Scintilla European project, the successful research results

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***Abstract*— The Scintilla FP7 project is ended in December 2014, the fruitful results of 3 years development and tests will be presented. SCINTILLA offers the capacity to finding a reliable alternative to Helium-3 based detection systems since the gas which is predominantly used in nuclear safeguards and security applications has now become very expensive, rare and nearly unavailable. SCINTILLA benchmarks results are based on international standards. Radiation Portal tests were carried out at the Joint Research Centre (JRC) in Ispra (Italy).**

The scintilla project addresses few mains issues. The first is to develop neutron detectors for Radiation Portal Monitor (RPM) and the second is the need of new wearable integrated solutions for Spectrometric Personal Radiation Monitor (SPRM). The partners which provide technical systems of the scintilla project are INFN-ANSALDO, CEA, SYMETRICA and SAPHYMO.

For RPM, the objective is to find reliable alternatives to Helium-3 historical neutron detector and provide technical solutions which cope with tests for reliable mobile and cost effective.

For Spectrometric Personal Radiation Monitor (SPRM), SCINTILLA is innovating in technology areas that offer complementary capabilities for detecting and identifying gamma,

Two CZT (Cadmium Zinc Telluride) addressing contexts of used by first responder technologies, one is a wearable detector and the second is a gamma camera complemented by advanced image processing technologies.

***Index Terms*— Homeland security, Safeguards, Nuclear measurements, neutrons, Helium 3**

I. INTRODUCTION

THE objectives to solve the shortage of ^{3}He neutron detector for Radiation Portal Monitor (RPM) is solved by tree different technics, CEA develop system based on EJ200 plastic scintillator set, INFN ANSALDO proposed a Gd-lined plastic scintillator and SYMETRICA a LiZnS neutron sensor. The neutron detection systems started from TRL4 to reach TR7. SCINTILLA aims was to build an innovative devices and best-of-breed technologies for the enhanced detection and identification of difficult-to-detect radioactive sources and nuclear material. Neutron detectors are tested to know their ability to reach the standard of RPM. JRC ITRAP facility allows all partners to carry out tests in the conditions of standards requirements for RPM applications. Tests are performed for vehicles (car, truck or containers) and for pedestrians. The facility allows adaptive conditions to perform standards tests for RPM. The systems are designed to answer to the ANSI [1] and IEC [2] specifications for RPM .

- Vehicle RPM from INFN/ANSALDO and CEA
- Vehicle RPM from SYMETRICA and SAPHYMO
- Vehicle and Pedestrian SRPM from SYMETRICA

Figure 1: Vehicle RPM from INFN/ANSALDO and CEA

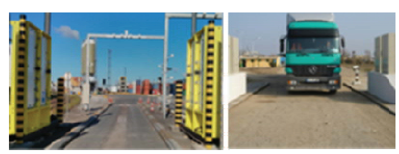

Figure 2: Vehicle RPM from SYMETRICA and SAPHYMO

Figure 3: Vehicle and Pedestrian SRPM from SYMETRICA

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In addition the following technologies from external partners attended:

- Liquid scintillator based vehicle RPM (single-sided) from University of Michigan
- Plastic scintillator based vehicle RPM (single-sided) from Thermo Fisher
- Boron-based neutron module for vehicle RPM from General Electric Reuter Stokes
- Inorganic scintillator based gamma module for vehicle RPM from Sitael

The equipment below complete the technologies tested:

- Two versions of the gamma camera from CEA
- Backpack gamma/neutron system from Thermo Fisher

The section II describes test bed and blind benchmark principles are details. Benchmark results for R&D systems and COTS equipment's are presented under section III. Gamma camera is described under section IV. section V.

II. Benchmark principles

The tests concentrate on radiometric properties. The test benchmark and blind benchmark are performed to qualify equipment's capabilities in a common platform. The portal configuration (distance from source) is full-size double-sided vehicular portals with 5 m distance between pillars.

Figure 4: JRC Track in the dynamic laboratory for benchmark

A. Neutron detection test

The response to neutron radiation for RPM-type of equipment was performed in dynamic conditions. When a testing neutron source passes through a portal at the constant reference speed (1 m/s for pedestrian, 8 km/h for vehicle) it should trigger an alarm with at least 95% probability. In order to assure the required probability the RPM should alarm at least 29 times out of 30 trials. The reference neutron testing source is a Cf-252 source with emission of 20'000 n/s (±20%), gamma-shielded with 1 cm steel and 0.5 cm lead.

The source effectively used (NC5549) had an emission of 21000 n/s at the date of the tests. The test has been executed also in non-standard conditions.

B. False alarm

False alarm principle: FAR (False alarm rate) in a portal is required to be less than 1 over 10'000 transits. Generally this is reached by setting the alarm threshold at a level at least equal (or grater) to the background plus 4 times sigma (where sigma is the standard deviation of background). This should be also proven experimentally. During the benchmark some overnight FAR tests were executed, even though the short time did not allow the reach a statistic sufficient to certify the 1/10000 probability. The FAR test was done by transiting repeatedly the conveyor without any radioactive source just to trigger the occupancy sensor.

C. Neutron and high gamma flux

The presence of a strong gamma radiation may affect the performance of the neutron detector. Tests were carried out in order to verify that gamma radiation does not induce a false neutron signal in absence of neutron field and gamma radiation does not mask a real neutron signal in presence of neutron field. The tests were executed by placing a Cs-137 source allowed reaching a gamma dose rate of 0.02 mSv/h at the detector surface.

D. Identification results

All tests were based on the ANSI and IEC standards for SRPM dealing with spectroscopic and identification features using individual radioisotopes, special nuclear material and mixtures of sources (masking scenarios).

E. Naturally Occurring Radioactive Materials

NORM's detection was tested outdoor in June 2014.

III. Benchmark results (dynamic mode)

Seven vehicular radiation portal monitors (RPMs) and two (one vehicular and one pedestrian) spectroscopic radiation portal monitors (SRPMs) were tested in the third and final SCINTILLA benchmark held at JRC's ITRAP laboratory in Ispra in November 2014. A short summary of main results is presented here.

A. Neutron detection test

All portals, except one, have passed the minimum standard requirement alarming in 100% of cases with the bare (gamma shielded) standard source.

Some tests with more challenging conditions were executed to test beyond-the-standard capabilities and are described in chapter IV.

B. False alarm

The benchmark duration did not allow testing long enough in order to verify a FAR up to 10^{-4}. Anyway only portals based on plastic scintillators have evidenced a relatively high FAR (above 1/1000), whereas all the other prototypes have shown a FAR definitely below 10^{-3}.

C. Neutron and high gamma flux

Portals based on organic (plastic and liquid) scintillators have shown to saturate when exposed to strong gamma source, so they give false neutron alarm under this conditions.

The other technologies proved to be more resilient to gamma fields: they did not provide false neutron alarm with a strong gamma source and the preserved their neutron detection capacity (alarming when exposed to a standard neutron source in addition to the strong gamma).

D. Response to gamma radiation

All portals alarmed in 100% of cases with the standard gamma sources of medium and high energy; some alarmed only partially with sources of low energy (Am-241 and Co-57).

E. Identification results

This test is significant only for the spectroscopic portals (SRPM). They were performed using individual radionuclides, special nuclear material and mixtures (masking scenarios).

In all conditions the tested portals passed the requirement of >90% correct positive identification, even though in some cases false positives appeared.

IV. Beyond the standards for response to neutron radiation, benchmark results

Additional tests were done with the objective to verify detection capabilities beyond the standards; in particular:

- Moderated/shielded source (4 and 8 cm HDPE)
- Higher transit speed (up to 3 m/s)
- Transit at the top of the detection area
- Sources with intensity at 2/3 (13’000 n/s) and 1/3 (7’000 n/s) of the standard requirement

Some of the portals (in particular those based on Li, B and Gd converters) proved capability to detect neutrons also under conditions more challenging than the standard requirements.

V. Benchmark result gamma camera (static mode)

Only CZT gamma cameras (named Myriagami and Hispect) developed at CEA were tested during the SCINTILLA benchmarks. Moreover there are currently no standards defining the required performances of this type of instrument.

Lacking of any reference target set by standards and of a comparison to another similar commercial instrument, it is not possible to benchmark the gamma cameras versus a predefined performance. The activities performed during the third benchmark were mostly a test-bed service in order to understand the capacity and limitations of the gamma cameras.

A. Sensitivity and detection capability

This parameter can be measured by exposing the camera to a point gamma source during a certain exposure time such to clearly detect the presence of the source. In order to cover the full range of photon energy (low, medium, high) the test should be done using ^{241}Am, ^{57}Co, ^{133}Ba, ^{137}Cs and ^{60}Co.

The reference dose rate produced by the sources at the reference point of the instruments shall be 0.05 μSv · h^{-1}. The selected dose rate of 0.05 μSv · h^{-1} was chosen in order to test the sensitivity limitation of the two cameras. An additional test shall be performed with a dose rate of 0.5 μSv · h^{-1} to test the sensitivity of the system against the requirement for the usage case scenario defined in the Scintilla project.

Table 1: Sensitivity test: time to localization (TTL) with a SNR of 10 sigmas.

Gamma sources	Activity	Distance	Estimated dose rate	Myriagami TTL	Hispect TTL
^{241}Am	2.59 MBq	100cm	0.01 µSv/h	320 s	20 s
^{133}Ba	700kBq	100cm	0.03 µSv/h	80 s	38 s
^{57}Co	1.4 MBq	170cm	0.01 µSv/h	44 s	20 s
^{137}Cs	500 kBq	100cm	0.04 µSv/h	44 s	155 s
^{60}Co	200 kBq	100cm	0.06 µSv/h	52 s	>300s
^{60}Co	5.3 MBq	170cm	0.56 µSv/h	18 s	34 s

B. Angular resolution and field of view

Angular resolution was measured by using two identical ^{133}Ba point sources initially overlapping and then moving them apart until the camera can clearly distinguish the two sources. Measured resolution is 2.5 degrees for Hispect camera and 4 degrees for Myriagami camera.

Field of field can be tested by moving a source from the centre of the field of view to the sides in 5 cm increments, and measuring the camera response in terms of sensitivity and localization capability. The source strength shall be strong enough to assure that the result is not biased by the intrinsic camera sensitivity. The Hi-spect gamma camera exhibits a narrower field of view (36°) than that of Myriagami (44°).

C. Radionuclide identification

The identification capabilities of the two gamma cameras are tested alongside with the localization capabilities by exposing the instruments to different gamma sources in both bare and shielded configuration.

The list of radioisotopes for this test includes:

- NORM: ^{226}Ra, ^{232}Th

- Industrial radionuclides: ^{57}Co, ^{60}Co, ^{133}Ba, ^{137}Cs, and 241Am

- Special nuclear materials: HEU (highly enriched uranium, ^{235}U >90%), RG-Pu [Reactor grade plutonium (> 10% ^{240}Pu)], WG-Pu [Weapons grade plutonium (< 10% ^{240}Pu)]

Table 2: Identification test: number of exact identification achieved with confidence in 300s.

Gamma sources	Activity	Distance	Estimated dose rate	Myriagami	Hispect
^{241}Am	2.59 MBq	100cm	0.01 µSv/h	3/5	22/22
^{133}Ba	700kBq	100cm	0.03 µSv/h	10/12	15/15
^{57}Co	1.4 MBq	170cm	0.01 µSv/h	8/8	11/11
^{137}Cs	500 kBq	100cm	0.04 µSv/h	3/9	1/6

^{60}Co	200 kBq	100cm	0.06 µSv/h	0/3	1/3
^{60}Co	5.3 MBq	170cm	0.56 µSv/h	3/3	7/7
WGPu	6.63 g	100cm	0.04 µSv/h	4/4	6/6
HEU	54.8 g	100cm	0.01 µSv/h	4/4	6/7

Hispect shows better identification capabilities than Myriagami.

In addition, masking scenarios in which a Special Nuclear Material is exposed together with another source of similar or higher radiation intensity shall be performed. The list of scenarios for such test includes:

- WGPu + ^{137}Cs
- WGPu + ^{133}Ba
- HEU + ^{57}Co
- HEU + NORM (^{226}Ra or ^{232}U)

Figure 5: Example of a 5 min image acquired by Hispect camera with a 55g HEU sample (automatically identified by the software in green) at 1 meter and a masking ^{57}Co source (16.8 MBq, identified in red).

VI. CONCLUSION

The Scintilla program shows that it is a profitable for researchers to use common tests platform. Sharing the mobile platform and radioactive source from JRC add with an independent analysis increase the confidence on results.

The Lithium 6, Gd-lined and plastic scintillators with EJ200 or had proven their efficiency for RPM applications. These systems would then become a real and complete alternative to the ^{3}He shortage. The technologies can be used in a wide range of security applications.

The Scintilla feedback enforces the utility in Europe to share test-platform for qualifying system.

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