EXPOSURE HISTORIES OF PAIR LUNAR METEORITES EET 96008 AND EET 87521. K. Nishiizumi[1], J. Masarik[1], M. W. Caffee[2], and A. J. T. Jull[3], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450 (kuni@ssl.berkeley.edu, masarik@ssl.berkeley.edu), [2]CAMS, Lawrence Livermore National Laboratory, Livermore, CA 94550 (caffee1@llnl.gov), [3]NSF Arizona AMS Laboratory, University of Arizona, P.O. Box 210081, Tucson, AZ 85721 (jull@u.arizona.edu).

The lunar basaltic breccia, EET 96008 is the eighteenth fragment thought to represent fourteen lunar meteorites. The recovered mass of EET 96008 is 53.0 g. We received four subsamples for this study. We report here preliminary results of cosmogenic ^{14}C (half-life = 5730 y), ^{41}Ca (1.04x10^5 y), ^{36}Cl (3.01x10^5 y), ^{26}Al (7.05x10^5 y), and ^{10}Be (1.5x10^5 y).

Most lunar meteorites have complex cosmic ray exposure histories, having been exposed both at some depth on the lunar surface (2π irradiation) before their ejection and as small bodies in space (4π irradiation) during transport from the Moon to the Earth [e.g.1, 2]. These exposures were then followed by residence on the Earth's surface, the terrestrial residence time. Unraveling the complex history of these objects requires the measurement of at least four cosmogenic nuclides. The specific goals of these measurements are to constrain the depth of the sample at the time of ejection from the Moon, the transit time from the time of ejection to the time of capture by the Earth, and the residence time on the Earth's surface. These exposure durations in conjunction with the sample depth on the Moon can then be used to model impact and ejection mechanisms.

Since some lunar meteorites, specifically Calcalong Creek, Y-791197, Y-793169, and QUE 93069/94269 contain SCR (solar cosmic ray) produced nuclides [2, 3, 4] which indicate negligible ablation during atmospheric entry, searching for SCR effects is an important component of this study. To investigate SCR effects in EET 96008, we measured ^{10}Be, ^{26}Al, ^{36}Cl, and ^{41}Ca in 4 sub-samples having different shielding depths. Exterior samples, 8 and 11, are from opposite sides of the meteorite. Sample 8 was sub-divided into one comprising material from 0-2 mm (including fusion crust) depth and one from 2-3.5 mm depth from surface. Sample 11 represent material from 0-2 mm depth from surface (including fusion crust). The interior sample, 12 was extracted from about 1 cm greater depth than the exterior sample and about 2 cm apart from sample 8. A sample for ^{14}C measurement was also collected from interior.

Each sample was dissolved in an HF-HNO_3 mixture along with Be and Cl carriers. The concentrations of Mg, Al, Ca, Mn, and Fe in aliquots were determined by atomic absorption spectroscopy. The AMS measurements were performed at the Lawrence Livermore National Laboratory (^{10}Be, ^{26}Al, ^{36}Cl, ^{41}Ca) and at the University of Arizona NSF-AMS facility (^{14}C). The preliminary results are shown in Table 1. The quoted errors come from the AMS measurement and represent ± 1σ.

The concentrations of cosmogenic radionuclides, with the exception of ^{41}Ca, are the lowest among those measured in lunar meteorites. The concentrations of cosmogenic radionuclides are identical to those of EET 87521 lunar meteorite which, for comparison, are shown in Table 1 [5, 6, 7]. These meteorites possess similar, chemical, mineralogical, and textural properties [8, 9]. Both were found in the same icefield, Meteorite City at Elephant Moraine. We conclude EET 96008 and EET 87521 (recovered mass is 30.7 g) are fragments of the same fall. The low concentrations of spallation products ^{10}Be, ^{26}Al, and ^{36}Cl coupled with the relatively high concentration of neutron captured nuclide ^{41}Ca in EET 96008 and EET 87521 indicate exposure to galactic cosmic rays at depth, in a 2π geometry. The most likely site for this exposure is the lunar surface. The determination of exposure parameters requires production rates applicable to the observed exposure geometry. From radionuclide activities in the Apollo 15 drill core, which extend to a depth of about 400 g/cm^2, production rates can be determined. However, the nuclide concentrations in the meteorites are lower than the observed values in Apollo 15 drill core, indicating exposure at a greater depth. Therefore, production rates for burial deeper than 400 g/cm^2 were calculated using two methods. The first uses the theoretical GCR production rate calculation as given by the LAHET Code System (LCS) [10]. For target chemistry the average chemical composition of EET 87521 [8] was used. The second method employs an extrapolation of the Apollo 15 depth profile to below 400 g/cm^2. The target chemistry of the samples was accounted for by normalizing the observed nuclide concentrations in the EET meteorites to those of the Apollo 15 core chemical composition. The elemental production ratios were calculated using LCS.

In Fig. 1, the observed activities for the EET 96008 and EET 87521 are plotted along with the calculated profiles by LCS. The height of each box represents experimental error and the width indicates possible depth on the Moon, assuming zero terrestrial age. The five nuclides, especially ^{14}C, do not yield a unique exposure depth. The most likely explanation for this disconcordance is a long terrestrial residence time, during which nearly all of the ^{14}C (<0.33 dpm/kg) and much of the ^{41}Ca decayed. Assuming negligible production during its transit to Earth, the minimum ^{14}C terrestrial age is 18 ky. To reconcile the ^{41}Ca activity with the ^{10}Be activity, 80±30 ky of terrestrial age is required. After correction of 80±30 ky terrestrial age, all four nuclides are consistent with an ejection depth of 540-600 g/cm^2.

To test the validity of the short transit time assumption SCR-produced ^{26}Al and ^{36}Cl concentrations in the surface of EET 96008,8 were measured. These activities are slightly higher than those in other subsamples of EET 96008 although the excesses are only detectable at 2σ or 3 σ. Nevertheless these measurements can place limits on transit time from the Moon to the Earth. If we assume the ablation depth was 1-3 g/cm^2, the required 4π exposure time is 2-4 ky. A 4π exposure of this duration would not alter the GCR produced concentrations of these nuclides, with the exception of ^{14}C. Transit ages significantly longer than this, 10 ky for example, result in multiple solutions to shielding depth.

In summary, EET 96008 and EET 87521 are fragments of the same fall and were ejected from 540-600 g/cm^2 depth on the Moon. The transition time from the Moon to the earth was significantly less than 10 ky and the terrestrial age is 80±30 ky. Taken together, the lunar meteorites that were ejected from depths shallower than 1000 g/cm^2 had a transition times shorter than 150 ky from the Moon to the earth. The 18 collected fragments in our possession most likely represent 12 or independent ejection.

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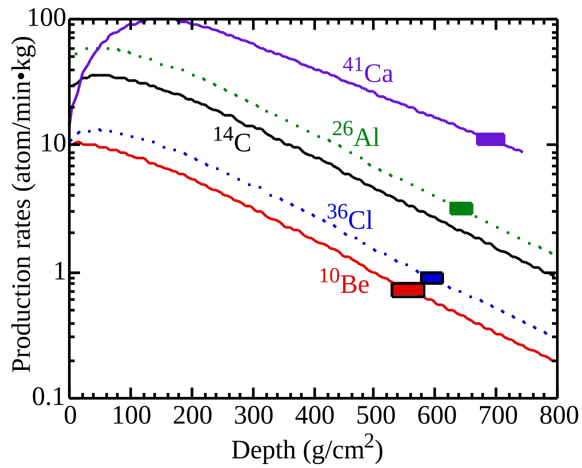

Figure 1. The observed activities for the EET 96008 and EET 87521 are plotted along with the calculated profiles by LCS.

Table 1. Cosmogenic radionuclide concentration in EET 96008 and EET 87521

EET	Distance from surface (mm)	Wt (mg)	^{10}Be dpm/kg meteorite	^{26}Al dpm/kg meteorite	^{36}Cl dpm/kg meteorite	^{41}Ca dpm/kg meteorite	^{41}Ca dpm/kg Ca	^{14}C dpm/kg meteorite
96008,8	0-2	59.0	0.77±0.05	3.27±0.19	1.04±0.06	11.1±1.4	150±20	-
96008,8	2-3.5	27.2	0.67±0.09	2.76±0.30	0.87±0.08	9.2±1.9	129±27	-
96008,11	0-2	66.1	0.85±0.04	2.93±0.17	0.86±0.04	11.8±1.0	153±14	-
96008,12	Interior	53.9	0.70±0.05	2.90±0.18	0.88±0.06	11.2±1.3	137±16	-
96008,42	Interior		-	-	-	-	-	
	Average		*0.78±0.04*	*2.99±0.11*	*0.90±0.09*	*11.2±1.1*	*145±11*	
87521,48 [5]	Interior	128.8	0.66±0.04	3.22±0.13	0.84±0.02	11.6±0.7	160±10	-
87521,49 [7]	Interior		0.7±0.1	3.2±0.2	0.97±0.15	11.6±1.0		
87521,70 [6]	Interior		-	-	-	-	-	<0.33