المركز الوطني للعلوم والتكنولوجيا النووية
Centre National des Sciences et Technologie Nucléaire

23rd WiN Global Annual Conference: Women in Nuclear Meet Atoms for Peace, 24–28 August 2015 Vienna, Austria

DEVELOPMENT AND APPLICATIONS OF DEUTERIUM-DEUTERIUM (D-D) NEUTRON GENERATOR

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INTRODUCTION

A new deuterium-deuterium (D-D) neutron generator has been developed for non-destructive neutron inspection techniques. The neutron generator is composed of three major components: An RF-Induction Ion Source, the Secondary Electron Shroud, and the Diode Accelerator Structure and Target. The generator produces monoenergetic neutrons (2.5 MeV) with a yield of 10^{10}n/s using 25-50 mA of beam current and 125 kV of acceleration voltage. Three nuclear analytical technique were tested and optimized to be used with the neutron generator : (1) Prompt γ-ray neutron activation analysis (PGNAA) of ^{10}B concentrations in Si and SiO_2 matrices was carried out using a germanium detector (HPGe) and the results obtained are compared with a PGNAA system using a NaI detector. (2) The radiography facility used in the measurements and simulations employs a fully high-voltage-shielded, D-D neutron generator. Both fast and thermal neutron images were acquired with the generator and a Charge Coupled Devices camera. To shorten the imaging time and decrease the noise from gamma radiation, various collimator designs were proposed and simulated using MCNPX. Design considerations included the choice of material, thickness, position and aperture for the collimator. (3) Optimization of a D-D neutron generator based explosive detection system (EDS) was performed using Monte-Carlo simulation. The shape and the thickness of the moderators and shields are optimised to produce the highest thermal neutron flux at explosive position and the minimum total dose at the outer surfaces of the explosive detection system walls. In addition simulation of the response functions of NaI, BGO, and $LaBr_3$-based γ-ray detectors to pure chemical elements is described.

D-D NEUTRON GENERATOR

Characterization and Measurement of the neutron yield of the D–D neutron generator

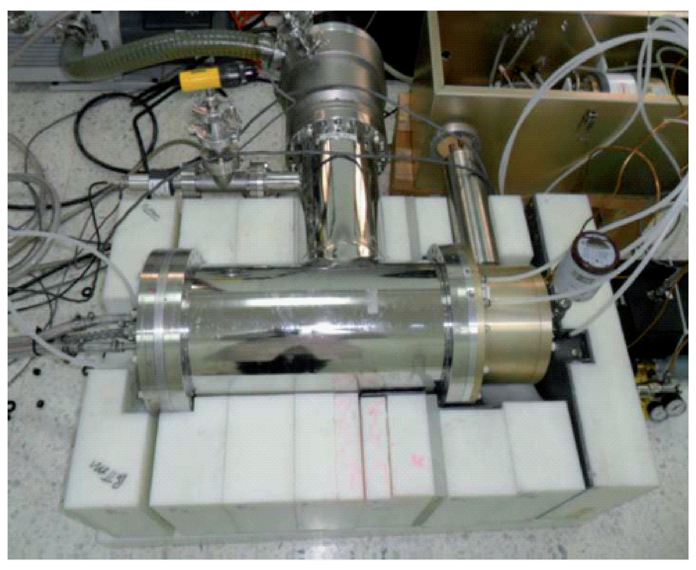


Fig. 1 The D–D 110 neutron generator.

The generator consists of three major components: RF-Induction Ion Source, the Secondary Electron Shroud, and the Diode Accelerator Structure and Target. It is designed to produce a yield of 10^{10} neutrons per second with a 2.5 MeV energy through the following DD fusion reaction.

$$^2_1H + ^2_1H \rightarrow ^3_2H(0.82MeV) + ^1_0n(2.45MeV)$$

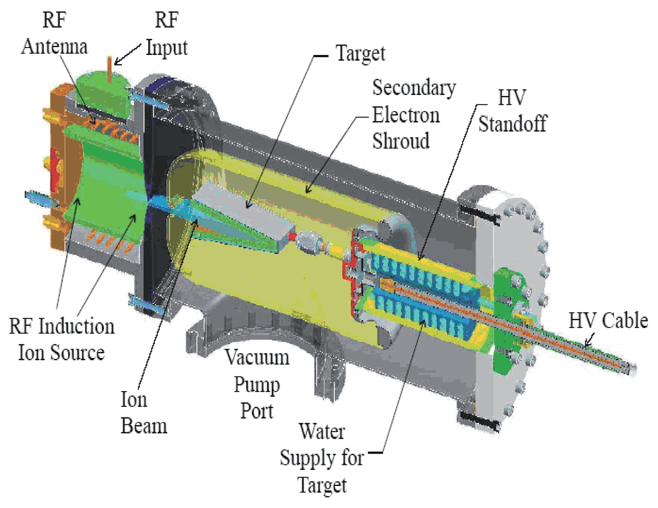


Fig.2 Sectional view of Model DD-110 generator head.

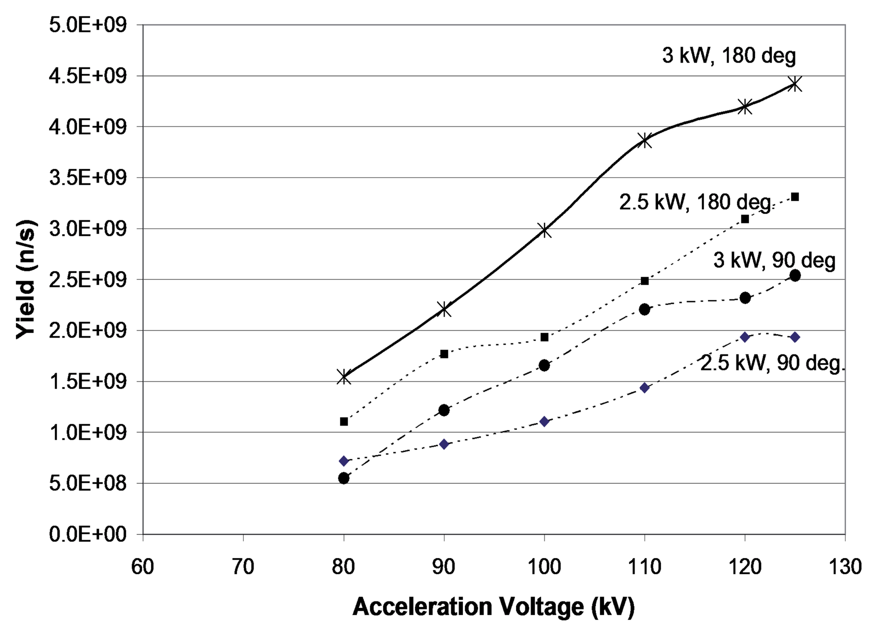


Fig. 3 The neutron yield (n/s) as a function of accelerator voltage for two different measurement angles and two different plasma powers.

➡The highest neutron output was achieved with an acceleration voltage of 125 kV and RF input power of 2.5 kW. The production of monoenergetic neutrons (2.5MeV) with a neutron yield of 4.5×10^9 n/s was achieved

PGNAA OF BORON WITH D-D NEUTRON GENERATOR

PGNAA experimental setup

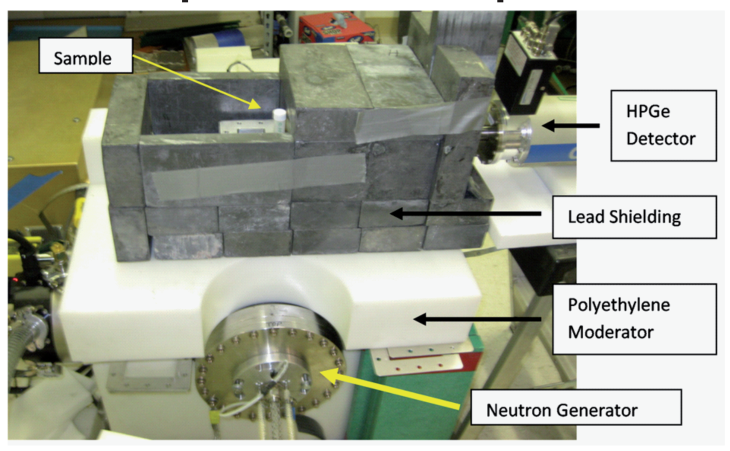
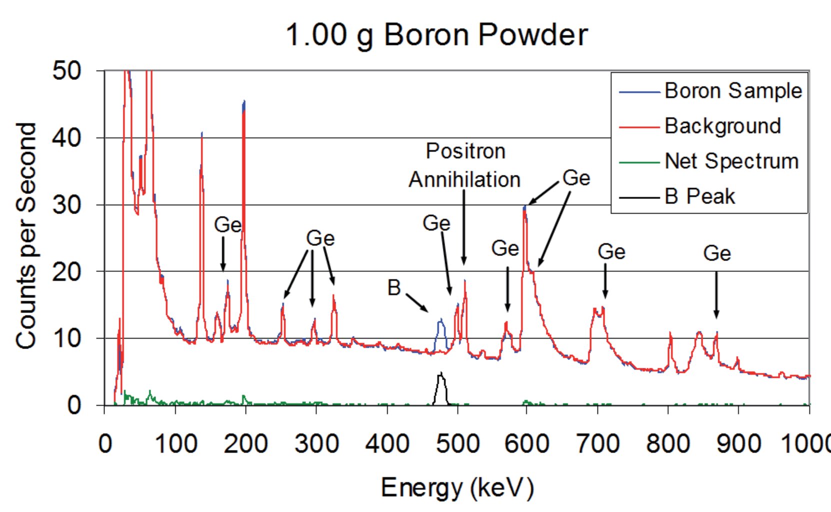


Fig.4 D-D neutron generator surrounded by a polyethylene moderator, a top which sits the lead shielding

Sample preparation

Fig.5 Boron samples in Si and SiO_2 matrix with ruler to demonstrate scale.

Boron measurement with HPGe and NaI detector



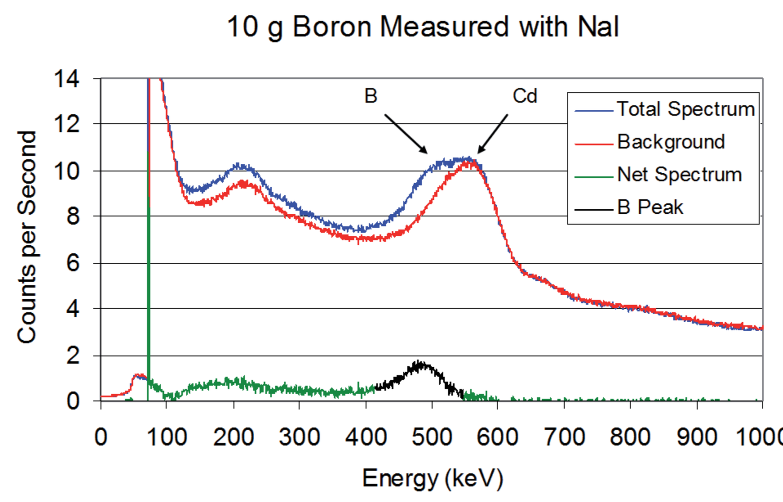


Fig.6 Typical energy spectrum measured with the HPGe detector. Fig.7 Typical energy spectrum measured with a NaI detector.

➡From the boron measurements conducted in this system performance study, the thermal neutron absorption cross section could to be calculated to within 3.8%.

REFERENCES

Acharya R (2009) Prompt gamma-ray neutron activation analysis methodology for determination of boron from trace to major contents. J. Radioanal. Nucl.Chem281:291–294

Elbio C, Burkhard S, Florian G (2005) Construction and assembly of the neutron radiography and tomography facility ANTARES at FRM II. Nucl Instrum Method Phys Res A 542:38–44.

Takahashi, Y., et al., 2011. Landmine detection method combined with backscattering neutrons and capture γ -rays from hydrogen, Appl. Radiat. Isot. 69, 1027–1032.

NEUTRON RADIOGRAPHY (NR) WITH D-D NEUTRON GENERATOR

Experimental neutron radiography configuration

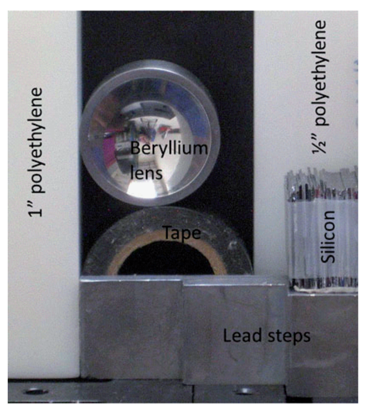
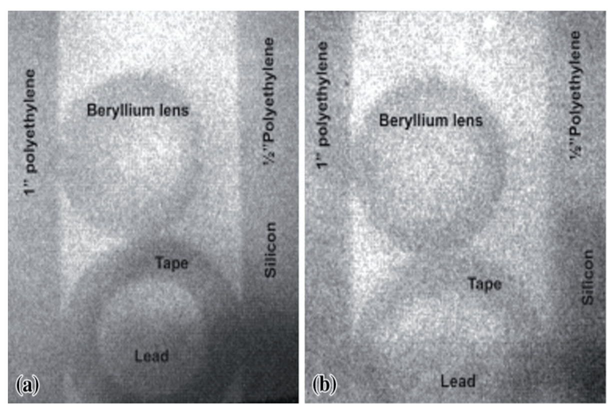


Fig.8 Set of objects that are imaged by thermal and fast neutron radiography.



(a) (b)

Fig.9 Radiographs of the objects taken using D–D neutron generator based thermal neutron (a) and fast neutron (b) radiography facility.

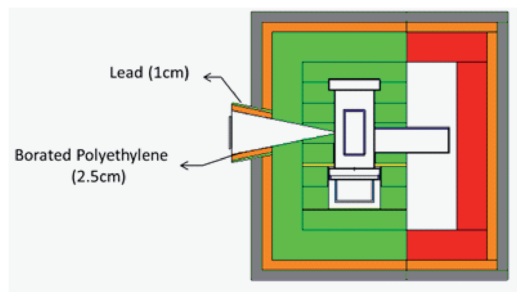


Fig.10 Best Thermal NR Configuration

Table1. The thermal neutron radiography parameters for different L/D ratio.

L	D	L/D	F_{th}(n.cm^{-2}.s^{-1})	TNC (%)	n/γ (n/cm^{2}mR)
Experimental collimation					
150	15	10	3.06E+03	25	5.91E+05
Optimized collimation					
150	15	10	3.25E+04	27	1.65E+06
Optimal configuration					
50	4	12.5	3.29E+04	24	3.16E+06

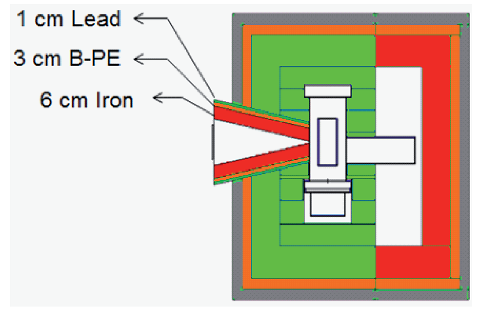


Fig.11 Best Fast NR Configuration.

Table2. The fast neutron radiography parameters for different L/D ratio.

L	D	L/D	F_{fast} (n.cm^{-2}.s^{-1})	Uncollided F_{fast} (n.cm^{-2}.s^{-1})	μ_G(cm)
Experimental Collimation					
150	15	10	3.69E+04	1.88E+04	0.05
Optimized Collimation					
150	15	10	6.26E+04	2.19E+04	0.05
Optimal configuration					
50	4	12.5	1.83E+05	7.55E+04	0.040

EXPLOSIVE DETECTION SYSTEMS (EDS) WITH D-D NEUTRON GENERATOR

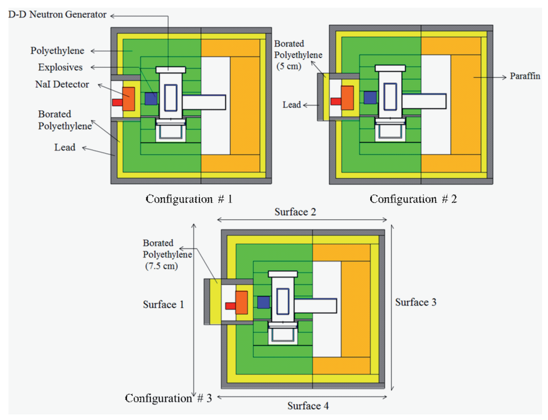


Fig. 12 MCNP geometry of EDS based on a D-D neutron generator and 8''x4'' NaI detector

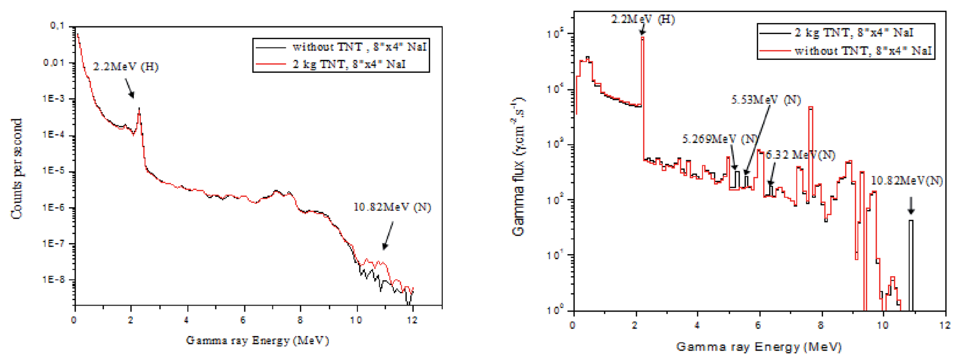


Fig. 13 (a) Gamma flux at the 8''x4'' NaI detector with and without 2 kg of TNT explosive, (b) Detector response of the 8''x4'' NaI detector

➡ The 2.2 and 10.82 MeV gamma rays from hydrogen and nitrogen, respectively, appeared in the spectrum as well as the 5.269, 5.53 and 6.32 MeV nitrogen lines.

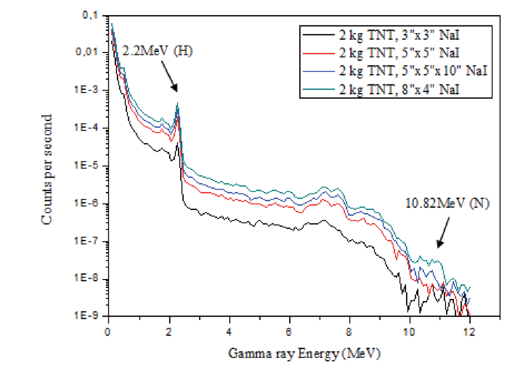


Fig. 14 Detector response of the 8''x4'', 3''x3'', 5''x5'' and 5''x5''x10'' NaI detectors with 2kg of TNT explosive

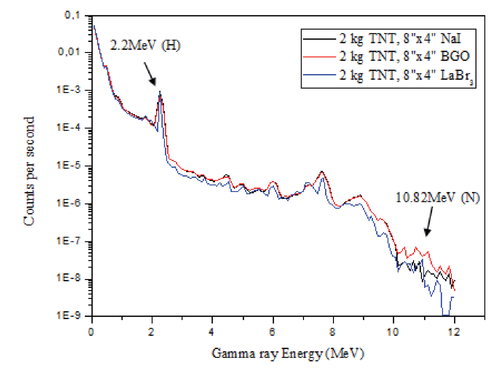


Fig. 15 Detector response of the 8''x4'' NaI, BGO and LaBr3 detectors with 2 kg of TNT explosive

➡ The photo peak of the (8''x4'') detector is larger than that of the (3''x3'') and (5''x5''x10'') detectors.
➡ $LaBr_3$ detector has higher resolution than both the NaI(Tl) and BGO detectors.

CONCLUSIONS

The study performed here demonstrates that D-D neutron generators with an output of 10^8 to 10^{10} n/s can successfully be used for PGNAA.

D-D neutron generator is suitable for neutron radiography, the collimator provides significant improvement in neutron flux and a decrease in background radiation compared to the experimental arrangement.

The 2.5 MeV neutrons produced from the D-D neutron generator with an output of 10^{10} n/s could be used to detect explosives with an (8''x4'') NaI detector.