Nuclear Science and Technology Symposium - NST2016
Helsinki, Finland, 2-3 November 2016

The NINS3 Research Project

Pauli Peura, Camille Bélanger-Champagne, Thomas Kerst, Paula Eerola, Peter Dendooven
Helsinki Institute of Physics
Gustaf Hällströmin katu 2, 00560 Helsinki, Finland
pauli.peura@helsinki.fi, camille.belanger-champagne@helsinki.fi, thomas.kerst@tut.fi, paula.eerola@helsinki.fi, peter.dendooven@helsinki.fi

Juha Toivonen
Tampere University of Technology
Korkeakoulunkatu 10, FI-33720 Tampere, Finland
juha.toivonen@tut.fi

ABSTRACT

The Novel Instrumentation for Nuclear Safety, Security and Safeguards (NINS3) project builds upon existing knowledge gained in research projects that have been conducted earlier at STUK, the Finnish Radiation and Nuclear Safety Authority and Tampere University of Technology (TUT). In the NINS3 project, a GEANT4 Monte Carlo simulation framework has been developed allowing detailed simulations of passive tomography of spent nuclear fuel assemblies and active neutron interrogation systems to be made. In addition, laser-enhanced alpha-particle detection from a distance is a promising method for standoff alpha detection. The NINS3 project pursues the development of these three non-destructive assay methods for improvement of nuclear safety, security and safeguards.

1 INTRODUCTION

Nuclear power and nuclear methods are widely used around the world. Also chemical, biological and even explosive materials are common in laboratory environments. Thus there is a constant need to improve the deterrence against the unauthorized use of CBNRE (Chemical, Biological, Nuclear, Radiological and/or Explosive) materials. One path to follow is the improvement of radiation detection technologies. Non-Destructive Assay (NDA) methods offer increased safety characteristics as inspections can be made without the need to open the object under study.

The Novel Instrumentation for Nuclear Safety, Security and Safeguards (NINS3) project begun in 2015. The project is a direct consequence of the 2013 Finnish Government Resolution of the Comprehensive Reform of State Research Institutes and Research Funding [1] and has natural connection to the Finnish Nuclear Energy Research Strategy [2]. The project partners are Helsinki Institute of Physics (HIP), Tampere University of Technology (TUT), Radiation and Nuclear Safety Authority in Finland (STUK) and a consortium of companies in Finland involved in or in need of radiation measurements. The project is based at the Helsinki Institute of Physics (HIP).

2 THE NINS3 PROJECT

The NINS3 project includes three Research and Development (R&D) topics:

1. Passive tomography of spent nuclear fuel,
2. Alpha radiation and threat detection and imaging from a distance,
3. Active neutron interrogation of unknown objects.

In addition to the research topics, there is an active research to business (R2B) aspect in the project where new Intellectual Property (IP) is protected and the commercialization potential of the project outcomes is investigated and pursued.

2.1 Passive tomography

Finland and Sweden are steadily proceeding towards permanent disposal of spent nuclear fuel [3]. Before clearance for permanent storage can be granted, the integrity of each spent fuel assembly against gross and partial defects has to be verified [4]. From the safeguards perspective, the technology used for inspections should provide credible assurances that no diversion of nuclear material has occurred before the final disposal [4,5]. Passive gamma-ray tomography is an NDA method for spent fuel assemblies, with a demonstrated spatial resolution down to single fuel-pin level [6,7]. The prototype unit produced under the IAEA Support Programme JNT1510 has been shown to detect single missing pins from BWR and VVER-440 type fuel assemblies. However, there is a need to be able to optimize the measurement time and the reliability of the radiation detectors [7].

An efficient way to optimize the design parameters of a planned instrument is to use Monte Carlo (MC) simulations to compare the effects of various design choices. The simulations can provide predictions of the performance of complicated systems where analytical calculations would be tedious and time-consuming. In the NINS3 project, a passive tomography and an active neutron interrogation instruments are simulated using a GEANT4 [8] MC framework.

The current version of the simulation model, for further development of the passive tomography technology, features a full parameterization of radioactive sources and radiation detectors. In Figure 1, the implemented simulation geometry of a VVER-440 fuel assembly is shown.

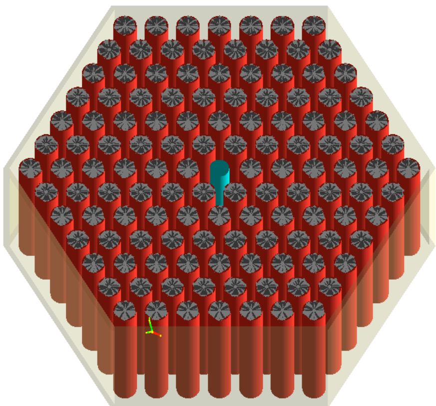

Figure 1. The simulated geometry of a VVER-440 reactor fuel assembly that is used in the GEANT4 simulations. The fuel pellets, in grey, are enclosed in the red fuel rods while the blue rod in the middle marks the position of a water channel.

The simulation model will be verified against experimental results obtained with the JNT1510 tomography prototype. With the help of the MC simulations an optimized design of a tomographic instrument will be made. This work will also support the commercialization of an optimized spent fuel tomography device.

2.2 Alpha radiation detection from a distance

Alpha-particle emitting nuclides are very radiotoxic when ingested or inhaled. Thus they are important from the point of view of protection against CBNRE threats. A laser-enhanced method to detect alpha-radiation sources from a distance is being developed in the NINS3 project. Due to the short range of alpha particles in air, the detection of alpha radioactivity is typically performed using surface-contamination meters. Detection from a distance, and through certain materials, would improve the safety of radiation workers and would add an alternative tool for alpha-radiation detection for improved nuclear security.

As the alpha particles propagate in air, they ionize the air molecules causing the emission of ultraviolet (UV) light. This radioluminescence is usually rather weak making the detection of the UV light challenging in normal lighting conditions. In collaboration with TUT, STUK and the European Commission, this detection technique was successfully demonstrated [9]. However, the measurements were performed in total darkness due to the high daylight sensitivity of the cameras used.

Passive and active ways to enhance UV light emission will be investigated at TUT within the NINS3 project. For the passive method, the concentration levels of environmental gases close to the alpha-source have been altered to triple the radioluminescent yield of the passive detection method. For the active method, a laser setup has been constructed, that will allow the investigation of the enhanced fluorescence light yield around alpha-particle sources using Laser Induced Fluorescence (LIF).

Only a small fraction of the radioluminescence spectrum does not overlap with the spectrum of sunlight, making it an indicator of the presence of alpha radiation even under normal lighting conditions. A comparison of the radioluminescence spectrum and the solar spectrum is shown in Figure 2. The possibility to use LIF to enhance this region of the spectrum to detectable levels will be investigated.

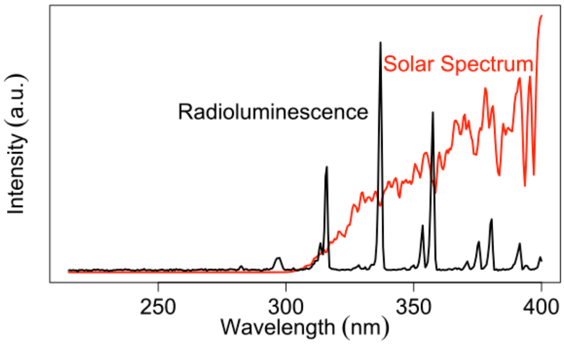

Figure 2. Comparison of the radioluminescence spectrum with the solar spectrum (not to scale). The latter one is usually many orders of magnitude higher in intensity and eclipses most of the radioluminescence. A small fraction of the radioluminescent light is emitted at short enough wavelengths to avoid this effect.

2.3 Active neutron interrogation

A flux of neutrons from a neutron source can be used to identify unknown objects. As the neutrons interact with the materials under study, for example via inelastic neutron scattering, gamma rays are emitted. As these gamma rays are isotope specific, the elemental composition of the unknown objects can be extracted by detecting the gamma rays. Neutrons and high-energy gamma rays are well suited for the detection of even concealed contraband, as matter does not easily attenuate them. However, a hidden object can be inside a large container making the localization efforts difficult [10].

The NINS3 research efforts have a direct link to a Finnish Ministry of Defence funded MATINE project where a new active neutron interrogation instrument is being developed. Monte Carlo simulations in GEANT4 within the NINS3 project are used in the design of the new instrument. The goal is to optimize the gamma-ray signals that originate from fast-neutron and thermal-neutron reactions. This separation can be achieved via appropriate moderation of neutrons from a neutron generator. The simulated effect of the moderator thickness on the fast neutron (E_n = 1–2.5 MeV) intensities and arrival time at the location of the unknown object is shown in Figure 3. Figure 4 shows simulation results of the gamma rays emitted by a TNT-filled artillery shell. In addition to the design optimization, the use of gamma-ray imaging in conjunction with active neutron interrogation is investigated in the NINS3 project.

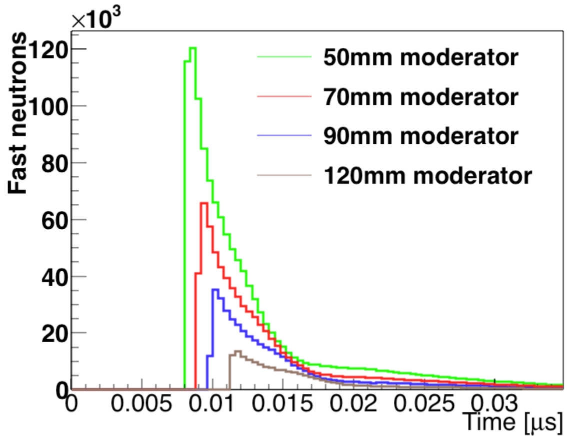

Figure 3. The MC simulation results show how the polyethylene moderator thickness affects the arrival-time distribution of fast (E_n = 1–2.5 MeV) neutrons within an unknown-object volume.

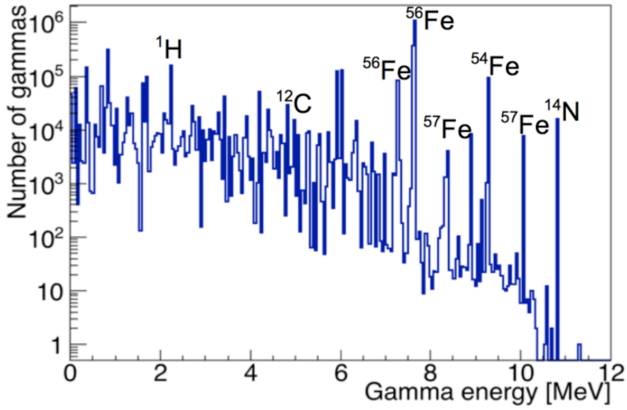

Figure 4. The emission spectrum of gamma rays resulting from neutrons impinging on a TNT-filled artillery shell as calculated in the MC simulation. The most prominent peaks in the energy spectrum are marked with their nuclide of origin.

3 OUTLOOK

In the NINS3 project, a laser setup for the study of laser-enhanced detection of alpha-radioactive sources from a distance will be finalized. Increase in the UV-light yield from an alpha-particle source would allow for faster and safer assessment of a threat. Furthermore, a GEANT4 MC simulation framework has been constructed. The simulations are used to optimize the design of a passive gamma-ray tomography device and an active neutron interrogation instrument. Through the development of NDA methods for various radiation detection scenarios, the NINS3 R&D contributes to nuclear safety, security and safeguards.

ACKNOWLEDGEMENTS

The authors would like to thank Hannes Vainionpää and Harri Toivonen for the valuable input to the R&D Topic 3. The NINS3 project is funded through the FiDiPro Program of Tekes, The Finnish Funding Agency for Innovation. Support for the project is also provided through the NINS3 consortium.

REFERENCES

[1] Radiation and Nuclear Safety Authority, STUK, "National Programme for Radiation Safety Research", STUK-A 260, 2015, ISBN 978-952-309-272-3

[2] Ministry of Employment and the Economy, "Nuclear Energy Research Strategy", Energy and the climate, 17/2014, 2014, ISBN 978-952-227-866-1

[3] IAEA, "Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste", IAEA-TECDOC-1755, 2014

[4] STUK, "Safeguards for Final Disposal of Spent Nuclear Fuel", STUK-YTO-TR 199, 2000

[5] IAEA Nuclear Energy Series, "Technological Implications of International Safeguards for Geological Disposal of Spent Fuel and Radioactive Waste", No. NW-T-1.21, 2010

[6] F. Lévai *et al.*, "Feasibility of Gamma Emission Tomography for Partial Defect Verification of Spent LWR Fuel Assemblies", STUK-YTO-TR 189, 2002

[7] T. Honkamaa *et al.*, "A Prototype for passive gamma emission tomography", IAEA Symposium on International Safeguards: Linking Strategy, Implementation and People, Vienna 2014

[8] S. Agostinelli *et al.*, "GEANT4 – a simulation toolkit", NIM A 506, 2003, 250–303

[9] J. Sand *et al.*, "Imaging of alpha emitters in a field environment", NIM A 782, 2015, 13–19

[10] A. Buffler, J. Tickner, "Detecting contraband using neutrons: challenges and future directions", Radiat. Meas. 45, 2010, 1186–1192