IMPROVEMENTS IN X-RAY SPECTROMETRY FOR PLANETARY SURFACE EXPLORATION.

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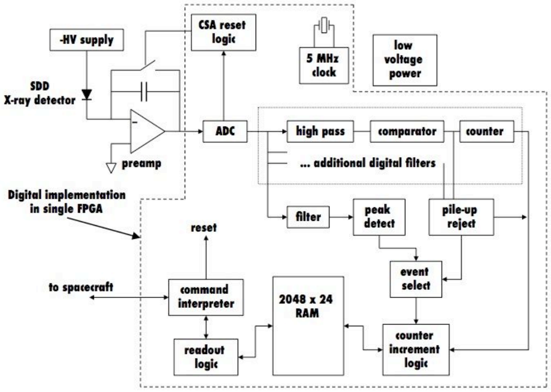
Introduction: There have been dramatic advances in the technology for X-ray spectrometry in recent years. Ever thinner and stronger window materials, that are more transparent to low energy X-rays, have extended the useful range to all but the 3 lightest elements in the periodic table. Silicon drift detectors (SDDs), first proposed by Gatti in 1984 [1], are now in routine commercial use. Early versions were included on the APXS instruments for the Mars Exploration Rovers [2]. Their much smaller electrode size and capacitance imply faster response, higher count rates, and the possibility of operation at room temperature [3]. They have also been optimized for light element quantification. Digital pulse processing is replacing analog processing because it can handle the shorter shaping times and incorporate improved pulse pileup rejection, both important to take full advantage of the capabilities of an SDD. Miniature X-ray tubes are available that weigh less than 6 grams and operate with about 1 watt. They permit construction of X-ray fluorescence units with very low mass, power, and size yet have performance comparable to that of terrestrial laboratory units [4].

Increased Scientific Return: These developments allow improvements in the information that can be obtained by XRS instruments and a consequent increase in the scientific return. Measurement of light-element X-rays (carbon and oxygen) provides robust quantitative constraints on organic and water contents. Better energy resolution and better statistics means that minimum detection limits can be reduced and that the scattered radiation can be exploited. Lower detection limits allow measurements of trace elements at lower levels and with better precision. Such measurements are important for a wide variety of studies concerned with petrogenesis, provenance and aqueous interaction and for distinguishing planetary formation models [5]. One well known example is that of the incompatible elements phosphorus, rare earth elements, and potassium (KREEP), whose concentrations in components of the highland crust have implications for early lunar differentiation [6]. Another important example would be the ability to better constrain the origin and history of minor solar system bodies (asteroids, comets, moons) by making detailed comparisons to the known classes of meteorities for the full spectrum of volatile, refractory, lithophile, chalcophile and siderophile elements [5].

The Compton and Rayleigh scattered radiation provides information about light elements in situations where they cannot be measured directly, such as on bodies with an atmosphere. If the energy resolution can be improved enough, then several light elements can be individually quantified by detailed fitting of the Compton profile. The combination of SDDs and digital pulse processing will help make this possible. Digital pulse processing has the flexibility to output the actual noise spectrum, facilitating the use of deconvolution methods to further improve resolution. Miniature X-ray tubes provide improvements in detection limits, more flexibility in the choice of excitation source to reduce interferences, and allow data collection in very short times with reduced energy per spectrum. They may also make it possible to collect data in short enough times to allow measurements not otherwise possible, such as chemical stratigraphy of the subsurface or from touch-and-go probes.

Other Advantages: Reductions in mass, volume, and power can also be realized using digital technology and SDDs. The ability of SDDs to operate at higher temperatures reduces the need for detector cooling, which is a major power drain if required. Digital techniques achieve better results with less power, mass, and volume than the corresponding analog methods, with increased flexibility as well.

Components: We are developing a series of components that take advantage of these improvements, including X-ray detectors, pulse processors, X-ray tubes, high voltage power supplies, and rugged X-ray windows. These components could be combined into several possible instruments for different missions and provide both quantitative and qualitative improvements in scientific return. On airless bodies, almost all of the periodic table could be quantified, including the biogenic elements and direct measurements of water content. On bodies with an atmosphere, trace element detection could be obtained comparable to terrestrial laboratories and light element information can be extracted from the scattered radiation. A diagram of our detection system is shown below.



Future XRS Instruments: There are several possible instruments that could take advantage of the increased capabilities of the components under development. Two examples are an extremely capable XRS for a penetrator (such as those proposed for the Moon, Europa, and Enceladus) and a very rapid spectrometer for touch-and-go operation (e. g., on a tethered pod under a Titan airship or on an asteroid or comet contact probe). These two examples are roughly at extreme opposite ends of the spectrum of very small, slow, low power instruments versus larger, very fast instruments.

Penetrator. The penetrator XRS (which we have proposed for the MoonLITE mission) would use two conventional radioisotope sources with SDDs and a common digital pulse processor. It would access the lunar regolith via a rugged window without the need for drilling or other mechanical sample introduction methods. Using two sources with separate X-ray detectors allows optimization of light element quantification without compromising the detection limits for KREEP and other trace elements. The lunar subsurface temperature is ideal for SDD operation, so the power required for cooling is eliminated. A digital pulse processor that incorporates such traditionally analog functions as charge reset and baseline restoration further reduces the size, mass, and power requirements sufficiently for penetrator deployment. This design produces an extremely capable instrument that can be deployed to anywhere on the Moon. Such a complete ground-up redesign is warranted by the shock hardening required to survive penetrator impact. The redesign will also assist in meeting this requirement by simplifying the electronics to a few microchips on a single small board.

Touch-and-Go Probe. The use of an X-ray tube in place of a radioisotope source provides much higher excitation flux and reduces the time for spectrum collection. Using an SDD optimized for high count rate and a digital pulse processor with good pileup rejection, count rates as high as 10^5 per second can be accommodated by the detector system. A one-watt miniature X-ray tube can produce the required excitation if the geometry is carefully controlled. With this configuration, a high quality spectrum can be collected in as little as 10 seconds. Detection limits for trace elements of a few parts per million and major element precision better than 1% relative can be achieved. Such an instrument can be fit into about 3000 cm^3 with a mass of less than 2 kg using modern high voltage encapsulating materials and digital electronics. It uses a few watts of power but only during spectrum collection, implying tens of joules per spectrum. This makes it ideal for touch-and-go operations while hanging from a tether under a balloon or on an asteroid or comet probe.

Conclusions: The advances made in X-ray spectrometry in the last 10 years will allow new instruments to be designed with significantly increased scientific returns. To take full advantage of these developments, the instrument must be designed to include several of these advances working together. The scientific return can be increased not only by improved precision for the elements typically measured using XRS but also by extending the elemental range. The most valuable improvement is the capability to directly measure carbon and oxygen, yielding information about oxidation, water, and organic content.

References: [1] Gatti E. and Rehak P (1984) Nuc. Instr. Meth. Phys. Res., 225, 608-614. [2] Reider R. et. al. (2003) JGR 108, 8066, DOI 10.1029/2003JE002150. [3] Lechner P. et. al. (1996) *Nuc. Instr. Meth. Phys. Res., A 377*, 346-351. [4] Kelliher W.C., Carlberg, I. A., Elam W. T., and Willard-Schmoe, E (2007) APL–UW Technical Report 0703, http://www.apl.washington.edu/projects/XRFS_TR0703/TR0703_START.html (verified Jan. 6, 2009). [5] Taylor, S. R. and McLennan, S. M. (2009) Planetary Crusts: Their Composition, Origin and Evolution. Cambridge, 378pp. [6] Lucey P. et. al. (2006) *Rev. Mineralogy. Geochem., 60*, 83-219.