Chapter 5

The High Energy X-Ray Timing Experiment (HEXTE)

P. R. Blanco, R. E. Rothschild & the HEXTE team.

Center for Astrophysics & Space Sciences,

University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0424, U.S.A.

email: pblanco@ucsd.edu

5.1 General Principles

The HEXTE consists of two independent clusters each containing four NaI(Tl)/CsI(Na) phoswich scintillation detectors passively collimated to a 1^{o} FWHM field-of-view and co-aligned with the PCA (**Figure 5.1**). Each detector has a net open area of about 225 cm^2 and covers the energy range 15-250 keV, with an intrinsic spectral resolution better than 9 keV at 60 keV. The phoswich detector architecture employed ensures a low background through the efficient shielding of the primary NaI detector crystal by the CsI shield/light guide crystal. The two clusters contain mutually orthogonal “rocking” mechanisms, which can be moved independently to provide near-simultaneous measurements of the internal and cosmic x-ray backgrounds at 1.5^{o} or 3^{o} on either side of the source. The HEXTE’s increase in sensitivity over its predecessor (HEAO-1 A4) is attained by virtue of its larger collecting area (~8 times the HEAO-1 A4 area) and improved suppression of systematic effects compared to previous satellite-borne instruments in this energy range. The actively shielded cluster organization for the HEXTE reduces systematic background variations, while further systematic effects have been eliminated by the use of continuous *Automatic Gain Control* **(AGC).** The entire system requires about 45 W, exclusive of heater power, weighs about 400 kg, and is allotted 5 kbit/s of telemetry on average. The HEXTE was designed and built at the Center for Astrophysics & Space Sciences, the University of California, San Diego. **Table 5.1** summarizes the HEXTE instrument’s characteristics.

The HEXTE instrument detects each incident x-ray photon individually, and outputs data from these events in flexible formats to provide spectroscopy and timing from 7.6µs upwards, limited primarily by photon statistics (for faint sources) and the restrictions on the telemetry rate (for bright sources). An x-ray photon interacting with sufficient energy deposition will generate an event which has arrival-time and energy-related parameters associated with it. (However, note that like the PCA, the

HEXTE is a spectro-photometer, not an imaging instrument, and no position information is obtained from the detectors). For brighter sources, the high event rates will allow only a fraction of this information to be telemetered at the allocated 5 kbit/s. The HEXTE on-board data processor therefore permits the selection of any desired subset of the event data to be transmitted, consistent with this telemetry rate. In addition to two Standard Modes, three Science Modes (described later) are available to users, providing the necessary flexibility in data formatting and compression, in order to achieve the timing and energy resolution requirements required for their scientific objectives.

TABLE 5.1. High Energy X-ray Timing Experiment Characteristics

Characteristic	**Value**
Detectors	2×4 NaI(Tl)/CsI(Na) phoswich scintillators
Field of view	2.2 ^{o} FWZI, 1^{o} FWHM (Section 5.3.1)
Energy range	15-250 keV in 256 channels (Section 5.3.2)
Energy resolution	$\Delta E/E \propto E^{-0.5}$, 15% at 60 keV (Section 5.3.4)
Time sampling	7.6 µs (maximum), 0.98 ms (bright sources)
Net open detector area	890 cm^2 per cluster (Section 5.3.3)
Live-time fraction on-source	60% (Section 5.3.9)
Count rate from Crab Nebula (12-250 keV)	250 count/s per cluster
Count rate from internal background (12-250 keV)	90 count/s per cluster (Section 5.3.7)
Source/background dwell cycle	16 to 128 s, 2 s motion (Section 5.2.3)
Gain Calibration source	^{241}Am (lines at 17 and 60 keV)
Gain variation	<1% (Section 5.3.6)
Allocated telemetry rate	5 kbit/s (orbital average)

5.2 Physical Description

Each HEXTE cluster consists of a mounting structure that attaches to the RXTE spacecraft and an array of 4 detector modules, each containing a phoswich detector, photomultiplier tube (PMT), collimator, gain control detector and associated electronics. These detector units are mounted on a shaft which can rotate to either $\pm1.5^{\circ}$ or $\pm3.0^{\circ}$ about the nominal source-pointing direction of RXTE (**Figure 5.1**). The two clusters are oriented such that the axes of their rocking motions are mutually orthogonal, while the on-source look directions are closely co-aligned. This enables the sampling of four background positions about the source pointing (**Figure 5.3**).

Each detector unit utilizes two types of detectors. The primary function of the instrument (to measure high energy cosmic x-rays) is accomplished via thallium-doped sodium iodide (NaI(Tl)) scintillation crystals viewed by photomultiplier tubes. In addition, particle detectors are used to reject contaminating events from cosmic ray interactions, and to provide a signal from the calibration source which is used for automatic gain control.

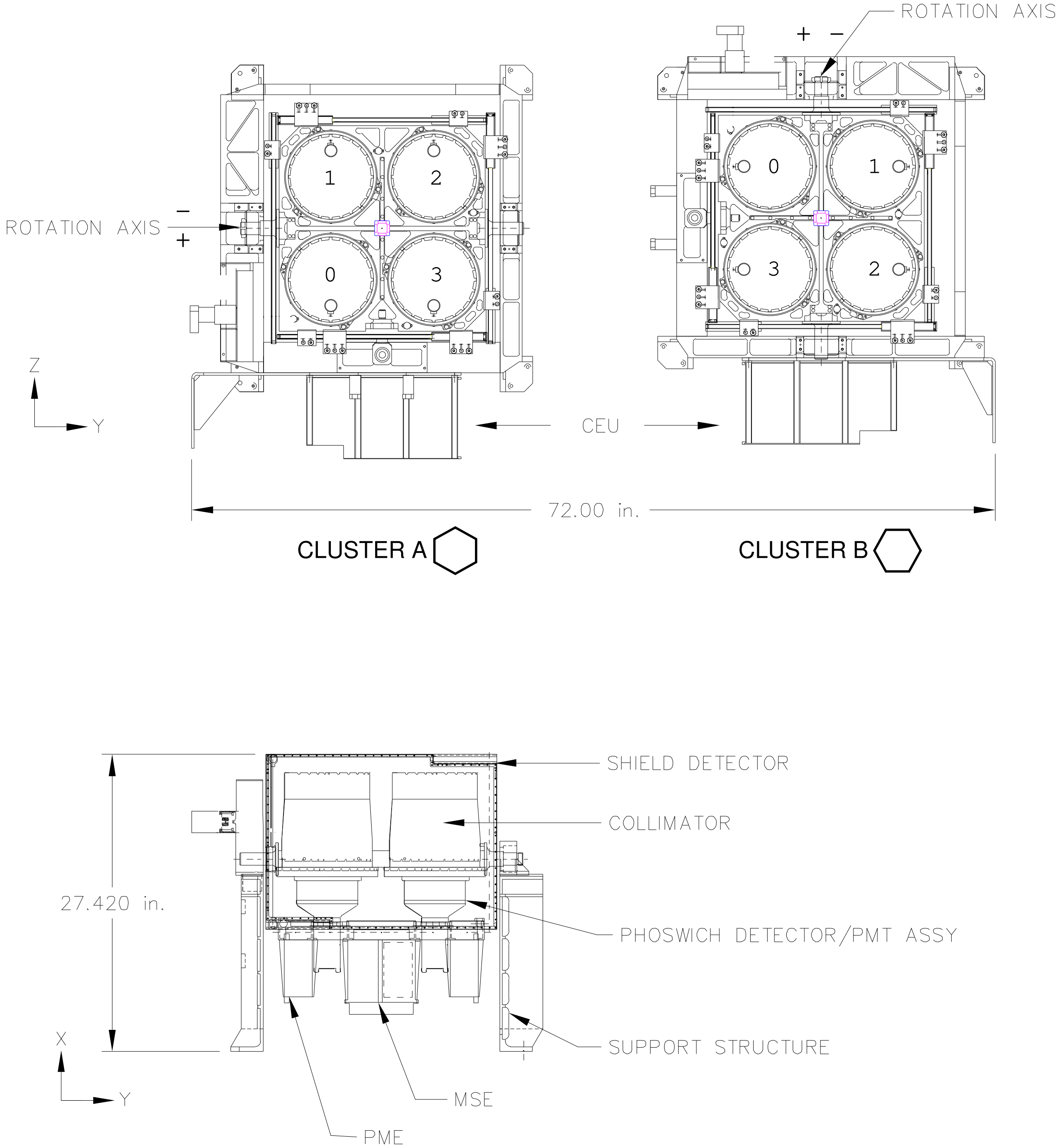

FIGURE 5.1. (a) Top view of the two HEXTE clusters, oriented as mounted on the spacecraft with orthogonal rocking axes; the phoswich detectors are numbered as they appear in telemetry. The hexagons below each cluster show the orientation of the collimator cells. (b) Side view of cluster A with the CEU removed shows the Module Support Electronics (MSE), Phoswich Module Electronics (PME), shield detectors, collimators, and the phoswich detector/photomultiplier tube assemblies. The RXTE spacecraft's *(x,y,z)* axes are shown in each view.

5.2.1 Phoswich X-ray Detector Assemblies

Detection of x-rays from astronomical sources is accomplished by a 4 phoswich scintillator/photomultiplier tube assemblies in each HEXTE cluster. The field of view of each detector is defined by a Pb collimator which also houses the gain control source and coincidence detector. Magnetic shielding in 3 connected sections surrounds the photomultiplier tube, the detector crystal housing and the collimator (see **Figure 5.2**). In this way each phoswich photomultiplier tube is embedded within a magnetic shield environment to reduce the effects of orbital variations of the external magnetic field.

5.2.1.1 Phoswich Detector/Photomultiplier Tube Modules

The primary HEXTE detectors consist of NaI(Tl) scintillation crystals of diameter 7.2 in and thickness 0.125 in, each optically coupled to a single 5-in photomultiplier tube (PMT) through an intervening 2.25-in thick CsI(Na) shield crystal and 0.25-in thick quartz window, as shown in Figure 5.2. The CsI(Na) crystal tapers down to the quartz window diameter, which matches the photomultiplier photocathode diameter (4.5 in typically). The CsI crystal provides uniform viewing of the primary NaI crystal by the photomultiplier and active anticoincidence shielding against x-ray events not originating in the forward direction, and events with only partial energy loss in the NaI. This configuration is known as a *phoswich.*

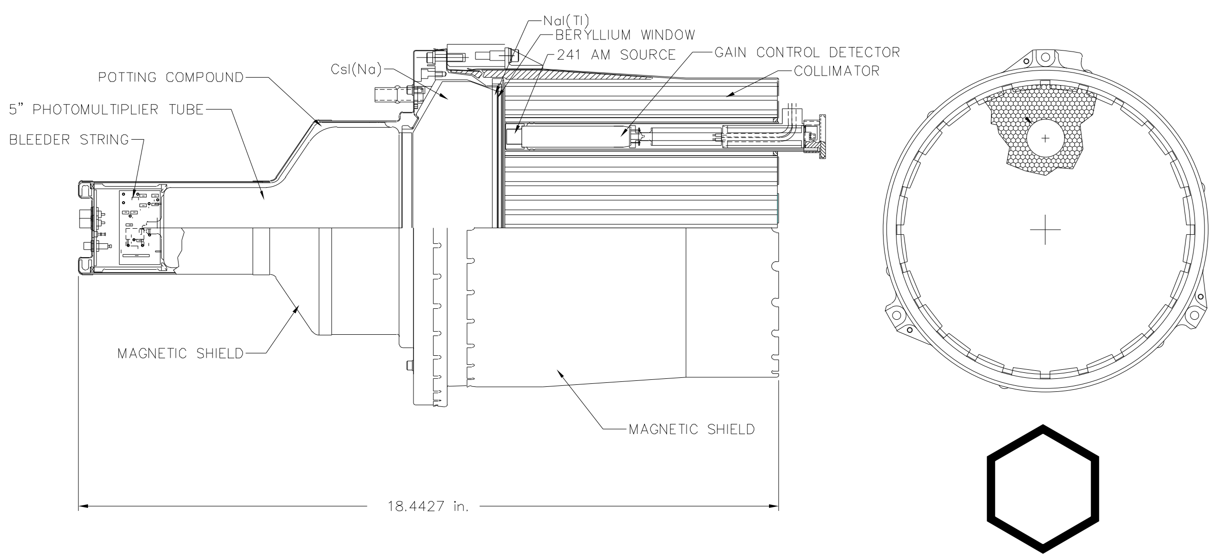

FIGURE 5.2. Side (cutaway) and top views of a HEXTE phoswich detector assembly, showing the photomultiplier tube, phoswich detector, collimator and gain control detector with part of the external magnetic shield. The top view shows the position of the gain calibration source and detector in the field of view, together with an expanded view of a single hexagonal collimator cell shown in the same orientation.

When an x-ray in the HEXTE energy range enters a phoswich detector, it will generally interact with an Iodine atom in the NaI crystal. This interaction occurs at a single point in the crystal and causes an electron to be ejected from the atom. This electron then excites the light-generating modes of the crystal to create a “scintillation” (pulse of light), whose intensity is proportional to the energy of the original x-ray. This light is viewed through a CsI light guide by a photomultiplier tube. This tube converts the pulse of light into an amplified electrical charge pulse. Thus, the HEXTE amplifiers and subsequent electronics deal with a peak voltage of the pulse that is, again, proportional to the x-ray’s initial energy. By calibrating the exact relation between incident x-ray energy loss and the digitized value of the voltage pulse height, the inferred incident energy of the x-ray is revealed.

Charged particles, such as are found in orbit, also cause the detectors to emit light that is picked up by the photomultiplier tubes, and such events must be identified so they can be ignored electronically (they outnumber x-rays by about 100 to 1). Those particles entering from the sides are detected by the plastic anti-coincidence shield detectors which surround each HEXTE cluster (**Section 5.2.2.1**), while cosmic rays entering the face of the detector will generally interact in both the NaI and CsI crystals.

The scintillation pulses generated within the two crystals exhibit different characteristic rise times: roughly 0.25 µs in NaI(Tl) and 0.63 µs in CsI(Na). Each signal from the photomultiplier tube is pulse-shape analyzed to distinguish pure NaI(Tl) energy loss (i.e. a good event) from events containing some proportion of the slower component, indicating an energy loss in the CsI(Na) shield crystal (i.e. an event to be rejected). Rejected events can be either charged particles that stimulate both crystals, or incompletely absorbed Compton-scattered x-rays that deposit only partial energy in the NaI crystal.

The crystals are contained in an opaque, hermetically sealed housing to prevent degradation of the NaI by water vapor and to shield the photomultiplier from stray light. The housing incorporates a 0.020-in thick beryllium x-ray entrance window to provide a light seal and a minimum of low energy photoelectric absorption of incident x-rays. The crystals are wrapped in teflon sheet, 0.010 in thick, and are highly polished to provide the maximum uniform light collection by the photomultiplier tube, and, therefore, maximize energy resolution. The photomultiplier tube and its attendant high voltage divider network (bleeder string), coupling elements, and connectors are surrounded by potting material to meet vibration and thermal requirements, as well as to prevent electrical discharges at all ambient pressures. Ribbing moulded into the potting material provides a light seal and the compression properties to absorb thermal expansion and contraction without stressing the photomultiplier tube. The entire potted assembly is contained within a metallic housing that also acts as a magnetic shield.

5.2.1.2 Collimators

The field-of-view of the HEXTE phoswich detectors is defined through the passive collimation of incident x-rays by a honeycomb structure of hollow hexagonal tubes, which are constructed from a composite of 94% lead and 6% antimony (for strength). The structure is epoxied within a magnetic shield housing (see Figure 5.2). Due to the manufacturing process the walls of each hexagonal tube are 0.004 in thick on four of the six edges, and twice that on the other two. Thus, the mean wall thickness is 0.005 in. The collimator tubes are 7.14 in long and 0.125 in across as measured from flat-to-flat of the hexagons. This gives a Full Width at Half Maximum (FWHM) response of about 1° and a

Full Width at Zero Intensity (FWZI) response of about 2.2° diameter; the response as a function of off-axis angle is shown in **Figure 5.4**. The open fraction of the collimator assembly is approximately 85%, such that each detector has roughly 225 cm^2 of face-on open area to the sky when viewed through its collimator.

The detector crystal housing also contains a 0.2-in thick ring of lead that suppresses high energy x-rays incident on the crystals from the side. Similarly, the collimator housing incorporates a lead ring to block radiation entering obliquely close to its base.

5.2.2 Particle Background Detectors

Since the HEXTE's phoswich x-ray detectors are also sensitive to cosmic ray particles, each HEXTE instrument cluster includes a set of particle anticoincidence shield detectors. Each cluster also contains a single trapped-radiation particle detector which monitors the particle environment and provides control signals for the raising and lowering of all detector high voltages in the event of increased particle fluxes, primarily in the *South Atlantic Anomaly* (**SAA**). In addition, each phoswich assembly is equipped with an α-particle coincidence detector associated with its ^{241}Am calibration source used for gain control.

5.2.2.1 Shield Anticoincidence Detectors

The anticoincidence shield system consists of four flat scintillation detector modules configured in a four-sided box around the x-ray detectors (see **Figure 5.1**). These shields provide a prompt indication of a phoswich event which may have been generated by an energetic particle interaction in the passive mass elements of the instrument. A particle intersecting the detector volume also intersects a shield with 85% probability. The 0.25-in thick plastic scintillator sheets (Bicron 440) are viewed by two 0.5-in photomultiplier tubes via two wavelength-shifting light guides positioned along two sides of each sheet. The anticoincidence detectors are used to reduce spurious background from effects such as Cerenkov radiation in the photomultiplier glass and secondary particles generated in the collimators.

5.2.2.2 Particle Monitors (SAA detection)

Each instrument cluster includes a single particle monitor detector for measurement of the ambient particle flux of the detector systems as they pass through the trapped radiation belts of the South Atlantic Anomaly (SAA). Each particle monitor consists of a simple hemispherical shaped plastic scintillator (Bicron 440) of about 0.4 in diameter coupled to a 0.5-in photomultiplier tube and surrounded by a thin absorber to define the low energy cutoff to which the unit will respond (~0.2 MeV). These detectors provide a signal to the control system to reduce the photomultiplier high voltages during times of high particle flux. This protects the phoswich and shield PMTs from high anode currents which would cause long-term gain changes due to aging effects.

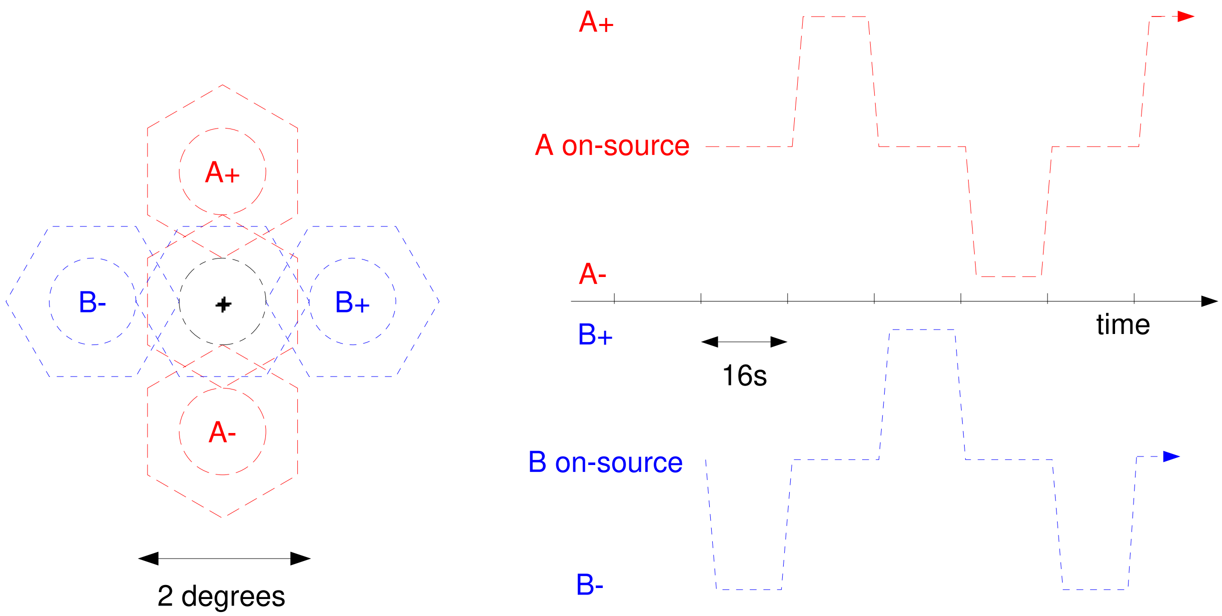

FIGURE 5.3. (a) **Source and background fields of view. Circles denote the FWHM response, and hexagons the field-of-view boundaries. (b) Timing pattern for synchronized two-cluster source/background beamswitching; note that the resulting on-source coverage is continuous (1.5 degree beamswitching and 16s on-source dwell time assumed here).**

5.2.2.3 Gain Control Detectors and Calibration Source

Each phoswich detector module has a calibration x-ray source mounted in the collimator immediately above its entrance window, in the detector's field-of-view (Figure 5.2). The calibration source consists of a small quantity (activity level about 18 nCi) of the radionuclide ^{241}Am suspended within a solid cylindrical pellet of scintillation plastic (Bicron 440). The scintillation plastic is optically coupled to a 0.5-in photomultiplier tube. ^{241}Am is chosen as the dopant in the scintillator since its primary decay scheme yields a 59.6 keV x-ray in coincidence with an ~4 MeV α–particle. The 59.6 keV photon exits the plastic and serves as a calibration reference line for the phoswich detector while the α-particle, which is stopped within the plastic, generates a coincidence signal to indicate that the event originated in the calibration source. **Section 5.3.6** details how these AGC events are used in a feedback loop and for continuous gain monitoring.

5.2.3 Source/Background Beamswitching Mechanism

A simple rocking mechanism is used to move each cluster's detectors between alternate on- and off-source fields-of-view. The rocking axes are fixed relative to the spacecraft (Figure 5.1), and the off-source positions can be selected to be either 1.5° or 3.0° from the source, with the option of one- or two-sided rocking. A beamswitch cycle consists of *dwelling* (i.e. accumulating data) at the on-source position, moving to an off-source position, dwelling there, rapidly moving back to the on-source position, dwelling there, moving to the other off-source position, dwelling there, and finally rapidly moving back to the on-source position. This cycle is then repeated continuously throughout any given observation. The on-source dwell time can be selected to be 16, 32, 64 s or 128 s. These motions are phased with respect to the data taking intervals such that a cluster spends the full dwell time when on-source, but uses 2s of the dwell time allotted to off-source observing for the motion from and to the on-source position. Data acquisition is inhibited for 2 s during these transitions off- and onto source; consequently, 4 s less is available for the off-source dwell time each cycle. Movement of the two clusters is synchronized such that at least one cluster is taking data on-source at any time; the nominal timing pattern is shown in **Figure 5.3b**. Since the rocking axes of the two clusters are orthogonal to each other, four background regions are usually sampled around a given source position by HEXTE, as shown in **Figure 5.3a**. Thus, the presence of a contaminating in a single background region can be identified, and one other background field will still be available for the cluster in question. The HEXTE clusters can be configured individually to avoid contaminating sources in advance through use of 3.0° and/or one-sided rocking (two-sided rocking is recommended, if possible).

The rocking mechanism may also be commanded to dwell indefinitely (i.e. *stare*) at any of the on- or off-source positions in order to satisfy scientific objectives such as fast timing on bright sources where background subtraction is not important. The cluster mechanism's position during any data taking interval is indicated in telemetry by one of six indications: -3°, -1.5°, 0°(two settings), +1.5°, or +3°. A secondary position readout comes from a 10-bit shaft encoder that provides a continuous measure of the mechanism cam angle, and is used as a diagnostic in case of a failure in the system.

5.3 Performance

Performance estimates for the HEXTE instrument have been derived from a combination of pre-launch calibration results, dedicated calibration observations made during In-Orbit Checkout, and continuing calibration observations performed during the RXTE mission.

5.3.1 Field-of-View (Beam Profile)

The HEXTE detectors' field-of-view is defined passively by the honeycomb of hexagonal tubes that make up the collimators. As for the PCA, each HEXTE detector/collimator assembly has been aligned such that its peak response direction is close to the nominal look-direction (x-axis) of RXTE. For sources off-axis, the detector open area visible through the collimators is decreased geometrically; the collimator response as a function of off-axis angle θ is therefore the convolution of a hexagonal aperture with itself. For the collimator tube dimensions given earlier, 50% of on-axis response is reached at about $\theta = 0.5^{\circ}$, while zero response defines a roughly circular boundary at $\theta = 1.1^{\circ}$. A model collimator response is shown in **Figure 5.4**, normalized to unity on-axis ($\theta = 0^{\circ}$). The cross-sections are consistent with laboratory measurements using a real collimator. In practice, the sharp peak of the collimator response is smoothed out somewhat by the deviations in the alignment of the detectors within each HEXTE cluster (~1 arcmin, as measured during in-orbit checkout), and by the slow residual motion (<0.1 arcmin) of the spacecraft's pointing axis. Ideally the collimator response

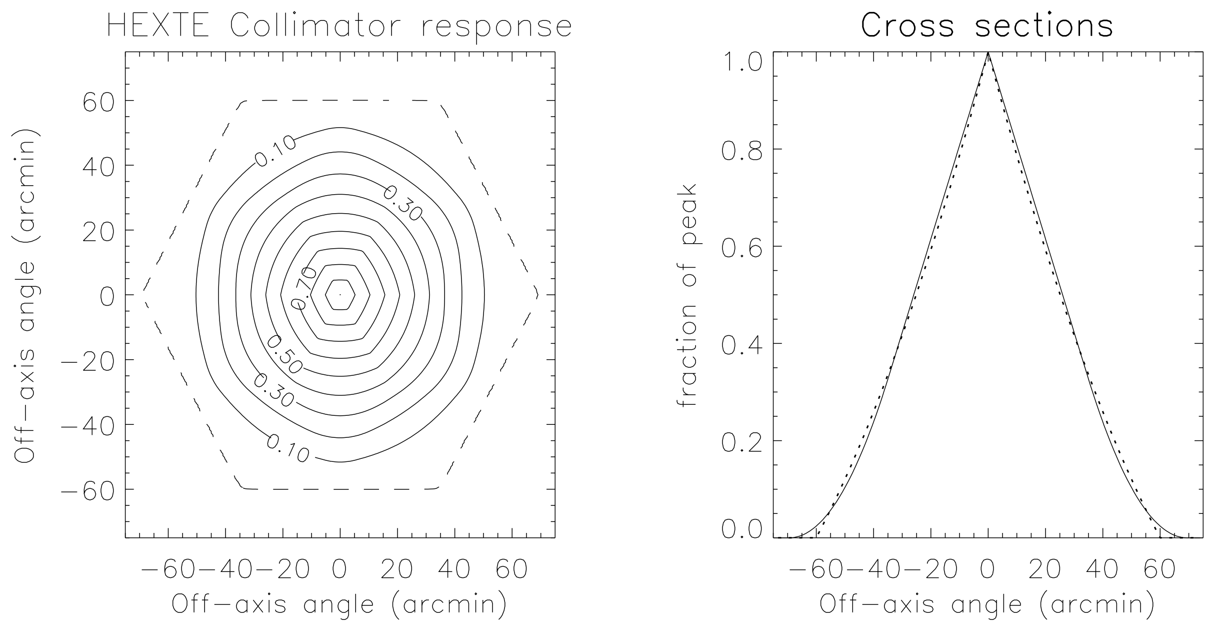

FIGURE 5.4. Indealized collimator response ("beam profile") of the HEXTE field-of-view; in-orbit data shows this to be broadened by a gaussian of ~7 arcmin FWHM. (a) Two-dimensional response, with the hexagonal cells oriented horizontally; contour levels are at 0 (dashed line), 10, 20...100% of peak. (b) Cross sections of the collimator response along the point-to-point (solid line) and flat-to-flat (dotted) directions through the peak..

will be independent of energy, but in practice a small fraction (~1%) of the incident source flux may be Compton-scattered off the interior of the collimator walls. The resulting detected spectrum would then be a function of the source spectral shape, but for most sources this would be a negligible addition to the background.

5.3.2 Energy Range

Scintillation pulses are analyzed by the event selection logic and assigned a *Pulse Height Analyzer* (**PHA**) channel number from 0 to 255 which is a measure of incident photon energy (in fact, the PHA channel number ≈ peak energy in keV). At normal gain, these channels are roughly 1 keV wide and arranged such that the PHA channel number corresponds to the peak photon energy in keV. The minimum acceptable energy is defined by the *Lower Level Discriminator* (**LLD**) which may be set to any value from 5-50 keV, though values in the range 10-30 keV prove the most useful. The *Upper Level Discriminator* (**ULD**) level defines the upper bound of the instrument, which corresponds to about 250 keV at nominal gain

5.3.3 Effective Area

The *on-axis effective area* of a HEXTE detector is defined as its efficiency in producing an a detected scintillation pulse event for each incident x-ray photon, multiplied by its open area to the sky in the

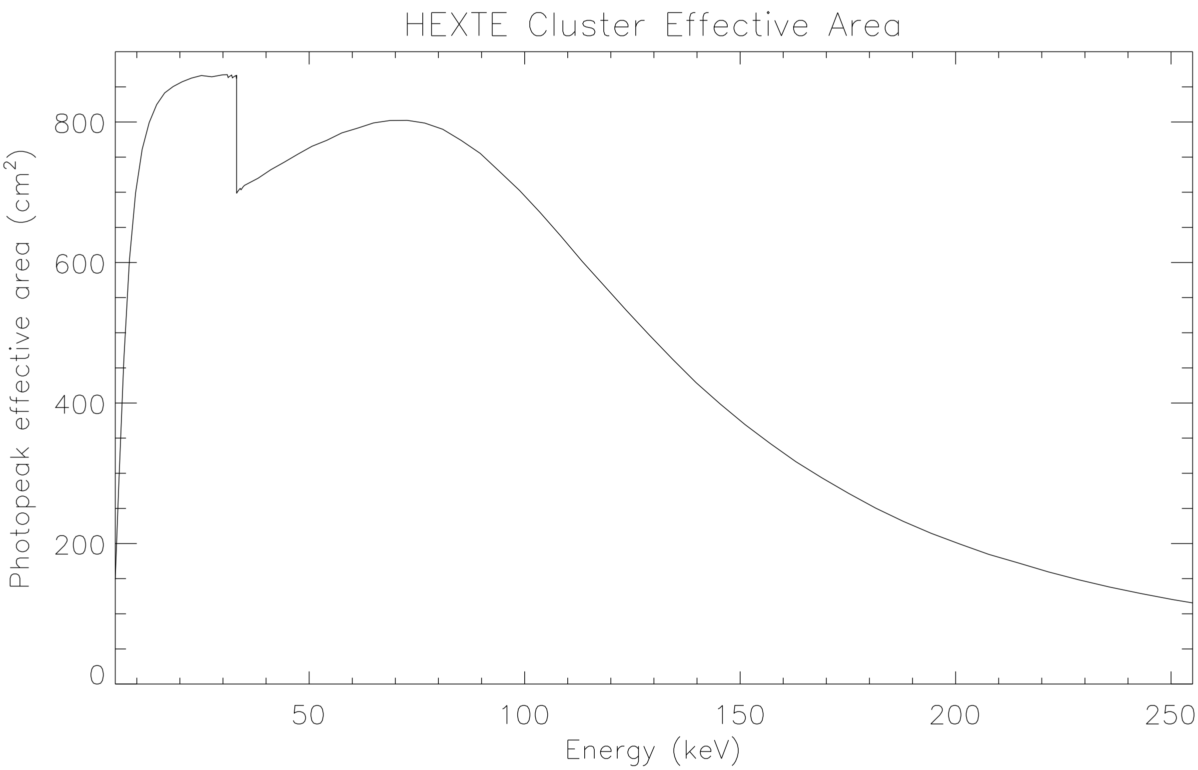

FIGURE 5.5. On-axis effective area of the four HEXTE phoswich+collimator assemblies which comprise HEXTE Cluster A, assuming a net open area of 890.342 cm^2 per detector. The Iodine K-edge is at 33.17 keV. Note that this curve must be scaled by the live-time fraction (Section 5.3.8) before calculating count rates.

on-axis look direction. *Non*-detected photon interactions include absorption in the detector window, those partial energy loss events in the NaI (Compton scattering) which are captured and rejected by the CsI layer, and photons which pass through the NaI undetected.

Extensive Monte-Carlo simulations of the phoswich detectors have been performed. **Figure 5.5** shows the effective area as a function of energy for "photopeak" interactions, i.e. complete x-ray energy loss in the NaI, which is the significant contributor to the HEXTE's sensitivity (these events appear as diagonal elements in the response matrix); this curve has been scaled to Cluster A's net open area of 890 cm^2. The sharp edge at 33.17 keV is the K-escape energy of Iodine. Note that in order to estimate the *measured* count rate for a given source, this effective area must be multiplied by the detector *live-time fraction* (**Section 5.3.9**)

5.3.4 Spectral Resolution

X-ray photons of a given energy will produce a spread in detected pulse height due to the Poisson fluctuations in the number of photo-electrons produced per event. The intrinsic energy resolution of the phoswich detectors can be described roughly by a gaussian function with FWHM increasing as $\sqrt{\text{Energy}}$, to which must be added a small term proportional to energy due to the gain variations across the face of each detector. For an average phoswich detector, the resolution FWHM (in channels or keV) at PHA channel e ($\approx E$ keV) is given approximately by

$$FWHM = \sqrt{e} \times \sqrt{0.0055e + 1.09}$$

Summing data from the detectors in a HEXTE cluster degrades this resolution somewhat due to this lightly different PHA channel centroids of the line-spread function in each detector at a given energy. Nevertheless, the 256 PHA channels (numbered 0-255) still over-sample the HEXTE resolution by at least a factor of 2. The user may select contiguous sub-ranges of PHA channels and/or group them on-board into larger spectral bins, according to the Science Mode telemetry format in use.

5.3.5 The HEXTE Response Matrix

All of the effects described above - detection efficiency, detector gain and spectral resolution -can be embodied in the HEXTE response matrix, which describes the transformation from an input photon spectrum to a PHA count rate spectrum (to which one must add the internal background). An example of such a matrix is shown in **Figure 5.8**, which shows the (almost linear) energy/PHA channel conversion gain, and the increase in resolution-broadening with energy. The photopeak response,

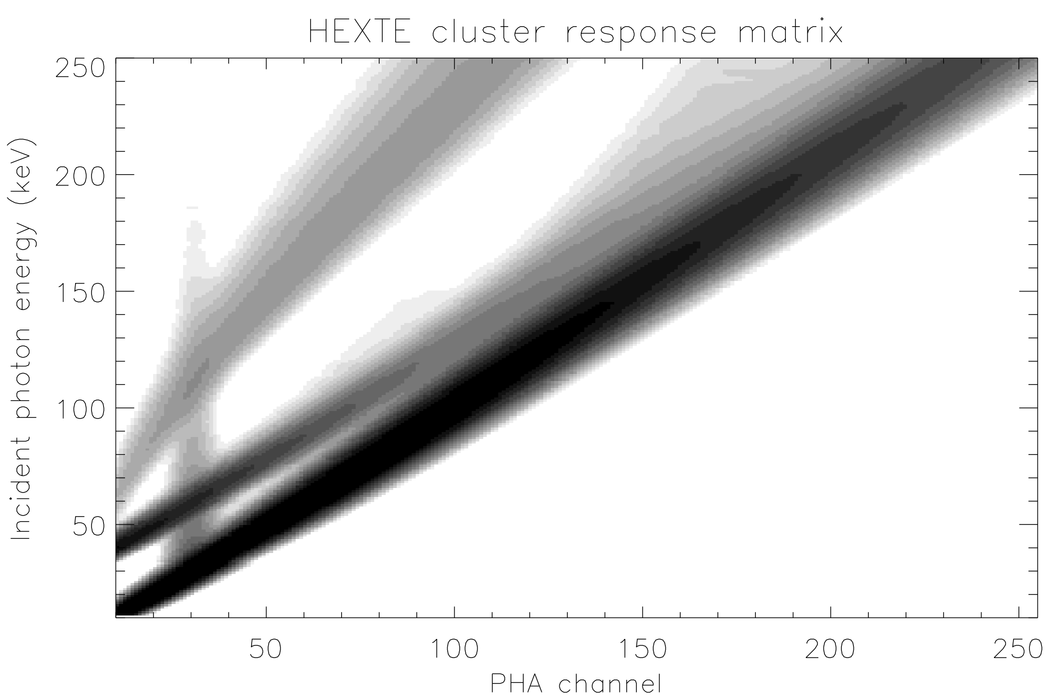

FIGURE 5.6. Model HEXTE detector response matrix, showing the PHA channel spectra produced by photons from 10 to 250 keV in units of counts per (photon cm^{-2}) on a logarithmic scale covering 3 orders of magnitude. The dominant terms are the resolution-broadened photopeak (diagonal) and K-escape interaction peaks (offset diagonal). At a much lower level, Compton scattering and partial energy loss events in the CsI also contribute. The vertical feature is due to K-shell x-rays from the "dead layer" in the detector.

described earlier provides the dominant, diagonal term in this matrix. However, there are significant off-diagonal terms, which are also broadened by the pulse-height resolution. For instance, the K-escape interaction with Iodine reduces an incoming x-ray's apparent energy by 33 keV, giving rise to a secondary peak in the response for a given input energy above this threshold. Other terms in the matrix arise from interactions such as Compton-scattering in the NaI, Compton back-scattering of x-rays from the CsI, and the detection of Iodine K-shell x-rays ejected from a "dead layer" which absorbs incoming x-rays without producing a primary scintillation. The HEXTE team are continually improving the accuracy of the response matrix through Monte-Carlo modelling of the detector materials and geometry, and by comparison with model fits to in-orbit data on bright sources.

5.3.6 Automatic Gain Control and Calibration Spectrum

Even with the magnetic shielding around each detector, the gain (or pulse-height/energy relation) is affected by the magnetic fields encountered throughout an orbit. Secular changes in the gain also occur due to aging of the phototubes. To counteract these effects, the AGC system is designed to stabilize each phoswich detector's gain, such that photon events of a given energy will always produce counts in the same PHA channels. X-rays of 59.6 keV energy from the ^{241}Am source interact in the NaI in coincidence with the associated alpha particle interaction in the gain control detectors

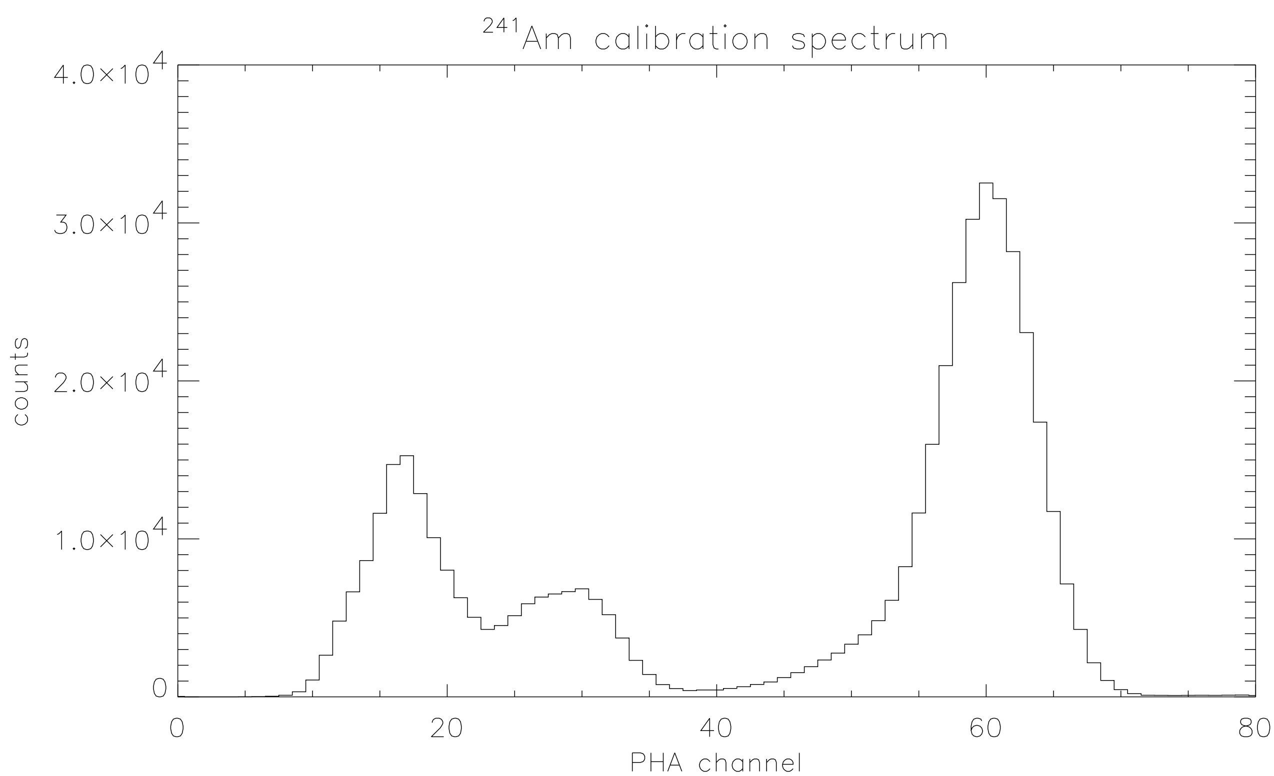

FIGURE 5.7. HEXTE PHA histogram spectrum of the ^{241}Am gain control and calibration source.

(described above). These NaI events are used to provide the gain control feedback signal that adjusts the PHA conversion gain to preserve the energy/PHA channel relation. Coarse gain settings are accomplished by selecting one of 256 high voltage steps (5% gain change per step) and fine steps can be commanded by the AGC system within the range 0.2% to 0.0125%. The AGC updates the gain every 0.5 s. In this manner short-term gain variations are kept to <1%.

All events detected in the phoswiches in coincidence with the α–particle events in the gain control detectors are separately accumulated into a calibration spectrum which is acquired over 32 Instrument Data Frames (8.5 minutes). The result is a very clean ^{241}Am spectrum with a line at 59.6 keV, a blend around 25 to 30 keV, and the L-shell blend around 17 keV (**Figure 5.7**). These spectral features will provide constant monitoring of the gain and resolution for each phoswich detector throughout the mission. With this system, meaningful comparisons and co-additions of datasets may be made between spectral observations taken many months apart.

5.3.7 Background Spectrum and Background Subtraction

The anti-coincidence shielding around each HEXTE cluster vetoes almost all particle scintillations in the detectors. The remaining background spectrum is intrinsic to the HEXTE and is dominated by x-rays emitted in the decay of radioactive products, which are produced by high energy particles interacting with the detector materials (principally lead in the collimators and iodine in the phoswiches themselves). During an orbit of the RXTE this background will vary by a factor of 1.5 to 2. To a first approximation the HEXTE background rate outside the SAA region is proportional to the cosmic ray particle flux, which varies from point-to-point due to geomagnetic cutoff. There are delayed components after passage through the SAA, however, from the activation of radioactive daughters in the detector material itself, as well as in surrounding matter, by SAA protons.

A typical HEXTE cluster background spectrum from RXTE Cycle 1 is shown in **Figure 5.8**. The large spectral feature at 30 keV is a blend of x-ray lines from de-excitation of spallation-created daughters of Iodine in the detector (which decay promptly by K-capture). The next-largest feature at 73-87 keV are K x-rays from the Pb collimators. The total background in the 15-250 keV range is 90-100 count/s per HEXTE cluster.

Background estimation is provided to a very good first order by the source/background beamswitching. The current DEFAULT on-source dwell time for the HEXTE is 16 s, which is the least efficient; however the effectiveness of removing systematic background variations using longer dwells is still under investigation. Estimates of secular variations in the HEXTE background have been made based on HEAO-A4 data, and predict that systematic errors in background subtraction can be kept below the Poisson noise level over a 5×10^5 s observation of a faint source; early results from RXTE Cycle 1 appear to confirm this. However, longer exposure times will not be able to elicit a fainter detection since they will be compromised by cosmic x-ray background fluctuations and other systematics.

For a given 16 s on-source data accumulation, the background rate estimate will be the average of the last 6 s of the previous off-source accumulation plus the first 6 s of the following off-source accumu-

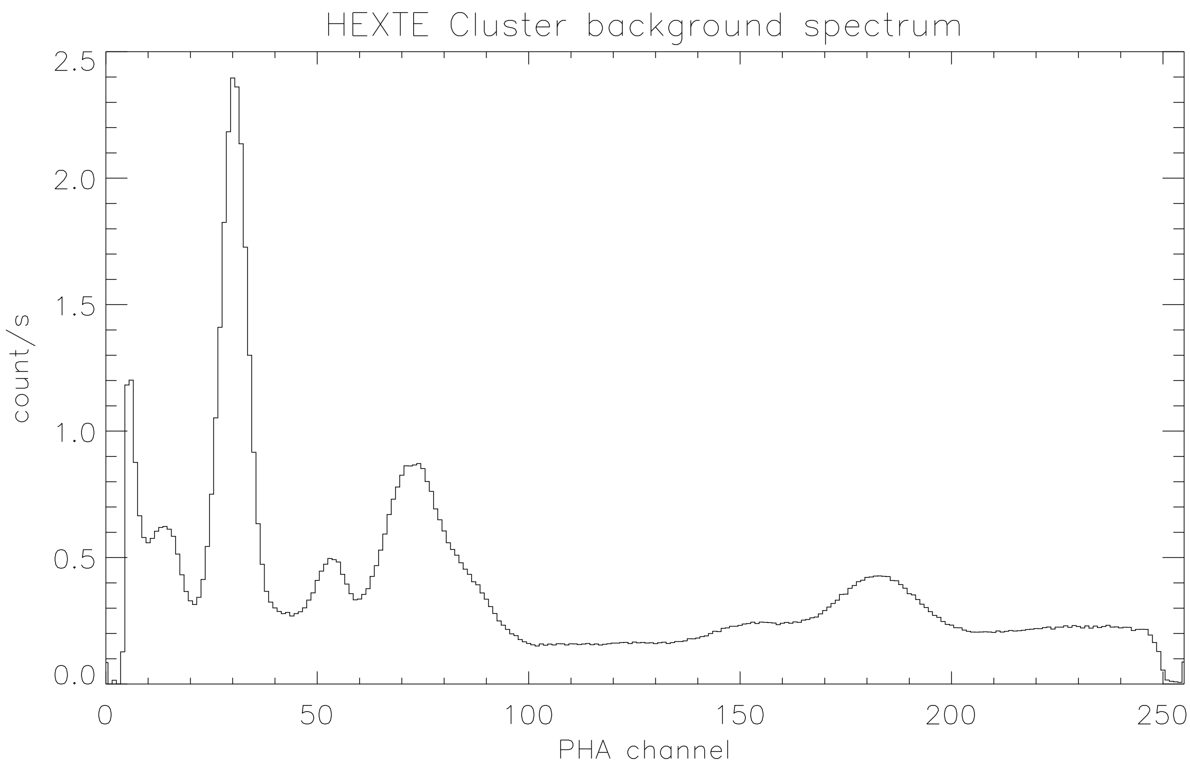

FIGURE 5.8. Measured in-orbit background spectrum for HEXTE cluster A (sum of 4 detectors); the PHA channel number roughly corresponds to energy in keV. Spectral features are due to x-rays from the radioactive decays products induced in the detector materials by energetic particles.

lation. (Remember that 2 s is lost at each end of the off-source observation while the rocking mechanism is in motion). For a typical background rate of 90 count/s per HEXTE cluster, the resulting interpolated background rate is limited by Poisson statistics to about 3% accuracy per cycle.

The observer will typically co-add the two off-source datasets for each cluster, after testing for the presence of a contaminating source. Users may also wish to make an empirical fit to the off-source data versus time for estimating the on-source background contribution. For those observations where off-source observations are not made (e.g. dwelling on-source for temporal investigations of bright sources), the HEXTE background may be modelled using orbital parameters and particle veto rates, but not to the precision available when beamswitching. If background estimates are important in this case, users are encouraged to contact the HEXTE team for advice.

5.3.8 Time Sampling

The HEXTE is capable of time-tagging events to 7.6 µs when used in Event List mode. For high count rate sources, which would saturate the telemetry in this mode, users may still perform fast timing in Temporal Bin Mode, which can produce light curves with time bins as small as 1 ms (**Section 5.6**). Calibration of the absolute timing accuracy is performed via the spacecraft clock, while relative timing tests between the HEXTE and the PCA have verified the coincidence to within the 7.6 μs precision of the HEXTE measurements.

5.3.9 Dead-time and "Lost Events" Data

Dead-time in the HEXTE originates in the detector electronics, which takes 16–30 μs to process a typical scintillation pulse (but much longer for MeV particles, see below). This dead-time is measured for each HEXTE detector assembly by a gated counter which increments for each 1/2 spacecraft clock cycle (1.91 μs) for which the detector electronics is busy. The dead-time counter is also incremented during the on- (off)-source motion of the HEXTE cluster which lasts for 2 s, and is included in the dead-time count for the preceding (following) off-source dwell.

The dead-time counter's value is normally telemetered every 16 s (but as fast as every 1 s in Spectral Bin and Burst List modes). For dead time estimates on shorter timescales, modelling of the source behavior becomes necessary. While an accepted event is being pulse-height analyzed after passing the event-selection criteria, the HEXTE processor can also register the detection of up to 3 *Lost Events*, which are those accepted events which were received while the analyzer electronics were still busy (and the dead time counter was incrementing). Although no energy information is available for these events, they can be used to model bright, rapid (<1s) changes in source flux, and as an aid to absolute flux determination.

During RXTE's Cycle 1 it was discovered that the dead-time counter value alone underestimates the time for which the event selection logic is unavailable for event processing, due to the long periods of dead-time following impacts by high energy particles (known as XULD events). A typical charged particle rate is 150 count/s per phoswich, with each event causing about 2.5 ms of deadtime. This results in a dead-time fraction ~40%, which is equivalent to a reduction in the HEXTE's effective area by the same amount. While the dead-time counter does not account adequately for such events, accurate dead-time estimates can be recovered in the data analysis by a simple combination of dead-time counter values and HEXTE Housekeeping monitor rates (specifically, the ULD and XULD rates), all of which are telemetered every 16 s. On shorter time scales the particle rates are roughly constant, but for a particle rate of 150 count/s, the Poisson uncertainty in the dead-time is 8% on 1 s timescales.

The HEXTE proposal preparation materials, including the PIMMS and *HEXTEmporize* software, as well as the response matrices and background spectra used in XSPEC simulations, include the effects of this additional dead-time at the orbital average level (40%). Therefore, users do not need to make explicit corrections for dead-time when planning HEXTE observations.

5.3.10 Performance changes since launch

5.3.10.1 Changes in spectral resolution

As the photomultiplier tubes age, their efficiency at converting scintillations into an electrical signal is reduced. The Automatic Gain Control system adjusts the detector high voltages to compensate for this effect, such that the energy/channel relation for each detector will remain constant throughout the mission. However, the reduced efficiency is accompanied by a decrease in spectral resolution which cannot be corrected by the AGC system. In the first 15 months of launch, this has caused the FWHM response of an individual detector, expressed as $\Delta E/E$, to increase by 2% (eg. from 15.5% to 15.7% at 60keV). Despite this small increase, acceptable spectral fits may still be obtained to all data throughout RXTE Cycles 1 to 3 using a single set of response matrices.

5.3.10.2 Loss of spectral information from phoswich detector PWB2

On 1996 March 6 at 11:27:12 UT, detector 2 in cluster B (**Figure 5.1**) lost its ability to provide spectral information; all accepted photon events between the lower and upper energy discriminators produce counts in PHA channels 1 and 2 only, regardless of their incident energy in this range. However, data from this detector may still be used to provide a broad-band flux as a function of time. The only drawback is that without a gain calibration spectrum, automatic gain control is no longer possible for this detector, resulting in a drift of the high voltage as the spacecraft passes through the changing magnetic field in its orbit. This translates into gain variations (or variations in the effective upper and lower energy bounds) of around 2% per orbit, with a secular gain decrease of the same order over a month. Bright, soft-spectrum sources will therefore produce count rate variations in this detector due to the changing effective lower energy bound. However, for most faint source observations this effect should be negligible and this detector operates effectively as a 10-250 keV photometer. Note that since the PHA channels 1 and 2 lie outside the pre-defined PHA channel ranges of Archive Temporal Bin mode (q.v.), counts from PWB2 will not appear in this mode's telemetry.

5.4 Data System

The HEXTE data system is based on a Harris MD-80C286/883 microprocessor running at 4.915 MHz which controls data collection, processing and output to the telemetry stream. Available memory includes 128 kilobytes of Read-Only Memory (ROM) and 512 kbyte of Random Access Memory (RAM).

5.4.1 HEXTE Timing Signals and the Instrument Data Frame (IDF)

Data input, data processing, data output, and various functions within HEXTE utilize the following telemetry timing signals as a reference:

- Engineering Major Frame: 64.0 second period
- Science Major Frame: 1.0 second period (64 per Engineering Major Frame)
- Science Minor Frame: 0.03125 second period (32 per Science Major frame)
- Spacecraft clock: 1.048576 MHz frequency.

Since the shortest on-source/off-source beamswitching cycle period is one Engineering Major Frame, consisting of four on- and off-source phases of roughly equal length, it is convenient to define a time unit consisting of 16 Science Major Frames:

- *Instrument Data Frame* (**IDF**): 16.0 s period.

The source/background beamswitching cycle is defined in multiples of this 16 s IDF. All data accumulation and output intervals in the Science Modes described later are multiples or sub-multiples of the IDF.

The HEXTE electronics also contain two crystal-controlled oscillators for precision timing: a 9.830 MHz oscillator provides a timing reference for the microprocessor, and an 8.000 MHz oscillator provides a reference frequency for the electronics' pulse height and pulse shape time-to-digital converters.

5.4.2 Event Selection

The event selection logic provides the criteria used to accept or reject an event. In addition to anti-coincidence shield rejection, the input pulse is compared against lower and upper levels by discriminators, and *Pulse Shape Discriminators* (**PSD**s) define an acceptable range in pulse rise-time. These will normally be used to provide clean NaI-only pulses with total energy loss measured and maximum background rejection. These good events are passed to the pulse height analyzers which convert the energy-related pulse height into an 8-bit channel number. *Pulse Shape Analyzers* (**PSA**s) convert the rise-time-related pulse shape into a 6-bit number.

5.4.3 Event Definition

For each phoswich event that passes the event selection logic, data from the various detectors and other subsystems are combined to form the 7-byte *event code* that contains all the possible information about the event. The event code byte map is summarized in **Table 5.2**. This event code is the basis for all scientific processing; if the event selection logic does not pass an event, it cannot be included in the HEXTE telemetry. Lost Events (defined earlier) are counted and this number is included as a 2-bits in the event code of the event being analyzed when they arrived.

From Table 5.2 it can be seen that event code bytes 5 and 6 are unnecessary for most user observations, since these contain either redundant time counters, or flags which are zero under normal operation. Byte 4 contains diagnostic pulse shape information, which may be used for subsequent event selection but can be omitted for bright sources, and for observations with a high setting for the Lower Energy Bound. The event information of interest to most users is therefore contained in bytes 0-3, which are available directly in Event List Science Mode, or can be reformatted into one of the binned Science Modes to keep within telemetry constraints when the count rates are high.

5.5 Standard Telemetry Formats and Data Products

The HEXTE flight software has three basic types of telemetry data products: Housekeeping, Standard Modes, and Science Mode. Housekeeping and data from the Standard Modes are produced in fixed format for every HEXTE pointing to provide basic spacecraft diagnostic information, and basic spectral and timing information for the source under study. The Science Mode is selected and configured by the user to meet the scientific needs of their observing program, and is described along with other Guest Observer configurations in the following section. Housekeeping and Standard Modes run continuously and produce roughly 1 kbit/s of telemetry data, leaving 4 kbit/s (on average) for the selected Science Mode.

5.5.1 Housekeeping

Housekeeping contains (1) the analog-to-digital conversions of various temperatures, voltages, and currents, which are available on 64 and 128 s timescales, (2) the instrument configuration (i.e. digital status) which is available on 16, 64 and 128 s timescales depending upon the parameters, and (3) the rates accumulators for all discriminator and coincidence functions, which are available every 16 s. Phoswich-related rate accumulators, which record particle events responsible for dead time, collect data for 4 s sequentially at each of the 4 phoswiches.

5.5.2 Standard (Archive) Modes

The purpose of the HEXTE Standard Modes (also known as Archive Modes) is to provide a basic temporal and spectral record of every source observed, independent of the Science Mode chosen by the user. Two Standard Mode data products are generated within HEXTE every 16 s in a fixed format. The dead time for each phoswich detector is included with the Standard Modes data each IDF (16 s), and the data products themselves are described below:

5.5.2.1 Archive Spectral Bin Mode (Energy Spectra)

This mode produces a compressed pulse height histogram (energy spectrum) for each phoswich detector every 16 s. The first 64 PHA channels are combined two-at-a-time into the first 32 archive spectrum bins with 16-bit depth per bin; the second 64 phoswich PHA channels are combined four-at-a-time into the next 16 archive histogram bins with 8-bit depth per bin; and the final 128 phoswich PHA channels are combined eight-at-a-time into the last 16 archive histogram bins with 8-bit depth per bin. This compression causes only a small loss of information; virtually all cosmic x-ray sources

TABLE 5.2. Contents of the seven HEXTE event code bytes generated for each processed event.

Byte	Bit	Description[1]	Byte	Bit	Description[1]
0:	0	PHA Bit 0 (≈1 keV)	**4:**	0	Science Major Frame Counter Bit 3 (8 s)
Pulse Height channel	1	PHA Bit 1 (≈2 keV)	**Pulse Shape channel**	1	AGC Flag
	2	PHA Bit 2 (≈4 keV)		2	PSA Bit 0
	3	PHA Bit 3 (≈8 keV)		3	PSA Bit 1
	4	PHA Bit 4 (≈16 keV)		4	PSA Bit 2
	5	PHA Bit 5 (≈32 keV)		5	PSA Bit 3
	6	PHA Bit 6 (≈64 keV)		6	PSA Bit 4
	7	PHA Bit 7 (≈128 keV)		7	PSA Bit 5
1:	0	Event Time Bit 0 (7.629394535 μs)	**5:**	0	Shield 1 Flag
7.63 μs	1	Event Time Bit 1 (15.25878907 μs)	**Shield Event Flags**	1	Shield 2 Flag
timing	2	Event Time Bit 2 (30.51757813 μs)		2	Shield 3 Flag
	3	Event Time Bit 3 (61.03515625 μs)		3	Shield 4 Flag
	4	Event Time Bit 4 (122.0703125 μs)		4	Shield 5 Flag (not used)
	5	Event Time Bit 5 (244.140625 μs)		5	CsI (PSULD) Flag
	6	Event Time Bit 6 (488.28125 μs)		6	XULD Flag
	7	Event Time Bit 7 (976.5625 μs)		7	Test Pulse Generator (TPG) Flag
2:	0	Event Time Bit 8 (1.953125 ms)	**6:**	0	Science Major Frame Counter Bit 0 (1 s)
2 ms	1	Event Time Bit 9 (3.90625 ms)	**Frame**	1	Science Major Frame Counter Bit 1 (2 s)
timing	2	Event Time Bit 10 (7.8125 ms)	**counters**	2	Science Major Frame Counter Bit 2 (4 s)
	3	Event Time Bit 11 (15.625 ms)		3	Science Major Frame Counter Bit 3 (8 s)
	4	Event Time Bit 12 (31.250 ms)		4	Science Major Frame Cntr Bit 4 (16 s)
	5	Event Time Bit 13 (62.500 ms)		5	Science Major Frame Cntr Bit 5 (32 s)
	6	Event Time Bit 14 (125.00 ms)		6	Science Major Frame Cntr Bit 6 (64 s)
	7	Event Time Bit 15 (250.00 ms)		7	Science Major Frame Cntr Bit 7 (128 s)
3:	0	Event Time Bit 16 (500.00 ms)			
Detector	1	Lost Events Counter Bit 0			
Identity,	2	Lost Events Counter Bit 1			
Lost	3	Detector ID Bit 0			
Events,	4	Detector ID Bit 1			
1 s	5	Science Major Frame Cntr Bit 0 (1 s)			
timing	6	Science Major Frame Cntr Bit 1 (2 s)			
	7	Science Major Frame Cntr Bit 2 (4 s)			

1. The time or spectral sampling precision corresponding to each event bit is shown in parentheses.

in the 10-250 keV range decrease in intensity with energy, while the HEXTE's FWHM spectral resolution (measured in PHA channels) also broadens with energy.

5.5.2.2 Archive Temporal Bin Mode (Light Curves)

This mode produces four light-curves with 16-bit bins from the sum of all 4 phoswich detectors in a cluster, with 1 s temporal sampling every 16 s. The four light curves represent the PHA channel (and, therefore, approximate energy in keV) ranges of 15-29, 30-61, 62-125, and 126-250.

5.6 Guest Observer Configurations

The HEXTE observing configuration is based upon a dictionary of 23 different commands, each with an associated set of parameters. Most of these commands are outside the domain of users, including the event selection logic, the AGC configuration, and the heater settings. Those settings which must be defined for each HEXTE cluster by the user are listed below:

- Configure the source/background beamswitching mechanism
- Select the Lower Energy Bound
- Select the Science Mode telemetry format, and its parameters
- Configure the Burst Trigger (if selected)

The HEXTE clusters may be configured together, or separately (e.g. with one cluster staring on-source and the other performing source/background switching). If a user wishes a configuration other than that available to users in general, the HEXTE team must be contacted in advance.

5.6.1 Beamswitching (Rocking) Mechanism

The rocking mechanism is configured by selecting:

1. `On-source dwell time:` 0 (continuous stare), 16, 32, 64, 128 s, or DEFAULT (currently 16 s).

If "DEFAULT" is selected, the HEXTE team will set the dwell time to provide the best background subtraction, as determined from in-orbit calibrations. Note that 4 s is always lost from the off-source dwell to allow for motion off- and then back on-source during the time the other cluster is dwelling on-source (Figure 5.3). The selectable beamswitch (rocking) angles for each cluster are either:

2. `continuous stare (dwell = 0s):` 0° (i.e. on-source), +1.5, -1.5, +3.0, -3.0 degree positions, or
   `two-sided source/background switching:` ±1.5 or ±3.0 degree beamswitching, or
   `one-sided source/background switching:` +1.5, -1.5, +3.0, -3.0 beamswitching

Users may also request the DEFAULT pointing directions, which will be on-source for stare (0 s dwell time) observations, or $\pm 1.5^{\circ}$ source/background switching otherwise. Users should research and specify the sky positions of any possible contaminating sources within a 2.5° radius of their source of interest, so that contaminating sources in the background fields can be avoided by using 3° or one-sided rocking once their observation is scheduled. In such cases, 3° two-sided rocking is normally preferred, since users will still have two independent measurements of the background. The HEXTE team have provided a software program, *HEXTErock*, which calculates the sky coordinates of the various off-source cluster positions for a given observing configuration. Using a graphical interface, *HEXTErock* may also be accessed on the World Wide Web via the RXTE Guest Observer Facility web site.

5.6.2 Lower Energy Bound

The lower energy bound of the science processing from the phoswich detectors (which includes both Standard and Science Mode data) can be selected in the range 5 keV to 30 keV, to the nearest 0.2 keV. Values between 10 and 30 keV prove the most useful, and the DEFAULT value of 10 keV will be the most commonly scheduled, although usable spectral data will begin at around 15 keV.

For a medium-bright steep spectrum source, however, a user may be able to keep within telemetry limits and still use Event List mode (see below) by increasing the lower energy threshold and thereby sacrificing the lowest energy PHA channels. For very bright sources, or high background conditions, increasing the lower energy bound will also decrease the overall detector dead time, and the consequent need for Lost Events data Note though that increasing the lower energy bound will also prevent events below the new threshold from appearing in the Standard Modes data products.

Setting a lower energy bound *below* the default value of 10 keV does increase the overlap in spectral coverage with the PCA instrument, but the HEXTE's decreased effective area and higher background rate at low energies makes such settings of dubious practical use, except for spectral features in the PCA/HEXTE overlap range, and for burst-triggering. Therefore, if a lower energy bound below the DEFAULT value of 10 keV is desired, users should contact the HEXTE team for advice.

5.6.3 Science Modes

In addition to the Standard Modes provided for all observations, each HEXTE cluster provides a Science Mode which can be specified by the user. There are three basic Science Modes. Event List mode transmits information about each incoming event, and therefore the telemetry rate depends on source strength. Spectral Bin mode produces binned PHA spectral data with up to 256 spectral bins at 1 to 16 s intervals, while Temporal Bin mode produces light-curves with sub-second time bins covering up to 8 contiguous spectral bands. Both of the binned modes have a fixed telemetry rate for the user's selected spectral and temporal sampling. A fourth mode (Burst List) can be enabled to run in parallel with any of these three basic Science Modes to capture photon events from rapid outbursts. Finally, if the Standard Mode data products prove sufficient for a user's scientific goals, then "IDLE" Science Mode may be selected for one or both of the HEXTE clusters.

All Science Mode packet data headers (sent every 16 s) contain the dead time average per detector, the rocking mechanism position, and the parameters of the particular Science Mode. The HEXTE Science Mode is normally implemented by uplinking a table of parameters and then selecting them. It is not necessary for both clusters to use the same Science Mode, but this is usually desirable, especially if source/background beamswitching is selected for both.

The HEXTE Science modes, and their relevant parameters, are described below. The HEXTE Feasibility Chapter gives more information on their uses, with specific examples. The HEXTE team have also provided a software tool, *HEXTEmporize*, to assist users in selecting the appropriate parameters for their observations, consistent with their source count rates and the HEXTE's telemetry constraints.

5.6.3.1 Event List Mode (Event-by-Event)

The Event List mode is an event-by-event list of a user-selected subset of the 7-byte event code for each photon detected. This list is stored in a variable length buffer, since the number of events are dependent on the source intensity, up to the maximum buffer size which corresponds to a telemetry rate of 23 kbit/s per HEXTE cluster. Any combination of the 7 bytes comprising the event code may be selected for inclusion in telemetry, but only the first 5 bytes provide useful information to observers. Subsequent data analysis will be able to generate light curves and/or spectra, depending upon the event code bytes selected. The user must therefore make the following selections:

1. `Include byte #0?`: Yes or No...
2. `Include byte #1?:` Yes or No...
3. `Include byte #2?:` Yes or No...

...and so on for all 7 bytes. Refer to **Table 5.2** for the contents of each byte in the 56-bit event code. This mode will be appropriate for the majority of sources observed by the HEXTE; faint sources may be observed using bytes 0-4 for maximum spectral and temporal sampling.

5.6.3.2 Spectral (Histogram) Bin Mode: Energy Spectra at 1 s to 16 s intervals

The Spectral Bin mode produces a pulse height histogram (energy spectrum) at time intervals from 1s to 16 s, either for each detector, or, alternatively for the sum of all 4 detectors in a cluster. This mode is appropriate for producing spectra of bright sources which cannot be accommodated by Event List mode. The histograms can be tailored to each observation and telemetry rate by choosing the frequency at which spectra are generated, the grouping of PHA channels into spectral bins, and highest PHA channel (or highest energy) of interest. The count capacity of each bin must be chosen to be adequate for the expected count rates in each bin. The selectable parameters of this mode are:

1. `Number of histogram spectra per detector per IDF (16s interval):` 2, 4, 8 or 16 (corresponding to one histogram spectrum every 8, 4, 2 or 1 s).

   Note that the dead time counter will be transmitted with each histogram spectrum, i.e. as fast as every 1 s if 16 spectra per IDF is selected. This is the shortest timescale on which the dead time counter can be sampled in any Science Mode.

2. `Number of distinct detector IDs per cluster:` 4 (separate detector spectra) or 1 (= sum of 4 detectors). Separate detector spectra are always recommended.

These first two parameters determine the total number of spectra produced per IDF. The energy coverage and spectral binning of these spectra are set by specifying:

3. `Highest PHA channel # required` (roughly, the highest energy in the spectrum in keV): 127, or 255 (remember that HEXTE PHA channels are numbered starting from 0).

4. `Number of spectral bins: 64,` 128, or 256 (but never more than the highest PHA channel #+1).

Each spectral bin will then bin together a number of PHA channels given by (highest PHA channel+1) ÷ (number of spectral bins per histogram). Since the PHA channels over-sample the HEXTE's energy resolution by at least a factor of 4, this rebinning causes minimal loss of spectral information.

Finally the capacity of the spectral bins (maximum number of counts they can hold) must be specified:

5. `Depth of the spectral bins:` 4, 8 or 16 bits (0-15, 0-255 or 0-65535 counts).

5.6.3.3 Temporal (Multiscalar) Bin Mode: Light Curves in 1 to 8 Spectral Bands

This telemetry mode provides light curves with time bins from 0.98 ms to 1 s, with 2, 4, 6 or 8 spectral energy ranges (hence the "Multi-"scalar name). These data may be provided for each detector in a cluster, or the sum of all 4 detectors. This mode is only applicable to observers of very bright sources and should only be selected in consultation with the HEXTE team.

One of the (up to) 8 light curves may be assigned to accumulate the Lost Events data on the same time scale as the other light curves. This enables the proper intensity to be calculated for each time bin for a very bright source. Note that as for Event List mode, the dead time is reported only as a 16-s average at the end of each IDF. The user-selectable parameters for this mode are:

1. `Total number of light curve spectral bands:` 1 to 8

2. `Include a Lost Events light curve in one of these bands?:` Yes or No

3. `Number of distinct light curve detector IDs per cluster:` 4 detectors, or 1 = sum of 4

These determine the total number of light curves telemetered in this mode. The spectral bands covered by each light curve are then set by specifying:

4. `Lowest PHA channel # for 1st light curve spectral band:` 0 to 254
5. `PHA upper channel # for 1st spectral band's light curve:` 1 to 255
   `PHA upper channel # for 2nd spectral band's light curve:` 2 to 255
   `PHA upper channel # for 3rd spectral band's light curve:` 3 to 255...

...and so on for the number of spectral bands selected. Note the important restriction that the channel ranges so specified *must be contiguous and in ascending order.* The HEXTE Feasibility Chapter provides recommended values for the PHA channel boundaries.

Finally, the time sampling and time bin depth for all the light curves must be selected:

6. `Number of time bins per IDF (16s interval):` 128, 256, 512, 1024, 2048, 4096, 8192, or 16384. (These correspond to time bin sizes of 125, 62.5, 31.25, 15.625, 7.8125, 3.09625, 1.953125, or 0.9765625 ms).
7. `Time bin depth:` 4, 8 or 16 bits (0-15, 0-255 or 0-65535 counts/bin).

5.6.3.4 Burst Trigger/Burst List Mode

This is a specialist mode used to capture a "snapshot" of full temporal/spectral resolution event data in cases when the source is too bright for Event List mode. If this mode is desired, users must first contact the HEXTE team for advice on the settings described below.

When enabled, the Burst List mode runs in parallel with one of the three primary Science Modes, accumulating an Event List (event code bytes 0-3) in a circular buffer containing 25560 events per cluster. Upon satisfaction of a burst trigger, the buffer accumulates a software commandable number of post trigger events, then freezes its contents, and awaits the command to download its contents in place of the normal science data. In addition, since this mode is expected to be used for high and variable count rates, dead time counter values are stored at 1 s sampling for the 12 IDFs after the trigger.

After downloading the contents of the Burst List buffer in about 2.5 minutes, the data processor awaits a ground command to reset the buffer and re-enable the trigger, and then automatically returns telemetry to the selected Science Mode. Dead time counter values will also be available at 1 s sampling for the 12 IDFs after the trigger.

A burst trigger can be generated by any of four sources: a digital ground command, a trigger received from the EDS electronics, a trigger received from the other HEXTE cluster, or an internally calculated burst trigger. Ground commands can disable the response from internal or external sources of triggers. The ground command trigger can also be used to take a "snapshot" of a bright source will full spectral and temporal resolution.

A local burst-trigger can be issued on the detection of an increase in the recent average event rate exceeding a threshold, which is user-selectable. However, this internal trigger mode will only be useful for observations with no source/background switching, i.e. staring on-source, since a spurious trigger would be generated each time a cluster moved on- or off-source.

The complete list of user parameters for this mode is:

1. `Set burst trigger:` NO (i.e. off), EXTERNAL (from the EDS, or other cluster), or INTERNAL.

Then if the INTERNAL burst trigger is set:

2. `Integration interval:` 3.9, 7.8, 15.6, 31.3, 62.5, 125, 250, 500 ms, 1, 2, 4, 8, or 16 s, (corresponding to 4096, 2048, 1024, 512, 256, 128, 64, 32, 16, 8, 4 or 1 intervals per IDF)
3. `No.of integration intervals (`***m***`)for running average:` 4, 8, 16, 32, 64 or 128
4. `Trigger` χ^2 `threshold:` 1 to 100 (for internal trigger only)
5. `Percentage of events to be stored before/after trigger:` set in 0.5% steps from 0-100%

The χ^2 threshold statistic is calculated from the number of counts n_1 in the most recent integration interval, and the total number of counts $N_m = \Sigma\, n_i$ summed over m intervals:

$$\chi^2 = \frac{(n_1 - N_m/m)^2}{(n_1 + N_m/m^2)}$$

Therefore, triggers will occur both for an increase or drop in count rate. For this reason, the internal burst trigger is normally activated only when the cluster is staring on-source, since source/background beamswitching would otherwise cause false triggers which do not relate to the source.

Once the trigger is satisfied, the Burst List is frozen in the HEXTE data buffer until it is downloaded to ground and Burst List processing is commanded to resume. However, subsequent triggers are still counted by the on-board processor, and this number is telemetered to ground (the counter is reset upon dumping the contents of the Burst List buffer).