Source characterization of Purnima Neutron Generator (PNG)

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Introduction:

The use of 14.1 MeV neutron generators for the applications such as elemental analysis, Accelerated driven system(ADS) study, fast neutron radiography requires the characterization of neutron source i.e neutron yield (emission rate in n/sec), neutron dose, beam spot size and energy spectrum.

Purnima Neutron Generator [1] has been upgraded and made operational at higher yield. An absolute determination of 14.1-MeV neutron yield is carried by foil activation technique and beam spot size was measured on quartz window with CCD. The neutron generator has been tested at neutron yield of 1x 10^{10} (n/sec) with beam spot size of ~ 4mm at target position. For absolute measurement of 14.1MeV neutron flux the reactions ^{27}Al (n, p) ^{27}Mg, ^{63}Cu (n, 2n) ^{62}Cu and F^{19} (n, 2n) ^{18}F were chosen because of their higher threshold energies (3.25 MeV, 11.03 MeV and 12 MeV respectively), So that the low energy neutron (i.e DD 2.45MeV) contamination can be avoided in measurement. Induced y-ray activities from ^{27}Mg, ^{62}Cu and ^{18}F were measured with High Purity Germanium (HPGe) detector.

In this paper, we present a series of experiments carried out to characterize this neutron source. The neutron source has been quantified with neutron emission rate, neutron dose at various source strength and beam spot size at target position.

Experimental Set up and method:

Neutron Generator set Up: Purnima Neutron generator (PNG) [1] operates in DT & DD mode producing mono-energetic neutrons of 14.1MeV and 2.45MeV respectively. D+ Beam current is extracted from RF ion source and focused with einzel lens. Beam is accelerated up to 300 keV on a titanium-tritiated target with copper backing plate. The beam power dissipated in the TiT is removed with chilled water circulating around target. The neutron production is regulated by acceleration voltage and RF ion source parameters. Operation of the PNG is controlled by PLC based control unit from outside the Neutron Generator Hall.

With PNG a series of experiments carried out to measure neutron emission rate, neutron dose and d+ beam spot size focused at the target position.

a) Neutron Emission Rate:

To determine the neutron emission rate (neutron yield) of high intensity Neutron Generator, four sets of foils were prepared. Each set contains standard foil of Al (dia=5mm, thick=1mm), Cu (dia=1.5cm, thick=0.5mm) & Teflon (dia=5mm, thick=1mm), placed parallel to each other. One foil set was placed at a distance of 15 cm from target and at an angle of 0° with respect to D+ beam direction. This foil set was irradiated and induced activity was measured using a calibrated n-type HPGe gamma spectrometry system, shielded with 10cm of Pb and 5mm of Al. Spectrum was collected at 8k MCA (PCA II) card coupled to HPGe.

The neutron flux and neutron emission rate was calculated using eqs (1) & (2)

$$\boldsymbol{\varphi = \frac{Q}{4\pi x^2}} \quad \textbf{(1)}$$

Where, Φ=neutron flux (n/sec/cm2)

Q is the neutron emission rate (n/sec)

$$\mathbf{Q = \frac{4\pi x^2\ \lambda A C_p\ e^{\lambda t_2}}{N_a m a_i \varepsilon P_\gamma \sigma (1-e^{-\lambda t_1})(1-e^{-\lambda t_3})}} \quad \textbf{([2)}$$

Where, λ is decay constant(sec^{-1}),x(cm) is distance between neutron source(target) and foil set, A(gm) is atomic mass number of sample, C_p is the photo peak area (counts at 843keV, 511keV, 511keV for ^{27}Mg, Cu^{62} & F^{18} respectively),N_a is Avogadro number[3], m is atomic weight(gm) of sample, a_i is the isotopic abundance, ε is photo-peak efficiency(fig) of HPGe, P_y is gamma abundance ,σ is reaction cross section[2], t_1, t_2 and t_3 are irradiation, cooling and counting time respectively.

This Experiment was repeated with four sets of foils at different operating parameters of accelerating HV and RF ion source current (I) Table1.

Exp Set	HV (kV)	I (uA)	t1 (min)	x (cm)
Set1	182	120	10	15
Set2	100	104	12	15
Set3	81.5	95	15	15
Set4	60	71	25	15

Table1.Operating parameters of PNG for experiments (set 1-4)

At these parameters calculated neutron emission rate is given in Table2. Maximum neutron yield obtained was 1x10 ^{10} n/sec. The results were compared /cross checked with three different foils (aluminum, copper and Teflon) placed at same position and time.

b) Dose measurement:

Neutron dose data are very important in view of shielding requirement and precautions to prevent personnel hazards.BF3 Neutron Monitor was placed at the distance of 80cm from the neutron target at the angle of 90° with respect to target position. The time integrated neutron dose was measured with each experiment mentioned above. Neutron dose variation is shown in Table2 and plotted in fig (2). It was observed that neutron dose variation was linear with increasing neutron source strength.

c) Beam spot size measurement

Neutron radiography experiments require collimated focused beam. Beam aperture is one of major parameter to determine Image quality. To measure beam spot size we have replaced the tritium target with a quartz window. Accelerated D+ ion beam hitting on the quartz target was focused by controlling einzel lens voltage, extraction voltage, D+ beam current and accelerating high voltage. Beam spot on quartz window was imaged online with a CCD, digitized and stored in PC. Beam spot size calculated by FWHM of beam line profile at central position was ~4mm (Fig3.), with parameters of Einzel lens voltage (12.5kV), extraction voltage (4-5kV), D+ beam current (100uA) and high voltage HV (100kV).

Such a small beam diameter is needed to carry out the fast neutron radiography experiments for better resolution.

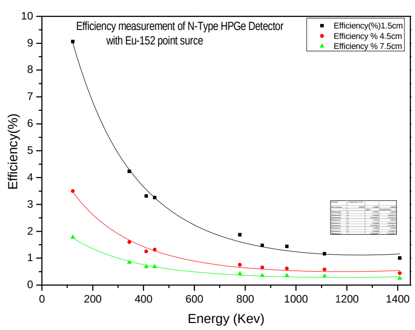

Fig 1. Efficiency curve of N-Type HPGe detector used for counting

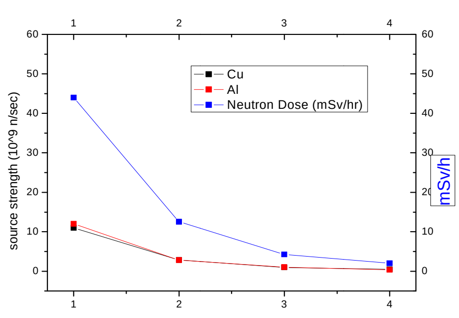

Fig 2. Neutron Dose variation with increasing neutron source strength

Exp set No	Source strength with foil activation (n/sec)			Neutron Dose (at 60 cm from target inside the NG room)
	27Al(n,p) 27Mg	63Cu(n,2n) 62Cu	F19(n,2n) F18	
1	1.2*10^10	1.1*10^10	1.08*10^10	44.00mSv/hr
2	2.84*10^9	2.87*10^9	-	12.54mSv/hr
3	1.05*10^9	1.0*10^9	1.06*10^9	4.25 mSv/hr
4	4.0*10^8	4.8*10^8	-	2.05 mSv/hr

Table: 2 experimentally measured 14MeV neutron Source strength

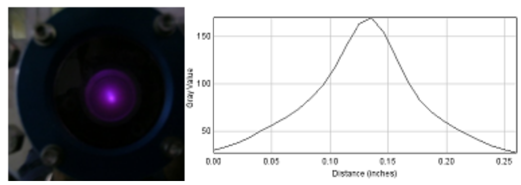

Fig 3. Beam spot size taken CCD snap shot and line profile at central position of the beam spot

Results and Discussion:

The measured emission rate and neutron dose at varying HV and Ion source values are shown in table1 and plotted in Fig2.Emission rate was calculated assuming a neutron point source and isotropic in nature with the neutron energy of 14.1MeV. Table (1&2) shows strongly dependent of emission rate on the ion source parameter as well as on HV. It can be seen from the results that the emission rate measured by the three reactions are same. We have observed the Neutron dose shows a linear variation as with increase of neutron source strength. FWMH of beam spot measured was ~4mm, is needed for radiography experiments.

Conclusions:

The characterization of 14.1-MeV Purnima Neutron Generator (PNG) has been carried out. Maximum Neutron emission rate achieved was $1x10^{10}$ n/sec. Neutron dose variation measured with increasing source strength is linear. Minimum beam spot measured on quartz was 4mm. The potential application of PNG are elemental analysis, ADSS benchmarking experiments, neutron radiography, detector response study, and nuclear data generation are under progress. Pulse mode operation of PNG will be shortly implemented for various experiments.

Ref:

[1] "2.45MeV/14MeV Neutron Generator Facility"T.Patel, Saroj Bishnoi* and Amar sinha Proc.18th NSRP-2009) MLS, Univ. Udaipur Rajasthan,India

[2] www.nndc.bnl.gov for cross-section data

[3 http://physics.nist.gov for physical constants