**THE MEAN LIFE SQUARED RELATIONSHIP FOR ABUNDANCES OF EXTINCT RADIOACTIVITIES**

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**We discovered that the abundances of now extinct radioactivities (relative to stable reference isotopes) in meteorites vary as a function of their mean life-times squared. This relationship applies to chondrites, achondrites, and irons but not to calcium-aluminum inclusions (CAIs).**

Certain meteorites contain excesses in isotopic abundances from the decay of radioactive isotopes with half-lives much less than the age of the solar system. These short-lived radioactivities are now extinct, but they were alive when meteorites assembled in the early solar system. The origin of these radioactivities and the processes which control their abundances in the solar nebula are still not well understood. Some clues may come from our finding that the meteoritic abundances of now extinct radioactivities (relative to stable reference isotopes) vary as a function of their mean lifetimes squared. This relationship applies to chondrites, achondrites, and irons, but not to CAIs. This points to at least two different processes establishing the abundances of short-lived isotopes found in the meteoritic record.

**The relationship:** Abundance ratios of short-lived radioactivities determined from the excesses in isotopes of their decay products versus their mean lives are plotted in Figure 1 in logarithmic form. As usual, stable isotopes ($N_{ref}$) of the same element (except for Pu) are used for normalization. For elements with several stable isotopes, the one involved in the production of the short-lived radioactivity or that of similar nucleosynthetic origin is used.

In contrast to CAIs (red open squares), the abundance ratios from chondrites, achondrites, and irons (solid blue symbols) correlate with the mean lives squared of the given radioactivities over several orders of magnitude. The line shown is the best fit line (henceforth called "main-trend") through the chondrite data. Excluded from the fit are the two points marked by white crosses. One is p-process $^{92}$Nb that is normalized to mainly s-process $^{93}$Nb. The other is the $^{26}$Al/$^{27}$Al ratio from (Al-rich) chondrules, and the higher value may reflect incorporation of larger amounts of CAI material into chondrule precursors. The Figure also shows recent data for $^{60}$Fe in chondritic troilite ([4,5] dark green symbols with white dot) normalized to $^{58}$Fe. These results need further investigation to understand their implications in the context here.

The slope of the best-fit line is two, hence the abundance ratio ($N/N_{ref}$) of a given radioactive isotope is proportional to the square of the mean-life ($\tau$)

$$N/N_{ref} \propto \tau^2$$

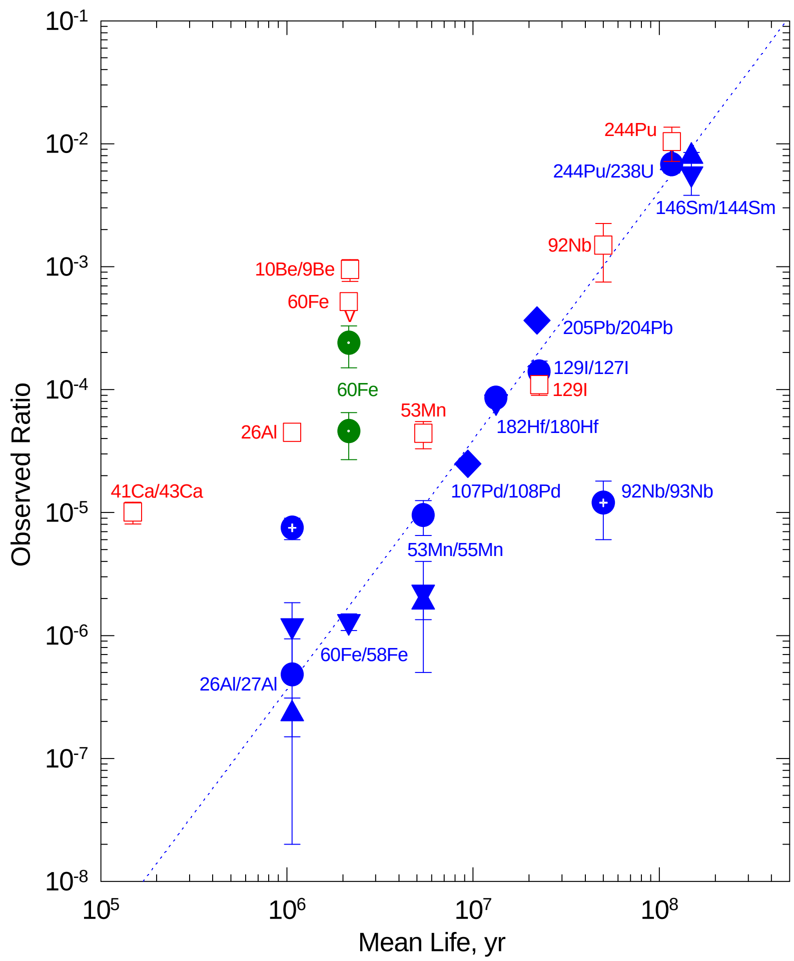


**Fig. 1**. Normalized abundances of extinct isotopes *vs*. their mean lives. Solid symbols: circles = chondrites, triangle down = eucrites, triangle up = angrites, diamonds = irons. Open squares are for CAIs. Data sources see [3].

The limit for this relationship appears to be ~ 1 Ga because the $^{235}U/^{238}U$ ratio (not shown) still perfectly fits on the line. At first glance, the correlation between the abundances of the extinct radioactivities and their mean lives squared is unexpected. The short-lived radioactivities are produced in different amounts in different stars and at different times throughout galactic history. Uniform production models predict a linear relationship [e.g., 1], but not a squared one. Our companion abstract [2] explains how the mean life squared relationship can emerge during the pre-history of the solar system. Here we describe a few implications of the relationship.

**Chondrites, achondrites & irons:** The straight line in Figure 1 points to a single, homogeneous, and common source containing the short-lived isotopes alive at the time when chondrites, achondrites, and iron meteorites formed. This source is easily identified as the presolar molecular cloud. The presence of proportionally larger quantities of the longer–lived isotopes (e.g., $^{146}Sm$ $\tau$ = 150 Ma) implies that their accumulation occurred over several of their lifetimes. The relationship further implies that the radioactivities were separated from their fossil decay products that had accumulated *prior* to incorporation of the short-lived radioactivities into these meteorites. The decoupling of associated parent and daughter nuclides in solids can take place during grain processing in the ISM as well as during heating events in the solar nebula itself. The functional relationship between mean lives and measured abundance ratios in Fig. 1 can only be established if isotopic excesses from the decay products accumulate during a common time interval in an isolated, initially homogeneous system. Because the main trend line connects the various extinct radioactivities, it also provides a common reference time that ties the individual chronometers associated with each extinct radioactivity.

**CAIs:** Data for CAIs plot near or above the main trend line in mean life vs. abundance diagram (Fig. 1). There is no clear trend as seen for the other samples above. The higher abundance ratios of several isotopes in CAIs rule out that CAIs obtained their complete inventory of short-lived isotopes from the same source that supplied these isotopes to chondrites, achondrites and irons. Several points for CAIs plot above the main trend line which indicates that they retained daughter nuclides, in contrast to the material on the line that lost the decay products prior to solar nebula formation.

The excesses in abundance ratios from CAIs over those from the main trend, the well known excesses in neutron-rich stable isotopes (e.g., $^{48}Ca$, $^{50}Ti$ , $^{54}Cr$) and the ~5% excesses in $^{16}O$, plus the postulate that the solar nebula formed near/in a supernova-laden OB Association [1,2] revives the question of whether CAIs could be supernova condensates. Relatively “fresh” condensates from supernovae in vicinity of the presolar molecular would only have short residence times in the ambient ISM which decreases their destruction probabilities and dilution by material already in the ISM.

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