A REFINED METHOD FOR THE CALCULATION OF RESIDENCE TIMES AND SHIELDING DEPTHS FOR TWO-STAGE IRRADIATION MODELS AND THE DETERMINATION OF THE DEPTH DEPENDENCY OF COSMOGENIC $^{131}\text{Xe}/^{126}\text{Xe}$ AND $^{83}\text{Kr}/^{78}\text{Kr}$, O. Eugster, Physikalisches Institut, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland.

Our present study of the exposure history of Shorty Crater soils (1) demonstrates that samples from three different depths from the drive tube 74001 experienced a galactic cosmic-ray exposure prior to the Shorty Crater formation 19 m.y. (2) ago. This paper is an attempt to unravel the exposure history of this material by assuming a two-stage exposure model. Furthermore, we shall derive the quantitative depth dependency of the cosmogenic ratios $^{131}\text{Xe}/^{126}\text{Xe}$ and $^{83}\text{Kr}/^{78}\text{Kr}$. All analytical data are given in (1). As data of improved quality will be obtained from the >26 μm fraction of the soils from 72 g/cm² and from 95 g/cm² depth, all results obtained at present are preliminary.

Following the procedure outlined in our previous work on Shorty Crater rocks (2) the duration $T_1$ and shielding depth $d_1$ for the early stage of cosmic irradiation can be derived if the duration $T_2$ and shielding depth $d_2$ for the late stage are known. For the soils from drive tube 74001 we shall assume $T_2$ to be the Shorty Crater age of 19 m.y. (2) and $d_2$ the sampling depth within the drive tube.

Eqs. 1 and 2 give the relations between $T_1$ and $T_2$ and the production rates $P_1$ and $P_2$ at the shielding depths $d_1$ and $d_2$, resp., for the Kr- and Ar-systematics.

$$T_1^{81} = (T_{app}^{81} - T_2) \frac{P_2^{83}}{P_1^{83}}$$

(eq. 1)

$$T_1^{38} = \frac{38_{\text{ArC}} - P_2^{38} T_2}{P_1^{38}}$$

(eq. 2)

The values for $P_1$ and $P_2$ as a function of depth were calculated as outlined in (2) using Reedy's (3) data; for $T_{app}^{81}$ and $38_{\text{ArC}}$ see (1). Eq. 1 is an approximation for which the ratio $P_1^{81}/P_1^{83}$ is assumed to be depth independent. The error resulting from this approximation for $T_1^{81}$ is estimated to be ± 3%. The $T_1^{81}$ values are independent from noble gas concentrations and absolute production rates in contrast to the $T_1^{38}$ values, for which, however, production rates depend largely on the Ca concentration which is well known for 74001 (5.3 %) (4), and for which the Ar concentration was measured by isotope dilution. The two free parameters $T_1$ and $d_1$ for a particular sample are determined by eqs. 1 and 2, and the resulting $T_1$ vs. $d_1$ diagrams for 74001,121/2 and for 74001,110 are shown in the upper portion of Figs. 1 and 2, resp. The intersections indicate the shielding depth and the exposure time for the early stage.

As will be shown below the determination of the shielding depth $d_1$ from such a diagram is most accurate if two isotopes of the same noble gas are plotted which were produced from the same target elements but with different depth dependency such as $^{131}\text{Xe}/^{126}\text{Xe}$ and $^{83}\text{Kr}/^{78}\text{Kr}$. The quantitative depth dependencies of these two ratios were derived applying eqs. 3 and 4, resp.
Two-stage irradiation model

Eugster, O.

for the data from 74001,121/2, and respecting the following boundary conditions: monotonic increase with depth with a saturation value at 450 g/cm$^2$ (3 and 5) and values for 10 g/cm$^2$ as measured for the orange soil 74220 (2).

\[
\begin{align*}
\frac{p^{131}}{p^{126}} &= \frac{131\text{Xe}_C - (p^{131}/p^{126})_1 p^{126} T_2}{126\text{Xe}_C - p^{126} T_2} \\
\frac{p^{83}}{p^{78}} &= \frac{83\text{Kr}_C - p^{83} T_2}{78\text{Kr}_C - (p^{78}/p^{83})_1 p^{83} T_2}
\end{align*}
\] (eq. 3)

In Fig. 3 the resulting depth dependencies of these ratios are shown. For $p^{131}/p^{126}$ it is quite similar to that calculated from spallation rates, experimental cross sections, and neutron fluxes (5). The lower portions of Figs. 1 and 2 demonstrate the depth dependencies of the $T_1$ values based on the Xe and Kr isotopes for which the production rate ratios in Fig. 3 were applied. Due to the procedure used the $d_1$ values for the intersections for sample 74001,121/2 (Fig. 1) are normalized to the values obtained for the pair $T_1^{131}/T_1^{78}$. The $T_1$ values, however, depend on the target element abundances and on the noble gas concentrations. For the Kr isotopes the intersections correspond to $T_1 = 24$ m.y. and 12 m.y., resp., in good agreement with the $T_1$-values from the $81\text{Kr}-83\text{Kr}/38\text{Ar}$ systematics, whereas the Xe isotopes indicate higher $T_1$ values probably due to the assumption of erroneously low target element abundances.

With the knowledge of the depth dependency of $p^{131}/p^{126}$ and $p^{83}/p^{78}$ the determination of the $T_1$ and $d_1$ values of a two-stage irradiation model is simple and accurate. First, $d_1$ is obtained either from $(p^{131}/p^{126})_1$ calculated from eq. 3 or from $(p^{83}/p^{78})_1$ (eq. 4). Then, $T_1$ is calculated from eq. 1. For the calculation of $p^{83}$ and $p^{126}$ see (2). This procedure yields $d_1$- and $T_1$-values which are not sensitive on the uncertainty of the target element or noble gas abundances. E.g. for a sample such as 74001,121/2 a ±20 % error of the absolute production rate or of the noble gas abundances results in a shift of the $d_1$ value of only about ±5 g/cm$^2$ and of the $T_1$ value of about ±1 m.y.

For the three samples the following parameters were obtained characterizing the early stage of exposure: 74001,121/2—$T_1 = 24$ m.y., $d_1 = 65$ g/cm$^2$; 74001,110—$T_1 = 12$ m.y., $d_1 = 40$ g/cm$^2$; and 74001,101—$T_1 = 8$ m.y., $d_1 = 30$ g/cm$^2$. These results are discussed in (1).

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Two-stage irradiation model

Fig. 1. $T_1$ (exposure time in the early stage) versus $d_1$ (shielding depth in the early stage) diagram for >26 μm fraction from soil 74001,121/2. The intersections indicate residence time and shielding depth at the early stage of exposure for a two-stage exposure model.

Fig. 2. $T_1$ versus $d_1$ diagram for bulk soil 74001,110. See also caption to Fig. 1.

Fig. 3. Preliminary depth dependency of the cosmogenic ratios $^{131}\text{Xe}/^{126}\text{Xe}$ and $^{83}\text{Kr}/^{78}\text{Kr}$ obtained for soil from drive tube 74001. The lines are fitted in the manner described in the text to the data points obtained from sample 74001,121/2. Data point for 10 g/cm² from orange soil 74220 (1).