SPI ISSW SOFTWARE REQUIREMENTS

SPI Team Assessment

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Scope

This document assembles the instument-specific requirements on the capabilities of the software system for INTEGRAL data analysis at ISDC, complementing the requirements for ISDC-generic software functions.
This document was established after the July 1997 ISDC SRD Review, re-structuring the ISDC SRD in its ISSW aspects (ref. Email ISDC PM 16 Jul 1997).
This implies the SR categories (and structure of this SRD):

Observation and Status Monitoring: SPI Specific Aspects
Quicklook Analysis: SPI Specific Aspects
Standard Analysis: SPI Specific Aspects
Off-Line Analysis: SPI Specific Aspects
Performance Monitoring for the SPI Instrument
Inflight Calibration of the SPI Instrument
Response Determination for the SPI Instrument
Background Handling for the SPI Instrument
Science Analysis Functions

The document is assembled and maintained by the Spectrometer Software Development Sites, with the ISDAG Coordinator as Editor.
Changes are assessed by the ISDAG group through a *formal change request* procedure.

Document History:

- 15 Sep 1997 Issue 1 collection & rearrangement from SPI URD and Software Dictionary
- 15 Oct 1997 Issue 2 trimming of Issue 1 as directed by ISDAG comments
- 15 Nov 1997 Issue 3 inclusion of additional inputs by subsystem development sites
- 15 Dec 1997 Issue 4 trimming of Issue 3 as directed by ISDAG comments
- 25 Jan 2000 Issue 5 adapt to WP evolution & ISSW discussions, trim to essentials, for Team review and update. Add WP cross references.
- 01 Mar 2000 Issue 6 Include ISSW Team Updates after ICD/SRD review

Functional Requirements:

1. Raw Data Provision and Sorting: SPI Specific Aspects

ISDC input data from SPI will originate from the spacecraft telemetry, and from the flight instrument calibration equipment (GSE), and from the instrument simulation software system (SIM). The SPI instrument data have to be separated into databases for the categories

1. instrumental housekeeping and status (rates, voltages, *tbd* status parameters)
2. detector event messages (time tag, detector-identifiers, *tbd* pulseheights, pulseshape information, *tbd* flags)
3. auxilliary science data (onboard spectra, *tbd*)
4. data taking parameters (Target Flags, others *tbd* for GSE and SIM data)

Statistics about telemetry composition and data types must be generated and maintained.

WP 1.1 Raw Data Decomposition Support

2. Status Monitoring: SPI Specific Aspects

The instrumental performance is determined per science window in the categories:

1. Instrument science operation mode: check if mode parameters *tbd* are within specified ranges *tbd* . Check that mode transity are within appropriate time window *tbd* (as expected from telecommands / ISOC database). Compare mode as given by MOC records to mode as reflected in SPI data (through *tbd* flags and *tbd* hk values and *tbd* rates).
2. Instrument integrity monitoring: check if the anticoincidence and detector rates are within *tbd* specified ranges and *tbd* ratios (for achieving the specified sensitivity). Also monitor the housekeeping values' behaviour over scientifically and instrumentally relevant time scales *tbd*. Monitor housekeepng and ancillary data for their characteristic variations, compare this with expectations for optimum instrument performance, and derive characteristic averages, variances, outliers and trend results. Analyze detector event messages and rate data for their characteristic values and variations, compare this with expectations for optimum instrument performance, and derive characteristic averages, variances, outliers and trend results.

For longer time intervals (~weekly), a deeper instrument performance analysis is performed: Determine the detector and shield thresholds from event messages and special in-flight calibration data. Analyze detector energy spectrum, determine and monitor parameters of specific features (like instrumental calibration lines) (energy, width, intensity). Determine trends of the variations of event rates, thresholds, characteristics of spectral features, on different timescales directed by mission events (orbits etc.) or radioactivity timescales

Further, derive an "assessed mode" that is used in subsequent analysis, identifying the "good time" intervals. Flag the "assessed modes" with usage categories (INVALID, SLEW, NORMAL, *tbd*).

An appropriate database for instrument detector rates and housekeeping (and mission data) is to be established, to be analyzed for trends that may have a science implication (e.g. buildup of activation background) (off-line performance analysis, see below).

WP 1.3. Performance Validation (OSM Support)

WP 1.4. Performance Validation (deep SPI PerfAn)

WP 1.5. Performance Validation (data quality tags)

3. Quicklook Analysis: SPI Specific Aspects

Sophisticated statistical tests *tbd* will serve as the criteria for definition of a significant change of actual data with respect to reference skies. The parameters of these tests are *tbd*. They must be definable in a flexible manner *tbd* , yet maintaining an accurate criteria database.

Extract and monitor the rate data of the ACS system for gamma-ray burst signatures, and generate alerts above a *tbd* threshold.

WP 7.1. Transient Detection

WP 8.1. Burst Detection

4. Standard Analysis: SPI Specific Aspects

4.1. Instrument Data Calibration

The instrument event-type data must be corrected for temporal instrumental effects (gain changes) in order to allow application of the properly calibrated instrument response in scientific analysis in the domains of spectral, imaging, and timing analysis. See Calibration Section for Detailed Requirements

WP 1.2. Inflight Calibration Analysis

4.2. Data Preparation for Analysis

Select and bin calibrated event messages such as to conform exactly to a response matrix derived for a specific application. Determine the instrument dead time for these analysis channels. Define the analysis groups for Imaging Analysis. Provide the response and background datasets as applicable for these data groups.

WP 3.1. Event Binning

WP 3.2. Deadtime Determination

WP 3.3. Analysis Group Preparation

4.3. Standard Imaging Analysis

Perform imaging search for point sources in standard spectral bands. Extract parameters (location, fluxes in spectral bands, significance) for each detected source.

WP 4.2. Imaging Point Sources

5. Off-Line Analysis: SPI Specific Aspects

Off-line analysis may be applicable for Performance Monitoring (by ISDC Staff, and remotely by SPI Instrument Experts) for longterm performance studies and for anomaly followup work.

Routinely, off-line analysis encompasses all Science Analysis as specified below. It may be executed locally at ISDC, remotely at Guest Observer or Instrument Team Sites, or from remote Instrument Team Sites on special equipment at ISDC.

6. Performance Monitoring for the SPI Instrument

Here we identify all SPI specific aspects which go beyond the OSM functions specified above, i.e., off-line performance analysis that addresses time scales beyond individual science windows and weekly OSM.)

An appropriate database for instrument detector rates and housekeeping (and mission data) is analyzed for trends that may have a science implication (e.g. buildup of activation background).

Supporting the Performance Analysis, a technical software model of the instrument must be established. This model predicts changes in performance parameters as a function of instrument command status and radiation environment.

The software model supporting the state-of-health analysis will be needed in a basic configuration before launch, and will be enhanced as the instrument knowledge grows, during calibration analysis, and with the mission time.

WP 1.4. Deep SPI PerfAn

Technical software model of SPI: not addressed. Unfeasible?UoS?

7. Inflight Calibration of the SPI Instrument

1. Analyze in-flight calibration data *tbd* to establish actual correction parameters *tbd* for the raw event parameters *tbd*
2. Analyze in-flight calibration data *tbd* to establish actual correction parameters *tbd* for the preflight instrument response.
3. The instrument event-type data must be corrected for temporal instrumental effects (gain changes) in order to allow application of the properly calibrated instrument response in scientific analysis in the domains of spectral, imaging, and timing analysis.
4. Adjust the instrument response to actual performance parameters (within *tbd* tolerance steps)

WP 1.2. Inflight Calibration Analysis

ISDC Routine to correct events

WP 2.2. Response Matrix Generation

8. Response Determination for the SPI Instrument

Generate the spatial and spectral components of the Instrument Response by combining Monte-Carlo and Ray-Tracing techniques. This yields the instrumental-system reponse, to be translated into celestial-system response by another software function which accounts for the observation patterns and data selections. Prelaunch calibrations will be compared to prelaunch simulations, and used to correct/optimize the simulation tools.

General Introduction:
The instrument response to celestial photons from point sources and extended sources must be established in the domains of

- spectral information
- imaging information
- timing information

with respect to source energy and incidence direction within the field of view, in order to enable scientific analysis through deconvolution and/or forward-folding (see science analysis requirements below). An instrument simulation system must be provided to generate event-type data from a specification of the sky appearance in above three domains. Input data to the response analysis are either prelaunch calibration data, or simulation system data, or mission data.
Two levels of response detail must be provided:

1. The detailed precise response, for deep science analysis
2. An approximated simplified resonse, for explorations, visualization, studies and quicklook analysis.

Further Comments:
It is yet to be defined how appropriate data spaces shall be defined to optimize analysis in each of the three domains; it is anticipated that three different data space definitions will exist, although it is conceivable that different data space bin resolutions in a unified data space might be adequate. The simulation system finally shall encode the know-how about the instrumental response, in order to supplement prelaunch calibration measurements. There may exist a range of simulator incarnations for different purposes, with variable computational cost, e.g. tabulated or analytical response approximations for quick analysis algorithm exploration, or a detailed physical photon event tracing package for detailed study of particular response characteristics. The incidence directional range of the simulator must be all-sky (e.g. for use in determination of background events from earth atmosphere).
The spectrometer instrument contains 'fully coded' and 'partly coded' parts of ist field of view. Different approaches of analysis for these two parts are required, possibly a 'combined analysis' is feasible.
It is expected that several incarnations of response data will exist, both from using different input data, or from using different expertise or assumptions. Some of these incarnations will be subject to very few revisions (e.g. the preflight calibration result), while others will be regularly updated (e.g. the inflight response from simulations).
For all response simulations, a detailed mass model of the SPI instrument is established and maintained in a format which can be directly applied in the simulations.

8.1. Simulations for Response Generation

Perform GEANT simulation of calibrated event messages (for an idealized instrument, no resolution-broadening included) for specified celestial source input (source location, line energy or spectral shape, intensity).
Generate response matrices (*tbd*) in instrument coordinates *tbd*, for subsequent Response Generation through instrumental-resolution adjustment, coordinate transformation, and appropriate interpolations (see below).
WP 2.1. Response Simulation

8.2. Response Generation for Specific Pointings

Convert applicable response matrices derived from simulated events or prelaunch calibrations, or the analytic response functions into response matrix as applicable to a set of observational data selected for deconvolution/fit/ analysis. Deliverables are *(tbd: template libraries / set of software / set of databases for specific cases)*
WP 2.2. Response Matrix Generation

8.3. Response Validation

Convert multi-dimensional response matrix into visualizations of appropriate projections; derive parameters (width, efficiency,...)
Evaluate and compare the different response representations to data as derived from celestial sources simulations, and calibration runs. Derive measures for differences between simulated response and these datasets.
SPI-internal Response Analysis; not for ISDC System

9. Science Analysis Functions

9.1. Imaging of Point Sources

The event data must be deconvolved into sky images using the instrument response, for sources with emission spectra as

- single line
- multiple lines
- continuum (as power-law and thermal Bremsstrahlung; more shapes later)

Prior knowledge about the source(s) is used. Spectral characteristics can be defined to help the imaging process. The imaging process can be controlled through its equations and parameters *tbd*.

The spectrometer instrument contains 'fully coded' and 'partly coded' parts of it's field of view. Different approaches of analysis for these two parts are required, possibly a 'combined analysis' is feasible.

A source catalogue conversion tool to a binned dataspace is provided.

Included are high-level data access tools for the Imaging Response, Pointing Information, Good-Time Intervals, Energy Bin Bounds, Deadtime Info, and Source Catalogue.

WP 4.2. Imaging Point Sources
WP 3.4. Skymap Convolution

9.2. Imaging of Extended and Diffuse Emission

Deconvolve binned event matrix for a set of observations into photon sky image by application of the imaging response matrix. Additional prior information is included through the default map. A tool for conversion of astronomical maps to SPI dataspace is provided ("skymap convolution", see below), using observation patterns generated by the ISDC Observation Simulator.

Instrumental and cosmic diffuse backgrounds are adressed through global background parameters in the dataspace; additional background models can be optionally included and fit in amplitude. The Maximum Entropy method of image construction is applied. Error calculation is optionally performed for the resulting map.

Included are high-level data access tools for Analysis Group Definition, Pseudo-Detector Definition, and resulting Skymaps (although these are generic SPI analysis tools and do not have specifically to do with the functions of this section).

WP 4.3. Imaging Diffuse Emission and Surveys
WP 3.4 Skymap Convolution

9.3. Spectral Deconvolution

Select event data for specific celestial source under study, also using the imaging and timing signature of the source

Deconvolve event histogram into photon spectrum by application of the inverted spectral response matrix, through the following methods:

1. iterative improvement of the data fit to a hypothetic photon spectrum as convolved into dataspace with the instrument response
2. successive subtraction of the strongest identified feature (subtract features conforming to instrument response, in order to enable identification in photon space)

WP 4.5. Spectral Deconvolution for Diffuse Emission and Surveys
WP 4.2. Imaging Point Sources

9.4. Spectral Model Fitting

Select binned data for source(s) under study, optionally using background and spatial information from an imaging analysis as additional input, extract those for the XSPEC system, and use this to perform a forward-folding spectral deconvolution, i.e., determination of the parameters of any spectral model from a library of astrophysically relevant models.
Included are high-level data access tools for Count Spectra.
WP 4.4. Data Extraction for XSPEC Spectral Analysis
WP 4.7. Source Model Fitting (Spectral Domain)

9.5. Spatial Model Fitting

Select event data for specific celestial source region under study, also using the (hypothetical or otherwise deternined) spectral and timing signatures of the source region
Convert a sky model (e.g. CO distribution, star catalogue ..) into model format as needed by the image determination programs
Determine the parameters and parameter errors for a specific source model, as compared to the data after folding with the instrument response. A likelihood analysis is envisaged, with production of model parameter maps, and error matrix values and diagrams. Models will be comprised of point-like sources, or extended and diffuse sources, or combinations of both.
WP 4.6. Source Model Fitting (Imaging Domain)

9.6. Model Fitting in Full Data Space

Determine the parameters and parameter errors for a specific source model, as compared to the data after folding with the instrument response. A likelihood analysis is envisaged, with production of model parameter maps, and error matrix values and diagrams. Models will be comprised of point-like sources, or extended and diffuse sources, or combinations of both.
WP 4.8. Source Model Fitting (Imaging and Spectral Simultaneously)

9.7. Timing Analysis

Select event data for specific celestial source region under study, also using the (hypothetical or otherwise determined) imaging and spectral

signatures of the source, using also the corresponding instrument reponses.
Determine the parameters and parameter errors for a specific light curve model, as compared to the data after folding with the instrument response (e.g. likelihood fit).
(This is the instrument-specific software part; Following is not!).
Determine the signal power in harmonic series of a predetermined pulsing period. Analyze source / source region / spectral parameter trends over time intervals long compared to individual observations. Monitor variability characteristics of known sources over the characteristic (externally determined) source variation scales.
WP 5.1. Source Timing Analysis

9.8. Background Study

In order to identify proper methods for background modelling, a multi-dimensional interactive event data display and analysis system must be provided for exploration of background features in the data. This toolbox must support data selection (to enhance instrumental background, and to maximize signal for specific characteristics under study), and result parametrization and fitting (to derive background modelling algorithms), and correlation analysis tools in the multi-dimensional data space defined by event and auxilliary parameters (e.g. spectral line shape versus detector temperature). Inputs are event data, housekeeping data, and auxilliary data on pointing, attitude, orbital phase.
Background is recognized through lines from specific isotope decays or deexcitations; spectral decomposition into significant line features, and their identification (as correlated groups) with isotope(s) is the tool provided for this. A tool for automatic line identification and parametrization is provided *(SPI-internal)*.
A detailed physical & geometrical background simulation system (based on the response simulation software) shall translate neutron and proton fluxes (specified spectrum, intensity, incidence direction) into instrument detector events.
WP 6.1. Background Exploration
WP 6.2. Background Simulation

9.9. Background Modelling

The analysis of SPI data will include background treatment through free parameters referring to instrumental background-only. The data-space components adjusted by these parameters can be generic (count level per detector), or amplitudes of more complex dataspace templates, which are derived through studies of the instrumental background. This subsystem addresses establishment of such templates for instrumental background in the data-space of SPI.
The instrumental response with respect to non-celestial instrument events must be determined in the domains of

- spectral data space (measured energies per detector, selected for imaging parameters of the source)
- imaging data space (measured count rate pattern of the 19 detectors in a range of measured energy)
- timing information (measured event arrival times per detector)

We prepare following instrumental background model types:

1. prompt internal background (total) (amplitude referenced to a ratemeter set)
2. spacecraft activation model library (amplitude of specific templates derived from ratemeters, orbit parameters, mission time, through algorithms specific to each background component)

The resulting background modelling in each of the three data space domains must be parametrized such that it can be adjusted to differerent observation periods.

Different background modelling algorithms are to be developed during the mission; before launch, at least one empirical and one physical approach of modelling the background must be available.

The generic software functionality is:

Convert applicable simulated events OR the evaluated bgd characteristics (given by the analytic functions and the parameters derived with the 'parametrization') OR selected measured event messages (which are selected/assumed to be a background measurement) into background matrix/model as applicable to data selected for deconvolution/fit.

Included are high-level data access tools for Background Models

WP 3.5. Background Model Preparation

9.10. Observations Analysis

No special instrument-specific software is expected here. Nevertheless we summarize in this section the requirements on ISDC tools from our perspective.

Translation tools must be provided to convert specification of a science observation (source position, flux, significance goal) into a technical observational sequence, as constrained by celestial time, attitude constraints, field-of-view limitations.

Secondly, actual observation history may also be used as input, to determine and visualize the effective constraints imposed onto a specific astronomical object.

Graphical tools must be available to visualize the result as skymaps showing the target and constraining parameters such as sun/moon trajecories.

Tools must be provided to:

Study data combination selections which optimize sensitivity for particular sources, based either on existing or on intended observations

evaluate the constraints of observation scheduling and selection with respect to specific celestial sources

Translate specified goals for a source / source region exposure into selection schedule for source pointings, observation time per pointing, and data selection criteria. Consider constraints from instrument field of view, and instrumental background

Evaluate a given observation and data selection schedule with respect to exposure charactieristics for a specific source / region

9.11. Science Result Combinations

No special instrument-specific software is expected here. Nevertheless we summarize in this section the requirements on ISDC tools from our perspective.

Combine science results from deconvolution or model analysis, to generate combined results, evtl. with overlays of models or science interpretations. Examples are: Combine images of restriced sky regions into a large-scale sky image. Extract a spectrum for a source region from a set of sky images generated for narrow energy bands. tbd

9.12. Multi-Instrument Analysis

No special instrument-specific software is expected here. Nevertheless we summarize in this section the requirements on ISDC tools from our perspective.

(It is likely that we will eliminate this section altogether: This analysis presents a challenge beyond ISSW and instrument-specific functions. It was not appreciated in the ISDC User Requirements assessment. We should leave it as a tbd *slot, probably. Nevertheless: here is what we have said to this topic before....)*

Select event data for specific celestial source under study, using crude (hypothetical or otherwise determined) imaging, spectral, or timing signatures

of the source, and convert the data from different instruments to conform to an appropriate data space
Convert the responses of different instruments to a common standard image and data space, as directed by the intended analysis
Convert the background models of different instruments to a common standard image and data space, as directed by the intended analysis
Convert astrophysical source models to the format and binnings as needed for subsequent analysis
Determine the parameters and parameter errors for a specific source model, as compared to the combined instrument data after folding with the instrument responses (e.g. likelihood fit)
Determine the parameters and parameter errors for a specific source spectral model, as compared to the combined instrument data after folding with the instrument responses (e.g. likelihood fit)
Determine the parameters and parameter errors for a specific sky image model, as compared to the combined instrument data after folding with the instrument responses (e.g. likelihood fit)
Determine the parameters and parameter errors for a specific source lightcurve, as compared to the combined instrument data after folding with the instrument responses (e.g. likelihood fit)

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