K internal conversion of the ^{93m}Nb 30.8-keV gamma ray

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As part of our program to test internal-conversion theory [1], we are studying the M4 transition from the isomeric first-excited state at 30.8 keV in ^{93}Nb. In all previous measurements we have used our well-calibrated HPGe detector but that proved impossible in this case because of the low energy of the Nb K x rays (at 16.521 keV - 18.982 keV) , the extreme weakness of the 30.8-keV γ ray, and the fact that random summing of the K x rays led to peaks very close to the 30.8-keV γ ray. Instead we used a Si(Li) detector, which is well suited for measurements of the spectra, having better energy resolution and high intrinsic efficiency in the relevant energy range.

Because no other gamma rays are emitted in the decay of ^{93m}Nb, the measurement of the K internal conversion coefficient [ICC(K)] for the 30.8 keV gamma ray is very straightforward. We rely on the equation

$$\alpha_K = \frac{N_K}{N_\gamma} \cdot \frac{\varepsilon_\gamma}{\varepsilon_K} \cdot \frac{1}{\omega_K}\ , \qquad (1)$$

where ω_K is the K-shell fluorescence yield; N_K and N_γ are the respective peak areas of the K x rays and the γ ray; and ε_K and ε_γ are the respective detector photopeak efficiencies. For the Nb fluorescence yield, we use the recommended value of ω_K = 0.751(4) [2].

To measure ICC(K) for the 30.8 keV gamma ray of ^{93}Nb, it is necessary to (a) prepare a source of ^{93m}Nb, (b) use a Si(Li) detector to measure the photon spectrum containing the Nb K x rays and the ^{93m}Nb gamma ray, (c) determine the number of events in the corresponding peaks, and (d) determine the relative detection efficiency. Part (a) was described in a previous report [3].

Nb K x rays and ^{93m}Nb gamma rays were recorded using a Trump(TM) [4] data acquisition card, the accompanying Maestro(TM) software [5], and a personal computer. Signals from the Si(Li) detector's preamplifier were processed using a TC 249 amplifier [6]. The data acquisition rate was limited to about 50 events per second mainly by the emission rate of the source at hand and by our choosing the appropriate minimum source-to-detector distance taking account of the diameter of the source (19 mm) and the position of the 6 mm diameter Si(Li) crystal inside the detector can and behind a 6.7- mm-diameter Be window. The most serious challenge in the measurement came from the low detection rate of the 30.8-keV ^{93m}Nb γ rays (about 4 events per hour) and the comparably-sized background detection rate in the same vicinity. Consequently, to reduce the statistical uncertainty, the spectrum has to be accumulated over a time period of many months. The spectra are being saved, however, at least once daily.

During the measurements, the Pile-up Rejector (PUR) feature on the TC 249 was turned off. This was done in order to assess relative intensities of the peaks that arise from random summing of Nb K x rays. In the present measurements, at a resolution of about 340 eV FWHM, the peak caused by coincident detection of two Nb $K_{\alpha 1}$ x rays (at 2 x 16.615 keV) is clearly separated from the Nb γ-ray peak at 30.8 keV. This was not the case when we first attempted the measurement with our HPGe detector, which required the two peaks to be unfolded from one another and led to a prohibitively large uncertainty in the extracted area of the 30.9-keV peak. This is what led us to the decision to use a Si(Li) detector instead.

The spectrum shown in Fig. 1 shows a subset of the data collected from the ^{93m}Nb source. The measurement is still in progress at the time this report is being written.

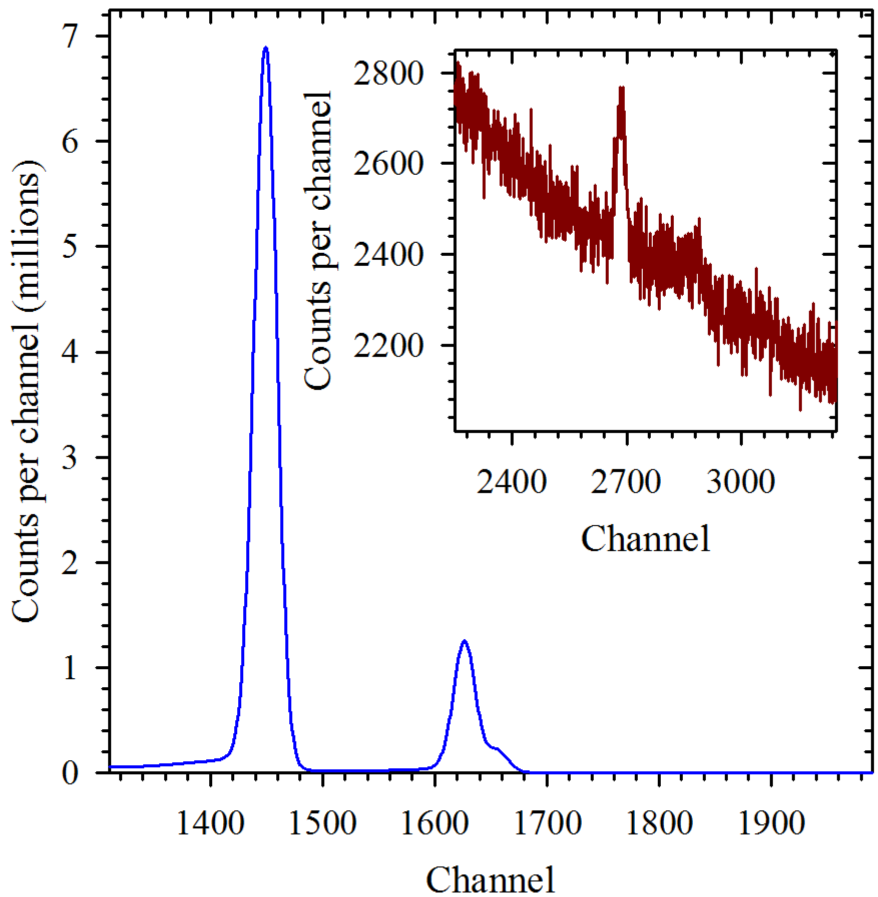

FIG. 1. A subset of the data collected from the ^{93m}Nb source. The blue line shows the spectrum of Nb K x rays, while the brown line in the insert shows a zoomed-in region of the same spectrum around the ^{93m}Nb gamma ray at 30.8 keV, along with the (barely visible) *K* x-ray sum peaks on its high-energy side.

We determined the numbers of events in the peaks of interest using software that we wrote and specifically customized for the present application. The software employs a fitting function that includes Gaussian peaks (integrated over channel limits) with exponential low-energy tails (convolved with the appropriate Gaussian function and integrated over channel limits), peak-specific low-energy-side background modeled as a second-degree polynomial multiplied by the complement of the step function having discontinuity at the centroid of the Gaussian component, all convolved with the appropriate Gaussian function. Here "the appropriate Gaussian function" means "the Gaussian function normalized to unit area and having standard deviation equal to that of the Gaussian peak component". The overall background (present in the absence of the peaks) is modeled as an eight-order polynomial. Of course, any of the presented features can be limited or turned off, so that only the features that are necessary are used and only to the extent that is necessary. While fitting of the ^{93m}Nb γ-ray peak was straightforward, requiring only a single Gaussian component and a linear overall background, fitting of the *K* x-ray peaks proved to be much more challenging.

Photon energy dependence of the detector's absolute efficiency was established from CYLTRAN [7] Monte-Carlo calculations, which were based on the geometry of the setup (including the detector structure). To verify the results of the calculations, we measured the spectrum of Ag K x rays and the 88-keV γ rays from a ^{109}Cd standard source. A good match between the results of these measurements and the CYLTRAN calculations was obtained after a slight adjustment of the (otherwise not precisely known) geometric input parameters. It should be noted that all we need is the detection efficiency of the 30.8-keV γ rays *relative* to the Nb *K* x rays, which is much less sensitive to the geometric parameters in comparison with the *absolute* efficiency.

A preliminary result that we obtained for the ICC(*K*) of interest (based on less than half of the number of events now collected) is $\alpha_K = 26.2(15)\cdot10^3$. This result is in good agreement with ICC calculations that take account of the atomic vacancy (see Ref. [1]). Already our result agrees with one previous measurement, $\alpha_K = 25.8(15)\cdot10^3$ [8], and convincingly rules out the other, $\alpha_K = 17.0(30)\cdot10^3$ [9]. By the time the measurement is complete, we anticipate reducing our uncertainty by nearly a factor of two.

A considerable effort was made to determine the energy of the ^{93m}Nb gamma ray with competitive precision. We accomplished this by performing additional measurements using a source of ^{241}Am, analyzing selected peaks in the recorded spectrum, and establishing a reliable energy scale for the measured ^{93m}Nb spectrum. A preliminary result obtained with less than half of the events now collected is 30762.2(62) eV, for which the error bar is already better than that reported in the literature [10] by about a factor of 3.

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