Fe-Ni ISOTOPE SYSTEMATICS IN THE EAGLE STATION PALLASITE. D. A. Papanastassiou1, J. H. Chen2, and B. P. Weiss3, 12 Science Div., Jet Propulsion Laboratory, Caltech, 1M/S 183-335, 2M/S 183-601, 4800 Oak Grove Drive, Pasadena, CA 91109-8099, 3Dept. EAP Sciences, MIT, Cambridge, MA 02139 (dap@jpl.nasa.gov, james.h.chen@jpl.nasa.gov, bpweiss@mit.edu)

We report Ni isotope ratio results for Ni from metal and olivine in the Eagle Station (ES) pallasite. The investigation was undertaken because (1) previous work on pallasites showed evidence for in situ decay of \( ^{53}\text{Mn} \) (\( t_{1/2} = 3.7 \text{ Ma} \)) in olivines [1-3] and of \( ^{107}\text{Pd} \) (\( t_{1/2} = 6.5 \text{ Ma} \)) in metal [4]; (2) evidence for the in situ decay of \( ^{60}\text{Fe} \) (\( t_{1/2} = 2.62 \text{ Ma} \)) in eucrites [5-6]; (3) possible early formation of pallasites based on Re-Os data [7]; and (4) very high Fe/Ni ratios in pallasite olivines [6,8]. The purpose of this study is to identify potential general isotope anomalies in Ni and direct evidence for the in situ decay of \( ^{60}\text{Fe} \) in Eagle Station. The pallasite metal sample we analyzed was free from rust and impurities. The olivine sample was leached in cold ethanol and then in 2M HCl to remove rust from the surface of the crystals. After dissolution with HF a small amount of chromite rich residues was separated and saved. We followed the Ni analytical procedures developed in Chen et al. (2009) [9]. An update is given in Chen et al. [10].

The results are shown in Table 1 and indicate that the \( ^{60}\text{Ni} \) and \( ^{64}\text{Ni} \) values of ES samples (FeNi metal and olivine) are within the uncertainties for terrestrial standards. We have listed our best estimate for the \( ^{64}\text{Ni} \) value for the metal, based on a small correction for \( ^{64}\text{Zn} \) mass interference. The \( ^{64}\text{Ni} \) value is also normal. From the Fe/Ni ratios and uncertainties of \( ^{60}\text{Ni} \), we can calculate upper bounds on the values of the initial \( ^{60}\text{Fe}/^{56}\text{Fe} \) for the pallasiteparent bodies. In an \( ^{60}\text{Ni} \) versus \( ^{56}\text{Fe}/^{58}\text{Ni} \) diagram (Fig. 1), we plot our data for Eagle Station and also for other pallasite olivines and metals [11]. The inferred limits for the initial \( ^{60}\text{Fe}/^{56}\text{Fe} \) values are < \( 10^{-9} \) for Salta and < \( 8 \times 10^{-10} \) for Brenham and Thiel Mountain based on the observed \( ^{60}\text{Ni} \) and extremely high \( ^{56}\text{Fe}/^{58}\text{Ni} \) ratios (6600 to 17000) [11]. The Fe/Ni ratio for the ES olivine is less than for these other pallasites but still high enough to yield an upper limit for \( ^{60}\text{Fe}/^{56}\text{Fe} \) of < \( 2 \times 10^{-9} \).

The new high precision results show no excess in \( ^{60}\text{Ni} \) and agree with the less precise and lower Fe/Ni data reported previously for Omolon and Thiel Mountain olivines [6,11]. The pallasite Ni data provide no evidence for the in situ decay of \( ^{60}\text{Fe} \) in the pallasite parent bodies or would require a long interval between the injection of \( ^{60}\text{Fe} \) and the differentiation of the pallasite parent bodies. Alternatively, the pallasites cooled over a sufficiently long time (more than 10 Ma) for the Ni in the olivine to equilibrate with the FeNi, after the \( ^{60}\text{Fe} \) decay. Previously, we reported excess \( ^{107}\text{Ag} \) in the metal of Brenham (\( ^{107}\text{Ag} = 52\pm 7 \)). The \( ^{107}\text{Pd}/^{107}\text{Pd} \) value for Brenham, (1.1±0.14)\( \times 10^{-7} \), suggests a formation time of \( \sim 7 \) Ma after formation of the Gibeon, IVA iron [4]. As discussed below, this isolation time is long enough to prevent any resolvable effect to be detected, even with our current high precision for \( ^{60}\text{Ni} \). Previously published Ni isotopic data for pallasite metals show either normal values (Eagle Station, Albin, Brenham and Molong [12] and Molong [13]) or anomalous values (Admire, Esquel and Brahin [14]). Based on our data, we conclude that, despite extremely high Fe/Ni ratios in the pallasite olivines, we do not detect a \( ^{60}\text{Ni} \) anomaly in either metal or olivine from 4 pallasites. The TIMS FeNi data from these pallasites yield strict upper limits of \( 8 \times 10^{-10} \) to \( 10^{-9} \) for the initial \( ^{60}\text{Fe}/^{56}\text{Fe} \) in the pallasite parent bodies.

In contrast to the \( ^{60}\text{Fe}-^{60}\text{Ni} \) system, there is evidence in some pallasites for the in situ decay of \( ^{53}\text{Mn} \) [2, 15]. Ion probe data [15] show relatively high \( ^{53}\text{Mn}/^{55}\text{Mn} \) ratios, (1.2 to 4.2)\( \times 10^{-5} \), for Sprinwater, Albin, and Brenham, while [16] report no resolved effects in Albin, Brahin, Springwater and Imilac. A calculation of ion probe Mn-Cr data to remove instrumental bias, indicates no Mn-Cr effects in pallasites [17]. In comparison, TIMS data on Omolon [2] show (\( ^{53}\text{Mn}/^{55}\text{Mn} \) of (1.3±0.2)\( \times 10^{-6} \). These differences may reflect the effects of Cr diffusion and variations in Mn/Cr on a local scale (for SIMS) as opposed to the bulk olivine Mn/Cr measured for TIMS analyses.

For sulfides in unequilibrated ordinary chondrites, ion probe data showed (\( ^{60}\text{Fe}/^{56}\text{Fe} \) of 1.1\( \times 10^{-7} \) and 1.7\( \times 10^{-7} \) [18] or 7.3\( \times 10^{-7} \) [19]. The recalculation of the data indicates no effects in sulfides, while some chondrules from unequilibrated ordinary chondrites still show evidence for \( ^{60}\text{Fe}/^{56}\text{Fe} \) of (1-3)\( \times 10^{-7} \) [17]. Our TIMS work on chondrules from unequilibrated ordinary chondrites shows a limit\( ^{60}\text{Fe}/^{56}\text{Fe} \) of \( \sim 10^{-8} \) [10]. This is also consistent with careful MC-ICP-MS work on unequilibrated ordinary chondrites [20]. Based on the very high Fe/Ni ratios we have obtained for the pallasite olivines our upper limit for \( ^{60}\text{Fe}/^{56}\text{Fe} \) is \( 8 \times 10^{-10} \). This corresponds to about a factor of 10 less than the values for unequilibrated ordinary chondrites or a time interval of ~9 Ma. Hence, the pallasites could have formed and cooled relatively shortly after the
time defined by the $^{60}$Fe-$^{60}$Ni system for unequilibrated ordinary chondrites.

We reported very high excesses of $^{53}$Cr and $^{54}$Cr in the ES metal reflecting spallation Cr [21]. Our data are compatible with the results on Carbo published by Qin et al. [22]. The large spallation effects for Cr in FeNi are due to the long exposure age of Eagle Station and the low abundance of Cr in the FeNi. The $^{60}$Ni, $^{61}$Ni and $^{64}$Ni data for Eagle Station metal are normal and show no spallation effects. Hence, the normal value we observe for $^{64}$Ni indicates the absence of a nucleosynthetic effect for $^{64}$Ni, in contrast to the $^{54}$Cr effect for Cr in olivine and metal. Therefore, $^{64}$Ni effects are not correlated with endemc $^{54}$Cr effects. It may not be surprising that bulk FeNi does not show $^{60}$Ni anomalies. But we intend to check for Mo and Ru isotope anomalies in Eagle Station metal.


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![Figure 1](https://example.com/figure1.png)

**Figure 1.**

Table 1. Ni isotope data in the Eagle Station pallasite

<table>
<thead>
<tr>
<th>Sample</th>
<th>$^{56}$Fe/$^{58}$Ni</th>
<th>$\varepsilon_{60}^b$</th>
<th>$\varepsilon_{61}^b$</th>
<th>$\varepsilon_{64}^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eagle Station</td>
<td>2590</td>
<td>$0.12\pm0.12$</td>
<td>$0.31\pm0.40$</td>
<td>-1.4±1.5</td>
</tr>
<tr>
<td>Metal</td>
<td>7.4</td>
<td>$-0.10\pm0.10$</td>
<td>$0.25\pm0.41$</td>
<td></td>
</tr>
</tbody>
</table>

$^a$All ratios are normalized to $^{62}$Ni/$^{58}$Ni=0.05338858; uncertainties are 2σ. $^b$The $\varepsilon$ values are calculated as deviations relative to the standard, expressed in parts per 10$^4$. $^c$Corrected for $^{62}$Zn isobaric interference.