PEAKS IN GERMANIUM PLANETARY GAMMA-RAY SPECTRA: AN UPDATE. R. C. Reedy[1], W. V. Boynton[2], D. K. Hamara[2], L. G. Evans[3], J. Brückner[4], and O. Gasnault[5], [1]Planetary Science Inst., 152 Monte Rey Dr., Los Alamos, NM 87544 USA <reedy@psi.edu>, [2]Lunar & Planetary Lab., Univ. Arizona, Tucson, AZ 85721 USA, [3]NASA Goddard Space Flight Center, Code 691/CSC, Greenbelt, MD 20771 USA. [4]Max Planck Inst. für Chemie, D-55128 Mainz, Germany, [5]Centre d'Etude Spatiale des Rayonnements, 31028 Toulouse Cedex 4, France.

Introduction: Gamma ray spectrometers using germanium (Ge) detectors are now often used to elementally map planetary surfaces, e.g., Mars Odyssey [1], Kaguya (SELENE) [2], and Messenger [3]. The high energy resolution (<1%) of Ge helps to isolate and identify peaks, and over 200 peaks have been seen in these planetary spectra, e.g., [4,5].

Peak fitting is essential to properly get abundances of most elements. Much work has been done on fitting peaks in Ge spectra since [4], especially on the fitting of the continuum under peaks as well as better understanding the nature of peaks and how to fit them.

Peak Fitting: To get the area under a gamma-ray peak, one needs to carefully define the strong continuum under the peaks, identify all peaks and know their shapes (narrow or Doppler-broadened Gaussian and occasionally odd shapes), and know the magnitude of any radiation damage effects, such as low energy tails [6]. The choice of what to use is often subjective, and much of what we have learned is given below.

Continuum. Every planetary gamma-ray spectrum consists mainly of a nearly-featureless continuum made by many processes, mainly scattering of gamma rays in the planet. Groups of channels on both sides of an energy region of interest are usually used to calculate the continuum under the peaks. Because there are hundreds of peaks, it often is not easy to find channels in a spectrum where there are no peaks. Sometime the channels near a peak region appear to be without peaks, but examination of a much larger energy region can show that there are weaker or broad peaks. Fig. 1 shows the energy region with many peaks of interest between 2199 and 2243 keV. Only a few channels between 1900 and 2420 keV (near 1920, 2190, and 2400 keV) do not have any peaks and were fitted with a quadratic equation. Previous continua were often determined from smaller energy regions nearer these peaks. Most of the channels between the blue and purple vertical lines that define the region used for the continuum fit were not used because they contain peaks, often broadened. Similar large energy intervals are now used around many other peak regions.

Peaks. Some peak-fitting codes automatically add peaks to a spectrum. However, we have found that adding peaks just to get the best fits is usually not correct for the peaks of interest. A good understanding of the peaks present and their physics is needed.

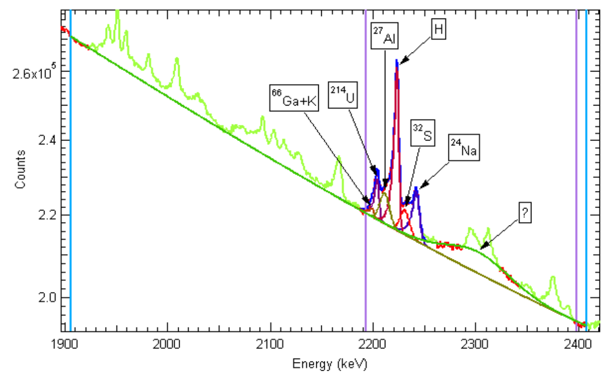

Fig. 1. Peaks and continuum under the peaks around the 2223 keV H capture peak. A broad peak (labeled ?) is near 2300 keV. Portions of the spectrum in green were ignored.

We prefer to identify all peaks and use their exact energies. We also use the known shapes of the peaks, usually based on many other peaks in a spectrum. Most peaks are not broadened and have a Gaussian shape (e.g., [4]).

Peaks in solids from excited levels with half-lives less than ~0.5 ps are Doppler broadened to ~10 keV because the excited nucleus is still recoiling from the reaction that produced it when the gamma ray is emitted, e.g., ^{27}Al(n,nγ) at 2211 keV. Gamma rays made in the martian atmosphere, e.g., ^{16}O(n,nγ) at 6129 keV, are Doppler broadened to ~50 keV. A special case of broadening is for the 478 keV gamma ray from the ^{10}B(n,αγ) reaction, where recoil due to the emission of the α particle produces a ≈15 keV wide flat-top peak.

Peaks in most planetary Ge spectra show the effects of radiation damage, especially well-defined low-energy exponential tails [6]. With more radiation damage accumulated, these tails start closer to the maximum of the peak. Ge detectors that are heavily radiation damaged also show a bump on the lower parts of the low-energy tail [7,8]. In Mars Odyssey spectra, a few such bumps have been observed but are small until late in the mission.

Code Used for Fitting Mars Odyssey Gamma-Ray Spectra: Because of the unique conditions for planetary gamma-ray spectra, a special code was written in Igor Pro™ (WaveMetrics Inc.) for the fitting of Mars Odyssey spectra. Two energy regions below and above the energy region with the peaks of interest are selected. The channels inside these 2 regions are used to determine the continuum. Peaks are then added, and their shape parameters specified. Shapes determined from their systematics in a whole spectrum can be used, or shapes of several peaks can be coupled, which is useful for weak peaks near a strong peak. Ranges of channels can also be marked to be ignored in the fitting process. A similar code with fewer options and based on IDL has been developed at CESR for analyses of Kaguya gamma-ray spectra.

This code for Mars Odyssey spectra has recently been modified to be more flexible with the addition of new continuum shapes and the ability to use more peaks (needed for the energy region in Fig. 1, where there are ~10 peaks). A special fit was developed for the flat-topped ^{10}B(n,αγ) peak around 478 keV.

Some peaks of interest, e.g., U at 609 keV and ^{56}Fe(n,nγ) at 847 keV, are on top of long (~50 keV) high-energy tails of peaks from Ge(n,nγ) reactions, such as at 596 and 834 keV. A formula to fit these 'sawtooth' peaks in Ge spectra has also been developed.

New Peak Fits: Fig. 2 shows the energy region around the U peak at 1764.5 keV and the ^{28}Si(n,nγ) peak at 1779.0 keV. Using channels far from these peaks for the continuum helped to show the presence of a broad peak from excited ^{16}O at 1755 keV. Fig. 3 shows the region about the Ca peaks at 1942.7 keV and the Cl peaks at 1951.1 and 1959.3 keV. A wide peak (?), probably from excited ^{18}O, is at 1978 keV.

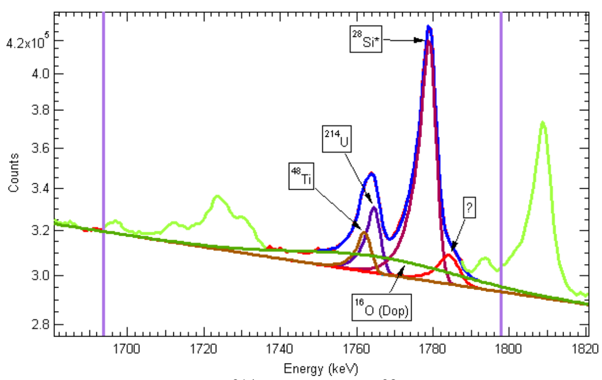

Fig. 2. Peaks in the U-^{214}Bi-1764 and ^{28}Si-1779 complex.

Discussion: Improved fitting procedures for peaks in planetary gamma-ray spectra have been developed. Most continua have been shown to be fairly flat when the channels in the spectrum used to determine them are properly selected.

Additional peaks have been observed in many spectra, including broad peaks, e.g., those in Figs. 1-3. There are broad peaks from ^{16}O(n,nγ) near 6916 and 7115 keV. The centers for the peaks for these atmospheric Doppler-broadened peaks are usually shifted to a different energy. The peak near 2300 keV in Figure 1 could be from excited atmospheric ^{14}N at 2312.6 keV, although its center appears to be at too low an energy.

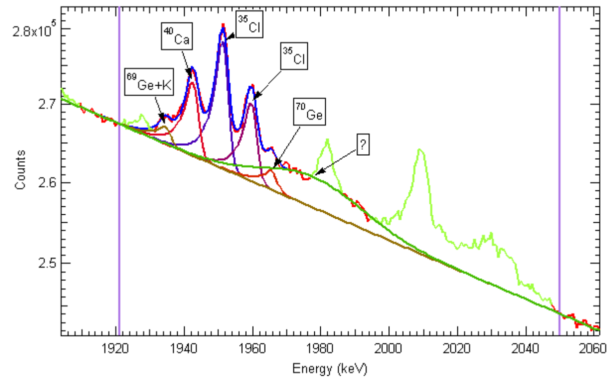

Fig. 3. Peaks in the ^{40}Ca and ^{35}Cl complex.

These revised fits have shown that the fits sometimes used previously for some peaks are probably poor. For examples, several peaks were found near the peak from excited ^{27}Al at 1014.0 that make it difficult to get a good fit. The weaker peaks around the ^{1}H(n,γ) peak at 2223.0 keV, including Doppler-broadened scattering peaks for ^{27}Al and ^{32}S at 2211 and 2230 keV, are in complex regions that are hard to fit well. Fits have been developed for the neutron-capture peaks for ^{27}Al and ^{32}S at 7724.0 and 5420.6 keV, respectively, and their single-escape peaks.

Because many peaks have backgrounds from matter near the Ge detector, new spectra were created to get these backgrounds. Count rates for background peaks for prompt gamma rays are now tied to indicators for the fast and thermal flux near the Ge, such as the 48Ti(n,γ) peak at 1381.7 keV. Thus, many of the backgrounds used for elemental gamma rays from Mars have changed, usually by small amounts.

Most elemental maps previously published [1] are not strongly affected by the new fits and backgrounds. These improved fitting techniques for planetary gamma-ray peaks developed for Mars Odyssey will be useful for Kaguya and Messenger spectra.

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