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► To cite this version:

Adrien Sari, Frédérick Carrel, Amélie Grabowski, Frédéric Lainé, Bruno Espinosa, et al.. Deployment of the First Photofission Measurement System Dedicated to SNM Detection in Europe: Outcomes and Future Prospects. 2019 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), Oct 2019, Manchester, United Kingdom. pp.9059765, 10.1109/NSS/MIC42101.2019.9059765 . cea-04560144

HAL Id: cea-04560144

<https://cea.hal.science/cea-04560144v1>

Submitted on 27 Apr 2024

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Deployment of the First Photofission Measurement System Dedicated to SNM Detection in Europe: Outcomes and Future Prospects

Adrien Sari, Frédérick Carrel, Amélie Grabowski, Frédéric Lainé, Bruno Espinosa, Jean-Philippe Poli, Pawel Sibezyński, Ian Della-Rocca, Mark Foster, Asénath Etilé, Olivier Roig, Serge Maitrejean, Sébastien Rogerat, Thibaut Berthelie, Estelle Gasser, Micha Slegt, René de Goede, Joris Groeneveld, Hans de Wilde, Marcel Heerschop

Abstract—Special Nuclear Material (SNM) such as uranium and plutonium isotopes could be potentially used to make a nuclear bomb involved in a terrorist attack. To prevent illicit trafficking of SNM in Europe, inspection of cargo containers at borders is required. X-ray scanning is widely used by customs to control suspect containers. However, this technology is not the most adapted to bring to light SNM signature. Therefore, a second line technology based on the photofission reaction could enable to detect SNM in a non-destructive manner. In the frame of the C-BORD European project, several teams specialized in photofission have joined forces to design an active photon interrogation system enabling to detect SNM hidden in cargo containers. The system is based on the use of a linear electron accelerator (linac). First, high-energy photons generated by Bremsstrahlung in the conversion target of the linac irradiate a suspect area of the cargo container. Secondly, prompt and delayed particles emitted following photofission reactions are detected if SNM is present. The largest seaport in Europe (Maasvlakte, in the suburbs of Rotterdam, Netherlands), where 9 MeV linacs are used by Dutch customs for X-ray scanning, has been chosen as test site. In order to deploy a full system taking advantage of all photofission signatures, different subsystems have been developed. In this paper, first, we give an overview of the photofission system. Then, we show how the system has been deployed at the Rotterdam seaport in September and October 2018 and tested on mock-ups of cargo containers. Finally, we show that setting up a photon interrogation system on an industrial facility initially designed for X-ray scanning is a challenge which has been successfully met in the frame of the C-BORD project to deploy the first photofission measurement system on an industrial site in Europe. The outcomes of this first deployment will be exposed and the future challenges to be addressed will be discussed.

Index Terms— Active photon interrogation, cargo containers, homeland security, linear electron accelerator (linac), photofission, uranium

I. INTRODUCTION

Special Nuclear Material (SNM) such as uranium and plutonium isotopes could be potentially used to make a nuclear

bomb involved in a terrorist attack. To prevent illicit trafficking of SNM in Europe, inspection of cargo containers at borders is required. X-ray scanning is widely used by customs to control suspect containers. However, the latter technology is not the most adapted to bring to light SNM signature. Therefore, a second line technology based on the photofission reaction [1] could enable to detect SNM hidden in containers in a non-destructive manner. Both fissile actinides (^{235}U , ^{239}Pu , etc.) and fertile actinides (^{238}U , ^{240}Pu , etc.) can undergo photofission. The energy threshold of the photofission reaction is around 6 MeV for all actinides.

C-BORD is a Horizon 2020 European project of 42 months of duration which started in June 2015 [2]. The project involved eighteen organizations from nine European countries. In the frame of the C-BORD project, several teams specialized in photofission joined forces to design an active photon interrogation system enabling to detect SNM in cargo containers with a view to improving homeland security in Europe. The system is based on the use of a linear electron accelerator (linac). First, high-energy photons generated by *Bremsstrahlung* in the conversion target of the linac irradiate a suspect area of the cargo container. Secondly, prompt and delayed particles emitted following photofission reactions are detected if SNM is present. The largest seaport in Europe (Maasvlakte, in the suburbs of Rotterdam), where 9 MeV linacs are operated by Dutch customs for X-ray scanning, has been chosen as test site.

In this paper, first, we give an overview of the photofission system. Then, we show how the system has been deployed at the Rotterdam seaport in September and October 2018 and tested on mock-ups of cargo containers. Finally, we present the outcomes of this first photofission system deployment in Europe and discuss the future challenges to be addressed.

Manuscript received December 12, 2019.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653323. Disclaimer: this text reflects only the author's views and the Commission is not liable for any use that may be made of the information contained therein.

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II. OVERVIEW OF THE PHOTOFISSION SYSTEM

When X-ray scanning of a cargo container highlights an area which is suspected to hide SNM, the photofission measurement is required as second line technology. The photofission system is composed of different subsystems, developed by technical partners from the C-BORD consortium, which are dedicated to the detection of prompt neutrons, delayed neutrons, and delayed gamma-rays.

III. DEPLOYMENT AT THE ROTTERDAM SEAPORT

After more than two years of experimental tests using a Linatron-M9 linac at the SAPHIR facility (CEA Saclay, France) [3] and optimizing the subsystems, the photofission system has been deployed in September and October 2018 at Maasvlakte — the largest seaport in Europe — which is located in the suburbs of Rotterdam, Netherlands. Fig. 1 and fig. 2 show one side of the photofission system in the X-ray tunnel where cargo containers are transported by truck.



Fig. 1. One side of the photofission system in the X-ray tunnel.

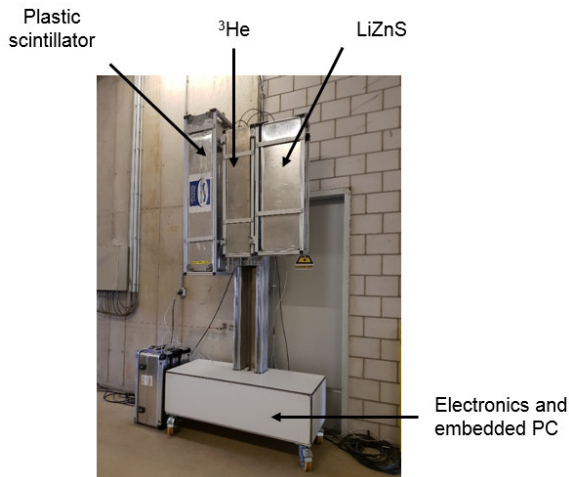


Fig. 2. Focus on the subsystems dedicated to the detection of delayed neutrons and delayed gamma-rays.

IV. FIELD TRIALS AND EXPERIMENTAL RESULTS

Experiments carried out at the Rotterdam seaport involved 10 feet mock-up containers with a matrix either of aluminum, fertilizer, or tobacco. In order to test the system with a real life scenario: depleted uranium was hidden by customs in a position

unknown by technical partners. Fig. 3 shows a view of an X-ray scan and a suspicious area where SNM could be present.

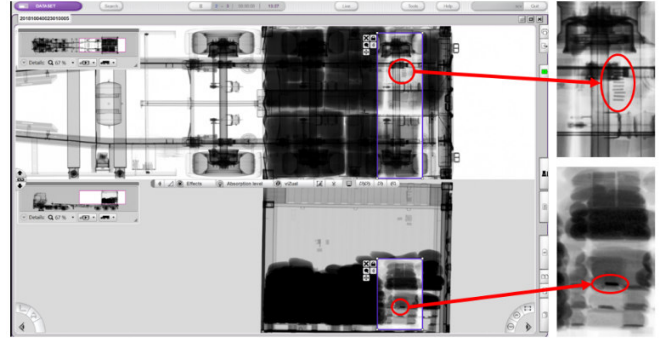


Fig. 3. Dual view X-ray pictures. Focus on suspicious shapes and dense objects.

The photofission measurement was performed in a stationary mode (the top linac operated at 100 Hz). First an active background was acquired. Then, the suspicious area was irradiated during 10 min. In case of a significant signal increase at 3σ , each subsystem shows a red light on the graphical user interface which enables to operate the full photofission system.

Moreover, acquisitions carried out during regular X-ray scans in a dynamic mode (mechanical conveyor speed at $40 \text{ cm}\cdot\text{s}^{-1}$) enabled to detect radioactive neutron sources in mock-up cargo containers and demonstrated that the photofission subsystems are also effective for passive measurement.

V. OUTCOMES AND FUTURE PROSPECTS

Setting up a photofission system on an industrial facility initially designed for X-ray scanning is a challenge which has been successfully met in the frame of the C-BORD project and enabled to deploy the first photofission measurement system on an industrial site in Europe. Experimental data were acquired for various configurations of cargo container mock-ups and real life scenarios.

The logical follow-up of this project would be to perform measurements on commercial containers. However, technical developments on the photofission subsystems should be pursued seeking to extend their use to passive measurement with a view to localizing and identifying radioactive sources. Furthermore, in order to meet the rising demand of customs in Europe, a new photofission system specifically adapted to a mobile linac could be developed. Nevertheless, designing a photofission system based on a 7 MeV linac would be a new challenge to address as the photofission energy threshold is around 6 MeV.

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