PRODUCTION RATES OF NOBLE GASES IN THE NEAR-SURFACE LAYERS OF EUROPA BY ENERGETIC CHARGED PARTICLES AND THE POTENTIAL FOR DETERMINING EXPOSURE AGES. T. D Swindle[1], R. C. Reedy[2], and J. Masarik[3], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721-0092 USA (tswindle@u.arizona.edu), [2]Institute of Meteoritics, MSC03-2050, University of New Mexico, Albuquerque, NM 87131 USA (reedy@cybermesa.com), [3]Department of Nuclear Physics, Komensky University, Mlynska Dolina F/1, Sk-842 15 Bratislava, Slovakia (Jozef.Masarik@fmph.uniba.sk).

Introduction: The surface of Europa is expected to be extremely active, undergoing tectonic and/or tidal geological activity [1, 2] and sputtering/deposition [3], as well as impact cratering [4]. Determination of the actual age of the surface at one or more places would greatly simplify trying to sort out what processes are occurring, and at what rate. If there is K present, as the spectral and compositional modeling discussed below predict, it should be possible, in principle, to determine K-Ar crystallization ages [5, 6]. Whether or not there is K present, a consideration of the environment suggests we can determine an energetic particle exposure age if we can make in situ measurements of the abundances of major elements and of noble gas isotopes. This requires instrumentation that is within reach of current technology [6, 7]. In this abstract, we calculate production rates for noble-gas isotopes in a simplified Europan surface, to quantify the amount of light noble gases produced by exposure to energetic particles.

Europa's environment:

Energetic particle environment. The two primary sources of energetic particles at the Moon are galactic cosmic rays (GCRs), which typically have energies in the GeV range and can penetrate more than a meter into the surface, and solar energetic particles, which occur irregularly, have energies in the MeV range, and penetrate millimeters to a few centimeters. Europa will also have energetic particles in two different energy regimes, although there will be differences. Galactic cosmic rays will reach the surface of Europa. The flux will be higher by ~20% as a result of being less deep within the heliosphere. This could be partially offset by Europa's depth within the jovian magnetosphere. Overall, the GCR flux should be roughly similar to that at the Moon.

Solar energetic particles will have a lower flux near Jupiter and most will not penetrate the jovian magnetosphere. However, Europa's surface will be bombarded by particles accelerated by and trapped in Jupiter's magnetic field [8, 9]. These jovian magnetospheric particles have an energy distribution similar to that of a soft solar particle event, with an exponential rigidity spectral shape [10] having a shape parameter R_0 of about 35 MV. Their fluence is comparable to a good-sized solar particle event. But since they are constant, their flux is higher than the average solar energetic particle flux at the Moon by about 3 orders of magnitude.

Surface composition. To first order, Europa has a crust of ice. However, there is a prominent "dark" or "non-ice" material as well. Spectral [11], theoretical [12], and experimental [13, 14] work all suggests that this material consists of salts, most prominently highly-hydrated sulfate salts of magnesium, sodium, and calcium, plus some alkali chlorides.

Expected effects on the production of noble gases. Noble gases are produced by energetic particles only as a result of nuclear reactions. In the case of spallation reactions, only noble gas nuclei lighter than the target nucleus can be produced. So in a pure ice, only He could be produced, although He could be produced copiously from O. However, with Europa's non-ice component (especially Na, Mg, Ca, and K), Ne and Ar could be produced as well. In addition to spallation reactions, neutron capture can occur, because the cascade of reactions started by the energetic particles ends up producing thermal neutrons. Hydrogen thermalizes neutrons very well, so H_2O, whether in the form of ice or of water of hydration in a salt, will result in a large flux of thermal neutrons that can make ^{36}Ar from capture reactions with ^{35}Cl.

Calculations: For illustrative purposes, we have performed a set of calculations to determine just how large some of these effects would be expected to be. We have assumed a lunar GCR flux, although the incident fluence at Europa might be slightly different. The presence of hydrogen in the surface of Europa will affect the energy distribution and depth dependence of GCR particles, especially for thermal neutrons. For the jovian magnetospheric particles, we have used an average of four proton flux spectra measured near Europa by Galileo [9]. The contribution of heavier trapped ions to nuclide production is assumed negligible as their energies per nucleon is low and most will stop before inducing nuclear reactions.

For the composition, rather than taking a single one of the proposed salts, we have taken a proposed composition of the Europan ocean [12], and simply taken all of the non-water components in their relative abundances in the ocean and combined that with various amounts of water (ice). In fact, this is unlikely to

match any particular composition on Europa (since it ignores the real history of the evolution of compositions, involving both fractional crystallization [12] and sputtering [3]), but it should serve to show the order of magnitude of effects possible.

For reactions induced by GCR particles, production rates were calculated with the LAHET Code System (LCS) [15]. This code is important for consideration of the effects of H on the transport of secondary neutrons. Production rates by trapped jovian protons were calculated using the model of [10] that was developed for solar energetic particles. Production of neutrons by such low energy protons is usually negligible but should be calculated with LCS given the very high flux of trapped jovian protons.

Results: Results for calculations assuming 80% H_2O are shown in Figures 1 and 2. Calculations, and the depths in figures, assume a density of 1 gm/cm^3. Since O is the primary target element for production of ^{3}He [16], the production of ^{3}He by GCR (Fig. 1) is comparable to that on the Moon or asteroids, while production of ^{21}Ne and ^{38}Ar is reduced by a factor of a few (but not eliminated) because of the lower abundance of target elements. Production by trapped jovian protons (Fig. 2) dominates for the upper few centimeters, although the irradiation environment is so energetic that this material might be sputtered away.

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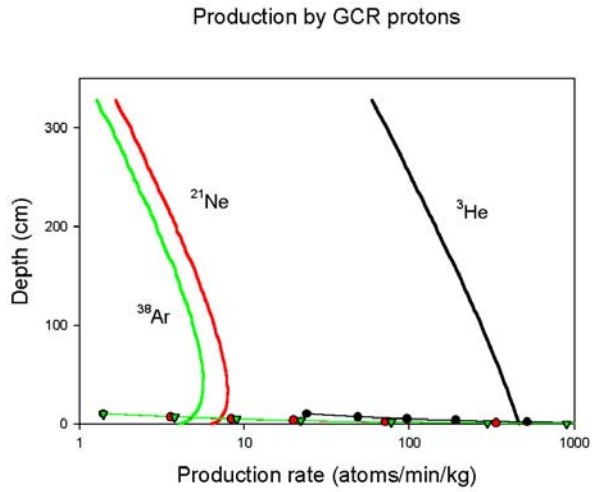

Fig. 1: Production of ^{3}He, ^{21}Ne and ^{38}Ar by GCR protons near the surface of Europa. Symbols near the bottom of figure are for jovian magnetosphere protons (see Fig. 2). Note that production rates are given in atoms/minute/kg (= 1.96x10^{-11}cmSTP/gm/Ma). Typical lunar production rates of ^{21}Ne and ^{38}Ar are roughly 50 atoms/min/kg [17].

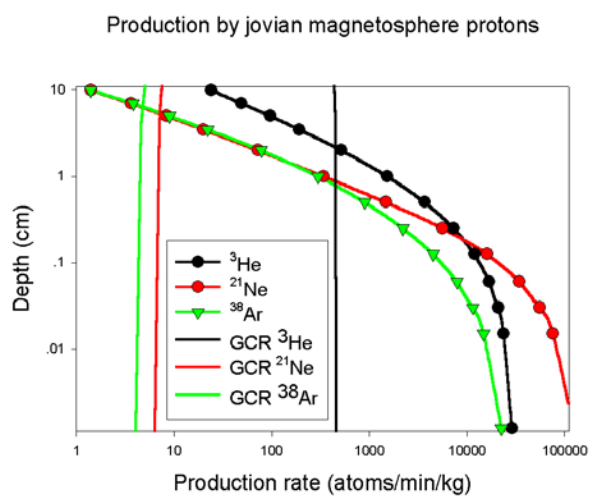

Fig. 2: Production of ^{3}He, ^{21}Ne and ^{38}Ar by jovian magnetosphere protons in the top 10 cm of the surface of Europa, compared with production by GCR protons.