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# INITIAL RESULTS WITH THE BERKELEY ON-LINE MASS SEPARATOR - RAMA*

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## Introduction

We have for some time been interested in developing a reasonably fast and universal (having little or no chemical selectivity) on-line mass analysis system to expand our capabilities in studying nuclei far from stability. The system selected was originally proposed by Nitschke[1] and is termed RAMA, an acronym for Recoil Atom Mass Analyzer. Basically, this system utilizes the helium-jet method to transport activity to a Sidenius hollow-cathode ion source which is coupled to a mass spectrometer. A comprehensive discussion of RAMA will appear elsewhere.[2]

## Present System

A schematic diagram of the overall RAMA system is given in Figure 1. The RAMA helium-jet employs chemical additives in the helium (presently ethylene glycol) which, in the presence of sufficient ionizing radiation, builds up aerosols.[3] Attachment of the radioactive nuclides to these high molecular weight aerosols is necessary to insure good transport efficiency and a small opening angle for the activity as it exits the 1 mm ID, 5.8 m long stainless steel capillary tube. Transport efficiencies of between 10 and 60% have routinely been achieved, though the latter is much more typical when conditions are optimized.

The capillary exit is aligned with a skimmer (1mm orifice) at a distance of approximately 7 mm. This skimming removes most of the helium while allowing a majority of the activity to pass through the skimmer undeflected. One series of tests with $^{20}Na$ activity demonstrated an opening angle of 2.8° for 55% of the activity. (Many tests of the RAMA system have been performed with the β-delayed alpha-emitter $^{20}Na$, produced via the $^{24}Mg(p,\alpha n)$ reaction at 38 MeV, due to its easily identifiable alpha groups and its short half-life of 445 msec.)

As seen in Figure 1, the skimmed activity then enters the RAMA hollow-cathode ion source. This ion source has been operated using both tantalum and tungsten filaments, with the former lasting on the average ∿ 50 hours at 1600 °C. Tungsten filaments have been tested for periods of up to 100 hours at temperatures exceeding 2000 °C. Under the arc conditions prevalent at these temperatures, the species of interest is ionized primarily to +1 (recent tests indicate $^{40}Ar^{+1}/^{40}Ar^{+2} \approx 100$ under normal arc conditions (Arc Current = 1.0 - 1.5A; $V_{ARC}$ = 180-250V).

In our setup, good ion source efficiency as well as optimal mass resolution depend strongly upon the arc conditions. Different arc conditions can change the emittance of the source, so that it is no longer well matched to the acceptance of the spectrometer system. The arc conditions are governed by three independently adjustable parameters: electron density (filament temperature), electron temperature (arc voltage), and neutral gas density.

Internal beams of $^{40}Ar^{+1}$ and $^{20}Ne^{+1}$ ions from the RAMA ion source were used to determine the effects of various optical devices in the mass analysis system. The first device after the ion source is an Einzel lens; this electrostatic element is used to focus the beam into the Wien filter, a crude velocity selector used to separate the large component of $He^{+1}$ (arc support gas) produced in the ion source from the nuclide of interest.

The beam then enters the main mass analysis system which consists of an electrostatic quadrupole triplet, a sextupole, a dipole, and a second sextupole. The quadrupole triplet is necessary to match the beam profile to the acceptance of the dipole analyzing magnet. The first (upstream) sextupole corrects for second-order aberrations while the second (downstream) sextupole rotates the focal plane by 60° so that it is normal to the analyzed beam. When all components are optimized, values of $m/\Delta m$ from 170 to 210 are obtained. This resolution was calculated from the equation $\text{Res} = \frac{D}{2w}$ where D is the measured dispersion of 164 cm and w is the measured width in cm at one-tenth maximum (FW.1M).

Figure 2 presents the mass spectrum of most of the tin isotopes after the optics parameters were optimized. This spectrum was obtained with a CEM (Channeltron Electron Multiplier) which permits calibrations to be done with very low intensity beams. Quick calibrations are routinely obtained during an experiment to monitor any small changes in operating conditions not easily detectable by external means.

Once the activity has been focused through a symmetrically opening slit system in the focal plane onto a collection foil, the decay products from the nuclides of interest are detected by a counter on the focal plane. Alternatively, the activity can be physically removed from the collection point by a 180° rotary-solenoid-operated flipper-wheel system. In order to characterize the decays of the various nuclei of interest, solid state detector telescopes, a plastic scintillator telescope for high energy β- particle detection, and γ-ray detectors are being incorporated into the flipper-wheel system.

Initial Experiments

The initial tests involved checking various optics parameters with $^{20}Na$ activity as well as $^{211}At$ produced via the $^{209}Bi(\alpha,2n)$ reaction at $E_\alpha$ = 27 MeV. Efficiencies for various components of the RAMA system for Na and At as well as for Te and Dy, which will be discussed below, are given in Table I.

After these tests, one sequence of experiments was performed to confirm the mass assignments of a number of the short-lived, high-Z rare-earth alpha particle emitters produced by (HI,xn) reactions on various targets. The initial reaction studied was $^{142}Nd(^{12}C,xn)^{154-x}Dy$ with the intention of observing the alpha emitters $^{150}Dy$ and $^{151}Dy$, which are made in high yield ( $>$ 500 mb). Further experiments confirmed the mass assignments of other N = 84, 85 rare-earth alpha particle emitters from terbium through ytterbium with half-lives ranging from 4.1 h to 400 msec. Figures 3 and 4 are examples of these alpha particle emitters while Table II summarizes our observations compared to the literature assignments.[4]

Some of the odd-Z rare-earth alpha emitters were also investigated. These nuclides exhibit substantial isomerism, with the excitation functions for the low-spin isomers shifted relative to the high-spin isomers by as much as 18 MeV, much more than is usually observed in excitation function shifts for isomer production in other mass regions. This is particularly noticeable for $^{151}Ho$, when produced by the $^{141}Pr(^{16}O,6n)$ reaction, has a peak yield for the high-spin isomer at 123 MeV relative to 105 MeV for the low-spin isomer.[5] This situation was investigated with the RAMA system to clarify the mass assignments of these isomers because the excitation function for $^{151}Ho^{(LOW\ SPIN)}$ peaks very near that for $^{152}Ho^{(HIGH\ SPIN)}$, and thus could conceivably have been an isomer of $^{152}Ho$. Our experiments did, however, confirm the earlier mass assignments.

A more recent experiment has verified the mass assignment of $^{111}Te$ through the observation of the beta-delayed protons associated with its decay. The mass of this neutron-deficient Te nuclide was originally controversial with Macfarlane and Siivola[6] assigning the 19 sec β- delayed proton activity to $^{110}Te$ and Bogdanov et al.[7,8] assigning it to $^{111}Te$. Figure 5 shows that the known proton spectrum appears at the mass 111 position so that the observed protons can be attributed to the decay of $^{111}Te$; this has been separately confirmed by recent work reported from UNILAC.[9] Further studies in this region have led to the observation of delayed protons from $^{109}Te$ and the recently[9] discovered $^{112}I$ produced by the $^{102}Pd(^{12}C,5n)$ and $^{102}Pd(^{14}N,4n)$ reactions, respectively.

## Planned Improvements

Several instrumental changes are planned for the near future. First, the entire ion source-extractor region will be modified to improve the geometry (and hopefully the efficiency) and to permit easier ion source access for changes and maintenance. Increasing the high voltage extraction from its present value of 10.5 kV will be investigated to reduce the beam emittance and improve the transport efficiency of the ion optical system. In order to remove the activity from the focal plane further than is now allowed by the flipper wheels, a fast tape transport system is being designed and built. An X-ray detection capability is being added for continuing experiments in the A = 50 closed shell region. Future studies will also involve searching for light, neutron-deficient, beta-particle emitters, such as $^{27}P$ produced by the $^{28}Si(p,2n)$ reaction.

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Table I. RAMA Efficiencies

| | $^{20}Na$ | $^{111}Te$ | $^{150}Dy$ | $^{211}At$ |
|---|---|---|---|---|
| He-jet | 20%[a)] | 60% | 10%[a)] | 15%[a)] |
| Skimmer | 70% | 60% | 60% | 70% |
| Ion Source | $0.2_3$% | $0.1_2$% | ∿0.2% | 0.2% |
| Magnetic Analysis[b)] | 50% | 50% | 50% | 50% |
| Overall | 0.016% | 0.02% | 0.01% | 0.01% |

a) Not Optimized.
b) Calculated based on measured ion source emittance.

Table II. Rare-Earth Alpha-Particle Emitter Mass Confirmations.

| Nuclide | Z | $E_\alpha$ Observed[a] (MeV) | $E_\alpha$ Literature[b] (MeV) | $t_{1/2}$ Observed | $t_{1/2}$ Literature[b] |
|---|---|---|---|---|---|
| $^{149}Tb^{g}$ | 65 | 3.95 | 3.95 | 4.07±.1 h | 4.1 h |
| $^{151}Dy$ | 66 | 4.07 | 4.07 | 17.5±.5 m | 17.7 m |
| $^{150}Dy$ | 66 | 4.23 | 4.23 | 7.1±.7 m | 7.2 m |
| $^{152}Ho$ (High Spin) | 67 | 4.45 | 4.46 | 53±4 s | 52 s |
| $^{151}Ho$ (High Spin) | 67 | 4.51 | 4.52 | 36±2 s | 35.6 s |
| $^{153}Er$ | 68 | 4.68 | 4.67 | 35±4 s | 36 s |
| $^{152}Er$ | 68 | 4.82 | 4.80 | - | 9.8 s |
| $^{154}Tm^{m}$ | 69 | 5.02 | 5.04 | - | 3 s |
| $^{155}Yb$ | 70 | 5.19 | 5.21 | - | 1.65 s |
| $^{154}Yb$ | 70 | 5.32 | 5.33 | - | 400 ms |

a) Typical errors are ± 0.03 MeV.

b) Ref. 4.

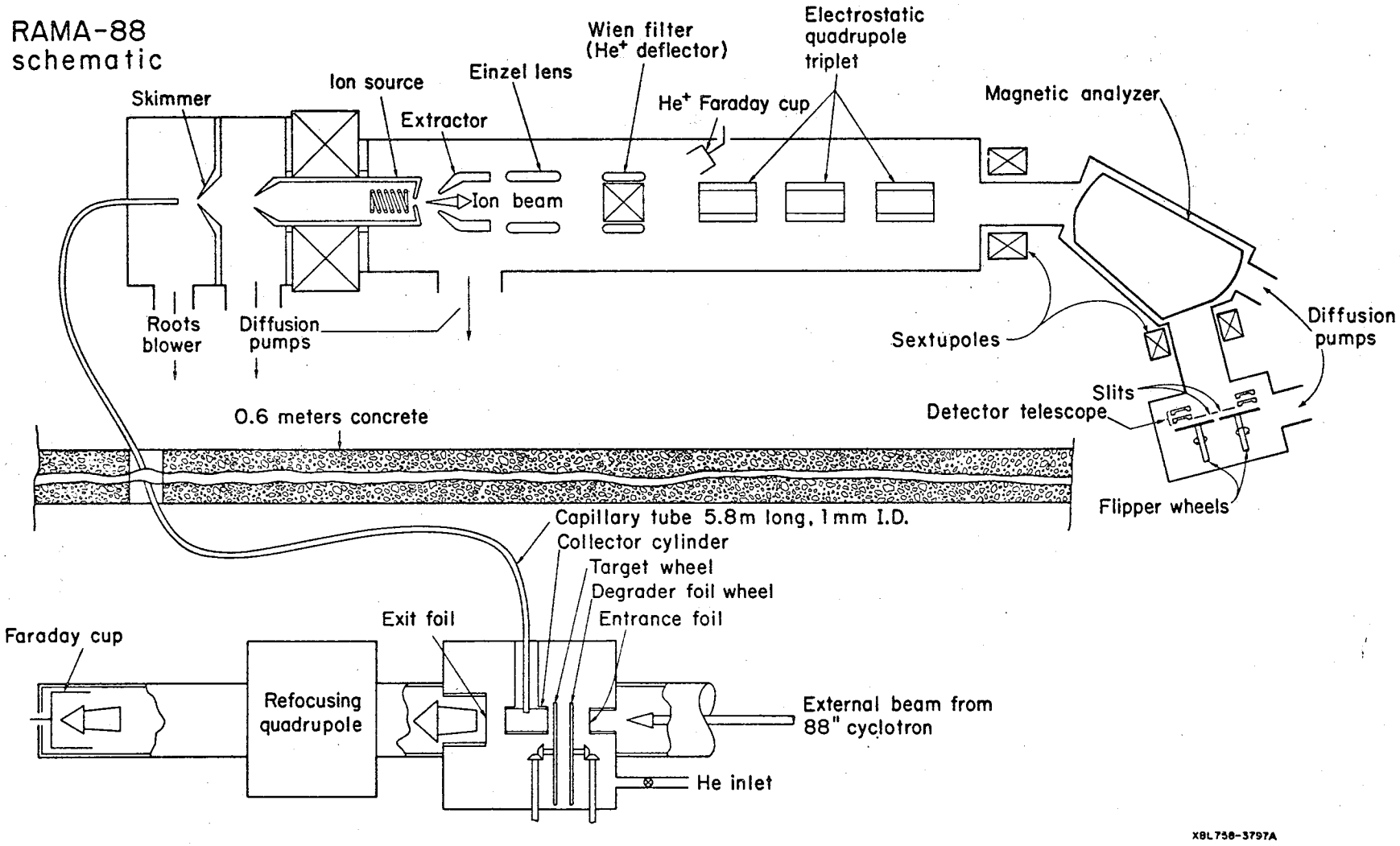


Fig. 1. Overall schematic diagram of RAMA.

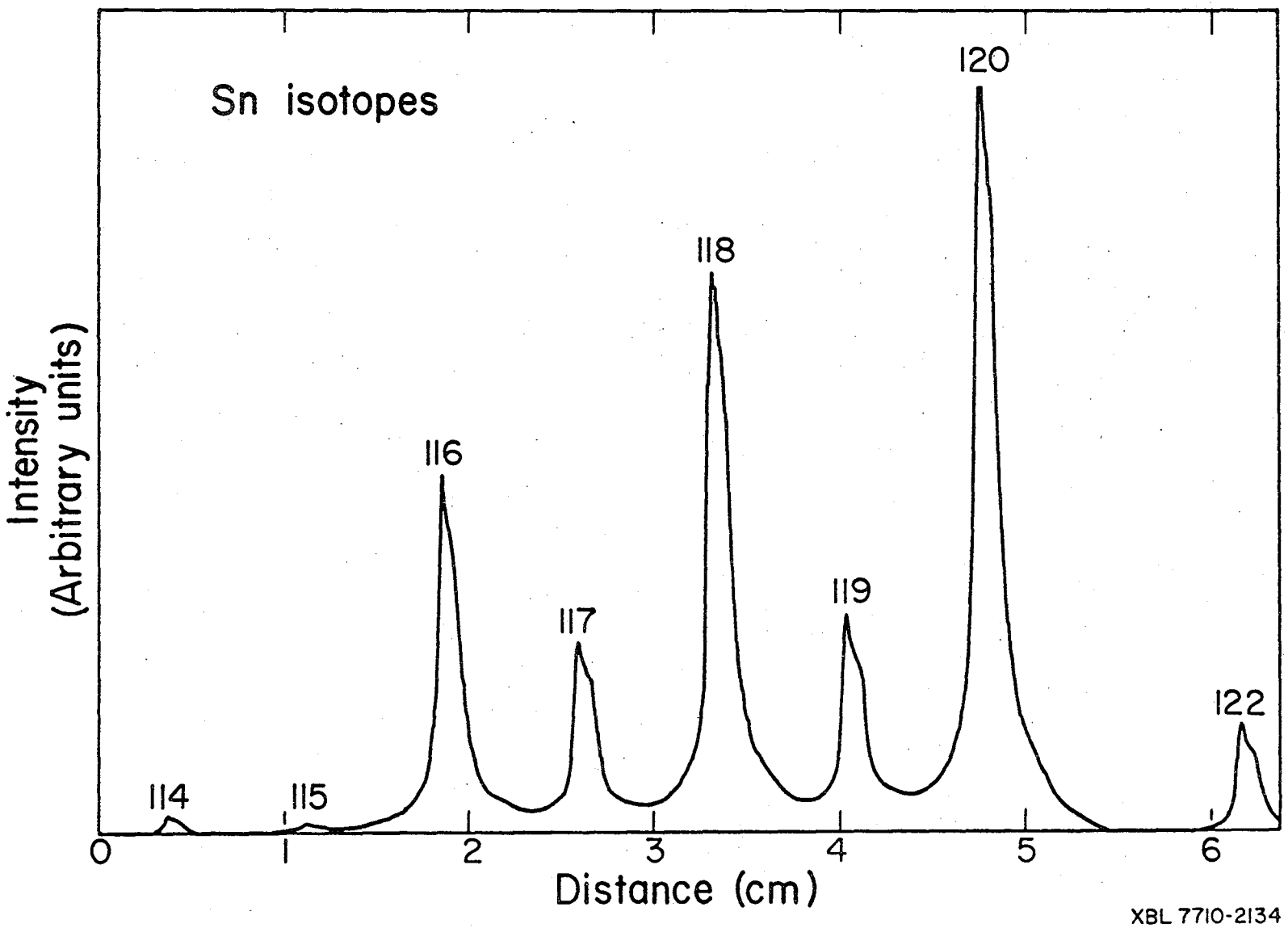


Fig. 2. Channeltron Electron Multiplier scan of stable tin isotopes from 114 to 122. The valleys between adjacent masses do not go completely to zero because of response time in the CEM electronics and a small amount of tailing.

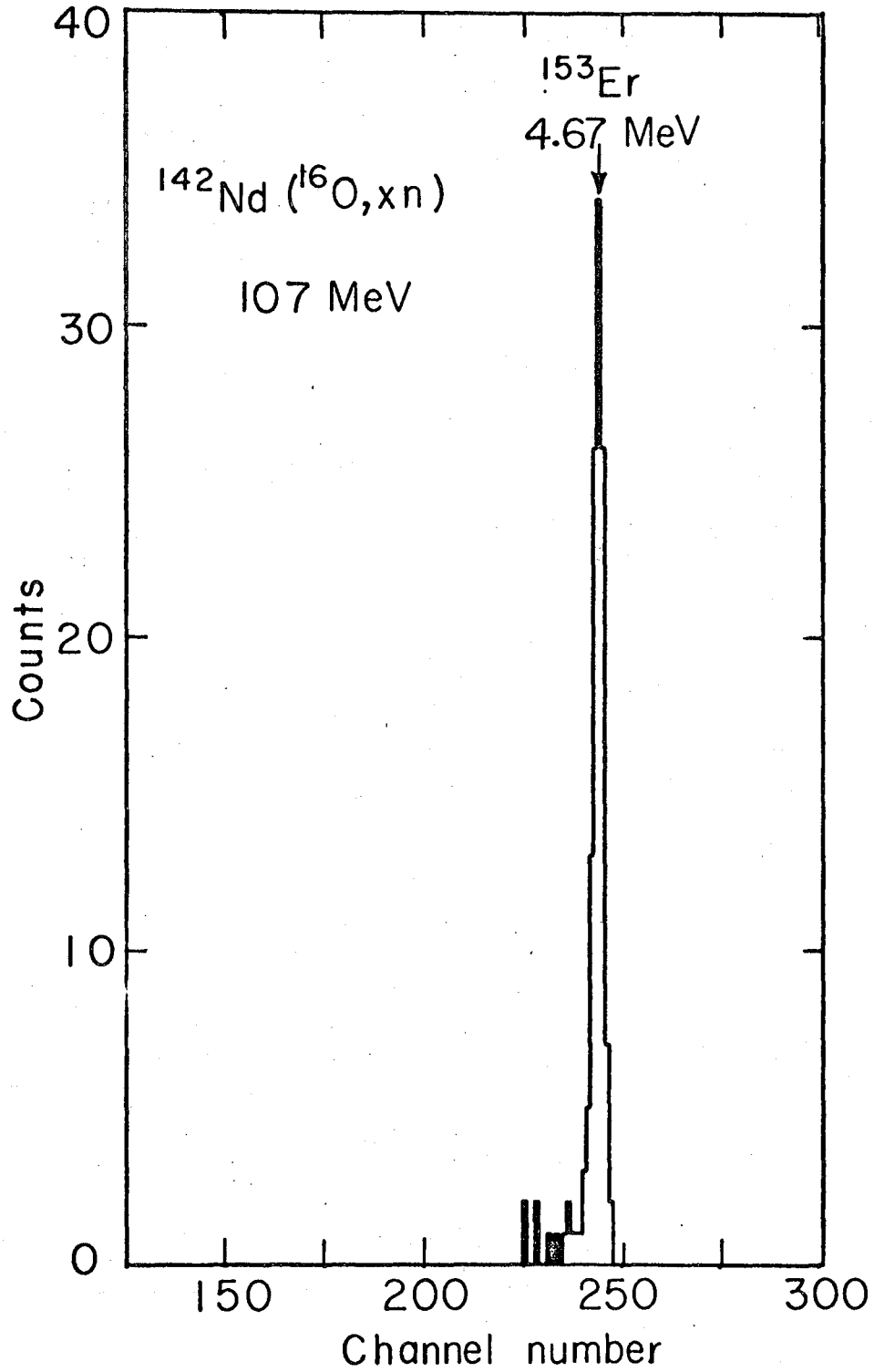


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Fig. 3. $^{153}$Er alpha spectrum at the mass 153 focal plane position produced by the $^{142}$Nd($^{16}$O,5n) reaction.

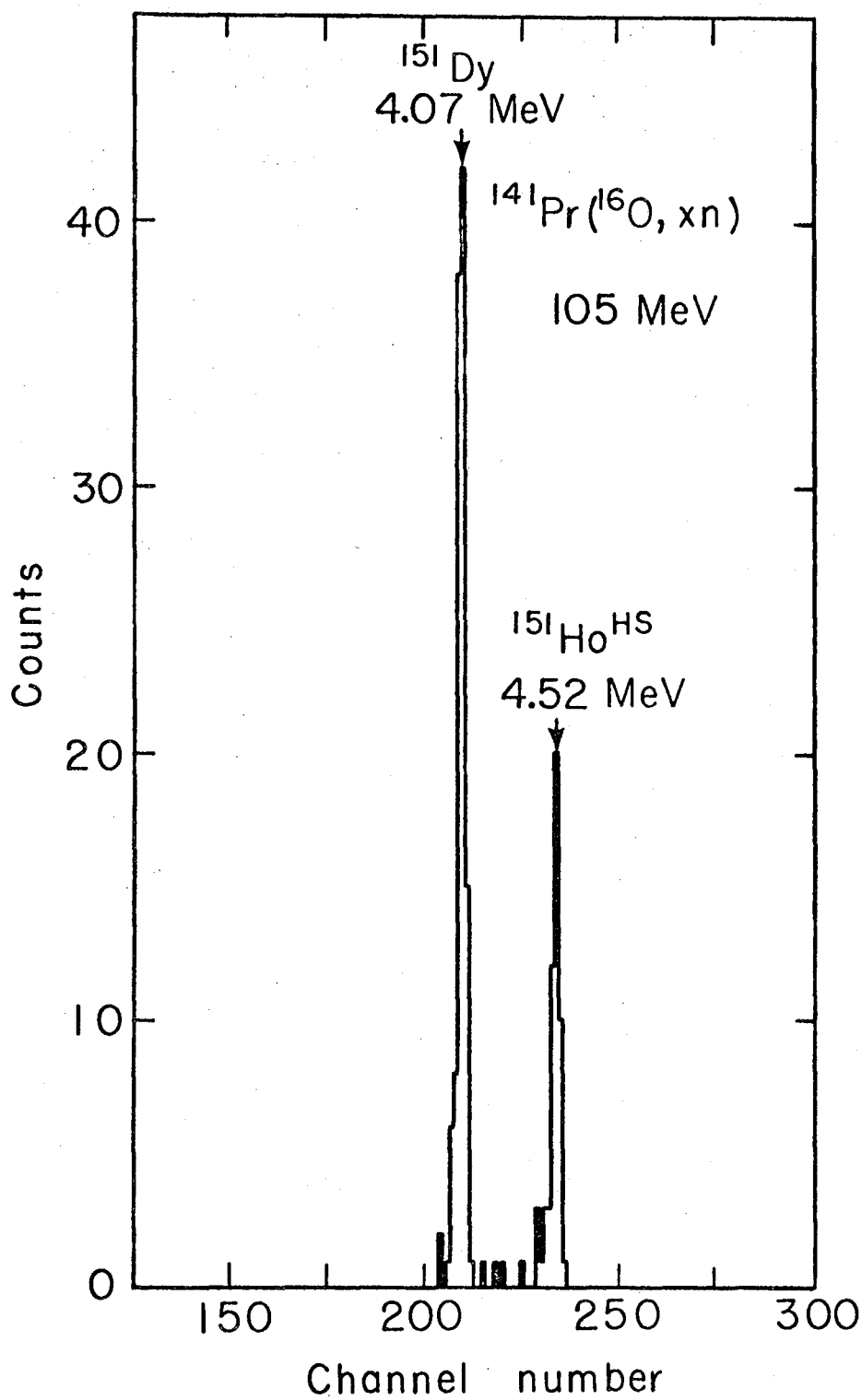


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Fig. 4. Mass 151 spectrum with $^{151}$Dy and $^{151}$Ho (High Spin) from $^{16}$O reactions on $^{141}$Pr.

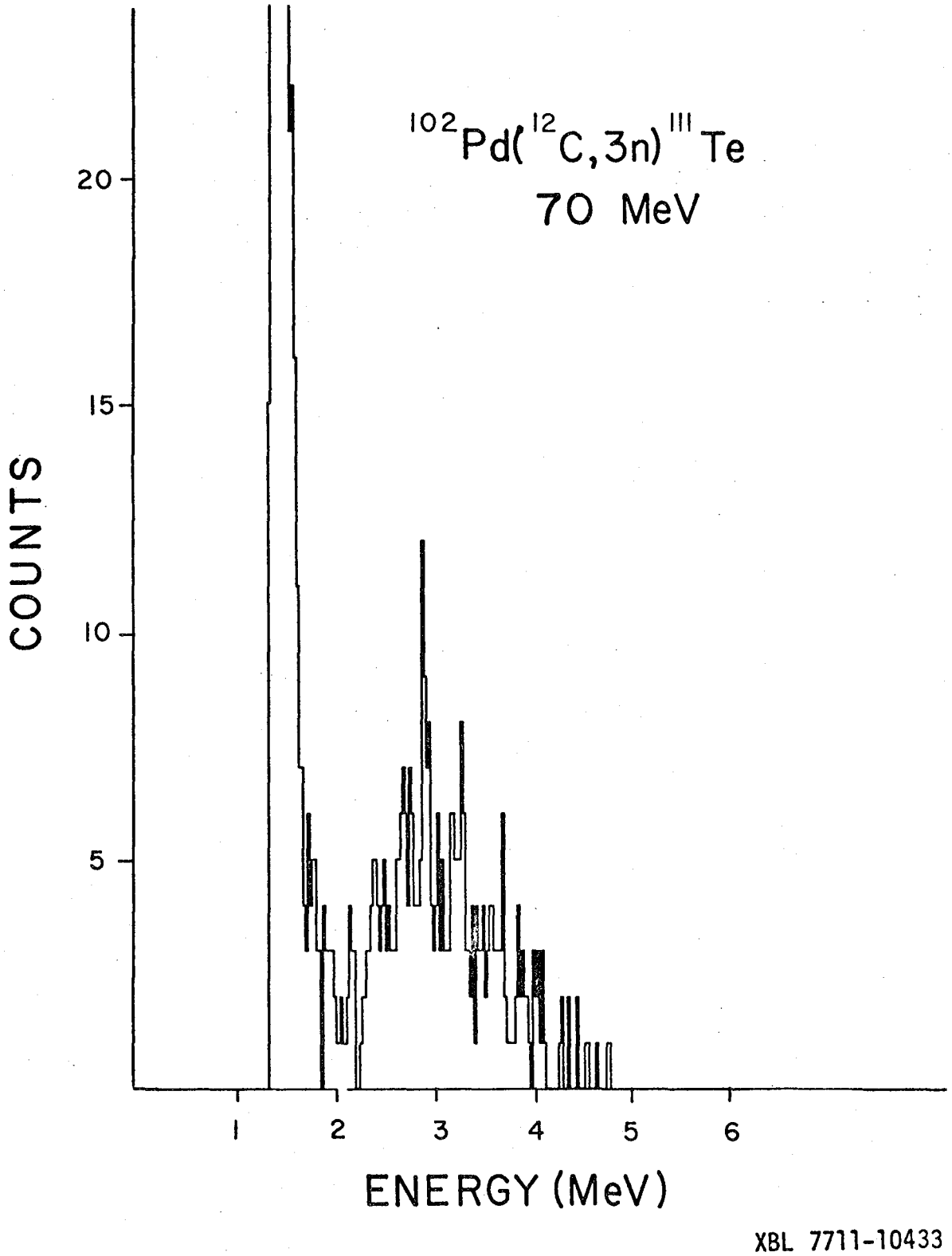


Fig. 5. Proton spectrum at the mass 111 position from $^{111}$Te produced by the $^{102}$Pd($^{12}$C,3n) reaction at 70 MeV.

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