ISOTOPIC EVIDENCE FOR A MARTIAN REGOLITH COMPONENT IN MARTIAN METEORITES.

**Introduction:** Noble gas measurements in gas-rich impact-melt (GRIM) glasses in EET79001 shergottite showed that their elemental and isotopic composition is similar to that of the Martian atmosphere [1-3]. The GRIM glasses contain large amounts of Martian atmospheric gases. Those measurements further suggested that the Kr isotopic composition of Martian atmosphere is approximately similar to that of solar Kr. This suggestion was validated by [4] after detailed comparison of the lunar and Martian meteorite noble gas data. Subsequently, Garrison and Bogard [5] carried out improved noble gas measurements on GRIM glasses (,8 and ,104) which showed that the lighter isotopes of Kr in GRIM glasses are slightly enriched relative to the lighter Kr isotopes in solar wind implanted into lunar soils, suggesting a mass-fractionation trend of 0.5-1.0% per amu (Fig. 1). The Kr relative to the lighter Kr isotopes in solar wind implanted into lunar soils, suggesting a mass-fractionation trend of 0.5-1.0% per amu (Fig. 1). The data-average from [2] and [3] for GRIM glass ,27 shows a slightly lower mass fractionation trend compared to the data-average from [5] for ,8A and ,8B glasses. Considering the uncertainties in the measurement of ,27 and ,8 glasses, we adopt a value of 1.03 for (80Kr/84Kr)Mars and (80Kr/84Kr)solar. As a result, we obtain a value of 0.042 for the (80Kr/84Kr) ratio in Martian atmosphere. Furthermore, the data plotted in Fig.1 show a large enrichment of 80Kr in GRIM glasses relative to solar Kr. This plot shows that 80Kr excesses are heterogeneously distributed in GRIM glasses suggesting a possible contribution from a source other than the Martian atmosphere. This additional 80Kr source is usually attributed to neutron capture reactions by 79Br on Mars [1,2,3].

In 2002, Rao et al. [6] investigated possible neutron capture effects in the Martian regolith. They attempted to estimate the neutron fluence that irradiated the constituent materials in GRIM glasses ,27, ,8, ,104; Shergotty and Nakhla salt assemblages using 80Kr and 149Sm isotopes. 149Sm captures neutrons to produce 150Sm. The isotopic deficit in 149Sm was more precisely determined than the 150Sm isotopic excess because of a possible isobaric interference in the 150Sm measurements. The isotopic deficits in 149Sm which were accurately determined in ,27 GRIM glasses (multiple measurements) yielded an average neutron fluence [Φn] of (10±4) x 10¹⁴ neutrons / cm² [6]. The Sm isotopic deficit (c149 = − 0.57 ± 0.17) could not have originated from the Martian atmosphere, as it has no Sm. It could be produced only by in-situ neutron irradiation of Martian regolith materials that contains Sm.

Earlier, Rao et al. [6] determined 80Kr (neutron capture) excesses in GRIM glasses by subtracting the Martian atmospheric Kr and the spallation produced Kr from the measured Kr isotopic composition [5]. They assumed that the Martian atmospheric Kr composition is similar to solar Kr [4]. As a result, the 80Kr excesses determined in the GRIM glasses showed a positive correlation with Martian atmospheric implanted 129Xe. This result suggested that the 80Kr excesses were mainly introduced into the GRIM glasses from the Martian atmosphere by shock processes similar to those for 129Xe. Further, these observations led to the inference that the 80Krn – 80KrM mixing ratio in the Martian atmosphere is ~ 9%. (80Krn is atmospheric Kr exclusive of the neutron capture and spallation components). The neutron fluences calculated from 80Krn excesses apparently disagreed with those based on 149Sm isotopic deficits in the same GRIM glasses.

**Revised interpretation of 80Krn excesses:** To find out the reasons for these differences in the calculated neutron fluences, we revisit the issue of neutron capture Kr isotopes in these glasses. We adopt the updated Martian atmospheric Kr composition based on recent measurements of the Kr isotopic composition in GRIM glasses ,8; ,104; and Shergotty of [5], where Kr light isotope enrichment (80Kr and 82Kr) relative to solar wind Kr [4] is clearly shown (Fig. 1). The 80Krn excesses calculated here for GRIM glasses and Nakhla using the updated Martian atmospheric Kr composition [5] are given in Table 1. The calculation methodology is similar to that discussed in [6]. The 80Krn excesses obtained for GRIM glasses and Nakhla are plotted against 129Xe in Fig. 2, which shows that there is no correlation between 80Krn and 129Xe in these GRIM glasses. Moreover, if the 80Krn is introduced by implantation of Martian atmosphere into these samples, the 80Krn / 80KrM mixing ratio is expected to be the same in both nakhlites and shergottites. The experimental results show otherwise. The 80Krn / 80KrM ratio in shergottite GRIM glasses ranges from 2-6, whereas the same ratio in Nakhla ranges from 40-45. These observations indicate that the observed 80Krn excess in GRIM glasses can not be completely attributed to only implanted Martian atmosphere.

The other possibility for the production of 80Krn excesses in these glasses is by neutron capture by 79Br.
as in the case of neutron capture by \(^{149}\text{Sm}\). The \(^{149}\text{Sm}\) isotopic deficit in GRIM glasses results from exposure of glass-precursor regolith materials containing Sm to a neutron fluence \([\Phi_n]\) of \((10\pm4) \times 10^{14} \text{ n/cm}^2\) [6] as discussed above.

We examine below whether a similar neutron fluence could produce the observed \(^{80}\text{Kr}_n\) excess in GRIM glasses. For this purpose, we need to know the target Br abundance in the regolith material that was shock-melted to produce the GRIM glasses. The Br abundances in these glasses were determined by INAA [7] and by XANES (this study). The Br content of GRIM glasses ,27 and ,8 are 0.38 ppm and 0.36 ppm, whereas the Br content of ,104 and Shergotty glasses are 0.83 and 0.72 ppm, resp. Further, the Br content in Nakhla is 4.1 ppm. The neutron fluences in individual glasses are determined from the observed \(^{80}\text{Kr}_n\) excesses, Br abundances, and the \(\sigma_{\text{eff}}\) values (effective neutron-absorption cross sections) calculated according to Lingenfelter et al. [8] method. The results are given in Table 1.

The neutron fluence, \([\Phi_n]\), in these GRIM glasses range from \((2–6) \times 10^{14} \text{ n/cm}^2\) and compares favorably with that determined using \(^{149}\text{Sm}\) isotopic deficits within a factor of \(\sim2\). In particular, \([\Phi_n]\) values calculated for EET79001,27 of \((2.4\pm1.3)\) and \((3.9\pm1.8) \times 10^{14} \text{ n/cm}^2\), resp., using \(^{80}\text{Kr}_n\) are in adequate agreement with \((10\pm4) \times 10^{14} \text{ n/cm}^2\) determined from the \(^{149}\text{Sm}\) measurements on ,27 glass. These results suggest that both the \(^{149}\text{Sm}\) isotopic deficits and \(^{80}\text{Kr}_n\) excesses in GRIM glasses from EET79001 and Shergotty have a common source in the Martian regolith, and were likely produced by similar neutron capture reactions in glass-precursor regolith materials on Mars. In contrast, the host rock constituent materials in Lith A and B yield considerably lower neutron-fluence [6]. The order of magnitude lower fluence in Nakhla than in the GRIM glasses also is consistent with failure to find a detectable \(^{149}\text{Sm}\) deficit in nakhlites ( \([\Phi_n]\ < 0.6 \times 10^{14} \text{n/cm}^2\)).

**Conclusions:** The \(^{80}\text{Kr}_n - ^{80}\text{Kr}_m\) mixing ratio in the Martian atmosphere obtained here is \(\sim3\%\). These neutron-capture reactions presumably occurred in the glass-precursor regolith materials containing Sm- and Br-bearing mineral phases near the EET79001/ Shergotty sites on Mars. The irradiated materials were mobilized into host rock voids either during shock-melting or possibly by earlier aeolian / fluvial activity.


**Fig.1.** Kr isotopic composition in EET79001 GRIM glasses normalized to mass 84 and solar wind Kr.

**Fig. 2.** Neutron-produced \(^{80}\text{Kr}_n\) excess versus Martian atmospheric \(^{129}\text{Xe}\) in GRIM glasses and Nakhla.

**Table 1.** Neutron fluences in shergottite GRIM glasses and Nakhla meteorite.