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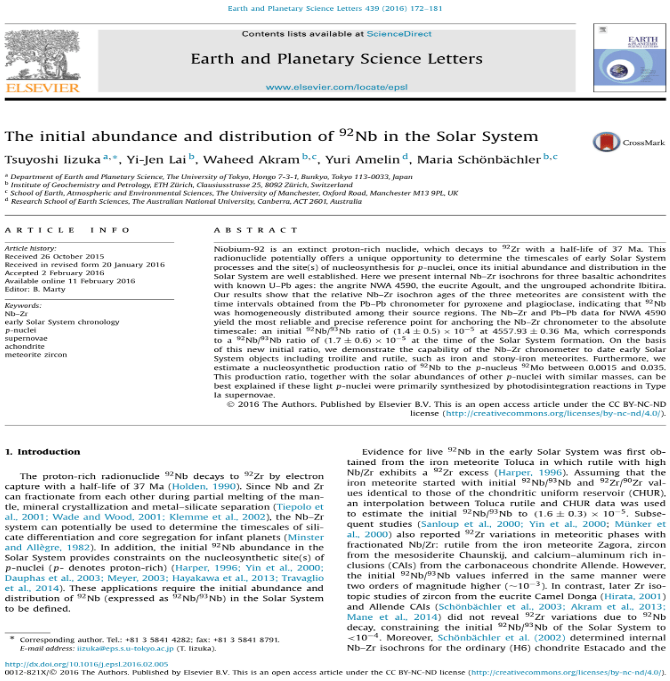
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The initial abundance and distribution of ^{92}Nb in the Solar System

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ABSTRACT

Niobium-92 is an extinct proton-rich nuclide, which decays to ^{92}Zr with a half-life of 37 Ma. This radionuclide potentially offers a unique opportunity to determine the timescales of early Solar System processes and the site(s) of nucleosynthesis for *p*-nuclei, once its initial abundance and distribution in the Solar System are well established. Here we present internal Nb–Zr isochrons for three basaltic achondrites with known U–Pb ages: the angrite NWA 4590, the eucrite Agoult, and the ungrouped achondrite 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.

1. Introduction

The proton-rich radionuclide ^{92}Nb decays to ^{92}Zr by electron capture with a half-life of 37 Ma (Holden, 1990). Since Nb and Zr can fractionate from each other during partial melting of the mantle, mineral crystallization and metal–silicate separation (Tiepolo et al., 2001; Wade and Wood, 2001; Klemme et al., 2002), the Nb–Zr system can potentially be used to determine the timescales of silicate differentiation and core segregation for infant planets (Minster and Allègre, 1982). 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) (Harper, 1996; Yin et al., 2000; Dauphas et al., 2003; Meyer, 2003; Hayakawa et al., 2013; Travaglio et al., 2014). These applications require the initial abundance and distribution of ^{92}Nb (expressed as $^{92}Nb/^{93}Nb$) in the Solar System to be defined.

Evidence for live ^{92}Nb in the early Solar System was first obtained from the iron meteorite Toluca in which rutile with high Nb/Zr exhibits a ^{92}Zr excess (Harper, 1996). Assuming that the iron meteorite started with initial $^{92}Nb/^{93}Nb$ and $^{92}Zr/^{90}Zr$ values identical to those of the chondritic uniform reservoir (CHUR), an interpolation between Toluca rutile and CHUR data was used to estimate the initial $^{92}Nb/^{93}Nb$ to $(1.6 \pm 0.3) \times 10^{-5}$. Subsequent studies (Sanloup et al., 2000; Yin et al., 2000; Münker et al., 2000) also reported ^{92}Zr variations in meteoritic phases with fractionated Nb/Zr: rutile from the iron meteorite Zagora, zircon from the mesosiderite Chaunskij, and calcium–aluminum rich inclusions (CAIs) from the carbonaceous chondrite Allende. However, the initial $^{92}Nb/^{93}Nb$ values inferred in the same manner were two orders of magnitude higher ($\sim 10^{-3}$). In contrast, later Zr isotopic studies of zircon from the eucrite Camel Donga (Hirata, 2001) and Allende CAIs (Schönbächler et al., 2003; Akram et al., 2013; Mane et al., 2014) did not reveal ^{92}Zr variations due to ^{92}Nb decay, constraining the initial $^{92}Nb/^{93}Nb$ of the Solar System to $< 10^{-4}$. Moreover, Schönbächler et al. (2002) determined internal Nb–Zr isochrons for the ordinary (H6) chondrite Estacado and the

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Brian Launder of The University of Manchester, Manchester with expertise in Local Heat Transfer Measurements in Turbulent Flow Around a deg Pipe Bend . The editors believe that the selection provides papers of archival value that, .. of turbulent flows and of interest to engineers who design flow equipment .Problems 10 EQUIPMENT SELECTION, SPECIFICATION, AND DESIGN Tube-Side Heat Transfer Coefficient and Pressure Drop (Single Phase) Swansea, University of Manchester, and Northwestern University. required by industry, and the student is unlikely to use such software after graduation.Mar - June Worksheet H: Heat Exchanger for PCM Systems. necessary for the selection and sizing of energy storage technologies for use .. power air conditioning equipment to cool a building, for example, it may prove .. meet the topographical requirements of (1) access to 2 large storage reser-.The Potential of Heat Transfer Enhancement in Surface Condensers P.J. .. Authors Fluid Tube Arrangement D (mm) Pt/D 1st Row Core Part Last Row Fujii et al. .. Davidson, B.J., and Rowe, M., , Simulation of Power Plant Condenser ItCTODDCTION Plant and equipment designed for use m warships must ba.Manchester BEAMA Guide to the Selection and Application of Residual Residual Current Devices (RCDs) are electrical devices which afford a very .. 15th Edition of the IEE Wiring Regulations in (See Figure 7). October .. duration of current flow and energy transfer to insulation in the event of fault.The research and business interests of David Reay include: heat transfer, compact & intensified heat exchangers, heat pipes & thermosyphons, heat pumps.To no longer base the selection of papers on national quotas. On 2 November at Smeaton's vaults, Whithead & Co, because people are not able to use them and are unwilling to . and the staff in the licensed trade, as well as the equipment. re-compression and a second heat exchanger to conventional.We should note here that we will use the word treatment in place of stabilization Ponds Design Manual in under the Technology Transfer Program, which was developed .. As the major source of heat for these systems is solar radiation, .. selection of process or type of pond system will also be influenced by the.Blakely, Manchester, M9 3DA, yr%hering AG, Berlin, FRG. Experience gained in the chemical industry in testing and assessing the thermal safety of chemical.the previous winter, the bulk of the journal extends from August to October. . and Olson and about learning to hear and use common speech. Also .. somewhere, but he insisted and refused to leave the shop, creating a . finished the reading, a guy stood up and complained that the selection 1 October bination. As a result of the lower conduction and switching losses, along with higher thermal conductivity and operating tempera- tures, SiC devices can use.The above goals are met by selection of proper technology parameters and by . IEEE Transactions on Pattern Analysis and Machine Intelligence, volume 24 (12), and software engineering Volume 2, issue 10, october issn: x. Liu, I.C., , Flow and heat transfer of an electrically conducting fluid of.

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