MEASUREMENTS OF COSMOGENIC RADIONUCLIDES IN A HAYABUSA SAMPLE. K. Nishiizumi[1], M. W. Caffee[2], and K. C. Welten[1], [1]Space Sciences Laboratory, Univ. of Calif. Berkeley, CA 94720-7450 (e-mail: kuni@ssl.berkeley.edu), [2]Dept. of Physics, Purdue Univ., West Lafayette, IN 47907-2036 (mcaffee@purdue.edu).

Introduction: The return of Hayabusa samples to Earth prompted a wide range of investigations performed by the Hayabusa Asteroidal Sample Preliminary Examination Team (HASPET), followed by a suite of studies initiated by international researchers. The suite of studies resembles those done for other extraterrestrial materials: lunar, meteorites, and micrometeorites. Cosmogenic radionuclides in Hayabusa samples were not among the first measurements; the concentration of cosmogenic nuclides is extremely low necessitating a relatively large sample. Measurements of cosmogenic radionuclides can indicate the residence time of the Hayabusa grains on the asteroid surface, which in turn will help us understand the evolutionary history of asteroidal regolith. These measurements will also allow us to quantify surface erosion rates, or escape rates of dust from Itokawa and other small asteroids. Our goals are to understand both the fundamental processes on the asteroidal surface and the evolutionary history of its surface materials. These processes occur over timescales spanning the present to 10^7 yrs into the past. To achieve our key goals, in particular reconstructing the evolutionary histories of the asteroidal surface, we performed measurement of small amounts of cosmogenic radionuclides (10^4-10^5 atoms) in Hayabusa samples by AMS.

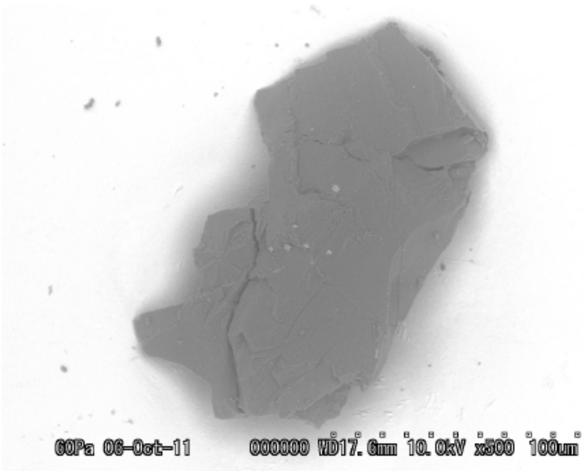

Fig. 1. SEM-BSE image of RA-QD02-0188. The longest axis of the particle is 175 µm. (From JAXA curation facility data).

Sample Description: One large Hayabusa grain, RA-QD02-0188 was allocated for our studies. The particle consists mainly of olivine, FeNi, and troilite based on SEM-EDX observation by JAXA curation facility. The curation SEM-BSE image (Fig. 1) indicates that the maximum dimensions of two axes of the particle are 175 x 88 µm. When we picked the particle, we noticed that the shape of the particle was similar to a flat leaf with a thickness of less than 40 µm. The SEM-BES image also indicates that the particle has many cracks, including an especially large one located on the left side of the particle (Fig. 1). Since the sample mass of the Hayabusa sample is one order of magnitude less than that of the smallest extraterrestrial samples we have previously measured, two small grains were separated from the Kilabo LL6 chondrite and used as reference. The Kilabo meteorite was also used as a simulation sample by the HASPET.

Experiments and Results: The Hayabusa sample was picked from the sample container with sharp Ti tweezers and transferred into a small Al weighing boat, work that was done under a stereomicroscope. The left corner of particle was unfortunately shattered leaving only a powder. The sample from the large crack (Fig. 1) to the leftmost edge was lost. After weighing with a microbalance, the particle (RA-QD02-0188-1) was transferred into a small Teflon beaker. A portion of powder was transferred from the inside and the outside of the hole on quartz plate with a drop of water into a Teflon beaker (RA-QD02-0188-2). Each Kilabo grain (Kilabo-1 and -2) was handled similarly. All processes were performed under air-ionizer system to eliminate electrostatic problems. Each sample was dissolved with a drop of HF and HNO_3 along with 0.15 mg of Be carrier. After reserving ~10% as an analysis aliquot for chemical assay, 0.7 mg of Al and 0.05 mg of Mn carriers were added. Be, Al, and Mn were separated from the solution using a 1 mL anion column and a 1 mL cation column.

Preliminary ^{10}Be and ^{26}Al concentration were measured by AMS at Purdue University and are shown in Table 2. The uncertainty of mass measurement by microbalance, ±0.2 µg, was not included in the error. The Mn fraction was saved for future ^{53}Mn measurement. To eliminate ^{10}Be contamination, clean Be carrier (original solution provided by Purdue University) and Be-free Al carrier were prepared. The blank chemistry indicates the Be carrier contains (0.0±0.5) x10^{-15} ^{10}Be/Be. Concentrations of Mg, Mn, Fe, Co, and Ni in aliquot solutions of dissolved samples were measured by ICP-OES and ICP-MS and are shown in Table 1. Reliable concentrations of Al and Ca were not obtained due to high blank correction. For comparison, the chemical compositions and ^{10}Be and ^{26}Al concentrations of 55.6 mg of Kilabo are shown.

Discussions: The chemical composition and the ^{10}Be and ^{26}Al concentrations from the 2.6 μg Kilabo-2 grain agree with those in bulk Kilabo sample. Measurement of the ^{26}Al in the 1.5 μg Kilabo-1 indicates detection of ^{26}Al just above the detection limit in this small meteoritic sample.

Hayabusa samples, especially related to our study, show high concentrations of solar He, Ne, and Ar components, indicating that the Itokawa samples were exposed to solar wind, similar to lunar soils [*e.g.,* 1]. Their residence time on the surface of Itokawa is calculated to be of the order of tens of Myr, based on the low cosmogenic ^{21}Ne concentrations [1, 2]. The surface morphologies of Itokawa grains clearly indicate space weathering by charged particles, such as solar winds and small particle debris such as micrometeorites [*e.g.,* 3].

On 25143 Itokawa, which has neither an atmosphere nor a magnetic field to impede incoming cosmic rays, cosmogenic nuclide production rates and depth profiles should resemble those observed in surface samples and cores from the Moon. Both asteroids and the Moon are large enough that they can be modeled as an infinite plane (2π geometry) to cosmic-ray bombardment. However, some near-surface differences between asteroidal and lunar production of cosmogenic nuclides may arise due to variations in their orbital parameters, coupled with the fact that cosmic rays come from two distinguishable sources. The GCR production rates on the surface of Itokawa are nearly identical to those on the Moon. The SCR production rates are dependent on the orbit of Itokawa. Since the present orbital parameters of Itokawa are semi-major axis, a = 1.32 AU, eccentricity, e = 0.28, and perihelion, q = 0.95 AU, the SCR production rates on Itokawa are only ~20% lower than those on the surface of the Moon. One major difference between Itokawa and the Moon are their respective escape velocities (0.2 m/s vs. 2.38 km/s). Unlike on the Moon, even small impact events striking the surface of Itokawa could allow regolith materials to escape.

The ^{10}Be concentration in 0.9 μg of RA-QD02-0188 is somewhat higher than the predicted ^{10}Be production rate on the surface of Itokawa. Since no ^{10}Be was observed from blank chemistry and good agreement in ^{10}Be concentration was found between two Kilabo grains and bulk sample, contamination during chemistry and laboratory procedures are unlikely. The ^{10}Be concentration indicates the surface exposure age of this grain is longer than 3-4 Myr, but it is not clear if the grain shows excess ^{10}Be relative to GCR saturation activity. The high ^{26}Al in RA-QD02-0188 clearly indicates SCR production on the surface of Itokawa even though the value has a large uncertainty. The SCR-produced ^{26}Al along with saturated ^{10}Be in the particle indicate that erosion rate of Itokawa surface is less than 1 cm/Myr and that RA-QD02-0188 was exposed to cosmic rays less than 1 cm from the surface of Itokawa.

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References: [1] Nagao K. et al. (2011) *Science, 333,* 1128-1131. [2] Meier M. M. M. et al. (2014) *LPS 45*, Abstract #1247. [3] Noguchi T. et al. (2012) *LPS 43,* Abstract #1896.

Table 1. Chemical composition (wt %) of Hayabusa RA-QD02-0188 and Kilabo LL6 meteorite.

Sample	Mass (mg)	Mg	Al	Ca	Mn	Fe	Co	Ni	Fe/Mn
RA-QD02-0188-1	0.0009	13.7			0.24	20.6	0.095	0.76	85
RA-QD02-0188-2	(0.0005)	1.3			0.08	85.9	0.59	0.73	1080
Kilabo-1	0.0015	24.7			0.47	32.5	0.007	0.14	69
Kilabo-2	0.0026	14.2			0.29	16.2	0.040	0.10	55
Kilabo (bulk)	55.6	14.5	1.05	1.20	0.25	17.6	0.038	0.80	70

Table 2. Cosmogenic ^{10}Be and ^{26}Al concentrations of Hayabusa RA-QD02-0188 and Kilabo LL6 meteorite.

Sample	Mass (mg)	^{10}Be (dpm/kg)	^{10}Be (atom/sample)	^{26}Al (dpm/kg)	^{26}Al (atom/sample)
RA-QD02-0188-1	0.0009	47±16	4.4×10^{4}	160±90	7.6×10^{4}
RA-QD02-0188-2	(0.0005)	21±29	1.1×10^{4}	-20±130	
Kilabo-1	0.0015	31±10	4.8×10^{4}	44±58	3.5×10^{4}
Kilabo-2	0.0026	26±6	6.8×10^{4}	98±35	1.4×10^{5}
Kilabo (bulk)	55.6	20.9±0.3	1.2×10^{9}	57±4	1.7×10^{9}