THE IMPORTANCE OF PARTICLE INDUCED X-RAY EMISSION (PIXE) ANALYSIS AND IMAGING TO THE SEARCH FOR LIFE ON OCEAN WORLDS. D.F. Blake,[1] P. Sarrazin,[2] Kathleen Thompson,[2] T. Bristow,[1] P. Sarrazin,[2] T. Hoehler,[1] and R. Quinn.[1] [1]Exobiology Branch, MS 239-4, NASA Ames Research Center, Moffett Field, CA 94035 (david.blake@nasa.gov), [2]SETI Institute, Mountain View, CA 94043.

Introduction: Microbial life exploits microscale disequilibria at boundaries where valence, chemical potential, pH, eH, etc. vary on a length scale commensurate with the organisms - tens to hundreds of μm. These disequilibria can exist within cracks or veins in rocks and ice, at inter- or intra-crystalline boundaries, at sediment/water or sediment/atmosphere interfaces, or within fluid inclusions trapped inside minerals or ice. Detection of accumulations of the biogenic elements C,N,O,P,S at appropriate concentrations on or in a mineral/ice substrate would constitute permissive evidence of extant life, but context is also required.

Map-X is an arm-deployed instrument placed directly on the surface of an object to be analyzed [1-2]. During an analysis, either an X-ray tube or a radioisotope source bombards the sample with X-rays (tube) or α-particles and γ-rays (radioisotope), resulting in X-ray Fluorescence (XRF) from the sample. Fluoresced X-rays pass through a focusing lens that projects a spatially resolved image of the X-rays emitted from the sample onto an X-ray sensitive CCD. Energies and positions of individual X-ray photons are recorded. In a 1-3-hour analysis, several thousand images are stored and processed in real-time.

In searching for evidence of life on Ocean Worlds, detection & quantification of the biogenic elements C, N, O, P, S, as well as the cations of the rock-forming minerals (Na, Mg, Al, Si, K, Ca, Ti, Cr, Mn, Fe) and anions such as Cl, Fl are important in establishing permissive evidence for life and context. While either an X-ray tube source (XRF) or a radioisotope source such as ^{244}Cm (XRF/PIXE) can be used for fluorescence, ^{244}Cm (used in all of the Alpha-Particle X-ray Spectrometer (APXS) instruments to date [3]) is preferred because the γ-rays at 14 and 18 KeV fluoresce the mid-range elements Ca – Mo, and the α-particles at 5.8 MeV strongly fluoresce the lower atomic number elements including C, N and O. With such a source, a florescence analysis yields the biogenic elements C, N, O, P, S, as well as the cations/anions important for providing contextural mineralogy.

Calculation of k-values for detection and quantification of elements of interest: We used GEANT4 [4] to model fluorescence of the biogenic elements and cations of the rock forming minerals with a 30 mCi ^{244}Cm source. Calculations shown in Table 1 assume integration over a sample area of 2.5 cm X 2.5 cm and an accumulation time of 10^4 sec (~3 hours). The accumulation time for Table 2 was increased to 10^5 sec (~28 hours).

We calculate the significance level k as the number of counts in a characteristic peak divided by the square root of the background below the peak. k>2 signifies successful detection at the 95% confidence level, k>10 signifies successful quantification. Table 1 shows results for a water ice matrix. Table 2 shows results for C and N on a zero background substrate through which Europa analog ice meltwater has been filtered.

Element	Energy (KeV)	Weight %	k-value
C Kα	0.282	0.1%	8.3
N Kα	0.392	0.1%	18
Na Kα	1.04	0.1%	23
Mg Kα	1.25	0.1%	33
P Kα	2.02	0.1%	80
S Kα	2.31	0.1%	72
Cl Kα	2.62	0.1%	57

Table 1. Significance level k for detection and quantification of biogenic and other low-Z elements present at 0.1% in a water ice matrix. 30 mCi ^{244}Cm source, 10^4 sec run time, k>10 indicates successful quantification.

Element	Energy (KeV)	Concentration	k-value
C Kα	0.282	1 microbe / 100X100 μm sieve area	28
N Kα	0.392	1 microbe / 100X100 μm sieve area	11

Table 2. Significance level k for detection and quantification of C and N on a zero background substrate through which melted Europa analog ice meltwater has been filtered. 1 microbe per 100X100 μm sieve area over a 2.5 cm X 2.5 cm substrate. 30 mCi ^{244}Cm source, 10^5 sec run time, k>10 indicates successful quantification.

Discussion: Monte Carlo simulations demonstrate the value of XRF/PIXE for extant/extinct life detection on Ocean Worlds. A ^{244}Cm-sourced XRF/PIXE imager such as the MapX imaging spectrometer [1-2] would be invaluable for quantifying the biogenic elements as well as elements useful in determining the context of a life detection measurement.

References: [1] Blake, D.F. et al. (2017) LPSC XLVIII # 1370. [2] Blake, D.F. et al. (2016) IPM 2016 #4006. [3]. Rieder, R., et al. (2003) *JGR-Planets, No. E12, 8066, doi:10.1029/2003JE002150, 2003*. [4] Agostinelli, S. et al. (2003) *Nucl. Instr. and Methods in Phys. Research A*, **506**, 250-303.

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