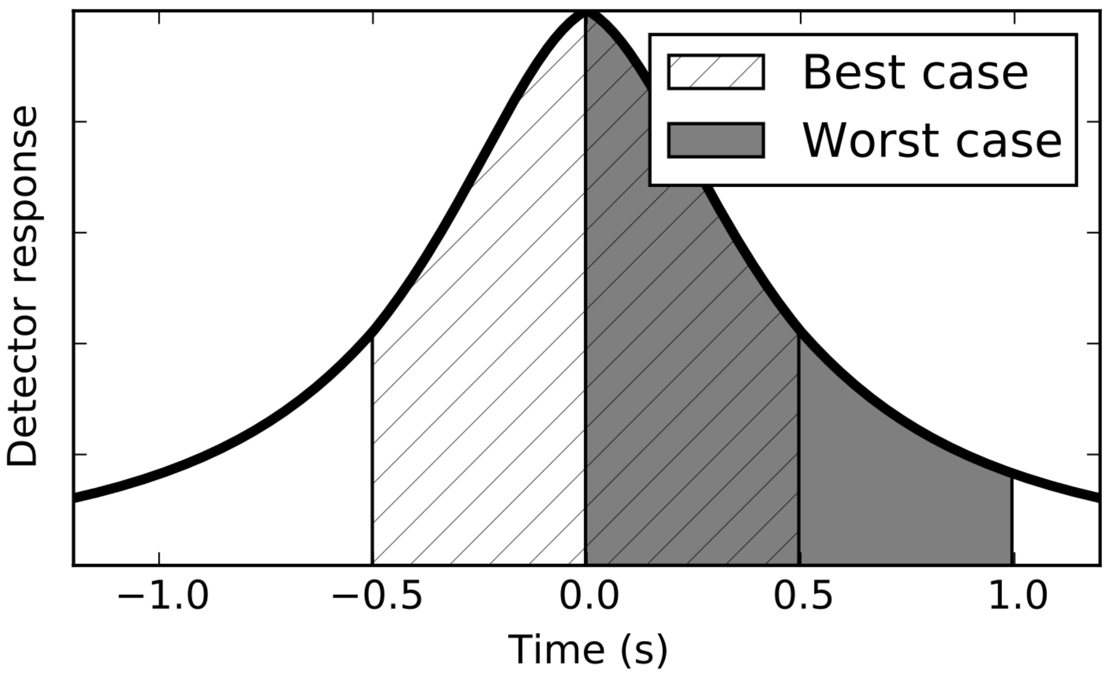


Figure 5. Worst and best integration times.

It is clear then that the best detector response can be obtained if the integration periods are always aligned such that the middle of one period is located at the time of the peak of the response curve. This can be done by instead of performing measurements with fixed integration times, performing measurements where each pulse registered by the detector is logged individually with a time stamp of the event. This is called list mode measurement. Using data from list mode measurements, all possible alignments of the integration periods can be tested which means that the previously mentioned best-case scenario can always be obtained.

When making stationary measurements of dynamic radiation fields, the count rate in the detector from background sources vary only very slowly with time. Thus the background can be described as providing a mean number of pulses per second in the detector. This means that the number of pulses from the background in a measurement increases linearly with time of measurement. Studying Figure 4, it can be seen that the number of pulses per second from the source which is measured starts out very low as the source is moving towards the detector but is still some distance away. The number of pulses per second will then increase rapidly as the source gets close to the detector, only to decrease rapidly as the source moves away from its closest point to the detector. It is clear that having a integration time that is too long will result in a measurement which is dominated by pulses from the background. If instead the integration time is to short, the probability of the detector registering enough pulses from the source to positively detect it will be low. The conclusion is that there exists an optimal integration time where the probability of distinguishing between the pulses from a source and the background pulses is the best. This integration time is dependent on many factors such as background count rate, speed of source and minimum distance between source and detector. The optimal integration time for a specific source-detector setup can be calculated theoretically. Using list mode measurements, several integration times can be tested at the same time to further increase the probability of detecting a source.

3’’ x 3’’ NaI(Tl)

The 76.2 mm diameter by 76.2 mm length NaI(Tl) detectors are mainly used in backpack systems for mobile measurements in the Swedish radiation protection organization. The detectors are relatively cheap and quite robust due to them being packed in aluminum tube which provides thermal and mechanical protection. Their widespread use makes it relevant to test them with regards to sensitivity to high-energy gamma photons from neutron sources.

The alarm algorithm used a moving average of the signal that was updated with each new detected pulse (the detector system was operated in list mode). The integration time of the moving average was optimized to 5.5 seconds. The results of the dynamic tests are presented in Table 2.

Table 2. Alarms/source passes for 3”x3” NaI detector with a detector-track distance of 1 m. The alarm level was set to be within the standard requirements for false positive alarm rates.

	Alarms
Bare Cf-252	4/50
Cf-252 and 4 cm HDPE	6/50

4l NaI(Tl)

4l NaI(Tl) detectors are mainly used in car borne and airborne measurement systems. Their large size results in a detector with excellent efficiency for measuring radioactive sources of low activity or high activity sources from long distances. This makes these detectors relatively well suited for measuring high-energy gamma rays from neutron sources or prompt gammas caused by neutron radiation. To increase the sensitivity to neutron radiation, the detector was used together with a PVC moderator large enough to enclose the detector on 4 sides with 10 cm PVC. The electronics package used with this detector is the ORTEC DigiBASE.

The alarm algorithm used a moving average of the signal that was updated with each new detected pulse (the detector system was operated in list mode). The integration time of the moving average was optimized to 4 seconds. The results of the dynamic tests are presented in Table 3.

Table 3. Alarms/source passes for 4 l NaI detector with a detector-track distance of 1 m. The alarm level was set to be within the standard requirements for false positive alarm rates

	Alarms without PVC	Alarms with PVC
Bare Cf-252	40/50	50/50
Cf-252 and 8 cm HDPE	50/50	50/50

3 tube He-3 based n-detector

The He-3 based neutron detector is of type GR460 (Exploranium, Canada). The detector itself is a PE-box of dimensions 1195mm by 355mm by 100mm with a wall thickness of 18mm. Three He-3 tubes of type 25384 (LND Inc, USA) with a total volume of 4743 cm3 at a pressure of 3 atm are used in the system.

The detector is intended for mobile use, and its electronics package is limited to performing 1 second long measurements. The alarm algorithm used a moving average of the signal that was updated with each new 1-second measurement. The integration time of the moving average was optimized to 4 seconds. The results of the dynamic measurements are presented in Table 4.

Table 4. Alarms/source passes for the He-3 based detector with a detector-track distance of 1 m and 2.5 m. The alarm level was set to be within the standard requirements for false positive alarm rates

	Alarms at 1 m distance	Alarms at 2.5 m distance
Bare Cf-252	50/50	50/50
Cf-252 and 8 cm HDPE	50/50	50/50

3.3 Environics Oy detectors

Environics Oy tested a RanidPort Mobile portal monitor. The portal monitor utilizes the same technology as that of the RanidPort-N system described in section 3.1. The RanidPort Mobile is designed for mobile use and does not have the plastic neutron moderator that the RanidPort-N monitor has. However, the effect of adding plastic plates on three sides of the monitor was tested. The detector is shown in Figure 6.

Figure 6. RanidPort Mobile portal monitor.

The results of the measurements are presented in Table 5. It is evident, that adding plastic moderators around the gamma spectrometer significantly improves its neutron signal.

Table 5. Alarms/source passes for the RanidPort Mobile portal monitor with a detector-track distance of 1 m. The alarm level was set to theoretically be within the standard requirements for false positive alarm rates. The detector was surrounded on three sides with PE.

Detector set-up	Source	Alarms
No booster	Bare	14 /50
	4 cm HDPE	43 /50
	8 cm HDPE	40 /50
2 cm PE Booster	Bare	34 /50
	4 cm HDPE	50 /50
	8 cm HDPE	49 /50
4 cm PE Booster	Bare	42 /50
	4 cm HDPE	50 /50
	8 cm HDPE	48 /50

3.4 GE Reuter-Stokes $^{10}_{5}B$ Detectors

GE Reuter-Stokes manufactures neutron counters of many different types, since 1956. With a few exceptions, any previous detector can be remade, identical mechanically and matching the performance exactly. Every detector is custom made for the specific applications.

Early 2010, GE Reuter-Stokes demonstrated that **$^{10}_{5}B$ lined proportional counters** could serve as an alternative to $^{3}_{2}He$ Neutron Detection Modules (NDM) used in Radiation Portal Monitors. A series of third party testing, and DNDO qualification program were performed on this potential alternative. At the end of 2010, GE Reuter-Stokes launched a commercial $^{10}_{5}B$ Neutron Detection Module that could be used as an alternative to $^{3}_{2}He$ neutron detectors.

$^{10}_{5}B$ lined proportional counters, just like $^{3}_{2}He$ proportional counters, are made from a metallic housing, with a small diameter anode, filled with a proportional gas. A thin layer of highly enriched $^{10}_{5}B$ is deposited on the internal shell of the detector housing. GE Reuter-Stokes developed a coating process that allows optimize $^{10}_{5}B$ coating thickness.

The neutron interaction on the $^{10}_{5}B$ layer creates a $^{7}_{2}Li$ and an α particle (see Figure 7). One of the decay particle will, eventually, loses its energy in the proportional gas, creating a cascade of electrons, which can be collected by the anode wire.

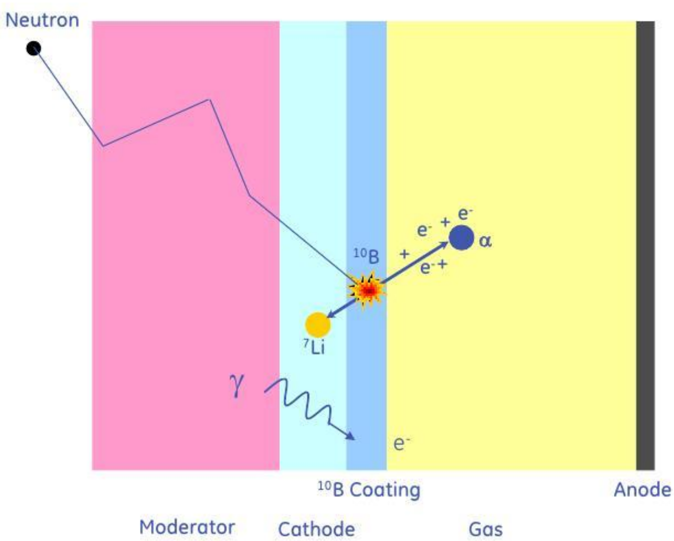


Figure 7. ^{10}B neutron capture reaction in the boron layer of the detector.

The $^{10}_{5}B$ lined proportional counter works on the same physics principles as a $^{3}_{2}He$ proportional counter. Therefore, GE Reuter-Stokes $^{10}_{5}B$ NDM is as close as it gets to a Drop-In replacement to the existing $^{3}_{2}He$ NDMs, with very minor tweaking.

Since its commercial launch in 2010, GE Reuter-Stokes made significant progress in optimizing the High Density PolyEthylene (HDPE) modular design to reach the highest sensitivity while reducing the number of $^{10}_{5}B$ lined proportional counters. Through modeling and experimenting with different design, GE Reuter-Stokes can provide $^{10}_{5}B$ NDMs with sensitivity reaching $4.5 \frac{cps}{ng\ ^{252}_{98}CF}$. The width, length, and height of the NDM can be modified to fit the customer’s needs. Figure 8 presents one NDM.

Figure 8. GE Reuter-Stokes $^{10}_{5}B$ NDM.

GE Reuter-Stokes puts the $^{10}_{5}B$ NDMs through a series of temperature, vibration, and nuclear tests to ensure the highest quality possible. The $^{10}_{5}B$ NDMs can operate safely between -40°C and +55°C with no change in count rate. The modules are vibrations tested with levels up to 1.5g in each direction. The $^{10}_{5}B$ NDMs are sensitive to less 10^{-6} in a 0.1mSv/hr $^{60}_{27}Co$ gamma radiation field. Additional testing at 1Sv/hr gamma radiation field is planned.

GE Reuter-Stokes attended the NKS Nove Dynamic Testing, with a demo unit reaching a sensitivity of $2.8 \frac{cps}{ng\ ^{252}_{98}CF}$. The results of some of the measurements performed during this session are presented in Table 6 and Figure 9-10.

Table 6. Stationary Measurements

Source	Results
1m – Unmoderated 1m – 4cm moderator 1m – 8cm moderator	(101.57 ± 0.58)cps (98.94 ± 0.74)cps (57.90 ± 0.56)cps
2.5m – Unmoderated 2.5m – 4cm moderator 2.5m – 8cm moderator	(20.76 ± 0.26)cps (19.50 ± 0.25)cps (11.17 ± 0.19)cps
5m – Unmoderated 5m – 4cm moderator 5m – 8cm moderator	(8.65 ± 0.12)cps (7.97 ± 0.12)cps (4.61 ± 0.09)cps

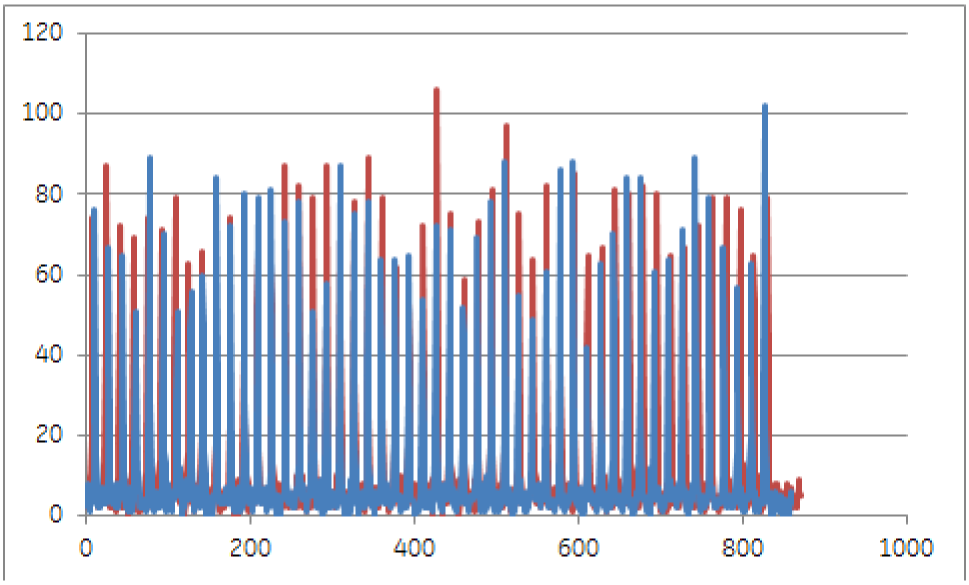


Figure 9. Source 1m away unmoderated

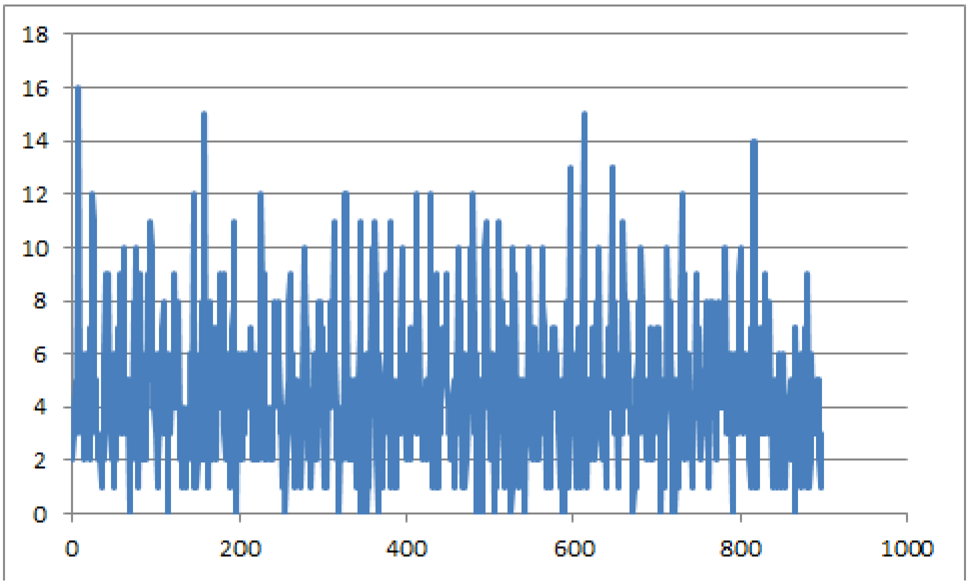


Figure 10. Source 5m away with 4cm HDPE

Even when the NDM was standing 5 m away from the source, one can see fluctuations beyond the statistical variations.

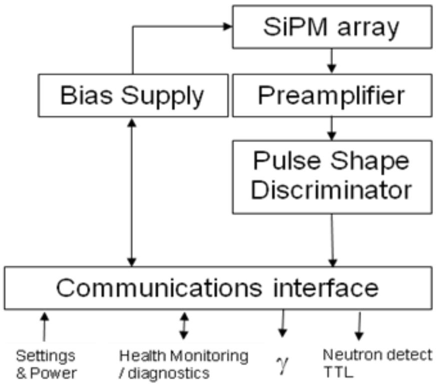
3.5 Symetrica Ltd. detector

Instrument

The instrument under test is a compact low-power He^3-free neutron detector developed for use in portable and wearable applications. The design has already been deployed in pairs in a backpack. In these tests we wished to benchmark the technology when used as a "wearable" system, with the detectors built into a jacket. To that end two units were tested, one each on the back and front of a body phantom.

This detector uses Li^6F/ZnS screens coupled to a bulk wavelength-shifting plastic which transmits scintillation light to an array of silicon photomultipliers (SiPMs). Scintillation pulses are processed by on-board neutron/gamma discrimination logic and TTL pulses are emitted for counting. A temperature-stabilised SiPM bias supply is provided by the same PCB as the discrimination logic.

Figure 11 shows the instrument, its specification and underlying technologies.



- **Absolute efficiency**†*: 0.67cps/ng bare Cf^{252} at 1.5m
- **Thermal neutron efficiency**: ~36%
- **γ-ray rejection***: 4.1 x 10^{-8} ± 1.0 x 10^{-8} (Cs^{137})
- **GARRn***: 0.98 ± 0.02 (200μSv/hr Cs^{137})
- **Mass**: 1080g
- **Dimensions**: 22 x 22 x 2.5 cm

* Averages from initial production batch
† Single unit on a 50x50x10cm HDPE torso phantom

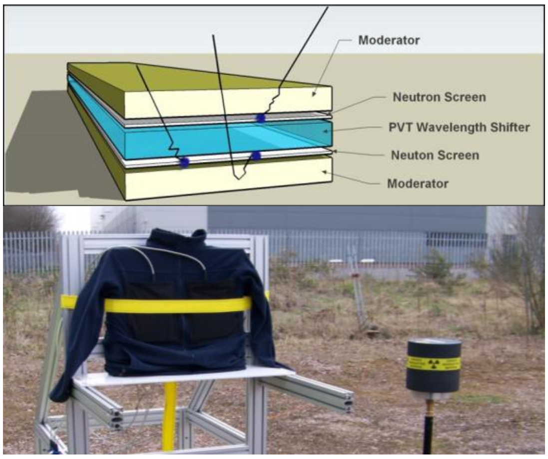


Figure 11. Clockwise: The instrument under test, its internal flow diagram, a single panel being tested for absolute efficiency, product specifications.

The instrument was tested using Symetrica's own software, Deep Discovery™, which provided data logging and detection logic. The detection algorithm used relies on a rolling integration window of two seconds and a fast tick time of 200ms.

Testing

The system was tested in the configuration as seen in Figure 12, against the IEC 62694 specification for backpack instruments. The Cf^{252} source (20k n/s) was at 1.5m moving at 1.2m/s.

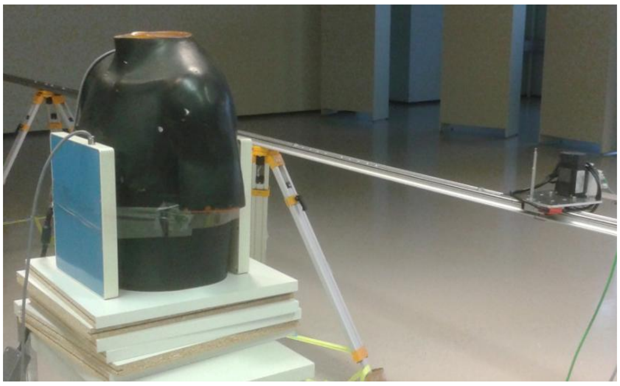
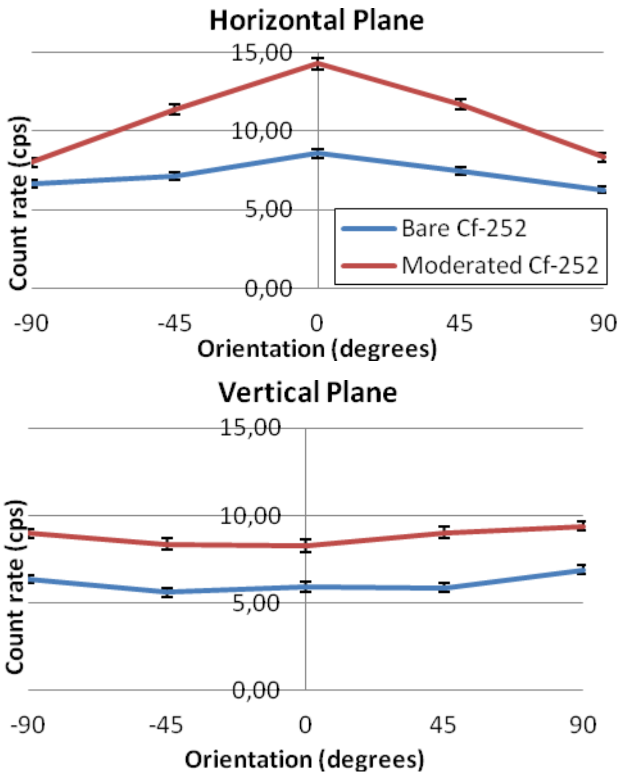


Figure 12. The test configuration for IEC 62694. The system is tested in ten orientations, rotated in two planes. Tests are carried out with both a bare and moderated (4cm HDPE) Cf^{252} source. Note that two units are fitted to the body phantom.

Table 7 shows the performance of the instrument during the dynamic detection test, and the static sensitivity test.

Table 7. Left: Dynamic detection results. Right: Static sensitivity as a function of instrument orientation.

	Detections/10 passes	
Horizontal plane	**Moderated Cf^{252}**	**Bare Cf^{252}**
-90	10	10
-45	10	9
0	10	10
45	10	10
90	10	8
Vertical plane		
-90	10	9
-45	10	10
0	10	10
45	10	10
90	10	10
Total =	100	96
False alarms in 6hrs =	0	



The instrument was also tested for gamma-ray rejection. It was exposed to 10mR/hr Cs^{137} radiation for three exposures of thirty seconds, as per IEC 62694. No false positives were observed, so the test was passed.

Conclusions

We can see that the instrument passed the parts of IEC 62694 tested here. The dynamic detection test was passed closely, though it is believed that the margin of success can be increased by reducing the detection threshold or the gamma/neutron discrimination threshold. Further testing will need to be carried out characterise these trade-offs. The directional variation in sensitivity is quite strong and we intend to exploit it in a jacket system to provide directional indication.

We conclude that the sensitivity represented by this pair of detectors in a jacket configuration is a useful target for a real jacket-worn system. We hope that we will be able to test such a system at NOVE 2015.

3.6 Thermo Fisher detector

A Thermo Scientific FHT 1377 GN-2 PackEye radiation detection backpack was tested. The backpack is designed for effectively addressing the problems of orphaned sources, radiation contamination, and source for malicious intent. In addition to a gamma detector, the backpack contains two Li-6 doped flat scintillation detectors (22 x 23 x 2.3 cm). The neutron detectors are of the same type as the detectors presented in section 3.5. The backpack is presented in Figure 13.

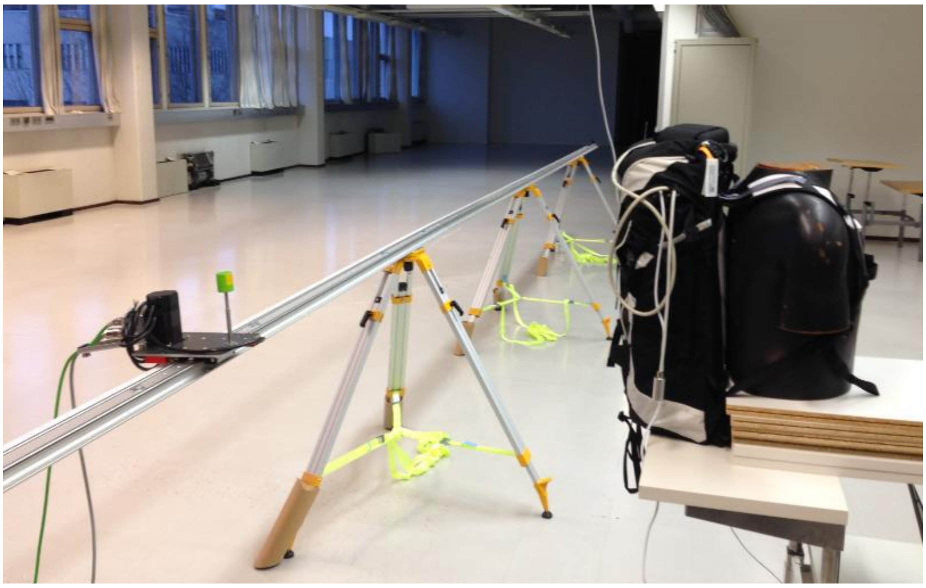


Figure 13. Thermos backpack during the NKS NOVE measurements.

Figure 14 presents the normalized net neutron count rate as a function of distance. The response was stationary at different positions on the track. It is evident from the figure that for this detector and in-door neutron testing, 1/r is a better approximation for the critical path than $1/r^2$.

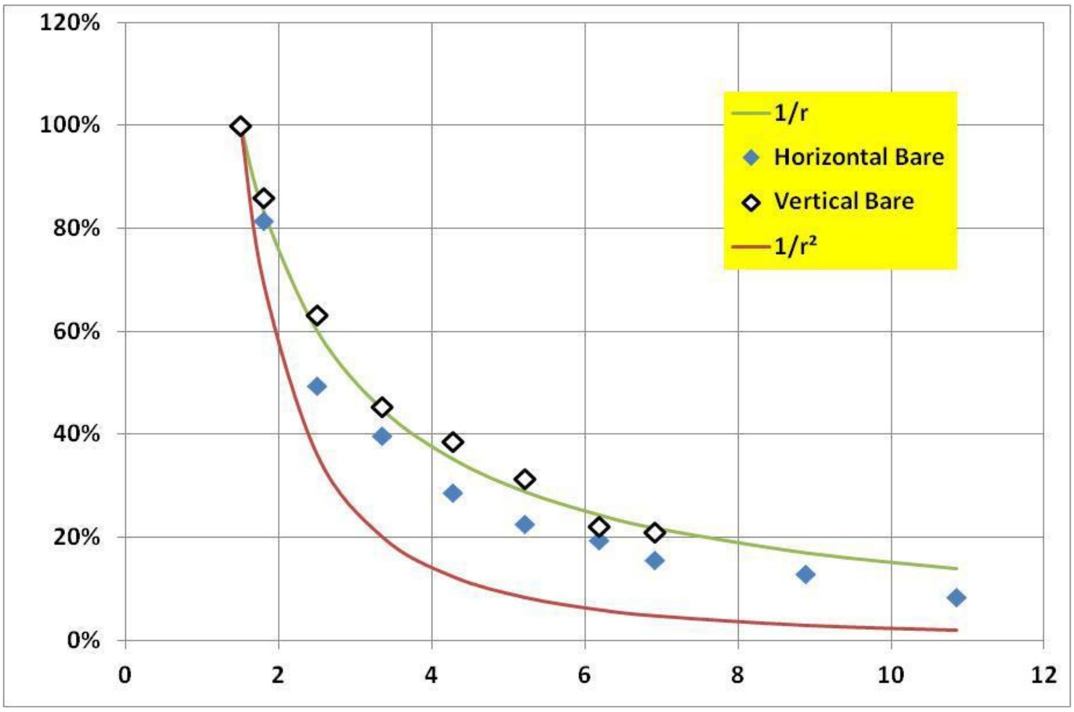


Figure 14. Normalized neutron count rate of the Thermo backpack. The x-axis shows the source-detector distance in meters.

4. Conclusions and discussion

A large number of novel and conventional neutron detectors were tested under the same experimental conditions. This report presents both the different techniques used as well as measurement results. The project was a natural continuation of the stationary measurements performed in 2013. As in the previous year, one of the most important results is the knowledge transfer between the Nordic countries in particular and the neutron detection community in general. The project attracted international interest and several private companies joined with their own funding.

During the seminar in Oslo, the results were presented and discussed. Certain problems in intercomparison testing where identified, such as the effect of neutron scattering in the measurement hall and the false positive alarm rate. While the standard provides a minimum performance level, the standard tests are not necessarily designed to facilitate a comparison between different detectors. The majority of the detectors did not have problems passing the detection requirement set by the standards.

Monte Carlo simulations are one possible future task. Especially in the case of the indirect gamma spectrometric neutron detection approach, better knowledge on the relevant neutron reactions may enable further optimization of the neutron signal.

When detecting a source, not only the detector efficiency but also the signal processing algorithm is important. Several different processing approaches were discussed and used by the different groups. The simplest way of performing dynamic measurements is to do subsequent measurements with a fixed, short measurement time. However, one conclusion of the present project was that the detection performance can be greatly improved by using other methods, such as a moving average of the signal or list mode data analysis (see (Peräjärvi et al, 2014) for a state-of-the-art report on list mode data acquisition). The chance of detecting the source depends on the ability to optimize the measurement integration time window. This optimization can be performed in different ways.

5. References

Holm, P et al.2012. Neutron detection with a NaI spectrometer using high-energy photons. Nucl. Instrum. and Methods in Phys. Res. A. 697: 59-63. http://dx.doi.org/10.1016/j.nima.2012.09.010.

Holm, P et al. 2014. A capture-gated neutron spectrometer for characterization of neutron sources and their shields. Nucl. Instrum. and Methods in Phys. Res. A. 751: 48-54. http://dx.doi.org/10.1016/j.nima.2014.03.021

Peräjärvi, K et al, 2014. List-mode data acquisition based on digital electronics. European Commission Joint Research Centre.
doi:10.2788/88299

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Disclaimer

The views expressed in this document remain the responsibility of the authors and do not necessarily reflect those of NKS. In particular, neither NKS nor any other organisation or body supporting NKS activities can be held responsible for the material presented in this report.

APPENDIX A: Minutes of the NKS NOVE seminar in Oslo

Participants:
Philip Holm, Kari Peräjärvi, Harri Toivonen, Torbjørn Gäfvert, Morten Sickel, Jonas Nilsson, Mathieu Boucher, Jonathan Dipple, Mark Foster, Jukka Härkönen

Place:
Radisson BLU Scandinavia Hotel, Oslo, Norway

Agenda:
4.12

12:00 Opening (NRPA/Torbjørn Gäfvert) + tour de table
12:15 Lunch
13:20 Project info: testing track & IEC standards
13:40 STUK presentation
14:20 Lund presentation
15:00 Coffee break
15:15 Environics Oy presentation
15:55 GE presentation
16:35 End of day 1

5.12:

8:30 Symetrica Security Ltd presentation
9:10 Thermo Fisher presentation (held by P. Holm)
9:50 Coffee break
10:05 Discussion
12:00 Lunch
13:00 Discussion continues
14:30 Coffee break
End of seminar

Outlines and main findings
The testing track and standards were described in the beginning of the seminar. All participants had tested their detectors, except for NRPA, who organized the seminar. The results of the measurements performed in STUK were presented (see final report of the project) and the detection methods were discussed.

The United States does not allow the use of He-3 in American portal monitors. This has created a need for novel detection techniques. However, because of the limitation set by the U.S., the demand for He-3 is lower and it is thus available to some extent outside the U.S.

The experience of the participating private companies is that the detector standards are not in general use, since customers use their own specifications. However, the standards can still be important for the customers as a reference.

The participating groups were satisfied with the testing opportunity provided by the NKS project and showed interest in continuing the collaboration.

Bibliographic Data Sheet **NKS-342**

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Author(s)	Philip Holm[1], Kari Peräjärvi[1], Harri Toivonen[1] Jonas Nilsson[2] Torbjørn Gäfvert[3] Mathieu Boucher[4], Jonathan Dipple[4] Mark Foster[5] Jukka Härkönen[6] Michael Iwatschenko-Borho[7]
Affiliation(s)	[1]Radiation and Nuclear Safety Authority, STUK, Finland [2]University of Lund, Sweden [3]Norwegian Radiation Protection Authority, NRPA [4]GE Reuter-Stokes [5]Symetrica Security Ltd. [6]Environics Oy [7]Thermo Fisher
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Project	NKS-B / NOVE
No. of pages	24
No. of tables	7
No. of illustrations	14
No. of references	2
Abstract max. 2000 characters	A large number of novel and conventional neutron detectors were tested under the same experimental conditions. This report presents both the different techniques used as well as measurement results. The measurements were performed at the Metrology laboratory of the Finnish Radiation and Nuclear Safety Authority using a Cf-252 source moving on an automated track. The project was a natural continuation of the stationary measurements performed in 2013. The following organizations participated in the project: - Radiation and Nuclear Safety Authority, STUK, Finland - University of Lund, Sweden - Norwegian Radiation Protection Authority, NRPA - GE Reuter-Stokes - Symetrica Security Ltd. - Environics Oy - Thermo Fisher

The results were presented and discussed in a seminar in Oslo, Norway. Certain problems in intercomparison testing where identified, such as the effect of neutron scattering in the measurement hall and the false positive alarm rate. IEC standards where used as a reference for the test. While standards provide a minimum performance level, standard tests are not necessarily designed to facilitate a comparison between different detectors. The majority of the detectors did not have problems passing the detection requirement set by the standards.

Key words Neutron detection