Measurement of Alpha Particles on the Exterior Surface of the Neutral-Current Detectors in SNO

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Abstract

The Sudbury Neutrino Observatory (SNO) will utilize an array of proportional counters, the bodies of which are nickel tubes made by chemical vapor deposition onto an aluminum mandrel. The exterior surfaces of these tubes must have low alpha particle levels, since alphas react with ^{17}O in the heavy water of the detector to produce neutrons, the signal of a neutrino event. A proportional counter was built and several measurements were made in order to determine this alpha level. Although the results are not yet fully understood due to a strong background signal from the counter itself, the neutron production rate from the ^{17}O reaction is estimated at 5 n/yr, with an upper limit of 14 n/yr. This rate is acceptably low.

1 Introduction

The Sudbury Neutrino Observatory (SNO) is a water Cerenkov detector filled with 1000t of heavy water. It will detect solar neutrinos through the neutral-current, charged-current and elastic scattering reactions. SNO will also include an array of ^{3}He-filled proportional counters that will detect neutrinos from the neutral-current reaction

$$^{2}H + \nu_x \rightarrow p + n + \nu_x$$

only. These will detect the free neutrons emitted in the neutral-current reaction through the reaction

$$^{3}He + n \rightarrow ^{3}He + p\ .$$ [1]

The bodies of the neutral-current detectors (NCDs) consist of ultra-pure nickel tubes made through chemical vapor deposition. Because the proportional counters use neutrons as their neutrino detection signal, the bodies of the NCDs themselves must be free of contamination that could result in the production of neutrons. Alpha particles from the ^{238}U and ^{232}Th chains could produce neutrons in two ways: [2]

1) Alpha particles can break up deuterium in the heavy water through the reaction

$$\alpha + d \rightarrow n + p + \alpha\ .$$

The minimum alpha energy for this reaction is 6.66 MeV, and there are three decays in the ^{238}U and ^{232}Th chains that produce alphas of at least this energy. These are the decays of ^{214}Po in the uranium chain, with an energy of 7.83 MeV, and the decays of ^{216}Po and ^{212}Po in the thorium chain, with energies of 6.78 and 8.78 MeV respectively.

2) The heavy water contains a small amount of ^{17}O, which can interact with alpha particles to produce neutrons through the following reaction:

$$^{17}O + \alpha \rightarrow n + {}^{20}Ne.$$

The Q-value for this reaction is 0.5871 MeV; since this is greater than zero all alphas in the uranium and thorium chains can cause this reaction.

Because of these reactions, it is necessary that the alpha background on the NCDs be low. An electropolishing procedure is used to remove as much contamination from the tubes as possible, but it is necessary to evaluate the effectiveness of this procedure by measuring alphas on the tubes both before and after the procedure. An additional concern results from the storage of some of the tubes in a cave in Index, WA which contained a high concentration of radon. It must be ensured that the background remaining from the decay of this radon and its daughters is low. Because of the short lifetime of most of the radon daughter products, the primary source of alphas is the decay of ^{210}Po in the ^{238}U chain, which produces a 5.3 MeV alpha. This alpha is too low-energy to break up deuterium, but could still cause the ^{17}O reaction.

A stainless steel proportional counter was used to measure the alpha background on the exterior surface of the nickel tubes; the method, results and conclusions are presented in the following sections.

2 Data Acquisition and Analysis

The external alpha counter (EAC) is a proportional counter made out of stainless steel (see Figure 1). It is a cylinder roughly 30 inches long and 6 inches in diameter, and has a slit approximately 3 inches wide on which the tube to be measured is placed. It is filled with P-10 gas, a mixture of 90% argon and 10% methane, which flows continuously through the counter. A thin copper wire runs down the center and is raised to an operating voltage of 1400 volts. Alpha particles are detected via a cascade of electrons in the gas, which results in a voltage on the wire proportional to the alpha energy deposited in the gas. This voltage is sent through an SHV connector and coaxial cable to an integrating preamp, which turns the signal into an integrated pulse. It then goes to an Ortec 855 amplifier, which shapes the pulse into an approximate Gaussian normalized to the same area. This Gaussian is sent to an ADC, which converts the height of the pulse (representative of the total voltage) to one of 2048 channels. The signals received in this way are displayed on the data acquisition computer.

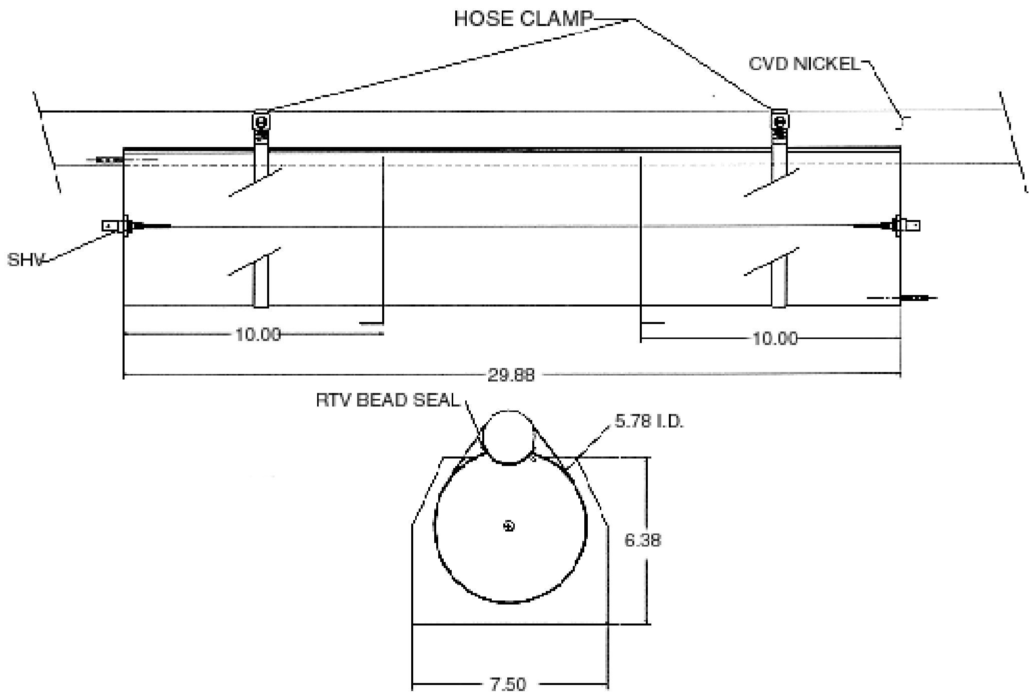

Figure 1. A schematic of the external alpha counter, courtesy of Tom Burritt. Dimensions are in inches.

The signal is calibrated with a ^{241}Am source that emits photons with energy 59.5 keV. Figure 2 shows the resulting signal when the source is placed near the EAC. Above the signal threshold, which is set at channel 150, it shows a low energy cosmic ray background, a trailing edge due to photoelectric conversion in the nickel, and a distinct peak due to the reaction

$$\gamma + Ar \rightarrow Ar^{+} + e^{-}$$

in the gas. The cosmic ray background from a two minute run with the Am source removed is shown in Figure 3. The binding energy of the electron is also converted to ionization through X-ray and Auger emission. The recoil of the argon atom is small, so the peak can be placed at 59.5 keV with reasonable accuracy. An electronics gain of 100 $\times$ 2.9 on the 855 puts the Am peak at about channel 550, as shown in the figure; this corresponds to about 108 eV per channel. Bringing the gain down by a factor of 50, to 2 $\times$ 2.9, increases this number by a factor of 50, to about 5.4 keV per channel. This puts the expected 5.3 MeV ^{210}Po peak just under channel 1000.

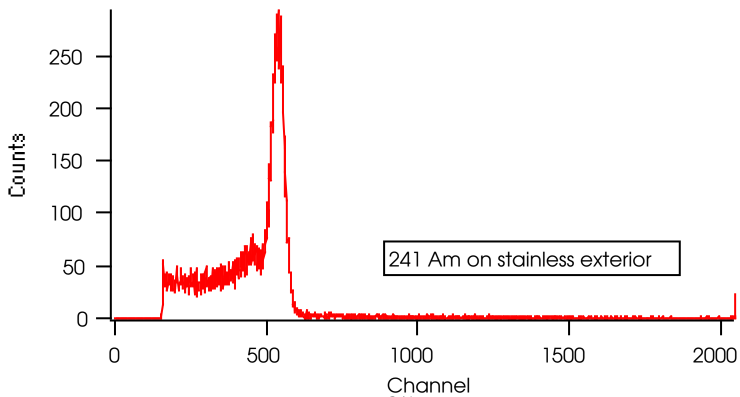

Figure 2. The spectrum due to the ^{241}Am source used for calibration. The large peak just above channel 500 is at 59.5 keV.

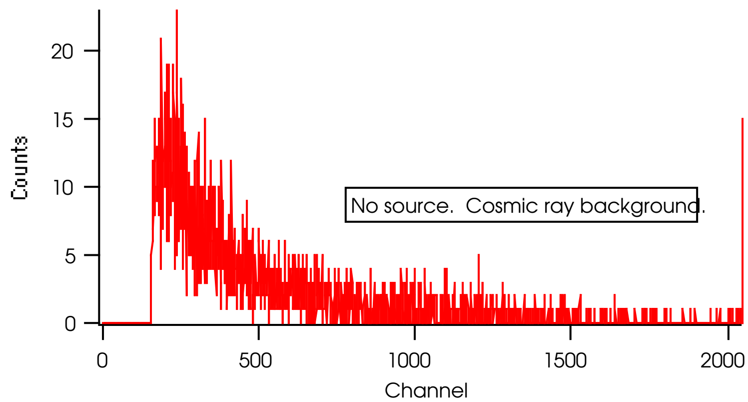

Figure 3. The cosmic ray background seen during a two minute run when the calibration source is removed.

This calibration is done at both the beginning and end of each alpha-detecting run, since the position of the peak is very sensitive to changes in pressure. The value used for calibration is the average of the two measurements, and the error is given as half the difference of the two measurements, expressed as a percentage of the average. This is the calibration error noted on Figs. 4 to 7; the resolution of the detector is coarse enough to make this error insignificant.

An initial alpha run of about an hour was done first with each tube, to be sure that all the air was purged out of the detector. The more formal measurements were made during runs of several hours, generally done overnight. They were done on an unpolished tube, a polished tube, a tube known to be clean and a stainless steel tube intended to measure the background due to the detector itself. An attempt was also made to shield the detector with aluminum foil; this was not successful due to the broad-spectrum background from the aluminum. The results of the Am calibration were used to plot the results of these measurements as counts as a function of energy.

3 Results

The first measurement was done on tube T094, an unpolished tube which had been stored at Index. The run was 797 minutes long. The results are plotted in Figure 4. There are

195 counts between 5 and 5.6 MeV, giving a rate of 352 ± 25 counts/day, with the error coming from Poisson statistics. The area of the tube exposed to the counter is 353 ± 15 cm^2. Assuming that all the alpha activity is due to the tube (a poor assumption, as will be shown) results in a rate of 9970 ± 840 ± 420 counts/m^2/day, with the first error due to statistical uncertainty and the second to the uncertainty in the area. The cosmic ray background at this energy is negligible; we have calculated that the maximum energy of a minimum-ionizing cosmic ray passing diagonally through the counter is 0.3 MeV.

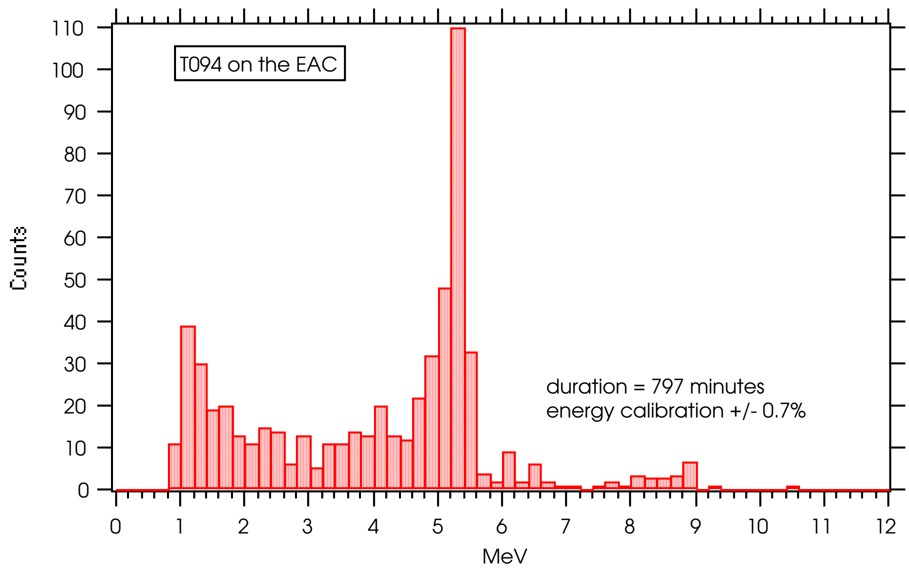

Figure 4. The spectrum obtained for an unpolished tube on the EAC. The peak between 5 and 5.6 MeV corresponds to a rate of 9970 ± 840 ± 420 counts/m^2/day (assuming that all activity is due to the tube).

The second measurement was a 921 minute run on tube T052, which had been electropolished after its return from Index. The results of this run are plotted in Figure 5. This shows 311 counts between 5 and 5.6 MeV, giving rates of 486 ± 28 counts/day and 13,770 ± 920 ± 590 counts/m^2/day.

These two runs were done with the same gas bottle, eliminating contaminants from the gas as a factor in the differences in these results. It should also be noted that the initial alpha runs of an hour or so showed a broad, low peak around 7-8 MeV. This mostly disappeared on the longer runs, suggesting that it was due to the decay of radon daughter products in the air being purged out of the detector.

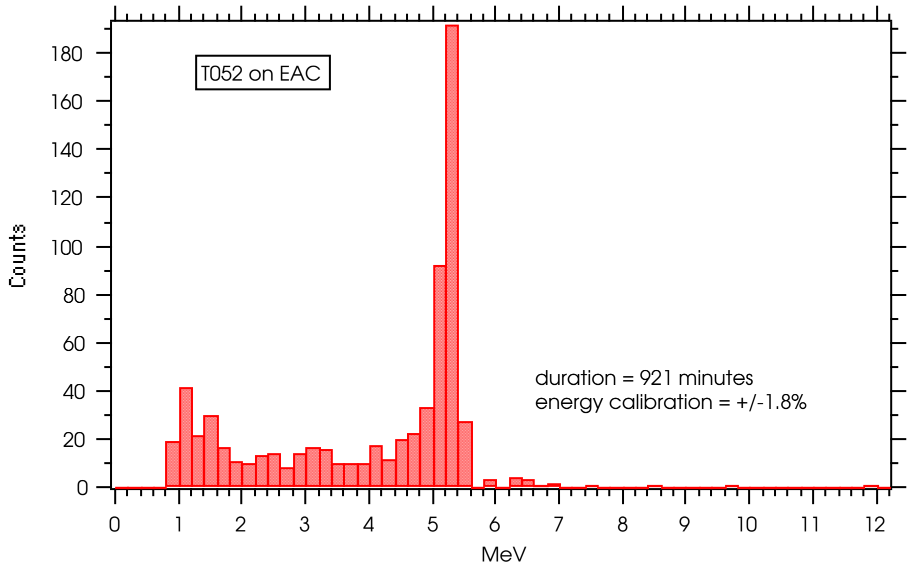

Figure 5. A polished tube on the EAC produced a rate of alphas between 5 and 5.6 MeV of 13,770 ± 920 ± 590 counts/m^2/day.

These results, with the polished tube having a higher rate than the unpolished tube, were not expected, and further measurements were made in an attempt to understand the background of the detector. A run was performed on a tube which had never been to Index and was thought to be clean (this was the tube known as the "tiger tube" due to the markings on the outside). This run was 1215 minutes long. The results are plotted in Figure 6. There are 260 counts between 5 and 5.6 MeV, giving rates of 308 ± 19 counts/day and 8730 ± 640 ± 370 counts/m^2/day.

Finally, a tube made out of stainless steel, the same material as the detector, was obtained, and a 547 minute run was done with this. It resulted in 116 counts between 5 and 5.6 MeV, giving a rate of 305 ± 28 counts/day. See Figure 7.

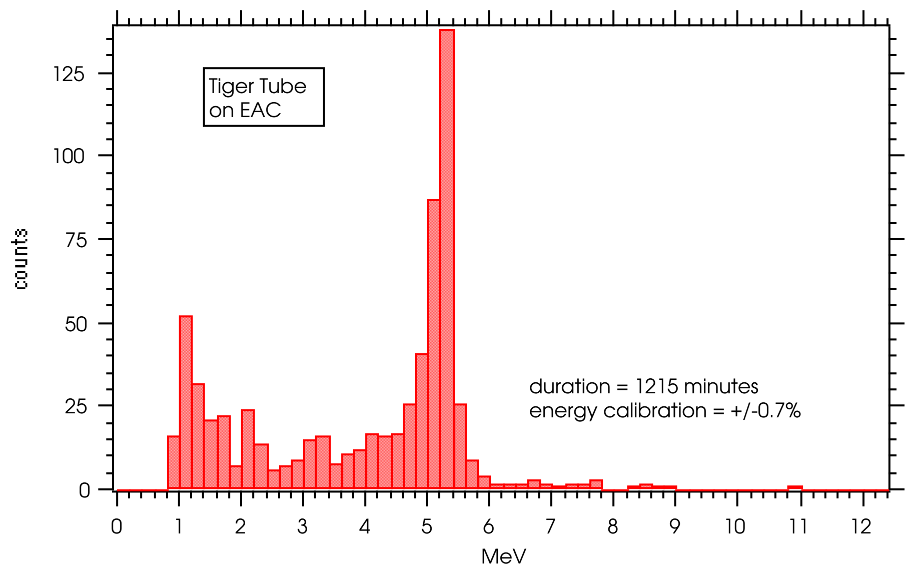

Figure 6. A clean tube produced a 5-5.6 MeV alpha rate of 8730 ± 640 ± 370 counts/m^2/day.

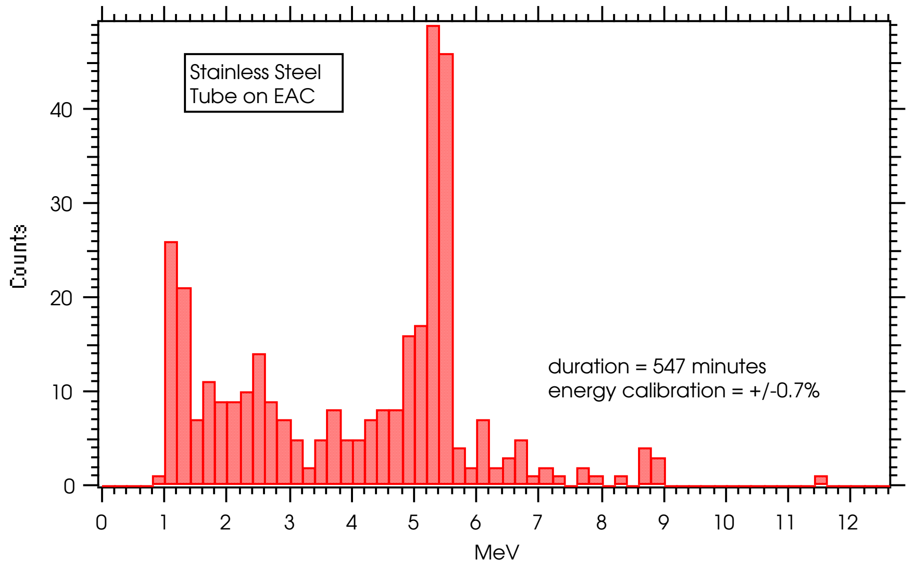

Figure 7. Measurements were made on a stainless steel tube, the same material as the detector. The result was a rate of 305 ± 28 counts/day, similar to the 308 ± 19 counts/day rate obtained from the clean tube.

Table 1 summarizes the results of these measurements.

Tube	**Rate (counts/day)**	**Rate (counts/m^2/day)**
Unpolished	352 ± 25	9970 ± 840 ± 420
Polished	486 ± 28	13,770 ± 920 ± 590
Clean	308 ± 19	8730 ± 640 ± 370
Stainless Steel	305 ± 28	---

Table 1. Rates of alphas between 5 and 5.6 MeV obtained on various tubes with the external alpha counter. The surface activities are calculated under the assumption that all the activity is on the surface of the tube under test.

4 Conclusions

It is obvious from these results that there is a significant background due to alphas from the EAC itself. It is also clear that the alphas we are observing are the 5.3 MeV alphas from the decay of ^{210}Po. Although other alpha lines in the range 5 to 6 MeV could be misidentified as ^{210}Po given the calibration uncertainties, all U and Th chain activities other than ^{210}Po would be accompanied by other alpha peaks in the spectrum. The fact that we see only one peak indicates that we are observing the decay of ^{210}Po at the end of the chain. Much of this Po comes from the detector itself; the fraction is not yet determined.

The results would also seem to indicate that electropolishing makes the situation worse instead of improving it. It is possible, however, that the polished tube had a much larger concentration of Po on its surface to begin with, so that the electropolishing, while reducing the amount, did not bring it below the level of the unpolished tube. More measurements would have to be taken in order to understand the situation, ideally on the same tube both before and after it was polished. This was not done because the RTV seal leaves a significant mark on the tubes and we wished to contaminate as few of them as possible.

Although these results are not fully understood, they do determine an upper limit of Po contamination of 15,280 counts/m^2/day, from the upper limit of the largest result found. This is undoubtedly an overestimate, due to the large background of the detector itself and a smaller one due to cosmic rays. A more realistic estimate would take the rate found from the clean tube as a measurement of the background due to the counter itself. When this is subtracted, the alpha rate becomes approximately 5000 ± 1200 ± 200 counts/m^2/day.

These alpha rates translate into neutron rates as follows. The rate of neutron production in the heavy water depends on the concentration of ^{17}O in the water, the cross-section for the reaction, the stopping power of the alphas in D_2O, and the number of oxygen atoms.

The alpha particles produce neutrons through the reaction [2]

$$^{17}O + \alpha \rightarrow n + {}^{20}Ne.$$

The cross-section for this reaction is

$$\sigma(E) = 8.67 \times 10^{-25}\ [-\ln(23.805 - E_\alpha) + 3.146] \quad \mathrm{cm}^2.$$

The stopping power *dE/dx* of alphas in heavy water was calculated by SRIM; [3] Figure 8 shows the result, which was used by IGOR to calculate the rate of neutron production per alpha. This is given by: [2]

$$Rate\ per\ \alpha = \eta_{17}\ N_O \int_0^{5.3} \sigma(E) \left(\frac{dE}{dx}\right)^{-1} dE\ ,$$

where η_{17} is the isotopic abundance of ^{17}O, measured to be 1.7 x 10^{-3}, and N_O is the number of oxygen atoms per gram, 3.0 x 10^{22} g^{-1}. Using the cross-section and stopping power above results in a rate of 2.0 x 10^{-8} n/α.

The total length of nickel tube in the NCD array is 770 m, and each tube has a diameter of 0.0516 m. This results in a total area of 125 m^2. The upper limit of 15,280 counts/m^2/day gives 1.9 x 10^6 alphas per day; when this is multiplied by the reaction rate of 2.0 x 10^{-8} n/α, the result is 0.038 n/day or 14 n/yr. The more realistic estimate of 5000 counts/m^2/day gives a smaller rate of 5 n/yr. These rates, low though they are, will be further reduced by decay of 138-day ^{210}Po in the interval between the measurements reported here that took place in July 1999, and the time of deployment of NCDs in SNO. In all cases where the ^{210}Po activity on nickel counter bodies has been followed over time, the ^{210}Po has been observed to decay. It is evidently not supported by 22-y ^{210}Pb.

The standard solar model predicts a neutron detection rate in SNO of 5000 n/yr. [1] Thus these rates represent a background of 0.28% and 0.1% of the solar signal, respectively. Even at the upper limit, this level is acceptably low. It can therefore be said that although the results of the measurements with the EAC are not completely understood, they do indicate a sufficiently low background to make neutron production through the ^{17}O reaction a small concern. Further measurements would be necessary to better understand the background due to the counter and thus state the reaction rate more precisely.

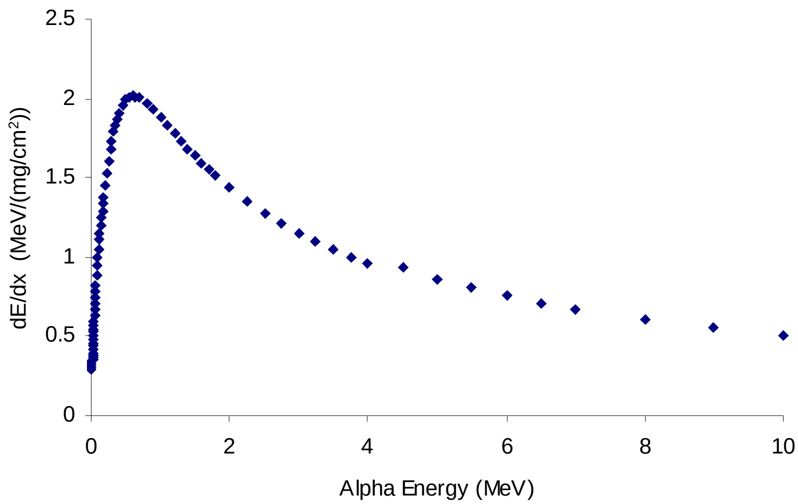

Figure 8. The total stopping power *dE/dx* of alpha particles in D_2O.

References:

1 K.M. Heeger, "A Method for Determining the Neutral-Current Interaction Rate in the Sudbury Neutrino Observatory." Research proposal, unpublished. (1999)

2 J.A. Dunmore and R.G.H. Robertson, "Background Neutron Sources to the Neutral-Current Signal in SNO." Unpublished. (1998)

3 SRIM, The Stopping and Range of Ions in Matter. © 1998, 1999, IBM Co.