**Apollo 15 and 16 X-Ray Fluorescence Spectrometers - Energy Channels and Field of View/Surface Resolution Discrepancies**

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**Energy Channel Boundaries**

There is some discrepancy in the overall energy range of the Apollo 15 and Apollo 16 X-Ray Fluorescense Spectrometer detectors and the individual channels in the literature. The Apollo 15 Preliminary Science Report [1972] gives the overall range as 0.75 to 2.75 keV in normal mode, but the accompanying block diagram (Figure 1) shows the 8 channels with values (in keV) of 0.69, 1.02, 1.35, 1.65, 2.01, 2.34, 2.67, and 3. It is not clear from the diagram or accompanying text if these numbers represent the midranges or

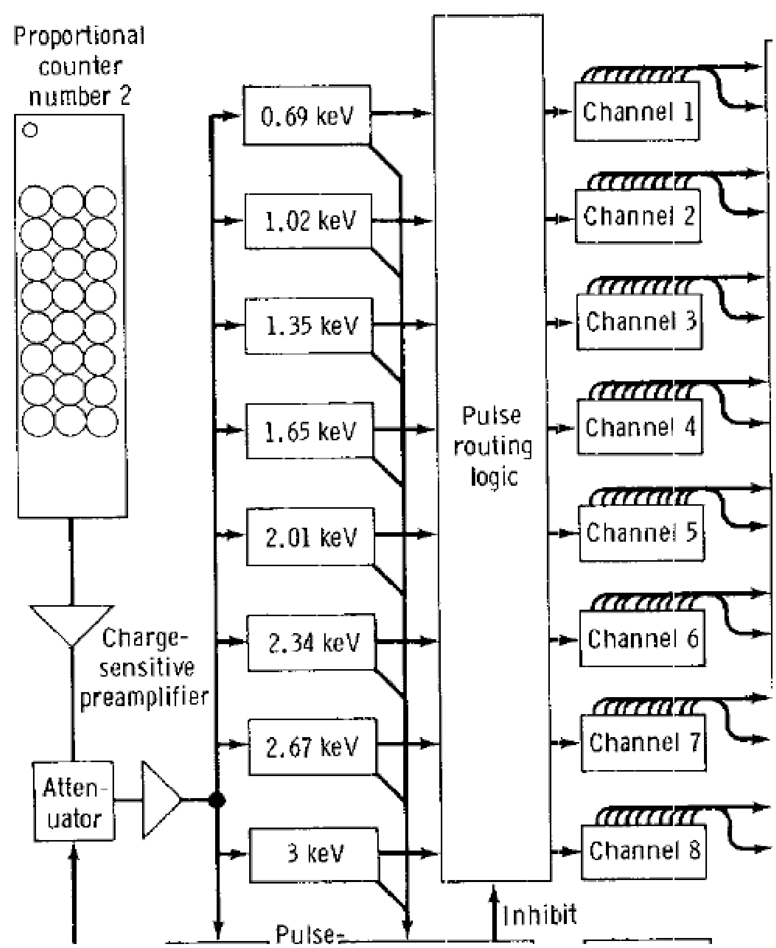


Figure 1: Portion of the block diagram from the Apollo 15 Preliminary Science Report [1972] showing the energy values for each channel in normal mode.

upper or lower boundaries of the channels. (The Apollo 16 Preliminary Science Report [1972] does not give the instrument details, but states it was "essentially identical" to the Apollo 15 instrument.) The same block diagram is shown in Adler et al. [1975] and in the ASE Final Report [1972]. The Adler et al. [1975] paper states that signals were proportional to energies from 0.75 to 3.0 keV. The information received with the data when they were archived at the NASA Space Science Data Coordinated Archive (NSSDCA) also states the energy range is from 0.75 to 3.0 keV in "seven equal energy intervals". But the Adler et al. [1972a, 1972b] papers quote a range of 0.75 - 2.75 keV. Jagoda et al. [1974] give the most complete description of the energy channels, describing them as covering 0.69-1.02, 1.02-1.35, 1.35-1.68, 1.68-2.01, 2.01-2.34, 2.34-2.67, 2.67-3.00, and 3.00-up. This also puts the Mg K-alpha emission line calibration at 1.254 keV in channel 2, which is where it appears in the data (Kuulkers, personal communication, 2016). At the bottom of the range the difference between 0.69 and 0.75 is likely within the measurement uncertainty, but at the upper part of the range the difference between 2.75 and 3.00 could be significant. We have quoted the Jagoda et al. [1974] values in the instrument description as the most likely based on the information above. For the normal mode, a small uncertainty in the boundary location for each channel is probably not significant as the boundaries between each channel are unlikely to be very sharp.

The discrepancy is more severe for the higher energy extended, or attenuate, mode. Most sources give the channel energies in the attenuate mode as twice the channel energies in the normal mode (Apollo 15 Preliminary Science Report [1972], Jagoda et al. [1974], Adler et al. [1972a, 1972b]). This would give a full range of the first 7 channels of about 1.4 to 6.0 keV (using the values from Jagoda et al. [1974]). However, in examining the data, Kuulkers [personal communication, 2016] noted that the 5.90 keV calibration pulse from the Fe-55 source peaked in channel 6 (Figure 2). A simple doubling of the normal channel ranges would have put 5.90 keV in channel 7 (5.34 - 6.00). Furthermore, later papers (Trombka et al. [1974a], Metzger et al. [1974]) discuss energy intervals from 2.0 keV to 7.9 keV. Plots in the Trombka et al. [1974a] and Gilman et al. [1980] papers show points at energies of very roughly 2.3, 3.2, 4.1, 5, 5.9, 6.5, and 7.5 keV. Gilman et al. [1980)] also discuss energy ranges from 2.0 - 7.9 keV and a plot shows a point in channel 4 at about 5 keV. For a simple doubling channel 4 would cover 3.36 to 4.02 keV and 5 keV would be in channel 6. Clark [personal communication, 2016] notes that in practice the attenuate range was not exactly double the normal range, despite the many references to the contrary, and that the range may have been least well known at the higher energies.

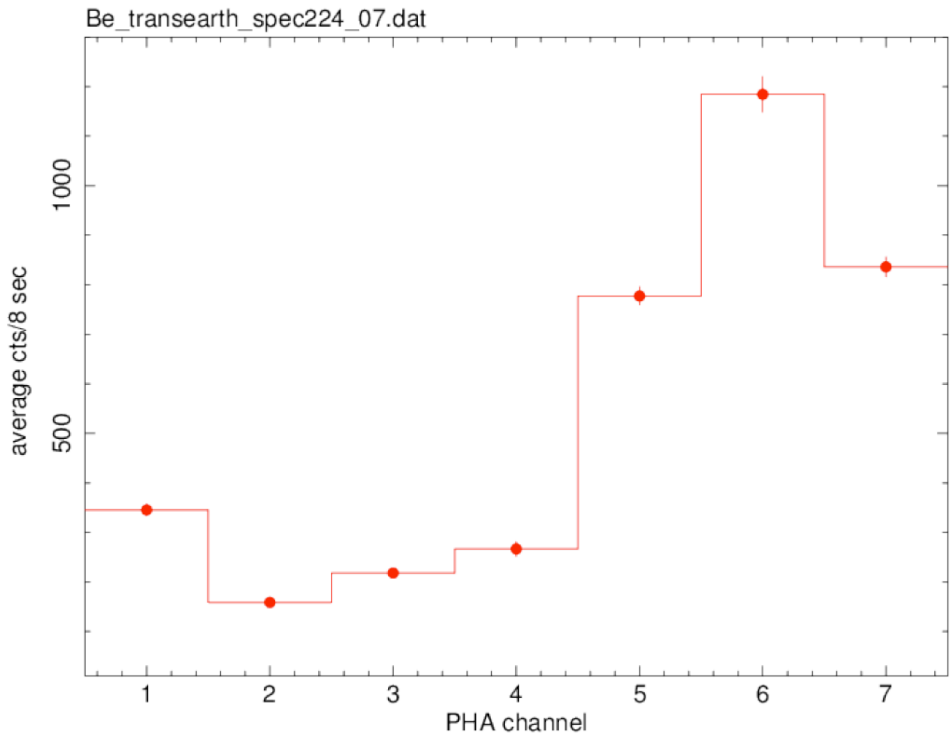

Figure 2: Output from a calibration run showing the peak from the Fe-55 source (5.90 keV) in channel 6 (Kuulkers, personal communication, 2016).

Certainly the calibration signal at 5.90 keV peaking in channel 6 is a clear indicator that the lower range of channel 6 is below this value. The Trombka et al. [1974a] and Metzger et al. [1974] papers appear to recognize this as well. Judging from the earlier work, and helpful comments from Kuulkers and Clark, we hypothesize that the points shown in Trombka et al. [1974a] and Gilman et al. [1980] represent the approximate upper energy boundary of each channel, and the channels in the attenuate mode roughly cover: 1.4-2.3, 2.3-3.2, 3.2-4.1, 4.1-4.9, 4.9-5.8, 5.8-6.7, 6.7-7.6, 7.6-up.

In summary, we have quoted nominal values for the normal and attenuate mode channel energies, but it must be noted that there is significant uncertainty associated with these, particularly in the higher channels of the attenuate mode.

| Channel | Normal Mode Range (keV) | Attenuate Mode Range (keV) |
|---|---|---|
| 1 | 0.69-1.02 | 1.4-2.3 |
| 2 | 1.02-1.35 | 2.3-3.2 |
| 3 | 1.35-1.68 | 3.2-4.1 |
| 4 | 1.68-2.01 | 4.1-4.9 |
| 5 | 2.01-2.34 | 4.9-5.8 |
| 6 | 2.34-2.67 | 5.8-6.7 |
| 7 | 2.67-3.00 | 6.7-7.6 |
| 8 | 3.00+ | 7.6+ |

**Field of View and Surface Resolution**

Almost all references specify the field of view as ±30 degrees (60 degrees total) full width, half maximum (FWHM) in two perpendicular directions for the Apollo 15 and Apollo 16 X-Ray Fluorescense Spectrometers. The notable exception to this is Trombka et al. [1974b], which gives a field of view of ~44 degrees. FWHM is the total angular width at which the collimator drops to one-half its peak response. At the surface, this corresponds to an instantaneous viewing area of 115 km for a spacecraft altitude of 100 km. The Apollo Scientific Experiments Data Handbook gives an estimated field of view at 60 nautical miles altitude as 60 x 80 nautical miles (111 x 148 km). This would correspond to a field of view of 26.5 x 33.7 degrees. In practice, however, the experiment exhibited a response which was a complex function of sighting angle (Adler et al. [1975]). Figure 3 shows the pattern of coverage for an extended source on the Moon. The transmission function out to about 30 degrees is shown in Figure 4. From these diagrams it appears the FWHM is not a simple single value, but is closer to ±8 degrees (Figure 3) to ±15 degrees (Figure 4), with little significant contribution coming from beyond a ±20 degree field of view.

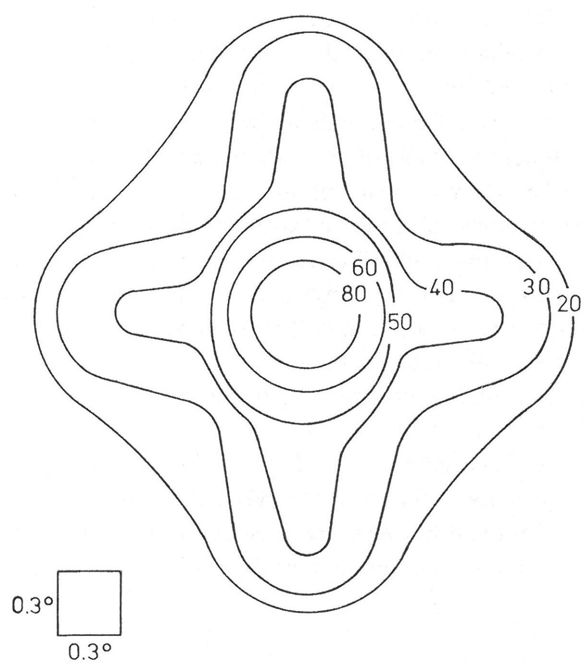


Figure 3: Field of view of the X-ray spectrometer for an extended source during lunar surface operations. The percentages are relative to the central value of 100%. The rectangle represents a 0.3 degree latitude by 0.3 degree longitude bin on the surface (Adler et al. [1975]).

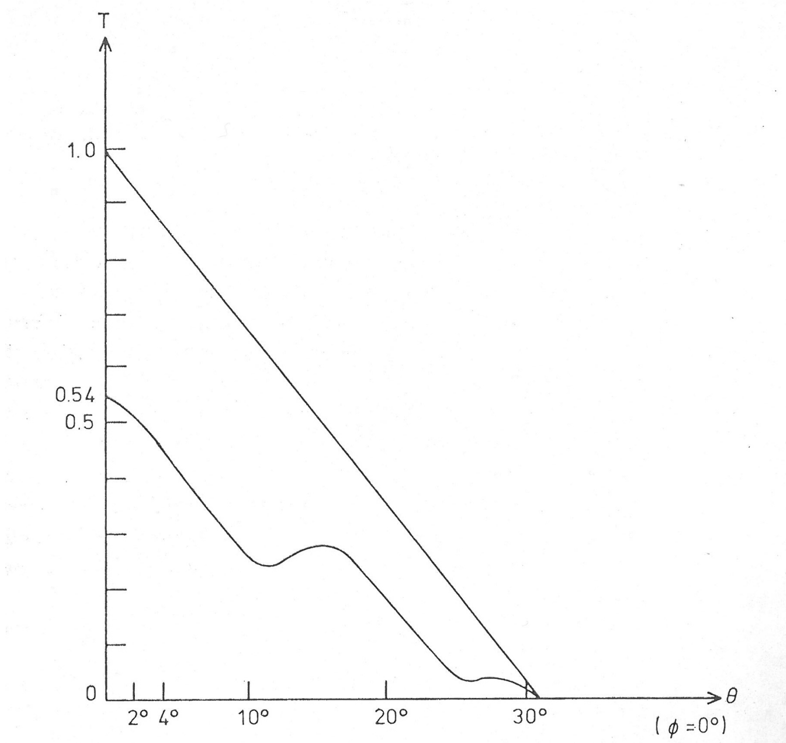

Figure 4: Transmission function of the X-ray spectrometer compared to a triangular response function (Adler et al. [1975]).

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