HIGH PRECISION NICKEL ISOTOPIC ANALYSES IN METEORITES. J. H. Chen¹, D. A. Papanastassiou², G. J. Wasserburg³, ¹Science Division, ²M/S 183-601, ³M/S 183-335, Jet Propulsion Laboratory, Caltech, 4800 Oak Grove Dr., Pasadena, CA 91109-8099, ³The Lunatic Asylum, GPS Div., 170-25, Caltech, Pasadena, CA 91125 (James.H.Chen@jpl.nasa.gov).

Introduction. Evidence for $^{60}$Fe ($\tau_{1/2} = 1.5$ Ma) has been obtained in eucrites [1-3], consisting of excesses in $^{60}$Ni, in phases with high Fe/Ni, but no well-defined isochrons were determined. Tachibana and Huss [4] reported evidence for $^{60}$Fe from measurements of $^{60}$Ni excesses in troilite from Krymka and Bishunpur, with inferred initial $^{60}$Fe/$^{56}$Fe of (1.1±0.2)×10^{-7} and (1.7±0.5)×10^{-7}. Mostefaoui et al. [5] reported initial $^{60}$Fe/$^{56}$Fe of (7.3±2.6)×10^{-7} for FeS in Semarkona. These measurements were obtained with ion probes, in sulfide phases with very high Fe/Ni.

Recent work on Ni isotopes, using MC-ICP-MS, indicates a complex picture. Moynier et al. [6,7] showed excesses of up to 1.5 εu in $^{60}$Ni/$^{58}$Ni in some chondrites and iron meteorites and reported an initial $^{60}$Fe/$^{56}$Fe (3±0.2)×10^{-6}, higher than any previous estimate. Cook et al. [8] did not find any resolvable excess in $^{60}$Ni/$^{58}$Ni at the level of ±0.15 εu. Quitté et al. [9] analyzed FeNi and sulfide from iron meteorites and found no $^{60}$Ni effects in the FeNi at ±0.3εu. In some sulfides, they found large and correlated effects in ε$^{60}$Ni (-4.17 to +0.18εu) and ε$^{61}$Ni (-0.81 to +17.23εu). In irons, Bizzarro et al. [10], reported high precision Ni data and claimed small shifts of -0.28±0.11εu to -0.11±0.07εu in $^{60}$Ni and -0.61±0.27εu to -0.30±0.21εu in $^{62}$Ni. In Murchison, they reported normal $^{60}$Ni/$^{58}$Ni, but a shift of 0.36±0.10 εu in ε$^{65}$Ni. Völkening and Papanastassiou [11, 12], using TIMS, determined Fe and Zn isotopic anomalies in FUN CAI. Birck and Lugmair [13] reported TIMS Ni results on Allende CAI and found shifts of a few εu in $^{60}$Ni, $^{62}$Ni and $^{64}$Ni. If their Ni data are renormalized to $^{62}$Ni/$^{58}$Ni, only 1 out of 5 inclusions shows a small ε$^{60}$Ni<1εu.

Methods. We developed, last year, analytical techniques for the measurement of Ni isotopes by MC-ICP-MS and by TIMS [14]. In this work, we use TIMS, which shows fewer mass interference problems and, in our experience, yields more reliable results. We developed new chemical procedures for the separation of Ni, using several stages of ion exchange, solvent extraction, and precipitation, to minimize mass interferences from compounds of Cu, Mg, Sc, Ti, Fe, and Zn. We succeeded in removing most interfering impurities. In particular, interferences at mass 58 and 64 from $^{56}$Fe and $^{64}$Zn and from molecular ions were reduced to less than 1×10^{-6} and 2×10^{-4}, respectively. We also improved the thermal ionization efficiency for Ni to ≥1%. The Ni data are normalized to $^{62}$Ni/$^{58}$Ni = 0.05338858 [15].

Iron Meteorite Results. The reproducibilities for the Ni isotopes for a period of a few months are shown as an error envelope (2σ mean, n=14) in Fig. 1-3, and are ±0.1εu for $^{60}$Ni and ±0.6εu for $^{61}$Ni. Using TIMS, we determined that, for samples of FeNi from 5 iron meteor-ites of different groups (Bennett County, Bella Roca, Gibeon, Piñon and Odessa), the ε$^{60}$Ni are the same as terrestrial normal to within ±0.1εu, and ε$^{61}$Ni are normal to ±0.7εu (Fig. 1). For $^{56}$Fe/$^{58}$Ni in FeNi as low as 7 (Hoba, Piñon; i.e., enriched in Ni, relative to solar)) and the limit $^{60}$Fe/$^{56}$Fe<2.4×10^{-7} (cf results on Chainpur, below) we expect a deficit in $^{60}$Ni of -0.1εu, which is not resolvable. The Ni data on sulfide samples from two irons are shown in Fig. 2 and have larger uncertainties, due to low Ni concentrations and possibly some mass interference problems. Three analyses of a sulfide from Toluca (FeS-1a-c) and an analysis of a 2nd sulfide from Toluca (FeS-2) show normal values within the uncertainties. The data show no evidence for $^{60}$Ni excesses and yield limits on $^{60}$Fe/$^{56}$Fe of <2×10^{-9} (measured $^{56}$Fe/$^{58}$Ni=5200). Two sulfide samples (FeS-1 & FeS-2) from Odessa show larger uncertainties and
hints of up to +0.4σ shifts in 60Ni and +0.8σ in 61Ni. These two sulfide analyses showed unusual, higher interferences at mass 59 and these small shifts in Odessa sulfides could be due to residual mass interferences.

**Chondrite Results:** We have analyzed also two pyroxene chondrules from the Chainpur chondrite. The results indicate normal 60Ni abundance to ±0.5 σ. For 56Fe/58Ni=48 and 74, for chondrules 1 and 2, we calculate initial values 60Fe/56Fe <9×10^-8 and <2.4×10^-7. In addition, we analyzed the bulk meteorite and a sulfide from St. Séverin (LL6). The specimen contains an unusually large sulfide vein (2mm×10mm) with a mixture of euhedral troilite crystals, massive sulfide and metal grains, indicating a primary origin of the sulfide. Analyses of the whole rock sample and three aliquots of the Ni from this sulfide vein are shown in Fig. 3. Analyses of the bulk and two analyses of the troilite show normal isotopic values. One analysis of the troilite sample shows a +1.0σ shift in 61Ni and no resolvable effect in 60Ni. With the measured 56Fe/58Ni of 1040, we calculate an initial 60Fe/56Fe <4×10^-9.

**Discussion.** The Ni results we have obtained are in agreement with Ni isotope analyses on FeNi by [8,9,10]. However, we do not confirm the reported large isotopic shifts in the sulfides of either Toluca or Odessa using the MC-ICP-MS [9], indicating, from our experience, the greater potential danger of significant, hard to correct mass interferences for plasma ionization. We do not confirm any resolvable shifts for 60Ni in FeNi in iron meteorites as reported by others using the MC-ICP-MS [6, 7]. The Chainpur chondrules show small Fe/Ni enrichment factors of ~3 relative to the average solar value. Therefore, we do not expect to find large shifts in 60Ni. While St. Séverin was formed early in the solar system with a U-Pb age of 4.552 Ga [16], Re-Os data on the St. Séverin sulfide [17] indicate a recent redistribution (<2.3Ga), and it is, therefore, unlikely that effects on the St. Séverin sulfide [17] indicate a recent redistribution (<2.3Ga), and it is, therefore, unlikely that effects in Ni would have been preserved in the sulfide. Timmes et al. [18] reviewed the production of 26Al and 60Fe in Type II supernovae (SN) and pointed out the strong coproduction of these radionuclides in the O/Ne zone in massive stars. Using these calculations, Wasserburg et al. [19] obtained an average production ratio for 26Al/56Fe ~ 8.6 for contributions to the solar nebula, from SNII. Based on the typical (26Al/27Al)0 in CAI, they calculated for a SNII source, 60Fe/56Fe between 3×10^-7 and 1×10^-5. They viewed a search for 60Ni effects as a sensitive test for a supernova trigger for the formation of the solar system. For the solar 60Ni/56Fe = 0.0156 (56Fe/58Ni=25), shifts in 60Ni of 0.2 to 8.3 σ would be expected. Therefore, enrichments in Fe/Ni in mineral phases of only a factor of 10 above the solar value should yield clear effects in CAI and also in ordinary chondrules, if they formed in the first three million years, of solar system history. 60Ni effects in CAI and in ordinary chondrules would be important as a test of whether the observed 26Al in CAI can be associated with a SNII provenance. The results on Chainpur chondrules indicate a limit of 60Fe/56Fe <2.8×10^-7, which is compatible with initial ratio reported by [4]. There is clearly a need for a continued search for effects in high Fe/Ni chondrules, in unmetamorphosed chondrites.


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