Abstract. An Absolute Neutron Dosimeter was developed to be used as a calibration standard for the Radiation Metrology Laboratory at CCHEN. The main component of the Dosimeter consists of a Proportional Counter of cylindrical shape, with Polyethylene walls and Ethylene gas in its interior. It includes a cage shaped arrangement of graphite bars that operate like the Proportional Counter cathode and a tungsten wire of 25 µm in diameter µm as the anode. Results of a Montecarlo modeling for the Dosimeter operation and results of tests and measurements performed with a radioactive source are presented.

1. Introduction
The possibility of measuring Absorbed Dose in a given material from physical measurements was proposed, by L.H. Gray in 1944, for ionizing radiations and neutrons (via secondary charged particles), through the so called Bragg-Gray principle [1]. This principle establishes a method to measure the Absorbed Dose by means of the presence of a cavity with gas, centered in a point of the irradiated material. This principle, considered as a basic concept in Radiation Dosimetry, allows measuring Absorbed Dose with any instrument based on the ionization effect in radiation absorbing materials. The Absolute Neutron Dosimeter developed at CCHEN operates under the Bragg-Gray principle. The Dosimeter consists of a low pressure Proportional Counter simulating a small cavity inserted in the neutron exposed material. In this case the material exposed is Polyethylene and the gas in the cavity is Ethylene. The fact that both materials have the same atomic composition leads to an important simplification in the relation given by the Bragg-Gray principle. The measurement of Neutron Absorbed Dose using a Proportional Counter requires a calculation according to expression 1) as recommended in ICRU-26 [2]

\[ D_0 = 1.602 \times 10^{-7} \frac{C}{\rho V} \sum h N(h) \]  

Where \( D_0 \) is the Absorbed Dose in mGrays, \( C \) is a calibration factor that relates channel number with units of keV·µm\(^{-1} \), \( N(h) \) is the number of events recorded in the channel \( h \), \( \rho \) is the gas density in g/cm\(^3\), \( V \) is the gas volume in cm\(^3\) defined by the electric field and the dimensions of the Proportional Counter.

The main motivation of this work is to provide to the Radiation Metrology Laboratory at the CCHEN, an instrument capable of performing an absolute measurement of the Neutron Radiation Absorbed Dose. This laboratory is the national reference for the calibration and certification of
instruments and Dosimeters used for radiological protection purposes. The contribution of an absolute measurement will help to validate their work in the field of neutron dosimetry.

2. Dosimeter Description
The design of Proportional Counters for use as Neutron Dosimeters has been described elsewhere [3]. The main structure of the dosimeter consists of a cylindrical shell made of Polyethylene (Figure 1-A) with Ethylene gas (99.99% purity) in its interior. The principle of operation is based on the elastic scattering of protons in the radiator material (shell), by the incoming fast neutrons. Considering that Polyethylene is not an electrical conductor, the cathode also includes a structure of aligned graphite bars on the internal wall of the shell (cage shaped) parallel with the axis of the above mentioned Polyethylene cylinder (see Figure 1-B and Figure 2). The graphite bars help to define the electric field inside the Proportional Counter.

![Figure 1. Internal view of the Dosimeter Chamber](image)

In previous publications other authors chose to install a metallic cathode behind the Polyethylene radiator [4]. They never explained how they solved the problems of accumulation of space charge that this could cause. A group from the “Korea Research Institute of Standards and Science” in South Korea, reports a more recent design [5]; they decided to include a fine graphite deposit (they called it “graphite dust”) in the internal wall of the Polyethylene radiator. It is clear that with this solution, they solved the problem of the nonconductor Polyethylene cathode. Nevertheless, they do not explain how they took into account, the loss of energy of the emerging protons from the Polyethylene wall, in the graphite layer.

![Figure 2. Internal view of structure, showing graphite bars](image)
The configuration used for the cathode in this work, avoids accumulation of undesired space charge within the volume of the detector, which would lead to distortion of results. In addition, this cathode structure has a transmission of 82% for protons emerging from the polyethylene wall that enters to the gas volume, a factor that does not depend on the energy of the emerging protons.

The ideal solution for the cathode problem is to use A-150 plastic [6], which is considered as ‘tissue equivalent’ in addition of being an electrical conductor. The combination of Polyethylene – Ethylene as proposed in this work offers a more cost effective solution, and is acceptable with the appropriate correction [7], as a dosimetric reference.

The anode of the Proportional Counter (see Figure 1-C) is a 25 µm in diameter tungsten wire. It is stretched between the axial ends of the Polyethylene cylinder, installed and centered inside the field electrodes. These cylindrical electrodes (see Figure 1-D) are made of plastic. They provide an electrical insulation to the anode wire form the rest of the Proportional Counter. Each electrode has a layer of graphite over its outer surface which is connected to a polarizing power supply to allow the electric field, in the Proportional Counter, to be spatially well defined [8].

In order to perform energy calibrations, an 241Am alpha source has been installed inside the Dosimeter (see Figure 1-E). Calculations of the energy lost of the alpha particles in ethylene inside the Proportional Counter were made with the help of the software SRIM-2004 [9]. An electromechanically controlled shutter blocks the alpha particles when the Dosimeter is in use (see Figure 1-F).

The Proportional Counter and its calibration system are located in a vacuum chamber (see Figure 1-G). A pressure transducer located next to the chamber measures the internal pressure. The Ethylene gas flows constantly through plastic gas lines (2 meters long) from the Dosimeter chamber to a computer controlled system that keeps the gas pressure and flow stable. An evaluation of this system indicates that pressure is measured to a precision of ±3%.

The electrical signal from the anode is amplified and shaped by a standard spectroscopy linear amplifier. Events are recorded in a conventional MCA, to obtain the Event Size Distributions.

3. Results
Nine completely independent measurements of Absorbed Dose for a 241Am-Be neutron source were performed. The Dosimeter parameters used are: gas pressure: 12Torr, anode bias voltage: 650V, field electrodes voltage: 174V, source - Dosimeter distance: 20cm, elapsed time of measurements: 60 min.

A typical Event Size Distribution obtained is shown in Figure 3. From this evaluation, the mean value for the Absorbed Dose measurements is 0.0632 mGy/h. The estimated precision, including the dispersion in the pressure value, is ±3.7%. This corresponds to three significant digits in the measured value.

![Figure 3. 241Am-Be source Event Size Distribution Measurement](image-url)
Results of a Montecarlo model of the Dosimeter operation for a $^{241}$Am-Be neutron source are shown in Figure 4. It has been obtained by adding eleven mono-energetic neutron energy values in the right proportions. It is clear that the model reproduces the shape of the distribution obtained with the Dosimeter. Close to 140 keV the reduction in the events number corresponds to the so called “Bragg drop”, which also appears in the distribution obtained from the measurements.

![Figure 4. 241Am-Be source Event Size Distribution Simulation](image)

To evaluate the accuracy of the Dosimeter, the measured Absorbed Dose Value was compared to a calculated Absorbed Dose Value using Neutron Fluence calculated for a $^{241}$Am-Be source at 20 cm and the corresponding Mean Neutron Fluence to KERMA conversion factor [10]. The measured value was found to be 11.7% larger that the calculated one.

4. Discussion
A preliminary estimation of the accuracy indicates a discrepancy of 11.7% between the measured and the calculated values. This exceeds the precision limits stated before. It could be attributed to geometric limitations in the measurements setup, (which leads to neutron scattering in walls, floor, shielding, etc.). Therefore, as a conservative criterion, the precision accepted for the Dosimeter limits the measured values to two significant digits. A better-defined neutron field should be used for a more accurate specification.

5. Conclusion
An Absolute Neutron Dosimeter has been developed showing a precision that allows two significant digits in the measured value. It is based on a low pressure Polyethylene Proportional Counter. Evaluations indicate that the device meets the requirements to become a neutron calibration standard for the Radiation Metrology Laboratory at CCHEN.

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