Elemental Technetium as a Cosmic-Ray Clock

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1. Introduction. Several radioactive isotopes have been proposed as clocks for the study of the mean cosmic ray confinement time, τ_e. Measurements of ^{10}Be and ^{26}Al [1,2] give a value for τ_e of about 10 Myr when one uses a leaky box cosmic ray propagation model. It is important to obtain additional measurements of τ_e from other radioactive isotopes in order to check whether the confinement is the same throughout the periodic table.

We investigate the possible use of Tc (Z = 43) as a cosmic clock. Since all isotopes of Tc are radioactive, one might be able to group these isotopes and use the elemental abundance as a whole. We were led to this investigation by our involvement with the HNC-LDEF-IB detector [3]. In its original conception, this detector contains 45 trays of plastic track detectors with collecting area $A\Omega \approx 100\ m^2$ sr, to be exposed for ~2.5 years in a 57° orbit. Of the 45 trays, 4 are to be optimized for identification of nuclei with $30 \le Z \le 70$ ($\sigma_Z \le 0.20e$) and 41 are optimized for $Z > 70$ ($\sigma_Z \le 0.25e$).

The results of our calculations are somewhat inconclusive for two reasons. First, the β^+ decay half-lives of two of the Tc isotopes relevant to our calculation are not known. Second, the dependence of the Tc abundance on the mean confinement time is rather weak when one considers the number of events expected in 4 trays of plastic track detectors. However, a future, finite measurement of the β^+ half-lives and the possible use of the entire collecting area of the HNC to detect Tc nuclei (although with a larger σ_Z) could make the use of Tc as a cosmic-ray clock more attractive.

2. Propagation Calculation. We used a propagation equation of the form:

$$\frac{\partial J_i(E,x)}{\partial x} = -\frac{J_i}{\Lambda_i(F)} + \sum_k \frac{J_k}{\Lambda_{ik}(E)} + \frac{\partial}{\partial E}[w_i(E)J_i]$$

where Λ_i is the mean free path for losses of species i due to nuclear fragmentation and radioactive decay, Λ_{ik} is the mean free path for gains of species i from species k, and w_i is the absolute value of the ionization loss rate. The solution of this equation is weighted over a path length distribution $P(x,\lambda)$ giving the final flux:

$$J_{Fi}(\lambda) = \int_0^\infty dx\, P(x,\lambda)\, J_i(x)$$

We used the standard leaky box model

$$P(x) = \frac{1}{\lambda} \exp\left(-\frac{x}{\lambda}\right)$$

with $\lambda = 7.80$ g/cm^2 in a medium consisting of 90% H and 10% He by number. Given the uncertainties in our calculations, we did not it consider appropriate to calculate abundances with other pathlength distributions. For the initial fluxes, we used the Cameron abundances [4] with the following ionization potential correction [5]

$$\begin{array}{ll} \exp[-0.27\,(7.0)] & (I < 7 \text{ eV}) \\ \exp[-0.27\, I] & (7 \le I \le 13.6 \text{ eV}) \\ \exp[-0.27\,(13.6)] & (I > 13.6) \end{array}$$

where I is the first ionization potential in eV.

Table 1 shows the Tc isotopes used in the calculation:

Table 1

Isotope	Decay Mode(s) & (half-life in years)
^{95}Tc	E.C. ($\tau_{1/2} = 2.28 \times 10^{-3}$), β^+($\tau_{1/2}$ = unknown)
^{96}Tc	E.C. ($\tau_{1/2} = 1.18 \times 10^{-2}$), β^+($\tau_{1/2}$ = unknown)
^{97}Tc	E.C. ($\tau_{1/2} = 2.60 \times 10^{6}$)
^{98}Tc	β^- ($\tau_{1/2} = 4.20 \times 10^{6}$)
^{99}Tc	β^- ($\tau_{1/2} = 2.14 \times 10^{5}$)

Note: E.C. ≡ electron capture decay. Half-lives for this mode refer to neutral atoms.

Three of the isotopes (^{95}Tc, ^{96}Tc and ^{97}Tc) have electron capture decay modes. We incorporate electron attachment and stripping into the propagation equation using the method described by Letaw, Silberberg and Tsao [6]. Table 1 also shows that the β^+ branching ratios in ^{95}Tc and ^{96}Tc are not known. Positron emission is energetically allowed but it has not yet been observed [7]. We use two extreme values for the β^+ half-lives: a) $\tau_{1/2} = \infty$, i.e., we assume that the isotopes are stable; b) $\tau_{1/2} = 0$, i.e., the isotopes decay as soon as they are created.

<u>3. Results and Discussion</u>. Figures 1 to 3 show relative abundances of Tc with respect to Sn-Ba elements (Z = 50 to 56) as a function of mean confinement time τ_e. The results have been integrated over all energies. In Figs. 1 and 2, we see that the abundances of ^{98}Tc and ^{99}Tc are very sensitive to changes in τ_e. These isotopes would be good cosmic clocks if they could be resolved from the other ones. Figure 3 shows the elemental abundance of

Tc. The upper curve corresponds to β^+ decay with $\tau_{1/2} = \infty$. The lower curve corresponds to $\tau_{1/2} = 0$. There are two error bars drawn in Fig. 3. The larger one corresponds to the statistical fluctuations expected if only 4 trays of plastic detectors are used in a 57° inclination orbit (~50 events). The smaller bar corresponds to the statistics expected if all 45 trays of the HNC were used to collect Tc (~550 events). As mentioned earlier, just 4 trays have been optimized for identification of nuclei with $30 \leq Z \leq 70$. The other 41 trays of detectors are optimized for $Z \geq 70$ and their resolution in the region around $Z = 43$ is not yet known. Even if the Tc abundance measurement were to have negligible errors, we can see that the uncertainty in the β^+ makes it hard to reach any conclusions regarding the mean confinement time.

Only in the most favorable of circumstances (knowing the β^+ decay branching ratios and using the entire collecting power of the HNC) would we be able to use Tc as a cosmic clock in the upcoming HNC-LDEF-IB cosmic ray mission.

References

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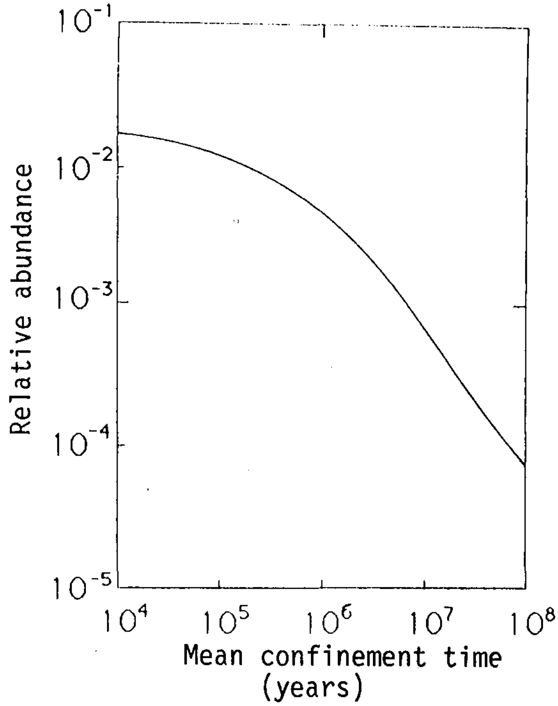

Fig. 1. Relative abundance of ^{98}Tc with respect to the Sn-Ba elements.

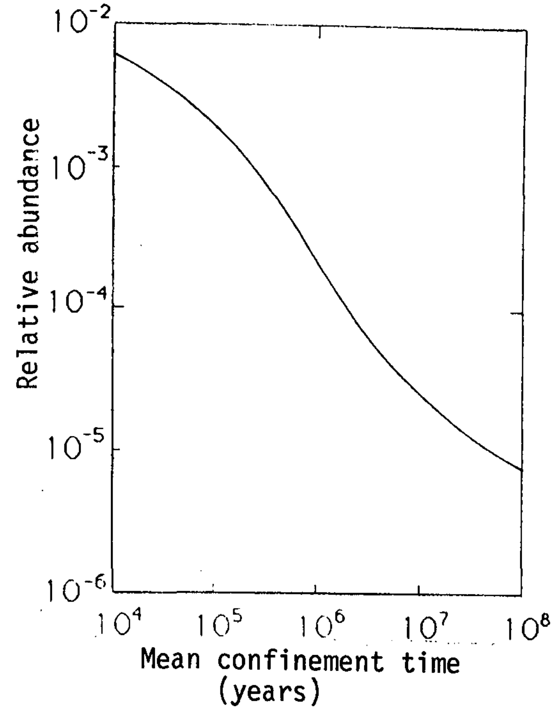

Fig. 2. Relative abundance of ^{99}Tc with respect to the Sn-Ba elements.

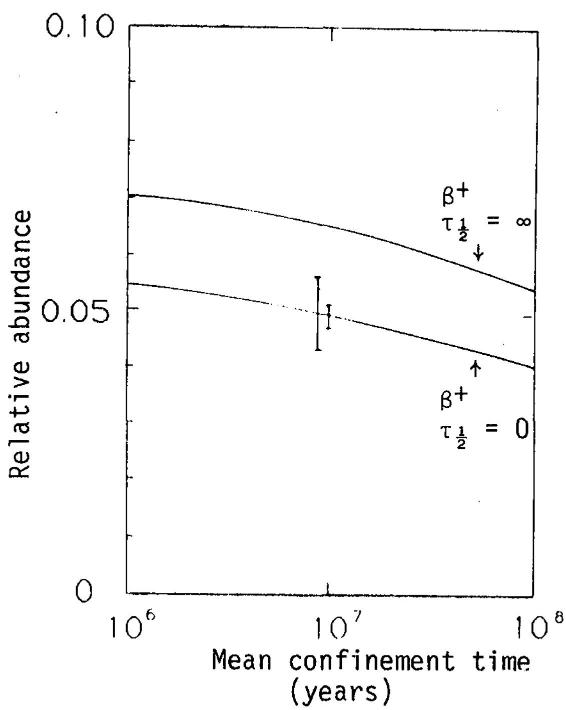

Fig. 3. Relative abundance of elemental Tc with respect to the Sn-Ba elements. The small error bar corresponds to using 100% of the collecting area of the HNC (45 trays). The large error bar corresponds to using ~ 9% (4 trays).