EPITHERMAL NEUTRON CAPTURE BY ^{167}Er IN LUNAR SAMPLES. E. Albalat[1] and F. Albarède[1], [1]Ecole Normale Supérieure de Lyon, 46 allée d'Italie 69364 Lyon Cedex 7, France (emmanuelle.albalat@ens-lyon.fr)

Introduction: Interaction of energetic cosmic rays with the lunar surface produces secondary particles including neutrons by nuclear reactions. These neutrons are thermalised in the soil and can be captured by some nuclides with high neutron capture cross-section. This process induces changes in isotope composition of elements such as Cd, Sm, Gd. Data on isotopic variations induced by neutron capture in lunar samples have been used to study the gardening of the lunar regolith [1,2]. They have also been used to evaluate neutron fluence and correct cosmic-ray bombardment effects on isotopic composition of some elements such as W, Nd or Ti [3-5]. Neutron energy spectrum is usually determined through Gd and/or Sm neutron capture isotopic variation measurements because ^{157}Gd, ^{155}Gd and ^{149}Sm are the three nuclides with the highest neutron capture cross-section σ [6]. Some studies however suggest that athough Gd and Sm provide an approximation suitable for a measure of the capture of thermal neutrons, they may be inadequate in the epithermal range [5, 7, 8].

In a recent work, we showed that neutron capture by ^{167}Er could be measured in seven lunar samples. The neutron capture cross-section of ^{167}Er has a resonance in the epithermal range not covered by ^{157}Gd, ^{155}Gd or ^{149}Sm. The capture cross-sections of this epithermal resonance and of thermal neutrons are comparable, whereas, for the others nuclides, the thermal neutron capture cross-section prevails over the resonances (Fig.1).

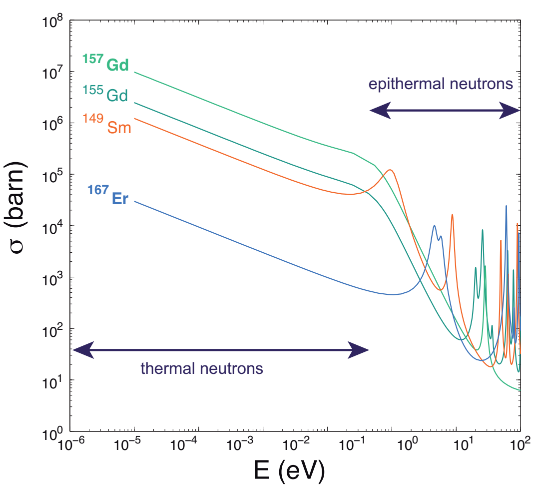

Fig. 1: Neutron capture cross-section of ^{167}Er compared to those of the nuclides mainly used for neutron capture effect studies as a function of neutron energy.

In this work, we compare the isotopic variations of Er and Gd due to neutron capture in seven lunar samples in order to determine how ^{167}Er can improve our knowledge of the neutron energy spectrum in the epithermal range on the Moon and other planetary objects exposed to cosmic rays bombardment.

Samples and analytical methods: We analysed Er and Gd isotopic compositions in three basalts (15597, 75055, 12002), two soils (14163 and 64501), one breccia (62295) and one norite (78236). These samples have different exposure ages. The detailed sample description and the analytical procedure used to measure Er isotopic composition can be found elsewhere [9]. Er and Gd isotopic compositions were measured on the same digestion. Gd was separated from the light-rare-earth-element fraction by reverse extraction chromatography on Ln.Spec (Eichrom Inc.) with HCl as eluant. The separation yield was of ~100 %. The isotope compositions were measured on a Nu Instruments MC-ICP-MS Nu Plasma 1700 at ENS Lyon using a Desolvation Nebuliser System (DSN-100).

Isotopic variation due to neutron capture: The extent of neutron capture for an isotope is usually expressed by ε the number of neutrons captured per atom for a given nuclide [6,10]. For ^{157}Gd,

$$\varepsilon = \frac{(^{158}Gd/^{157}Gd)_{sample} - (^{158}Gd/^{157}Gd)_{standard}}{(^{158}Gd/^{157}Gd)_{sample}} \qquad (1)$$

where $(^{158}Gd/^{157}Gd)_{standard}$ represents the ratio of a sample not exposed to cosmic rays. Mass dependant fractionation is corrected by normalizing the data to a reference ratio not affected by cosmic rays. In this study, the normalization of Er ratios was not possible so that we expressed the isotopic variation due to neutron capture as a new parameter Δ graphically defined in Fig. 2.

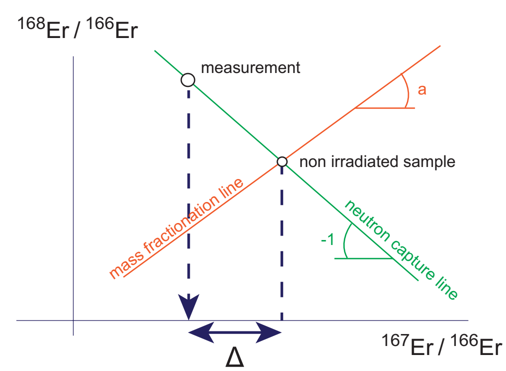

Fig. 2: Geometry sketch for the calculation of neutron capture isotopic variation Δ on Er isotopic ratio.

The extent of neutron capture for various nuclides, and hence the ε and Δ values, depend on their neutron capture cross-sections and reflects the intensity of neutron flux. Ratios of ε are approximately equal to the ratios of neutron capture cross-sections, e.g., $\varepsilon^{155}Gd/\varepsilon^{157}Gd \approx \sigma^{155}Gd/\sigma^{157}Gd$ [6,10,11]. Expression (1) is not exact because burnout of the target nuclide is neglected. We show that replacing ε by Δ provides a most robust approximation.

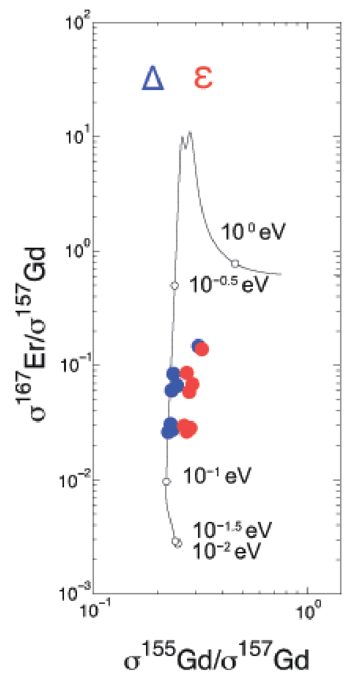

Fig. 3: Comparison of ratios of measured Δ and ε values and corresponding neutron capture cross-section ratios for lunar samples. The curve represents the $\sigma^{167}Er/\sigma^{157}Gd$ as a function of $\sigma^{155}Gd/\sigma^{157}Gd$ for neutron energy ranging from 0.01 eV to 1 eV. The points are the experimental ratios.

Epithermal neutron capture: To compare information given by Gd and Er on the neutron energy spectrum, we plotted $\Delta^{157}Gd$ vs $\Delta^{155}Gd$, and $\Delta^{157}Gd$ vs $\Delta^{167}Er$ in Fig. 4. The positive correlation obtained between $\Delta^{155}Gd$ and $\Delta^{157}Gd$ reflects that $\sigma^{155}Gd$ and $\sigma^{157}Gd$ are proportional and therefore that the energy of the neutrons involved in the capture is the thermal range. In contrast, the lack of correlation between $\Delta^{157}Gd$ and $\Delta^{167}Er$ implies that the measured isotopic anomalies of Gd and Er involves neutrons from different energy windows. With respect to the relative values of neutron capture cross-sections taken from literature (Fig. 1), Fig.4 shows that the Er anomalies associated with neutron capture provide information on that part of the neutron flux that lies in the epithermal range.

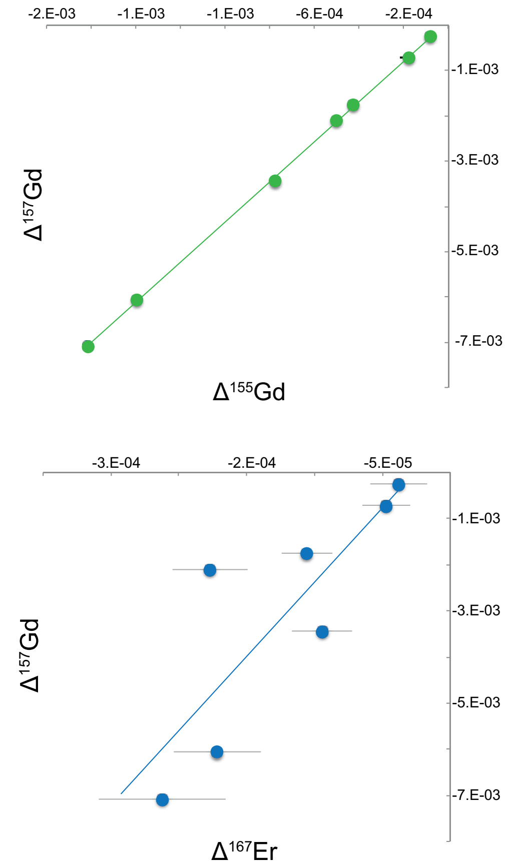

Fig. 4: Relationship between $\Delta^{157}Gd$, $\Delta^{155}Gd$ and $\Delta^{167}Er$, the number of neutrons captured respectively by ^{157}Gd, ^{155}Gd and ^{167}Er. The error bars missing are lower than the symbols.

It has been argued, that better proxies are needed to evaluate the epithermal neutron fluence used to correct for the capture of epithermal neutrons for Lu-Hf chronology [7]. Neutron capture by Pt isotopes has recently been used to correct epithermal neutron capture for Hf-W chronology system in iron meteorites [8]. In this context, Er neutron capture anomalies provide a precise and robust dosimeter of epithermal neutron capture in silicate samples.

References: [1] Russ G. (1972) *EPSL, 13, 384-386* [2] Hidaka H. and Yoneda S. (2007) *GCA, 71, 1074-1086* [3] Leya I. et al. (2003) *GCA, 67, 529-541* [4] Nyquist L. E. (1995) *GCA, 59, 2817-2837* [5] Zhang J. et al. (2012) *Nature Geosci., 5, 251-255* [6] Lingenfelter R. E. et al. (1972) *EPSL, 16, 355-369* [7] Sprung P. et al. (2010) *EPSL, 295, 1-11* [8] Kruijer T. S. et al. (2012) *EPSL, in press* [9] Albalat E. et al. (2012) *EPSL, 355-356, 39-50* [10] Russ P. G. (1971) *EPSL, 13, 53-60* [11] Sands D. G. et al. (2001) *EPSL, 186, 335-346*