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Prompt Gamma Neutron Activation Analysis for Explosive Material Detection Based on IECF Neutrons

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Abstract

Explosive material detection using prompt gamma neutron activation analysis (PGNAA) was implemented using MCNPX calculation code. Eight explosive compounds have been tested under 2.45 MeV neutrons of D-D fusion in an Inertial Electrostatic Confinement Fusion (IECF) Facility. The main purpose of this research is to use the high-energy neutrons of fusion to detect the materials instead of the ordinary methods of detection, like x-ray detection. The results showed that TNT had the best efficiency in (n,γ) reactions, while the most fluence of passing photons through detector surface is for ammonium nitrate and nitroglycerin analysis as a target. The results had high conformity with other researches, so that can be used for the conceptual design of an IECF material detection.

Keywords: Prompt Gamma Neutron Activation Analysis, Explosive Materials, Inertial Electrostatic Confinement Fusion, D-D fusion neutrons, MCNPX Calculation Code.

Introduction

Inertial electrostatic confinement fusion (IECF) is one of the various methods for confinement of a hot fusion plasma, offering many potential applications including simplified support structures and the ability to create non-Maxwellian plasmas that can be used with a variety of fusion fuels [1]. In fact, IECF is an opportunity to generate fast high-flux neutrons from a small fusion reaction area. It can be used for many applications [2] such as explosive material detection [3].

Many researches have studied IECF sources. D-D [4], D-T [5] and D-^{3}He [6] can be used as IECF neutron or proton sources.

D-D neutrons have lower energy (2.45 MeV) and yield compared with D-T neutrons (14 MeV), so that thermal neutron flux can be obtained with D-D neutrons. The mentioned benefit and other advantages of D-D neutrons make possible the usage of deuterium gas to be used in IECF device [7].

Almost all of the IEC devices operating around the world are simply working in glow discharge regime (a frequently used process as source of atomisation and excitation in spectrometric determination of trace elements) with deuterium gas, resulting in 10^7 to 10^8 neutrons/second in a continuous mode. This neutron reaction rate has been proven to be usefully applicable for Prompt-Gamma Neutron activation analysis (PGNAA) [8].

Preparation of the materials

In this work, eight explosive material compounds; Ammonium Nitrate (AN), Ethylene Glycol Dinitrate (EGDN), Cyclotetramethylenetetranitramine (HMX), nitrocellulose (NC), Nitroglycerin (NG), Pentaerythritol tetranitrate (PETN), Cyclotrimethylenetrinitramine (RDX) and Trinitrotoluene (TNT) were used. The used materials and their characteristics are shown in Table 1.

Table 1. Used materials and their characteristics [9]

Explosive Material	Compound Characteristics		Mass Fraction of Elements			
	Formula	Density ($\frac{g}{cm^3}$)	H	C	N	O
AN	NH_4NO_3	1.72	5.04	-	34.99	59.97
EGDN	$C_2H_4N_2O_6$	1.49	2.65	15.80	18.42	63.13
HMX	$C_4H_8N_8O_8$	1.89	2.72	16.22	37.84	43.22
NC	$C_6H_7O_2(ONO_2)_3$	1.49	2.92	27.13	12.13	57.82
NG	$C_3H_5N_3O_9$	1.6	2.22	15.87	18.50	63.41
PETN	$C_5H_8N_4O_{12}$	1.77	2.55	18.99	17.72	60.74
RDX	$C_3H_6N_6O_6$	1.82	2.72	16.22	37.84	43.22
TNT	$C_6H_2(NO_2)_3CH_3$	1.65	2.22	37.02	18.50	42.26

Experiment and method

The neutrons resulted from D-D fusion reactions of IECF (Inertial Electrostatic Confinement Fusion Facility) with an energy of 2.45 MeV were irradiated on the explosives of Table 1. the simulation has been implemented in MCNPX calculation code [10] and MCNPX VISUAL EDITOR [11] was used to show the geometry of the experiment. The F4 tally with MT=102 was used to calculate the (n,γ) fluence and F2 tally was used to measure the fluence of the passing gamma ray through the detector surface. Prompt photons are produced from neutron collisions in MCNPX [10]. Delayed gammas can be controlled and measured by some other cards in simulation process as a new study case. 2D and 3D views of experiment, depicted using mcnpx visual editor are shown in Figure 1.

(a) (b)

Figure 1. (a) 2D and (b) 3D MCNP Model of IECF Facility.

Results and discussion

The results are shown in Figures 2 and 3.

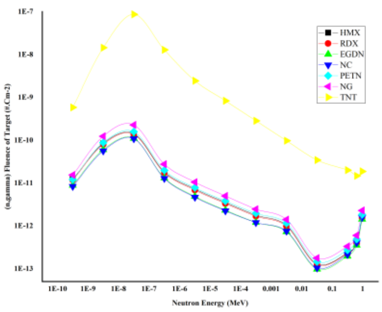

Figure 2. (n,γ) fluence of incident neutron on the target.

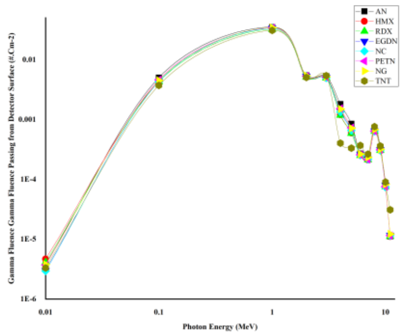

Figure 3. The fluence of passing gamma ray through the detector surface.

Accordint to figures 2 and 3, the results show that TNT has the most (n,γ) fluence. For the gamma fluence passing through the detector surface, AN and NG have the most fluence, but the results for other materials are almost the same. Since the gamma-rays resulted from the neutron-gamma reaction can be emitted at different angles or different energies after the reaction, figure 2 shows a graph of the fluence of the particles reaching the detector after the reaction which has been demonstrated in figure 3. For example, in the case of TNT, which has the highest levels of flux in the neutron-photon reaction, the photon flux reaching the detector shows low levels at low energies, but at higher energies, it has the highest levels. This can be due to the energy distribution, directions, and also collision types. Therefore, energy, direction, and the type of gamma-neutron collisions can be considered as important studies for further works in future researches.Regarding that, the neutrons produced from the IEC experience different reactions after production (such as collisions with the walls of the device), the energy and the fluence of 2.45 MeV neutrons are decreased. Also, the other important points are the reaction and absorption cross section values of the neutrons at different energies for different materials, which results in the occurrence of the maximum absorption in 1 MeV, and probably the other amounts of the incident neutrons experience different reactions. The results of this study are in perfect agreement with the results of Hossny et al.’s research [12].

Conclusion

These results are going to be used in IR-IECF facility which in fact is the main difference of this research rather than others. The results gave us good data to build an explosive-detection facility based on IECF neutrons and PGNAA method. The points about the energy distribution, directions, and also collision types and the types of gamma-neutron collisions can be considered as important ideas for further researches. The experiment also could be established for other materials like non-explosive ones and also be compared with these results.

References

1. G. H. Miley and S. K. Murali, *Inertial electrostatic confinement (IEC) fusion*, Springer (2014).
2. R. F. Radel, et al., *Detection of highly enriched uranium using a pulsed D-D fusion source, Fusion Sci. Technol.* 52, 1087 (2007).
3. A.L. Wehmeyer, *The Detection of Explosives Using an Inertial Electrostatic Confinement D-D Fusion Device*, (2005).
4. A. A. Harms, et al., *Principles of Fusion Energy: An Introduction to Fusion Energy for Students of Science and Engineering*, World Scientific (2000).
5. R. L. Hirsch, *Inertial-electrostatic confinement of ionized fusion gases, J. Appl. Phys.* 38, 4522 (1967).
6. R.P. Ashley, et al., *Steady-state D3HE proton production in an iec fusion device, Fusion Technol.* 39, 546 (2001).
7. A. Sadighzadeh, et al., *Prediction of Neutron Yield of IR-IECF Facility in High Voltages Using Artificial Neural Network, J. Eng.* 2014, 6 (2014).
8. A.A. Zaeem, et al., *Preliminary results of a miniature cylindrical inertial electrostatic confinement fusion device equipped with inductively coupled plasma generator, J. Instrum.* 14 (2019).
9. A.O. Babatunde, et al., *Constructed wetlands for environmental pollution control: A review of developments, research and practice in Ireland, Environ. Int.* 34, 116 (2008).
10. J.F. Briesmeister, *MCNP– A General Monte Carlo N-Particle Transport Code, Los Alamos Natl. Lab.* 790 (2000).
11. A. Schwarz, et al., *MCNP/MCNPX Visual Editor computer conde manual*, (2011).
12. K. Hossny, et al.y, *Detecting shielded explosives by coupling prompt gamma neutron activation analysis and deep neural networks, Sci. Rep.* 10, 1 (2020).