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RECENT MODIFICATIONS TO THE MANITOBA DEUTERIUM IMPLANTATION ACCELERATOR AND A STUDY OF THE PROPERTIES OF THE ONLINE NEUTRON MONITOR DETECTOR†

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ABSTRACT

Deuterium molecules have been implanted into Palladium, Titanium and Indium targets in recent experiments at Manitoba by means of the 60 keV, 100 μA D_2^+ 'Narodny' ion accelerator. Neutrons from D-D interactions involving beam particles with previously stopped D atoms were detected by a large plastic scintillator viewed by two Photomultiplier tubes. We describe recent modifications to the accelerator made to improve the quality of the implanting beam, and some of the properties of the neutron detector used.

INTRODUCTION

Interest in warm/cold fusion of deuterium nuclei was stimulated by the March 1989 announcement[1] of possible nuclear fusion at room temperature. The experiment involved electrolysis of heavy water using a platinum anode and a palladium cathode. The electrolysis sent deuterons to sites in the palladium generating, according to the scientists involved, several times more heat energy than the electrical energy consumed. Later results[2] from a similar experiment reported only minor amounts of heat generation but did produce some neutrons, typically 200 per hour, as a signature for nuclear processes being involved.

The University of Manitoba group attempted to simulate the electrolysis experiment in a similar but different non-equilibriumsituation without involving heavy water as an intermediate material. Assuming that the formation of a high concentration of deuterium nuclei in the surface region of the target material (palladium) was a prerequisite for the cold fusion phenomenon, we used the Narodny implanter to directly inject nuclei into the surface at concentrations far in excess of the earlier measurements.

In this experiment[3] a significant rise in neutron production was observed after nine hours of implantation with a 100 μA beam of 60 KeV D_2^+ ions (containing some D^+ and D° contamination). Later, a further experiment was carried out in which similar results were obtained for titanium implantation and were confirmed for palladium. Little excess heat was observed. We now propose to repeat this work using an analyzed ion beam.

MAGNETIC DEFLECTION AND ANALYSIS SYSTEM

The deuterium ion beam accelerated in the Narodny accelerator, though largely molecular D_2^+, has a significant component of atomic D^+ and neutral deuterium whose precise concentration is unknown. To understand the nature of surfaces implanted with atomic and molecular ions - the composition of the beams must be known precisely. In order to solve this problem a 0.1 Tesla magnet was installed to bend the beam from the Narodny ion source into the horizontal plane. The separate beams of molecular and atomic D and ultimately the undeflected neutral beam can now be used to initiate surface changes according to species.

The magnet, a 178 mm diameter circular electromagnet, has been modified into a sector magnet with unity magnification i.e. the image and object distances are equal. To improve the magnetic field uniformity, the magnet poles were aligned to a precision better than 0.01 mm. and the homogeneity of the field after alignment was determined by field mapping for a coil current of 18.0 amperes and a 51 mm gap. Iron diaphragms were designed and appropriate shims were used to terminate the fringing field and complete the conversion to a sector magnet. The shims were positioned in such a way that the maximum possible area of the pole faces can be effectively utilized. The gap between iron diaphragms

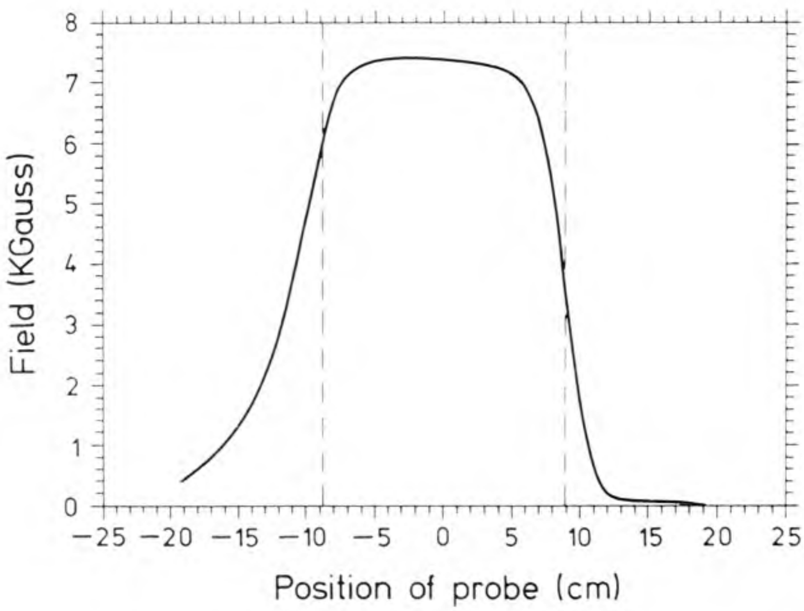

Figure 1. Field mapping of the magnet with shims and one of the iron diaphragms in place for the current and gap width described in the text.

and the shims was optimized to 10 mm. Fig. 1 illustrates the mapped field. The radius of curvature for the beam was selected to be 110 mm. A computer controlled power supply was designed and built for the analyzing magnet. The magnet is installed below the original target chamber on the linear accelerator. A 51 mm. diameter vacuum pipe carries the accelerated beam through the magnet to a new sample chamber where further experiments involving the implantation of gaseous ions in metals will be performed. The immediate concern is to study the separation of D^+ and D_2^+ species in the analysis system, which is underway.

THE ONLINE NEUTRON MONITOR

Experiments[3] conducted at the University of Manitoba on the implantation of heavy metals (Pd, Ti and In) with low energy deuterons led to the observation of neutrons from the $D(d,n)^3He$ interaction. As the concentration of deuterons in the heavy metal matrix increases, these deuterons form the target nuclei for bombardment by subsequent deuterons. Since some deuterons have energy exceeding the threshold energy of the reaction, neutron emission is expected. One searches the supply of generated neutrons for any anomalies in the production rate, or in the absolute number of neutrons produced during the experiment. Two strategies were adopted for the observation of these neutrons:

i. By placing a piece of In close to the target heavy metal, a meta-stable state, ^{115m}In, was formed by inelastic neutron scattering. After the implantation experiment had finished, the decay of the meta-stable state was observed in a low background environment. The total number of neutrons generated during the experiment was then estimated.

ii. A cylinder of NE-102 plastic scintillator was placed in the vicinity of the implantation chamber, and direct monitoring of neutron production observed. This device is called the On-line Neutron Monitor (ONM) and an investigation of the character of the neutron generation rate as a function of time in the experiment was made.

These methods can be checked against one another, since the record of the second experiment can be summed to yield an estimate of the total number of neutrons detected during the experimental run.

The ONM can operate as a proton recoil type neutron spectrometer and is designed to respond to fast neutrons in the energy range of about one to ten MeV. It consists of a cylindrical piece of NE-102 plastic scintillator viewed by two RCA 4522 photomultiplier tubes and provides a proton rich target for incoming neutrons[3]. Cosmic ray muons are continuously detected by the ONM. These signals have a definite spectrum and can be used to monitor the constancy of the overall gain of the detection system and help define the energy calibration of the detector. Environmental gamma rays are registered by the system and can contribute to the observed spectrum. Because of the high thermionic noise exhibited by the photomultiplier tubes, chance noise coincidences can be included in the data record. Finally, since both photomultiplier tubes view each other, light caused by afterpulses in the one tube can be detected very efficiently by the other. All of these effects place practical limits on the range of energies to which the ONM is sensitive.

In the energy range up to 10 MeV, the neutron-proton (n-p) elastic scattering system produces neutrons isotropically in the centre of mass frame and thus all scattering geometries are equally probable. While the energy gained by the recoil proton may range from zero to the incident neutron energy on average, the proton receives half the incident neutron energy. In the energy range up to a few MeV, the light output of NE-102 is not a linear function of proton energy. The proton deposits much more energy per unit path length than can be converted into scintillation light[4]. As a result, the calibration of the spectrometer output in terms of proton energy is cumbersome. Since electrons in the same energy range deposit relatively little energy per unit path length, the light output of NE-102 increases linearly with electron energy. The ONM calibration is expressed in terms of equivalent electron energy, and the incident neutron (proton) energy is related to that electron energy.

Compton scattering of gamma rays of known energy is used to calibrate the ONM. A sodium iodide detector at a fixed scattering angle detects the scattered gamma ray and thus defines the energy of the Compton electron within the scintillator. The energy calibration of the ONM is shown in figure 2. Also included is a calibration point from cosmic ray muons.

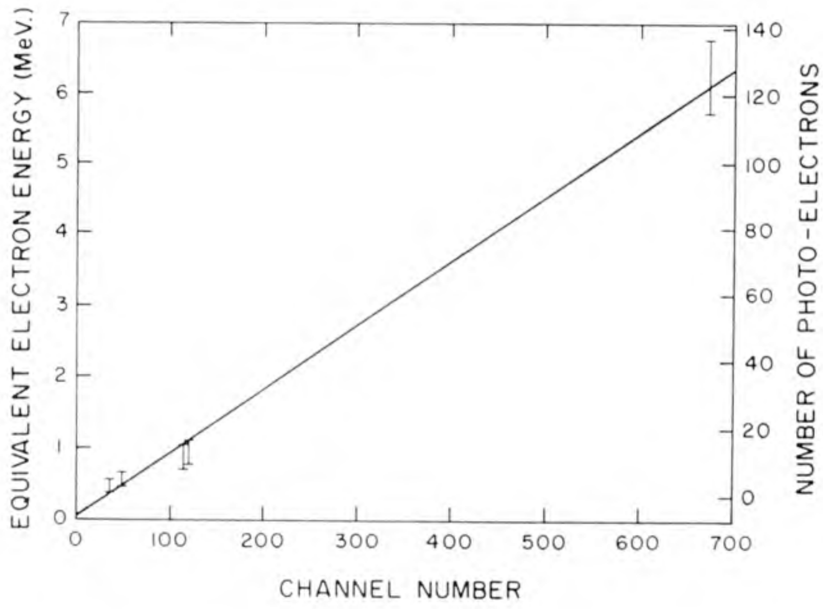

Figure 2. Calibration of the Online Neutron Monitor by compton scattered electrons from the gamma ray sources ^{22}Na and ^{137}Cs, and cosmic ray muons.

To estimate the light output and efficiency of the ONM, a prediction of the spectrum from neutrons of energies between one and ten MeV was made using a monte carlo simulation developed by Stanton[5].

The neutron is followed through the scintillator until it falls below a certain energy or it escapes from the detector, so that multiple scattering of the neutron within the scintillator can be included. Scattered protons are also monitored and if they escape from the scintillator a suitable light output is assigned. Only collisions between neutrons and protons that result in energy deposit in the scintillator within the integration time of the ADC (50 ns) after the first collision are included in the estimate. For neutrons in the energy range one to five MeV, n-p scattering dominates and neutron - Carbon (n-C) elastic scattering contributes little light because the highly ionizing, recoiling carbon nucleus quickly saturates the scintillator.

The results of the monte carlo simulation, coupled with the muon and Compton scattering calibration of the ONM demonstrate that the ONM is capable of detecting neutrons with energies of a few MeV. To confirm the calibration of the ONM, the detector was exposed to neutrons of known energy, using a technique developed by Filichenkov et al[6]. The Filichenkov method uses an alpha-beryllium neutron

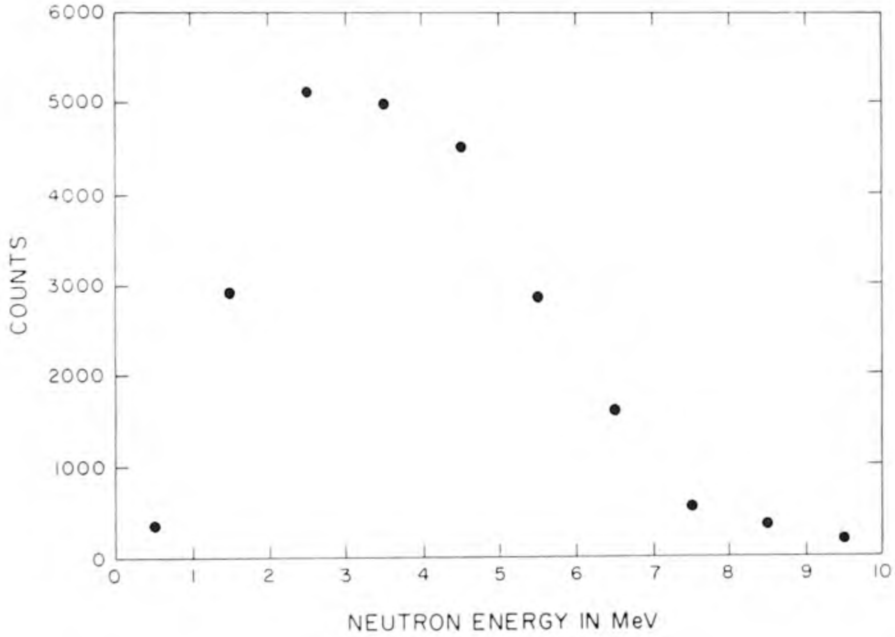

Figure 3. A neutron kinetic energy spectrum taken with the Online Neutron Monitor and a Am-Be neutron source. Energy axis values are determined by the neutron flight time.

source, in our case Am-Be. The neutrons are produced when an alpha particle and a ^{9}Be nucleus combine to make ^{13}C in an excited state, which quickly decays to ^{12}C by emitting a fast neutron. If the ^{12}C is created in its first excited state, that state decays immediately by emitting a 4.4 MeV gamma ray. The time interval between the detection of the 4.4 MeV gamma ray and the detection of an event in the ONM is measured by a time digitizer unit (TDC), yielding the energy of the neutron. A time-of-flight spectrum is shown in figure 3.

The goal of this exercise is to determine the energy calibration of one of the ONM energy spectra taken during one of the experimental runs. Figure 4 shows the energy spectrum detected during an implantation run where D was implanted into Pd[3]. Two features are prominent in the spectrum. The first, seen at the higher energy end of the spectrum, is the distribution due to the passage of cosmic ray muons and electrons. At somewhat lower energies, a broad peak is observed resulting from emissions due to the experiment. Clearly, the broad peak corresponds to neutron energies that are somewhat high if n-p elastic scattering is to explain its presence in the spectrum.This work is continuing.

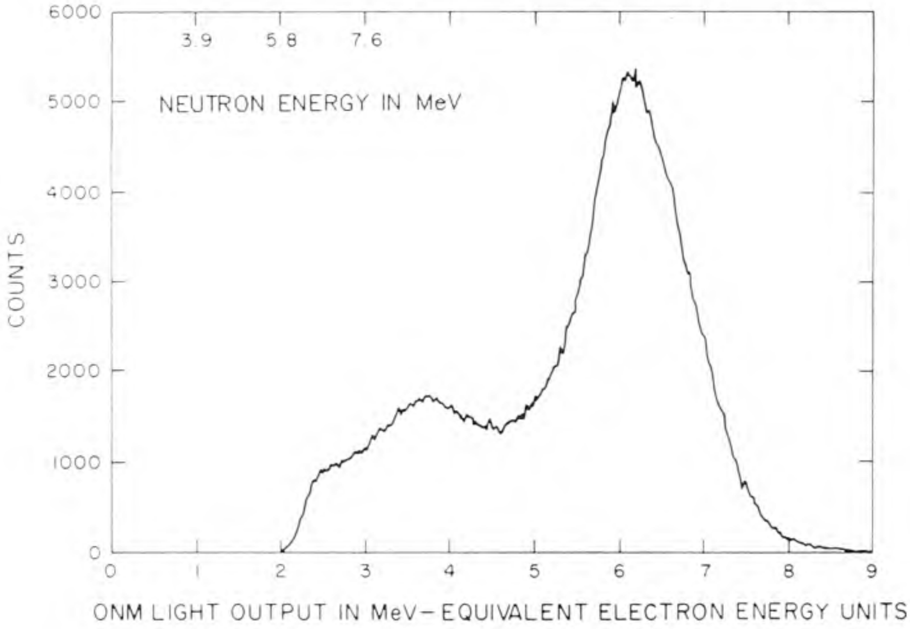

Figure 4. An energy spectrum of detected events taken during a D-Pd implantation run illustrating the cosmic ray and neutron like events. The horizontal axis is calibrated for equivalent electron and neutron energy values.

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