COMPLETE SUBSURFACE ELEMENTAL COMPOSITION MEASUREMENTS WITH PING. A. M. Parsons, for the PING Team, NASA Goddard Space Flight Center, Code 691, Greenbelt, MD 20771, Ann.M.Parsons@nasa.gov

Introduction: The Probing In situ with Neutrons and Gamma rays (PING) instrument will measure the complete bulk elemental composition of the subsurface of Mars as well as any other solid planetary body. PING can thus be a highly effective tool for both detailed local geochemistry science investigations and precision measurements of Mars subsurface resources in preparation for future human exploration. As such, PING is thus fully capable of meeting a majority of both near and far term elements in Challenge #1 presented for this conference. Measuring the near subsurface composition of Mars will enable many of the MEPAG science goals and will be key to filling an important Strategic Knowledge Gap with regard to In situ Resources Utilization (ISRU) needs for human exploration. [1, 2] PING will thus fill an important niche in the Mars Exploration Program.

Instrument Technology Description: Although there are many possible variations in the application of PING technology, for simplicity, this discussion will concentrate on *in situ* measurements of the subsurface of Mars. Later sections will expand on other possibilities such as remote sensing applications.

PING consists of a pulsed neutron generator (PNG), a gamma ray spectrometer, and neutron detectors. 14 MeV neutrons emitted isotropically from the PNG penetrate the surface and interact with the material to produce characteristic gamma rays with energy specific to the isotope involved. Detected lines in the gamma ray spectrum show what elements are present; the line intensities measure the amount of each element. The time it takes for the fast neutrons to slow down in the material is, among other things, indicative of the amount of hydrogen present in the material. Thus measuring the neutron count rates at the surface both during and between fast neutron pulses is very important.

For comparison, the Dynamic Albedo of Neutrons (DAN) instrument on the Mars Science Laboratory (MSL) uses some of the same principles as PING, but since it is missing the crucial gamma ray component, it can only infer the existence of hydrogen, while PING can determine the complete quantitative elemental composition, accessing a large part of the Periodic Table, as illustrated in Figure 1.

The technology choices for the three components and their efficient coordination into a single instrument system determine the ultimate performance of PING. The choice of neutron generator is especially important
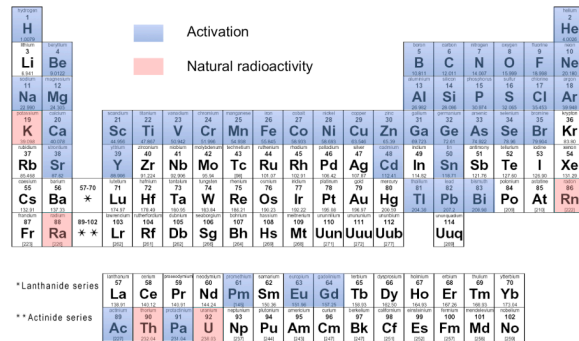

Figure 1. This color-coded Periodic Table shows the elements that PING can detect.

since it must be tuned to operate well with the gamma ray spectrometer, both during the pulse and between pulses. The PING gamma ray data between bursts are affected by the presence of high neutron absorbing materials such as iron, so it is important to be able to alter the PNG pulse width and pulse period to accommodate any changes in material composition it encounters in different locations. A high neutron emission rate is also important because it reduces the time needed for each measurement. A long-lived, high rate PNG with complete flexibility in pulse width and pulse frequency is crucial to the effective implementation of this technique. The DAN PNG lifetime is short and its flexibility in pulse timing and rate is too limited for it to be practical for use with a gamma ray spectrometer.

Operational Advantages and Capabilities: The ~1 m penetration depth of the neutrons allows an assay of subsurface composition without the need for extracting regolith samples. Because the fast neutrons are emitted isotropically, the measurement volume is approximately a ~1 m radius hemisphere beneath PING. Averaging over this volume reduces the effects of small highly localized anomalies. PING thus produces the bulk elemental composition of a given location and provides chemical context for measurements by other types of instruments.

Since x-rays are much less penetrating than high-energy gamma rays, familiar X-ray instruments such as APXS and XRF can only probe a small shallow spot on the surface (~few mm radius, ~100 microns deep). Since PING has access to the same elemental composition information, x-ray and gamma ray instruments are quite complementary – especially when identifying and characterizing surface effects.

PING measurements of elemental composition can be used to infer mineralogy and can be valuable as a check on the mineralogical interpretations of IR spectroscopy results. Moreover, the interpretation of neutron-only measurements is highly composition dependent. The addition of gamma ray data quantifies the composition and allows quantitative H concentrations as well.

When placed on a rover, PING can be sent out as part of a robotic reconnaissance mission to quickly map an area, searching for the best locations to find material for either ISRU or sample selection for sample return missions. Quick-look PING analysis would provide near-real time results, informing rover operational decisions.

Current Development and Feasibility: PNGs with great flexibility and long life have been used for decades on Earth and can easily be made flight-qualified since the conditions of their use in areas such as oil well logging are comparably harsh to the rigors of space use. Relatively light PNGs can be made available for flight; indeed, MSL is already flying a PNG instrument with DAN. The added PNG capabilities needed for PING will not affect the mass or durability of the PNG.

GSFC has been working for years studying PING at a unique test site [3]. This outdoor test site [4] contains large (1.8 m x 1.8 m x 0.9 m) Concord Grey Granite and Columbia River Basalt formations that have each been independently assayed so that the elemental composition of each material is known to the ppm level. We test PING using these standards to get an absolute calibration. Being outdoors eliminates backgrounds from neutron or gamma ray interactions in nearby walls or shielding inside a laboratory. This facility thus provides singularly realistic planetary analogues for reliable development of the technique.

We construct layered structures of cm-scale high density polyethylene, basalt and granite plates on top of these formations to simulate subsurface layering configurations where the polyethylene is used as an analog for water. PING has successfully identified subsurface hydrogen as well as show sensitivity to different layering configurations. These experiments demonstrate PING's ability to meet Challenge #1.

Implementation Variations: Future Possibilities:

The above description illustrated only the *in situ* applications of neutron/gamma ray techniques. Remote sensing neutron and gamma ray instruments have been very successful in the past. For example, the GRS and HEND instruments on Mars Odyssey formed an excellent map of Mars' elemental composition. Remote sensing instruments depend on the weaker neutron flux that comes from the interaction of galactic cosmic rays with the atmosphere and the planetary material. Thus, remote-sensing instruments can make large-scale whole-planet composition maps while *in situ* instruments like PING with its powerful PNG, take a much shorter time to produce complete composition information over a smaller area.

There are a number of options for gamma ray spectrometers that can be used with PING. Scintillators have a tremendous heritage but often are lacking in good energy resolution. Newer materials such as the lanthanum halides and maybe SrI_2 offer better energy resolution and may be an excellent choice. When the best resolution is required, solid state detectors such as high purity germanium and now cadmium zinc telluride (CZT) can be used. Unfortunately, mass limitations of landed payloads can often make the complex HPGe detectors impractical. Arrays of room temperature semiconductors such as CZT now display energy resolution comparable to HPGe and are a promising choice for the PING gamma ray spectrometer of the future. Position sensing CZT arrays currently in existence could allow background suppression by identifying gamma rays that do not come from the direction of the planet. PING capability does not depend on the particular neutron detectors available in the future.

Conclusions: PING, a combination of PNG and gamma and neutron spectrometers, is a promising instrument for measuring the full bulk elemental composition of the near subsurface of Mars. The emphasis of this summary has been on PING for *in situ* measurements aided by bringing a PNG to the Mars surface, but similar techniques using neutron and gamma ray instruments in combination have been flown with superb results such as with Mars Odyssey's elemental maps. Neutron/gamma instruments such as PING and its many variants are highly adaptable to a large variety of mission roles and are a valuable complement to commonly used instrument technologies. Mineralogy instruments such as infrared spectrometers benefit from PING's elemental content information to eliminate some of their interpretation ambiguities. X-ray instruments, which only measure surface composition, benefit from subsurface measurements from PING so that surface and bulk effects on Mars soil can be separated. A final benefit is that PING can make its measurements without needing to drill or even contact the surface. Thus, a rover-mounted PING can quickly map the full elemental composition of large areas.

References: [1] 2010 MEPAG Goals Report; [2] Report of the MEPAG Precursor Strategic Analysis Group (2012) in preparation; [3] A. Parsons et al., (2011) *NIM-A*, *652*, 674–679. J. Bodnarik, et al., (2010), *Lunar and Planetary Sci. Conf. #2581*.