NICKEL ISOTOPIC COMPOSITION OF FE-NI METAL FROM IRON METEORITES AND THE BRENHAM PALLASITE.
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Introduction: The former presence of the short-lived radionuclide ^{60}Fe ($t_{1/2}$ = 1.49 My) has been reported from numerous meteoritic components. Excesses of the daughter isotope, ^{60}Ni, have been found in ordinary [1,2] and enstatite chondrites [3], which originated from primitive parent bodies, as well as eucrites [4] and iron meteorites [5], which formed in differentiated parent bodies. In addition to ^{60}Ni, excesses of daughter isotopes of the short-lived radionuclides ^{107}Pd ($t_{1/2}$ = 6.5 My) and ^{53}Mn ($t_{1/2}$ = 3.7 My) have been reported from iron meteorites [6,7]. These short-lived nuclides and their decay products can provide high-resolution chronometry of iron meteorites and, in the case of ^{60}Fe, may also have contributed to heating and differentiation on their parent bodies. Moreover, recent studies indicate that iron meteorites may contain nucleosynthetic anomalies for some elements [8]. Therefore, the five isotopes of Ni were analyzed in eight different iron meteorites to determine if any contained excess ^{60}Ni from the decay of ^{60}Fe and to search for the presence of any nucleosynthetic anomalies. Evidence for the former presence of live ^{107}Pd and ^{53}Mn has been reported for the Brenham pallasite [6,9]. Hence, it also was included in this investigation.

Samples and Methods: Samples were chosen to represent a wide variety of iron-rich meteorite groups including magmatic and non-magmatic irons and a main-group pallasite. Specifically, Fe-Ni metal from the following meteorites was analyzed: Canyon Diablo (IAB), Dayton (IIICD), Coahuila (IIAB), Santa Luzia (IIAB), Casas Grandes (IIIAB), Gibeon (IVA), Hoba (IVB), Cape of Good Hope (IVB), and Brenham (main-group pallasite). In addition to meteoritic samples, we also analyzed samples of terrestrial Fe-Ni metal (josephinite). For each sample, a small (< 50 mg) piece was digested in a Teflon beaker using reverse *aqua regia* (2:1 mix of conc. HNO_3 to conc. HCl). Nickel was separated using a combination of anion and cation exchange chromatography. In addition to the natural samples, several aliquots of NIST SRM 986 Ni standard were processed through the Ni separation chemistry. The total procedural blank for Ni is typically <2 ng and is insignificant in comparison to the amount of Ni in the samples.

Ni isotope measurements were made at the Isotope Geochemistry Laboratory of the Field Museum using a Micromass IsoProbe multi-collector ICPMS. Samples were measured via the standard-sample bracket technique using the NIST SRM 986 as the Ni isotope standard. Samples were corrected for mass bias using an exponential law and ^{62}Ni/^{58}Ni ≡ 0.053388 [10]. In addition to measuring the five Ni isotopes, ^{57}Fe and ^{66}Zn were monitored and used to correct isobaric interferences on ^{58}Ni from ^{58}Fe and on ^{64}Ni from ^{64}Zn. The analytical protocol consisted of alternating between standard (NIST SRM 986) and sample solutions, with each being measured for 200 seconds. Each 200 s measurement (consisting of 20 cycles of 10 s integrations) is preceded by 4 minutes of wash-out and a 60 s integration of the background. Each reported datum (Figs. 1 and 2) comprises the mean of a minimum of four repeat measurements.

Results: Figure 1 shows the results of our analyses (conducted over a period of seven months) of Ni terrestrial standards for the ^{60}Ni/^{58}Ni ratio after the mass bias correction. Each datum in Fig. 1 represents the mean of multiple standard-sample brackets, where SRM 986 served as the standard and either an Aesar Ni

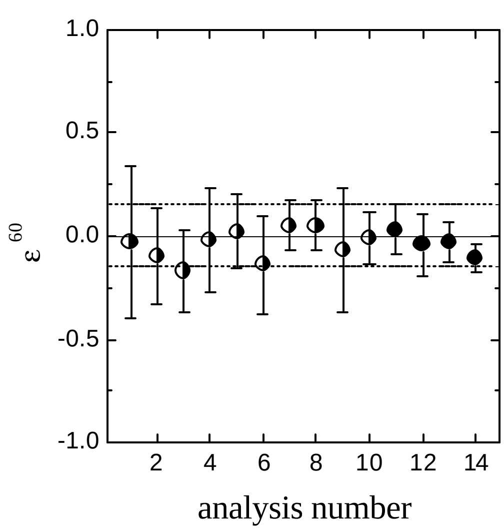

Fig. 1: Mass bias corrected ^{60}Ni/^{58}Ni ratios in epsilon units (ε^{60}) for Ni terrestrial standards; Aesar Ni standard (half-filled symbols) and chemically processed SRM 986 (filled symbols). Error bars are $2\sigma_m$. The external precision (2σ) is shown by the two dashed lines.

concentration standard or the chemically processed SRM 986 was treated as the sample. The data are reported in epsilon units, given as:

$$\varepsilon^{i} = [(R_{sample} - R_{standard})/R_{standard}] \times 10^{4}$$

where R is the mass bias corrected $^{i}Ni/^{58}Ni$ ratio (i = 60, 61 or 64). Error bars represent the standard error of the mean ($2\sigma_m$) and were calculated as:

$$2\sigma_m = (2\sigma/\sqrt{n}) \times [1 + (20/n^2)]$$

where n is the number of repeat measurements, and the term $[1 + (20/n^2)]$ is a factor to account for a small n. As can be seen in Fig. 1, the mean value of the mass bias corrected $^{60}Ni/^{58}Ni$ ratio in the terrestrial standard materials is zero, and the external precision (2σ) is ± 0.15 ε. Similarly, the means of mass bias corrected $^{61}Ni/^{58}Ni$ and $^{64}Ni/^{58}Ni$ ratios in these terrestrial standard materials are also zero and have external precisions (2σ) of ± 0.85 ε and ± 1.27 ε, respectively.

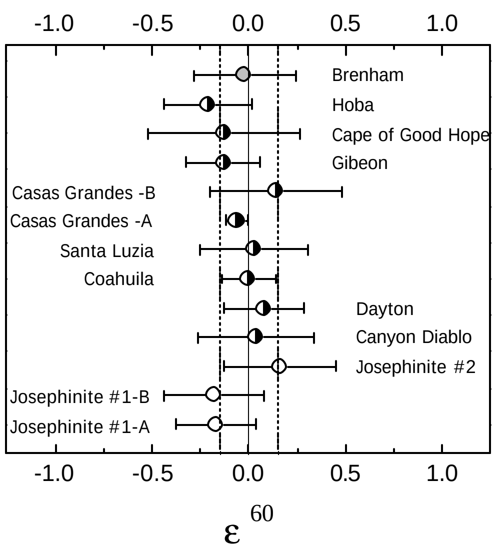

Fig. 2: Mass bias corrected $^{60}Ni/^{58}Ni$ ratios in epsilon units (ε^{60}) in Fe-Ni metal of terrestrial josephinite (open symbols), iron meteorites (half-filled symbols) and the Brenham pallasite (gray symbol). Error bars are $2\sigma_m$. The external precision (± 0.15 ε) is shown by the two dashed lines (2σ).

Figure 2 shows the mass bias corrected $^{60}Ni/^{58}Ni$ ratios in the natural samples analyzed. All samples are identical to SRM 986 within the uncertainties. Similarly, mass bias corrected $^{61}Ni/^{58}Ni$ and $^{64}Ni/^{58}Ni$ ratios in all samples are identical to SRM 986 within uncertainties.

Discussion: Recently, variations of up to 1.5 ε in the $^{60}Ni/^{58}Ni$ ratio (attributed to the presence of radiogenic ^{60}Ni) were reported in a variety of meteorites, with "significant" excesses of radiogenic ^{60}Ni in the metal phase from Canyon Diablo and Casas Grandes [5]. However, our results (Fig. 2) do not confirm these findings, which also were obtained via multi-collector ICPMS. The Canyon Diablo sample yields an ε^{60} value of 0.04 ± 0.30 and two separate analyses of Casas Grandes (A and B in Fig. 2) yield ε^{60} values of –0.06 ± 0.06 and 0.14 ± 0.34.

The lack of a resolvable excess in radiogenic ^{60}Ni (*i.e.*, exceeding the 2σ external precision of ± 0.15 ε) and the corresponding Fe/Ni ratio in the metal phase of each meteorite analyzed may be used to estimate the minimum time interval (ΔT_{min}) required between the beginning of the solar system, as defined by the formation of CAIs, and the formation time (*i.e.*, the time of cooling through the closure temperature of the Fe-Ni system) of that meteorite. The Fe/Ni ratios of the metal in the meteorites analyzed range from 4.81 (Dayton) [11] to 16.8 (Coahuila) [12]. Thus, if one assumes a solar system initial $^{60}Fe/^{56}Fe$ ratio of 1.6×10^{-6} [13], the ΔT_{min} for the metal in these iron-rich meteorites ranges from 1.3 to 4.0 My.

The lack of resolvable excesses in radiogenic ^{60}Ni in the metal of iron meteorites does not preclude the presence of live ^{60}Fe in their parent bodies. However, without clear evidence of its presence, no assessment can be made concerning the role of ^{60}Fe as a potential heat source for planetesimal differentiation. In addition to the absence of detectable radiogenic ^{60}Ni excesses in any of the meteoritic samples analyzed, no anomalies were found in ^{61}Ni or ^{64}Ni within the analytical uncertainties.

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