MAUD Project - development of a new portable detector for alpha and beta surface contamination mapping

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Abstract

The characterization and the localization of surface contamination is of first importance during the decommissioning process of a nuclear facility. Yet, there is currently no device capable of giving a real-time image of the surface contamination by α or β emitters. The MAUD project (supported by the French National Radioactive Waste Management Agency Andra) is aiming at developing a new type of portable detector capable of reconstructing the radioactivity image on a solid surface in real-time, and to provide an accurate mapping of contamination at the scale of a facility.

In this paper, the technological developments performed to realize the prototype of the project are presented. The optimization of the detection system is discussed as well as the choice of the read-out electronics. Then, the preliminary characterization of the detector response to ion-izing radiations, using alpha and beta emitters, is presented.

KEYWORDS: Autoradiography, surface contamination, alpha and beta radiations.

Introduction

Characterization of radioactive contamination on solid surfaces is a mandatory step of the dismantling process of any nuclear facility. In particular, the knowledge of the localization, and the nature, of the contamination is critical in order to define properly safety measures and to adapt the waste treatment accordingly. As a consequence, the waste activity must be precisely characterized in order to optimize the waste disposal. Thus, there is a strong need in dismantling applications for a device capable meas-uring the radioactivity on a surface and localizing it with good accuracy. However there is currently no portable and efficient tool capable of answering this need, particularly for alpha and beta emitters at low and intermediate level activity. Besides waste management, such device would prove to be extremely valuable for the radiological survey of a facility all along the dismantling progression.

The MAUD project (Digital AUtoradiography Measurements), is aiming at developing a new device which meets the previous expectations. The autoradiography method, which has proven to be very promising for dismantling application[1,2,3], was chosen to develop a nondestructive measurement of the contamination. The challenge of developing such detector is related to the necessity of measuring short range radiations such as soft β (e.g. from Tritium) or α particles (e.g. from Uranium). In the following paper, the specifications of the detector are discussed before presenting the instrumental development performed in the scope of the project. Subsequently, the preliminary results obtained with a laboratory prototype are presented.

Specifications of the detection system

MAUD being an industrial project, the detector specifications were carefully defined to match as much as possible the requirements of dismantling process. In particular, decisions regarding the mechanical structure and the development of Human Computer Interaction were made carefully to obtain a detector easy to handle during operations in hazardous environment. Aside from these industrial considerations, the detection system was optimized to detect short range particles, as detailed in the following section.

Among the various radioisotopes which are likely to contaminate a nuclear facility, many decay by the emission of a charged particle: an electron from β-emitters (^{3}H, ^{14}C, ^{36}Cl…), or an Helium nuclei from α-emitters (U, Pu, Am…). For such emitters, the maximum range in solid matter is usually below one millimeter (see Table 1 for details) making the detection of these radiations a tedious work. Among all isotopes, Tritium is well known for the very small range of the emitted beta electron making any detection very laborious. The radiation being completely stopped by few millimeters of air and less than ten microns of solid matter, nondestructive Tritium detection in a facility field is currently a technological bottleneck.

Range in matter (mm)						
	^{3}H	^{14}C	^{36}Cl	^{238}U	^{239}Pu	^{241}Am
Air	7.6	$3.2\ 10^{2}$	$3.1\ 10^{3}$	$3.3\ 10^{1}$	$4.5\ 10^{1}$	$4.9\ 10^{1}$
Water (liquid)	$6.7\ 10^{-3}$	$2.8\ 10^{-1}$	2.8	$2.9\ 10^{-2}$	$4.0\ 10^{-2}$	$4.3\ 10^{-2}$
Mylar	$5.2\ 10^{-3}$	$2.2\ 10^{-1}$	2.1	$2.2\ 10^{-2}$	$3.0\ 10^{-2}$	$3.3\ 10^{-2}$
Aluminium Oxyde	$2.2\ 10^{-3}$	$8.8\ 10^{-2}$	$8.6\ 10^{-1}$	$1.0\ 10^{-2}$	$1.5\ 10^{-2}$	$1.6\ 10^{-2}$

Table 1: **Typical range in matter of radiation from various α and β emitters**
Approximated range, in various material, for typical alpha and beta emitters.
The range is estimated using the ESTAR and ASTAR database[4].

The common detectors used in dismantling applications are usually radiation protection devices such as contamination monitors (e.g. LB 124 from Berthold Technologies or CoMo 170 from NUVIA Instruments). These devices are able to detect most alpha and beta emitters, even at trace level, but don't provide any localization information. Additionally, they are usually not able to detect Tritium, even at relatively high activity level.

The MAUD project is aiming at developing a new generation of detectors, providing an accurate surface contamination mapping, with similar detection sensitivity to existing detectors. Various autoradiography detectors, used in Biology, already meet these requirements[5,6] but such devices are laboratory tools and, thus, not suited for in situ application.

Taking into account all these considerations, the specifications for the MAUD project were defined as follow:

- Nondestructive measurement
- Portable and easy to handle device
- High mechanical resistance
- Real time image of contamination (resolution between 1 mm^2 and $1cm^2$)
- Alpha and Beta radiation detection (including Tritium)
- Contamination mapping at a facility scale

Additionally, the identification of the measured radiations was defined as a secondary objective.

Developments of the MAUD prototype

From the project specifications, the MAUD collaboration developed a first device to achieve the various objectives. This first detector was used as a laboratory prototype to demonstrate the relevance of the technical decisions made during the development. The construction of the first industrial detector is currently being performed by the Biospace Lab Company[7] and should be tested in dismantling facilities early 2019 (in France).

A scheme of the prototype is shown in Figure 1. The radiation detection principle is based on the scintillation process of a solid material. The light emitted by the latter is detected using a Sillicon PhotoMutilpliers (SiPM) array in direct contact with the scintillator. The SiPM analogic output is digitalized by a data acquisition system (DAQ), which is directly connected to a computer in order to perform data processing and display the measurement result.

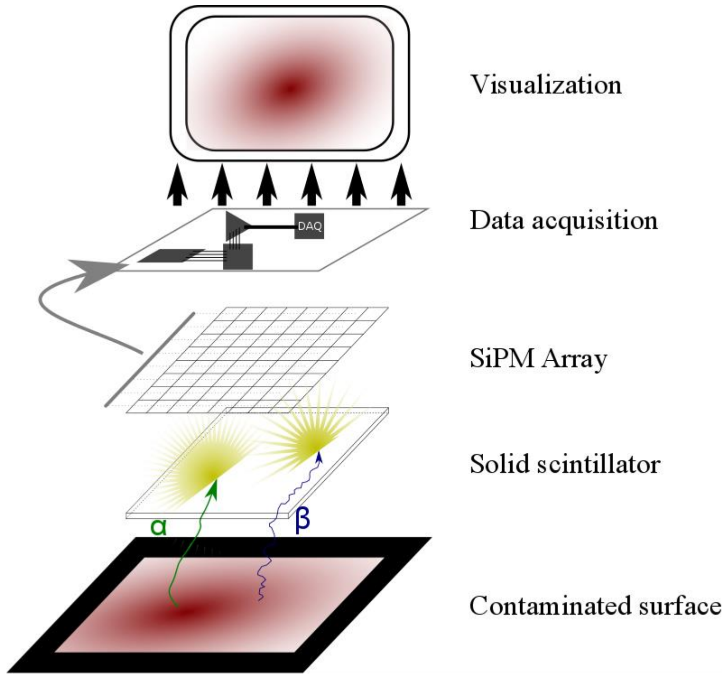

Figure 1: **Schematic view of the MAUD detector**

The entrance of the detector is a solid scintillator which can be adapted to each application. The scintillation material is directly responsible of the radiation detection, by converting the energy loss of the emitted particle in visible light. Solid scintillator can be used for a very wide range of applications and are perfectly suited for alpha and beta measurements[8]. As mentioned previously, in order to optimize the Tritium detection, no entrance window is placed in front of the scintillator which is in direct contact with the contaminated surface. The choice of the scintillator material is therefore constrained by mechanical resistance and contamination considerations.

The light produced by the scintillator is detected using several SiPM arrays. Lately these detectors have drawn a lot of attention as alternative to Photomultipliers or Intensified cameras. In particular, they are known to perform photon counting or very low light level measurements[9] and have started to be used in a wide range of applications[10,11]. In the scope of MAUD, the SiPM technology meets perfectly the project requirements with high quantum efficiency, high sensitivity and well-suited position resolution (the size of one SiPM vary typically from 1 to 40 mm^2). Besides, the SiPM array size can be adapted to the specificities of each dismantling facilities. The industrial prototype of the MAUD collaboration is based on a 64 SiPM array for a surface coverage of 25 cm^2 and an image resolution of about 35mm^2.

The DAQ is being developed in order to handle several SiPMs arrays to cover a large surface (several dozen of cm^2). The signals are processed in parallel (amplified, filtered and then selected) before being digitized by a 15 bits Analog-to-Digital Converter (ADC). In order to be suitable for a large range of applications the DAQ of the prototype is being designed in order to handle up to 100 kHz counting rate.

Preliminary results

The results presented in this section were obtained, in a laboratory, with a test bench using two 4x4 SiPM arrays (32 channels in total). The setup response to radiations was studied using low activity sources and various configurations. A single solid scintillator and a common exposure time were used for all the measurements presented in the following investigations.

To estimate the sensitivity of the detection system, various alpha (^{238}U, ^{239}Pu, ^{241}Am…) and beta sources (^{3}H, ^{14}C, ^{36}Cl, $^{90}Sr/^{90}Y$) were used. For all the radiations, the device has shown significant evidences of radioactivity measurement over the laboratory background. A first qualitative estimation of the detection sensitivity gives comparable results with existing commercial devices. However, this estimation requires a more quantitative analysis and is currently refined using calibrated sources and a numerical simulation. Yet, the detection of tritium with the device is a promising accomplishment for the MAUD project.

Secondly, the position resolution of the measurement was investigated using a beta radiation sample. A ^{36}Cl low activity source was collimated using a 3 mm thick Polymethyl methacrylate (PMMA) mask. A 3 mm diameter hole (smaller than the surface of one SiPM) was pierced in the center of the mask in order to let a small portion of the radiation go through. The source was placed on the top of one of the two SIPM arrays, the other being located further away in order to evaluate the natural background in the laboratory. The Figure 2 displays the reconstructed activity for each SiPM array of the setup. The number of counts obtained is rather homogenous all over the first array (without the source), while the second array exhibits a clear discrepancy in the measured activity. In particular, one SiPM has a much higher count compared to the other pixels of the array. This excess is a signature of the source location and an average of the SiPM positions, weighted by the individual measured activity, provides a proper position reconstruction. The spreading of the light signal over the neighboring pixels revealed to be rather limited ensuring an accurate reconstruction of the initial position of the source.

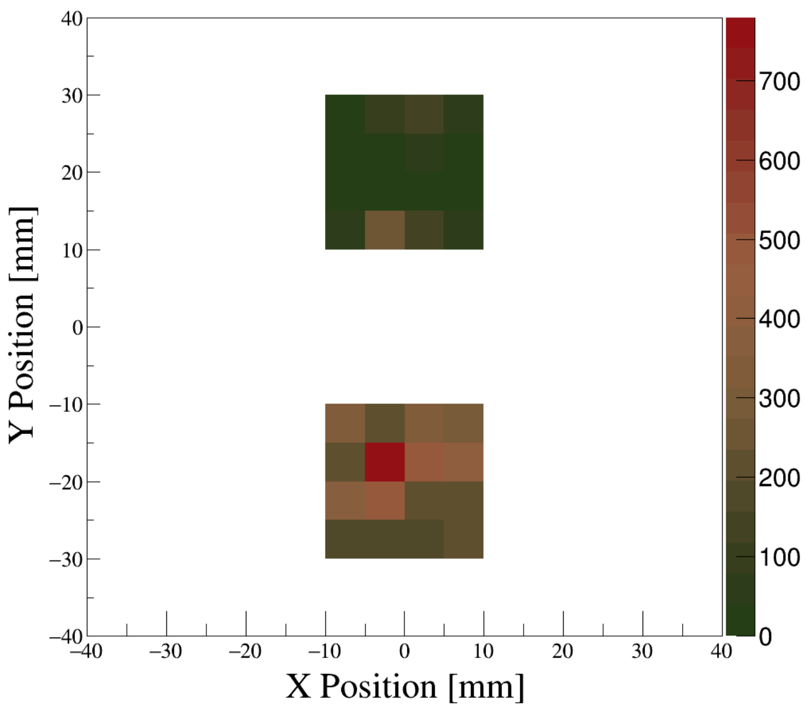

Figure 2: **Position mapping using ^{36}Cl beta source**

Position reconstruction of a ^{36}Cl source using MAUD prototype. Two 4x4 SiPM arrays were used by a plastic scintillator. The source was collimated using a 3mm thick PMMA mask with a 3 mm diameter hole. The red color corresponds to the highest measured activity (where the source was located) while the green color indicates the natural background of the laboratory.

Lastly, isotope identification using the MAUD prototype was investigated. In principle, one can discriminate the radiations using the light distribution coming from a scintillator. The latter, is directly related to the energy loss of the radiation in the material. Assuming that all radiations are stopped in the scintillator, the light distribution collected by the SiPM is directly correlated to the energy distribution of the detected particles. In the case of the beta radiation, the energy distribution is broad and can extend up to few MeV. On the other hand, the energy distribution of alpha radiation is narrower and located typically between 4 and 9 MeV.

To investigate this opportunity, the collected light distribution of the MAUD detector has been studied with one beta source (^{14}C) and one alpha source (^{239}Pu). The results are displayed in Figure 3, in which the light distribution exhibits two different trends. On the one hand, the shape of the ^{14}C light distribution is rather broad and the maximum is located at a rather small number of photons. On the other hand, the ^{239}Pu light distribution is more condensed around a central value and the maximum of the distribution is located at a much higher number of photons. As mentioned previously, these preliminary observations were expected from the scintillator properties and confirm a very promising property of the detection system. Indeed, the shape and the maximum position of the distribution should discriminate the alpha from the beta radiation when using MAUD device. Additionally, the possibility to distinguish the radiation from various alpha and beta emitters is currently investigated by the collaboration.

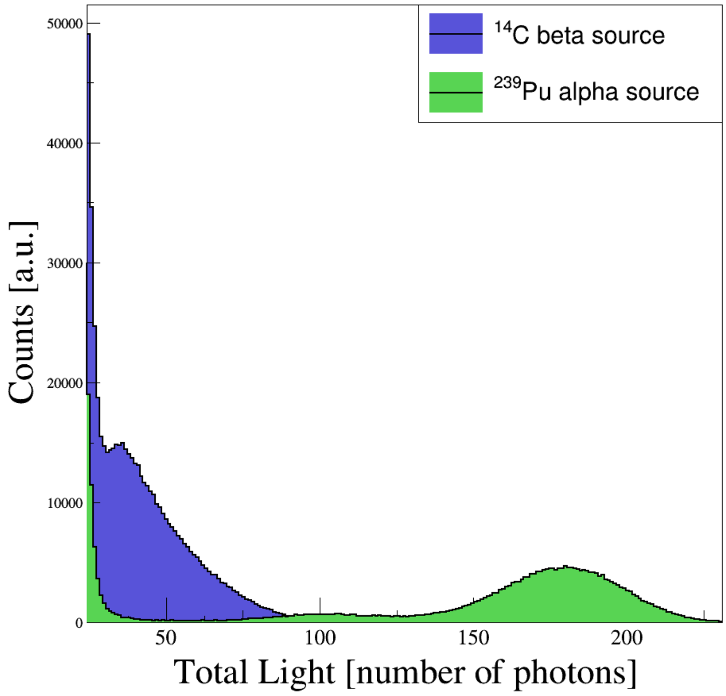

Figure 3: **Characterization of beta and alpha source**

Total light distribution accumulated in the 32 channels of the MAUD laboratory prototype. The green distribution corresponds to the data taken with a ^{239}Pu source (alpha emitter) while the blue distribution correspond to the ^{14}C source (beta emitter).

The full characterization of the MAUD detection system is still on going and will be finalized in the up-coming months. The response of the device to contaminated samples coming from dismantling facility will be investigated as well.

Conclusion

In this paper, recent developments and studies realized during the MAUD project were presented. The project aims at providing a nondestructive technique to characterize, on solid surfaces, the contamination by radionuclides difficult to measure (mainly α and β emitters). The preliminary results obtained in laboratory are very promising and an industrial prototype should be tested in a dismantling facility early 2019.

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