Apollo 15 and 16 X-Ray Fluorescence Spectrometers - Experiment Calibration

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Preflight calibration

The first test involved measuring the gain (output) and resolution characteristics for each candidate detector. About twice as many were made (~6) as needed to fly (3), each was tested, and the ones with the closest match of characteristics were chosen for flight, the others remaining as 'spares'. An X-ray source (Fe 55 @5.9 keV) was obtained and placed in front of each detector window. The response of each detector to X-ray source was measured in terms of channel of 'peak' of iron line as a function of applied voltage. The response of each detector to X-ray source was also measured in terms of resolution (line width) and found to be 18% at the 5.9 keV line.

Once flight detectors were selected, they were differentially filtered. Filters were added to allow separation of the closely spaced Si (1.75 keV), Al (1.5 keV), and Mg (1.25 keV) lines. All detectors had a Be window to preferentially cut off shorter wavelength lines below the Mg line, which would otherwise swamp the detector. One was left 'bare', with no additional filters, the second had an Mg filter added, and the third had an Al filter added. The Mg filtered detector would cut off signal from Al, the Al filtered detector would cut off signal from Si, and the bare detector see all three lines. So, the next step involved confirming the filter thicknesses by measuring the detector response (dependent on thickness and given density for a given elemental filter) to an alpha source used to produce lines from Mg and Al targets placed directly in front of each detector. These tests confirmed the thickness of the Be window as 1 mil (0.001 inch), and the thicknesses of the filters as 0.2 mil for Mg and 0.25 mil for Al.

Finally, the detector was assembly was collimated to achieve a 60-degree field of view, and the response of the collimated detectors measured. This was done by moving a collimated (point) source through the field of view and measuring the variations in the detectors response. The response as a function of position in the field of view is given in the paper Adler et al. (1975).

In-Flight Calibration

The in-flight calibration device consists of a calibration rod with radioactive sources (Mg and Mn K-radiation) that normally face away from the proportional counters. Upon internal command from the X-ray processor assembly, the rod is rotated by solenoid drive 180 degrees, position the sources to face the proportional counters. Magnetically-sensitive reed relays provide feedback signals indicating when the rod is fully in calibration or fully in non-calibration mode, generating the appropriate flag-bits in the telemetry. The calibration cycle repeats every 16 minutes for 64 seconds. When in calibration mode, the detectors operate at twice the gain, shifting from the normal 0.75 to 2.75 to 1.5 to 5.5 keV. When the instrument is turned on, it automatically goes into calibration mode. Otherwise, it repeatedly operates for 6 hours in normal mode followed by 2 hours in calibration mode.

Data Reduction Process used for Apollo XRF data

The raw data, as illustrated in the tables, is read in for processing. The first processing step involves correcting for instrument background. Background is calculated (average total for each detector during each integration period) during each orbit when the surface is not illuminated when no fluorescent lines or scatter are being generated from the surface by the sun.

The estimated intensities for Si, Al, and Mg and errors on these estimates are calculated using matrix inversion to solve for three unknowns in three equations, where, T, for a given detector, is observed counts with background removed, f, for given detector and element, is a ‘filter factor’, or the attenuation from the combined filters, and B is the unknown intensity of the element:

$T1 = f_{1S}i\ B_{Si} + f_{1Al}\ B_{Al} + f_{1Mg}\ B_{Mg}$
$T2 = f_{2S}i\ B_{Si} + f_{2Al}\ B_{Al} + f_{2Mg}\ B_{Mg}$
$T3 = f_{3S}i\ B_{Si} + f_{3Al}\ B_{Al} + f_{3Mg}\ B_{Mg}$

Then, to reduce geometric effects, Al and Mg are ratioed to Si, which is relatively constant.

A primary source of spurious variation is the variation in solar output. It can be seen in variations in averages of data points over the same terrain from orbit to orbit. The solar monitor was designed to keep track of that variation, but saturated on Apollo 15. On Apollo 16 an additional layer of Be was added, but the exact thickness is not known. Thus, two empirical approaches were used to ‘normalize’ the data. Bielefeld et al. (1976) did a straightforward empirical normalization (low pass filtering) of data from orbit to orbit. An attempt was made (Clark and Adler, 1978) to use the observations of an earth-orbiting satellite that was simultaneously collecting measurements of the sun. The problem was that there was overlapping coverage only about 50% of the time. So, an alternative strategy was developed which allowed all the data to be normalized while preserving real orbit-to-orbit variation (Clark and Hawke, 1981). Si is relatively constant in abundance, averaged over large swaths of the lunar regoliths. Variations in Si intensity, once the systematic variations resulting from changes in solar incidence angle as a function of distance from the subsolar point were removed, were thus mostly due to variations in solar intensity. Thus, Si intensities, corrected for solar incidence angle, were correlated to Solrad data on the level of solar activity, where it was available. Once that relationship was established, Si intensities were used to normalize XRF ratios.

In addition, data were subjected to various filtering strategies. Overlapping pairs of 8-second integration data points were averaged, to produce 16-second sliding average, which enhanced statistics while maintaining minimal spatial separation. As part of the Lunar Consortium (Bielefeld et al., 1977; Clark et al., 1978), continuous images were produced from spectral data by binning that data in ¼ x ¼ degree bins. Then, a series of sliding boxcar filters was applied to simulate the instrument field of view, where most of the signal was weighted toward the center. Once these continuous images were produced, elemental abundance data could be, and was, correlated with other related consortium data, not only albedo and topography (highland rocks are high in Al, albedo, and topography), but age, elemental abundances from gamma-ray data, near IR spectral units, magnetic and gravity anomalies (Clark et al., 1976, 1978; Clark and Hawke, 1981, 1987, 1991).

References

Adler et al., 1975
Adler, I., Schmadebeck, R., Trombka, J.I., Gorenstein, P., and Bjorkholm, P., The Apollo 15 and 16 X-ray fluorescence experiment, Space Sci. Instrum., 1, 305-316, 1975.

Bielefeld et al., 1976
Bielefeld, M.J., Reedy, R.C., Metzger, A.E., Trombka, J.I., and Arnold, J.R., Surface chemistry of selected lunar regions, Proc Lunar Sci Conf 7th, 3, 2661-2676, 1976.

Bielefeld et al., 1977
Bielefeld, M.J., Andre, C.G., Eliason, E.M., Clark, P.E., Adler, I., and Trombka, J.I., Imaging of lunar surface chemistry from orbital X-ray data, Proc Lunar Sci Conf 8th, 1, 901-908, 1977.

Clark and Adler, 1978
Clark, P.E., and Adler, I., Utilization of independent solar flux measurements to eliminate nongeochemical variation in X-ray fluorescence data, Proc Lunar Planet Sci Conf 9th, 3, 3029-3036, 1978.

Clark and Hawke, 1981
Clark, P.E., and Hawke, B.R., Compositional variation in the Hadley Apennine region, Proc Lunar Planet Sci Conf 12th, 727-749, 1981. This has the description of the removal of solar variation empirically.

Clark and Hawke, 1987
Clark, P.E., and Hawke, B.R., The geology and geochemistry of the Undarum/Spumans/Balmer Region, /Earth, Moon, and Planets/, 38, 97-112, 1987.

Clark and Hawke, 1991
Clark, P.E., and Hawke, B.R., The lunar farside: the nature of the highlands east of Smythii, /Earth, Moon, and Planets/, 53, 93-10, 1991.

Clark et al., 1976
Clark, P.E., Andre, C.G., Adler, I., Weidner, J., Podwysocki, and M., Palus Somni: anomalies in the correlation of Al/Si X-ray fluorescence ratios and broad-spectrum albedo, Geophys. Res. Lett., 3, 421-424, 1976.

Clark et al., 1978
Clark, P.E., Eliason E., Andre C., and Adler I., A new color correlation method applied to XRF Al/Si ratios and other lunar remote sensing data, Proc Lunar Planet Sci Conf 9th, 3, 3015-3027, 1978.