LIFETIME OF ^{44}Ti AS PROBE FOR SUPERNOVA MODELS

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^{44}Ti is created in the α-rich freeze-out during supernova explosions, where material cools in nuclear statistical equilibrium at low densities [1, 2, 3, 4]. Under these conditions the build-up of heavy elements is handicapped by the slow triple-α process and the production of ^{44}Ti depends critically on entropy and density conditions during the freeze-out [4, 5]. Of special interest is therefore the observation of the 1157 keV γ-ray line from the decay of ^{44}Ti. So far, the only source for this line is the supernova remnant Cassiopeia A [6]. The previously reported lifetimes for ^{44}Ti range from 67 y to 96 y [7, 8, 9, 10, 11] and prevented a meaningful determination of the ^{44}Ti mass of Cas A.

For this reason we measured the lifetime of ^{44}Ti using a novel experimental approach (for details see [12]). A mixed radioactive beam of ^{22}Na and ^{44}Ti was implanted into a stack of Al-foils and the resulting activities were measured using a well-shielded high-resolution Ge-detector. In this method the lifetime of ^{44}Ti was measured relative to the lifetime of the well known ^{22}Na thus reducing the systematic uncertainties. The lifetime of ^{44}Ti depends only on two ratios, the relative amount of ^{44}Ti and ^{22}Na in the beam, $N_{^{44}Ti}/N_{^{22}Na}$, and the resulting activities, $A_{^{44}Ti}/A_{^{22}Na}$.

A secondary radioactive ion beam was produced at the National Superconducting Cyclotron Laboratory at Michigan State University. A primary beam of ^{46}Ti with an energy of E/A = 70.6 MeV/u was directed onto a Be target located at the target position of theA1200 projectile fragment separator [13]. The separator was operated in medium acceptance mode and optimized for maximum ^{44}Ti transmission. All other N=Z fragments, including ^{22}Na, are also transmitted to the focal plane. The experiment was run in two modes. In the first, all fragments were implanted into a stack of Al-foils which consisted of seven foils with thicknesses of 50-457 μm. ^{44}Ti was implanted into the center of the third foil and ^{22}Na into the center of the sixth foil. The second mode provided for particle identification of the implanted species. For this reason the primary beam intensity was reduced and a set of detectors replaced the Al-stack. The set of detectors consisted of a Si ΔE detector, a position sensitive Parallel Plate Avalanche Counter and a plastic detector to measure the remaining energy. This allowed the identification of the implanted particles at the implantation spot by means of energy loss, total energy and time-of-flight as well as the determination of the fragment intensities across the implantation spot.

Fragments were implanted for an accumulated time of 29 hours switching every 3 hours to the second mode. The mean ratio of all runs is $N_{^{44}Ti}/N_{^{22}Na}$ = 76.78 with 1σ-errors of $\pm$0.73 (internal error) and $\pm$0.78 (external error). The absolute ^{44}Ti intensity was $\approx 5 \cdot 10^5$/s and a total of $\approx 5 \cdot 10^{10}$ ^{44}Ti ions were implanted.

The specific activities of the implantation foils were measured by detecting the characteristic γ-decay lines of the radio-isotopes using a Ge detector which was completely shielded with 10 cm of Pb to reduce the room background. A sample holder allowed the placement of the foils at distances of 13.9, 23.9, 44.0 and 83.9 mm from the surface of the Ge-crystal. Short-lived activities were allowed to decay during a period of three months following the implantation. The activities were measured in four cycles and during

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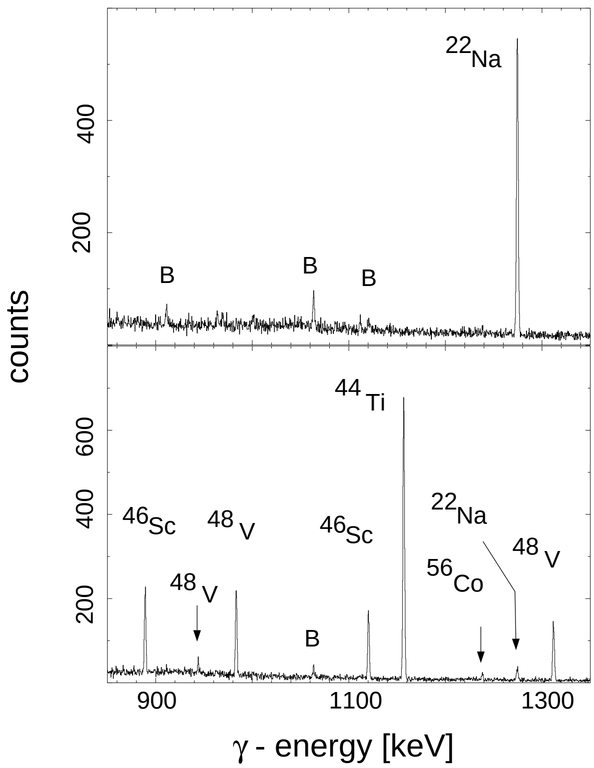

Figure 1: Relevant part of the γ-ray spectra with a ^{22}Na foil in place (top panel) and with a ^{44}Ti foil in place (bottom panel).

each cycle the foils were placed in each of the positions. The decay of ^{22}Na and of ^{44}Ti are very similar [14] and only small corrections are necessary to the ratio of the γ-intensities are needed to obtain the ratio of their activities. Figure 1 shows the relevant part of the γ-spectra with a ^{22}Na foil in place (top panel) and with a ^{44}Ti foil in place (bottom panel). The ratio of the ^{44}Ti and ^{22}Na activities were determined to $A_{^{44}Ti}/A_{^{22}Na}$ = 3.322 $\pm$ 0.054. This final value includes a small correction (1%) of the ^{22}Na activity to account for secondary ^{22}Na production in the implantation foils.

With these results for the ratios of the fragment intensities and the activities a ^{44}Ti lifetime of $\tau_{^{44}Ti}$ = (87.0 $\pm$ 1.9) y was determined. This value is in excellent agreement with the result of several new experiments which were measured simultaneously by different groups which deduced the lifetime from the decay curve of ^{44}Ti: (89.5 $\pm$ 2.9) y [15], (85.1 $\pm$ 0.9) y [16] and (87.6 $\pm$ 1.7) [17]. With the present lifetime, the observed γ-flux from Cas A [6], a date of 1680 AD for the explosion and distance of 3.4 kpc [18], supernova Cas A ejected a ^{44}Ti mass of (1.7 $\pm$ 0.5) $\odot$ 10^{-4} M$_{cdot}$. The remaining uncertainty of the lifetime of ^{44}Ti contributes little to the uncertainty of the ^{44}Ti (6%) which is now dominated by the experimental errors of the γ-flux and the distance measurements.

Future γ-ray missions, such as INTEGRAL [19], should improve the situation for Cas A, and might lead to the observation of ^{44}Ti γ-ray emission from additional supernovae. These, together with the present result for the ^{44}Ti lifetime, will provide considerably more stringent tests of supernova models than presently exist.

The authors gratefully acknowledge the excellent technical support by the staff of the National Superconducting Cyclotron Laboratory. We would like to thank E. Sugarbaker (Ohio State University) for the loan of a Ge-detector and D. Morrissey (Michigan State University) for pointing out the source of the secondary activities. This work was supported in part by the National Science Foundation, the Natural Science and Engineering Research Council of Canada, and the Compton GRO guest investigator program (DHH).

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