ASTRO-H

INSTRUMENT CALIBRATION REPORT
SXS DETECTOR QUANTUM EFFICIENCY
ASTH-SXS-CALDB-QUANTEFF

Version 0.1

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ISAS/GSFC

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DOCUMENT TITLE: SXS Detector Quantum Efficiency			
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Introduction

1.1 Purpose

This document describes the measurements used and the calculations made to obtain the Quantum Efficiency (QE) for the SXS detector array. We define the QE as the x-ray stopping power of the detector pixels, which is determined by the x-ray absorber material (HgTe) and thickness. The filling fraction of the array is not addressed here; it is treated in detail using the SXS teldef CALDB file, which contains the positions of the corners of each absorber, enabling calculation of the size and position of each absorber and the gaps in-between.

1.2 Scientific Impact

The QE is used in the Ancillary Response Function (ARF) calculation for spectral analysis and in the flat field for imaging analysis.

2 Release CALDB 20160310

Filename	Valid data	Release data	CAL DB Vrs	Comments
ah_sxs_quanteff_20140101v001.fits	2014-01-01	20160310	001	Original ASCII file: QE_SXS_HgTe_v1.0.txt

2.1 Data Description

The SXS QE was derived based on areal density measurements of seven spare absorbers from the same batch of absorbers used to construct the SXS detector array. This work was performed under WOA-AstroH-DET-0117 and WOA-AstroH-DET-0127, which are archived using GSFC's internal Astro-H Management Information System (MIS). Relevant measurements from these documents are presented in this CALDB description report.

The area of each absorber was measured by taking images using a Zeiss AxioSkop microscope and attached camera. For two of the absorbers 1300 x 1030-pixel images were acquired with an AxioCam CCD camera that was previously calibrated at 1.0495 µm/pixel; for the other five absorbers 5184 x 3456-pixel images were acquired using a Canon EOS60D camera that was calibrated at 0.29935 µm/pixel. Using Graphic Converter, the lengths of each side of photographed absorbers were converted from pixels to microns. Each absorber was then placed on a Cahn microbalance to obtain its mass. The dimensional measurements together with the mass measurements were used to calculate the areal density.

2.2 Data Analysis

Background Information for QE Calculation

The QE of each microcalorimeter pixel describes the probability that a given X-ray will be stopped in the HgTe absorber. The QE of each absorber as a function of incident X-ray energy can be described using Equation 1:

$$QE(E) = 1 - \exp(-\mu_{HgTe}(E) * \rho * d) \qquad \textbf{Eq. (1)}$$

where $\mu_{HgTe}(E)$ is the mass absorption coefficient for HgTe , ρ is the density of the absorber, and d is the thickness of the absorber. The absorption coefficients for Hg and Te are known; assuming nominal stoichiometry of 1:1 we in turn know $\mu_{HgTe}(E)$ for the absorbers using the following equation:

$$\mu_{HgTe}(E) = (m_{Hg}\mu_{Hg}(E) + m_{Te}\mu_{Te}(E)) / (m_{Hg} + m_{Te}) \qquad \textbf{Eq. (2)}$$

where m_{Hg} and m_{Te} are atomic masses and $\mu_{Hg}(E)$ and $\mu_{Te}(E)$ are mass absorption coefficients from the literature. By measuring the area and the mass of the absorber we calculate the **"areal density" = Σ =** (mass of absorber / area of absorber). The areal density is equivalent to the quantity $\rho * d$. Re-writing Eq. 1 in terms of the areal density we find:

$$QE(E) = 1 - \exp(-\mu_{HgTe}(E) \;\; \Sigma) \qquad \textbf{Eq. (3)}$$

Assuming nominal HgTe density (ρ = 8.17 μg/ cm^3 [1]), the areal density also provides an estimate of the absorber thickness. Using Eq. 3 and neglecting uncertainty in the mass absorption coefficient, we derive the uncertainty on the QE:

$$\sigma_{QE(E)} = \quad \mu_{HgTe}(E) \quad (1 - QE(E)) \quad \sigma_{\Sigma} \qquad \textbf{Eq. (4)}$$

Areal Density Data

Measurements of spare SXS absorbers indicate that they have an areal density of **Σ = 85.7 ± 1 μg/mm^2,** implying a thickness of d ~10.5 ± 0.1 μm.

The quoted areal density is an average of the measurements of the seven spare absorbers; details of the measurements are given in Table 1. This average areal density is assumed for all SXS array pixels and thus a single QE value is calculated for the entire array (it is not a pixel-dependent QE). We adopt this approach since the variation in pixel areal density is small and the areal density measurements cannot be made on the absorbers used for the flight instrument.

The uncertainty on the areal density is dominated by uncertainty in the absorber mass. The uncertainty in the mass measurement is consistent with measurement error (uncertainty in the balance's zero point of order 1 μg) in combination with some degree of non-uniformity at the beveled edge (chipping, etc.). We do not ascribe this uncertainty to a real variation in absorber density.

Absorber ID	Area of Front Surface [mm^2]	Area of Back Surface [mm^2]	Mass [μg]	Areal Density* [μg/mm^2]
5-2	0.67011		56.0	84.08
9-4	0.66908		57.7	86.63
5-8	0.67223		56.7	85.13
5-18	0.67227		57.2	85.88
6-18	0.67178		58.1	87.23
1-22		0.66204	56.7	85.13
1-21		0.65993	56.6	84.98
Average:	0.6711	0.66099		85.7
Std. Dev.:	0.00128	0.00105		1.0

Table 1 Absorber measurement summary. *The absorbers are beveled such that the front surface is slightly larger than the back surface. The areal density is calculated by dividing the mass of each absorber by the average absorber area midway between the two faces (= (0.6711 mm^2+0.66099 mm^2)/2 = 0.666 mm^2).

Mass Absorption Coefficient Data

The Center for X-ray Optics (CXRO) at Lawrence Berkeley National Laboratory provides atomic scattering factor data for Hg and Te from 0.01–30 keV (see Ref. [2]). We used these data to calculate the Hg and Te photoabsorption cross sections and mass attenuation coefficients from 0.01–30 keV, and interpolated these data to provide a step size of 0.25 eV. The interpolation was linear in $\mu*E^{2.5}$, which was found to be well behaved. For Hg, we fit the L-shell cross-section data from 25–30 keV with a power-law index, and used this function to extrapolate the data to 40 keV. To extrapolate the Te data to 40 keV we again extrapolated based on a power-law fit to the L-shell cross-section but also added the K-edge at 31.814 keV based on fits to data provided by NIST (see References [3]-[5]). The Te mass attenuation coefficient data from 30 – 40 keV has the same functional form as the NIST data above 30 keV but is a factor of 1.083 higher, normalized to match the CXRO-provided data at 30 keV. Table 2 provides details of the extrapolation parameters.

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Element	Z	atomic mass	L-edge extrapolation index	K-edge energy	K-edge n	K-edge extrapolation index
Te	52	127.60	-2.936	31814 eV	6.34	-2.6688
Hg	80	200.59	-2.688	n/a	n/a	n/a

Table 2 Parameters used for calculating and extrapolating absorber mass attenuation coefficients. The L-edge extrapolation index is the power-law index used to extrapolate between the L-edge and K-edge (from 30–40 keV for Hg and from 30–31.814 keV for Te). The K-edge extrapolation index is the power-law index used to extrapolate above the K-edge energy; n is the factor increase in opacity just at the K-edge.

2.3 Results

We provide a file with two columns: x-ray energy and absorber stopping power or QE. The energy range is 10 to 40000 eV with a step size of 0.25 eV. Figure 1 shows the results. The curve was calculated using the average measured areal density of the absorbers (85.7 μg/mm^2) and the mass attenuation coefficients derived as described in 2.2. Figure 2 shows the 1-sigma uncertainty on the QE, derived using Equation 3, and Figure 3 shows the corresponding fractional uncertainty on the QE. The uncertainty on the QE is less than 1% over the science bandpass.

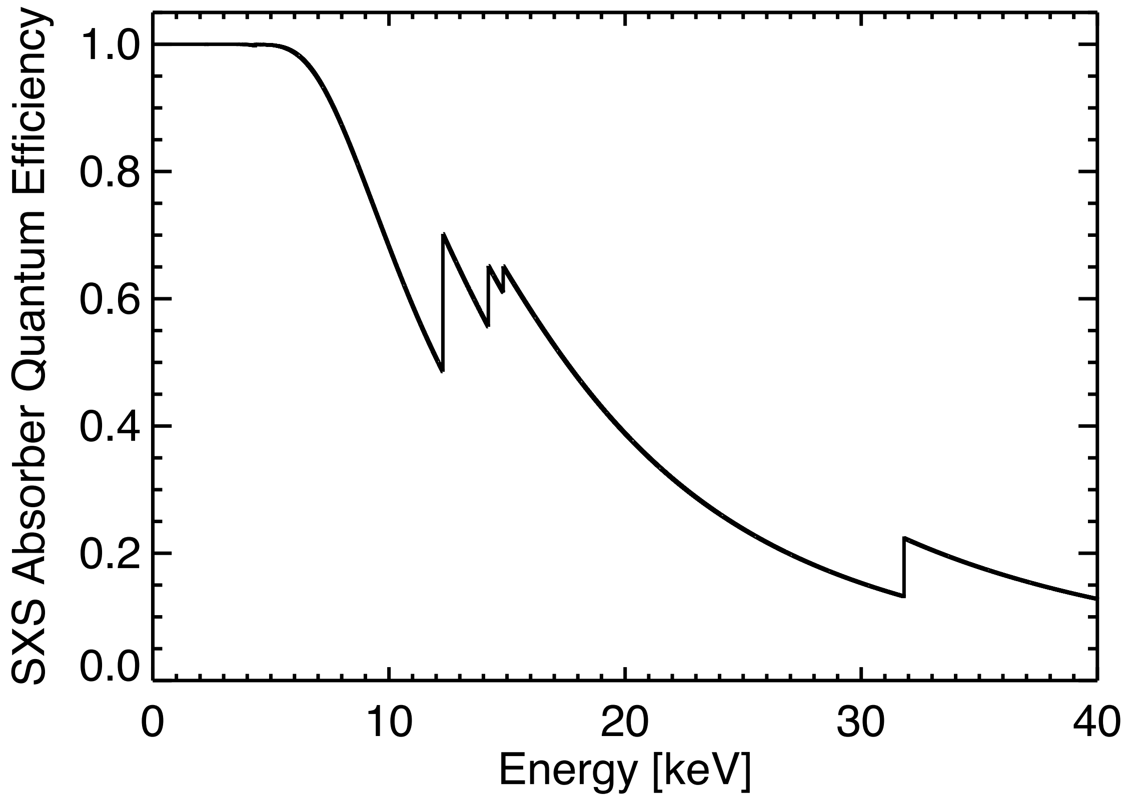

Figure 1 Absorption efficiency (QE) of SXS pixels.

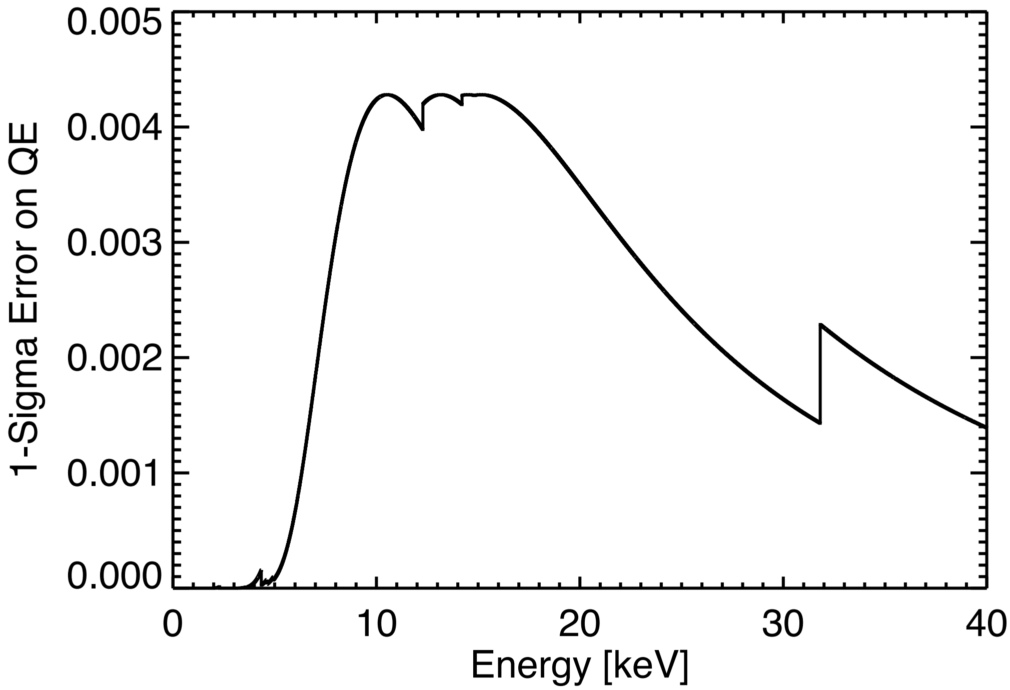

Figure 2 Uncertainty on SXS QE.

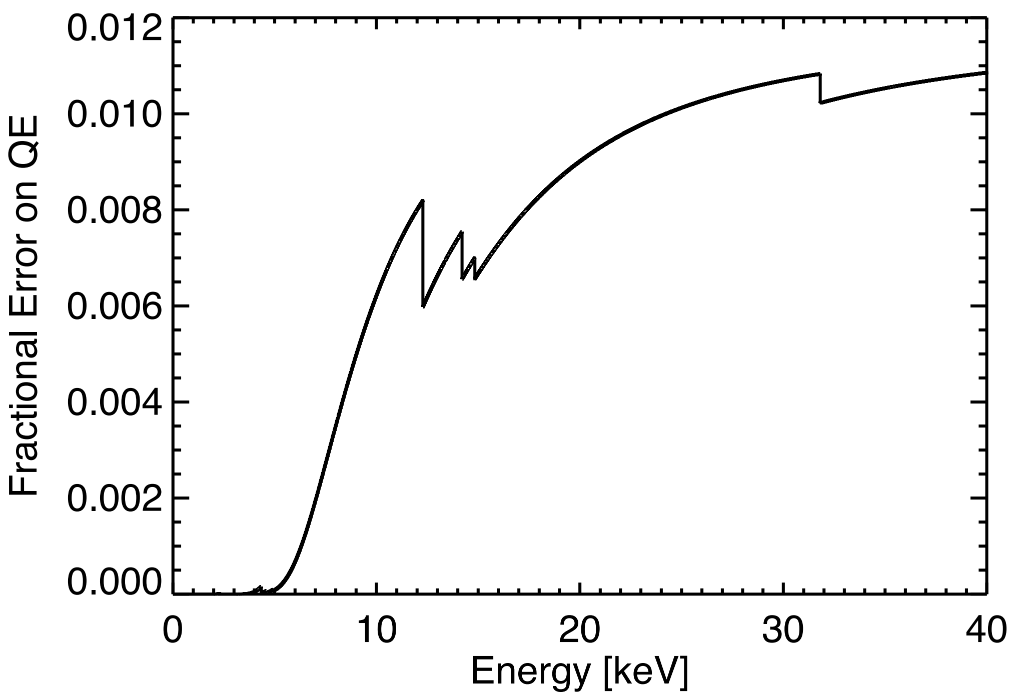

Figure 3 Fractional error on SXS QE.

2.4 Final remarks

This is the first documented release of this CALDB file based on absorber areal density measurements and literature values of the Hg and Te mass absorption coefficients.

3 References

[1] Handbook of Inorganic Compounds, CRC Press, Edited by D.L. Perry and S.L. Phillips (2000).

[2] B.L. Henke, E.M. Gullikson, and J.C. Davis. *X-ray interactions: photoabsorption, scattering, transmission, and reflection at E=50-30000 eV, Z=1-92*, Atomic Data and Nuclear Data Tables Vol. **54** (no.2), 181-342 (July 1993). http://henke.lbl.gov/optical_constants/asf.html

[3] http://www.nist.gov/pml/data/ffast/index.cfm

[4] C. T. Chantler. "Theoretical Form Factor, Attenuation and Scattering Tabulation for *Z*=1-92 from E=1-10 eV to E=0.4-1.0 MeV," *J. Phys. Chem. Ref. Data,* **24**, 71-643 (1995).

[5] C. T. Chantler. "Detailed Tabulation of Atomic Form Factors, Photoelectric Absorption and Scattering Cross Section, and Mass Attenuation Coefficients in the Vicinity of Absorption Edges in the Soft X-Ray (Z=30-36, Z=60-89, E=0.1 keV-10 keV), Addressing Convergence Issues of Earlier Work," *J. Phys. Chem. Ref. Data,* **29**(4), 597-1048 (2000).