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 $^{131}Xe/^{126}Xe$ and $^{83}Kr/^{78}Kr$, 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 $^{131}Xe/^{126}Xe$ and $^{83}Kr/^{78}Kr$. 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/cm^2 and from 95 g/cm^2 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.

$$T_1^{81} = (T_{app}^{81} - T_2) \quad P_2^{83}/P_1^{83} \qquad \text{(eq. 1)}$$

$$T_1^{38} = ({}^{38}Ar_c - P_2^{38}\, T_2) \;/\; P_1^{38} \qquad \text{(eq. 2)}$$

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 $^{38}Ar_c$ see (1). Eq. 1 is an approximation for which the ratio P^{81}/P^{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 $^{131}Xe/^{126}Xe$ and $^{83}Kr/^{78}Kr$. The quantitative depth dependencies of these two ratios were derived applying eqs. 3 and 4, resp.,

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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).

$$\left[\frac{P^{131}}{P^{126}}\right]_1 = \frac{{}^{131}Xe_c - (P^{131}/P^{126})_2 P_2^{126}\, T_2}{{}^{126}Xe_c - P_2^{126}\, T_2} \qquad \text{(eq. 3)}$$

$$\left[\frac{P^{83}}{P^{78}}\right]_1 = \frac{{}^{83}Kr_c - P_2^{83}\, T_2}{{}^{78}Kr_c - (P^{78}/P^{83})_2\, P_2^{83}\, T_2} \qquad \text{(eq. 4)}$$

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^{81}/T_1^{38}. 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 ${}^{81}Kr$-${}^{83}Kr/{}^{38}Ar$ 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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References: (1) O. Eugster, P. Eberhardt, J. Geiss, and N. Grögler (1978) this volume. (2) O. Eugster, P. Eberhardt, J. Geiss, N. Grögler, M. Jungck, and M. Mörgeli (1977) Proc.Lunar Sci.Conf. 8th, 3059. (3) R.C. Reedy (1976), private communication. (4) A. Stettler (1977), private communication. (5) D.S. Burnett, R.J. Drozd, C.J. Morgan, and F.A. Podosek (1975) Proc.Lunar Sci.Conf. 6th, 2219.

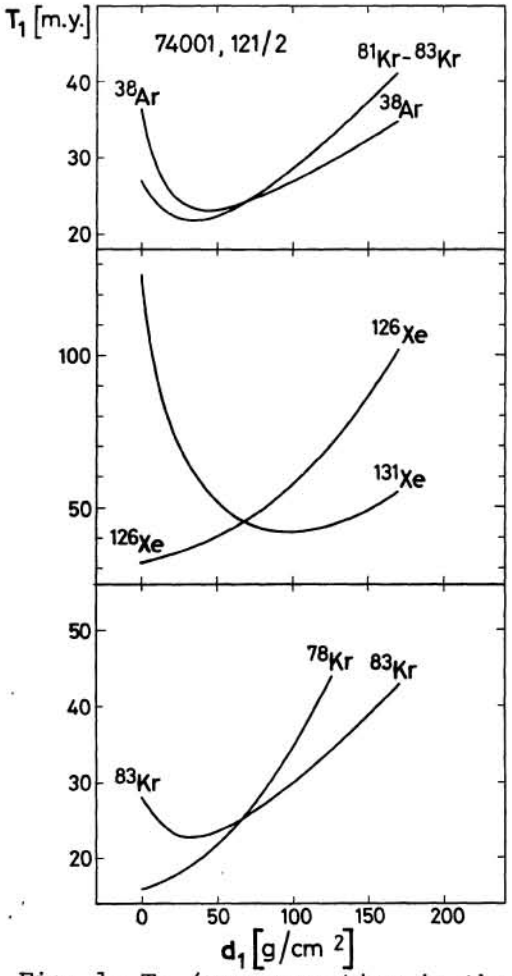

Fig. 1. T_1 (exposure time in the early stage) versus d_1 (shielding depth in the early stage) diagram for >26 µm fraction from soil 74001,121/2. The intersections indicate residence time and shielding depth at the early stage of exposure for a two-stage exposure model.

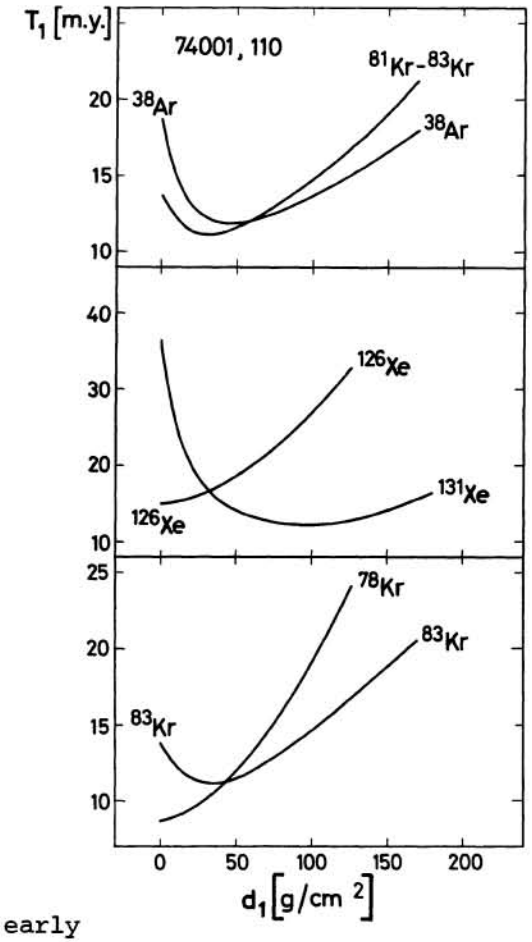

Fig. 2. T_1 versus d_1 diagram for bulk soil 74001,110. See also caption to Fig. 1.

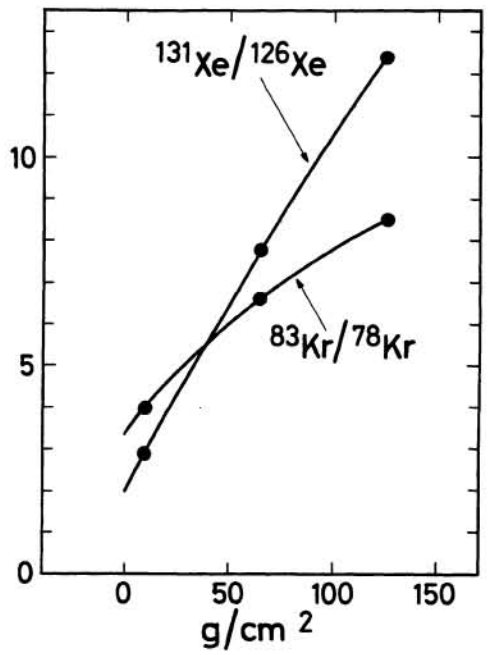

Fig. 3. Preliminary depth dependency of the cosmogenic ratios $^{131}Xe/^{126}Xe$ and $^{83}Kr/^{78}Kr$ obtained for soil from drive tube 74001. The lines are fitted in the manner described in the text to the data points obtained from sample 74001,121/2. Data point for 10 g/cm^2 from orange soil 74220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