# COSMOGENIC NUCLIDES IN COMETARY MATERIALS: IMPLICATIONS FOR RATE OF MASS LOSS AND EXPOSURE HISTORY;

G.F. Herzog[1], P.A.J. Englert[2], and R.C. Reedy[3], 1) Dept. Chem. Rutgers Univ., New Brunswick, NJ 08903 2) Dept. Chem. San Jose State Univ., San Jose, CA 95192 3) Los Alamos Natl. Lab., Los Alamos, NM 87545

As planned the Rosetta mission will return to earth with a 10-kg core and a 1-kg surface sample from a comet [1]. The selection of a comet with low current activity will maximize the chance of obtaining material altered as little as possible. Current temperature and level of activity, however, may not reliably indicate previous values. Fortunately, from measurements of the cosmogenic nuclide contents of cometary material, one may estimate a rate of mass loss in the past and, as a bonus, learn something about the exposure history of the comet. Perhaps the simplest way to estimate the rate of mass loss is to compare the total inventories of several long-lived cosmogenic radionuclides (Table 1) with the values expected on the basis of model calculations. Although model calculations have become steadily more reliable [e.g., 2], application to bodies with the composition of comets [3] will require some extension beyond the normal range of use. In particular, the influence of light elements on the secondary particle cascade will need study, in part through laboratory irradiations of volatile-rich materials. In the analysis of cometary data, it would be valuable to test calculations against measurements of *short-lived* isotopes.

**Importance of short-lived isotopes** - The inventories of short-lived isotopes at depths greater than a few centimeters should be relatively insensitive to mass wastage for the anticipated [1] erosion rates. Moreover, because the gradient of galactic cosmic rays in the inner solar system is small, ~2%/A.U. [4], the recent production rates of these (and longer-lived) radioisotopes do not depend sensitively on orbital parameters in the ranges considered. For these reasons, and just as in the lunar case [5], the short-lived radionuclides provide either a corroboration of the calculations or the data needed for fine tuning them.

**Measurement of short-lived isotopes** - During the return trip of ~3 y, isotopes with half-lives less than 1 y (e.g., $^{54}$Mn and $^{57}$Co) will have decayed away. Isotopes with somewhat longer half-lives would survive the trip and could be conveniently and non-destructively measured in the laboratory. However, cosmic ray bombardment *en route* would have altered their concentrations. Either of two approaches could prevent the otherwise irretrievable loss of information about these important isotopes. 1) *In situ* measurements. By mounting a detector in the reconnaissance craft it might be possible to detect and analyze $\gamma$-radiation emitted from the comet's surface. Backgrounds from the spacecraft and the $\gamma$-detector itself would make the detection of both prompt [6] and decay gammas from the comet difficult. Alternatively, a detector could be placed in a core hole [7,8]. The location would largely protect the detector and surrounding material from direct exposure to cosmic rays but signals from prompt $\gamma$'s may still overwhelm those from decay. 2) Spacecraft measurements. To measure the effects of cosmic-ray bombardments on the material during transport back to earth, one might include a $\gamma$-detector and/or certain passive devices in the spacecraft. Englert [8] discusses shielding arrangements. If these measurements are to be undertaken, detailed feasibility studies will be needed soon.

**Long-lived isotopes** - Table 1. Data for selected, long-lived cosmogenic radionuclides [9].

| Isotope | $^{32}$Si | $^{14}$C | $^{41}$Ca | $^{36}$Cl | $^{26}$Al | $^{10}$Be | $^{53}$Mn |
|---|---|---|---|---|---|---|---|
| Half-life | 150±25y | 5,730y | 0.1 My | 0.3 My | 0.7 My | 1.5 My | 3.7 My |
| Targets | S,Ca,Fe | O,N? | Ca,Fe | K,Cl?,Fe,Ca | Al,Si | C,O,Mg,Si | Fe,Ni |
| Det. Lim./$10^6$ at |  | 0.2 | 1 | 0.5 | 0.4 | 0.2 | 200 |

Figure 1 shows the fractional inventories of various radioisotopes that a comet would retain assuming the rates of mass loss given by [1]. These illustrative calculations assume negligible erosion rates in the distant past, constant erosion rates for the last 1000 y, and a constant cosmic ray flux throughout. We adopted production rates of the form $P = P_o e^{-\rho d}$ where $d = d_o$ initially and $d = d_o - \varepsilon t$ during the period of appreciable mass loss. In this simplified model, the longer-lived cosmogenic radionuclides are diagnostic for the anticipated range of erosion rates. Current techniques would make it possible to profile a large suite of long-lived cosmogenic radionuclides along the entire core with just 1-2 g of material. In the past, when the comet may have had considerably larger aphelia, production rates may have been higher by a factor of about 4 [10]. Figure 2 shows how the isotope inventories would increase with a higher, ancient flux which is taken as a constant, L, times the current flux. We have assumed the two-stage model described above with $T_2$ = 1000 y and an intermediate rate of mass loss of 0.2 g/cm$^2$-y. If we assume a non-increasing flux of galactic cosmic rays throughout the orbital history of the comet then cosmogenic radionuclide data will allow us to place a lower limit on the average rate of mass loss.

Information concerning certain short- and long-lived isotopes can be paired advantageously. For example the *ratio* $^7$Be/$^{10}$Be should be insensitive to chemical fractionation that may occur during volatilization processes and to the details of the secondary spectrum of cosmic-ray particles. On the other hand, in the simplest picture, significant mass loss on a time scale of millions of years or less will raise the $^7$Be/$^{10}$Be ratio. Taken in conjunction with an estimate of the rate of mass loss, the $^{22}$Na/$^{22}$Ne ratio provides information about the time the sample lay within a few meters of the surface.

The behavior of the cosmogenic radionuclides as the comet loses mass could well hold some surprises. Major production of $^7$Be, $^{10}$Be, and $^{14}$C will occur in $H_2O$(s) and $CO_2$(s). The fate of the $^{14}$C is uncertain. Lal et al. [11] have argued that nascent $^{14}$C in ice quickly forms CO. If so, it would be lost with the gas but otherwise, perhaps not. Similarly, some $H_2O$- or $CO_2$-derived $^x$BeO, which is nonvolatile, might conceivably remain behind when ices vaporized. If the isotopes are retained during the loss of ices, the inventories of $^{10}$Be and/or $^{14}$C would exceed expected values. Excesses in the amounts of these isotopes unaccompanied by excesses in long-lived isotopes not made from C, N, or O would provide a novel marker of cometary surface processes. Finally, we note that ionizing radiation may initiate the formation of polymers [12]. The determination of the $^{14}$C content (and perhaps the $^{10}$Be content) of polymeric material would therefore be of interest as a potential measure of its age. More generally, the cosmogenic nuclide contents will lead to an estimate of the total dose of ionizing radiation and this quantity may be useful in the interpretation of the properties of the cometary surface.

Fig. 1

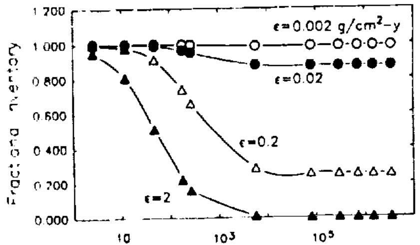
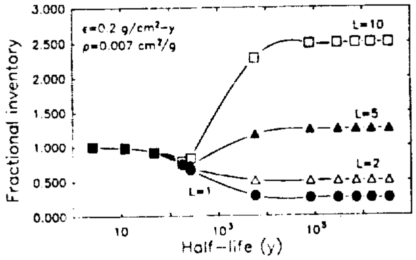


Fig. 2



**References:** 1. T.J. Ahrens et al. (1987) *Rept. SCI(83)3, Space Sci. Dept., ESA*, 1-64. 2. R.C. Reedy (1985) *Proc. 15th Lunar Planet. Sci. Conf., J. Geophys. Res.* **90**, C722-C728 3. A.H. Delsemme (1988) *Phil. Trans. R. Soc. Lond.* **A325**, 509-523. 4. J.A. Van Allen and B.A. Randall (1985) *J. Geophys. Res.* **90**, 1399-1412. 5. R.C. Reedy and J.R. Arnold (1972) *J. Geophys. Res.* **77**, 537-555. 6. A.E. Metzger et al. (1986) *Proc. 16th Lunar Planet. Sci. Conf., J. Geophys. Res.* **91**, D495-D504; J. Bruckner et al. (1987) *Proc. 17th Lunar Planet. Sci. Conf., J. Geophys. Res.* **92**, E603-E616. 7. L.G. Evans et al. (1986) *Proc. 16th Lunar Planet. Sci. Conf., J. Geophys. Res.* **91**, D525-D532. 8. P.A.J. Englert (1988) *LPI Tech. Rep. 88-07* , 75-6. 9. Adapted from D. Elmore and F.M. Phillips (1987) *Science* **236**, 543-550. 10. G.M. Raisbeck et al. (1985) *Meteoritics* **20**, 734-735; Reedy (1987) *Proc. 17th Lunar Planet. Sci. Conf., J. Geophys. Res.* **92**, E697-E702. 11. D. Lal et al. (1987) *J. Geophys. Res.* **92**, 4947-4952. 12. W.F. Huebner (1987) *Science* **237**, 628-630; D.L. Mitchell et al. (1987) *Science* **237**, 626-628.