OPERATION AND PERFORMANCE OF THE OSSE INSTRUMENT

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Abstract

The Oriented Scintillation Spectrometer Experiment (OSSE) on the Arthur Holly Compton Gamma Ray Observatory is described. An overview of the operation and control of the instrument is given, together with a discussion of typical observing strategies used with OSSE and basic data types produced by the instrument. Some performance measures for the instrument are presented, obtained from pre-launch and in-flight data. These include observing statistics, continuum and line sensitivity, and detector effective area and gain stability.

Introduction

The Oriented Scintillation Spectrometer Experiment (OSSE) is one of four scientific instruments on the Arthur Holly Compton Gamma Ray Observatory. Its primary capability is spectroscopy of astrophysical objects in the 0.05 to 10 MeV energy range. The instrument also has a number of secondary capabilities, including spectroscopy of gamma rays and neutrons with energies above 10 MeV; collection of timed-tagged spectral data for studies of pulsars and other variable sources; and collection of high-time resolution data in response to cosmic burst or solar flare triggers from the BATSE instrument on GRO.

Since the launch of GRO, the OSSE instrument has performed well, providing data on a large number of objects, including X-ray binary stars, pulsars, the Galactic Center and other galaxies and quasars. Analysis of the data collected by OSSE since launch has provided information on the in-flight performance of the instrument, particularly the background rates detected by the instrument and consequently the continuum and line sensitivity of the instrument. Some details of the in-flight performance of OSSE are presented, together with information on the instrument capabilities, operations, and a discussion of observing strategies applicable to OSSE. More detailed descriptions of OSSE and its associated data products are given in Johnson *et al.* (1989) and Strickman *et al.* (1989). Some details of the scientific objectives and methods of achieving these objectives for the OSSE instrument are given in Kurfess *et al.* (1989).

Instrument Description

The OSSE instrument (Figure 1) consists of four actively shielded NaI(Tl)-CsI(Na) phoswich detectors. Each detector has a 3.8° × 11.4° (FWHM) field of view, defined by a passive tungsten collimator. Each detector has an independent, single-axis orientation system which provides 192° of positioning in the GRO XZ plane, from 51° behind the +Z axis towards the −X axis to 51° below the +X axis towards the −Z axis. The long dimension of the collimator field of view is perpendicular to the XZ plane. The OSSE pointing system permits offset pointing from a target position for background measurements and also multiple target observations. Within the positioning range the four detectors are unobscured over 94° of position angle, from 6.5° behind the +Z axis to 2.5° above the +X axis. Beyond these angles the OSSE detectors block each other, and only either the upper or the lower detectors are unobscured.

OSSE INSTRUMENT

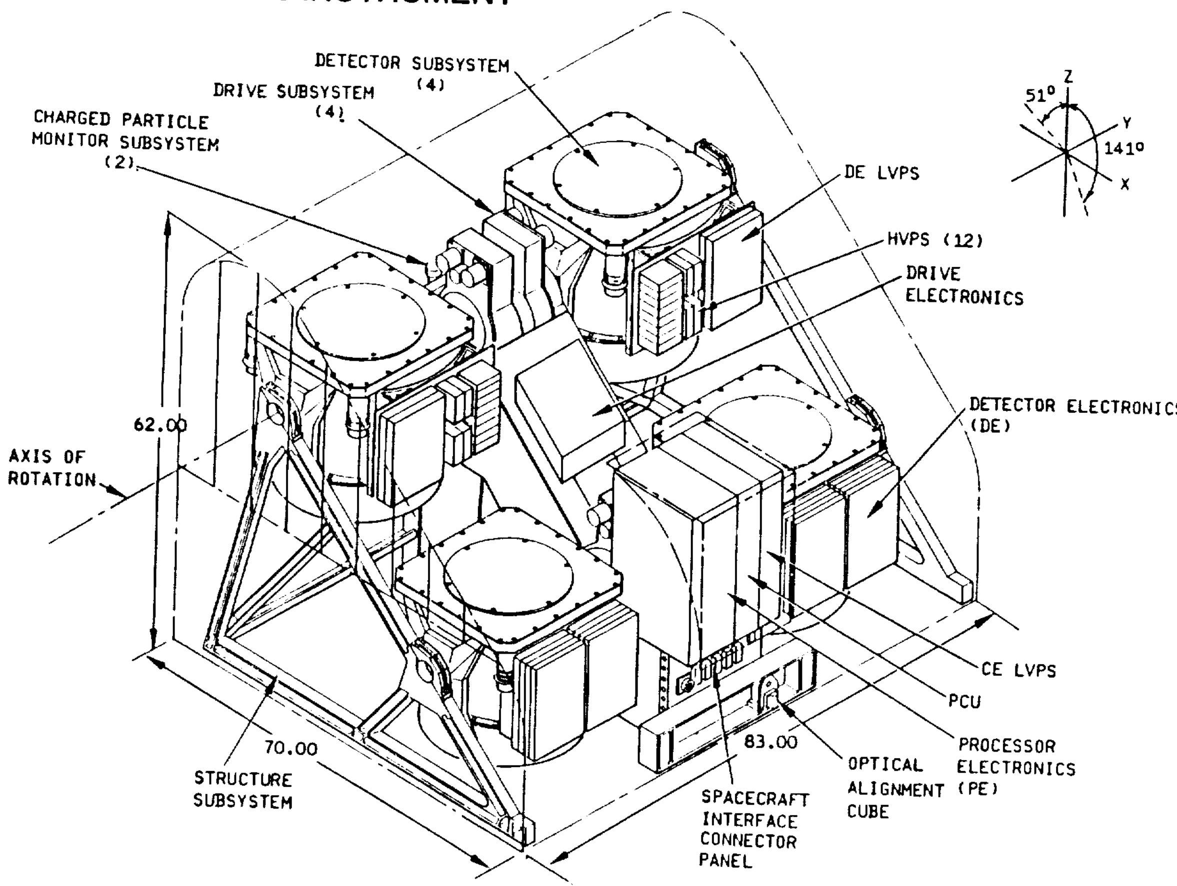

Figure 1: The OSSE Instrument

The detectors are controlled by a Central Electronics (CE) unit which coordinates the operation of the detectors, collects and formats data produced by the detectors, and provides the power, command and telemetry interface with the GRO spacecraft. A thermal shield consisting of multi-layer insulation covers the detectors and central electronics. A summary of the instrument characteristics is given in Table 1.

Figure 2 shows a single OSSE detector. The principal element of an OSSE detector is the 13-inch diameter phoswich scintillation crystal. The phoswich is 7 inches thick, viewed by 7 photomultiplier tubes, and fronted by the tungsten collimator. The phoswich and the collimator are surrounded by an annular anticoincidence shield, comprised of four NaI(Tl) scintillation segments. Each shield segment is viewed by 3 PMTs. The front of the detector is covered by a plastic scintillation detector sheet for charged particle detection, viewed by 4 PMTs.

In the phoswich, the 3-inch thick CsI crystal is optically coupled to the 4 inch thick NaI crystal, and provides active anticoincidence veto for the NaI crystal. Phoswich events from the PMTs are processed through three separate pulse-height and pulse-shape analysis systems, and the different scintillation decay time constants of the NaI and CsI crystals are used to select NaI events by pulse-shape discrimination. The three event analysis systems cover 0.05 – 1.5 MeV (Low), 1 – 10 MeV (Medium), and >10 MeV (High) energy ranges. The pulse-shape discrimination in the high energy range is also used to separate gamma ray and neutron events in the NaI portion of the phoswich, using the differing time characterstics of the secondaries produced by these interactions.

Table 1: OSSE Characteristics Summary

Detectors	
Type:	4 identical NaI-CsI phoswiches, actively-shielded, passively collimated
Aperture Area (total):	2620 cm^2
	1920 cm^2 at 0.511 MeV (photopeak)
Field-of-View:	$3.8^\circ \times 11.4^\circ$ FWHM
Energy Resolution:	8.2% at 0.661 MeV
	3.8% at 6.13 MeV
Time Resolution:	4 – 32 sec spectrum integrations
	0.125 or 1 msec in Pulsar EBE mode
	4 – 512 msec in Pulsar Rate mode
	4 – 32 msec in Burst mode
Experiment Sensitivities (500000 sec)	
0.05 – 10 MeV Line:	$\sim 3 - 8 \times 10^{-5}\ \gamma\ cm^{-2}\ s^{-1}$
0.05 – 1 MeV Continuum:	$0.005 \times$ Crab
1 – 10 MeV Continuum:	$0.05 \times$ Crab
Gamma Ray Bursts:	1×10^{-7} erg cm^{-2}
Solar Flare Line (10^3 sec flare):	$1 \times 10^{-3}\ \gamma\ cm^{-2}\ s^{-1}$
Solar Flare Neutrons (> 10 MeV):	5×10^{-3} n $cm^{-2}s^{-1}$
Pointing System	
Type:	Independent Single Axis
Range:	192° about the S/C Y-axis
Accuracy:	6 arcminutes
Speed:	2°/sec (max)
GRO – OSSE Interface	
Weight:	1820 kg
Power:	192 watts
Telemetry:	6492 bits/sec

Validated events from the phoswich must escape veto by the NaI annular shield and the plastic charged particle detector and pass pulse shape discrimination in the phoswich. The pulse height and pulse shape of each of these validated events are each digitized into 8 bits (256 channels) in each of the 3 energy ranges. The digitized pulse shapes are passed through energy-dependent pulse shape discrimination, for optimum rejection of events with energy loss shared between the NaI and the CsI in the phoswich.

The gain of each detector is controlled by an AGC system, which uses an LED flasher optically coupled to the phoswich. The high voltage applied to each PMT is controlled to keep the response to the LED flashes stable. The LED flashes are also monitored by a PIN diode light detector, with the PIN diode output used to control and stabilize the brightness of the LED. The gain of each detector is independently monitored with an internal ^{60}Co radioactive source, having an activity of 2 – 3 nanocuries.

A variety of data types are produced by the instrument, covering scientific spectral and timing data, calibration data and housekeeping data. Each detector independently accumulates spectra in the Low, Medium and High energy ranges for a selectable duration between 2 and 32 seconds. At the end of each accumulation the spectra are transferred to the CE and inserted into the OSSE telemetry stream. The Low and Medium spectra are 256 channels each, and the High range data consists of 16 channels of neutron data and 16 chan-

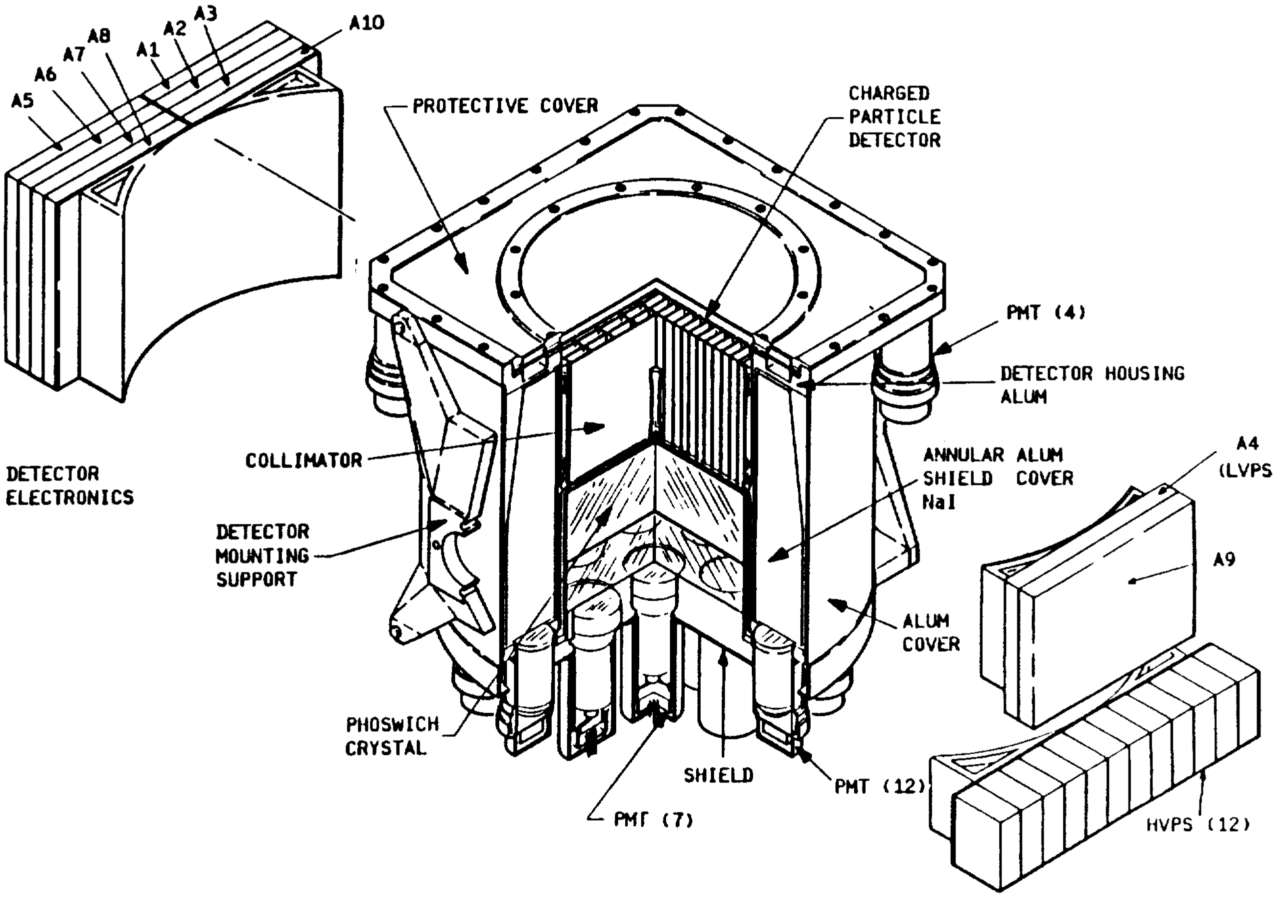

Figure 2: An OSSE Detector

nels of gamma-ray data. At standard gain the channels are nominally 6 keV wide in the Low energy range, 40 keV in the Medium range and 16 MeV in the High range.

OSSE supports a wide range of timing data types for variable sources. For pulsars and other rapidly variable sources, OSSE supports two pulsar data modes. Individual events may be time-tagged with a precision of either 0.125 or 1 milliseconds, in Event-by-Event (EBE) data. Alternatively, event count rates may be sampled over intervals from 4 to 512 milliseconds in Rate pulsar data. Corresponding energy information is also available for each of these pulsar data types. Either EBE or Rate pulsar data can saturate the OSSE telemetry capabilities, and so the event rate is restricted to events with energies in one of up to eight selectable energy range windows. EBE events are telemetered with the energy window identifier and 5 bits of energy information within the window energy range. Rate samples are identified by energy window only.

In addition to pulsar data obtained from phoswich events, OSSE can also respond to isolated events such as gamma ray bursts or solar flares by collecting 4096 samples of shield event rates at sample intervals of between 4 and 32 milliseconds, with shield events having energies between 0.1 and 8 MeV. This collection can be triggered by either OSSE shield rates or a trigger signal from BATSE. Operationally, only BATSE triggers have been used to initiate burst data collections.

Energy calibration spectra are collected in the Low and Medium energy ranges from tagged decay events in the internal ^{60}Co sources. Diagnostic information from each detector includes one dimensional energy spectra from a calibration pulse height analyzer, and two dimensional energy and pulse shape information from two separate pulse height analyzers. Diagnostic information may be collected from several different sources in

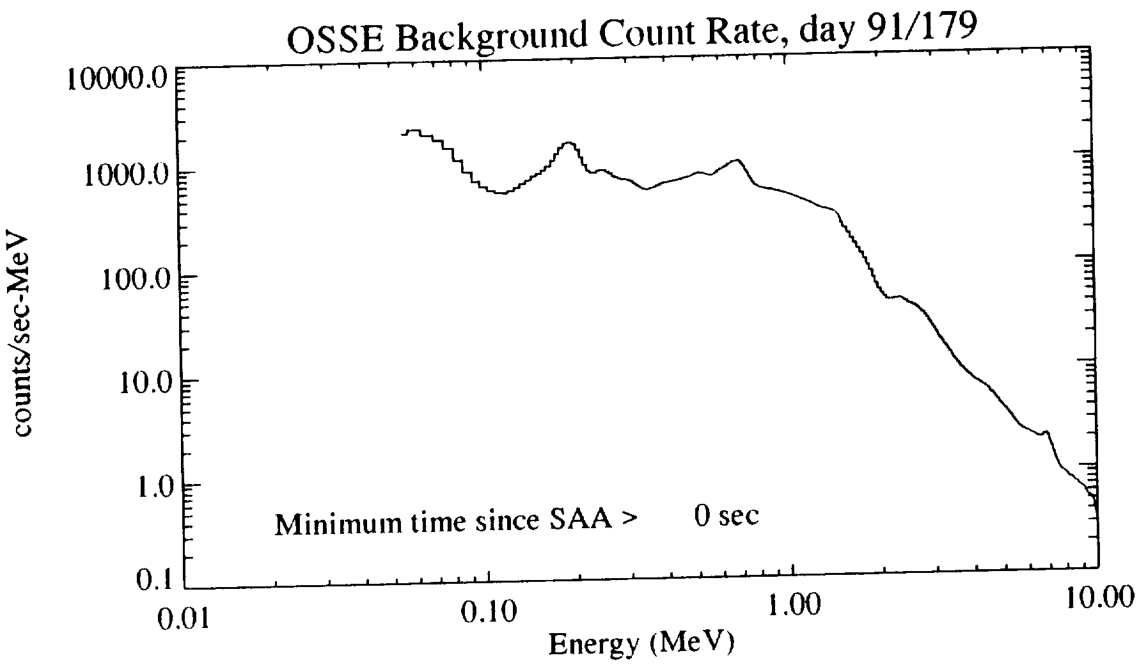

Figure 3: Typical OSSE Background Spectrum

each detector, including the phoswich, selected shield segments, the LED flasher, the PIN diode, and the Charged Particle Detector.

Instrument Capabilities and Performance

The performance and capabilities of OSSE were estimated before launch based on instrument calibration using a number of different radioactive sources and analysis of its expected response to the estimated orbital background flux by means of Monte Carlo simulations. However, the best measure of performance is provided by flight data. GRO was launched into a 28.5° inclination orbit, with an injected altitude of 462 km. As expected, the background rate in the detectors dominates the flux from most celestial gamma ray sources. The background is principally due to cosmic ray interactions and trapped particles in the detectors and the rest of the spacecraft. Figure 3 shows a typical background spectrum measured by OSSE, covering the Low and Medium energy ranges. A number of features are seen in the spectrum, identified with radioactive products resulting from energetic particle collisions in the spacecraft and detectors.

Figure 4 shows in summary form a number of features of the OSSE response. The plot shows a day of data from detector 3, for day 138 of 1991 (May 18), two days after the start of the first Phase I science observations by GRO. During this time OSSE observed the Crab Nebula and Pulsar as its primary target and the pulsar PSR 1957+20 as its secondary target (see below). The 24 hours of the day are marked horizontally across the plot. The count rate (counts/second) for fully validated phoswich events is shown in a number of different energy ranges. From the bottom to the top on the page the curves show the rates in the 0.05 – 0.1, 0.1 – 0.3, 0.3 – 0.8, 0.8 – 1.5, 1.5 – 3.0, 3.0 – 10.0 and >10 MeV energy ranges. Above these phoswich event rate curves, the event rates in the four shield segments of the detector are shown superimposed in a single plot. At the top of the page the calculated geomagnetic rigidity in GeV for the GRO position is shown.

A number of features are of interest in these plots. The 9 passages of GRO through the South Atlantic Anomaly for the day are readily apparent by the dropout of the count rates as the detector high voltages are turned off during these times. Approximately 12% of the day is spent in the SAA. The rates in the 0.1 – 3.0 MeV energy ranges show decays with a characteristic half-life of 25 minutes following the exit from

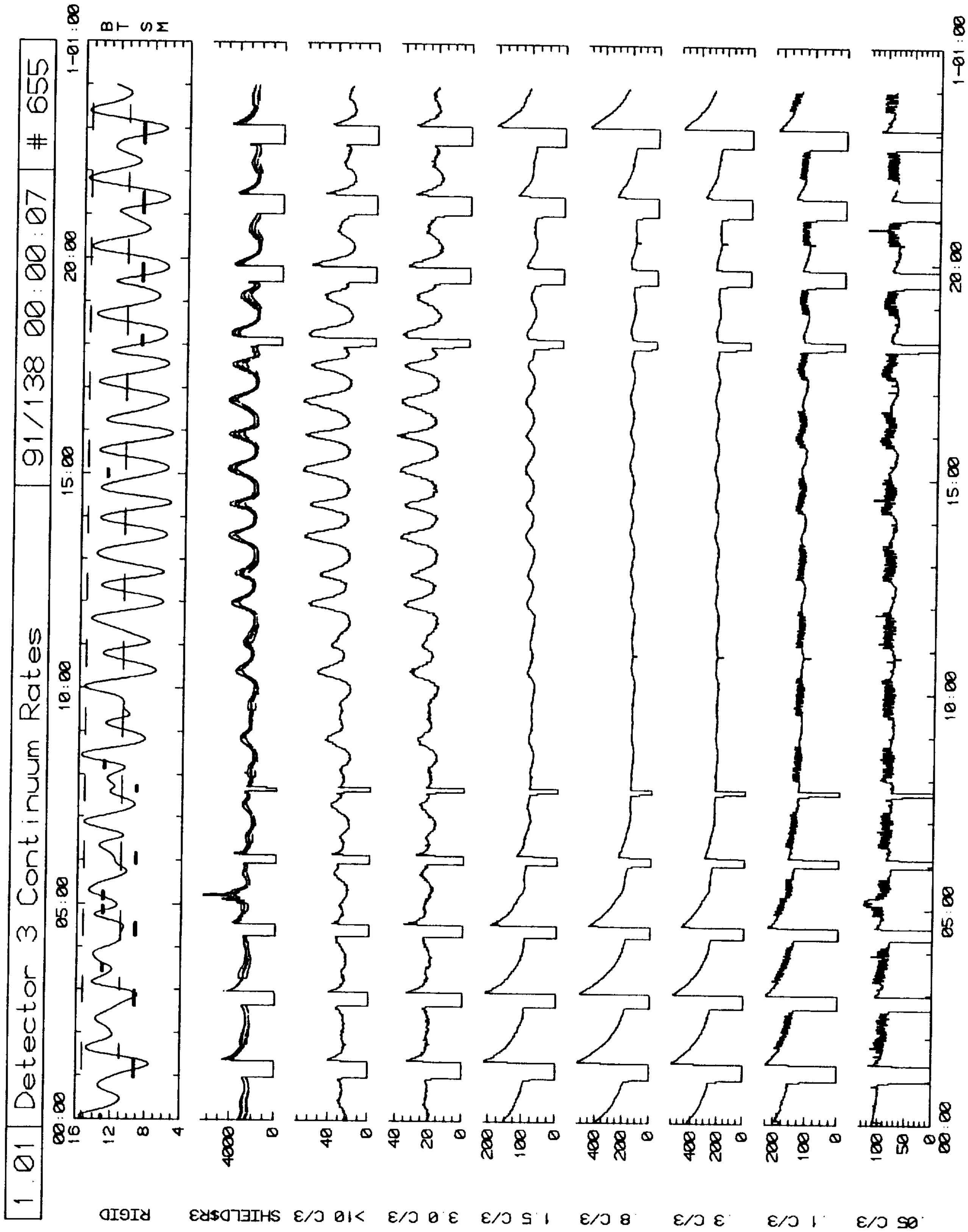

Figure 4: Daily Summary Plots for Detector 3, Day 138

each SAA passage. This is primarily produced by radioactive decay of ^{128}I produced in the phoswich from neutron capture on ^{127}I.

Geomagnetic modulation of the count rates is apparent at the higher energies, with the highest count rates occurring at the lowest cutoff energies. In the simplest geometry, the rigidity modulates at half the orbital period. This modulation reflects the cosmic-ray dependence of the local background and cosmic-ray related contribution to the internal background, and warns that measurement and subtraction of background from any celestial source observation must occur on a time scale fast enough to track the geomagnetic modulation of the background, or be dealt with by modelling and subtraction of rigidity effects in the data.

The lowest energy ranges also show some geomagnetic modulation of the measured rates. In the two lowest energy ranges, a more rapid modulation of the rates is also apparent, produced by alternating 2 minute observations of the Crab with 2 minute observations at offsets of 4.5° on either side of the Crab, to measure the local background spectra. This is the standard strategy for steady-state source observations, necessary to track the time-varying background. These rate plots show that the brightest object in the sky at these energies produces a small fraction of the events seen by the detector. However, the plots also show that the Crab is readily detectable by OSSE at energies up to 300 keV in a 2 minute observation. The Crab is seen at higher energies by OSSE, but its reduced flux at these energies requires longer integration times. The observations of the Crab alternate in each orbit with observations of PSR 1957+20, which is not readily apparent in the OSSE data.

Another feature in Figure 4 is the increase in the count rate in the lowest energy range and in the shield rates at about 05:10 UT. This was produced by an X2.8 class solar flare. While typical deadtimes for the detectors, produced by the anticoincidence systems and electronic processing times for events, are 10% in the Low energy range, 6% in the Medium range and 3% in the High range, very large solar flares such as those of June 1991 can increase deadtime to almost 100%.

Since the background flux detected by OSSE dominates any source flux except for transient events such as strong solar flares and gamma-ray bursts, the statistical significance of the measured background in any observing period dictates the corresponding sensitivity of the instrument in that period. Figure 5 shows the OSSE line sensitivity, for an integration time of 500000 seconds, corresponding roughly to the typical integration time on a target achievable in a two week period where OSSE observes two targets. The continuum sensitivity of OSSE for the same integration time is shown in Figure 6. The effective area for an OSSE detector, which is used in the calculations of both line and continuum sensitivity, is shown in Figure 7, reaching a peak of more than 500 cm^2 at 200 keV. An offset of 4.5° completely modulates the emission from a source on the boresight of the detector up to energies of about 400 keV. At higher energies, there is some flux leakage through the collimator, and the effective area is consequently reduced, primarily due to reduced detection efficiency.

The gain stability of each detector is an important aspect of the overall performance of the instrument, since rapid gain variations can degrade the energy resolution of the instrument and make the data reduction process more difficult. The performances of both the phoswich and the PMTs are sensitive to temperature variations, so that an essential factor of gain stability is temperature stability in the detectors. Figure 8 shows the temperature and gain variations of detector 4 in OSSE over a 15 day period. GRO was maneuvered for the start of a new observation period near the end of Truncated Julian Day 8449 (July 12), producing one of the largest changes in phoswich temperature and hence gain seen in the OSSE detectors since launch. Active heater control in each detector was designed to maintain the phoswich temperature at 20 C, and Figure 8 shows it comes within 0.5 C of this goal. Within a viewing period the solar illumination on GRO only slowly varies in direction, and temperature variations are less than 0.1 C. The corresponding gain changes in the detector, as measured from the Low energy range channel number of the 1.332 MeV line of the internal ^{60}Co source in the detector, are about ±0.15% due to the maneuver and less than ±0.1% over the rest of the viewing period.

Finally, the energy resolution of detector 3 is shown in Figure 9. Ground calibration data was used to measure

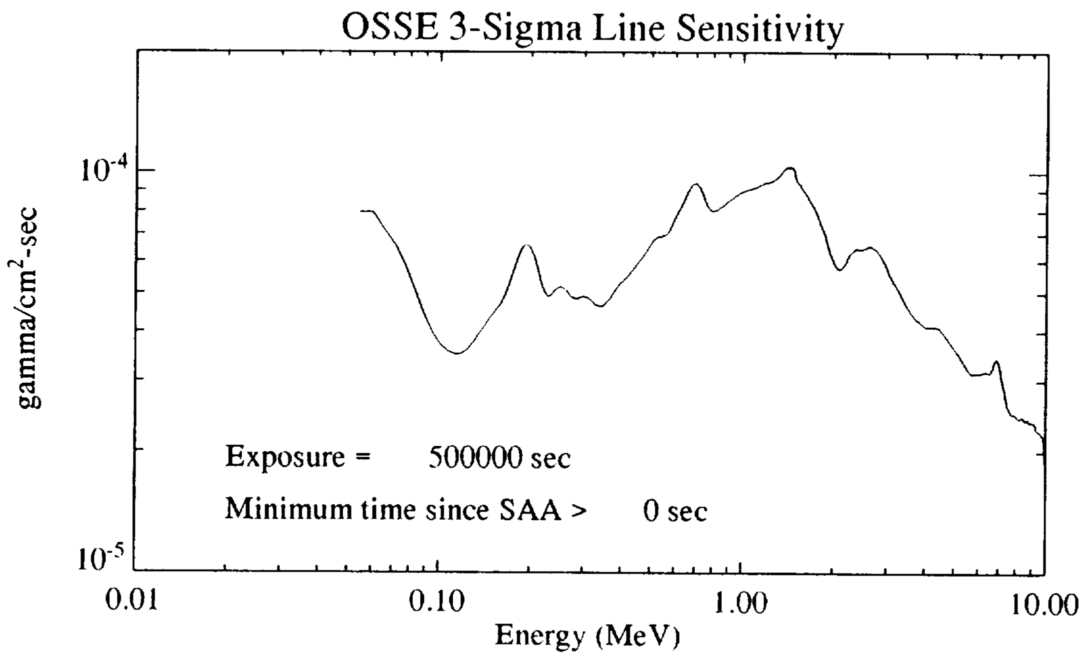

Figure 5: OSSE Line Sensitivity, Single Detector

the resolution at several energies, and an analytic curve fit to these data points is also shown.

Instrument Operations

Instrument operations cover the principal activities of carrying out an observation with OSSE and the initial processing of science and housekeeping data obtained from the instrument. Configuration control of the instrument itself and monitoring of its health and safety is carried out by a mission operations team at the Naval Research Laboratory.

With GRO in a low-earth orbit, a large fraction of the sky is blocked by the earth, and any object observed by OSSE has a high probability of being occulted by the earth. To improve the observing efficiency of OSSE, two targets are typically observed by OSSE in an orbit, with each target being observed while the other is occulted. Both targets must be on or near the 192 degree range in the XZ plane of GRO that is accessible to the OSSE detectors.

The relative integration times on each of these two targets is a function of their position with respect to each other and to the orbit of GRO. A target near the orbital pole may escape occultation by the earth and hence could be observed continuously, while a target in the orbital plane will be occulted for almost half of each orbit. Generally, there will be times in each orbit when both targets are visible simultaneously, and conversely times when both are occulted simultaneously. Depending on the relative scientific importance of the targets, useful observing time common to both targets may be allocated to one target or may be shared between the sources. Generally, one target will be designated the primary target and the other the secondary target, with the primary target having priority in relative observing time allocation.

OSSE supports up to four independent detector position sequences, stored in lookup tables, for different targets. This allows separation of confused sources and optimum observations of complex fields. Also a detector positioning table can be dedicated to the Sun when it is accessible to the OSSE detectors, so that the detectors can slew to the Sun when a BATSE solar flare signal is received by OSSE. If so configured, OSSE responds to a BATSE solar trigger within 3 seconds of the receipt of the trigger.

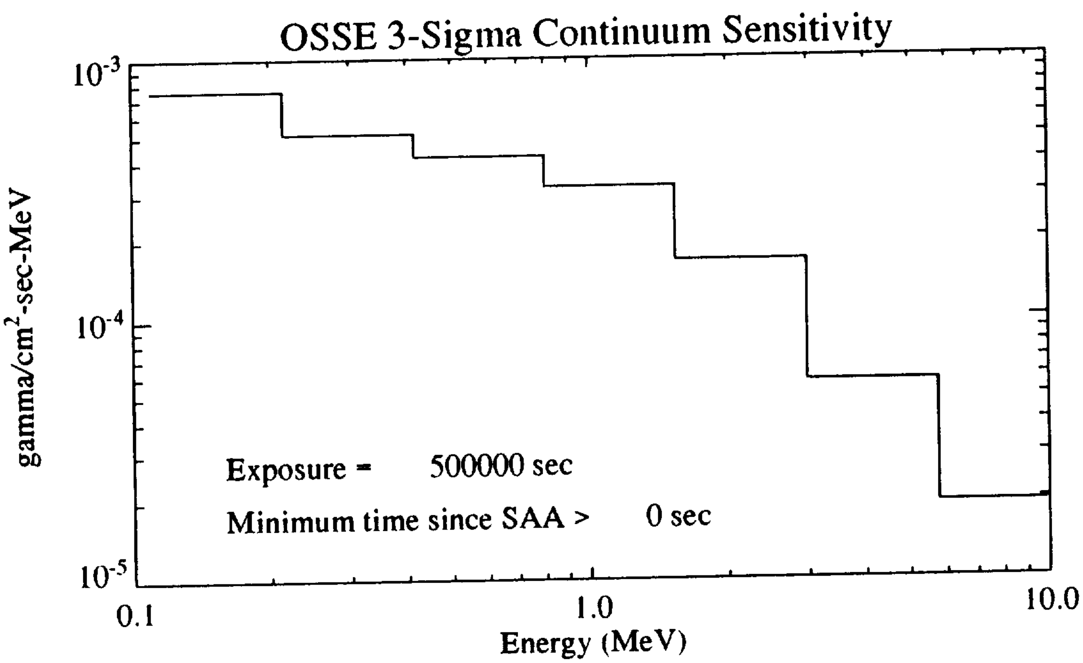

Figure 6: OSSE Continuum Sensitivity, Single Detector

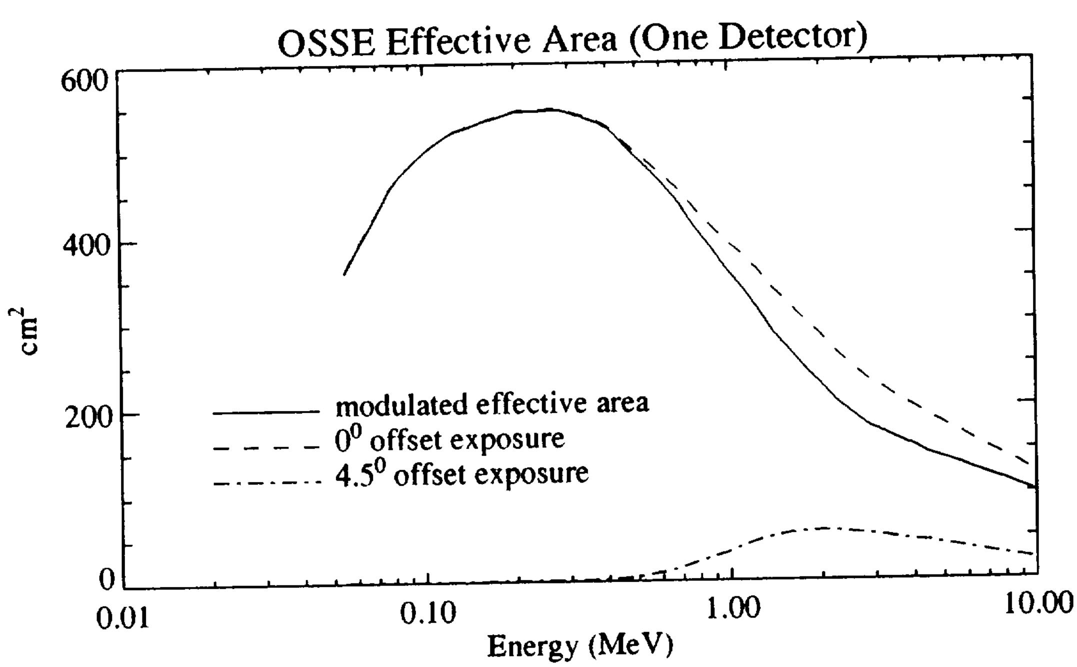

Figure 7: OSSE Effective Area

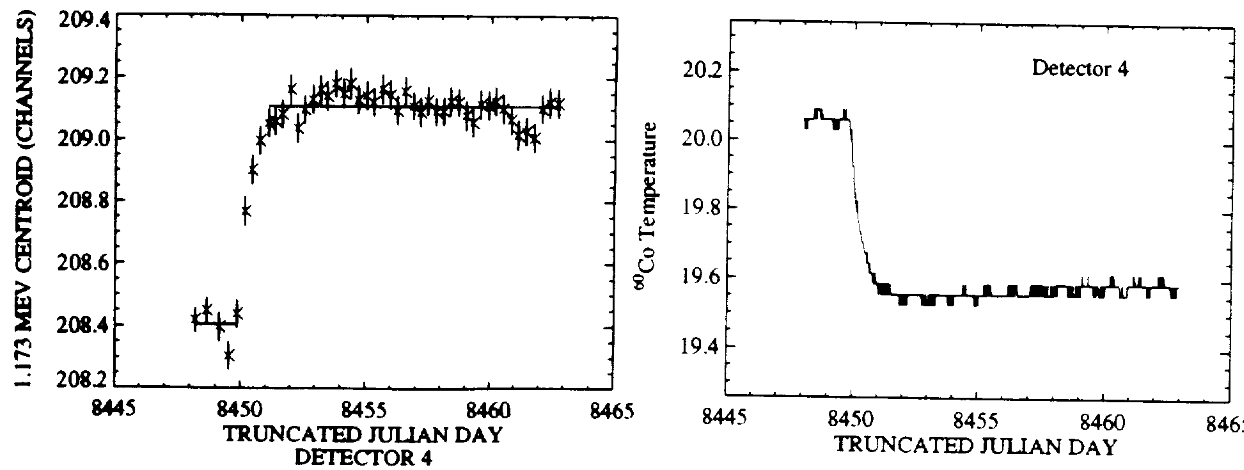

Figure 8: OSSE Temperature and Gain Stability

The mission operations team is responsible for converting the scientific objectives of an observation into a suitable instrument operating state, and the preparation of a command sequence to bring the instrument to that operating state. Very often there is some conflict between the scientific objectives of the primary and secondary target observations, so that some compromise in instrument configuration is required to best meet the objectives of both observations. In addition, a certain amount of customization of instrument configuration for each of these targets is possible. OSSE has the capability to execute internal command sequences when its detectors are commanded to a new target. These command sequences can provide limited instrument configuration changes such as redefinition of the pulsar data type to be collected from the target field. All instrument command sequences are verified for correctness before transmission to the instrument by the OSSE ground support equipment, which also preserves a complete history of OSSE configuration in a command state database.

The other prime function of instrument operations support is the receipt and processing of data from OSSE. After transmission of the data from GRO to the ground through TDRSS and processing through mission support facilities at Goddard Space Flight Center, OSSE data is electronically transmitted to NRL over the NASCOM X.25 network. OSSE data is received in three forms: Realtime, Quicklook and Production. Realtime data is transmitted with little processing from GRO during one or two 30 minute TDRSS contacts with GRO, and provides essentially instantaneous monitoring of the instrument. Quicklook data is minimally processed data from a single playback of a GRO tape recorder, and is received once per day, providing typically 3 hours of data. Production data is a fully processed 24 hour dataset, received once per day approximately 20–44 hours after being recorded on GRO.

Automatic processing of production data provides a standard set of daily data products, within approximately 8 hours of receipt of the production dataset. The principal data product is the set of spectra integrated for 2 minutes, for each offset pointing of each detector, and for all targets observed by OSSE on the day. Other data products include pulsar data, calibration data and diagnostic data. Most of the data are stored in a standard format consisting of Spectral Data Base (SDB) records, which are the basis of the OSSE data analysis system discussed in Purcell *et al.* (1991).

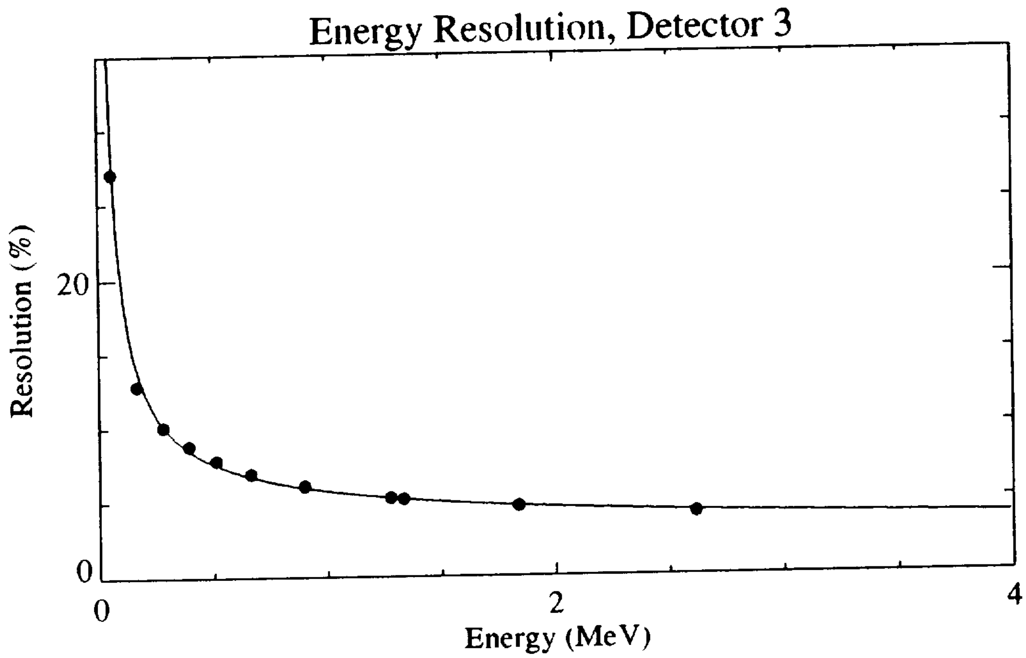

Figure 9: OSSE Energy Resolution

The basic data products obtained by processing a day of OSSE data are:

- OSSE telemetry, augmented with auxiliary data such as geomagnetic field and solar system barycenter vector.
- 2-minute Spectra (SDB), summed from raw OSSE spectra over each detector offset pointing, nominally 2 minutes long. Low, Medium and High energy spectra are included.
- Pulsar Data File, containing pulsar data plus OSSE pulsar mode and instrument configuration descriptors.
- ^{60}Co spectra (SDB), and associated line fit parameters. The ^{60}Co spectra are stored for both short (130 seconds) and long (1050 sec) integrations.
- Burst Data (SDB), containing the 4096 shield rate samples collected in response to a burst or solar flare trigger.
- 1-dimensional (energy) spectra and 2-dimensional (energy-shape) spectra (SDB) from selectable parts of each detector, through Calibration and Roving pulse height analyzers.
- Telemetry Scalar File, to record the time history of detector counting rates and other diagnostic and housekeeping information.
- Standard plot files, produced from the Telemetry Scalar File, for monitoring of instrument performance.
- Charged Particle Environment files, for tracking of spacecraft environment, used in analysis of instrumental background variations.
- Data quality information, observing statistics, database updates, etc.

Subsequent analysis of OSSE data is carried out asynchronously to receipt of the data and production of the above datasets. Combination of 2-minute spectra into longer periods of time is carried out using the higher level OSSE datasets such as background-subtracted spectra count and photon spectra that are derived from analysis of the above products.

Observing Strategies and Statistics

Given the wide range of the capabilities and data products of OSSE described in the previous sections, an overview of the considerations involved in the planning of observations for OSSE may be useful. Some major considerations are:

- Four programmable detector positioning tables are available, each providing up to 8 independent offset positions for each of the 4 detectors. The 8 offsets allow separate observations of closely spaced (a few degrees) sources or scanning observations of extended sources.
- Alignment of the collimator position angle may allow confusing sources to be separated, or enhance sensitivity for extended sources such as the galactic plane.
- Only the inner half of the detector scan range is accessible to four detectors. If a source is accessible with only two detectors, the other two may be used to observe another source simultaneously.
- Spectral data and pulsar data may be simultaneously collected from OSSE. However, because of limited telemetry bandwidth, larger amounts of pulsar data will require slower readout of spectral data. Typically, 16.384 second spectral accumulations allow a maximum pulsar EBE rate of 230 events/second.
- Eight energy windows are available for qualifying pulsar events, to restrict event rates. These windows may be shared between detectors, and in addition, pulsar data may be restricted to only on-target detectors, to prevent pulsar telemetry bandwidth being used for events from background offsets.
- The gain of the OSSE detectors may be varied. Observations have been carried out at double gain, to allow easier separation and measurement of spectral features at energies below 100 keV.
- OSSE provides a flexible response to BATSE triggers. In addition to collecting burst timing data, command sequences may be executed to provide additional responses to bursts or solar flares. For example, when the Sun is on or near the GRO XZ plane and accessible to the OSSE detectors, OSSE can be configured to slew the detectors to the Sun for a predefined duration, typically 1000 seconds, and to collect a variety of data products useful in studies of solar flares. Similarly, OSSE is configured to collect spectra from open shield segments in response to BATSE burst triggers, with the expectation that at least some of these spectra will capture the burst.

In conclusion, the configuration flexibility and multi-target capability of the OSSE instrument results in observing efficiencies of typically 70 – 100%, excluding time in the SAA. Therefore it is possible to achieve integration times of 500000 seconds per target in a 14 day observation.

References

Johnson, W.N., *et al.* 1989, "The Oriented Scintillation Spectrometer Experiment (OSSE) Instrument Description", in Proceedings of the GRO Science Workshop.

Kurfess, J.D., *et al.* 1989, "Scientific Objectives of the Oriented Scintillation Spectrometer Experiment", in Proceedings of the GRO Science Workshop.

Purcell, W.R., *et al.* 1991, "OSSE Spectral Analysis Methods and Techniques", in the Proceedings of the Second GRO Science Workshop.

Strickman, M.S., *et al.* 1989, "OSSE Data Flow and Analysis", in Proceedings of the GRO Science Workshop.