Eidgenössische
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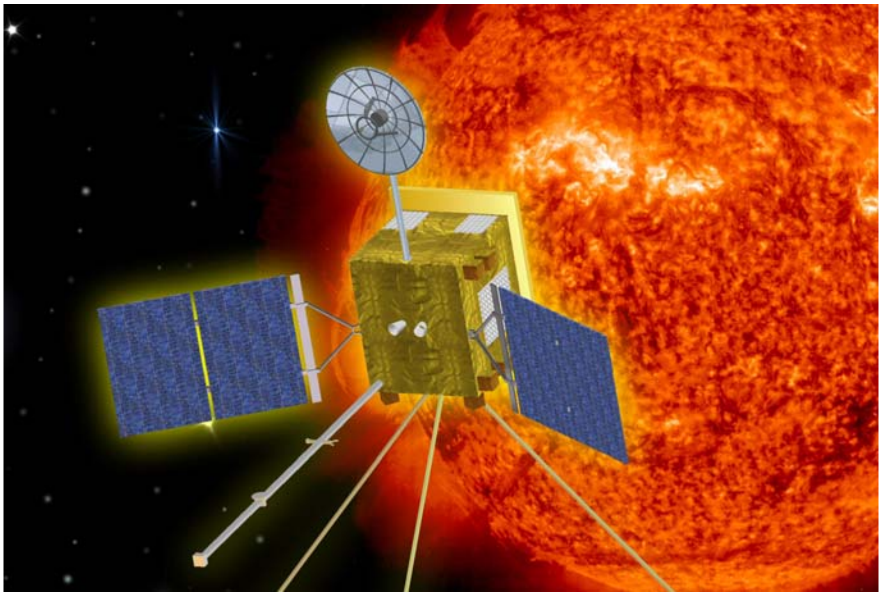
ETH Zurich

Part II

EXPERIMENT INTERFACE DOCUMENT - PART B

Solar Orbiter

STIX
(Spectrometer/Telescope for Imaging X-Rays)



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1 GENERAL INTRODUCTION

The Spectrometer/Telescope for Imaging X-rays, STIX, is a critical component of the Solar Orbiter (SolO) payload for achieving several of the major HELEX science goals. Through its X-ray imaging spectroscopy with unprecedented sensitivity and spatial resolution, STIX will provide the most reliable and quantitative information on the timing, location, intensity, and spectra of accelerated electrons near the Sun. Electrons that escape from the Sun during the same events can be measured in situ at SolO and tracked into the heliosphere through their radio type-III emissions. Thus, STIX provides an essential component of the SolO remote sensing and in-situ electron measurements necessary to achieve the HELEX goal of answering the question - "What are the sources, acceleration mechanisms, and transport processes of solar energetic particles?" This same combination of remote sensing and in situ observations will provide direct tracing of the magnetic connectivity from SolO back to the Sun, addressing a second major HELEX question - "What are the origins of the solar wind streams and the heliospheric magnetic fields?"

The different view angle provided by SolO, when combined with X-ray observations by the Sentinels and by other solar observations, will allow us for the first time to systematically study flare X-ray source sizes and geometries in three dimensions. X-ray directivity can also be determined, providing information on the directivity and pitch-angle distribution of the emitting electrons that cannot be obtained in any other way.

STIX will provide imaging spectroscopy measurements at the highest ever spatial resolution and sensitivity. At closest approach, STIX will resolve sources as small as 1,100 km, compared to 1,600 km for the Ramaty High Energy Solar Spectroscopic Imager (RHESSI, Lin et al. 2002). It will be able to detect events that are 15 times weaker than is possible with RHESSI. This high sensitivity opens a new window for exploring the relatively weak hard X-ray emission from the quiet corona and from electrons producing coherent radio emissions such as type III bursts. The frequent high-sensitivity observations of partially limb-occulted events will allow us to image hard X-ray emission from the corona, free from the bright "dazzling" footpoint sources, thus providing unique information about the suprathermal electrons closest to the site in the corona where their acceleration is believed to occur.

STIX uses a proven, indirect Fourier-transform imaging technique based on the use of fine X-ray collimators. Instruments using this same principle have been successfully flown on the Japanese Yohkoh mission (Kosugi et al. 1991) and the NASA RHESSI mission. STIX consists of two main parts that are independently mounted on the spacecraft: an imager and a spectrometer. The imager consists of 64 pairs of X-ray opaque grids with each pair mounted in front of one of 64 solid-state Cadmium Zinc Telluride (CZT) X-ray detectors that make up the spectrometer. The transmission through the grid pairs to the detectors is a very sensitive function of the direction of incidence of the X-ray flux. The relative count rates of the detectors behind the different sets of grids encode the spatial information that can be subsequently decoded on the ground to reconstruct images of the source region at different X-ray energies.

The STIX instrument performance summarized in Table 1-1 is optimized to fulfil the HELEX science requirements.

Table 1-1. Summary of STIX performance

Energy Range	4 – 150 keV
Energy Resolution	1-15 keV (energy dependent)
Effective area	12 cm^2
Finest angular resolution	7 arcsec
Field of view for imaging	1.5° (FWHM)
Field of view for source location	2.5°
Image placement accuracy	
Imaging mode	~4 arcsec
Location mode	1 -- 3 arcmin
Time resolution (statistics limited)	≥ 0.1 s

The very modest STIX resource requirements listed in Table 1-2 are fully compliant within the constraints in the PDD.

Table 1-2. Summary of STIX resources

	Mass [kg]	Power [W]	Telemetry [kbps]
Nominal	4.0	4.0	0.2
Margin	0.4	0.4	
Total	4.4	4.4	0.2

STIX operations are largely autonomous, insensitive to normal flight operations, and based on preloaded parameter settings (e.g. detector gain settings, time and energy binning algorithms, etc.).

STIX will provide a flare trigger over a SpaceWire bus in near real time for use by other instruments on SolO to initiate and optimize their burst mode operations. This is critical for the close coordination of the remote sensing and in situ observations that is needed to achieve the SolO science objectives. To further facilitate this coordination, several proposing PIs of other SolO instruments are included as STIX Co-Is. After selection, the STIX team will organize a workshop with other SolO instrument teams to discuss the use of the STIX flare trigger to optimize the science output of the SolO mission.

STIX data analysis and archiving will greatly benefit from the RHESSI heritage. The telemetered STIX data will contain the relative count rates of individual detectors. While time and energy binning is done on-board to save telemetry, image reconstruction is done on the ground. The STIX team will make the raw data and the analysis software publicly available within the shortest time possible. Furthermore, a catalog of reconstructed images and spectra will be provided. This will greatly reduce the complexity of STIX data analysis for non-expert users.

The STIX team is led by the PI, Prof. Dr. Arnold O. Benz, ETH Zurich, Switzerland. The PI will fulfil all the duties foreseen in the Solar Orbiter Science Management Plan. He is aided by the Co-PI, Dr. Säm Krucker, who serves as his deputy. A professional Swiss aeronautic and aerospace company with substantial experience in the field will provide help with management and quality control. Hardware contributions are provided by four European nations and NASA (see Table 3). The lead Co-I of the Imager is Prof. Dr. Gottfried Mann, AIP, Germany, who is a close collaborator with the RHESSI team. The lead spectrometer Co-I is Prof. Dr. G. Dissertori at ETH Zurich. The IDPU will be designed and built by SRC, Poland lead Co-I Prof. Dr. Janusz Sylwester, and the power supplies and flight software will be provided by AIAS lead Co-I Dr. Franta Farnik. Data reduction and archiving will be lead by Prof. Dr. André Csillaghy, FHNW, Switzerland, who led the data analysis part of the RHESSI software effort. The STIX team furthermore has 23 European science Co-Is who committed part of their time for STIX data analysis and interpretation.

One of the key advantages of the STIX team is its long heritage. Many of the Co-Is were closely involved in RHESSI, including the PI and Co-PI, and/or have experience with other X-ray missions such as the Czech Hard X-ray Spectrometer (HXRS) onboard the American MTI spacecraft (Farnik), and the SphinX instrument onboard the Russian CORONAS mission (Sylwester).

The Swiss Space Office is the lead funding agency and has sent a Letter of Endorsement to ESA. Further funding is expected to be provided by six national funding agencies in Europe (see Table 3) that will send Letters of Endorsement to the Swiss Space Office and ESA. Most of the STIX instrument will be designed and fabricated in Europe.

Table 1-3. **The STIX team and national funding agencies**

	Institution	**Lead Scientist**	**Funding Agency**
Management	**ETH** UCB	Benz Krucker	CH PRODEX

Imager	**AIP** UCB GSFC	Mann Hurford Dennis	DLR
Spectrometer	**ETH** AIAS	Dissertori Farnik	CH PRODEX CZ PECS
IDPU	**SRC** AIAS	Sylwester Farnik	PL PECS CZ PECS
AIT	**ETH**	Grimm	CH PRODEX
Data reduction archiving	**ETH** UGraz TCD LESIA Glasgow UCB GSFC	Csillaghy Veronig Gallagher Vilmer Brown Hurford Dennis	CH PRODEX AT PRODEX IRL PRODEX F CNES UK University
Science Operations	**ETH**	TBD	CH University

The STIX schedule is fully compliant with the overall SolO schedule.

This document corresponds to the proposed configuration as of January 2008, prior to the initiation of funded development activities.

2 KEY PERSONNEL AND RESPONSIBILITIES

2.1 Management Structure and responsibilities

STIX consists of a single instrument composed of an imager module, a spectrometer, and the Instrument Data Processing Unit (IDPU). The STIX consortium is a collaboration of a several institutes located in various countries (Table 2-1).

Table 2-1. STIX Consortium

Responsibility	Person	Institute	Country	Role
Principal Investigator	A.O. Benz	ETHZ	Switzerland	PI
Detector Scientist	O. Grimm	ETHZ	Switzerland	Co-I

Science Operation	TBD	ETHZ	Switzerland	Co-I
Data Reduction	A. Csillaghy	FHNW	Switzerland	Co-I
Spectrometer	G. Dissertori	ETHZ	Switzerland	Co-I
Deputy PI	S. Krucker	UCB	USA	Co-PI
Imager Scientist	G. Hurford	UCB	USA	Co-I
Grid assembly	B. R: Dennis	GSFC	USA	Co-I
Senior Scientist	R. P. Lin	UCB	USA	Co-I
IDPU	J. Sylwester	SRC	Poland	Co-I
IDPU	P. Orleanski	SRC	Poland	Co-I
ESGE	M. Kowalinski	SRC	Poland	Co-I
Imager	G. Mann	AIP	Germany	Co-I
Power Supply	F. Farnik	AIAS	Czech Rep.	Co-I
Flight software	R. Sysala	ESC	Czech Rep.	Co-I
Software	P. Gallagher	TCD	Ireland	Co-I
Software	A. Veronig	Univ. Graz	Austria	Co-I
Software	J.C. Brown	U. Glasgow	UK	Co-I
Software	N. Vilmer	LESIA	France	Co-I

This team has a Principal Investigator, Prof. Dr. Arnold O. Benz, at the Institute of Astronomy at ETH Zurich, Switzerland. The Principal Investigator is in charge of the coordination of the STIX team within aspects of science, technique, management, finance and relations to institutions or individuals outside the STIX team. The Principal Investigator major responsibilities are detailed in section 2.1.1.

The deputy PI is Dr. Sam Krucker, a Swiss citizen who is presently a Senior Fellow at the Space Science Laboratory of the University of California, Berkeley, USA. The individual units are lead by unit Co-Is, with Co-I institutions contributing to the unit. The management scheme is described in their management plan documents.

2.1.1 Principal Investigator (PI) and Co-Principal Investigator (Co-PI)

STIX is under the responsibility of the Principal Investigator (PI), Prof. Dr. Arnold O. Benz (ETH Zurich).

Principal Investigator (PI)

According to the SOLO EID-A, the PI will have the following responsibilities:

1. Sole managerial and decision making authority interfacing with the ESA Solar Orbiter Project Office.
2. Appointing an instrument development manager to manage the day to day activities of the instrument development team.
3. Provision of financial control in order to assure necessary resources to achieve the agreed delivery dates of all deliverables including technical data and instrument models.
4. Providing instrument support to system level anomaly investigations, tests, reviews, operations and scientific activities arranged by ESA.

5. Creating and maintaining an EID Part B which details the instrument design and interfaces answering requirements in the EID part A.
6. Ensuring compliance with all ITAR regulations in a timely manner. Surveillance requirements arising from ITAR regulations shall be reported to ESA and any costs associated with such requirements shall be borne by the PI.
7. Support and attendance to Science Working Team meetings as called by the ESA Project Scientist. As far as scientific requirements are concerned the PIs are committed to the Science Working Team to whom the Science Performance Report is submitted on regular basis (at every project review).
8. The PI shall produce a Management Plan covering the proposed investigation for the entire duration of the mission.
9. The PI shall comply with the scientific data policy of the Agency as defined in the Science Management Plan.
10. The PI shall ensure the timely delivery of all deliverable items according to scheduled dates defined in section 8.7 of EID-A.
11. The technical interface of the experiment to the Industrial Prime contractor shall be supported.
12. The PI shall participate in technical working groups and control boards as requested by the ESA Project Office (e.g. environmental control board).
13. The PI shall support ESA management requirements (e.g. investigation progress reviews, programme reviews, change procedures, product assurance, etc.), as outlined in the EID-A.
14. The PI will have the responsibilities specified in EID-A (par. 8.2.3), related to Science Management, Hardware procurement, Software Development, Verification, Product Assurance, Operations, Data Processing and Dissemination, and Financial Responsibilities.

The PI may be substituted by the PI deputy, whenever he is not able to attend meetings or workshops where his presence is mandatory.

Co-Principal Investigator (Co-PI)

The Co-PI, together with the Imager Scientist and Detector Scientist, will deal with the Unit Experiment Leads until completion of the satellite in-orbit commissioning and thereafter with the Science Operations Lead. During all phases of the project, the Co-PI will take responsibility for all the STIX scientific issues with the support of the Unit Science Leads and the STIX Science Team. In particular, he will advise the Unit Experiment Leads on technical matters when they affect the scientific performance of the Unit.

2.1.2 The STIX Project Office (SPO)

The STIX Project Office (SPO), led by the PI, will assist the PI in pursuing his specific duties, ensuring the STIX development coordination in accordance with basic requirements, and being an effective interface with the STIX Experiment Manager, the Science Coordinator, and the whole STIX team. The SPO will directly coordinate both Operations and Calibrations activities. The SPO will also provide the basic management resources and management support for the project.

As part of this support during the development phase of the mission, the SPO will support the creation and maintenance of a STIX Web page as an information tool for the scientific community and the general public. The Web page will also contain a reference list of all publications and presentations related to STIX and an evaluation by the STIX Executive Board about their compliance with respect to the instrument peculiarities. After launch, the Web page will be elaborated in order to allow direct access to the data archive. It will include the latest news about the Instrument performance as well as preliminary scientific results as they become available.

2.1.3 STIX Experiment Manager (EM) and Deputy Experiment Manager (DEM)

The STIX EM, based in Swiss Industry, will be responsible for the STIX development and technical activities in Phase B2/C. The STIX EM role is to coordinate all technical and programmatic activities, in accordance with the PI directives and in compliance with ESA requirements. He organizes regular project meetings, within the STIX team and/or with ESA, covering hardware and software aspects. The EM is also responsible for Product Assurance (see 2.1.5).

The PI delegates the investigation engineering management and technical oversight during the Phase B2-D implementation periods to the Experiment Manager, who is responsible for the successful delivery of the STIX instrument and ground system. The Experiment Manager, under the direction of the PI, keeps the budget, schedule and technical integrity of the investigation on-track. This includes following and documenting the development and construction phases of the STIX instrument and setting up the ground system testing and integration framework at ETH. He defines the requirements and interfaces of the major technical elements and ensures that they are compatible with the Solar Orbiter project plans. The EM's role declines to a consulting role after instrument delivery.

The STIX DEM (C. Monstein, ETHZ) is the deputy manager at the SPO. The PI delegates to him the experiment management in Phase B1 including a concept study. After Phase C/D he takes over from the EM and implements the mission operation plans. The DEM’s role declines after launch to a consulting role.

The EM and DEM are supported by a STIX system team. The STIX system team is composed by the following key people:

- System Engineer
- Imager Lead and Detector Lead
- AIT Lead

The system team will provide the coordination, control and support for all the instrument units. Dr. Oliver Grimm will be hired by ETH as soon as the project is approved. He will have also system engineering tasks in Phase B1.

The development and project management diagram of STIX instrument, showing the structure of the organization, hierarchical position and name of key people, is included in Appendix A.

2.1.4 The System Engineer

The System Engineer (TGD, ETH Zurich) will support the integration activities which will take place at PI's Institute at ETH Facilities, verifying the units acceptance testing, which consists in a series of functional and environmental tests having the purpose of demonstrating that the flight configured H/W (and, when applicable, S/W) is acceptable for flight and that it performs satisfactorily. He will assure that the standard ESA methods for verification are matched both for verification by tests providing:

- Confirmation of the functional characteristics of the Unit's performances
- Verifying that the experiment is capable of surviving the environmental loads foreseen during the mission;
- Indication of trend behaviors toward possible wear-out, non conformance and/or failures and, for verification by assessment;
- Similarity;
- Analysis;
- Review of Design/Inspection;
- Demonstration.

The System Engineer will guarantee the organization and procedures established to ensure that the evolution of the experiment occurs within an identifiable and controlled environment, i.e. assuring that, baselines are defined and documented, that approved configuration changes are implemented and tracked, and configuration status accounting is accomplished.

The EM in particular will responsible to:

- Maintain the document database;
- Maintain the Configuration Items Data List (CIDL),with oversight from the EM
- Provide assistance in maintenance of the project web page
- Ensure that only the latest versions of documents are distributed and available for use and that outdated documents are replaced.

2.1.5 Product Assurance

The EM is responsible for Product Assurance at ETH Zurich and Swiss Industry. Furthermore, he is responsible to coordinate the activity of PA for the whole experiment. He has to establish and control an effective PA Plan covering Quality Assurance, Reliability, Safety, Materials, EEE Components and Configuration Management He is responsible to produce a verification PA plan coherent and compliant with the EID-A requirements.

2.1.6 The AIT Lead

The AIT Lead (O. Grimm, ETH Zurich) will preside the integration activities which will take place at ETH (Workshop of the Physics Department at ETH Zurich) and Swiss industry, performing the units acceptance testing, which consists in a series of functional and

environmental tests having the purpose of demonstrating that the flight configured H/W (and, when applicable, S/W) is acceptable for flight and that it performs satisfactorily.
He will state if the of the functional characteristics of the sensor unit performances are compliant for:

- Measurement of Physical Properties;
- Electrical Test (Swiss industry);
- Functional Test;
- Environmental Test (Swiss industry).

2.1.7 Unit Experiment Management

At each Co-I Institute, a Unit Experiment Management (UEM) will be established. The UEM will ensure the unit development coordination in accordance with basic requirements and an effective interface with the EM and the STIX team (Part V, Appendix B).

2.1.8 The STIX Science Team

A STIX Science Team (SST) will support the PI in defining and monitoring the scientific requirements of the project. It is coordinated by the Scientific Coordinator. He will be the link between the PI and the scientific investigators named in each Unit. The SST members will be:

Scientific Coordinator
Leading Co-Is (Part V, Appendix B1),
Science Key-Persons from Co-I institutions (Part V, Appendix B2 and B4)
Other Co-Is (Part V, Appendix B2)
PIs from other SolO instruments (Part V, Appendix B3)

The SST is composed by all scientists participating to STIX. The SST prepares the Science Performances Report Issues, led by the SST coordinator. All SST members relate to the coordinator for the transfer of any scientific request or suggestion that may be of interest for the STIX development. Such inputs will be reported by the PI within the STIX Executive Board for further evaluation or implementation. SST Members advise the coordinator about any scientific initiative having potential interest for the project (specific Conferences, Workshops, Scientific Journal issues, any STIX-related study preparation, new member proposals, etc.). The coordinator will report such news to the STIX Executive Board for any formal decision. SST Members will have access to the STIX Web Page. The list of the SST members is given in Part V, Appendix B.

2.1.9 The STIX Executive Board

The STIX Executive Board (Part V, Appendix B1) is composed of the PI, the Co-PI, the Co-Is of the Units and of the Experiment Manager. The board is chaired by the STIX PI. The Board monitors and supports the PI responsibility on all aspects that may affect the scientific performances, also with regard to financial and program criticalities. Moreover, the SEB will assist the PI in evaluation and approval of the Science Performances Report Document and contribute to evaluate the Science Operations Plan. Other scientific and programmatic aspects will be faced, like scientific data distribution policy, conference participation & paper publication procedures, new memberships. The Board aims to make decisions based on consensus, but where voting will be necessary member will have one vote and the chairman has the decisive vote at an equal number of votes.

The Board will meet regularly throughout the whole STIX development phase, at least once every three months or more frequently if necessary.

2.1.10 Science Operations Manager

The Science Operations Manager (SOM) will be the point of contact with MOC and SOC during phase E. He/She will sequence commands and monitor instrument health for the entire investigation. The SOM will provide updates to the flight software for the IDPU, test and forward the sequences to the Solar Orbiter SOC. In turn, all the raw data received in MOC is collected by the SOM, who will deliver the data to the designated Co-I for their processing. The process data is collected by the SOM and then is sent back to the SOC for archiving.

All the operations will be documented and archived in the STIX Project Office data base. The selected data will be uploaded to the STIX web service.

The SOM will be under direct supervision of the Principal Investigator. The SOM reports to the PI and to the STIX Executive Board.

2.1.11 Education/Public Outreach (EPO) Manager

We are aware of the importance of bringing the latest information about Solar/Heliospheric Science to the education professionals and to the public in general. Therefore, an EPO manager (TBD, ETH Zurich) at the project office will take the responsibility of this duty. He will also coordinate possible EPO actions with other(s) SolO instruments.

3 INSTRUMENT DESCRIPTION

3.1 Scientific objective

STIX plays an important role in enabling Solar Orbiter to achieve one of its major science goals of understanding the acceleration of electrons at the Sun and their transport into interplanetary space. The remote-sensing X-ray measurements made with STIX will determine the intensity, spectrum, timing, and location of accelerated electrons near the Sun. These escaping electrons can then be tracked into the inner heliosphere through their type-III radio emission, observed by RPW (the Radio and Plasma Waves instrument), and detected in situ by STE (the SupraThermal Electron sensor) of the Energetic Particle Detector (EPD) suite, to provide direct tracing of the magnetic structure, field line length, and connectivity. In this way, STIX, together with RPW and STE, is able to magnetically link the heliospheric region observed in situ back to regions at the Sun where the electrons are accelerated.

Secondary science objectives are:

1) To determine the size and morphology of hot (>10 MK) thermal plasma and non-thermal hard X-ray sources on the Sun with a resolution of 400 km at 0.22 AU, about 5 times better than previously achieved.
2) To use comparisons with coincident observations from spacecraft at 1 AU and other solar-orbiting spacecraft (such as Inner Heliosphere Sentinels, if available), to measure the directivity of solar X-ray emission.
3) To use observations of partially-occulted ‘behind-the-limb’ flares in conjunction with other spacecraft observations (such as Inner Heliosphere Sentinels, if available), to isolate weak coronal components of hard X-ray emission from the bright footpoint sources and so determine the relationship between the energetic electrons that lose their energy in the corona and those that impact the chromosphere.

STIX will also be at least an order of magnitude more sensitive to weak sources than RHESSI or Yohkoh/HXT, a capability that is important for extending the flare size spectrum down to weaker events that may be important for heating the corona. Detecting weak HXR emission associated with small impulsive electron events that are ^{3}He-rich is also important for understanding the particle acceleration processes involved in this distinct class of events.

3.2 Scientific performance summary

The performance requirements for STIX are shown in Table 3-1

Table 3-1: Summary of STIX performance

Energy Range	4 – 150 keV
Energy Resolution	1-15 keV (energy dependent)
Effective area	12 cm^2

Finest angular resolution	7 arcsec
Field of view for imaging	1.5° (FWHM)
Field of view for source location	2.5°
Image placement accuracy	
Imaging mode	~4 arcsec
Location mode	1 – 3 arcmin
Time resolution (statistics limited)	≥ 0.1 s

3.3 Instrument description

3.3.1 Functional description

3.3.1.1 Measurement principle

Observationally, the objectives of STIX are to determine the location, spectrum and timing of transient X-ray emission on the Sun at energy ranges that encompass emission from both hot thermal plasmas and bremsstrahlung from energetic electrons. This is done by imaging the Sun as a function of time and energy, with enough spatial, spectral and temporal resolution to match the sources of interest. Comparing the resulting images at different energies yields the X-ray spectra of individual features (e.g. footpoints or flaring loops). Comparing the images as a function of time discloses the temporal behavior of the hot plasma and accelerated electrons. The data can also be combined to yield spatially-integrated light curves and spectra. In all cases, the basic element is a photometrically accurate, single image corresponding to a well-defined time and energy interval.

To X-ray spectrum can be interpreted to yield the properties of the electrons that generated the X-rays can be inferred from the X-ray spectrum. The distinction between a thermal plasma and nonthermal electron population is made on the basis of the shape of the X-ray spectrum with the latter having a characteristic power law (or broken power law) profile and the former representing a black body spectrum (corresponding to 10^6 to 10^8 K). The spectra are very steep and so good spectral resolution is required for their interpretation. There is also an Iron line complex at 6.7 keV which can be interpreted in terms of the thermal electron population. A typical flare typically generates both thermal and nonthermal emission, which are often not co-located (for example at the top and footpoints of magnetic loops). Therefore both good spectral and good spatial resolution is required.

Focusing optics are not a feasible option for arcsecond-class hard X-ray imaging within Solar Orbiter constraints. As a result STIX uses an indirect Fourier imaging technique based on X-ray collimation. Conceptually, the instrument is made up of three mechanically separate sections (Figure 3-1): X-ray transparent sunshades; a passive imager containing front and rear grids, and a spectrometer with the X-ray detectors and electronics. The imager is comprised of 64 subcollimators, each of which consists of a pair of well-separated X-ray opaque grids located in front of a corresponding single CZT X-ray detector in the spectrometer. The transmission of each grid pair is very sensitive to the direction of incidence of the X-ray flux, so that the relative count rates of the detectors behind the different subcollimators encode the spatial information that can be subsequently decoded on the ground to reconstruct an image of the X-ray source. The individual CZT detector elements associated with the subcollimators do not themselves provide spatial resolution. Instead, for each detected X-ray, they provide an output pulse proportional to its energy. By comparing the relative count rates among different detectors within a selected energy interval, the combined system functions as a high resolution X-ray imaging spectrometer. Pointing information is provided by the spacecraft aspect system with an internal STIX aspect system to intermittently establish the pointing offset of the X-ray optics.

3.3.1.2 Functional diagram

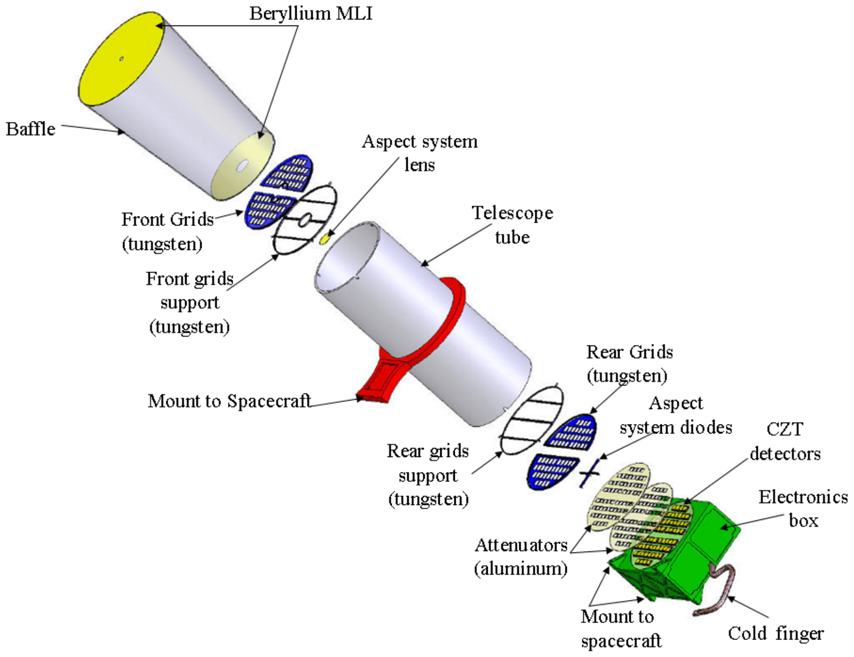

Figure 3-1. Conceptual sketch of the STIX instrument, made up of three mechanically-separate sections: the sunshades made of X-ray transparent, beryllium multilayer insulation; the imager with widely separated grids and aspect system; and the spectrometer containing CZT detectors and electronics behind a pair of movable attenuators. A directionally-sensitive fraction of the X-rays that enter the instrument on the left, are able to pass through both the front and rear grids to be recorded by the CZT detectors on the right. Imaging information is encoded in the relative count rates of the 64 detector elements. The two moveable attenuators are automatically inserted between the rear grids and the detectors as needed during large flares to prevent excessive count rates from low energy X-rays. The telescope tube is 55 cm long by 18.5 cm in diameter. A 22x20x18 cm deep box houses the attenuators, detectors and electronics.

3.3.2 Hardware description

3.3.2.1 Imager

As introduced in section 3.3.1, STIX telescope uses a set of 64 subcollimators, each of which consists of a pair of widely separated grids. The grid element associated with each subcollimator consists of a set of alternating equispaced slits, and X-ray opaque slats (Figure 3-2). Discrete X-ray detector elements, located behind each grid pair, measure the arrival time and energy of each X-ray. Imaging information is encoded in the relative count rates of the detector elements, each of which measures a distinct directionally-weighted fraction of the incident flux. The grid parameters are chosen so that the imaging information is provided in the form of spatial Fourier components of the source distribution (visibilities) in analogy with the imaging information provided by antenna pairs in a radio interferometer.

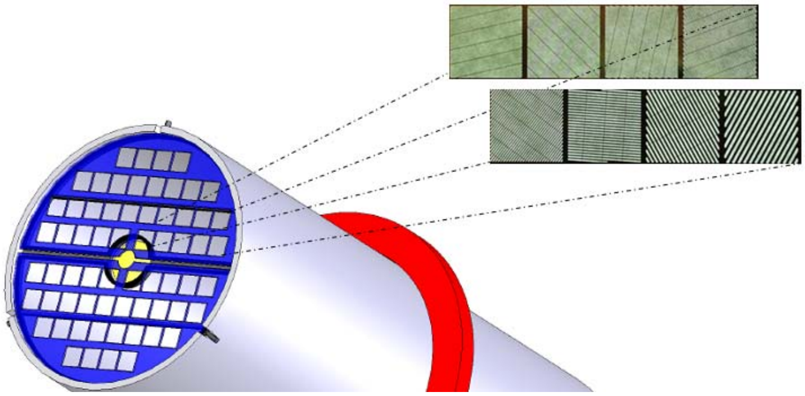

Figure 3-2. Schematic view of the STIX front grids mounted on the imager tube. The inset shows photographs of representative prototype grid elements fabricated to STIX specifications.

Considering a single subcollimator, the slits in the front and rear have identical pitch and orientation. As a result, the transmission oscillates in a periodic manner (between ~0 and ~50%) as a function of direction of incidence (in a plane orthogonal to the slits). The period of this variation is given by the ratio of the grid pitch to grid separation. For a stable instrument platform, the X-ray transmission of the grid pair does not vary with time. Rather it has a value between ~0 and ~50% determined by the directional distribution of the incident X-rays. The FWHM resolution of a subcollimator is defined as half the period of the angular response and is given by the ratio of half the grid pitch to the grid separation. The finest grids have a pitch of 38 microns and the separation is 55 cm, giving a FWHM resolution of 7 arcseconds.

Compared to the STIX configuration described in the Payload Definition Document (Annex 3), the proposed imager is shorter (55 cm vs. 90 cm) and larger in diameter (18.5 cm vs. 12 cm). These changes were made to increase the imaging FOV from 38 arcminutes to 1.5 degrees. Based on RHESSI results to date, the 7 arcsecond angular resolution is still sufficient to resolve almost all footpoint sources even at 1 A.U. while providing unprecedented spatial resolution at 0.22 A.U.

To see how STIX obtains measurements of spatial Fourier components of the source distribution, consider two ‘complementary’ subcollimators with identical slit pitch and orientation. The slits in one of the 4 grids are shifted by ¼ of the pitch so that the periodic spatial responses of the two subcollimators are identical except that their relative direction of peak response is shifted by ¼ of the period – viz. its phase is shifted by 90°. The count rates from the two complementary subcollimators measure the real and imaginary parts of the Fourier component. When combined with a measurement of the spatially-integrated X-ray flux (from other detectors) and with calibration information, the pair of subcollimators then yields a calibrated measurement of one Fourier component of the source distribution with a spatial period of twice the FWHM resolution.

Of the 64 subcollimators, 30 complementary pairs are used to measure 30 different Fourier components of the source distribution. The four remaining subcollimators are used to provide a measurement of the spatially integrated solar flux. They are also used to determine background counting rates and to assist with on-board source location. The 30 measured Fourier components are in the form of two orthogonal sets of 15 spatial periods each with logarithmically spaced FWHM resolutions of between 7 arcseconds and 8.8 arcminutes. This provides sensitivity to a wide range of source angular scales. When SolO is at 0.22 AU, these angular resolutions correspond to spatial resolutions of 1,100 km to 80,000 km on the Sun. The lower limit represents the finest spatial resolution achieved to date at hard X-ray energies, while the upper limit is still sufficient to provide sensitivity at the largest spatial scales likely to be observed.

Data processing to reconstruct the X-ray images is done on the ground, after the fact from the telemetered count rates of the 64 detectors. Well-established computational techniques are used that were developed originally for radio interferometry, and subsequently adapted to the analysis of X-ray data from Yohkoh/HXT and RHESSI (e.g. Hurford et al., 2002). Image quality will be comparable to that obtained with Yohkoh/HXT, albeit with much better spectral resolution.

The technique used to fabricate the STIX tungsten grids is based on the etch-and-stack process used successfully to make the finer RHESSI grids. They are fabricated by stacking up to 16 sets of etched tungsten sheets to a thickness of 0.4 mm. The required grid pitch values range from 38 microns to 2.8 mm. The grids illustrated in Figure 3-2 are fabricated as two sets of 18 x 9 cm (roughly semicircular) segments each of which contain 32 15x15mm etched areas corresponding to the grid elements for individual subcollimators.

Achievement of these grid parameters has been demonstrated by the high-quality RHESSI grids covering a comparable area with finer pitch (34 microns) and greater thickness (1 mm). Recent NASA-funded Small Business Innovative Research (SBIR) development contracts with Mikro Systems, Inc. have resulted in the ability to etch multiple subcollimator grids with different orientations and pitches on the same tungsten sheet. Prototype 4x4 arrays of STIX grids have been fabricated in this way with slits in different orientations and with pitches as fine as 20 microns. This capability allows us to avoid the difficult task that was necessary with RHESSI of separately mounting and aligning each front and rear grid element pair. It greatly simplifies the alignment process and ensures that the relative positions of the subcollimator elements remain stable (after allowance for thermal expansion).

The semicircular grid segments are mounted on a tungsten spider that provides mechanical support (see Figure 3-1) and maintains the relative locations of the two grid halves. The entire grid area thus has the same thermal expansion coefficient. The spiders, in turn, are mounted on opposite ends of an 18.5 cm diameter x 55 cm long carbon fiber reinforced plastic (CFRP) metering tube. The only significant optical alignment requirement is that the relative twist of the front and rear grid assemblies be maintained throughout the mission to 2 arcminutes. This is done using kinematic mounts between the grids and tube that are designed to accommodate differential thermal expansion without affecting the relative orientation of the front and rear grid assemblies. (A similar technique was used with RHESSI to achieve alignment tolerances that were 6 times more stringent).

Provided the relative twist alignment is maintained between the front and rear grids, the quality of the resulting images is optically dependent only on the inherent dimensional stability of the front and rear tungsten grid assemblies. Independent thermal expansion of the front and rear grid assemblies can be fully compensated during data analysis provided their temperatures are measured to a few degrees centigrade. Temperature gradients across each grid of up to 6º C have no impact on X-ray imaging performance. As a result, imaging with this technique is exceptionally robust and well-suited to the expected SolO range of thermal environments.

3.3.2.2 Detectors

STIX uses 64 discrete Cadmium-Zinc-Telluride (CZT) planar detectors, one behind each subcollimator, to provide good energy resolution while operating at room temperature. CZT detectors have been flown in space before, most notably on NASA's SWIFT MIDEX mission, where 32,768 such detectors are used [Kuvettli, 2003]. Each STIX detector has volume of 15x15x3mm, segmented into three zones: a 9x9mm active area, surrounded by a 1 mm buffer and 2 mm wide guard ring to minimize noise from edge-related leakage current. These are coupled via bump bonding technique to front-end electronics. Figure 3-3 shows that a ~1cm^2 area, 5mm thick CZT detector with guard ring can achieve ~3 keV threshold with ~1 keV FWHM resolution at ~6 keV at room temperature. The 3 mm thickness is fully effective at stopping 100 keV photons and retains useful sensitivity (~50% efficiency) at 150 keV.

Analog signal processing with ~2 microsecond shaping time will make use of radiation hard ASIC technology, optimized for low noise, and high counting rate capability (up to 10^5/s). Their output will be digitized by an array of 12-bit resolution ADCs on an electrical shielded printed circuit board in the top layer of the electronics box so as to not compromise the intrinsic resolution of the sensor. CZT detectors typically require bias voltages of 300-500 volts.

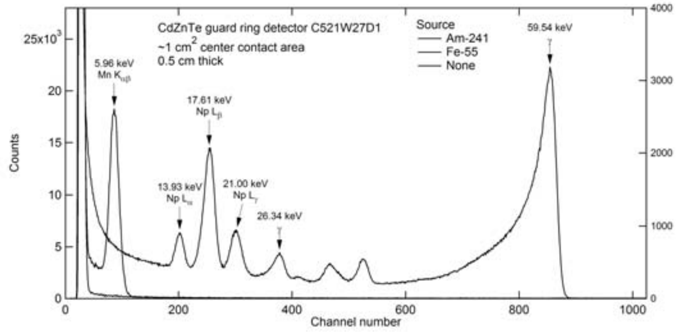

Figure 3-3. Spectrum of an Am^{241} and Fe-55 source obtained with a room temperature 1cm2, 5 mm thick CZT detector with a guard ring (~1 na leakage current), illustrating the energy resolution (1.37 keV FWHM at 5.96 keV) and energy threshold ~3.1 keV with 2 microsecond shaping time. (P. Luc private communication)

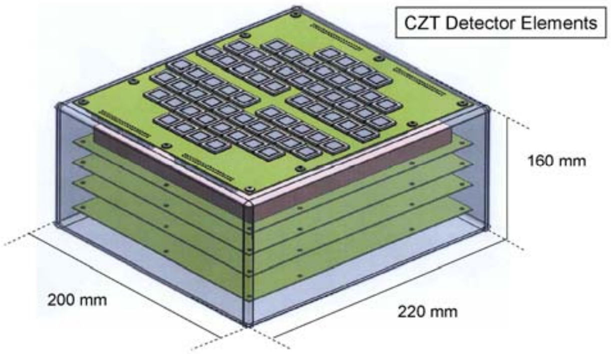

Figure 3-4. Sketch of the spectrometer module showing the 64 CZT detector elements. Attenuators and a thin light-tight Beryllium window (not shown) are mounted on the spectrometer module above the detectors.

The detectors are mounted in the front of the spectrometer module (Figure 3-4) that is located 2 cm behind the imager and separately mounted to the spacecraft. The separate mounting prevents the spectrometer module from transferring any mechanical stresses to the imager that might otherwise affect the relative twist alignment of the front and rear grids. The transverse coalignment requirement between the imager and detector/electronics module is modest, at the ±0.5 mm level. The degree of misalignment of the two modules, if any, can be inferred from the internal self-consistency of flare data, and appropriate corrections can be applied without materially affecting the quality of the resulting images. The longitudinal alignment (to ~1mm) is not critical to instrument performance.

Attenuators

The expected range of incident X-ray fluxes from solar flares is quite extraordinary. The ratio between the smallest microflare that STIX can detect and the largest X-class flare is 10^5. The ratio between the fluxes at 3 and 150 keV for a steep flare spectrum can be as high as 10^7 to 10^9; a further factor of 20 must be accommodated because of SolO's varying distance from the Sun. Although this range is partly accommodated by energy-dependent absorption by the Sun shade (which preferentially absorbs at low energies) and by the intrinsic dynamic range of the detectors, it is highly desirable to incorporate moveable X-ray attenuators. Their use enables the counting rate (and the resulting spectral distortion from pulse pile-up) to be limited for large events while still retaining full sensitivity to small events. As a result, the attenuators enable STIX to be responsive to the entire expected dynamic range of X-ray flux, including the factor of 20 due to the $1/r^2$ variation from the orbit. Such attenuators have proven to be effective and very reliable on RHESSI (Smith et al 2002). Based on internal (count-rate driven) logic, either or both of two attenuators (thick and thin) are inserted automatically when the count rates exceed preset thresholds. Each attenuator consists of a thin circular sheet of aluminium (~0.1 and $0.4 g/cm^2$ respectively) which preferentially absorb a known fraction of the low energy X-ray flux while having negligible effect at higher X-ray energies. The insertion mechanism is based on temperature-sensitive Shape Memory Alloy actuators also used on RHESSI, STEREO and THEMIS.

Sun Shades

The sun shade required by STIX plays two roles. First, it is a prime element on the thermal control system, reflecting most of the incident radiation, and so limiting the incident optical and IR solar flux that is seen by the instrument. Second, it serves to preferentially absorb the intense flux of low energy X-rays produced during large flares that would otherwise contribute to pulse pileup and live time issues for the detectors. By using low-Z materials, a thermally-effective Sun shade can be used which has acceptable X-ray absorption properties to permit observations down to ~3.5 keV. The Sun shade consists of a pair of thin multilayer beryllium/carbon-carbon windows, at the top and bottom of the spacecraft thermal shield. The top Sun shade has a central 5 mm diameter circular opening (transmitting 0.54 watts at 0.22 AU) for use by the STIX aspect system and the bottom shade has a corresponding 35 mm diameter opening.

3.3.2.3 Aspect System

The nominal spacecraft aspect control system requirement is sufficient for STIX to produce images without compromising its 7 arcsecond resolution. However, absolute placement of such images on the Sun makes use of the post-facto aspect solution and requires knowledge of the offset between the STIX X-ray optical axis the spacecraft aspect system. This offset will be measured to ~3 arcminutes during integration, but must be calibrated at the ~3 arcsecond level in flight. Because of the stability of the thermal environment, only occasional (every few days) cross calibration is required. This is accomplished with the STIX internal aspect system and does not require any specific spacecraft operations.

To provide this occasional cross calibration, the STIX aspect system has a singlet 3.5 cm diameter plano-convex lens built into the front grid assembly. This lens is illuminated through a 5 mm diameter circular aperture in the center of the Sun shade (with a placement requirement of ±2 mm). (Its alignment plays no role in the aspect calibrations.) The lens focuses a vignetted image of the Sun onto the rear grid plane. Measurement of the location of the optical solar limbs then defines the orientation of the STIX imager with respect to the direction to Sun center. Note that by mounting the aspect elements into the grid planes themselves, the calibration is independent of the mechanical properties of the tube.

Instead of using a set of linear diode arrays (or active pixel sensors equivalent) to determine the location of the limbs as used on RHESSI (Lin et al 2002), a simpler system is used which provides the occasional absolute measurement of the limb location. A set of small (10 micron and up) circular apertures in the rear grid are arranged in the form of a cross through the center of the rear grid assembly. Behind these apertures, a set of 4 long non-segmented photodiodes records the light passed by the apertures. When a solar limb passes over one of these apertures, there is a stepwise change in the output of the corresponding photodiode. Noting the spacecraft aspect system readout at these times (during data analysis) establishes the offset between the X-ray axis (as determined by the lens and aperture location) and the spacecraft aspect. The cross-calibration is performed every few days even if there is no deliberate spacecraft offpointing, since the apparent solar diameter is continually changing due to orbital motion. If spacecraft offpointing does occur, the aspect cross-calibration is achieved more frequently. After on-board data selection, this internal aspect system requires an average of 3 bits per minute of telemetry.

3.3.2.4 Instrument Data Processing Unit (IDPU)

The IDPU includes memories (ROM, RAM), for data accumulation and software, interfaces to the Payload Data Management Unit, a Housekeeping system, interfaces to other STIX electronics (detector ASICs, aspect diodes readout, attenuator control, and power supplies), and an autonomous state machine and rotating memory.

The instrument data processing unit is responsible for converting the digitized pulse amplitudes of the detectors to a compact form, suitable for telemetry. On the instrument side, the primary data interface is the digitized output from the detector ASICs, which provide an 18 bit word for each detected event (12-bits for pulse amplitude and 6 bits for detector identification). The fine pulse amplitude information is converted to one of 32 logarithmic energy bins (spaced to optimize coverage of the expected steep solar spectra in the energy range of interest) using a programmable lookup table. Counts as a function of energy and detector ID are accumulated in 32x64=2048 accumulators. The contents of these accumulators are then transferred to instrument memory 10 times per second along with the live time. This rotating 128 MByte memory provides transient storage for the accumulated counts with full time and energy resolution for a time (~1 hour) that is long compared to most flares.

Data rates are monitored as they accumulate in the memory with a latency of ~1 s to identify flare times, fluxes, and locations. This information is used to generate flare flags for optional use by other SolO instruments, and to make decisions on attenuator actuation. On a timescale of tens of minutes, the rotating memory data for flaring intervals is evaluated to identify the optimum combinations of time and energy binning, using criteria of statistical significance, time and energy-bin continuity, and flare-relevant time and energy scales. The data are then averaged over these intervals and the 64 data rates for a given time and energy interval form the basis for a single image. Since the imaging data is in the form of the relative count rates, the 64 rates are converted to the form of 32 4-bit binary fractions, which, along with the average rate and identifying information, form the basis of a 40-byte image.

Corresponding sums of detector-averaged data with higher time or higher spectral resolution are generated to provide spatially integrated light curves and spectra for context. During non-flaring intervals, the data are also accumulated for each detector with the full 12-bit energy resolution but much lower time resolution to provide the basis for monitoring background spectra and determining the detector energy calibration.

On board flare locations are inferred from count rate ratios calculated from linear combinations of detector rates. These ratios are used to reference a lookup table generated on the ground using known instrument calibration parameters. Detector-summed high spectral resolution data can also be selected to provide spatially integrated spectra as desired.

Aspect data handling by the IDPU is conducted by periodically interrogating the imager-associated a/d interface to the four photodiodes, and associating the digitized signal levels with the spacecraft clock. No on-board aspect interpretation is required. The cadence for this interrogation is normally ~10 times per hour. When spacecraft slewing operations are in progress, however, the cadence will be substantially increased.

Although the rate of STIX-generated data will be strongly dependent on solar activity, the data can be metered to the spacecraft memory at a more moderate (TBD) rate.

In addition to these STIX-specific instrument functions, the IDPU provides the normal functions of instrument level command interpretation and execution, commanding bias voltage levels in response to ground commands or internally generated criteria, commanding attenuator state changes, digitizing, monitoring and multiplexing instrument temperature sensor output, etc.

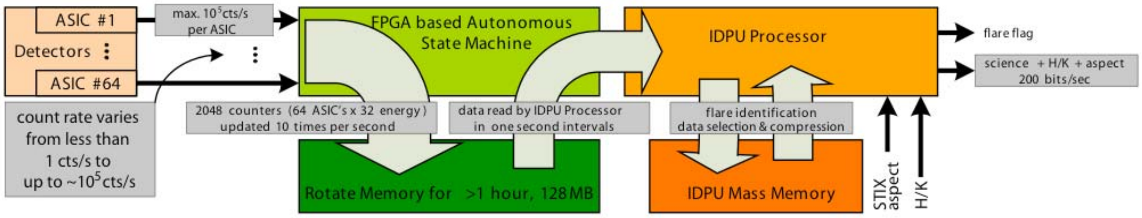

Figure 3-5. Summary of data flow within the IDPU

The data flow is summarized in Figure 3-5. Initial accumulation in the 128 MByte rotating memory is done autonomously using an FPGA-based hardware state machine. The same FPGA provides all necessary logic to interface the rotating memory to the main STIX processing unit. The interface is organized in such a way that the data can be accumulated by the state machine, while at the same time is available for access by the processing unit. The SpaceWire RTC (Remote Terminal Controller), currently under ESA development on ASIC base, is baselined for the core for digital data processing unit. It provides 50 MIPS of processing power with an additional 10 MFLOPS floating point unit included. Since the state machine handles the time-critical tasks, this RTC is more than sufficient to perform the processing tasks mentioned in previous paragraphs. The probability of SEU error in all memories will be investigated and, if necessary, the error detection and correction task for the memories will be performed by the EDAC subsystem implemented as a part of previously mentioned FPGA. The RTC ASIC interfaces the IDPU to the spacecraft via a SpaceWire link.

Flare Trigger and Location Measurement
STIX will use robust algorithms to generate a flare trigger that includes information on the intensity and location of the event. This information can be summarized (~0.1 bits/second) for optional inclusion in beacon mode telemetry to provide now-casting of events on the far side of the Sun. The flare trigger and location can also be provided promptly to the spacecraft DPU for optional transmission to other instruments for use in choosing observing modes or data selection.

The flare trigger will be generated by the STIX processing unit based on 1-second-averaged count rates in the rotating memory. Flares are manifest by relatively rapid increases in count rates, particularly at low energies. (Particle events can usually be distinguished by their spectrum.) Background, which will normally be negligible, can nevertheless be calculated using count rate ratios from the 4 central CZT detectors (Figure 3-6) to provide additional assurance that particle events do not generate false flare triggers. Flare triggers using similar data have been used on many missions (e.g. Yohkoh/HXT and SMM/HXRBS). More recently, fully automated flare identification and location algorithms are routinely applied during post analysis to generate the RHESSI flare catalog. Such algorithms will be adapted to STIX and tested extensively both with simulations and with 7+ years of RHESSI data.

Depending on the flare offset, three different methods will be used to determine flare location on board. The first relies on the shadowing of detectors near the outside of the array by the upper grid assembly. The ratio of selected outside subcollimators to the others yields source locations to ~3 arcminutes for sources that are between 9 and 75 arcminutes off-axis. If this indicates that the source is within ~36 arcminutes of the optical axis, the ratio of counts among the four central subcollimators can be also be used to provide confirmation (Figure 3-6). If these analyses indicate that the source is within the 1.5 degree imaging field of view, then the 8 subcollimators with the coarsest pitches can be used to provide two independent refinements of this location to ~1 arcminute. Previously uploaded parameters will be used to correct this value to account for calibration factors and instrument alignment.

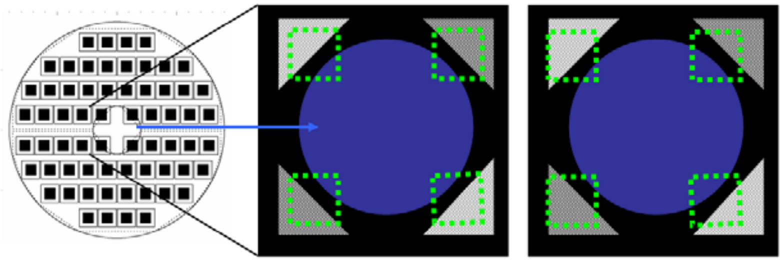

Figure 3-6. The central panel shows an expanded view of the four central subcollimators with the X-ray opaque area of the top grid assembly (black), aspect lens (blue, also X-ray opaque) and the open area of the four central subcollimators in the top grid assembly (two shades of grey, corresponding to two different X-ray absorbtivities). The projected locations of the active area of the corresponding CZT detectors, as viewed from the source direction are shown as the green boxes. The central panel shows the case of an on-axis source; the right panel shows the case for a source that is 18 arcminutes off-axis. While the sum of the illuminated areas of diagonally opposite detector pairs remains unchanged, for source offsets up to ~36 arcminutes their ratios depend on the two diagonal components of the source offset.

Software description

The on-board instrument-specific software tasks include:

- Interfacing to spacecraft DPU.
- Monitoring status data (temperatures, voltages, etc) and going into safe mode in the event of significant anomalies.
- Monitoring relative detector count rates to identify significant detector anomalies and issuing appropriate internal commands as needed.
- Monitoring average detector count rates and generating attenuator commands as needed.
- Selecting, averaging, and compressing flare imaging data as described in 3.3.2.
- Selecting, averaging, and compressing spatially-integrated spectra
- Averaging and compressing spatially-integrated light curve data.
- Formatting STIX data for inclusion in the telemetry buffer.
- Identifying flares and determining their approximate location for inclusion in beacon-mode telemetry (if any) and notification of the spacecraft DPU (if desired by other instruments or for spacecraft off-pointing).

Note that except for determining the approximate centroid location (from linear combinations of the count rates and a table lookup, there is no on-board image reconstruction.

3.3.3 Instrument data sheet (see Annex I)

3.4 Operational modes

STIX operations are autonomous, based on preloaded parameter settings. Examples of such parameters include the following:

1. Gain-setting parameters (to match gains of the individual detector elements);

2. Parameters to define criteria for the insertion and removal of attenuators; (Insertion or removal of attenuators is based on internal logic and requires no spacecraft-generated commands.)
3. Parameters used by the instrument data processor algorithm for the selection of imaging intervals for inclusion in telemetry.

No offpointing operations are required.

The science output of the STIX instrument would be greatly enhanced by operation during the cruise phase. This is particularly important if Solar Orbiter is co-observing with Solar Probe Plus.

4 INTERFACE DEFINITION

4.1 Definition of Instrument Identification and Labelling

TBD

4.2 Definition of Instrument Lifetime, Maintainability and Fault Tolerance

TBD

4.3 Definition of coordinate system for instrument and instrument units

TBD

4.4 Definition of Instrument Location and Alignment

4.4.1 Instrument Location

STIX is located behind the heat shield, internal to the spacecraft body.

4.4.2 Instrument Alignment Requirements/Stability

Instrument alignment requirements can be divided into three areas:

1. Internal alignment required to ensure efficient imaging;
2. External alignment to ensure that the STIX field of view is satisfactory;
3. Alignment requirements to ensure accurate (~4 arcsecond) placement of the resulting X-ray images on the Sun.

Most of the alignment requirements for this type of X-ray imaging are satisfied by the design and fabrication of the grids, which are inherently stable. As a result, many potential alignment issues are dealt with at the subsystem level. At the system level, the primary alignment requirement is to maintain the relative twist of the front and rear grid assemblies to within ±2 arcminutes (1σ), a requirement that is six times less stringent than on RHESSI. Thus, STIX achieves arcsecond-class imaging with arcminute-class alignment requirements.

An additional alignment requirement of ±0.4 mm is imposed on the transverse location of the rear grids with respect to the detector/electronics module.

The STIX optical axis is defined by the line from the center of rear grid (defined by the aspect apertures) and the optical center of the lens mount in the front grid.
This axis can be determined non-invasively (using the optical GSE) by viewing an external compact light source, both at the imaging subsystem level and following integration into the spacecraft. The absolute alignment requirement with respect to the spacecraft aspect system is 3 arcminutes, a value chosen to be a small fraction of the 1.5 degree imaging field of view.

In-flight determination of the offset between the spacecraft aspect system and the STIX imaging axis can be determined in flight by post-facto analysis of the output of the aspect photodiodes which will exhibit step-like increases or decreases in the their response as the solar limb covers or uncovers individual apertures. If there is no spacecraft offpointing activity, this will occur a few times per week because of the apparent changes in the solar diameter. If there are offpointing activities, this will occur more often. To maintain this knowledge, however, there is a requirement of arcsecond-class *stability* of the coalignment between the spacecraft aspect and the STIX imaging axis, on timescales (a few days) over which the thermal environment is to be stable. This alignment requirement affects only the placement of the X-ray images on the Sun. It has no effect on STIX imaging sensitivity, angular resolution, or image quality.

To support alignment during integration, a removable alignment cube can be mounted on the STIX imaging tube. The alignment of this cube relative to the instrument optical axis will be done by the IT.

STIX coalignment can be adjusted during spacecraft integration with shims as necessary.

4.5 External Configuration Drawings

TBW

4.6 Mechanical interfaces

4.6.1 Mechanical Interface Control Document

TBW

4.6.2 Definition of Instrument Size and Mass

4.6.2.1 Instrument Size Specifications

The STIX instrument consists of 4 independent components.

A 21.5 cm diameter thin MLI sunshade at the outer surface of the spacecraft thermal shield with a 5 mm diameter open aperture, located within 2 mm of the imager axis

An 18.5 cm diameter thin MLI sunshade in front of the imager module, at/near the inner surface of the thermal shield located within 2 mm of the imager axis. These dimensions do not include the TBD interface to the spacecraft heat shield baffle.

The imager module is an 18.5 cm diameter by 55 cm long cylinder kinematically mounted at its midpoint. The mount is fixed to the inner wall of the spacecraft. The cylinder axis is parallel to and 11 cm from the wall.

The spectrometer module is a 20 x 22 x 18 cm deep box, mounted (on the 20x18cm side) to the inner wall of the spacecraft immediately behind the imager module. (The electronics and detectors occupy a volume 20 x 22 x 16 cm deep with an additional 2 cm extension on the front to house attenuators.). It is transversely aligned to the rear of the imaging module to ± 0.4 mm. The alignment of the imaging and spectrometer modules can be monitored in flight from internal redundancies in the X-ray data.

4.6.2.2 Instrument Mass Breakdown

The instrument mass budget is shown in Table 4-1

Table 4-1. STIX Mass Budget (kg)

Windows	0.08
Grids	0.38
Aspect components	0.03
Imager tube and mount	0.61
Harness	0.3
Attenuators	0.13
Detectors and ASICS	0.38
Electronics	2.0
Thermal blankets	0.09
Total Mass	4.0
10% Contingency	0.4
Total mass including contingency	4.4

4.6.3 Baffles

The interface between the STIX imaging module and the heat shield feedthrough is TBD.

4.6.4 Doors

None required

4.6.5 Description of Mechanical Environment

The instrument will be designed to withstand the mechanical environment during all stages of AIT/AIV, qualification and acceptance testing and that produced at launch.

4.6.6 Structural Design

The structural design will be designed to comply with the safety factors defined in 4.6.6.1 of EID-A.

4.6.7 Payload Generated Disturbances

Moving parts in the STIX instrument consist of two attenuators (thick and thin), mounted on the sunward side of the spectrometer module. The attenuators are thin aluminium disks ~18 cm in diameter. When count rates exceed preset limits (typically due to flares) the instrument processor commands one or both of two attenuators to shift from one fixed position to another to attenuate the incident X-ray flux. This occurs at unpredictable times, depending on solar activity and, based on RHESSI experience, with a frequency of a few times per day on average. Successive attenuator motions are always separated by a few seconds. Only one attenuator is moved at a time. The motions can be temporarily disabled (by software command) if necessary, but during such periods, the STIX instrument may be saturated by high count rates. Software logic also sets override limits on the frequency of the motions. Shape memory based mechanisms, based on a design proven on RHESSI are used.

The mass of the thin and thick attenuators (including frames) is 23 and 60 grams respectively. For each attenuator, the linear displacement is 1 cm, transverse to the optical axis of the instrument. No torque is generated. The requirement for the duration of the motion is <1 second although, depending on the implementation, the duration of movement may be as short as ~100 ms. Acceleration profile is TBD.

4.7 Thermal interfaces

4.7.1 Thermal Control Definitions and Responsibilities

The thermal control definitions and responsibilities will be in compliance with those outlined in EID-A 4.7.

4.7.2 Thermal Environment

TBW

4.7.3 Thermal Interfaces – Definitions

TBW

4.7.4 Thermal Interfaces – Requirements

Thermal requirements for satisfactory performance of the X-ray optics are driven by the fact that the interpretation of the X-ray data depends on accurate (at the few micron level) *knowledge*, as distinct from control, of the relative 2-dimensional location of grid features within each grid. On larger scales, slow (timescale of 10’s of minutes or longer) relative transverse displacements and/or bending of the 55-cm long tube have no affect on the imaging or sensitivity, except in terms of absolute placement of the final image on the Sun. The imaging response is also largely immune to credible changes in the parallelism of the grid planes. The primary requirement to maintain imaging performance is that the relative *twist* between the front and rear grids be maintained throughout the mission to ±2 arcminutes (1 σ). Provided the symmetry of the CFRP winding is carefully controlled during manufacture, thermal gradients along the tube or in the external radiative environment are not expected to induce twist in the tube at this level.

In terms of the effect of temperature on the imaging performance, the knowledge requirement mentioned above implies that the temperature range across the grid must be no greater than 6ºC. If this condition is met, the assumption of uniform thermal expansion is satisfactory for data analysis purposes. Provided the grid temperatures are measured to 6º C, thermal expansion of the grids can be fully compensated in data analysis with no loss of image quality. Thus, except for survivability, there is no operational requirement per se on the average temperature of the two X-ray grids.

No optically-driven requirement has been identified for the maximum actual temperature *difference* between the two grids. There is, however, a requirement that the *prediction* of the temperature difference between the grids be correct to within ~50º C. This implies a corresponding limit to the range of allowable temperature differences. The reason for the relatively weak temperature difference requirement is that pre-launch expectations of the temperature difference can be pre-compensated in the grid design by making the pitches of the front and rear grids of the individual collimators different at room temperature.

The operational temperature range of the detectors is TBD but is expected to be -30 to +25 ºC. The electronics operational temperature range is TBD but is expected to be -30 to +30 ºC. Since the interior radiative environment is expected to reach 40 ºC, this implies that a hot element interface is necessary, particularly for the detectors. Internal heat dissipation in the spectrometer module is 4 watts.

4.7.4.1 Thermal control strategy

An important factor achieving the STIX thermal control requirements is that a sun shade consisting of two windows, opaque in the visible but transparent to X-rays, can be located in front of the imager module. The sun shade plays two roles. First, it is the prime element in the thermal control system, reflecting most of the incident radiation, and so limiting the incident optical and IR solar flux that is seen by the instrument. Second, it serves to preferentially absorb the intense flux of low energy X-rays produced during large flares that would otherwise contribute to pulse pileup and live time issues for the detectors. By using low-Z materials and a combined density of ~0.25 g/cm^2, a thermally effective Sun shade can be used which has acceptable X-ray absorption properties to permit observations down to ~3.5 keV.

The Sun shade consists of a pair of thin multilayer beryllium/carbon-carbon windows, at the top and bottom of the spacecraft thermal shield. The windows will be provided by the instrument team with mechanical interfaces specified by the spacecraft engineers. The top window has a central 5 mm diameter circular opening (transmitting 0.54 watts at 0.22 AU) for use by the STIX aspect system and the bottom window has a corresponding 35 mm diameter opening over the aspect lens.

In terms of performance of the imager module, since the grids are fabricated of tungsten, their primary thermal limitation is the ~micron thick layers of epoxy that bond the tungsten layers together. Grids for RHESSI, made to similar tolerances by the same technique, have performed well in qualification tests at 50 ºC. Since the upper temperature limit was not determined, however, a NASA-funded investigation is underway at Mikro Systems Incorporated to determine the thermal limitations of the grids and how this is affected by the choice of epoxy or other bonding material. Thermal performance of the grids can also be optimized through the use of thin (<1 micron) coatings with no significant impact on their X-ray response.

The telescope tube will be coupled radiatively to the spacecraft interior. No significant conductive heat flow is baselined. Since the imaging tube is passive, the thermal flux to be transferred is determined by the residual solar heat transfer through the window and the aspect lens. The latter is limited to 0.54 watts. There is no direct light path through the rear of the tube to the spectrometer module.

Modelling to date has assumed that the baffle through the heat shield provides minimal heat conduction to/from the interior elements of the heat shield. Since the baffle is not in the STIX X-ray field of view, its coating can be optimized on the basis of thermal considerations alone.

Figures 4-1 and 4-2 and Table 4-1 show the results of thermal modelling. The windows are assumed to have a “black MLI coating” with an α/ε of 1.14, consistent with the first layer VHT MLI used by EADS as found in Annex 11. Grids were conductively coupled to the tube and had a thin coating of low emissivity aluminum. The lens was conductively isolated from the front grid. The tube was radiatively, but not conductively coupled to the spacecraft. The interior radiative environment was 40 ºC. The spectrometer was maintained at 25 ºC. Baffle temperature was fixed at 350 ºC. The incident solar flux was 27,000 watts/m^2. Since other model runs with different coatings (e.g. 20,000 Angstrom Al2O3 on the MLI) yielded much lower Sun Shade temperatures, the results shown below are considered conservative.

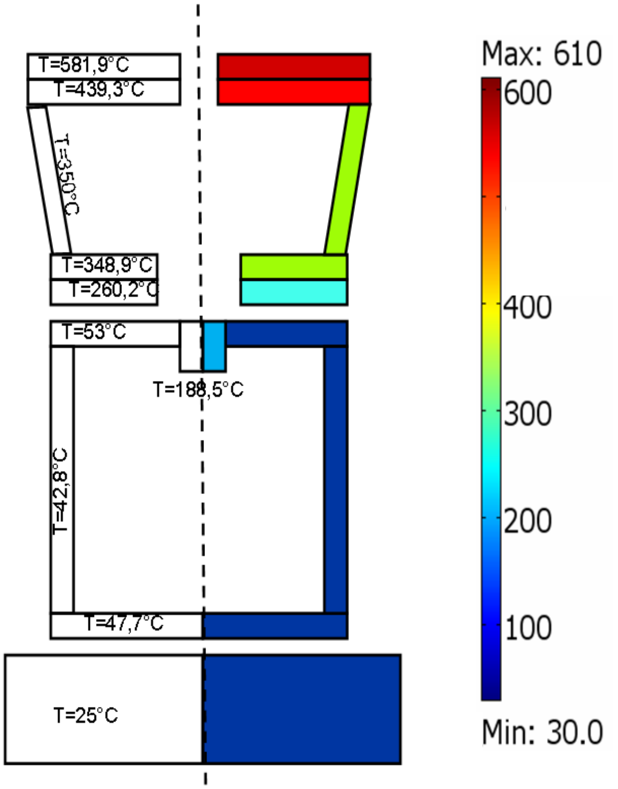

Figure 4-1. Thermal Modeling

Table 4-2. Temperatures from Thermal Modeling

Location	**T [°C]**
Outer layer of front MLI	582
Inner layer of front MLI	439
Inner layer of rear MLI	349
Outer layer of rear MLI	260
Front grid (average)	53
Lens	189
Rear grid (average)	48

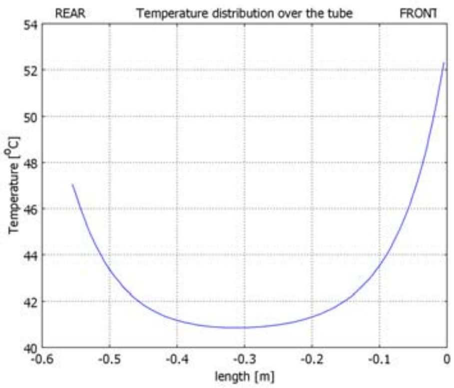

Figure 4-2. Temperature Distribution along Tube

The net heat radiated from the tube to the spacecraft interior was 5.8 watts. The net heat radiated from the rear grid to the spectrometer was 0.125 watts, which is small compared to the internally generated heat load of 4 watts. The temperature gradient along the length of the tube ranged from 53 C at the front to 40 C in the center. The temperature gradients across the grids were less than 2.5 degrees, well within imaging requirements.

Although the thermal design of STIX is at a very early stage, these results, based on conservative choice of window coating and worst case interior temperature, indicate that satisfactory performance can be achieved within the guidelines suggested in EID-A.

4.7.5 Thermal hardware interfaces

4.7.5.1 Instruments heaters

The requirements for heaters are TBD.

4.7.6 Thermal Hardware Interfaces

The detailed requirements are TBD but see Section 4.7.3.

4.8 Electrical Interfaces

4.8.1 Electrical Power Design and Interface Requirements

The CBE instrument power budget is 4 watts, exclusive of a 10% contingency.

Table 4.2. STIX Power Budget (watts)

IDPU processor	0.5
IDPU FPGAs and memory	1.0
High voltage power supply	0.5
Detector ASICs	1.0

Primary total	3.0
Total (assuming 75% conversion efficiency)	4.0

4.8.2 Data Handling Electrical Interface Requirements

TBD – will be compatible with EID-A requirements.

4.9 Software Interfaces

4.9.1 Software Interface Requirements

Interface requirements outlined in EIDA will be observed.

4.10 EMC design

4.10.1 General Concept

TBD

4.10.2 Design Requirements

None special but will be compatible with EID-A.

4.10.3 Performance Requirements

Will be compatible with EID-A.

4.11 Instrument Handling

4.11.1 Definition of Transport Container

Appropriate individual transport containers will be provided by the IT for the imager module, the spectrometer module and the Sun shades.

4.11.2 Instrument Cleanliness Plan

TBD

4.11.3 Physical Handling Requirements

No special requirements

4.11.4 Instrument Purging Requirements

No special requirements.

4.12 Environment Requirements

4.12.1 Cleanliness

No special requirements except to preserve the surface integrity of the aspect lens and photodiodes.

4.12.2 Radiation

Although the most radiation-sensitive components in STIX are the CZT detectors, they have operated successfully on Swift for more than 4 years in a low Earth orbit environment. Furthermore, a study (Kuvettli, 2003) of radiation damage from 30 MeV protons to CZT detectors of comparable dimensions (10x10x2.6 mm) showed that up to a fluence of 6×10^9 p/cm^2 the detector remained fully functional but with a gain reduction of 25% and a degradation of resolution. The STIX detectors will be located in the spacecraft interior, ~1 m behind the outer heat shield, where they can take maximum advantage of inherent spacecraft particle shielding. A uniform density model of the spacecraft indicates that for this location, the directionally-averaged shielding is equivalent to about 60 mm of aluminium. Extrapolating from Table 13 in the Environmental specification indicates that the mission-integrated fluence for this level of shielding would be 3×10^9 p/cm^2 (10 MeV equivalent). This suggests that the resolution and gain of the CZT detector after the nominal mission fluence is fully satisfactory for STIX to achieve all of its science goals. The expected gradual changes in gain and resolution will be monitored in flight. The issue of radiation damage is expected to be clarified by an ESA-funded study whose results are expected later in 2008, and by the Phase B1 study of the accommodation of STIX in the spacecraft.

Components shall be reviewed in order to evaluate their sensitivity to radiation. Preference shall be given to components with a low sensitivity to radiation. The EIDA, par. 4.12.2.2, defines component resistance to the radiation environment. Parts must have a LET threshold for SEU no less than 25 MeV cm2/mg. Parts sensitive to SEL must have a LET threshold no less than 100 MeV cm2/mg. The use of components which can withstand radiations between these limits may be considered after analyses and a sufficient shielding. On components for which available data indicate sensitivity to the expected radiation environment, additional shielding and/or lot acceptance testing may have to include radiation testing to demonstrate that the batch of components (or wafers) intended for flight-application is acceptable. If no radiation data are available for specific components, sample shall be subjected to Radiation Lot Acceptance Testing.

4.12.3 Micrometeorite Environment

The only components of the instrument that are potentially susceptible to micrometeorites are the CZT detectors and electronics. These are in the spectrometer module, located in the interior of the spacecraft, ~1 m behind the front of the thermal shield and so benefit from substantial spacecraft shielding.

5 OPERATIONAL INTERFACES

5.1 Definition of Instrument Modes

See section 3.4

5.2 Ground Operations

5.2.1 Ground Support Equipment Requirements

5.2.1.1 Mechanical Ground Support Equipment

No special Mechanical Ground Support Equipment (MGSE) is needed to handle the STIX instrument.

Each model of the instrument will be shipped in a custom made transport container according to Section 4.11.1.

An optical GSE will be provided to provide non-intrusive verification of grid alignment during instrument alignment and testing. The same GSE can be used to verify alignment after integration on the spacecraft provided the instrument optical axis is horizontal.

Appropriate mechanical GSE will be provided to enable the instrument to be illuminated by sealed radioactive sources to provide end-to-end testing of the imager and spectrometer systems.

5.2.1.2 Electrical Ground Support Equipment

Electrical Ground Support Equipment (EGSE) for various levels of the STIX instrument development will be required.

There will be an EGSE to support IDPU development that will emulate the spacecraft DPU. Additional capabilities will include provision to provide loads to simulate CZT detectors, aspect photodiodes and attenuator mechanisms and thermal sensors.

The same EGSE can be used to support testing at the instrument level. At the s/c level EGSE computing equipment and software will be required to support analysis of test results during I&T and during operations where it will interface with the Solar Orbiter ground segment.

5.2.2 5.2.2 Facility Requirements

No special facility requirements are required for STIX. At the subsystem level, STIX will make use of existing coordinate measuring machines at AIP and existing optical grid characterization facilities at Mikro Systems Inc.

5.3 Flight Operations

5.3.1 Ground segment

5.3.1.1 Operational Ground Segment

It is assumed that during science operations, the Operational Ground Segment performs out-of-limit checks of TBD STIX parameters and notifies the PI for anomalies.

5.3.1.2 Science Ground Segment

The Science Ground Segment is expected to provide STIX science, calibration and housekeeping data (raw data) together with TBD S/C auxiliary data from the Operational Ground Segment. These data are relayed to the PI data center, where the science data are processed and calibrated.

5.3.2 Mission operations

5.3.2.1 General

STIX operations are largely autonomous with minimum operational requirements. The instrument operations are based on preloaded parameter settings, examples of which include:

- Gain-setting parameters (to match gains of the individual detector elements);
- Parameters to guide insertion and removal of attenuators;
- Parameters used by the instrument data processor algorithm for the selection of data averaging intervals (e.g. for image selection). Mode commands from the spacecraft are used to select from preloaded multiple sets of these parameters. STIX has a great deal of flexibility in the parameterization of its data selection algorithms. This can be exploited, for example, to adjust the average volume of STIX data that can be matched to available spacecraft telemetry resources, while retaining the capability of continuously monitoring flare activity.

No specific operations are associated with solar activity since insertion or removal of attenuators in response to flares is based on internal logic and requires no spacecraft-generated commands. Energy and aspect calibration requires no spacecraft-generated commands.

5.3.2.2 Operational Approach

As discussed above, the STIX instrument will operate autonomously, excluding the commissioning phase. The Science Operations Manager (SOM) will be the point of contact with the MOC and the SOC during phase E.

5.3.2.3 Mission Planning and Implementation

The SOM will sequence commands and monitor instrument health for the entire investigation.

5.3.3 Instrument Deliverables to the Operational Ground Segment

The PI will provide a STIX computer located in the MOC. During the commissioning phase, the STIX members in the MOC will use this computer to receive STIX science and housekeeping data.

The SOM will provide updates to the flight software for the IDPU, and test and forward the sequences to the Solar Orbiter SOC.

5.3.4 Instrument Inputs to the Science Ground Segment

A fast and simple access to the PI Data Center will enable all STIX database synchronization with the SOC as soon as data are available.

Similar to RHESSI, EPO material such as science nuggets and documentation about the instrument and the mission will be made available to the SOC. Furthermore, a science paper archive concerning STIX results will be established based on our experience with the Max Millennium Archive (http://solar.physics.montana.edu/max_millennium/).

5.3.5 Mission Products

The STIX team is committed to a fully open data policy. It is our firm belief that the exciting data from Solar Orbiter and HELEX must be shared with the entire community to ensure maximum exploitation of this unique data set. To this aim, and after an initial commissioning and cross-calibration period, the STIX team is planning on the data products and delivery times as indicated in Table 5-1.

Table 5-1. STIX data products and delivery times

Level	Data Products	Time Lag from downlink
L-0	Time-ordered raw telemetry	≤24 hours
L-1	Quick-look light curves, images, and spectra Preliminary flare list and observing summary	~ one week
L-2	Fully calibrated light curves, images and spectra in physical units.	Four weeks
L-3	Other data, such as publications, descriptions, procedures, figures, etc. Final calibration data and flare list released after inspection by cognizant instrument scientists	As they become available

5.3.5.1 Science Telemetry

The science telemetry will include the count rates of the 64 subcollimators for a set of flare-associated, statistically significant time intervals chosen by the instrument digital processor. In addition, spatially integrated light curves and spectra with different combinations of resolution and integration times will be transmitted to provide context and to support energy calibration.

5.3.5.2 Other Telemetry

Other telemetered products will include time and aspect information, housekeeping data such as temperatures, voltages, etc., and attenuator states.

Since STIX will determine the timing, intensity and centroid location of flares on-board in real time, this information can be compressed (~0.1 bits/s) for optional inclusion in beacon mode telemetry (if available). This would provide the ability to monitor solar activity on the back side of the Sun.

5.3.5.3 Auxiliary Data

Auxiliary data will include calibration data acquired by pre-launch measurements. This includes grid and attenuator characteristics, detector energy and sensitivity calibrations, aspect system sensitivity, window and heat shield X-ray transmission, etc.

5.3.6 PI Support to Operations

With regard to the level and nature of the expert support at the MOC and SOC during the different phases of the programme, we propose a single point of contact, the Operations/Data Manager at the STIX Project Office. He/She will sequence commands and monitor instrument health during all the phases of the mission. The ODM will collect and integrate the commands and software form the different STIX sensors and will provide updates to the flight software for the CDPU. Every STIX Lead-Co-I will designate a competent Co-I, that will provide high level guidance, will develop the command sequence and will make any need change to the particular sensor flight software. These will be delivered to the ODM which will assemble, test and forward the sequences to the Solar Orbiter MOC.

5.3.6.1 Testing and Validation Sessions

TBD

5.3.6.2 Training

TBD

5.3.6.3 Operational Support

TBW

6 INSTRUMENT VERIFICATION PLAN

6.1 General

6.1.1 Introduction

6.1.2 Responsibilities

The responsibilities are discussed in Section 2.1.

6.1.3 Definitions

TBW

6.1.4 Documentation

Documentation will be in accordance with EID-A requirements.

6.2 Verification concept

6.3 Analysis

6.3.1 Structural Mathematical Analysis

TBW

6.3.2 Thermal Analysis

TBW

6.4 Testing

6.4.1 General

The detailed testing requirements will be in accordance with EID-A and will be developed in detail during Phase B1.

6.4.2 Functional Testing at Instrument Level

End-to-end functional testing at the instrument level will be done at ETH using suitably masked, sealed radioactive sources. Such a test, developed for RHESSI, will be adapted to STIX and provides independent confirmation of the imager alignment and overall operation of the system. In addition, the use of pulsers (TBD) in the front end electronics can be used to simulate the temporal and spectral characteristics of flares so as to confirm the proper operation of the instrument data selection and compression software.

6.4.3 Functional Testing at System Level

Radioactive sources can also be used following integration to provide end-to-end testing through from the spectrometer through the instrument and spacecraft data systems and the data analysis software. In addition the pulsers (TBD) can also be used at system level to confirm proper operation of the instrument data selection and compression software.

6.4.4 EMC Testing

Will be done in accordance with EID-A.

6.4.5 Structural Testing

Will be done at the subsystem and individual module level in accordance with the EID-A. The role of joint vibration tests of the imager and spectrometer together (in addition to their individual tests) will be evaluated during Phase B1.

6.4.6 Mechanism Testing

The attenuator mechanism can be tested at either the subsystem level, instrument level of system level through commands delivered through the instrument IDPU.

6.4.7 Thermal Testing

Thermal testing will be done at the subsystem level prior to integration. Instrument level testing and qualification will be in accordance with the EID-A.

6.5 Inspections

6.5.1 Visual Inspection

In addition to normal visual inspections, the optical GSE can be used to quantitatively and non-intrusively confirm grid alignment both before and after integration into the spacecraft.

6.5.2 Physical Properties

No special procedures are required.

6.6 Calibration

The approach to STIX test and calibration is that all subsystems are fully qualified and calibrated at the subsystem level before integration at the next higher level. A characteristic of this type of imager is that its imaging response can be fully calibrated by independent calibration of the detectors, individual grids and aspect elements. For example, except for the relative twist requirement, the X-ray performance of the imager depends on 2-dimensional knowledge, not 3-dimensional placement, of the imaging system components.

Calibration of CZT detector response will be done both before and after integration into the spectrometer.

Following instrument integration, but prior to delivery, an end-to-end test of instrument performance using sealed X-ray sources will be used to provide independent confirmation of instrument performance.

6.7 Final Acceptance

6.7.1 General Approach

The general approach will be in accordance with EID-A requirements.

6.7.2 Acceptance Review

The acceptance review will be in accordance with EID-A requirements.

6.8 System Level AIT

6.8.1 Model Philosophy

STIX will follow the STM-EM-EQM-FM-FS model approach. More information on the model philosophy is provided in Section 8.7.1.

Structural Thermal Model
The STIX STM will be used for tests at spacecraft level as described on page 129 of EID-A [AD-02]. The STIX STM imager and spectrometer modules will be representative in mass, CoG, stiffness, mounting, shape, and internal power dissipation. They shall include a representative harnessing. Within these requirements, dummy grids and detectors will be used.

Engineering Model
The EM serves for electrical tests on spacecraft and with the CDPU. EM shall be flight like electrically in most respects. Electronics parts may be commercial, but shall be from the same supplier as the FM parts. CZT detectors will be replaced by corresponding capacitances. Only a small number of the 64 identical detector interfaces will be implemented.

Engineering Qualification Model
The EQM shall be flight-like in all respects. Following qualification testing, it will be returned to the PI for refurbishment as necessary to become the flight spare.

Flight Model
The STIX FM shall have full flight standard verified by formal functional and environment acceptance tests.

Flight Spare
The flight spare will be the refurbished engineering qualification model.

6.8.2 System Integration and Test Flow

The approach to STIX test and calibration is that all subsystems are fully qualified at the subsystem level before integration at the next higher level. Furthermore a characteristic of this type of imager is that its imaging response can be fully calibrated by independent calibration of the detectors and of individual grids and aspect elements. Except for the relative twist requirement, **the X-ray performance of the imager depends on 2-dimensional knowledge, not 3-dimensional placement, of the imaging system components.** This enables a considerable simplification of the optical calibration of the system. Figure 6-1 provides an overview of the STIX test and calibration sequence.

Since the key alignment requirement is the relative twist of the front and rear grids, the stability of the CFRP imager tube is critical. This will be verified by fabricating a tube of twice the necessary length and cutting it in half. The twist stability under thermal stress will then be confirmed by rigorous testing one half while the other will be used for flight.

At the subsystem level, individual grid layers and assembled grid modules are optically characterized using coordinate measuring machines (to 2 micron precision) to establish the orientation of optical fiducials relative to grid slits following procedures developed for RHESSI. As part of the manufacturing protocol, the mass of individual grid layers before and after etching is also noted. These data can be converted to a set of grid parameters from which the grid transmission and modulation efficiency as a function of energy and incident direction can be determined to ~2% for both individual grids and grid pairs. Note that the X-ray imaging response of the assembled imager can be fully inferred from the calibration of the individual grids. Additional X-ray transmission calibrations will be done by AIP. Alignment of the grids on the imaging tube is done with reference to the optical fiducials on the grids.

The effective optical center of the aspect lens is determined with respect to fiducials on its mount, which in turn are located with respect to the optical fiducials on the front grids. Similarly the locations of the aspect apertures on the rear grids are measured with respect to the previously measured optical fiducials on the grids. All of these procedures were developed and used successfully on RESSI.

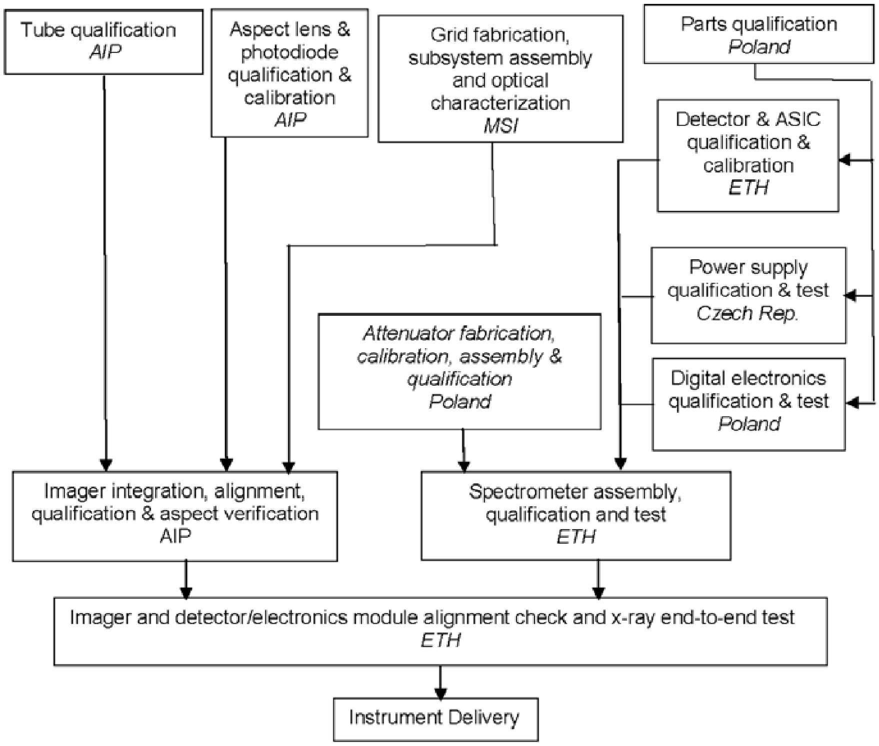

Figure 6-1. STIX test and calibration sequence

Using the same X-ray and optical facilities as for the grids, attenuator characteristics are optically verified and their X-ray transmissions as a function of energy and incident angle are measured before integration into the spectrometer.

The response of the detectors and electronics as a function of energy and rate is determined at the detector assembly level using X-ray sources before and after integration into the spectrometer.

Following delivery of the calibrated spectrometer and aligned imager system to ETH, suitably masked X-ray sources are used to perform an end-to-end confirmation of satisfactory performance of the imager/spectrometer combination.

The STIX EGSE will be based on PC/notebook system equipped interfaces/connectors/power supplies to support the following functions:
a) full functional testing of the STIX IDPU

b) analysis of instrument housekeeping data with appropriate displays and warning messages and provision for transitioning to a safe mode if necessary.
c) simulation/emulation of the central Solar Orbiter DPU
d) control & display of CZT detector array performance
e) emulation of realistic detector signals to support subsystem testing and simulation of various solar and background conditions

6.8.3 Ground Support Equipment

6.8.3.1 Mechanical Ground Support Equipment

No special Mechanical Ground Support Equipment (MGSE) is needed to handle the STIX instrument.

Each model of the instrument will be shipped in a custom made transport container according to Section 4.11.1.

An optical GSE will be provided to provide non-intrusive verification of grid alignment during instrument alignment and testing. The same GSE can be used to verify alignment after integration on the spacecraft provided the instrument optical axis is horizontal.

Appropriate mechanical GSE will be provided to enable the instrument to be illuminated by sealed radioactive sources to provide end-to-end testing of the imager and spectrometer systems.

6.8.3.2 Electrical Ground Support Equipment

Electrical Ground Support Equipment (EGSE) for various levels of the STIX instrument development will be required.

There will be an EGSE to support IDPU development that will emulate the spacecraft DPU. Additional capabilities will include provision to provide loads to simulate CZT detectors, aspect photodiodes and attenuator mechanisms and thermal sensors.

The same EGSE can be used to support testing at the instrument level. At the s/c level EGSE computing equipment and software will be required to support analysis of test results during I&T and during operations where it will interface with the Solar Orbiter ground segment.

7 PRODUCT ASSURANCE PLAN

7.1 General

7.1.1 Scope

This document specifies the product assurance organisation and program assurance plan for the STIX instrument on board of the SOLAR ORBITER mission. This Product Assurance (PA) Plan defines the PA programme, policy, procedures and practices relative to the activities to be used during definition, design, procurement, development, manufacture, assembly, test, and delivery phases (B/C/D) of the STIX programme.

The STIX PA Manager (PAM) is responsible for the release, distribution, and control of this PA. Revisions and changes will have to be discussed with STIX Team and ESA and documented on a Transmittal Notice.

Compliance with the requirements of the Solar Orbiter programme is essential to ensure the successful accomplishment in an efficient and cost effective manner.

7.1.2 Applicability

This document defines the policies and methods for PA activities in the STIX programme to be applied to all HW and to associated SW and GSE.

The STIX Team has the responsibility to implement these policies during all phases of the Programme, in accordance with Solar Orbiter requirements.

The STIX EM will also be responsible to impose the same policies to all Subcontractors.

ESA will overview all activities and has the right to approve and participate in the definition and implementation of policies and methods.

7.2 Product Assurance Management

7.2.1 General

The STIX Principal Investigator (PI), Arnold O. Benz (ETH Zurich), is responsible for ensuring the compliance of the PA with the contractual requirements.

He will appoint a STIX PA Manager (PAM). The PAM will be responsible to the EM and to the PI for preparation, management and implementation of the approved PA Plan. He will be the key person within the project for all PA matters, including those involving Subcontractors. The PAM will be supported by a staff of specialists from PA disciplines. The STIX PAM will be located in Swiss Industry and be the same person as the Experiment Manager.

The STIX PAM is the interface with ESA PA Manager for all the matters related to PA disciplines, and will be responsible to report to ESA the status of the PA activities, in accordance with the Programme requirements.

The STIX PAM will also have direct interface with the Units' PA Managers. He will coordinate the tasks to be performed by each unit developer concerning the PA activities.

The PAM is responsible for the following activities:

- implementation and maintenance of the PA tasks according to the contents of the present plan
- planning of PA activities
- verification that the required PA activities are covered
- directives and instructions to the Subcontractors PA Managers
- reviews and audits on processes and manufacturing procedures
- reporting on the status of PA activities
- implementation of a non-conformance processing system
- provision of support to Solar Orbiter representatives involved in PA work
- control of Subcontractors PA activities
- control of PA schedule

7.2.2 Organization

Each organisation shall nominate a person to be responsible for product assurance activities including:

- Monitoring of in-house product assurance system.
- Witnessing of incoming inspections, tests etc.
- Preparing deliverable documentation.
- Co-ordination of activities with the STIX PA Manager.

The local PA manager reports to the local project manager. In case of a conflict between the local PA manager and the local project manager, the matter shall be taken to the consortium project manager for resolution. The consortium PA manager shall be consulted.

The organisation chart of PA in the STIX programme is provided in APPENDIX 7.A.

7.2.3 Product assurance plan

PA tasks will be planned consistently with the programme schedule and taking into account the product characteristics.

PA planning is a direct responsibility of PAM.

7.2.4 ESA/Prime Contractor right of access

Authorised representatives of ESA, Prime Contractor and PI Team will have unimpeded right of access to all in-house facilities of consortium members, to relevant documentation and records.

The access shall have he objective of test observations, documentation reviews, hardware examination and participation at the Mandatory Inspection Points (MIPs).

7.2.5 Contractor and supplier surveillance

All Subcontractors will be selected according to the characteristics of the products to be provided, and their capability to meet relevant PA requirements.

The PA requirements to be imposed to Subcontractors will be tailored to the criticality of the product, and will be given in the Statement of Work relevant to the subject of the subcontract.

The Subcontractor will state its compliance to these requirements by means of a Compliance Matrix.

7.2.6 Identification and control of critical items

A Critical Item List (CIL) will be maintained current and presented at each design and readiness review. The CIL has to contain the following information:

- identification and risk evaluation
- activities for risk reduction
- report of the risk reduction implementation and the corresponding verification measures.

7.2.7 PA Database

The PAM shall plan and maintain an appropriate PA database. Swiss industry shall take over all necessary responsibilities.

7.2.8 Quality Records

The PAM is responsible to remind Contractor/suppliers maintaining quality records. The PAM will check and confirm effective performance of Quality Assurance activities and demonstrate the achievement of the required quality.

The PAM will organize the storage of the quality records in a safe way to prevent alteration, loss or deterioration, for at least three years after the end of mission.

7.3 Quality Assurance Management

A Quality Assurance (QA) comprehensive programme will be implemented in compliance with EIDA requirements. QA activities will be planned and carried out in accordance with Programme schedule.

The involved QA personnel will work under the directions of the PAM.

7.3.1 General requirements

The requirements issued in EID-A, section 7.3, will be applied to all HW and to associated SW and GSE.

7.3.2 Traceability and logbook

Logbooks will be used to provide traceability and verification of hardware, software, and associated GSE during assembly and tests.

Each part, material or product shall be identified by a unique and permanent identification number.

The logbook will also provide a record of work, inspections, etc. As a minimum, logbook entries are to chronologically contain date, time, description of event or activity and name of individual performing the activity.

Logbooks have to remain within the designated work area or with the assigned hardware.

The logbooks will be part of the End Item Data Packages (EIDP) to provide a full visibility of the product history.

7.3.3 Non-conformance control

A particular effort will be given to maintain an effective non-conformance reporting system in order to keep non-conformances under control during all phases of the manufacturing and test flow.

The control of non conformance will ensure that all items or materials failing to meet the applicable requirements are identified and withdrawn from the manufacturing cycle until the anomalies have been removed or alleviated by rework of the items, and the relevant corrective actions on areas involved with the anomaly have been identified and implemented.

Figure 7-1 shows the NCR procedure flow chart.

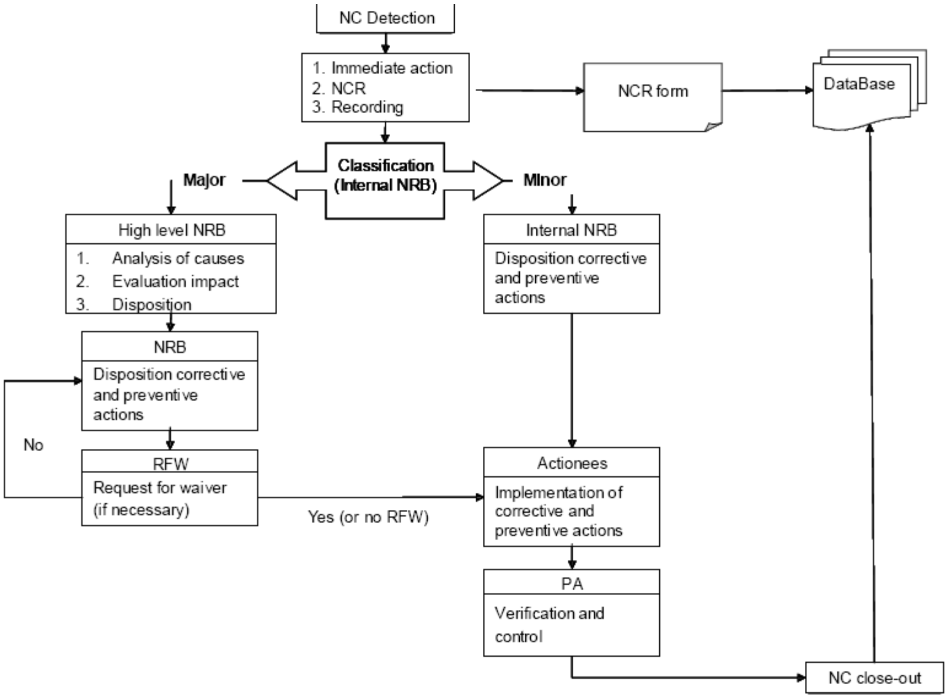

Figure 7-1. NCR procedure flow chart

7.3.3.1 Non-conformance classification

Non-conformances will be classified as major or minor. Classification shall be taken under guidance of the PAM.

7.3.3.1.1 Major NCR

Any non-conformance that can have an impact on one of the following parameters will be classified as major:

- performance
- interfaces
- reliability
- mission life
- maintainability
- weight
- health
- safety.

In addition, all NCR occurring on already delivered items, and on EEE parts supplied by ESA or by a procuring Agency for Solar Orbiter will be classified Major.

All Major NCR's will be processed in the frame of a Nonconformance Review Board (NRB).

Major NCR notification will take place via telefax within 48 hours from detection.

As part of the notification, the proposed date, place and time for NRB will be included.

7.3.3.1.2 Minor NCR

Minor non-conformances are those which do not affect points defined as major.

Minor NCR's are processed as dispositional by the issuing subsystem. They will be maintained and filed for STIX Team and ESA review.

7.3.3.2 Non-Conformance Reporting

The NCR will be notified and circulated by means of a dedicated form. The form to be used for NC reporting is given in Appendix B.

The information contained in the form will be, as a base, the following:

- NCR number, allowing identification of the originating company
- date of issue
- identification of the affected item
- identification of the step where the anomaly occurred
- identification of violated requirements
- description of the non-conformance
- non-conformance category (Minor or Major)
- presumed or identified cause
- proposed corrective actions / dispositions
- call of MRB, if necessary
- reference to any previous similar NCR
- signature of PA and Technical responsible (and EM if necessary)

All NCR's, independently from their classification, will be the subject of a periodical list to be circulated to STIX Team and ESA.

A statistical control will be maintained on NCR's, in order to identify the critical areas within the QA and Manufacturing flow, and identify the proper corrective action to avoid recurrence of the anomalies.

The results of statistics will be given as appendix of the periodical NCR list.

7.3.3.2.1 Non-conformance Review Board (NRB)

The NRB shall consist of at least one representative of the Product Assurance Team and one representative of the Project. Specialists may be invited and consulted.
The NRB objectives are:

- Identify the causes of the con-conformance

- Evaluate the consequences
- Propose corrective and preventive actions, including:
    - “scrap”
    - “use as is” (if a formal specification requirement remains violated, preparation and acceptance of a Request for Waiver or a specification change can be recommended. They are both subject to approval.
    - “repair”: qualified or standard repair procedure to be defined.
    - “rework”.
- To perform re-verification after repair or modification which may consist of re-inspection, re-test (a late modification may also affect the validity of previous qualification tests) and updating of previously established design analyses.

These action propositions are mentioned on the NCR.

7.3.3.2.2 Non-conformance closure

Once the appropriated actions are realized and controlled, the NCR is formally closed.

7.3.4 Alert system

All participants to STIX Programme will circulate any problem notification and/or alert received from external sources - or found in the Programme - and relevant to quality and application problems on parts to be used or in use in the programme.

It is a PAM task to verify that the alerts are notified to all partners, subcontractors and discuss and suggest the appropriate corrective actions.

ESA will immediately be notified of the alerts.

7.3.5 Handling, storage and preservation

PAM will verify that the manufacturing and test documentation contains the relevant handling instructions, or that dedicated procedures are present, whenever necessary. Handling requirements shall be clearly displayed on all equipment and packaging.

The visual inspections to be performed through the manufacturing flow will verify that the correct handling policies are implemented and followed. Eventual non-conformances constitute the basis for handling procedure modification.

PAM will witness all critical steps to ensure that all items are adequately protected against deterioration provoked by mishandling.

Whenever special handling tools are necessary, these will be maintained and checked to ensure that they are adequate and safe for their intended use.

Protective film, wrapping or special containers will be used in each case where a potential deterioration danger is identified.

Handling procedures for all equipment and packaging will be annexed to the EIDP.

7.3.6 QA requirements for Procurement

All requirements applicable to procured materials, parts or services will be clearly defined in purchase orders and associated specifications.

A Statement of Work (SOW), detailing all aspects of the tasks to be carried out by the subcontractor, will be issued for orders involving critical and/or complex technical aspects and having schedule impacts,

7.3.6.1 Selection of Procurement Sources

Manufacturers and suppliers will be selected and approved by the PAM for their proven capability to supply materials and component parts to the required specifications, within scheduled dates, together with the documentation to verify that the requirements of the procurement specifications have been met.

7.3.6.2 Procurement Documents

The purchase orders will be reviewed by PA to verify that the required items and/or materials are in accordance to the approval Declared Component Lists (DCL) and Declared Material list (DML).

Auditing on procurement documents, prior of release of purchase orders, will include:

- Latest revisions of drawings;
- Specifications;
- Inspection and test instructions or procedures;
- Reliability and quality requirements.

After the procured parts or materials have been received, the following controls will be done:

- Manufacturing date and shelf life information and data;
- Parts marking and identification;
- Accompanying documentation (Test reports, etc.).

7.3.6.3 Surveillance of Procurement Sources

PA Manager carries out surveys of facilities and Product Assurance Systems for critical materials and/or processes when required.

Contracts, purchase orders etc. shall include a statement indicating the requirement for quality control and traceability and the appropriate standard. Conformance documentation shall be requested and act as a point of entry into the manufacturer’s traceability system.

Items manufactured in-house shall be subject to the same controls, traceability will be required and only approved materials and processes shall be permitted.

7.3.6.4 Incoming Inspections

All received items will be subjected to Incoming Inspection in accordance with their quality requirements.

All received items will be identified, individually or at lot level, depending on applicable requirements, by means of an incoming inspection number allowing traceability of the item throughout the manufacturing process and after delivery.

Additional inspection activities may be requested in the event of problem areas detected on the item in previous programmes, or in case of criticality.

Incoming Inspections include:

- Review of the Certificate of Conformance and of delivered documentation with inspection/test results;
- Visual inspections for completeness and freedom from obvious damage or deficiencies;
- Sample testing or testing of all items for compliance of the most critical parameters.

Age sensitive items will also be notified by the respective PA to the Incoming Inspection, to avoid any damage due to wrong storage conditions. These items are marked with their expiration dates, and are used on the basis of first-in / first-out concept.

7.3.6.5 Procurement Requirements for EEE Parts

See section 7.6

7.3.7 QA requirements for manufacturing and integration

Items which are manufactured or assembled by Contractors, or by their subcontractors, will be subjected to QA inspection and test programmes, in order to ensure that the applicable requirements are met.
The Quality Assurance tasks will be to ensure that:

- The items inspected are compatible with drawings, specifications and procedures - the documents in use are under configuration control and are at the latest issue;
- The inspection records and historical records are correctly filled-in;
- The as-built configuration of the item is reflected by the accompanying papers.

Redlined documents are allowed, when the issue of upgraded version is not feasible within scheduled dates.

7.3.7.1 Manufacturing and Inspection Flow Chart

In close association with Historical Records, Manufacturing Flow Charts will be prepared to give graphic evidence of manufacturing and assembling operations.

These Flow charts will take into consideration elementary parts, or part lists, subassemblies and main assemblies, making reference to the processes involved with the manufacturing and assembling operations.

Inspection points will also be indicated and referenced.

7.3.7.2 Key and Mandatory Inspection Points (KIP/MIP)

In order to give a complete evidence of the status of works and quality of workmanship, planned and content-defined inspection points, requiring STIX Team and ESA agreement, will be established prior to proceed with the subsequent steps of the manufacturing flow.

The MIPs will be indicated in the Manufacturing Inspection Plan and in the correlated Flow Charts.

The MIPs will be performed by a representative of the group involved, the PA manager and ESA. When necessary, specialists shall be employed.

The PA manager will ensure that ESA receives timely notification on proposed MIPs with reference to the item to be inspected; type, time and location of the inspection.

7.3.8 Integration and testing

After completion of assembling and integration activities, QA will inspect the hardware prior of release for further steps.

This inspection has the scope to:

- Assess quality of processes and workmanship used for manufacturing;
- Verify that all documentation is under control and correctly completed;
- Identify discrepancies to expected configuration;
- Verify that all non-conformances are traced, implemented and closed, unless specific and agreed exceptions.

Qualification/Acceptance tests will be conducted following the instructions of the Test Plans and Test Procedures applicable to the item under test.

These documents will be reviewed and approved by QA to verify their compliance with programme requirements.

The test plan and test procedures will be submitted to STIX Team and ESA for review and approval before starting the Qualification/ Acceptance tests.

For Qualification and Flight items, a Test Readiness Review (TRR) will be conducted before starting of test activities.

The tests will be monitored by QA, with the following tasks:

- Ensure that the applicable test procedures are followed;
- Verify that test facilities are under the calibration system;
- Verify that the obtained data are correctly reported;
- Ensure that the detected non-conformances are reported and processed;
- Verify that the required test environmental conditions are respected;
- Stop the test in case of danger for personnel, or major damage to the item.

After completion of tests, Quality Assurance will review the obtained data for compliance with applicable requirements.

All detected discrepancies will be reported following NCR procedure.

7.3.8.1 Test Planning

Dedicated test procedures will be prepared for each test to be performed on the hardware.

7.3.8.2 Test Procedures

The contents of the test procedures will allow the following to be identified:

- Test items configuration;
- Detailed test methods;
- Test set up and equipment;
- Environmental test conditions;
- Test limits and tolerances;
- Pass/fail criteria.

Test procedures will be submitted to the STIX Team for review and approval in due time prior to their use. ESA will review the test procedures only at the instrument level.

7.3.8.3 Test Facilities / Equipment

Test facilities will be specified in the I&T plan.

All test equipment including commercial test equipment will be calibrated as required.

7.3.8.4 Test Witnessing

Development tests and formal qualification and acceptance tests will be monitored by QA personnel to ensure that procedures are followed, and that adequate records of the activities and test results are documented.

7.3.8.5 Test Reviews

A set of Test Reviews will be planned in order to cover all test activities on main items and equipment, and to give evidence to STIX Team and ESA of the status of works.

7.3.8.5.1 Test Readiness Review (TRR)

A TRR will be held prior of beginning of each test session on main items and equipment. The scopes of the TRR are the following:

- Identification/Verification of the As-built configuration;
- Status of non-conformances;
- Status of Requests for Waiver (RFW);
- Review and approval of Test Procedures;
- Test facilities and equipment review;
- Test schedule assessment;
- Release for testing.

7.3.8.5.2 Test Review (TR)

A TR will be held after the conclusion of each test session. The scopes of the TR are the following:

- Verification of test completion;
- Review of test results;
- Review of out-of-limits/non-conformances;
- Completeness of test data and reports;
- Release for the following activities.

7.3.8.6 Test Reports

Upon completion of each test, a test report will be prepared, evidencing the results and any non-conformances detected.

The contents of the test reports will allow precise identification of the conditions at which the tests are conducted, of the set up and equipment used, and finally of the behaviour of the item under test.

7.3.9 QA requirement for acceptance and delivery

The PI will establish a formal acceptance process and a formal Delivery Review for all items to be delivered.

7.3.10 QA requirements for support equipment

The PI will establish a formal acceptance process and a formal Delivery Review for all items to be delivered.

7.4 Safety assurance

7.4.1 General

The objectives of safety program are the minimization and control of all potential and/or verified hazardous conditions or operations accident that can cause safety hazard to personnel or damage to equipment or property.

7.4.2 Requirements

The guidelines for Safety of space applications are expressed by ESA PSS 01 40.

7.5 Dependability assurance

7.5.1 General

The Failure Modes Effects and Criticality Analysis (FMECA) will be generated starting from the early design stage, and maintained and updated throughout all design phases.

Failure Modes and effects will be analysed to determine the need for design changes or other actions.

Eventual failure modes or effects requiring corrective actions will be notified to the design engineers, and the relevant design changes will be discussed and introduced.

The main scopes of the FMECA are the following:

- To determine the effects of each failure mode on the performance of the unit/subsystem under analysis;
- To establish the criticality of the particular failure mode;
- To identify potential interface problems;
- To identify failure modes resulting non tolerable to the design conceptual configuration, in terms of established redundancies and operative modes.

7.5.2 Dependability analysis: Failure Modes, Effects and Criticality Analysis (FMECA)

The FMECA will be conducted at functional block level, taking as reference the reliability block diagram and the unit / subsystem functional block diagram.

The FMECA will be conducted at component level on:

- The critical parts, to identify potential failures whose effects exceed the technical requirement specification;
- The cross coupling of power/ground and signals lines, to evaluate that no failure mode can compromise the redundancy concept;
- The interface circuits, to verify that failure propagation to the external hardware connected functions is not possible.

The following Failure Effect Severity Categories will be used in the FMECA to allow immediate identification of Failure criticality:

- Category 1 :	The failure effects are not confined to the unit subject of the FMECA, but propagated to the connected units / systems
- Category 2 :	The failure shall not result in loss of more than 20% of the instrument throughput
- Category 3 :	Minor internal unit failures

Furthermore, the following code letters will complement the criticality categories:

- R :	the design affected by the failure contains redundancy that can perform same functions
- SH :	The failure is source of safety hazard
- SPF :	The failure is caused by single point failure

7.5.3 Hardware / Software Interaction Analysis (HSIA)

The FMECA to be performed on the items will take into account the associated on-board SW, and its interaction with the HW.

The goal of this activity is to avoid damage or overstress caused by SW commands, and to prevent increase of criticality of HW failures due to SW resulting actions.

7.5.4 Single point failures

The FMECA will allow the identification of single point failures existing in the design. A dedicated section of the FMECA will give their list.

For each identified Single Point Failure, a rational evidencing design characteristics, probability of occurrence, and methods to eliminate or at least to alleviate SPF effects will be given.

All eventual remaining SPF will be the subject of Request for Waiver to STIX Team and ESA.

The FMECA will be submitted to STIX Team and ESA for review and approval during the scheduled Design Reviews.

The form to be used for FMECA reporting is given in Figure 7-2

<table>
<tr><th colspan="15">FAILURE MODES EFFECTS AND CRITICALITY ANALYSIS (FMECA)</th></tr>
<tr><td colspan="5">Product:
Project/Phase:
System/Subsystem/Equipment:</td><td colspan="4">Prepared by:
Approved by:
Date:</td><td colspan="6">Document reference:
Issue:
Page of</td></tr>
<tr><td>Ident. number</td><td>Item/ block</td><td>Function</td><td>Failure mode</td><td>Failure cause</td><td>Mission phase/ Op. mode</td><td>Failure effects
a. Local effects
b. End effects</td><td>Severity</td><td>Failure detection method/ observable symptoms</td><td>Compensation provisions</td><td>Severity Number SN</td><td>Probability and PN</td><td>Criticality Number CN</td><td>Correction actions</td><td>Remarks</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 7-2. FMECA

7.5.5 Reliability prediction

Reliability prediction, in first issue, will be started at the beginning of the design, based on a review of design data existing at that stage.

Numerical assessment will allow the determination of design reliability with respect to the applicable numerical requirements expressed by specifications.

Reliability trades will be used to identify the impacts of alternative design solutions, and to assist in problem solving.

Computation will be made on the failure probabilities, starting from the elementary parts, and progressed up to the complete unit by application of the appropriate reliability theory.

The prediction will be performed for the nominal mission duration and the mathematical model assumed will be the exponential one.

The Reliability Prediction will be formalised in a document showing in detail:

- The reliability model used;
- The related formula;
- The reliability block diagram.

The Reliability Prediction will be updated according to design modifications, to ensure that mission reliability target is maintained.

As minimum, a new issue of the document will be released at each design review.

If the reliability target with the part count method is reached, no further method will be applied. If the target is not reached by part count method, a more detailed analysis will be conducted considering the real stress on part, since this approach gives in general an improvement of the reliability figures.

The reliability block diagram will be correlated with the unit / subsystem functional block diagram defined by design engineers.

7.5.6 Worst case analysis

The Worst Case Analysis ensures that the product electrical and/or mechanical performance is in compliance with the applicable specifications under worst case operating conditions.

Worst case analysis will be conducted by design engineering, with support from reliability engineer.

It will be performed on the unit critical elements, and/or on elements subject to accuracy performance requirements, or sensitive to environmental conditions.

The following parameters will be taken in account to prepare the Worst Case Analysis (WCA):

- Part parameter variations;
- Normal and contingency operating modes, including unit turn on and turn off;

- Full range of input voltages, currents and frequencies, and their rate of;
- Application over mission life;
- Thermal stress;
- Circuit Loading;
- Circuit stimulus;
- Aging and radiation effects;
- Potential mismatch in delay times.

All sources used to obtain data for calculation in WCA shall be mentioned and justified, as well as the implemented analytical methods.

Allowed design margins will be demonstrated by analysis or test.

The Worst Case Analysis will be submitted to STIX Team and ESA for review and approval.

The PAM is responsible for ensuring that WCA is effective and complete, and for the introduction of corrective actions generated by the analysis.

7.6 EEE parts selection and control

7.6.1 General

The following describes the activities necessary to assure utilisation of reliable Electrical, Electromechanical and Electronic (EEE) components, its procurement and control programme.

7.6.2 Component programme management

The PA manager shall monitor component quality, selection and procurement, and shall report to the progress meetings when necessary.

The PA manager shall be responsible for the preparation of a detailed EEE Component Control Plan which will describe the organization and the procedures to be compliant with the EIDA.

He/she shall be the interface between the consortium members and ESA Project Office.

7.6.3 Component engineering

The PA shall be responsible for the selection of components that are capable of meeting the performance, lifetime, stability, safety, quality and reliability required.

7.6.3.1 Prohibited Materials and Components

Materials which could cause safety hazard or contamination during all phases of the programme will not be selected and used, unless preventively approved by STIX Team and ESA.

Components containing materials which may constitute a safety hazard or can cause contamination shall not be used without prior approval of the project.

Some examples are:

- Beryllium Oxide;
- Cadmium;
- Zinc;
- Mercury;
- Radioactive materials;
- PVC.

Components or materials with known instability shall be avoided unless specifically approved.

Some examples are:

- Wet tantalum capacitors;
- Hollow core resistors;
- Variable resistors and capacitors. Radioactive materials, not specifically required
- PVC

Should one of these materials be necessary for use on STIX, dedicated plans will be prepared and established to minimise the effects on safety and contamination.

7.6.3.2 Radiation Sensitive Components

Components shall be reviewed in order to evaluate their sensitivity to radiation. Preference shall be given to components with a low sensitivity to radiation.

The EID-A, par. 4.12.2.2, defines component resistance to the radiation environment. Parts must have a LET threshold for SEU no less than 25 MeV cm^2/mg. Parts sensitive to SEL must have a LET threshold no less than 100 MeV cm^2/mg. The use of components which can withstand radiations between these limits may be considered after analyses and a sufficient shielding.

On components for which available data indicate sensitivity to the expected radiation environment, additional shielding and/or lot acceptance testing may have to include radiation testing to demonstrate that the batch of components (or wafers) intended for flight-application is acceptable.

If no radiation data are available for specific components, sample shall be subjected to Radiation Lot Acceptance Testing.

7.6.3.3 Component Derating

Critical components shall be stressed to the derated values specified in ECSS-Q-30-11A. Specific stresses, such as temperature, radiation, etc., shall be reviewed in order to assess the derating requirements.

7.6.4 Component selection and approval

7.6.4.1 Preferred Components

The ESA Preferred Parts List (EPPL) and the ESA / SCC Qualified Parts List shall be used as the primary bases for component selection. All components used in flight hardware shall comply with the standards stated in section 7.6.4.1 of the Solar Orbiter EID-A, as minimum.

For each component selected, which is not listed in one of the ESA- or NASA-PPL / QPL's, detailed justification and supporting information shall be provided on a Part Approval Document.

7.6.4.2 Non PPL Listed Components

The selection of all non-PPL-listed components shall be based on the knowledge regarding technical performance, qualification status or qualifiability and history of previous usage in similar applications.

Preference shall be given to components from sources which would necessitate the least evaluation / qualification effort.

7.6.4.3 Component Approval

All parts used shall be submitted for ESA approval by a Declared Component List (DCL).

Component approval includes approval of the manufacturer, the procurement specification with definition of all technical requirements, applicable screening and lot acceptance tests and the evaluation/ qualification programme if applicable.

A Part Approval Document (PAD) shall be prepared and submitted for approval for all parts. The PAD shall include:

- Non-repetitive PAD number (with revision if needed).
- Identification of experiment / experiment unit for which the part will be applied and numbers used per flight model.

- Part number(s), type, family (plus commercial equivalent).
- Generic specification, detail specification and amendments if applicable (with revisions).
- Proposed manufacturer and back-up if available.
- Radiation hardness data.
- Present qualification status (with reference).
- Results of preliminary evaluation.
- Proposed delta evaluation or full evaluation / qualification programme, if applicable. Test results are to be provided when available.
- Applied screening level.
- SEM / Precap Inspections if applicable.
- LAT levels.
- Destructive Physical Analysis (sample size and by whom).
- Signatures of requesting party and approval signatures.

An approval reference shall be entered on the DCL to maintain traceability.

7.6.4.4 Component Evaluation and Qualification

In case a valid and acceptable qualification cannot be demonstrated, a component evaluation and qualification test programme shall be implemented.

The programme shall cover the following elements:

- Design and application assessment for the parameters of the component which are essential for the intended application and which justify the use of a non-preferred part.
- Constructional analysis of the selected part (minimum three components) to assess the standards of fabrication and assembly, potential failure modes, materials and processes which may lead to deterioration or malfunction.
- Manufacturer assessment to assure that the organisation, facilities, production control and inspection system are adequate.
- Evaluation and qualification tests corresponding to those defined in the ESA/SCC specifications for similar technologies.

If necessary, consultants or procurement agents may be used to perform these tasks.

7.6.4.5 Declared Component List (DCL)

The PA manager will establish and maintain a declared components list, which will contain the following information:

- Part designation;
- Commercial components designation, characteristics (if necessary, like package, tolerance, etc.);
- Qualification status;
- Procurement specification;
- Quality level;

- Lot acceptance test level (only components for safety critical application);
- Manufacturer;
- Total quantity including the attrition (for information only).

The DCL should be approved prior to start the procurement activities.

7.6.5 Procurement requirements

Each type of component will be controlled by a procurement specification.

7.6.5.1 Procurement Specifications

Standard specification will be used as applicable.

If procurement specification has to be established they will be approved by STIX EM department and PA procurement specifications will be sent to ESA PO for approval.

The procurement orders are reviewed and approved by PA in front of the above requirements.

7.6.5.2 Component Screening and Burn-In

The following ESA/SCC test levels for the screening of components for the instrument shall be applied:

- Level B: for active components and critical passive components like crystals, filters, cermet-fuses, relays and switches;
- Level C: for other passive components not listed above;
- SSC Testing levels:
  - Testing level 1: applicable for critical flight-standard hardware;
  - Testing level 2: applicable for maintainable, non-critical flight hardware or single Instruments.

Alternative acceptable levels are:

- JAN S, for active components;
- MIL failure rate R or S for passive components.

In any case lot traceability shall be assured.

7.6.5.3 Lot Acceptance Test (LAT)

All components shall be subjected to Lot Acceptance Testing (LAT) as defined in the ESA/SCC specifications or QCI (Quality Conformance Inspection) as defined in the United States Military specifications.

- Level LAT1 or QCI compatible: the component is neither ESA/SCC nor United States Military qualified at the time of the procurement and level LAT2 is not applicable.

- Level LAT2 or QCI compatible: the component is not space qualified but has successfully supported other long life and/or high reliability space programmes and the reliability/evaluation data are still valid for the current design.
- Level LAT3 or QCI compatible: all cases not included in level LAT1 or LAT2. Level LAT3 tests may be replaced by incoming inspection. Level LAT3 tests may be omitted for qualified ranges of components (e.g. 54HC).

7.6.5.4 Hybrid Circuits

Hermetic hybrid circuits shall be procured according to relevant detail specification from sources which are ‘capability approved’ for space use.

They will always be entered on Part Approval Documents (PAD) for their approval by the PI and ESA.

7.6.6 Component quality assurance

As required in EID-A.

7.6.7 Off the shelf Equipment Declaration

Any Off-The-Shelf (OTS) equipments that the PI is expecting to use shall be declared and pre-agreed with the ESA Project office.

The PI shall review the components used in OTS equipment to verify compliance with the requirements of this document. The review shall consider the used parts’ list, radiation hardness, the derating rules, Worst Case Analysis and the equipment design. COTS components shall be treated as non standard parts.

7.7 Materials and process selection and control

7.7.1 General

The prescriptions for materials and process selection will be followed as described in EID-A.

7.7.2 Materials and process selection approval

The basic tasks are to control the selection, procurement, and qualification of materials and processes.

In order to keep these aspects under control, dedicated lists will be prepared and maintained consistent with the hardware design, starting already in the very early stage of design activities.

The PA materials and process specialist prepares these lists, defining the evaluation and qualification plan for those items that are not known or qualified.

These lists are the basic work tools for the activity.

Three different lists will be prepared:

- Declared Material List (DML);
- Declared Mechanical Part List (DMPL);
- Declared Process List (DPL).

The guidelines for preparation and update of the lists are those defined by ESA PSS 01 700.

Each material and process will be identified, with its applications and qualification status in space field.

The lists will be submitted to STIX Team and ESA for review and approval.

A new issue, implementing design updates, and the comments received to the previous one, is released for each of the design reviews.

Whenever a mechanical part, a material or a process has to be used, for which limited or no test and qualification data are available, and has therefore to be considered not qualified, a Request for Approval (RFA) will be issued and sent to STIX Team and ESA for evaluation.

Critical processes are identified as those that:

- Can have an effect on integrity and safety of the mission;
- Have never been used in space missions;
- Their quality cannot be assessed only by final visual inspection of end product.

Such critical processes will also be the subject of RFA, containing the suggested means, in terms of controls and qualification tests, to be carried out to minimise their criticality on the flight hardware.

Once all activities foreseen in the RFA's are completed, the STIX Team and ESA signatures will state their approval.

Whenever possible, precedence will be given to materials and processes already used with success in previous space programmes, or qualified in the framework of a formal qualification programme.

The peculiar mission environment will be taken in any case into account, and all selected material and processes will be evaluated for their mission application.

Materials will be selected in accordance with design, quality and performance requirements applicable to the mission.

Particular care will be given to avoid specific areas of concern, such as:

- Corrosion;
- Safety;
- Susceptibility to mission environmental conditions;
- Outgassing;
- Flammability;
- Galvanic effect;
- Radiation.

The possible impact of the above effects will be evaluated prior of material selection, referring to ESA ECSS documents for specific arguments.

The acceptance criteria for outgassing are:

- Less than 1% in terms of TML (Total Mass Loss);
- Less than 0.1% for CVCM (Collected Volatile Condensable Material), after test.

Due to critical effects of deposed contaminants on detector surfaces, more stringent requirements may arise as the design evolves.

Avoidance of materials having poor outgassing qualities in the STIX programme is a main task.

7.7.3 Materials control

Each material will be defined and controlled by a detailed specification, or a standard. These specifications identify the material properties, the applicable requirements, the methods for their use, the tests and the relevant acceptance criteria.

Materials having a limited life will be marked with their expiration date.

Expired materials can be re-qualified if they pass the applicable tests and demonstrate to possess still their required properties. Trace of this re-qualification will be filed by QA.

The incoming inspection controls will be tailored to the material characteristics and criticality.

Lot or individual test documentation will be kept in file to allow STIX Team and ESA review.

Detected anomalies will be treated by NCR and MRB.

STIX Team and ESA will be called to participate to MRB dispositions, in case of major problems.

Materials will be procured from sources which have demonstrated to be reliable in previous space programmes. Whenever possible and practicable, second source policy will be followed.

7.7.4 Process control

Processes are selected on the basis of their compatibility with the materials to which they have to be applied, and their capability to meet the specified requirements for quality and performance.

Precedence will be given to well-established processes, already used in previous space programmes.
Should it be necessary, due to the STIX programme peculiarities, to use nonqualified processes, dedicated evaluation and qualification specifications will be prepared and submitted to the STIX Team and to ESA for approval.

These specifications will detail all tests to be carried out to obtain confidence in the process performance prior of application on flight hardware.

Each process will be covered by a detailed specification, or a standard.

These specifications will be reviewed and approved by STIX Team and ESA prior of process application.

The process specifications will define all parameters to be maintained under control to ensure that the final product meets design requirements.

Manufacturing and control tools will be evaluated and maintained according to their schedule to guarantee proper results.

The environmental and cleanliness conditions of the areas where the processes have to be exploited will be specified and monitored to avoid contamination.

The personnel certification for processes requiring particular skills will be verified.

Materials to be used for the process will be included in the Declared Material List ,and their suitability for intended use will be proven.

Special processes, identified as critical in the Declared Process List according to the ESA PSS-01-70 definitions, will be subjected to strict survey.

Special plans and checklists will be prepared, and recalled in the Manufacturing and Inspection Plan, to evidence the periodicity and the contents of the controls to be carried out on critical processes.

The Manufacturing and Inspection Plan to be submitted to ESA and STIX Team will contain the list and the schedule of the process audits that each subcontractor will perform at its own facilities.

ESA and STIX Team will be allowed to participate to the audits, by advanced notification.

Critical areas identified in the manufacturing flow during production of the deliverable items will be the subject of dedicated audits.

7.8 Software product assurance

7.8.1 General

A comprehensive QA programme will be established to cover all phases of SW life cycle. This programme will cover all in-house or subcontracted activities.

Progress meetings, official reviews, key points and inspections will be planned and scheduled to ensure a close follow up on the activities.

7.8.2 Software product assurance activities

All the activities related to S/W Quality Assurance will be described in the document "S/W Quality Assurance Plan" to be issued for the SW associated to STIX items and their dedicated GSE.

The document will be based on ESA-PSS-05-0 taken as guideline document.

The applicability of all parts of this ESA PSS will be defined, for the test SW associated to GSE, in accordance with its intrinsic criticality.

7.8.3 Software product reviews and inspections

As baseline, the following Reviews will take place:

- System Requirements Review (SRR);
- Preliminary Design Review (PDR);
- Critical Design Review (CDR);
- Qualification Review (QR);
- Acceptance Review (AR);
- Operations Readiness Review (ORR);
- Software Inspection on Source Listing;
- Review of Test procedures and test plans;
- Witnessing of tests.

Complete traceability will be ensured in all Reviews, and a formal acceptance release will be considered mandatory prior to proceed to the following phases of SW development and test.

7.8.4 Hardware / Software Interaction Analysis (HSIA)

The FMECA to be performed on the items will take into account the associated on-board SW, and its interaction with the HW.

The goal of this activity is to avoid damage or overstress caused by SW commands, and to prevent increase of criticality of HW failures due to SW resulting actions.

7.8.5 Software configuration management

The contents of the SW QA Plan (SWQAP) will be, as minimum, the following:

- SW QA management and organisation description;
- Standards, practices and metrics in use;
- Verification and test control reviews;
- Audits;
- Problem reports and related corrective actions;
- Tools and techniques;
- Code and media control;
- SW Configuration management;
- Subcontractors and suppliers control.

7.8.6 Software problem reporting

SW non-conformances will be treated, classified and reported as the HW ones. Dispositions and corrective actions will be defined in concurrence with SW specialists.

7.9 Cleanliness and contamination control

The environment conditions, with respect to cleanliness and contamination control, will be maintained adequate to the requirements applicable to the product.

As basic definitions, all electronic units, starting from part level to complete unit, will be stored, handled, assembled and manufactured in FED STD 209, 100000 Class conditions.

Detectors, and other items associated to them, will be handled and assembled in areas with better cleanliness conditions, to be defined in the Cleanliness Control Plan that will be prepared and submitted to STIX Team and ESA for approval.

This Plan will define the policies for prevention from contamination of critical surfaces.
The contents of this Plan will be as minimum the following:

- Handling instructions for critical parts. If necessary, dedicated procedures will be prepared and implemented.
- Cleaning methods, with the definition of the points within the manufacturing flow where cleaning is required.
- Purity requirements for the cleaning agents to be used
- Prevention methods to avoid contamination, such as clean-room clothing, gloves, etc.
- Cleanliness level measurement and monitoring of all areas involved in the manufacturing process.
- Detection methods for the measurement of the contamination level on the critical surfaces
- Means to prevent contamination during the phases of Manufacturing, Assembling and Test.
- The final expected cleanliness budget.

Stores, assembling, test and inspection areas will be equipped in order to meet the requirements set forth in the Cleanliness Control Plan.

Whenever necessary, operations critical for cleanliness aspects will be carried out under laminar flow hoods.

8 MANAGEMENT PLAN

8.1 Introduction

This Plan and its Annexes define the management principles, approach and structure for the STIX project, leading to the realization of the full STIX end-to-end system, consisting of the Flight Instrument and the Ground Segment. Objectives of this plan are to insure interfaces with ESA and within the Consortium, to implement appropriate procedures and practices regarding communication, technical-, cost- and schedule control, to insure that plans and other established baselines are defined, followed and updated and that full visibility of project performance is established and sustained in order to achieve the scientific objectives of the project within schedule and budget at the lowest possible risk.

The following objectives are considered both essential and mandatory in the frame of this proposal:

- Clarify roles and responsibilities.
- Provide an effective and appropriate organization.
- Identify activities of planning, reporting and monitoring.
- Provide a clear list of deliverables.

The content of this document has been approved by the Principal Investigator and accepted by the involved Institutes.

8.2 Instrument Organization and Responsibilities

See section 2.1, “Management Structure and Responsibilities”

8.2.1 STIX Team Members and Associated Institutions

The STIX Team Members and Associated Institutions are listed in Part V, Management Plan”, Appendix B.

8.2.2 Key-Personnel

The key persons list is provided in Part V, Management Plan”, Appendix B1.

8.3 Communications within the programme

The PI agrees with the management requirements in section 8 of Solar Orbiter EID-A.

All formal communication concerning technical and programmatic aspects shall be made between the Principal Investigator, and the ESA Project Manager. No other party shall have formal authority, without written delegation.

Formal communication is defined to be a communication with a registration number in the configuration control system, independently of the medium used to transfer it (mail, fax, e-mail).

Any formal communication interchanged between PI and PS or other ESA entity shall be copied to the ESA Project office.

8.4 Project phasing and planning

A PERT-based project management software tool such as Microsoft Project shall be used by all contributing main partners (Institutes) involved in H/W and S/W design, building and test. The PI, supported by the Executive Team and Technical Manager, shall transmit regularly to ESA the status of the project development (schedule at high level).

8.4.1 Instrument Baseline Schedule

The STIX project shall support all reviews and meetings as required in EID A.

The top level STIX project reporting milestones shall correspond to the instrument level design reviews (see Section 3.3).

Solar Orbiter programme schedule and dates, as currently understood, are reproduced in Table 8-2.

Table 8-1. Milestones of Solar Orbiter mission

Event	Date
Instrument AO	October, 2007
Programme submission to ESA’s Cosmic Vision Downselect	Fall, 2009
Start of the 20-month Definition Phase	January, 2010
Start of 65-month Implementation Phase B2/C/D	January, 2012
Launch	January 2017

Taking into account the previous programme, it is planned to develop STIX according to the model production strategy reported in Table 6-1. A number of internal milestones shall be identified in the detailed STIX schedule to guarantee the timely delivery of sub-systems and channels to achieve the model delivery in due time.

Changes to the Baseline Master Schedule will only be made with the approval of the ESA Project Office. The resources and fraction of time available for all personnel can be found in Appendix B. This information is given for the following mission phases: Instrument Development Phase, Science Operations Phase, and Archival phase.

8.4.2 Project Control Objectives

The main objectives of the project control are to:

- Maintain a clear tracking of all major project development phases and appointments;
- Take the project development in line with major milestones imposed by ESA;
- Flag any critical event during project development to allow proper counteractions to be taken;
- Maintain an archive of all relevant documentation;
- Allow clear visibility to Solar Orbiter Project Office of all internal and interface activities.

The technical and programmatic aspects of the instrument programme shall be assessed between the STIX team and the ESA Project Office through:

- Regular progress reporting;
- Instrument progress meetings;
- A cycle of formal Instrument Reviews.

Evidence of the overall scientific performance of STIX shall be given to the ESA Project Office during the review cycle and through the regular progress reporting supplied by the PI. Detailed scientific aspects shall be reviewed within the context of the Solar Orbiter Science Working Team, as defined in the Solar Orbiter Science Management Plan.

8.4.3 Project Reporting

8.4.3.1 Internal Project Reporting

Regular instrument progress meetings shall be held at premises of the STIX team during all phases (design, development, production, test, verification and calibration) of the instrument development.

Evidence of major internal meetings shall be reported to ESA Solar Orbiter Project Office. These meetings are not a substitute for formal reviews or reporting. They are the routine ongoing process for ensuring the interface design integrity of the instrument, its compatibility with the Solar Orbiter system and monitoring the instrument programme's progress so as not to jeopardize the overall programme. These meetings are also the forum for flagging detailed technical interface problems. Corrective actions, including schedules, are agreed and implemented. A Product Assurance representative shall attend all progress meetings.

The EM ensures that project internal minutes of meetings (MNs) technical notes (TNs) and alerts are issued by the authority responsible for the execution of activities which shall impinge upon the activities of other project authorities where applicable. TNs are issued where engineering explanations of changes to system interfaces and/or system implementation are necessary.

Alerts for materials, components and processes are handled by the Product Assurance Manager, whose responsibility is to receive such alerts from higher programme authorities and ensure the prompt dissemination of information to the relevant design/engineering authorities within the STIX consortium.

8.4.3.2 Reporting to ESA

The PI shall submit 5 days after the end of each month, a Monthly Progress Report in which the current status of each activity is described and problem areas or potential problem areas are highlighted together with identification of proposed remedial action.

The Monthly Progress Report shall include the following topics:

- Overall summary, covering scientific and technical performance, status of design changes and open ECR's, overall progress status;
- Design Development and Verification status, covering status of design definition and verification of interfaces, test and calibration, GSE, operations;
- PA status, including NCR and RFW status;
- Programmatic status, including schedule and milestone reports;
- Science Performance status;
- Problem areas and corrective actions.

8.4.3.3 Instrument Progress Meetings

Regular Instrument Progress Meetings shall be held on the premises selected by the PIs during the design, development and verification programme of the instrument. These meetings will be conducted between the ESA Project Office / the selected Prime and the Instrument Team with the objective of ensuring that the interface technical design integrity of the experiment, its compatibility with the spacecraft system, and instrument programmatic are proceeding in a manner which will not jeopardise the overall programme.

As a minimum, the STIX Team shall be represented by the PI, the Co-Is, the EM, the Science Coordinators, and the Unit Experiment Managers. The meetings shall be held on a basis to be agreed with ESA.

The agenda of the progress meetings shall be proposed by ESA Solar Orbiter Project Office and agreed with STIX Project Office. Prior to each progress meeting relevant documentation (e.g., technical notes, hand-outs) shall be submitted to Solar Orbiter Project Office for evaluation in preparation to the meetings.

Detailed technical problems occurring on either side of the interface shall be flagged during these meetings and corrective actions, including their schedule impact, agreed and implemented.

During Progress Meetings, Action Items shall be issued to be treated as described in Section 3.3.5.

8.4.3.4 Instrument Schedule Control and Reporting

The EM shall continuously record progress achieved and maintain forecasts. The EM shall consolidate the progress and forecasts of all groups contributing to the instrument and compare schedule performance with respect to the overall Baseline Master Schedule. Where deviations to the baseline have occurred or are predicted, the EM shall develop and implement corrective actions.

For each milestone, the EM shall maintain a record of the baseline achievement date, the forecast achievement date and the actual date achieved. In order to track the progress, the PI shall provide to the ESA Project Office a monthly schedule report as part of the reporting procedure.

During the manufacture and test phases the frequency of schedule reports may be increased should the Agency judge progress to be critical.

8.4.3.5 Critical Path Analysis and Schedule Monitoring

The general management responsibilities of the PI's and Co-Is Institutes are reported in Section 2. They shall be identified in formal project management documents to be generated showing detailed activity charts, resources, critical path, etc. The form of these is open to ESA scrutiny and delivery dates are agreed with the ESA Solar Orbiter Project Office.

A continuous monitoring of project development with respect to reference schedule shall allow us to trace the development consistent with internal and external milestones and the identification of any deviation or problem.

An Action Item Tracking System (AITS) shall be maintained in order to control the following two interfaces:

- ESA Project Office - to - STIX Project Office;
- STIX Project Office - to - subordinate organisations.

Action items (AIs) naturally arise from the submission of Progress Reports, Minutes of Meetings and other ad hoc documents such as letters and/or e-mails and/or telefaxes. An Action Item Tracking Log is maintained by the TM at experiment top-level, identifying the following:

- AI Number;
- Originator Identifier (organisation & name);
- Date of Origination;
- Date of Required Close-out;
- Actionee (organisation & name);

- Status.

Also, an Action Item description sheet is raised for each AI which includes a brief description of the causes of the action and the proposed activities for close-out. Cross reference with the Tracking Log is via the AI Number. Other information to be included on the description sheet comprises elements (2)-(6) of the above list. A file of active AI description sheets is maintained. All inactive (closed-out) AI description sheets are archived for future reference. By this mechanism as proper control of activities and open point shall be maintained in order to guarantee the achievement of the major steps within the instrument schedule.

The mechanism reported above shall allow us to flag any criticality of the IFE development and to monitor compatibility of activities with schedule. Any deviation from expected timing shall be flag to competent bodies in the Project and proper actions shall be put in place to maintain or bring back the project in schedule. All events shall be promptly reported to Solar Orbiter Project Office for tracing and agreements on actions to be taken.

8.4.4 Instrument Breakdown Structures

8.4.4.1 Product Tree

The purpose of the STIX Product Tree is to provide a structured organization of all activities, define the title and the id number of each task. It is the framework for the management of the project.

The following levels of details have been identified in Table 8-3.

Table 8-2. Product tree level identification

LEVEL	I.D.	TITLE
LEVEL 0	INSTRUMENT	STIX
LEVEL 1	SYSTEM	STIX SYSTEM
LEVEL 2	MODULES / UNITS	

8.4.4.2 Work Breakdown Structure

A Work Breakdown Structure is provided in Part V, Appendix A.

8.5 Meetings and reviews

The PI will support the Mission Reviews with his scientific and technical team. The PI will provide the Review Data Packages in due time and in accordance with dedicated procedures.

8.5.1 Internal Reviews

The following internal design review will be held:

- Manufacturing Readiness Review (MRR) is the review where the manufacturing documentation of each deliverable item is presented by each subsystem to the PI and the EM Team. Objective of the review is to achieve the PI authorization to start manufacturing activities.
- Test Readiness Review (TRR) is the review where each deliverable item, acceptance and qualification test procedures are presented by each subsystem to the PI and the EM Team for acceptance. Objective of the review is to achieve the PI authorization to start the acceptance or qualification tests.
- Test Review Board (TRB) is the review where the acceptance or qualification test results, for each deliverable item, are presented to the PI and the EM Team. Objective of the review is to achieve the PI preliminary acceptance and the consent to shipment for AI&V.

8.5.2 Instrument Reviews

This section shows the major reviews associated with each phase as defined in the EID-A, par. 8.5.3.3.

8.6 Configuration management

Special attention will be paid by all the involved Institutes in the deliverable items configuration control.

Each item will have its own configuration control document reporting the applicable documents together with the relevant non conformance and request for waiver.

The item configuration control documents will be continuously updated and formally issued for the envisaged program review: MRR, TRR, TRB etc. The objective is to check that the instrument design is capable to achieve the science objectives and complies with requirements.

Within the STIX EM Project Office, a configuration control manager will be responsible for planning and organising the project configuration control.

8.6.1 Change Control

Documents that define the instrument and are submitted to control are specifications, planning and reporting documents, drawings and the change notices.

According to the EID-A, approval is required for the following documents:

- EID-B;
- Engineering Plan;
- User Manual;
- Database;
- Declared Material List;

- Declared Mechanical Parts list;
- Declared Process List;
- Single Point Failure List;
- Preliminary Hazard Analysis and Residual;
- Product Assurance Plan;
- Management Plan.

All verification documents including design analyses and test reports shall make reference to the current configuration status of the design being evaluated.

Each consortium group will maintain a list of documents and drawings related to its items and will be responsible for communicating changes, revisions etc.

8.6.2 Configuration Items Data List (CIDL)

For each Deliverable Item a CIDL will be issued. This CIDL is composed of:

- List of applicable documents,
- List of drawings,
- List of project documents,
- List of NCR,
- Configuration File of the Deliverable Item.

This list, updated for each review, becomes the current configuration status.

CIDL will be prepared and submitted for formal project reviews and included in the Acceptance Data Packages for qualification and flight hardware, software and EGSE.

8.6.3 Documentation referencing system

8.6.3.1 Document numbering

A Document Number combined with an Issue/Revision Number as the unique identifier will be used for tagging the STIX documents. The Document Number shall be Organization based and each section of the number shall be separated with the “-“ character.

The Document Number shall be built up in the following way:

Position	Code	Description/ Example
1-2	SO	Solar Orbiter Project (fixed)
3-5	STIX	STIX Instrument (fixed)
6-7	TT	Document Type code (e.g. TN=Tech. Note)
8-12	NNNNN	Document revision number (e.g. -0.1 … -9.9)

Therefore, a full example of the Document Number could be SO-STIX-TN-00001.
TT identifies the type of the document:

CP	Change Proposal
CR	Change Request
CS	Configuration Status List
DC	Document Change Notice
DP	Data Package
DS	Design Specification
DV	Development and Verification Plan
DW	Drawing/Diagram
EID	EID - Experiment Interface Document
HM	Hardware/Software Matrix
HO	Handout/Presentation
ICD	Interface Specification / ICD
LI	List (materials, components, parts, processes)
MN	Minutes of Meeting
NC	Non-Conformance Report
PA	Product Assurance
PL	Plan
PO	Proposal
PR	Procedure
PT	Product Tree
RD	Request for Deviation
RP	Report
RS	Requirement Specifications
RW	Request for Waiver
SC	Schedule
SS	Scientific Specifications
SW	Statement of work
TN	Technical Note
TP	Test Plan
TP	Test Procedure
TR	Test Reports
TS	Test Specification
VP	Verification Plan
VR	Verification Report
WB	Work Breakdown Structure

NNNNN Sequential number:
The first "N" digit out of the five digits will be coded as it follows:

STE = 1
SIS = 2

STIX = 3
LET = 4
HETn = 5
CDPU/LVDS = 6
GSE = 7

and as further meaning of the first digit code the following is assumed:

0	for management & flight H/W related e.g. EID-B, User manual, overall T Procedures, general Calibration Plan etc.,
8	for System S/W
9	Ground segment (e.g. Data distribution).

Examples:

"SO-STIX-TN-1nnnn": will identify a Technical note on the STE unit
"SO-STIX-MN-0nnnn": will identify a minute of a STIX meeting at system level.

8.7 Deliverable items

8.7.1 Spacecraft Deliverables

The STIX model philosophy is defined in Table 8-4.

Table 8-3. STIX model philosophy

ITEM/TYPE	**STM**	**EM**	**EQM**	**FM**
INSTRUMENT UNITS: Imager Module Spectrometer Module IDPU Data Reduction Software	Flight model fully representative in ter of: Mechanical desi mass, thermal and center of gravity	Fully representative from electrical and S point of view	Fully representative from electrical and S point of view.	Tested at acceptance level before delivery t instrument AIT
SYSTEM LEVEL	Flight model fully representative in ter of: Mechanical desi mass, thermal and centre of gravity	Fully representative from electrical and S point of view	Fully representative from electrical and S point of view.	Tested at acceptance level before delivery t instrument AI&V
STIX AIT	Physical properties, Static load and ther balance	Integration and functional test befor delivery to ESTEC	Thermal vacuum qualification testing, Vibrations.	AIT, acceptance tests, environmental tests, calibration
SOLAR ORBITER AIT ACTIVITIES	Integration on STM Spacecraft for mechanical & therm tests	Integration on EM Spacecraft Instrume Functional Test	Thermal vacuum qualification testing, Vibrations	Integration on flight spacecraft and flight campaign

This model philosophy has been adopted, in order to ensure the following goal achievement:

- Early mechanical qualification at instrument and satellite level via the Instrument Structural/Thermal Model (STM).
- Spacecraft full functional verification via the imager module and detector box.
- End to end test execution on flight fully representative hardware via the Instrument QM.
- Detectors modules full qualification before flight modules integration via the QM.
- Pre-calibration activities on QM.

8.7.1.1 Mathematical Models

A Structural Mathematical Model (SMM) and a Thermal Mathematical Model (TMM) of the instrument will be provided as defined in sections 6.3.1 and 6.3.2 of EID-A.
The SMM will cover the following analysis:

- Detailed Stress Analysis
- Mechanism Functional Analysis
- Dynamic Model
- Dynamic Analysis

The TMM have the following objectives:

- Verify that internal parts and materials are below their maximum allowed temperatures under acceptance/qualification testing;
- Verify the ability of the thermal design to maintain the internal required temperatures and intended heat flow pattern that ensure performance requirements under the worst flight cases
- Verify the compliance with the spacecraft interface requirements under the worst flight cases

The suggestions given in EID-A regarding with thermal design cases and software codes will be followed. A preliminary mathematical model was developed by GSFC and served as the basis for a more detailed model produced at SRC Wroclaw. The latter included the outcome of ESA’s thermal design studies. It is the basis of the engineering plans in Part I and III.

8.7.1.2 Structural and Thermal Model

The Structural/Thermal Model is considered essential for the characterization for the thermal and structural point of view. The STIX STM will be used for tests at spacecraft level as described on page 129 of EID-A [AD-02]. The STIX STM imager and spectrometer modules will be representative in mass, CoG, stiffness, mounting, shape, and internal power dissipation. They shall include a representative harnessing. Within these requirements, dummy grids and detectors will be used.

8.7.1.3 Qualification Model

The Qualification Model, demonstrative of the instrument technologies and the adopted design solutions, will be realized under sensor team responsibility and put under testing from the middle of the preliminary design phase.

The outcomes from this activity will be transferred into C/D phases for the development of the Flight Model (FM). The test activities on the STM will continue, thus providing useful input for the detailed phase C/D design of the experiment.

8.7.2 Engineering Model

The Engineering Model, demonstrative of the instrument technologies and the adopted design solutions, will be realized under sensor team responsibility and put under testing from the middle of the preliminary design phase. The outcomes from this activity will be transferred into C/D phases for the development of the Flight Model (FM). The test activities on the STM will continue, thus providing useful input for the detailed phase C/D design of the experiment.

8.7.3 Engineering Qualification Model

The EQM will be flight representative for the following areas:

- Physical Parameters
- Electrical
- EMC
- Harness
- On Board S/W
- Factory GSE
- Mechanical Structure
- to perform Qualification Test Certification;
- to be a fully Ground representative copy of the FM during the whole Solar Orbiter Mission.

The EQM shall have electrical and mechanical interfaces fully flight representative. Moreover, the electrical functionality shall be guaranteed. In other words, the instrument shall be able to execute TLC, generate telemetry data, and monitor internal activities. All the mechanisms shall be representative from electrical and EMC point of view, even though mechanically they could be limited.

The EQM is being assembled in accordance with the design. It will be compliant with all the requirements of Solar Orbiter mission and it will be delivered for the CDR review.

The EQM will be returned to the PI, refurbished and kept as Flight Spare. This model is being assembled in accordance with the design. The FM hardware and software will be compliant with all the requirements of the Solar Orbiter mission.

8.7.4 Flight Model

The STIX FM shall have full flight standard verified by formal functional and environment acceptance tests.

8.7.4.1 On-Board Software

The instrument on-board software will be compliant with the ESA software standard ECSS E40 and delivered together with the corresponding instrument models.

8.7.4.2 Ground Support Equipment

GSE will be delivered as part of the instrument model. There will be an Electrical GSE to simulate the interface to the spacecraft. A twist monitor will record the relative position of the two grids throughout the development up to the delivery.

8.7.5 Deliverables to Ground Segment

8.7.5.1 Deliverables to Operational Ground Segment

TBW, according to Solar Orbiter EID-A

8.7.6 Deliverables to Science Ground Segment

TBW, according to Solar Orbiter EID-A

8.8 Schedules

8.8.1 Instrument Project Schedule

A detailed schedule of the tasks to be performed for the implementation of the project, deliveries and reviews are provided as Appendix C.
The schedule includes:

- The nominal duration for each task according to links and constraints of the project and the required completion dates.
- Identification of deliverable items and dates.

8.8.2 Schedule of PI Deliveries

As defined in the EID-A, par. 8.7, the following hardware and software shall be deliverable items:

- Hardware
    - Structural/Thermal Model (STM)
    - Flight Model (FM)

    - Flight Spare (FS)
    - FGSE
    - EGSE
- Software
    - Flight EGSE
    - Sequences required to perform experiment bench level ESA acceptance tests
    - Sequences required for system level tests
    - Auxiliary software for investigations and diagnostics on STIX, EGSE or interfaces
    - Mathematical models

Schedule and delivery dates are provided as Appendix C.

8.8.3 Need dates of ESA Deliverables

As defined in EID-A, par. 8.8.3, Instrument Delivery dates will be according to the following plan:

STM: 4 years prior to launch (TBC)
QM: 3 years prior to launch (TBC)
FM: 2. years prior to launch (TBC)

9 DOCUMENT REFERENCES

Applicable Documents:
[A1] Solar Orbiter-EID A. SOL-EST-IF-0050. Issue 1, Rev. 0. 9 Oct. 2007

The following documents have been used as guidelines:

ECSS-10-04A	Space Environment replacing [PSS-01-609] Radiation Des Handbook
ECSS-Q-20 B	Quality Assurance
ECSS-Q-20-09 B	Template for Non Conformance Report
ECSS-Q-30-02 A	Template for FMECA
ECSS-Q-30-11 A	Derating – EEE components
ECSS-Q-40 A	Safety
ECSS-Q-60 A	EEE Components Control
ECSS-Q-60-01 A	European Preferred Parts List and its Management
ECSS-Q-70 A	Materials, Mechanical Parts and Processes
ECSS-Q-70-02 A	Thermal Vacuum outgassing test for the screening of space materials
ECSS-Q-70-08 A	The manual soldering of high-reliability electrical connections
ECSS-Q-70-28 A	Repair and modification of printed circuit board assemblies for sp use
ECSS-Q-70-36 A	Material selection for controlling stress-corrosion cracking

ECSS-Q-70-37 A	Determination of the susceptibility of metals to stress-corros cracking
ECSS-Q-80	Software Product Assurance
ECSS-Q-70-01A	Contamination and cleanliness control
PSS-01-301	Derating Requirements applicable to Electronic, Electrical, and Elec Mechanical Components for ESA Space Systems
PSS-01-605	Capability Approval Programme for Hermetic Thin Film Hyb Micro-Circuits
PSS-01-606	Capability Approval Programme for Hermetic Thick Film Hyb Micro-Circuits
PSS-01-608	Generic Specification for Hybrid Micro-circuits
PSS-01-701	Data for the Selection of Space Materials

10 ACRONYMS

ADP	Acceptance Data Package
AIT	Assembly, Integration and Testing
CCB	Configuration Control Board
CDR	Critical Design Review
CIDL	Configuration Item Data List
CIDL	Critical Item Data List
CSL	Configuration Status List
DCL	Declared Component List
DML	Declared Material List
DPA	Destructive Physical Analysis
DRB	Delivery Review Board
DVM	Design Verification Matrix
ECR	Experiment Change Requests
EEE	Electrical, Electronic, Electromechanical
EIDB	Experiment Interface Document – Part. B
EIDP	End Item Data Package
EM	Engineering Model / Experiment Manager
EQ	Engineering Qualification
EQM	Engineering Qualification Model
ESD	Electro-Static Discharge
FM	Flight Model
FMECA	Failure Mode Effect and Criticality Analysis
HSIA	Hardware/Software Interaction Analysis
KIP	Key Inspection Point
LAT	Lot Acceptance Test
LEM	Local Experiment Manager
MIP	Mandatory Inspection Point

MRB	Material Review Board
MRR	Manufacturing Readiness Review
NCR	Nonconformance Report
PA	Product Assurance
PAM	PA Manager
PAP	Product Assurance Plan
PI	Principal Investigator
PS	Project Scientist
QM	Qualification Model
RFA	Request for Approval
RFD	Request for Deviation
RFW	Request for Waiver
SOW	Statement of Work
SPF	Single Point Failure
SPO	STIX Project Office
STM	Structural Thermal Model
TR	Test Review
TRB	Test Review Board
TRR	Test Readiness Review
TRRB	Test Readiness Review Board
WCA	Worst Case Analysis

APPENDIX A: INSTRUMENT SUMMARY DATA SHEET

Name / acronym	**Spectrometer/Telescope for Imaging X-rays (STIX)**

Objectives	To establish the timing, location and spectra of energetic electrons near the Sun an provide a high-energy link between in-situ and remote imaging observations
	To determine the size, morphology, spectrum and location of hot thermal and nontherm ray sources
	In conjunction with other spacecraft, to measure the directivity (beaming) and chromospheric/coronal transport of energetic electrons

General description	X-ray imaging spectrometer which uses indirect (Fourier) imaging to achieve 7 arcse imaging with high spectral resolution from 4 to 150 keV

Reference P/L an heritage	Yohkoh/HXT
	RHESSI

Parameter	**Units**	**Value / Description**	**Remarks**
Sensor / detector			
		64 15x15x3-mm thick planar detectors each with guard surrounding a 9x9mm active area	
Dynamic range		<1 to 10^5 counts/s	Instrument dynamic range further exte by use of 2 moveable X-ray attenuators
Operating T	C	-30 C to +25C	At sensor.
Optics			
		Bi-grid collimator with tungsten Grids	
Unobstructed FOV	deg	1.5 degrees for imaging 2.5 degrees for spectroscopy and so location	~0.25 g/cm2 low-Z window require suppress low energy X-rays with 0.5 diameter clear aperture for aspect.
Energy passband		4 – 150 keV	
Pointing	N/A	Solar pointed	
Configuration			
Physical Units	No	Imager module Spectrometer module Two thin windows (sun shades) apertures for aspect	
Layout	N/A	Imager module located in fron spectrometer module. Windows located at top and botto baffle in s/c thermal shield	± 0.4 mm transverse coalign requirement between imager spectrometer modules. ± 2 mm transverse alignment of apertu windows.
Location S/C	N/A	Internally mounted, Sun-poi behind the spacecraft thermal shield	
Volume	cm	Imager module 55cm x 18 diameter Spectrometer 18x20x22cm	Includes 2cm depth for attenuators

		Windows 18.5 and 22.5cm diamete	Excluding mounts
Physical			
Windows	kg	0.08	
Grids	kg	0.38	
Aspect	kg	0.03	
Imager tube and mour	kg	0.61	
Harness Mass	kg	0.3	
Attenuators	kg	0.13	
Detectors and ASICS	kg	0.38	
Electronics	kg	2.0	
Thermal blankets	kg	0.09	
Total Mass	kg	4.0	CBE, exclusive of margin
Sensor Dimension	cm	64 @ 1.5 x 1.5 x 0.3	Including guard rings
Harness Length	cm	tbd	
Electronics Dimensio	cm	16x20x22	
Power			
Average	W	4	Before margins
Peak power	W	4	
Stand-by	W	tbd	
Data rate / volume			
Average data rate	Bits/se	200	
Peak data rate	Bits/se	200	
Minimum Data Rate	Bits/se	tbd	
Own data storage	MByt	256	
Thermal			
Electronics Dissipatio	W	4	
Heat load to radiator		< 6 watts	
Operating T range	K	-30 to +25C	At sensor
Non-operating range			
Other requirements	N/A	None special	
Cleanliness			
EMC requirements	N/A	None special	
DC magnetic	N/A	None special	
Particulate	N/A	None special	
Miscellaneous			
Mechanisms	N/A	2 mechanisms for automated inse of 23 and 60 g X-ray attenuators (displacements)	
Alignment		3 arcminutes	Internal aspect system
Orbit requirements		None special	
AIT/AIV requirement		None special	