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CONFIRMED PROTON RADIOACTIVITY* OF $^{53}Co^{m}$

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Proton-induced reactions on ^{54}Fe produce a proton activity [1.57 ± 0.03 MeV; 242 ± 15 msec] with a threshold of 26.3 ± 0.4 MeV which can only arise from $^{53}Co^{m}$. Failure to detect positron-proton coincidences in the decay of this isomer establishes its direct proton radioactivity.

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†National Research Council of Canada Postdoctoral Fellow.

Reactions of ^{16}O ions on ^{40}Ca have produced an activity [1] whose most plausible origin is the proton radioactivity of $^{53}Co^{m}$ ($\frac{19}{2}$ -) (see fig. 2 of ref. 1). However, (a) these heavy-ion experiments could not without question attribute the activity to this nuclide, and (b) the possibility that the observed decay in fact arises through beta-delayed proton emission was not conclusively eliminated. This paper reports further experiments which definitely establish the direct proton radioactivity of $^{53}Co^{m}$.

In order to confirm $^{53}Co^{m}$ as the parent nuclide, the external proton beam of the Berkeley 88-inch cyclotron was used to induce the $^{54}Fe(p,2n)$ reaction. Protons were detected in a counter telescope, consisting of a 14 μm ΔE detector followed by a 50 μm E detector, which fed a Goulding-Landis particle identifier, as well as in a single 50 μm E detector; both detection systems were followed by additional reject detectors. These systems were mounted behind a slotted, rotating wheel which controlled the duration of the beam pulse and protected the counters during the beam-on interval. Pulsing was achieved by modulating the voltage on the cyclotron dee; proton beam intensities of up to 8 μA on target were utilized.

An identified proton spectrum resulting from bombardment of an 840 $\mu g/cm^2$ ^{54}Fe target with 31.8-MeV protons is shown on the top of fig. 1. An analyzed beam of 3.39-MeV H_2^+ ions was used for energy calibration of both detection systems. From this calibration the energy of the proton group was determined to be 1.57 ± 0.03 MeV. Half-life information was obtained by using a 400 channel multiscaler whose address was advanced by a quartz-crystal oscillator; the half-life of the protons was determined to be 242 ± 15 msec. Both the energy and the half-life found in the ^{54}Fe + p reaction agree excellently with those found

in ref. 1. Proton irradiation of natural Cr and Fe targets at 35 MeV showed that at this energy the activity arises only from ^{54}Fe.

An excitation function for the production of this proton activity is shown on the bottom of fig. 1. Proton beam energies were measured using the high-resolution analysis magnet of the cyclotron. The threshold for this activity is determined to be 26.3 ± 0.4 MeV and the observed peak cross section is ∿ 0.5 μb. This threshold agrees well with the expected one of 26.14 ± 0.04 MeV [2] based on a $^{53}Co^{m}$ mass-excess of -39.44 ± 0.04 MeV constructed from the mass of ^{52}Fe (g.s.) plus a 1.60-MeV (c.m.) proton. As discussed in ref. 1 this mass-excess also leads to a $^{53}Co^{m}$ - $^{53}Fe^{m}$ mass difference in acceptable agreement with Coulomb displacement energy calculations. Since this fairly low threshold also precludes formation of any other nuclide energetically capable of beta-delayed proton emission, the excitation function data establish $^{53}Co^{m}$ as the parent nuclide.

In order to confirm the proton radioactivity of $^{53}Co^{m}$, the possibility of beta-delayed proton emission must be eliminated. The only avenue for delayed-proton decay of this isomer that can be considered remotely possible (noting the cross section arguments of ref. 1) would be allowed β-decay--with a quite small log ft--to a state near 9.08 MeV in ^{53}Fe (see fig. 2 of ref. 1). This β^{+}-decay (end point ≈ 1.36 MeV) must then be followed by proton decay to the 6+ ground state of ^{52}Mn; in this case a short lifetime for proton emission from the intermediate state would be expected due to the available low ℓ values and an anticipated larger reduced width [see ref. 1]. In order to determine whether such beta-delayed proton emission occurs, a search for positron-proton coincidences in the decay of $^{53}Co^{m}$ was conducted [3]. In this experiment positrons

were detected in a 0.5 cm thick plastic scintillator which subtended a solid angle of 0.12 sr, while protons were detected in the single 50 μm detector. An isotropic angular correlation is expected following normal allowed β - decay [4].

The coincidence experiments were conducted at a proton energy of 35 MeV. In order to monitor the correct operation of the coincidence electronics, positron - alpha-particle coincidences resulting from the decay of ^{20}Na produced via the ^{24}Mg(p, αn) reaction were observed at intervals throughout the bombardment of ^{54}Fe. The observed α-particle decay spectrum of ^{20}Na shown in the top of fig. 2 agrees with earlier work [5]. Coincidences were observed between positrons and alpha-particles [or protons] in the fixed energy range indicated by the arrows in fig. 2. A coincidence resolving time of 4 nsec was obtainable over this narrow energy interval. The observed coincidence data corrected for chance-coincidence background for this ^{20}Na decay are shown in the bottom of fig. 2; excellent agreement was found with the expected efficiency.

The proton spectrum following the decay of ^{53}Co^{m} observed in the 50 μm detector is also shown in the top of fig. 2. Since the low yield of the isomer prevented employment of the counter telescope due to its reduced solid angle, the proton peak rides on a background of α-particles from ^{8}B decay produced in reactions on the ^{54}Fe target and on the ^{12}C target impurity. Various subsidiary experiments (half-life measurements, spectra at other energies, different targets, etc.) established that the vast majority of the background events between the arrows in the ^{53}Co^{m} singles spectrum arise from ^{8}B decay and are <u>not</u> due to multiply-scattered β-particles. As such, β^{+}-α coincidences due to this ^{8}B background are to be expected.

Composite results for the coincidence runs corrected for chance-coincidence background from 37 hours of observation of the decay of $^{53}Co^{m}$ are shown in the bottom of fig. 2. The calculated coincidence background arising from ^{8}B decay is indicated in the figure. No peak resulting from β^{+}-p coincidences--which should lie in the region denoted by the horizontal arrows--is observable in this spectrum. After making all the efficiency corrections including allowance for 12% loss due to electron capture [6] in this hypothetical decay, we would expect 65 ± 8, β^{+}-p coincidence events in the denoted region of interest, whereas we observe 0 ± 15 events after correction for the β^{+}-α background due to ^{8}B. The absence of this peak establishes the fact that the 1.57-MeV proton group arising in the decay of $^{53}Co^{m}$ is <u>not</u> preceded by positron emission.

A review of the various modes of radioactive decay involving proton emission has been given by Goldanskii [7] in which the possibility of decay from isomeric states was also considered. Our results and those in ref. 1 defining the properties of $^{53}Co^{m}$ establish it to be the first example [7] of radioactive nuclear decay by direct proton emission. An additional direct proton decay of this isomer, populating the first excited state of ^{52}Fe, is energetically possible but has not so far been observed.

We would like to thank Don Landis for his assistance with the electronics.

References

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2. The threshold for $^{53}Co^{g}$ would be approximately 3 MeV lower based on the equivalent $^{53}Fe^{m}$ - $^{53}Fe^{g}$ separation. See K. Eskola, Phys. Letters 23 (1966) 471; I. Dernedde, Zeit. für Physik 216 (1968) 103.

3. The possibility that the observed proton group arises from β^{+}-decay to states above 9.08 MeV in ^{53}Fe, if followed by rapid proton emission to either of the first two excited states of ^{52}Mn, can also be excluded by the results of the β^{+}-p coincidence experiment. Conversely, retarded proton emission from the intermediate states would compete unfavorably with gamma de-excitation. Transitions leading to even higher states in ^{52}Mn would require $^{40}Ca(^{16}O,2np)$ cross sections > 1/5 (geometric). It is noteworthy that the high spin of the ^{52}Mn ground state makes it by far the most plausible final state in this hypothetical decay.

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Figure Captions

Fig. 1. Top: An identified proton spectrum arising from the bombardment of ^{54}Fe by 31.8-MeV protons. The arrows denote the energy region over which protons could be observed.

Bottom: The excitation function for the $^{54}Fe(p, 2n)^{53}Co^{m}$ reaction. The scale on the ordinate approximates the absolute cross section in nanobarns.

Fig. 2. Left: Alpha-particle energy spectra arising from the decay of ^{20}Na produced via the $^{24}Mg(p, \alpha n)$ reaction on a 0.5 mg/cm^2 natural Mg target. The energies indicated are the undegraded values. The data in the lower spectrum arise from coincidences between positrons and those alpha-particles in the energy region limited by the arrows in the singles spectrum.

Right: Composite energy spectra arising from the bombardment of a 3 mg/cm^2 ^{54}Fe target and its ^{12}C contaminant. The upper spectrum shows the 1.57-MeV (undegraded value) proton peak arising from the decay of $^{53}Co^{m}$ astride a background of α-particles from ^{8}B decay. The data in the lower spectrum arise from coincidences between positrons and protons or α-particles in the energy region limited by the arrows in the singles spectrum. The horizontal arrow in the coincidence spectrum indicates the expected position of the 1.57-MeV peak if preceded by positron emission.

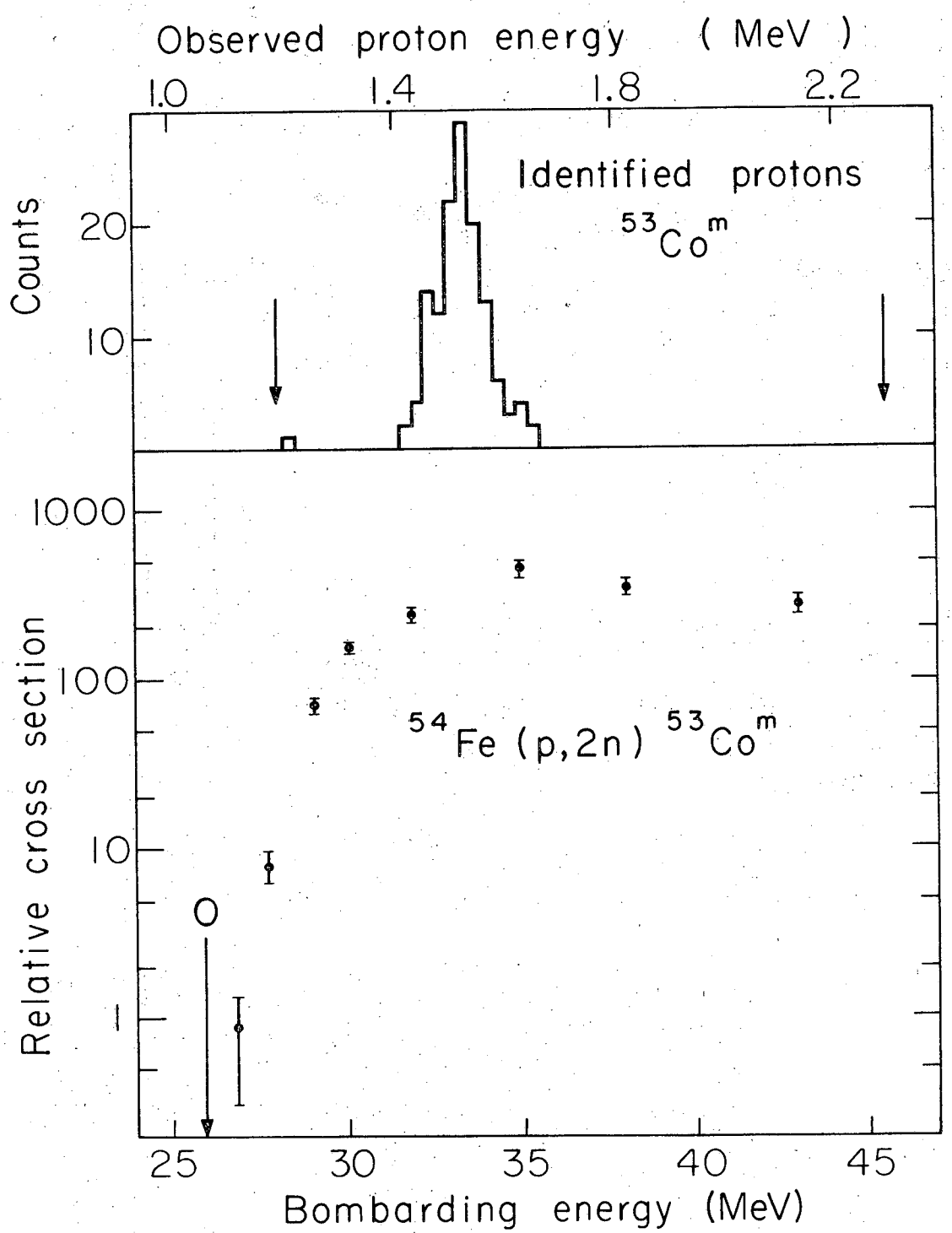

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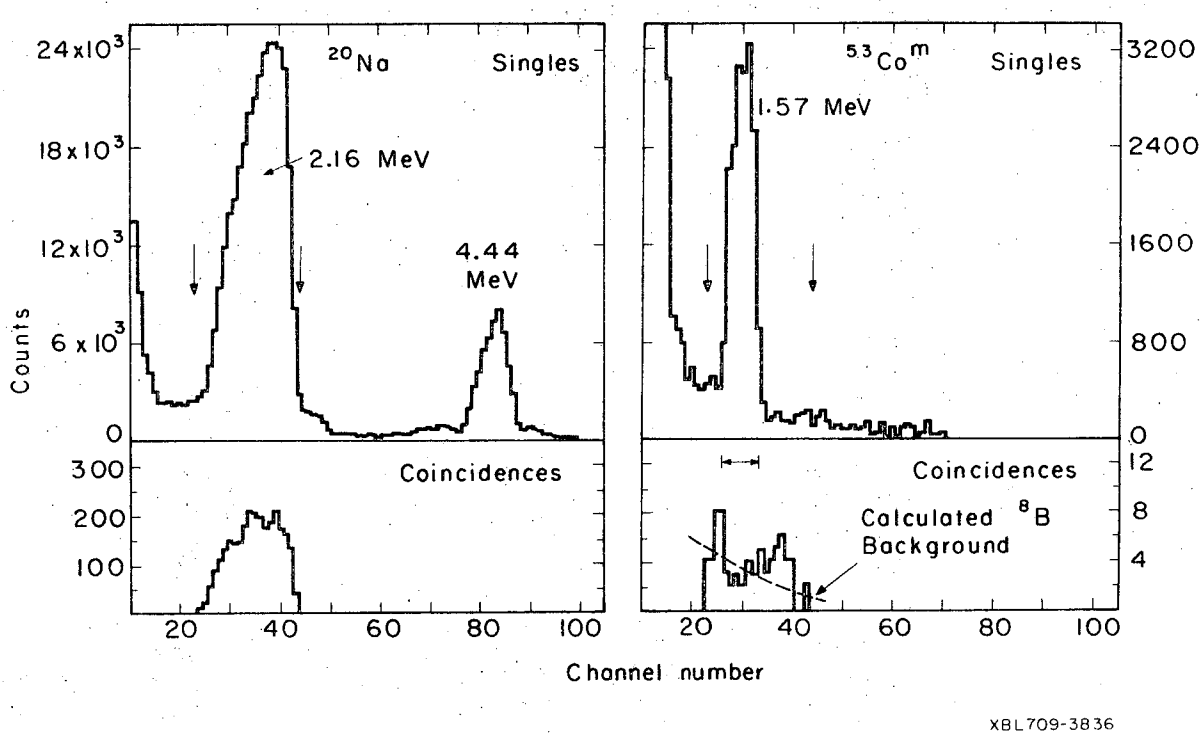
Fig. 1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18x10³
12x10³
6 x10³
0
Counts
²⁰Na
Singles
2.16 MeV
4.44 MeV
300
200
100
Coincidences
⁵³Co^m
Singles
1.57 MeV
3200
2400
1600
800
0
12
8
4
Coincidences
Calculated ⁸B Background
20
40
60
80
100
Channel number
XBL709-3836

Fig. 2

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