The initial abundance and distribution of $^{92}$Nb in the Solar System

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Niobium-92 is an extinct proton-rich nuclide, which decays to $^{92}$Zr with a half-life of 37 Ma. Because Nb and Zr can fractionate from each other during partial melting of the mantle, mineral crystallization and metal-silicate separation, the Nb-Zr system can potentially be used to determine the timescales of silicate differentiation and core segregation for infant planets. In addition, the initial $^{92}$Nb abundance in the Solar System provides constraints on the nucleosynthetic site(s) of $p$-nuclei ($p$- denotes proton-rich). These applications require the initial abundance and distribution of $^{92}$Nb (expressed as $^{92}$Nb/$^{93}$Nb) in the Solar System to be defined. Yet previously reported initial $^{92}$Nb/$^{93}$Nb values range from $10^{-5}$ to $>10^{-3}$ [1-6], and remain to be further constrained. All but one of the previous studies estimated the initial $^{92}$Nb/$^{93}$Nb using Zr isotope data for single phases with fractionated Nb/Zr in meteorites such as zircons and CAIs, assuming that their source materials and bulk chondrites possessed identical initial $^{92}$Nb/$^{93}$Nb and Zr isotopic compositions [1-5]. To evaluate the homogeneity of the initial $^{92}$Nb abundance, however, it is desirable to define internal mineral isochrons for meteorites with known absolute ages. Although Schönbächler et al. [6] applied the internal isochron approach to the chondrite Estacado and the mesosiderite Vaca Muerta, these meteorites include components of different origins and their formation ages are uncertain, which prohibits a precise determination of the solar initial $^{92}$Nb abundance.

Here we present Nb-Zr data for mineral fractions from four unbrecciated meteorites, which originate from distinct parent bodies and whose U-Pb ages were precisely determined: the angrite NWA 4590, the eucrite Agoult and the ungrouped achondrites Ibitira. Our results show that the relative Nb-Zr isochron ages of the three meteorites are consistent with the time intervals obtained from the Pb-Pb chronometer for pyroxene and plagioclase, indicating that $^{92}$Nb was homogeneously distributed among their source regions. The Nb-Zr and Pb-Pb data for NWA 4590 yield the most reliable and precise reference point for anchoring the Nb-Zr chronometer to the absolute timescale: an initial $^{92}$Nb/$^{93}$Nb ratio of $(1.4 \pm 0.5) \times 10^{-5}$ at 4557.93 ± 0.36 Ma, which corresponds to a $^{92}$Nb/$^{93}$Nb ratio of $(1.7 \pm 0.6) \times 10^{-5}$ at the time of the Solar System formation. On the basis of this new initial ratio, we demonstrate the capability of the Nb-Zr chronometer to date early Solar System objects including troilite and rutile, such as iron and stony-iron meteorites. Furthermore, we estimate a nucleosynthetic production ratio of $^{92}$Nb to the $p$-nucleus $^{92}$Mo between 0.0015 and 0.035. This production ratio, together with the solar abundances of other $p$-nuclei with similar masses, can be best explained if these light $p$-nuclei were primarily synthesized by photodisintegration reactions in Type Ia supernovae.

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