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UTILIZATION OF A PULSED D-T NEUTRON GENERATOR

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Abstract

In the past two decades the IAEA has supported the establishment of neutron laboratories in many developing countries by providing small D-T neutron generators. The neutron generator is basically a low energy (100–400 keV) ion accelerator capable of producing a continuous beam of deuterons with a current in the range between 1-2.5 mA. These neutron generators are primarily intended to be used for fast neutron activation analysis. This paper describes the utilization of a 14 MeV neutron generator in continuous and pulsed beam modes in applied neutron physics program at Chiang Mai University.

1. INTRODUCTION

The Fast Neutron Research Facility at Chiang Mai University is equipped with a nanosecond pulsed 14 MeV neutron generator, a multiparameter data acquisition and analysis system and various radiation detectors. Fast neutrons from the low energy ion accelerator are used in the field of radiation dosimetry, neutron induced nuclear cross sections measurement and elemental analysis. With minor modification, the accelerator can also be used as a gaseous heavy ion implanter.

The neutron generator is not necessarily limited to continuous beam operation. If properly modified, it can also be utilized for pulsed beam operation. The scope of utilizing such a neutron generator in analytical applications as well as in the studies of fast neutron reactions is extended considerably by pulsed beam operation. For example, the measurements of double differential neutron emission spectra at 14 MeV incident neutron energy for several materials related to the fusion reactor development program are best carried out by pulsed neutron time-of-flight (TOF) technique [1]. The feasibility of using a pulsed neutron generator for the measurement of light elements such as carbon, oxygen, and nitrogen has been successfully investigated [2, 3]. The main application field of pulsed neutrons in geology is the well logging analysis where a pulsed accelerator is used to produce 14 MeV neutrons. During the neutron burst, prompt γ rays resulting from neutron inelastic scattering and from reactions induced by high energy neutrons are detected. This method is a well established technique and has been adapted for down hole logging in both the coal and oil industries [4, 5]. Miscellaneous application of pulsed neutron generator has been reviewed by Csikai [5].

2. THE EXPERIMENTAL FACILITY

The Fast Neutron Research Facility (FNRF) operates a 200 kV, 5 mA high stability Cockcroft-Walton type accelerator producing 14 MeV neutrons for applications in fast neutron activation analysis and the study of neutron induced reactions. An associated alpha particle time-of-flight (TOF) spectrometer was established [6] with moderate energy resolution (1.2 MeV at 14 MeV neutron energy) and a well-behaved time independent background. The nanosecond pulsed neutron facility was installed in 1991 by modifying an existing continuous beam accelerator to incorporate beam chopping and bunching devices [7].

Neutron are produced from an AID J25 accelerator by the T(d,n) ^{4}He reaction. Continuous deuterium ions (D_1^+) from a radio frequency plasma ion source are accelerated to 140 kV by a 9 kHz switching frequency Cockcroft-Walton type D.C. high voltage power supply. The deuteron beam that comprises 75% atomic deuterons (D_1^+) and 25% molecular deuterons (D_2^+) is analyzed by an analyzing magnet. The D_1^+ ions are bent 90° to a pulsed beam channel while the D_2^+ ions are excluded by momentum discrimination. Beyond the analyzing magnet, the beam is transported through series of collimating slits and quadruple focusing magnets. The beam is chopped by double plate deflection system and then bunched to pulses with widths of 1.5 to 2.0 nsec at the neutron production target by a double gap klystron buncher. Beam sizes both in horizontal and vertical axes were monitored by means of a crossed wire beam profile monitor. The schematic diagram shown in Fig. 1 is a layout of the beam line components from the ion source to the target. A data acquisition system is controlled by a 16 MB MicroVAX II computer through a multiparameter buffer system (MBS) unit. Each reaction event detected by the main detector is recorded sequentially in list mode on disk. Our off-line analysis software allows dynamic selections for each correlated parameter in contrast to a conventional hardware resolution routine.

3. DOUBLE DIFFERENTIAL CROSS SECTION MEASUREMENTS

Studies of fast neutron induced reactions are of significance for an understanding of nuclear reaction theory as well as for practical applications. For example, the secondary neutron energy and angular distribution from the (n, xn') reactions on certain materials are of importance for the development of fission and fusion reactor systems and other accelerator based applications. The spectra of the emitted neutrons are usually measured using TOF technique.

In Chiang Mai, we have set up a high precision neutron TOF spectrometer system with flight path up to 12 m [8, 9]. Detail on the measurement and data reduction has been described recently [8]. A cylindrical sample about 3 cm in diameter and 5 cm long, was positioned at 90° relative to the incident deuteron beam with its axis along the axis of the beam line as shown in Fig. 2.

The neutrons were detected in a BC-501A liquid scintillating detector of diameter 25 cm and thickness 10 cm. The detector was coupled to a Hamamatsu R1250 photomultiplier tube via a partially coated taper light pipe. It was located at an extended flight path of 12 m inside a well shielded tunnel. Monte Carlo calculation indicates that scattering effect is less than 1% for this collimating system. Time-of-flight measurements were carried out at angles from 20° to 150° in step of 10°. The corresponding energy resolution at 14.1 MeV was about 415 keV FWHM.

The neutron spectrum was determined from the measured TOF spectra in separate energy regions. The γ rejection was observed for each of the TOF regions because the γ rejection technique was pulse height dependent. In consequence of the large size of the neutron detector, neutron and gamma events in the pulse shape spectrum were not completely separated and some neutrons were lost. This loss was estimated to be less than 1%.

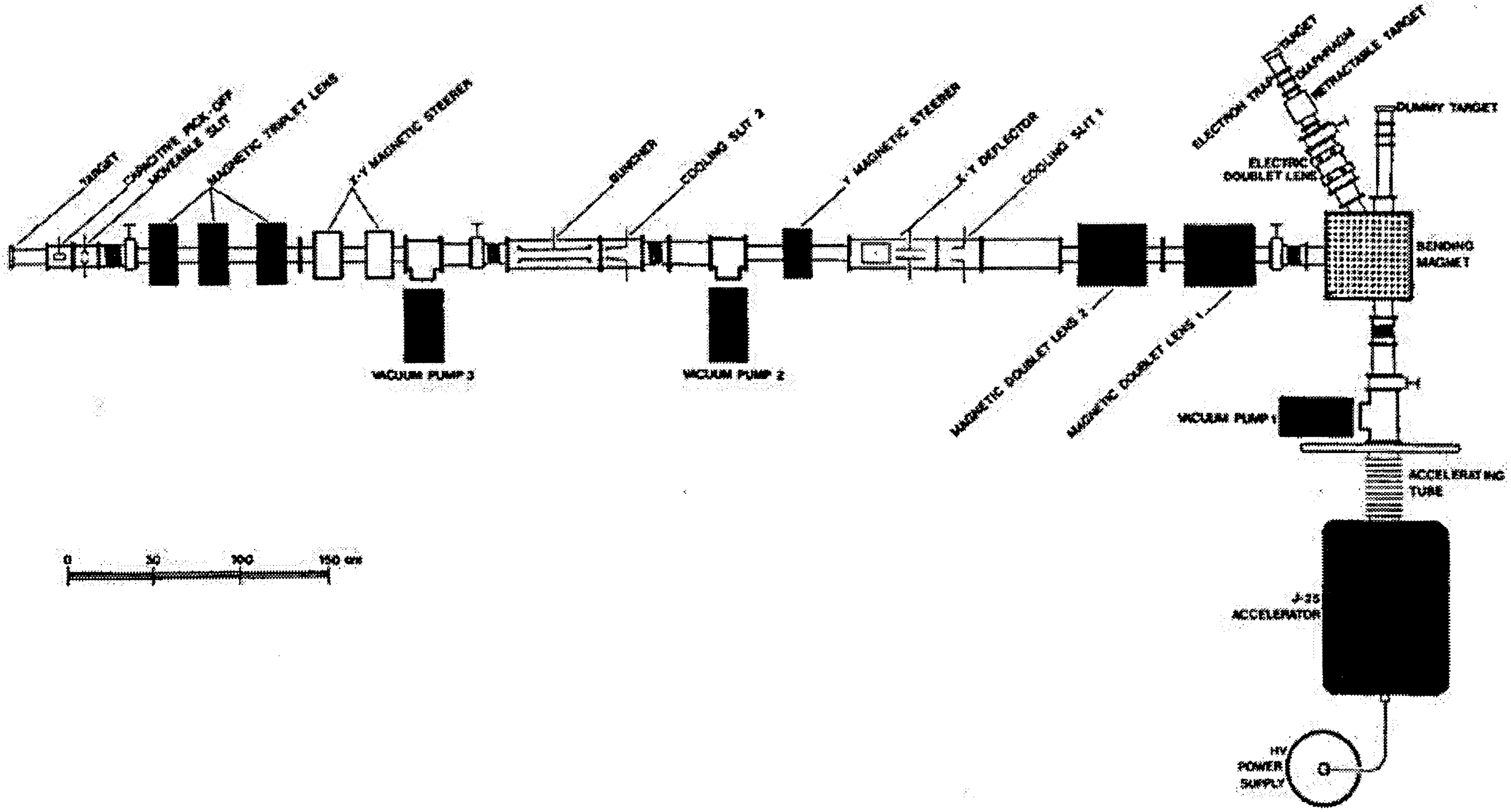

FIG. 1 Schematic diagram of the all pulsed beam line components and their geometrical arrangements.

Several corrections were made to the number of detected neutrons. The most significant one was due to multiple scattering. The overall systematic error for the value of the DDX of ^{209}Bi for example is estimated to be about 11%. The statistical uncertainty varies from less than 1% to about 39% in the discrete region of the spectra of neutrons emitted in backward angles.

In Fig. 3 we show our recent measurement at 20° compared with the result of Takahashi et al. [10]. The two different sets of measurement are in reasonable agreement. Because of better energy resolution, our data reveal more detailed structure in the region between 6 to 12 MeV.

Our angle integrated spectrum is compared in Fig. 4 with the calculated results of Demetriou et al. [11] based on the Feshbach-Kerman-Kooning theory. In their calculation, Demetriou et al. also include contribution from direct reactions that excite low energy vibrations as well as the giant resonance in the continuum, in addition to the incoherent multistep direct reaction, multistep compound and compound nucleus reaction.

The calculated spectrum reproduces the experimental data very well in the regions between 3 to 6 MeV and 9 to 12 MeV. In the region between 6 and 9 MeV where preequilibrium reaction dominates, the two spectra do not agree. The calculated spectrum slightly overestimates the number of emitted neutrons.

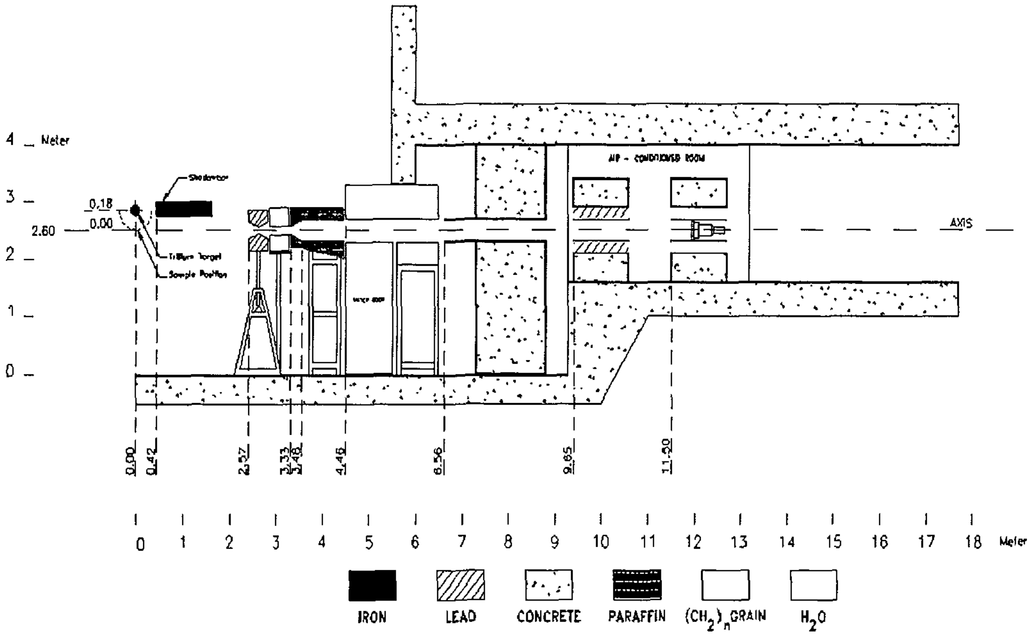

FIG. 2. Experimental arrangement for the DDX measurement [9].

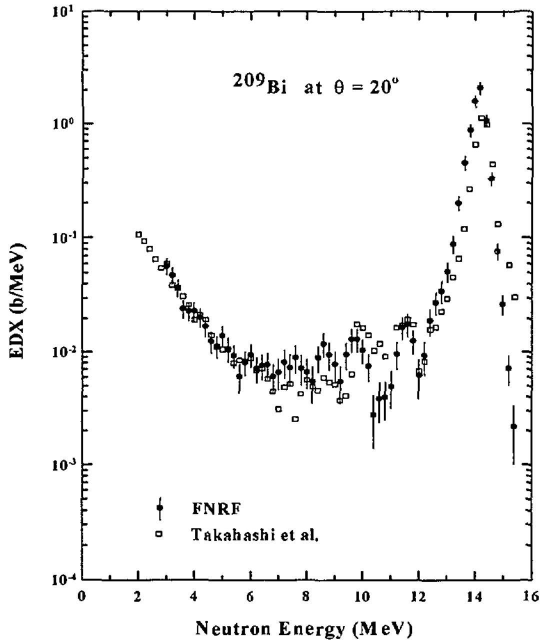

FIG. 3. Differential cross section of ^{209}Bi at 20^{0} Data of Takahashi et al. [10] are shown for comparison.

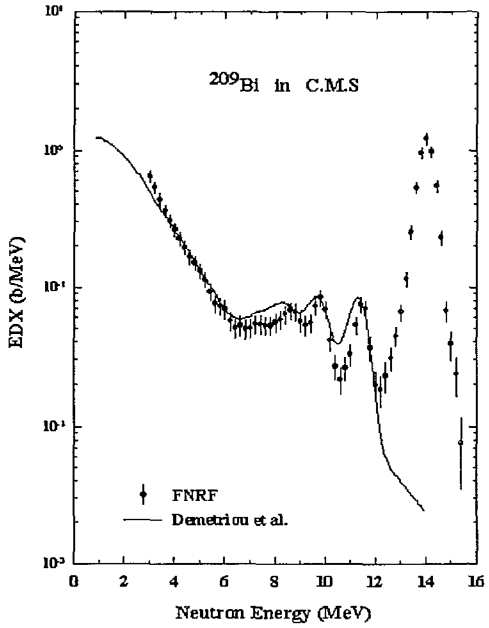

FIG. 4. Comparison of angle integrated spectrum of ^{209}Bi in the CM system with the calculated spectrum of Demetriou et al. [11].

4. PULSED TIME-OF-FLIGHT PROMPT GAMMA RAY ANALYSIS

A DT neutron generator is now routinely used in a variety of analytical applications, including nonintrusive inspection by means of prompt gamma ray analysis (PGA). Obtaining satisfactory results from this kind of measurement requires an associated trigger signal from either the alpha particle of the DT reaction when utilizing a continuous deuteron beam [12] or the induced signal from a capacitive pick-off when using a pulsed deuteron beam [3]. As is well known, the pulsed neutron time-of-flight (TOF) technique generally provides better signal to noise ratio than the associated alpha particle technique. We thus choose to work with the pulsed beam technique. Also, a pulsed neutron generator is not necessarily a large machine any more [13]. However, the production of wider neutron pulse is normally simpler and cheaper than a narrow one. The aim of this work was to investigate the quality and characteristics of the results obtained using both wide and narrow pulses.

The experimental arrangement is shown in Fig. 5. The gamma ray detector was a 5 inch diameter by 5 inch thick NaI(Tl) scintillator. The detector was placed inside a heavy shielding about 2.4 m away from the TiT target and 37 cm from the sample position, as shown in Fig.5. The two parameters (energy-time) data acquisition and analysis system is similar to the one that has been described elsewhere [8]. The threshold detecting was fixed at around 0.5 MeV gamma ray energy.

Our data acquisition system allows energy or pulsed height data of the gamma ray signals that are associated with any interval of the peak of the time spectrum to be selected off-line. Figure 6 shows pulse height spectrum from sample of liquid nitrogen using 2 nsec pulsed neutrons. Each spectrum belongs to different time gating as indicated in the insets. Our experiment indicates that the best signal-to-noise ratio was obtained with narrow neutron pulse (< 5 nsec).

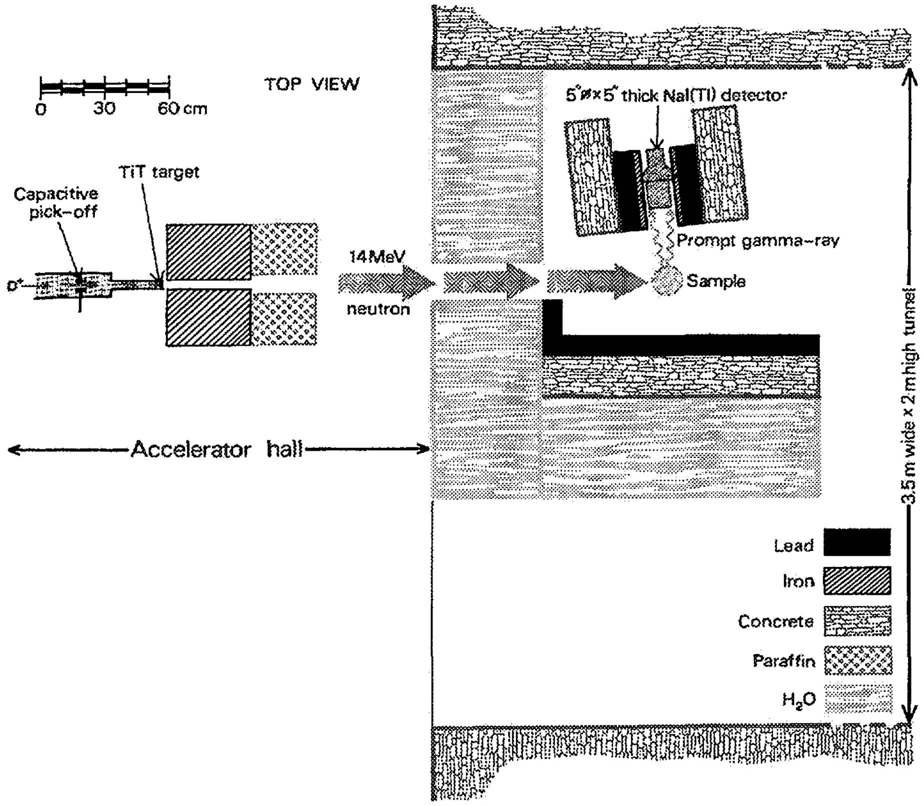

FIG. 5. Experimental arrangements for the pulsed TOF prompt gamma ray analysis [14].

Gamma ray spectroscopy performed using 1.4 kg of C-3 explosive with 2 nsec pulse reveals all expected photo peaks at 1.6, 2.3, 2.8, 3.7, 4.4, 5.1 and 6.1 MeV as shown in Fig. 7.

5. NEUTRON SOURCE AND DOSIMETRY

The neutron generator is normally used to produce monoenergetic 14 MeV neutron from the DT reaction and 3 MeV neutron from the DD reaction. We have investigated the properties of neutrons scattered from a circular surface of rotating paraffin scatterer using the MCNP code and the pulsed neutron TOF measurement [15]. Figure 8. shows the experimental arrangement.

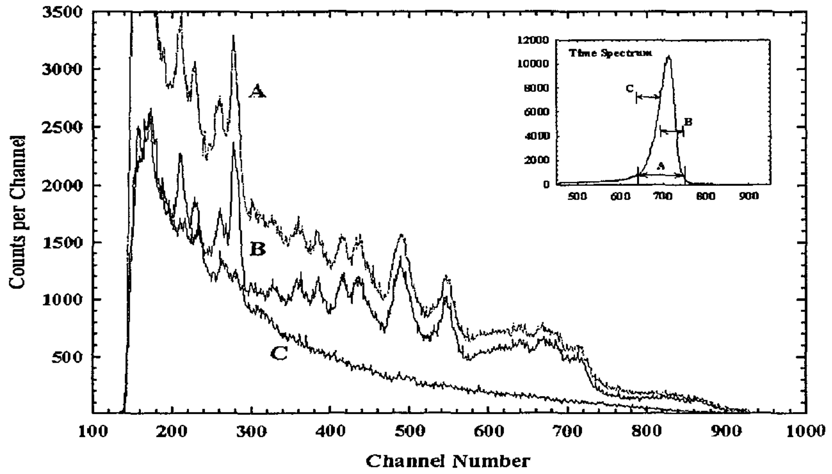

FIG. 6. Gamma ray energy spectrum of 20 kg liquid nitrogen using a 2 nsec width of neutron pulse [14]. Inset: selection of time window on the associated time spectrum (a = 90 nsec, b = 50 nsec, c = 40 nsec).

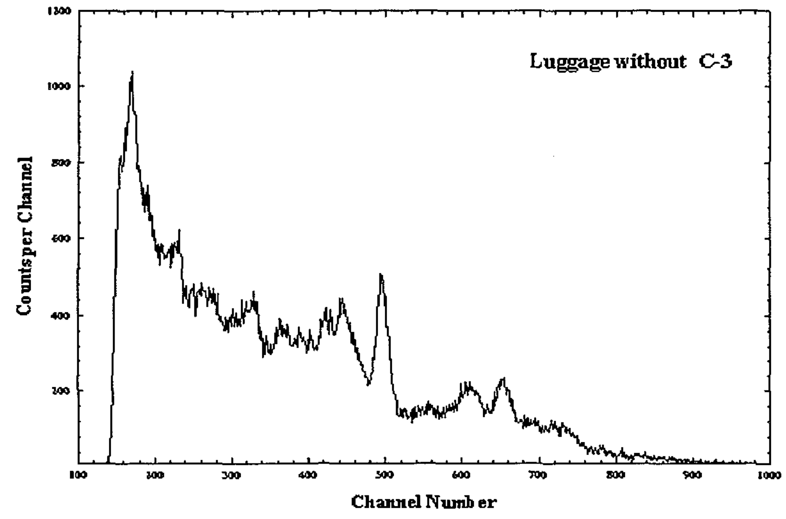

FIG. 7a. Time gated gamma ray spectrum of simulated passenger luggage.

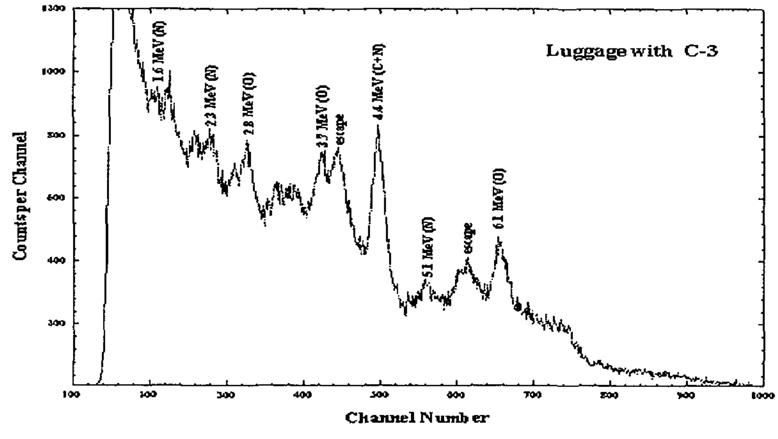

FIG. 7b. Time gated gamma ray spectrum of luggage containing C-3 explosive [14].

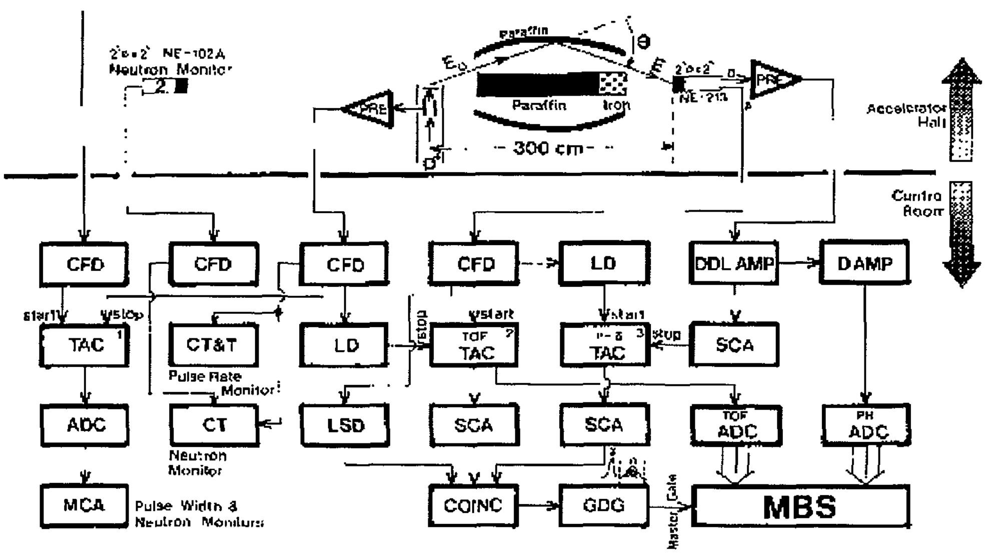

FIG. 8. Experimental set up for elastic scattering of 14 MeV neutron from a circular surface of rotating paraffin scatterer and the two parameter data acquisition system [15].

The neutron pulse height distributions obtained off-line by gating the pulse height events with appropriate TOF events in the specific time window of interest is shown is Fig. 9. It is noted that the yield of n + ^{12}C elastic scattering is fairly pronounced which can be used for calibration purpose. Elastically scattered neutrons from this type of scatterer has been successfully used for measuring the light output of a small NE-213 detector

Neutrons from the 14 MeV neutron generator can also be used to calibrate a neutron dosimeter. The different LET dependence of the low and high temperature glow peaks of CaF_2. The thermo luminescent material (TLD-300) allows the determination of neutron and gamma dose simultaneously. The method was calibrated for the 14 MeV neutron beams at FNRF [16]. Figure 10 and 11 show glow curves of a TLD-300 dosimeter after ^{60}Co and 14 MeV neutron irradiation.

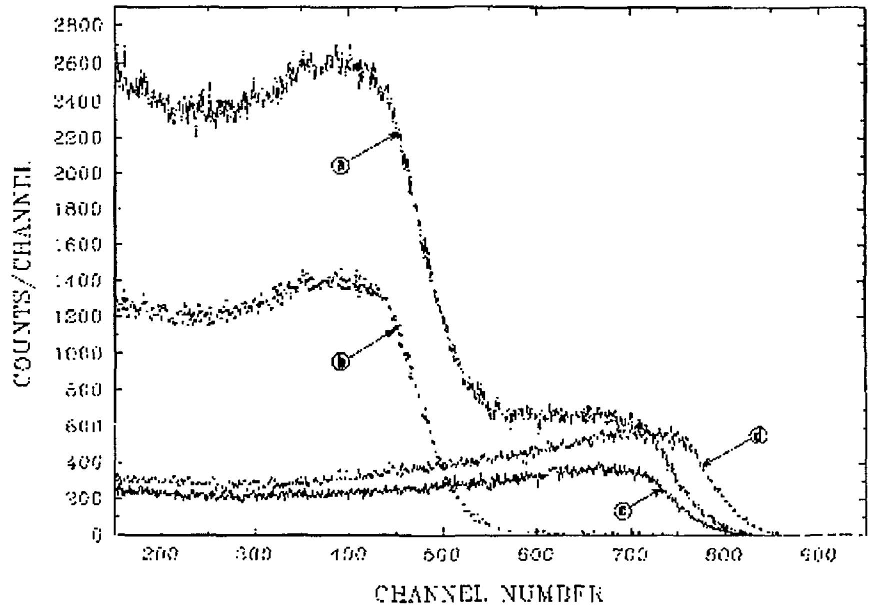

FIG. 9. The pulse height spectrum measured by the 5.08 cm dia x 5.08 cm thick NE-213 liquid scintillation detector. Separate spectra shown are (a) Scattered neutrons from full scatterer, (b) Scattered neutrons from hydrogen elastic scattering in front of the half scatterer. (c) Scattered neutrons from carbon elastic scattering in front of the half scatterer. (d) 14.1 MeV neutrons [15].

The relative neutron responses of both peaks in TLD-300 chips were found to be 0.10 and 0.32. Using this method, various dose distributions of neutron and gamma dose in a water phantom were measured and compared with the results of GM counter measurements and the Monte Carlo calculation as shown in Fig. 12.

6. ION IMPLANTATION

Basically, the 14 MeV neutron generator is a 200 kV ion accelerator using palladium tube to leak deuterium gas into the RF-ion source. At FNRF, we replaced the palladium tube with a thermo mechanical leak valve that enables us to use other gases such as N_2, CO_2, BF_3, etc. Implantation with gaseous ions such as nitrogen, oxygen, boron, argon are possible [17,18]. Surface modification with ion beam based technique has commanded great interest in recent years for improving mechanical, electrical and optical properties of materials [19]. A drift tube neutron generator can be most conveniently modified to be used as an ion implanter concurrently.

7. CONCLUSION

The 14 MeV neutron generator of Chiang Mai University has been utilized in both continuous and pulsed beam modes. Major applications are nuclear data measurement, elemental analysis with prompt gamma ray detection technique, calibrations of neutron detector and TLD-300. With minor modification, the accelerator can be converted into a heavy ion implanter for use to modify the surface properties of materials.

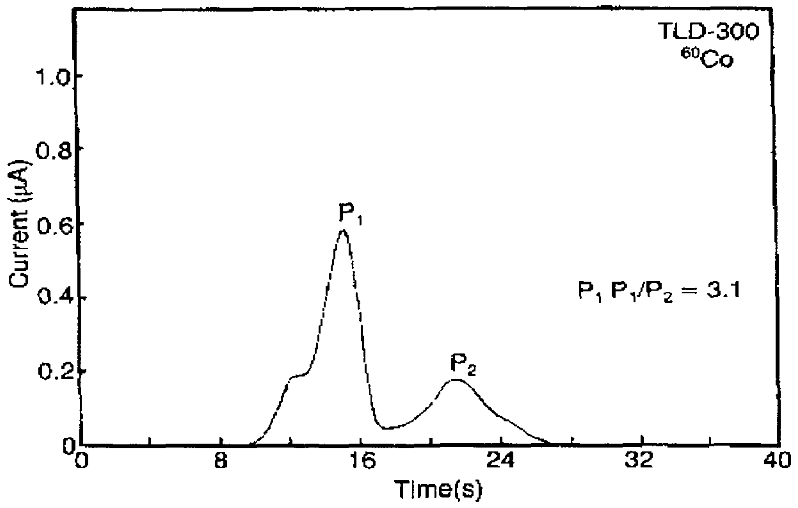

FIG. 10. *Glow curve of a TLD-300 dosimeter after ^{60}Co irradiation [16].*

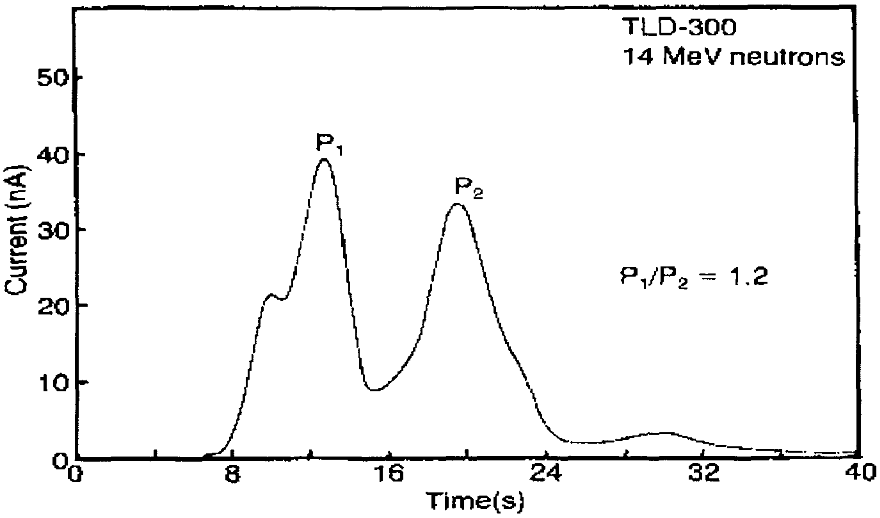

FIG. 11. *The glow curve of TLD-300 dosimeter after irradiation by a 14 MeV neutron beam [16].*

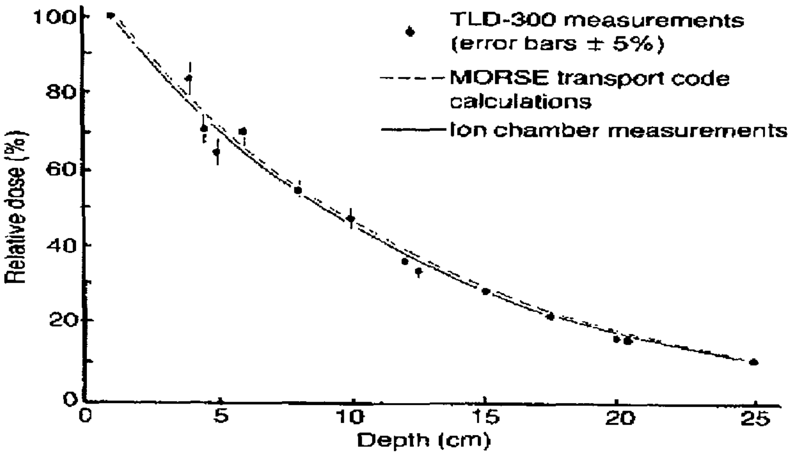

FIG. 12. *Comparison of determination of the depth dose $D_{total} = D_n + D_\gamma$ of the 14 MeV beam in water by the TLD-300 method, ion chamber measurement, and Monte Carlo transport code calculations [16].*

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