MATERIAL RECOGNITION BY MEANS OF DIFFERENT BREMSSTRAHLUNG BEAMS: IS THAT REALLY POSSIBLE?

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Abstract

At the Dipartimento di Fisica, Università di Messina, an X-ray source based on a 5 MeV electron linac has been designed. By means of the MCNP-4C2 code, several simulations have been performed to evaluate if the source can be used as a NDT device for material recognition purposes. In particular, being able to vary the electron beam energy for producing bremsstrahlung beams with different absorption, X-ray transmission through several materials and for different X-ray beams energy has been studied. First results have shown the capability of the system to distinguish dissimilar materials by properly choosing the X-ray beam end-point energy and processing the obtained transmission values. Since the uncertainties level in the material identification could be improved differentiating the response of the imaging system, a theoretical study has been performed to evaluate how X-ray beams obtained with different end-point energies, and eventually transmitted by properly chosen filters, are absorbed by different scintillators. The obtained results will be presented and discussed in order to give indications on the real chance to use the designed device for material recognition purposes.

INTRODUCTION

Material recognition can be achieved by means of the dual energy radiography technique which allows to determine the effective atomic number and electron density of the investigated materials by using two monochromatic X-ray beams thus univocally identifying them. However, the technique is limited to low energy (below 200keV) x-ray radiography and to light materials (Z<20), because it is based on the capacity to distinguish between Photoelectric effect and Compton scattering contributions. In fact, for the above energy and atomic number ranges, the linear attenuation coefficient μ can be represented as a function of energy composed by contributions from photoelectric absorption (which dominates at lower energy and is mainly dependent on the atomic number) and Compton scattering (which dominates at higher energy and is mainly dependent on the electron density).
As a consequence, the dual energy technique does not work for heavy or thick materials, for which ones high x-ray energies are required. However, as discussed in [1, 2], an attempt to achieve discrimination of materials has been done by considering two x-ray beams of different energies greater than 1.0 MeV and composing the resulting transmission values. The technique seems to work, at least to perform discrimination of four basic material groups.
Starting from these results, the chance to develop a material recognition technique based on the radiographic system designed at the Dipartimento di Fisica, Università di Messina, has been investigated as a part of the DARMA experiment supported by INFN (Istituto Nazionale di Fisica Nucleare).

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FIRST RESULTS

The designed radiographic system [3] consists of:
- a X-ray source driven by a 5 MeV electron linac providing variable electron current (1-100mA), energy and repetition rate (1-300Hz); the e-γ conversion is performed by means of a tantalum target properly dimensioned;
- a Gd_2O_2S (GOS) scintillator, 1.1mm thick and mounted on a brass backing;
- a CCD camera providing a good resolution and a low dark current ($< 10pA/cm^2 @ 25^oC$).

As discussed in [4], several simulations have been carried out by means of the MCNP-4C2 (Monte Carlo N-particle, version 4C2) code [5] to evaluate transmissions through Pb, Cu and Al samples of bremsstrahlung beams providing 1.0 MeV and 5.5 MeV end-point energies. We will refer to these two energy values as LE and HE, rispectively.
Note that for these first results, a 100% efficiency detector has been considered.

A composition of the obtained transmissions is shown in Fig.1 and it seems that material recognition can be roughly achieved.
The discussed simulation does not account for the real absorption efficiency of the scintillator screens used to provide the final light image. To obtain more realistic results, two detectors have been considered: a GOS, which is already part of the radiographic system, and a pixeled $Bi_4Ge_3O_{12}$ (BGO) scintillator screen, 20mm thick, which will be probably bought in the future.
Transmissions (or, equivalently, the radiographic signals) have been evaluated as the ratio between the energy de-

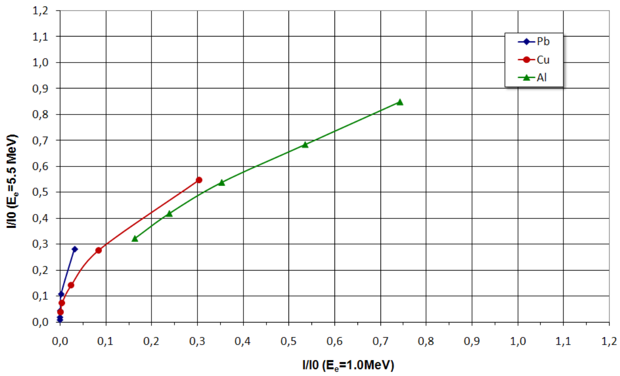

Figure 1: Transmission of the HE beam *versus* transmission of the LE beam. Ideal detector.

position in the scintillator screen, DE, resulting when an attenuator is inserted in the beam line and the energy deposition, DE_0, obtained without any sample.
In Figs.2, 3 the composition of the transmission of LE and HE beams as detected by each scintillator screen is shown.

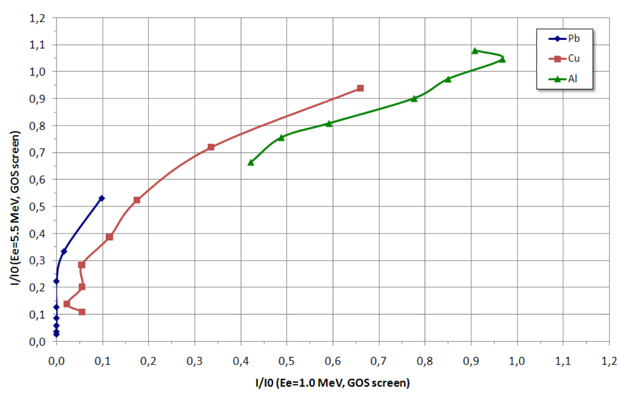

Figure 2: Transmission of the HE beam *versus* transmission of the LE beam. GOS scintillator.

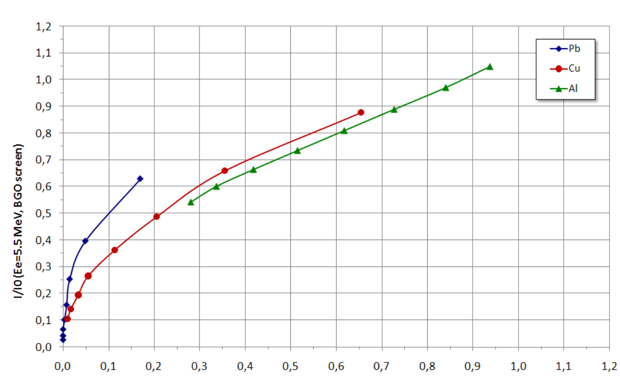

Figure 3: Transmission of the HE beam *versus* transmission of the LE beam. BGO scintillator.

Note that simulation results provide statistical errors lower than 10%.
It seems that the chance to make material recognition is still confirmed. However, curves are too close to each other (especially when the BGO scintillator is considered) thus allowing us to say that probably inserting experimental errors, material recognition cannot be properly done. It would be then appropriate to look for a better separation among the transmission curves.

A SCINTILLATOR SCREEN FOR EACH ENERGY: BASIC IDEA

A way to differentiate the transmission through materials could be the use of two scintillator screens which x-ray efficiencies are quite different.
To support this idea, simulations have been carried out to study the response of GOS and BGO detectors to the x-ray beams as produced by the considered bremsstrahlung source.
Both scintillators have been simulated and the transmission of an incident x-ray spectrum providing a 5.5 MeV endpoint has been evaluated.
In Fig.4 the incoming and outcoming x-ray spectra from scintillators are shown. As expected, GOS scintillator provides a radiographic signal lower than the one provided by BGO.

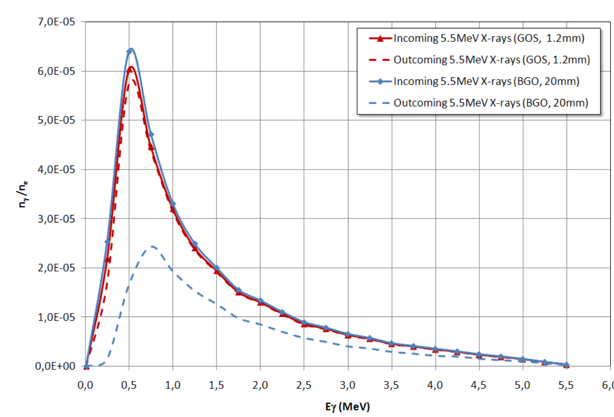

Figure 4: Incoming and outcoming x-ray spectra for GOS (1.2mm) and BGO (20mm) scintillators. $E_e = 5.5MeV$.

In fact, only few percent of low energy x-rays are removed from the incident bremsstrahlung beam being absorbed by the GOS scintillator. On the contrary, if the BGO is used, the removal of x-rays from the incident beam is stronger and also higher energy x-rays are removed from the incident beam thus contributing to the radiographic signal. A higher thickness of the GOS would surely better balance the difference between the two detector responses but the spatial resolution would be seriously affected.
The very different response of the two scintillators could probably justify the use of detectors depending on which x-ray energy is considered: GOS for the LE beam and BGO for the HE beam.

A SCINTILLATOR SCREEN FOR EACH ENERGY: SIMULATION RESULTS

The idea to use a screen for each energy has been then theoretically tested evaluating the transmission through the cited materials of the LE beam as detected by GOS and of the HE beam as detected by BGO.
The composition of the resulting transmissions is shown in Fig.5.

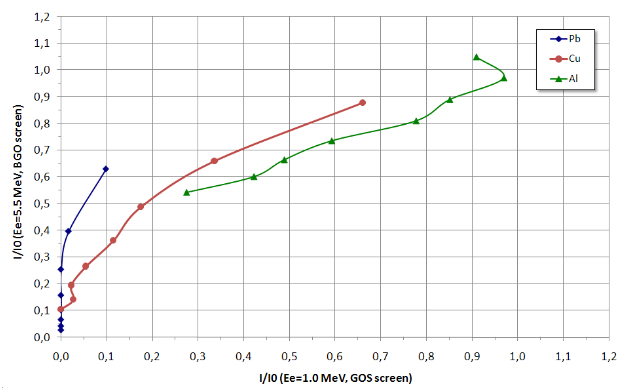

Figure 5: Transmission of the HE beam as detected by BGO *versus* transmission of the LE beam as detected by GOS.

Making a comparison among Figs.2, 3, 5 it can be stated that the combined use of GOS and BGO scintillator screens can provide a higher separation among the transmission curves. However, it is necessary to observe that:
- the separation among curves could be still not enough to state that inserting experimental errors, material recognition can be univocally achieved;
- the use of the GOS screen for the LE beam limits the maximum thickness that can be investigated, expecially when considering a high Z material such as lead. This can be due to the thickness of the GOS scintillator which enables only few percent of low energy x-rays to be absorbed thus weakly contributing to the radiographic signal; moreover, it can also be due to the efficiency of the GOS which is high for very low x-rays thus not revealing higher energy x-rays and getting worse when beam hardening is induced by thick high Z samples.

As a consequence, we can say that material recognition can be theoretically achieved but the use of the GOS scintillator screen in association with the chosen LE beam, limits the high Z material thickness that can be investigated. Nevertheless, this problem can be overcome by using a higher energy as the LE one despite a lower separation among transmission curves.

A FILTER FOR THE HE INCIDENT BEAM

A futher attempt to better separate the transmission curves has been made supposing to vary the HE spectrum by means of filters thus using the beam hardening effect to move the HE spctrum peak towards higher energies. Simulations have indicated that inserting a lead filter 40mm thick to modify the HE spectrum, we are able to well separate the LE and HE spectra, as shown in Fig.6.

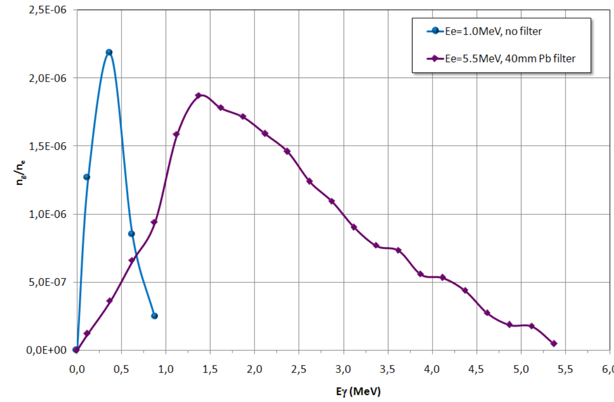

Figure 6: Non attenuated LE and attenuated HE spectra.

First transmission evaluations seem to not provide better results than the ones obtained without the use of the Pb filter and shown in Fig.5; nevertheless, a more accurate study is still in progress to better evaluate the HE beam filtering effect.

CONCLUSIONS.

The chance to make material recognition by using different bremsstrahlung beams and based on the radiographic system hosted at the Dipartimento di Fisica, Università di Messina, has been investigated in the framework of the DARMA experiment.
To improve first results, the use of two different scintillator screens, one for each energy, has been investigated to the same purpose. It seems that material recongnition can be theoretically achieved but it is necessary to perform experimental tests to definitely confirm this conclusion.
The use of filters has also been roughly investigated; more confident results will be soon available.
Work is still in progress to further understand if any other action can be theoretically made to improve the result.

REFERENCES

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[5] MCNP4C2, by Diagnostic Application Group, Los Alamos National Laboratory, New Mexico, U.S.A. and RSICC, Oak Ridge National Laboratory, Tennessee, U.S.A.