PROBABILITY OF COSMOGENIC NUCLIDE PRODUCTION RATES. Cornelia A. K. Mertens[1], My E. I. Riebe[1] and Henner Busemann[1]. [1]Institute of Geochemistry and Petrology, ETH Zürich, 8092 Zürich, Switzerland (cornelia.mertens@erdw.ethz.ch).

Introduction: A number of properties of a meteorite need to be known to be able to calculate cosmogenic nuclide production rates and, thus, cosmic ray exposure (CRE) ages: i) the concentration of target elements ii) the density iii) the pre-atmospheric size, and iv) the position of the sample in the pre-atmospheric body [1]. The combination of the latter and the density is referred to as the shielding depth. All factors are considered in the model by [1] (LM model) used to determine cosmogenic nuclide production rates. The chemistry and density can be measured, whereas the size of the pre-atmospheric body is only observed in rare cases. The position of the sample within the pre-atmospheric body is always unknown. When measuring *only* noble gases, the cosmogenic ^{22}Ne/^{21}Ne ratio is most commonly used to determine the shielding depth, as cosmogenic production of these two isotopes decreases at different rates with depth [2]. However, this ratio is influenced by the pre-atmospheric size and is only a reliable shielding indicator for radii R<60 cm [1]. Therefore, ^{22}Ne/^{21}Ne ratios can often only constrain possible combinations of meteoroid size and shielding depths.

In a Ne 3-isotope plot, meteorites plot on mixing lines between trapped and cosmogenic endmembers. Unless the data points plot directly on the cosmogenic component or a well-defined mixing line, the ^{22}Ne/^{21}Ne ratio cannot be determined precisely. The range of possible ^{22}Ne/^{21}Ne ratios increases with increasing distance of the data point to the cosmogenic component. In case the ^{22}Ne/^{21}Ne ratio can be specified, the number of combinations of shielding depth and pre-atmospheric sizes can be reduced. For each of these admissible combinations, a production rate of ^{3}He, ^{21}Ne and ^{38}Ar is given, from which CRE ages are calculated. If possible production rates can be narrowed down, then more precise CRE age ranges can be obtained. To this end, probabilities are assigned to the ^{22}Ne/^{21}Ne shielding ratios and production rates given in the model of [1].

Geometry: The LM model [1] assumes spherical pre-atmospheric shapes and considers 15 different meteoroid sizes from 10 to 500 cm in radius. Each meteoroid is divided into a number of spherical shells, and production rates for ^{3}He, ^{21}Ne and ^{38}Ar are calculated for each shell depending on the meteorite class and chemistry.

If a sphere is divided into *n* spherical shells with identical thickness, the shell volume decreases with increasing depth below the sphere surface (Fig. 1). The volume fraction v_i of each spherical shell is given by the following relation:

$$v_i = \frac{\frac{4}{3}\pi(r_i+t)^3 - \frac{4}{3}\pi r_i^3}{\frac{4}{3}\pi R^3} = \frac{(r_i+t)^3 - r_i^3}{R^3}$$

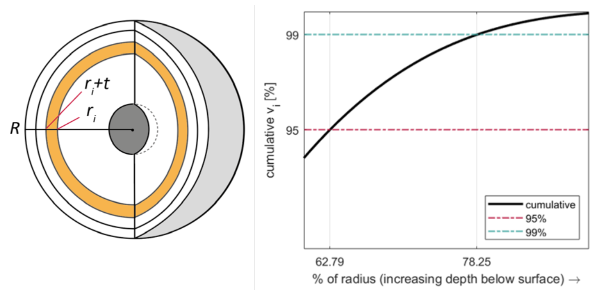

Fig. 1: Left: pre-atmospheric meteoroid, divided into spherical shells. Right: cumulative density function of the production rate probabilities.

The volume fractions of the shells represent a probability to find the corresponding production rate in the sphere. The cumulative density function of these probabilities shows that the inner 21.75% of the radius make up less than 1% of the total volume. Similarly, the inner 37.21% of the radius contain only 5% of the volume (Fig. 1). Therefore, production rates in this part of the pre-atmospheric meteorite can be neglected.

^{22}Ne/^{21}Ne Shielding. Analogously to production rates, ^{22}Ne/^{21}Ne shielding ratios can be assigned to each spherical shell and restricted by determining probabilities.

Mass ablation: In addition to restricting production rates due to the above geometric considerations, also mass ablation in the atmosphere can be accounted for to omit production rates in the outer part of the meteoroid. Here, the variability of production rates is especially large, so that the range of possible production rates can be significantly decreased (Fig. 2). Loss due to mass ablation in the atmosphere can span a wide range from some 35% to nearly 100%, depending on e.g. atmospheric entrance velocity [3]. Mass ablation for ordinary chondrites with R ≤ 60 is assumed to be 91.5% on average [4]. This is only an estimate, as a given meteoroid might not be spherical and may not be ablated uniformly.

Implementation: In the LM model, the number of spherical shells is different for each pre-atmospheric radius R. This makes it difficult to compare the probability of production rates between different radii. Therefore, each radius is divided here into 100 spherical shells and production rates P_i are interpolated for each shell.

Production rates are grouped in a chosen number of bins. For each bin, the sum of all production rates is taken, each weighted by the probability of its shell. This results in a weighted discrete probability density function (pdf) of all production rates (Fig. 3).

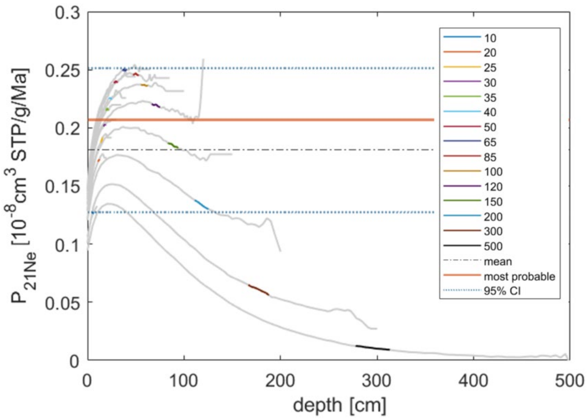

Fig. 2: Ne-21 production rates for 15 different radii from the LM model, using average carbonaceous chondrite chemistry as given in [1]. Original production rates are plotted in grey. Only the coloured sections of the production rates are left by excluding the inner 37% of the radius, neglecting thereby only 5 % of the pre-atmospheric mass and assuming 91.5% mass ablation.

The same can be done excluding production rates in the inner and the outer part of the sphere which are highly unlikely to have contained the given sample. The resulting pdf is highly skewed (Fig. 4). It is therefore advisable to determine a most probable production rate rather than an average production rate.

Additionally, further meteoroid radii that seem unlikely due to reasons such as an externally determined size of the meteorite can be excluded. Also, production rates can be narrowed down further if the cosmogenic $^{22}Ne/^{21}Ne$ can be determined with enough precision.

Expected value and confidence intervals. To calculate the expected or most probable production rate $\overline{P}$, the weighted mean of the distribution is calculated by:

$$\bar{P} = \frac{\sum_i P_i v_i}{\sum_i v_i}$$

The distributions tend to become more strongly negatively skewed when excluding low production rates in the inner part of the sphere or in the very outer parts. We chose to determine 95% confidence intervals (CIs), which can be computed by summing production rate probabilities from both sides of the distribution until reaching a max. of 2.5%, respectively. However, as we are looking at discrete distributions, the 2.5% might not be reached, especially from the right when production rate probabilities in the last bin are very large (Fig. 4). Therefore, production rate probabilities are summed from the right until reaching 2.5%. The difference between 5% and the reached value are then cut off from the left, so that the probability to find a certain production rate in the computed range is as close to the chosen, approx. 95% as possible.

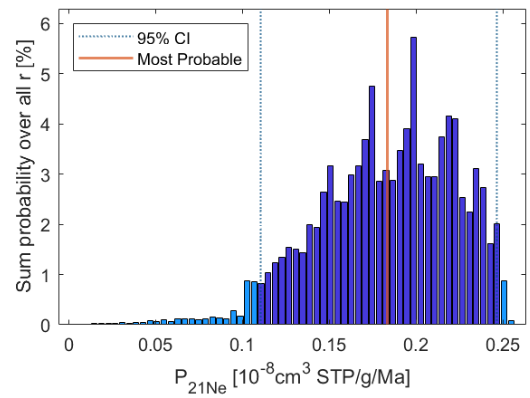

Figure 3: Discrete pdf of weighted production rates. 95% CIs are shown by dark blue colouring.

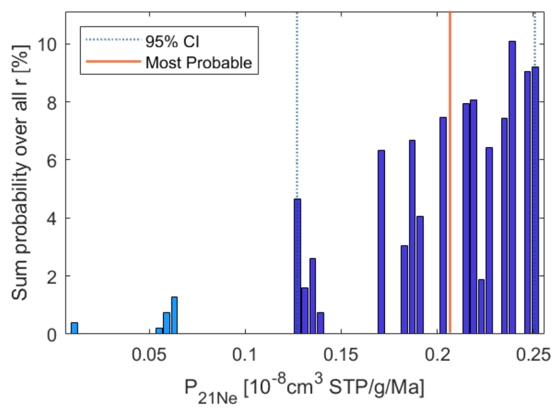

Figure 4: Discrete pdf of weighted production rates, excluding the inner 37% of the radius and assuming 91.5% mass ablation in the atmosphere. 95% CIs are shown by dark blue colouring.

Conclusion: Using geometric probability considerations, the range of likely cosmogenic nuclide production rates and CRE ages can be can be restricted using only noble gas data. Cosmogenic $^{22}Ne/^{21}Ne$ can be narrowed down accordingly.

References: [1] Leya I. and Masarik J. (2009) *Meteoritics & Planet. Sci., 44*, 1151–1154. [2] Wieler, R. (2002) *Rev. Mineral. Geochem., 47*, 125-170. [3] Alexeev V. (2003) *Sol. Syst. Res., 37*, 207-217. [4] ReVelle D.O. (2003) *J. Atmos. Sol.-Terr. Phys, 41*, 453-473.

Additional Information: The matlab code for calculating production rate probabilities is available on request.