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L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

**PLANS FOR A HIGH-RESOLUTION MEASUREMENT OF THE
TRITIUM BETA-SPECTRUM END POINT TO DETERMINE
THE NEUTRINO MASS**

**Plans pour la mesure à haute résolution du point terminal du spectre
bêta de tritium pour déterminer la masse de neutrinos**

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Résumé

Le spectromètre bêta, libre de fer, $\pi \sqrt{2}$ de Chalk River fait actuellement l'objet d'un perfectionnement et d'une remise en service qui permettront de mesurer avec précision la forme du spectre de tritium près du point terminal. Avec une source à bandes multiples et un ensemble détecteur à 60 éléments, on s'attend à une résolution énergétique totale de ≤ 19 eV FWHM. Les simulations par ordinateur des diagrammes de Kurie auxquels on s'attend expérimentalement sont présentées pour diverses hypothèses de masse d'antineutrinos.

*Rapport présenté au mini-congrès et à l'atelier sur la masse des neutrinos tenus à Cable, Wisconsin du 23 au 25 septembre 1982

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ABSTRACT

The Chalk River $\pi \sqrt{2}$ iron-free beta spectrometer is being recommissioned and upgraded for a precise measurement of the shape of the tritium spectrum near the end point. With a multiple strip source and 60-element detector array an overall energy resolution of ≤ 19 eV FWHM is expected. Computer simulations of the expected experimental Kurie plots are presented for various anti-neutrino mass assumptions.

*Presented at the Neutrino Mass Mini-Conference and Workshop, Cable, Wisconsin 1982 September 23-25

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The report of a non-zero mass for the electron anti-neutrino by Lubimov et al.¹⁾ has stirred interest in many laboratories throughout the world including ours at Chalk River. Since the world's largest iron-free beta spectrometer²⁾ is at our disposal, an experiment to remeasure the shape of the tritium beta spectrum is planned.

Our first step was to reassess the data of Lubimov et al. A computer program has been developed³⁾ to simulate experimental spectrum shapes, Kurie plots etc., under various assumptions e.g. resolution setting, response function, source strength, background counting rate, neutrino mass and the degrees of excitation of various final ^3He atomic states. With this program, using the response function shown in ref. 4, and the other parameters cited by Lubimov et al.¹⁾, it was found that the data in their paper are consistent with a neutrino rest mass of about 30 eV assuming that the ^3He atoms are excited by 43 eV in 30% of the decays, i.e. the atomic approximation of Bergkvist⁵⁾. A more precise analysis to establish error limits was not attempted since it is difficult to extract accurate data from their published Kurie plot and there is some doubt as to the validity of an atomic approximation for ^3H atoms bound to valine as indicated by the calculations of Ching and Ho⁶⁾.

For our experiment we are recommissioning the Chalk River spectrometer²⁾ which is located in the non-magnetic building, shown in Fig. 1. Since this type of spectrometer has a rather small transmission at high resolution, a number of improvements are planned:-

- a) the single proportional counter shown in Fig. 2 will be replaced by a 60-element proportional counter array having coincidence and anti-coincidence features to minimize the ambient background counting rate,

- b) a multi-strip source similar to that used by Bergkvist⁵⁾;
the initial plan is for 180 strips 10 cm long by 1 mm wide of
titanium hydride ($\approx 1\mu\text{g}/\text{cm}^2$) on quartz backing plates, and
- c) computer control of spectrometer settings and data
acquisition.

Calculations are in progress to determine the optimum geometry for the source array, detector array and baffle arrangement. With 1 mm wide defining apertures for each counter element we should realize an overall momentum resolution of $dp/p = 0.05\%$, i.e. a full width at half maximum of 18.6 eV at 18.6 keV. The properties of our expected spectrometer performance for the neutrino experiment are compared in Table 1 with those of others used for this experiment.

It is clear that the limiting factor in our experiment will be source thickness. We hope to be able to produce titanium tritide source layers as thin as $1\mu\text{g}/\text{cm}^2$. Experiments to determine feasibility are in progress.

A major concern is, of course, the energy shifts in the beta spectrum components due to the excitation of the ^3He atom. While the situation for the free tritium atom can be calculated with some accuracy⁵⁾, that for tritium atoms bound in solids is less clear⁶⁾. Also constancy of source quality during the experiment is essential; one must know the energy loss contribution to the energy response function to be able to analyse the resultant experimental data in a quantitative way.

We are advised by New England Nuclear that tritiated organic compounds such as valine, are unstable under beta bombardment and are not recommended for sources of high specific activity.

We have used the simulation program to give us some idea of how different degrees of excitation of the ^3He atom will affect the resultant spectrum shape for different assumed neutrino masses. The Kurie plots shown in Fig. 3 have arbitrarily been normalized (intensity and slope) at 18.05 keV. These simulations are for the experimental conditions we expect to achieve in practice. The upper part of Fig. 3 shows Kurie plots for zero neutrino mass and excitation of a 40 eV level in ^3He of 0%, 20% and 40%. In the lower part the change in normalized shape is shown assuming no ^3He excitation and several assumptions of neutrino mass.

To make comparison easier to visualize, we now take the zero mass zero excitation as our reference and plot differences, ΔK , for several mass excitation assumptions in Fig. 4. One notes that if nature is kind enough to give us only one excited state in ^3He at 40 eV then there is hope of being able to determine both the degree of excitation and neutrino mass given good statistics near the end point. The error bars shown are for a source strength of 370 MBq (10 MCi) an assumed background rate of only 0.1 cpm and a counting period of one day.

These simulations show that it would be advantageous to have a priori knowledge of the energies and degree of population of the final ^3He atomic states before attempting to extract the neutrino mass from the experimental data. Moreover it brings home the need for minimizing counter background both from cosmic rays and from scattered beta rays.

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TABLE 1

COMPARISON OF BETA SPECTROMETERS

<u>PROPERTY</u>	<u>STOCKHOLM</u> ⁵⁾	<u>MOSCOW</u> ¹⁾	<u>TOKYO</u> ⁷⁾	<u>CHALK RIVER</u>
Type	$\pi \sqrt{2}$	Toroidal	$\pi \sqrt{2}$	$\pi \sqrt{2}$
Radius (cm)	50	21.3	75	100
Momentum res. (%)	0.11	0.12	0.03	0.05
Source elements	85	18	?	180
Element height(cm)	10	1.8	?	10
width (cm)	0.17	0.26	?	0.1
Total Area (cm ²)	145	8.4	2	180
Transmission (%)	0.5	0.83	0.10	0.10
Dispersion (mm)	2000	3900	3000	4000
Det. slit width (mm)	2.0	3.0	$\approx 2(a)$	1.0
No. det. channels	1	3	$\approx 60(a)$	60
Overall res. FWHM(eV)	55	45	$\approx 25(a)$	19
Det. range (eV)	55	3x45	1450(a)	1120

(a) using a single wire position sensitive proportional counter. The effective slit width of 2 mm is an estimate⁷⁾.

Fig. 1 Cutaway sketch of the iron-free building housing the Chalk River $\pi/2$ beta-ray spectrometer. The largest degaussing coils are 8.4 m in diameter.

Fig. 2 The upper part of this figure shows a vertical section of the spectrometer coils and vacuum chamber. The lower part shows a plan section of the vacuum chamber. The single strip source and single counter will be replaced by a multi-strip source and a multi-element counter array.

Fig. 3 Predictions of the shape of the Tritium beta-spectrum Kurie's plot near the end point for the various assumptions discussed in the text.

Fig. 4

In these plots we show the differences in shape of Kurie plots near the endpoint under various assumptions. In each case the horizontal straight line corresponds to the zero neutrino-mass 100% ground-state excitation case shown in Fig. 3. The ΔK scale here is in the same units as for the K scale in Fig. 3.

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