DISTRIBUTION OF ^{92}Nb IN THE EARLY SOLAR SYSTEM. P. Mane[1], J. Render[2], G. A. Brennecka[2], J. I. Simon[3], and R. M. G. Armytage[4], [1]Lunar and Planetary Institute, USRA, Houston, TX (pmane@lpi.usra.edu), [2]Nuclear and Chemical Sciences Division, Lawrence Livermore National Laboratory, Livermore, CA, [3]NASA Johnson Space Center, Houston, TX, [4] Jacobs-JETSII, NASA JSC, Mail Code XI3, Houston, TX.

Introduction: Constraining the initial abundances of short-lived radionuclides in planetary materials helps determine the spatial and temporal distribution of interstellar material added during the initial stages of Solar System formation. Niobium-92 is a short-lived radionuclide produced by the p-process in supernovae [1-2]. It has a half-life of 34.7 ± 2.4 Ma and decays to ^{92}Zr [3]. As Nb can strongly be fractionated from Zr during the crystallization of clinopyroxenes, garnets, ilmenite and Mg-perovskite, the Nb/Zr ratio is sensitive to planetary-scale silicate differentiation processes, such as the separation of magma ocean residues, partial melting of mantle, and crust formation. Therefore, the ^{92}Nb-^{92}Zr system has the potential to be a powerful chronometer to date early Solar System events, however, the ^{92}Nb-^{92}Zr chronometer has been underutilized, partly because the initial ^{92}Nb/^{93}Nb ratio of the Solar System is poorly constrained.

The attempts to determine the Solar System initial ^{92}Nb/^{93}Nb ratio by analyzing Calcium-aluminum rich inclusions (CAIs) – the oldest dated solids in our Solar System [4] – remain inconclusive. This is primarily because both Nb and Zr exhibit similar refractory lithophile behavior and show limited fractionation in CAIs. Based on the analysis of 4 CAIs from CV3 and CK3 chondrites, a bulk CAI isochron is defined with the initial ^{92}Nb/^{93}Nb slope of $(1.3 \pm 0.7) \times 10^{-5}$ [5]. A more recent report of Allende (CV3) and Mokoia (CV3) CAIs demonstrated that CAIs with a non-group II REE pattern formed with a homogenous initial ^{92}Nb/^{93}Nb ratio of $(1.6 \pm 1.5) \times 10^{-5}$, whereas CAIs with group II REE pattern evolved with a relatively higher initial ^{92}Nb/^{93}Nb ratio of 3×10^{-5}, suggesting that the CAI-forming region might be heterogeneous in its ^{92}Nb distribution [6]. Additionally, a similar degree of differences is seen in the inner and outer Solar System budgets of ^{92}Nb [7]. Our goal is to evaluate the level of ^{92}Nb/^{93}Nb heterogeneity in the early Solar System by analysis of two well-characterized igneous achondrites, one from the inner Solar System (Erg Chech 002), and one from the outer Solar System (Northwest Africa (NWA) 6704).

Erg Chech 002 is an unbrecciated ungrouped achondrite of andesitic composition. This meteorite contains megacrysts of pyroxenes in a groundmass of augite, pigeonite, sodic plagioclase, Ti-chromite, ilmenite, troilite, merrillite, Ni-poor metal, and silica [8]. The U-Pb systematics of Erg Chech 002 suggest that it crystallized at 4565.56 ± 0.12 Ma, making it the

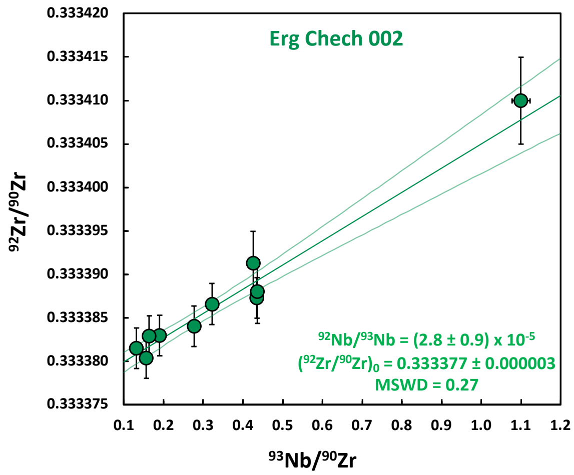

Figure 1. *^{92}Nb-^{92}Zr systematics of NWA 6704 define an initial ^{93}Nb/^{92}Nb ratio of $(2.79 \pm 0.92) \times 10^{-5}$ at the time of its crystallization.*

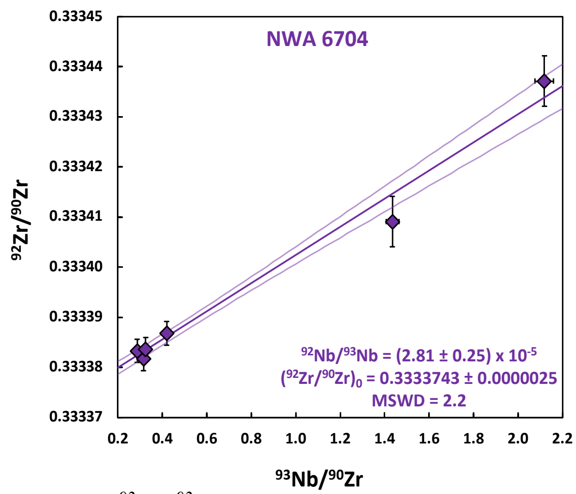

Figure 2. *^{92}Nb-^{92}Zr systematics of NWA 6704 define an initial ^{93}Nb/^{92}Nb ratio of $(2.81 \pm 0.25) \times 10^{-5}$ at the time of its crystallization.*

oldest known volcanic rock in the Solar System [9]. Nucleosynthetic anomalies in Cr isotopes indicate that Erg Chech 002 formed in the non-carbonaceous (NC) reservoir of the Solar System [10].

NWA 6704 is a an unbrecciated, ungrouped achondrite that shows medium- to coarse-grained cumulate textures. It contains low Ca-pyroxene, olivine, plagioclase, chromite, merrillite, metals and metal sulfides [11]. Based on the Cr, and Ti nucleosynthetic anomalies, combined with its O isotopic composition, NWA 6704 is classified as a carbonaceous (CC) achondrite [12]. The U-Pb systematics of NWA 6704 suggest that it formed at $4562.76^{+0.22}_{-0.30}$ Ma [13]. The ^{92}Nb-^{92}Zr systematics of NWA 6704 show a ^{92}Nb/^{93}Nb ratio of (2.72 ± 0.25) × 10^{-5} [7].

Methods: We crushed ~2 g each of NWA 6704 and Erg Chech 002 and performed mineral separation at the Lawrence Livermore National Laboratory (LLNL) and Center for Isotope Cosmochemistry and Geochemistry laboratory at NASA Johnson Space Center. Sample dissolution, chemical separation of Zr, and isotopic measurements were performed at the LLNL following analytical protocols described in [14-15]. Mineral separates and bulk samples were dissolved using the Parr digestion system and were processed using three ion exchange columns. The Zr isotopic compositions of samples and terrestrial standards were analyzed using a Neoma multicollector inductively coupled plasma mass spectrometer at LLNL. The Zr isotopic data were internally normalized to ^{94}Zr/^{90}Zr = 0.3381 using the exponential law. The analytical errors reported here are 2σ.

Results: The mineral separates of both achondrites show significant spread in ^{93}Nb/^{90}Zr and correlated excesses in their ^{92}Zr/^{90}Zr isotope ratio. The resulting isochron display slopes corresponding to ^{92}Nb/^{93}Nb = (2.79 ± 0.92) × 10^{-5} (MSWD = 0.27) for Erg Chech 002 (Fig. 1) and ^{92}Nb/^{93}Nb = (2.81 ± 0.25) × 10^{-5} for NWA 6704 (MSWD = 2.2) (Fig. 2). The highest ^{93}Nb/^{90}Zr ratios and ^{92}Zr excesses are seen in the opaque mineral fractions, likely reflecting chromite and oxide phases.

Discussion: The ^{92}Nb-^{92}Zr systematics of differentiated meteorites have been used to define the Solar System initial ^{92}Nb/^{93}Nb ratio and assess the distribution of ^{92}Nb in the early Solar System. Data from the ^{92}Nb-^{92}Zr internal isochrons of the Vaca Muerta mesosiderite, and Estacado ordinary chondrite (H6) provide an upper limit of 3 × 10^{-5} for the Solar System initial ^{92}Nb/^{93}Nb ratio [16]. A recent study reported internal ^{92}Nb-^{92}Zr isochrons for three basaltic meteorites: NWA 4590 (angrite), Agoult (eucrite), and Ibitira (ungrouped achondrite), whose ages and thermal histories are well-constrained [17]. Based on the angrite NWA 4590 data, the Solar System initial ^{92}Nb/^{93}Nb was determined to be (1.7 ± 0.6) × 10^{-5}. These results indicated a homogenous distribution of ^{92}Nb in the angrite, eucrite, and ungrouped achondrite source region [17]. A study of ^{92}Nb-^{92}Zr systematics in rutiles and zircons (that have also been dated by the U-Pb chronometer) from mesosiderites define a more precise Solar System initial ^{92}Nb/^{93}Nb ratio of (1.57 ± 0.09) × 10^{-5} [18]. A recent report on the basaltic achondrite NWA 6704 defined an initial ^{92}Nb/^{93}Nb ratio of (2.96 ± 0.27) × 10^{-5} [7], which is distinct from the initial ratio defined by the internal isochron of angrite NWA 4590 and mesosiderites, suggesting possible heterogeneity in the abundance of ^{92}Nb.

The initial ^{93}Nb/^{92}Nb = (2.81 ± 0.25) × 10^{-5} determined here at the time of crystallization of NWA 6704 is consistent with (2.96 ± 0.27) × 10^{-5} reported by [7], corresponding to a Solar System initial ^{93}Nb/^{92}Nb ratio of (3.08 ± 0.27) × 10^{-5} at the time of CAI formation at 4567.30 ± 0.3 Ma [4]. The ^{92}Nb-^{92}Zr systematics of Erg Chech 002 define a Solar System initial ^{92}Nb/^{93}Nb ratio of (2.89 ± 1.0) × 10^{-5}. Both the Solar System initial ^{92}Nb/^{93}Nb ratios defined by NWA 6704 and Erg Chech 002 are consistent with each other and therefore suggest that the inner and the outer Solar System (i.e., the NC and CC reservoirs) had a similar budget of ^{92}Nb. However, our data differ from the Solar System initial ^{92}Nb/^{93}Nb ratios defined by NWA 4590 [17] and mesosiderites [18]. This variation seen in the Solar System initial ^{92}Nb/^{93}Nb ratios may still suggest heterogeneity in the distribution of ^{92}Nb in the early Solar System. However, Erg Chech 002 is an NC achondrite that records higher Solar System initial ^{92}Nb/^{93}Nb, compared to other achondrites forming in the NC reservoir. The ^{26}Al-^{26}Mg short-lived system in Erg Chech 002 suggests a heterogenous distribution of ^{26}Al as well [9]. Therefore, heterogeneity in ^{92}Nb and possibly in other short-lived radionuclides may be more complex than that explained by the NC-CC dichotomy. We will collect data for Erg Chech 002 in anticipation of refining the uncertainties associated with the initial ^{93}Nb/^{92}Nb ratio.

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