# ELEMENT ABUNDANCES FROM MESSENGER'S GAMMA-RAY SPECTROMETER: BACKGROUND NORMALIZATION.

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**Introduction:** The MESSENGER Gamma-Ray Spectrometer (GRS) measures energy spectra of gamma rays emanating from the surface of Mercury. Analysis of these spectra provides elemental abundances of surface materials. The MESSENGER mission necessarily provides some data normalization challenges for GRS analysis. Among the most difficult is determination of the spacecraft background necessary to subtract from the spectral peaks in order to obtain abundances.

The GRS spectra are subject to background gamma-ray peaks having the same energies as emitted by Mercury in cases where the instrument and spacecraft materials contain the same elements as measured from the planet. When the measured elements from the planetary surface come from radioactive isotopes of Th, U, and K, the background peak count rates are constant due to the very long half-lives. In this case, peak count rates taken at high altitude where there is minimal peak contribution from the planet can be subtracted from peak count rates taken at low altitude to yield a peak count rate proportional to planet surface abundance of the element [1].

The normalization of gamma-ray spectra for elements on the planetary surface not having long-lived radioisotopes is considerably more complex. These gamma rays come from inelastic scattering and capture of neutrons in the regolith after the neutrons are generated by cosmic rays impacting the planet. A radiation transport computation was performed to generate the expected count rates in the neutron-generated gamma-ray peaks, for a fixed cosmic ray flux and a regolith composition approximating that expected. The background subtraction for neutron-generated gamma-ray peaks for elements that are also present in the spacecraft or GRS at significant levels, such as Fe, Ti, Al, and Mg, is complicated by a background increase due to neutrons from the planet interacting with the spacecraft at low altitude. We have been developing simple models involving planet-subtended solid angle and proxies for neutron flux at the spacecraft to correct for this background increase. Of course, there is no background subtraction for elements not present at significant levels in the spacecraft or GRS, such as Ca.

**Background Model for Flybys:** For the Mercury flybys, a simple background model was developed for gamma-ray peaks from inelastic scattering of neutrons. (Spectra from the short flybys have relatively poor count statistics, so analyzable peaks occur at relatively low energy, where the GRS has good detection efficiency. These peaks come primarily from inelastic scattering.) The background increase at low altitude was represented by a single amplification factor multiplying the background count rate at high altitude. If the peak count rate for a high-altitude spectrum sum over integration intervals is $C'$ and that for a low altitude spectrum sum is $C$, $c'$ is the expected count rate at high altitude for the radiation transport planet model having an assumed abundance $a$ for the element associated with the peak, $c$ is that for low altitude, and $E$ is the unknown multiplier required to obtain the actual abundance $Ea$, we can write two simultaneous equations for the unknowns $A$, $B$, and $E$:

$$(1)\ \ C' = B + c'E\ ,\ \ (2)\ \ C = AB + cE\ .$$

There is a substantial mass of Al in the GRS and spacecraft, such that the planetary signal for the expected few per cent planetary abundance is dwarfed by the background for Al inelastic scattering peaks, in which case $A \approx C/C'$ varies by only a few percent. Once the value for $A$ is known, the above equations can be solved to obtain $E = (C\text{-}AC')/(c\text{-}Ac')$ and the abundance $Ea$. For the flybys, bounds on Si, Fe, Ti, K, and Th abundances were obtained for Mercury's near-equatorial regions using this model with $A$ obtained from the Al 1014-keV peak [2].

**Two-Term, Two-Peak Background Model:** During the mission orbital phase, much better count statistics than during the flybys call for more accurate spacecraft background models, particularly to allow more accurate abundance calculations for elements that are abundant in the spacecraft, such as Al and Fe. The background can be modeled in more detail by using separate terms for the contributions from cosmic rays and from planetary surface neutrons impacting the spacecraft. If the spacecraft is approximated as isotropic, the cosmic-ray term can then be written as $g\ (1 - f\ )$, where $f$ is the fractional solid angle at a given altitude, indicating planetary shadowing of cosmic rays ($f$ = ½ at zero altitude). The planetary surface neutron term can be approximately written $b\ r\ f$, where $b \approx M\ \Omega\ T\ \varepsilon$ is a constant to be determined, $M$ is spacecraft mass, $\Omega$ is spacecraft solid angle, $T$ is transmission fraction of gamma rays in the peak of interest through the spacecraft, $\varepsilon$ is the GRS efficiency for these gamma rays, and $r$ is the gamma-ray flux for planetary neutrons (the integral over energy of the neutron flux from the planet times the gamma-ray production cross section for the gamma ray of interest). Neutron flux changes during transport through the spacecraft are ignored. In the initial implementation of this background model, it is assumed that the planetary gamma-ray contribution is approximately proportional to $f$. It is assumed that the element of interest has two relatively strong inelastic-scattering gamma-ray peaks, with planetary gamma-ray contributions $K\ f$ and $K'\ f$, so two equations can be written for the total count rates in each peak $C$ and $C'$, where $p = T'\,\varepsilon' / T\,\varepsilon$:

(3) $C = K f + g\,(1 - f) + b\,r\,f$ ,

(4) $C' = K' f + g'\,(1 - f) + b\,p\,r' f$ .

$g$ and $g'$ are determined at high altitude, and the cosmic-ray terms are stripped off. Altitudes for summing spectra are then divided into altitude bands. $C$ and $C'$ from each band are then least-squares fit linearly to the solid angle. The $r$ and $r'$ values are determined from neutron flux derived from a Mercury surface composition. $T$ and $T'$ are estimated from the spacecraft model and total cross sections. $K'$ and $K$ are then related by their Mercury model gamma-ray flux ratios and GRS efficiency ratio for the two energies, yielding two equations for the unknowns $K$ and $b$. Then the expected elemental abundance and flux values from the Mercury model for the two energies are compared to $K$ and $K'$ to obtain Mercury surface abundance values for each. This background model was applied to Al, which has two strong peaks at 1014 and 2211 keV. The spectra for the Al 1014-keV peak for high- and low-altitude sums are shown in Figs. 1 and 2, and the spectra for the Al 2211-keV peak for high- and low-altitude sums are shown in Figs. 3 and 4.

**Conclusions:** For inelastic-scattering peaks, the initial single-term, amplified-background model can be made more accurate if we can improve calculation of the amplification factor for elements having a relatively small spacecraft background, but for elements having a relatively large spacecraft background, the new two-term spacecraft model with cosmic-ray and planetary neutron contributions, or a variant of it, is likely necessary. An issue with this new model is that two strong peaks are required for the element of interest that can be fit rather accurately for each altitude band. It would be useful to develop a variant that had only a high-altitude sum and a low-latitude sum, for elements that do not have strong analyzable peaks, for summing over only spatial regions of interest to obtain regional abundances, and for reducing systematic abundance errors caused by systematic spatial abundance variation. Also, the model could be made more accurate by explicitly calculating gamma-ray detection efficiency from efficiency map interpolation using spacecraft attitude, rather than using a simple solid-angle altitude dependence for planet neutron spacecraft background.

**References:** [1] P. N. Peplowski et al. (2011) *Science 333*, 1850-1852; [2] E. A. Rhodes et al. (2011) *Planet. Space Sci. 59*, 1829-1841.

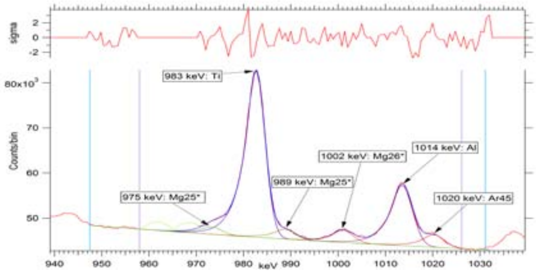

Fig. 1. Gamma-ray spectrum near Al 1014-keV peak, > 8000 km altitude. Data is fit to Gaussian peaks with tailing and a linear background, with residuals shown at top of graph.

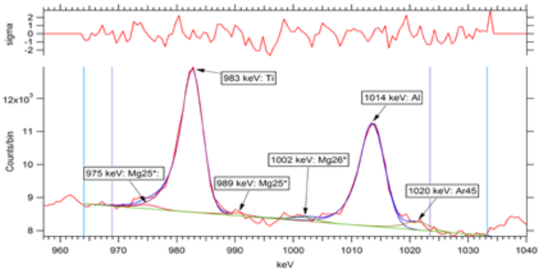

Fig. 2. Gamma-ray spectrum near Al 1014-keV peak, < 2000 km altitude. Details as in Fig. 1.

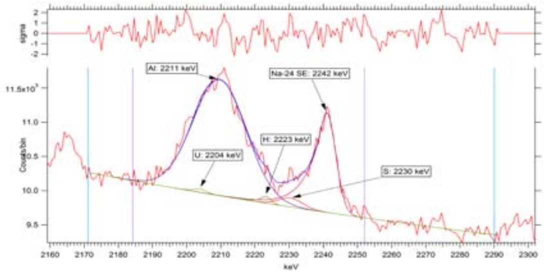

Fig. 3. Gamma-ray spectrum near Al 2111-keV peak, > 8000 km altitude. Details as in Fig. 1.

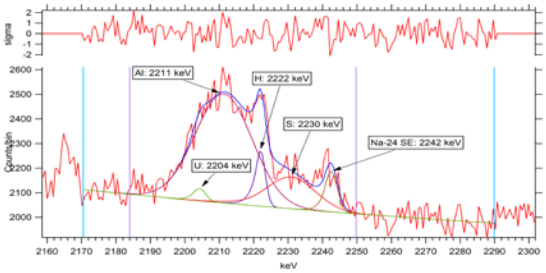

Fig. 4. Gamma-ray spectrum near Al 2111-keV peak, < 2000 km altitude. Details as in Fig. 1.