



iESA Instrument Assembly, Integration and Tests Plan

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Summary	This document presents the I&T Plan of the iESA HelioSwarm instrument leaded by IRAP iESA team for STM, EM, PFM and FS models.
Annexes	N/A

Distribution	HelioSwarm Team
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Applicable Documents (AD)

AD	Title	Reference	Version
1	iESA Design, Development Organization and Verification Plan	HelioS-PL-20000-IRAP-040	2.0
2	iESA Product Assurance Plan (PAP)	HelioS-PL-20210-IRAP-099	2.1
3	iESA cleanliness and contamination plan	HelioS-PL-20210-IRAP-115	1.0
4	iESA Instrument specification conformity and verification matrix	HelioS-LI-20200-IRAP-118	1.0
5	HelioSwarm Environmental Requirements Document	HS-2003-PREL-SE-REQ-ERD	2025-02-28

Reference Documents (RD)

RD	Title	Reference	Version
1	iESA Instrument Technical Specification	HelioS-SP-20000-IRAP-041	2.0
2	iESA Product tree	HelioS-MG-10000-IRAP-046	2.0
3	iESA FMEA (Failure Mode & Effect Analysis)	HelioS-MG-10000-IRAP-158	1.0
4	iESA Instrument Critical Item List (CIL)	HelioS-MG-10000-IRAP-173	1.0
5	iESA Documentation Management Plan	HelioS-MG-10000-IRAP-125	1.0
6	iESA FPGA Board specification	HelioS-SP-203401-IRAP-014	2.0



List of Abbreviations

AD	Applicable Document
AIT/AIV (AIT/V)	Assembly, Integration & Test/Verification
CEM	Channel Electron Multiplier
CNES	Centre National d'Etudes Spatiales
DDVP	Design, Development and Verification Plan
DPU	Digital Processing Unit/ iDPU
DRB	Delivery review Board
EBOX	Electronics box
EM	Engineering Model
ESA	European Space Agency
FDIR	Failure Detection, Isolation and Recovery
FEE	Front End Electronics
MAG	Flux Gate MAGnetometer
FPGA	Field Programmable Gate Arrays
FOV	Field-of-View
HK	Housekeeping
HS	HelioSwarm
HV	High Voltage
HVPS	High Voltage Power Supply
iESA	Ion ElectroStatic Analyzer
IRAP	Institut de Recherche en Astrophysique et Planétologie
I&T	Integration & Test (= AIT/V)
LAB	Laboratoire d'Astrophysique de Bordeaux
LPP	Laboratoire de Physique des Plasmas
LVPS	Low Voltage Power Supply
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
PFM	Proto-Flight Model
PU	Processing Unit
RD	Reference Document
S/C	Spacecraft
SCM	Search Coil Magnetometer
STM	Structural and Thermal Model
TBC	To Be Confirmed
TBD	To Be Decided
TRR	Test Readiness Review
TRB	Test Review Board



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1. INTRODUCTION

The goal of this document is to define the Assembly, Integration and Test activities of the iESA instrument.

This document is based on the following documents:

- Development plan [AD 1] and associated documents
- Product assurance plan [AD 2]

The purpose of the Assembly Integration and Test Plan is to define the set and sequence of activities of Assembly, Integration and validation which must be carried out for each model.

Furthermore, this document gives a wide glance on:

- each team member responsibility within the I&T activity,
- preliminary description of activities
- sequence of the activities
- estimated duration of each activity (task sheet)
- assembly and integration principles
- tests and verification activities
- the applicable models
- facilities descriptions
- the main ground support equipment (GSE) needed
- Logistics (transportation, storage, ...).

This document describes all I&T activities at IRAP before formal delivery to CNES.



2. INSTRUMENT OVERVIEW

2.1. iESA Hardware description

The iESA design is based on a top-hat electrostatic analyser design, which is composed of two concentric hemispheric plates for ion energy-per-charge selection. Such a design permits fine focusing onto the detectors at the analyser exit, in accordance with the requirement for high angular resolution measurements. The outer hemisphere potential is set to ground while the inner sphere potential varies according to the particle energy-per-charge to measure. The elevation angle selection is performed thanks to high voltages applied on deflector plates at the entrance of the analyser. A collimator is used between the deflectors and the top-hat entrance to perform the required energy and angular (in elevation) resolutions, while the azimuthal resolution is obtained through appropriate sectorization of the detectors and anodes.

iESA can be divided into two main units: the detector unit and the electronics unit. The detector unit first comprises the entrance deflectors which allow to sweep overlook angles $\pm 24^\circ$ in elevation out of the main detection plane (with 3° angular binning). The collimator is then used to provide the required energy resolution (8%) and angular resolution in elevation angles (3° as well). Deflected and collimated ions are then subject to energy-per-charge (E/Q) selection through the analyser and focused onto the main detection plane which comprises 16 channel electron multipliers (CEMs). These perform a 107 gain in charge collection (thanks to electron avalanching following the impact of ions on the entrance of CEMs) on anodes with a 3° resolution in azimuth over an angular range of $\pm 24^\circ$ as well. The CEMs are made in pairs by our provider, meaning that there are 8 CEM pairs in the azimuthal plane.

The high voltages required for the analyser, deflectors and CEMs are provided by a dedicated High Voltage Power Supply (HVPS) board. The anode signals will be amplified by 16 AMPTEKs A121 (a strong-heritage component that is currently flying on the Solar Orbiter PAS instrument for example), placed on the Front-End Electronics board (FEE) nearest the CEMs, and transmitted to counters FPGA board. The FPGA will also control most functions of the instrument (HV sweep, data formatting, etc.). Finally, iESA also comprises a Low Voltage Power Supply (LVPS) board.

All these subsystems can be identified in the analyser design, block diagram and mechanical view of the instrument. **Figure 1** shows the instrument block diagram.

iESA main units:

- The top hat (Analyzer) constituted with deflectors, collimator and the main detection plane with CEMs.
- The EBOX (Electronics box) is composed of 4 electronics boards interfaced with one mother board
 - ➔ The LVPS (Low Voltage Power Supply) generates the secondary voltage to iESA subsystems.
 - ➔ The FPGA Board contains iESA intelligence: the FPGA board manages the communication with iPDU through a redundant Space Wire link, drives all the iESA subsystems, manages the data processing and digitizes the EBOX housekeeping. One thermal sensor is read by the Spacecraft.
 - ➔ The HVPS Board manages the High Voltage system of the Top-Hat spherical concept.
 - ➔ The Front-End Board manages the counting of the science after the CEMs to be transmitted to FPGA.



Figure 1: iESA block diagram

2.2. iESA Embedded FPGA description

Refer to FPGA specification ref. HelioS-SP-203401-IRAP-014 [RD6]

The FPGA board is the central control monitoring and processing system in iESA. All iESA activities are triggered by commands sent by the spacecraft, through the iDPU, to iESA where they are received and processed by the FPGA.

The FPGA firmware is based on a wishbone bus architecture to interconnect the several functional blocks. SpaceWire commands are received via the SpaceWire controller and core block and then routed to the appropriate block via the wishbone interconnect.



iESA FPGA Architecture Diagram rev. 1

Figure 2: iESA FPGA Architecture

2.3. iESA Product tree

Refer to Doc. “Product tree” ref. HelioS-MG-10000-IRAP-046 V2.0 [RD 2]



2.4. iESA Interfaces

2.4.1. Mechanical interfaces

iESA is accommodated on the Hub satellite

Figure 3: iESA accommodation on the Hub (preliminary)

2.4.2. Electrical interfaces

Refer to EICD ref. HelioS-ICD-20300-IRAP-010 [AD 4]

The electrical interfaces between the iESA instrument and the spacecraft are the following:

- The Primary Power and Return bus via connector J01.
- Command and Data – Nominal bus via connector J02.
- Command and Data – Redundant bus via connector J03.
- (Red-tag element) HV air-safe plugs/control lines via connector J04.

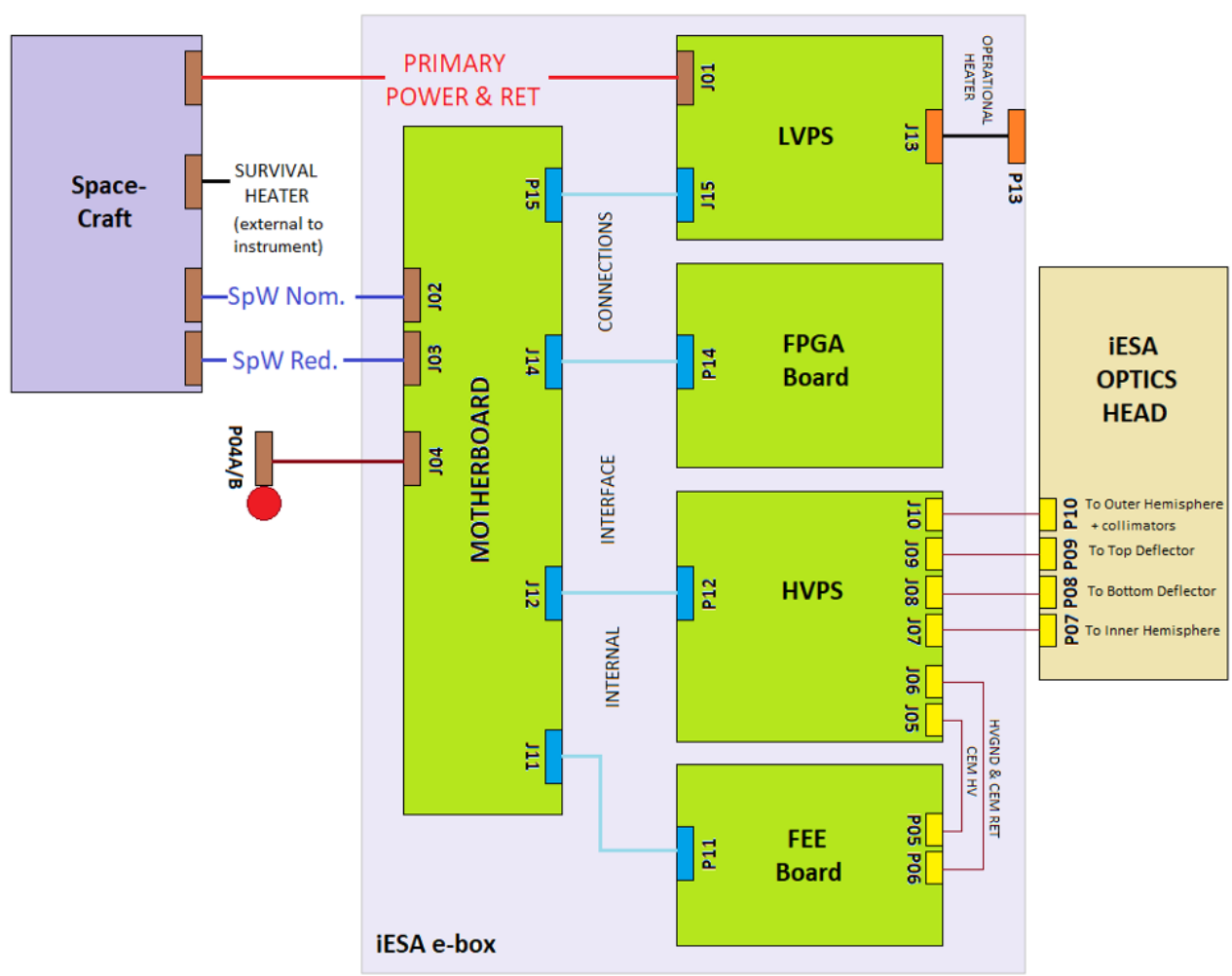


Figure 4: iESA External and internal electrical interfaces

2.4.3. Thermal Control System

At the time being, there is no specification for thermal control lead by the iESA architecture.

3. ASSEMBLY, INTEGRATION AND TEST ACTIVITIES

Each iESA subsystem will be pre-tested and critical components qualified. These include detectors, optics, electronics etc. LAB and UNH will deliver tested and calibrated subsystems (FEE, FPGA and LVPS boards). As currently scheduled, these activities will be carried out in parallel to ensure delivery schedules are met. These will then be delivered for instrument level integration at the lead institute (IRAP), where functional and pre-calibration tests will be carried out.

The pre-calibration tests are done to ensure that any problems relating to the condition of the instrument are resolved before full calibration and environmental tests are carried out.



The iESA instrument will be structurally tested (vibrations, shock), thermally tested (thermal vacuum cycling) and EMC tested. These tests will be performed at qualification or acceptance level, depending on the model.

Final tests of flight hardware at IRAP, before delivery to CNES, will be conducted in an ISO 7 or better cleanroom.

Instrument AIT/V include access to external test facilities for IESA that have been properly planned and budgeted.

The final set of tests will involve the full calibration of IESA before delivery to the Prime for S/C system level testing, with full assistance and guidance from UNH system engineers/PI office.

Verification will be achieved by tests, analysis, design or a combination of those if necessary. The requirements on both functions and equipment will be analyzed in the very early stages of the project within the IESA I&T team. Each requirement will be fully traceable through either an analysis document or a test procedure.

3.1. iESA Model Philosophy

In accordance with the development Plan [AD1], the model philosophy is described for the following items:

STM	Non-delivered Mechanical instrument qualification and sub-systems mechanical and thermal qualification (CEMs)
EM	Non-delivered Electrical architecture validation + Calibration + EMC qualification
Instrument Simulator	Delivered to NG
PFM	Delivered to NG Complete Proto Flight level Acceptance tests
FS	Spare Sub-systems kits

3.2. Testing, Verification and Qualification

The primary objectives of testing, verification and qualification activities are to demonstrate that:

- The design fulfills all the required performances and passes HelioSwarm mission environment tests successfully.
- The deliverable (P)FM is representative to the as-built status of the qualified hardware, and is free of workmanship failures, performs as required, and therefore is acceptable for flight.



3.3. Test Levels

A summary of the test levels to be applied for the iESA program is provided in the following Table

	EM	STM	(P)FM
Mechanical	N/A	Q	A
Thermal	N/A	(*)	A
Performance	T (Ion beam Calibration)	N/A	T (Full Calibration)
EMC	Q	N/A	A

(*) Thermal Balance only

Test – T

The Test program will be applied to test the model functionality.

Qualification Program - Q

The qualification program will demonstrate that the selected design in combination with the parts, materials and processes used in manufacturing the model submitted to qualification tests, meets the requirements specified in [AD5].

Acceptance program – A

The acceptance program will demonstrate that the design, in combination with the parts, materials and processes used in manufacturing the model submitted to acceptance test, meets the requirements specified in [AD5].

3.4. Verification Matrix

Refer to iESA Instrument specification conformity and verification matrix ref. HelioS-LI-20200-IRAP-118 V1.0 [AD 4]. I&T is concerned by the inspections and tests for verifying/validating and/or qualifying the instrument and subsystems.

3.5. iESA I&T flows

The I&T plan is written at this stage with preliminary details for integration and test. The I&T plan includes the preliminary flowcharts which will define the interactions between the actors of projects and the activities sequences.

Refer to Chapter 9 for the I&T flows of models.

3.6. Model representativeness with PFM

	STM	Simulator	EM	PFM
Mechanical I/F	Post PDR design	None	PDR+ design	Total
Mass	Post PDR design	None	PDR+ design	Total
Center of inertia	Post PDR design	None	PDR+ design	Total
Thermal behavior	Post PDR design	None	PDR+ design	Total
CEMs	Flight-like	None	Flight-like	Total
Functionality	None	CTL/CMD @ PDR	Flight-like	Total
FPGA code	None	Typical PDR design	Flight-like	Total
performance	None	None	First calibration	Total



4. ORGANIZATION AND MANAGEMENT

4.1. I&T interface with iESA Project

The I&T Manager interfaces directly with the Project Manager via normal communication (daily phone call, proximity to offices, weekly progress meeting, etc....).

In addition, the Project Manager, are invited to the weekly/daily I&T meeting (depending on the I&T sequence and multiple activities at the same time).

Whenever it is useful the architect (s) and / or responsible for the appropriate sub-systems can participate in the weekly/daily meeting of the I&T.

The main functions of the Architect, or the person in charge of a dedicated subsystem are:

- Write test requests and/or test plans
- Read and validate I&T procedures
- Provide support to I&T activities
- Validate the test results provided by I&T

4.2. I&T Human Resources

To perform all I&T activities for iESA instrument, a dedicated team together with support personnel, will be set as following:

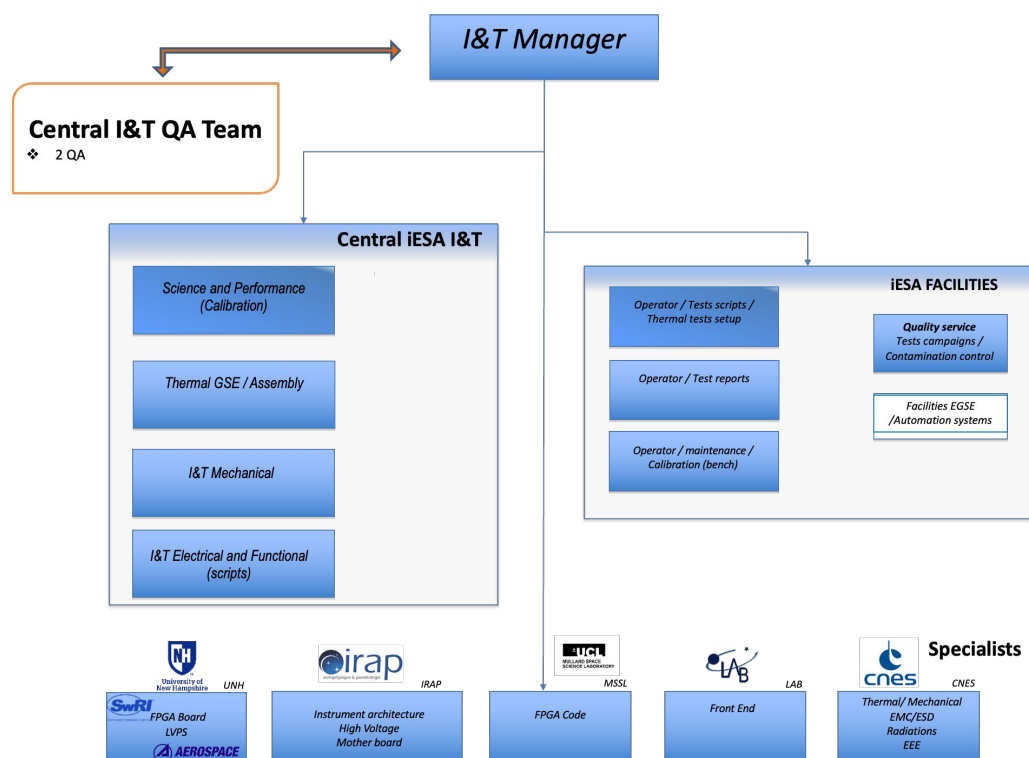


Figure 5: AIT/V organization chart



4.2.1. I&T Manager

I&T Manager oversees the integration & overall verification of iESA instrument.

He performs the following duties as a manager:

- Interface with iESA Project
- General planning of I&T tasks
- Evaluation of detailed integration, tests & verification procedures and reports
- Coordination among participating organizations
- lead role in organizing environmental tests
- participation in I&T reviews lead by QA (BT, CRE, etc....)
- management of I&T documentation with I&T QA
- Clean rooms management
- I&T risk management
- Management of I&T actions
- Communicating with PA manager about non-conformities and anomalies

4.2.2. Central I&T Team

The Central I&T team shall consist of an IRAP dedicated I&T team with a Science and Performance engineer for iESA CEMs and instrument Calibration, Mechanical engineer, an electrical and functional verification engineer, and a thermal-vacuum technician. The team shall be responsible for:

- development of integration & test procedures
- inspection of delivered items (under QA supervision)
- writing & implementation of procedures
- operation & maintenance of GSE

This team is located @ IRAP and may move to different sites where are done the integration and test activities.

There are linked with all architects and specialists (Mechanics, Thermal, EMC, Radiation, etc...) for maximum mutual understanding and flexibility.

1.1.1. Central I&T QA Team

The Central I&T QA team is located @ IRAP and under functional responsibility of I&T Manager and in coordination with PA/QA iESA Manager.

I&T QA's follow the overall I&T activities on the different sites and clean rooms. They are extremely mobile. In case an activity is mid or long term in another location, a dedicated I&T QA may be involved and dedicated to it. The intervention of I&T QA's is scheduled in advance and consolidated during I&T meetings.



4.2.3. Specialists supporting and advising I&T team

The specialists (architects, designers and experts) are clearly identified here after. They are invited to give their support and validate the results obtained by the I&T team.

All the specialists are solicited through the flow chart of iESA models. The I&T Manager is communicating with the organization whom the specialist is belonging. The intervention of specialist is scheduled in advance and consolidated during I&T meetings.

4.2.4. Electrical integration and functional verification engineer (EIFV)

The EIFV engineer:

- Prepares iESA electrical integration and functional verification activities: procedures preparation in accordance with Integration process and V&V Plan provided by the Project Manager
- Coordinates and executes the electrical and functional activities.

The electrical integration supports oversee the preparation and the execution of the activities, according to the organization setting up.



4.3. I&T Quality Assurance

Quality assurance (QA) shall prove that the system is compliant with the procedures established and specified in the I&T Plan during all phases. He assures the processing of all non-conformances until handover to CNES.

During I&T activities, QA representative takes part in controlling the processes by:

- Configuration support for hardware evolution and traceability,
- Coordination problem resolution activities,
- Assuring that incoming supplies and components meet the requirements,
- Coordinating the documentation preparation for the delivery to the customer.
- Performing QA controls and inspections during I&T activities, on documentation and hardware production.

All the activities, perimeter and responsibilities of the QA management are fully described inside the [AD2].

4.4. Interface between Equipment / Subsystem Suppliers and IRAP I&T

Interfaces are globally detailed in the Management Plan document.

During preparation phase, each equipment or subsystem supplier (UNH, MSSSL, LAB) provides the necessary entries (tests requests, specific GSE, ICD/MICD, etc...).

During iESA I&T phase, each equipment or subsystem supplier provides the necessary support for the I&T team during the integration, validation of interfaces and functional tests. The presence of competent staff is scheduled in advance in consultation with the I&T Manager. Minimum notice is required.

Before each delivery, the equipment or subsystem supplier is responsible of a stand-alone test with adequate results, and safe to mate tests on the concerned equipment or subsystem. DRB meeting is considered successful when handover from supplier to IRAP is accepted.

For each test, each equipment or subsystem supplier is involved in the test report, data analysis, results interpretation and conclusion of the tests.

For those iESA IRAP tests impacting the Supplier Qualification program (test coverage for example), a dedicated request from supplier to IRAP must be transmitted prior to TRR to be sure of test configuration, test scheduling and adequate data collection.



5. I&T ACTIVITIES

5.1. I&T Activities training program

Before the beginning of the I&T, anyone wishing to have permanent access to the cleanroom must attend a cleanroom training session.

5.2. I&T Reviews

The following reviews & meetings will be held to coordinate I&T activities, depending on the situations and activities. Here is given a light description of each expected reviews.

In integration and tests phase, planning is updated every week, considering activities already done, non-conformances management and new information.

5.2.1. Internal Progress Meetings

These meetings will be held on a daily and/or weekly basis and be chaired by I&T Manager.

Weekly meeting

During integration and testing, the different I&T contributors in different locations need to have mutual understanding and knowledge of the I&T activities recently done or to be expected. A weekly meeting of the I&T will be organized to:

- Brief of the planned tasks for the current week, incidents, problems and backup proposals
- Remind the activities and resources engagement, reorganize in case of reconfiguration
- Anticipate the short/mid-term activities with a dedicated TO DO LIST (date and responsibility) shared between IRAP and all I&T community

The duration of this meeting should be 2 hours max and involve:

- The I&T Manager and, when necessary, dedicated central I&T and QA people
- The IRAP and/or LAB representative and, when necessary, dedicated architects and designers
- The UNH representative when necessary
- The MSSL representative when necessary
- The CNES experts when necessary
- A representative of the project

Some other participants may be invited by I&T like EMC/Mechanical/Thermal specialists depending on the short-term activities.

Daily meeting

During integration and testing, the daily meeting of the I&T is organized as a quick routine in front of a whiteboard to:

- Brief of the activities of the day before, the tasks to be performed during the day, incidents and problems,
- Confirm or reorganize the activities initially planned for the current day,
- Anticipate the activities planned for the next day.

The duration of this meeting must be short (approximately 15 minutes, and involve the minimum number of people:

- The I&T manager
- One or more people from the I&T team
- I&T Quality Assurance community
- Dedicated specialist as necessary for the topic of the day
- A representative of the project (when available)

5.2.2. Integration Reviews and Test Reviews (TRR & TRB)

Refer to Product Assurance Plan [AD 2]

Integration reviews are held prior to the activity. This is to verify that all the tools, documentation and people are available and correctly equipped for these activities.

Main quality reviews are held prior, and after each environmental test. They aim to ensure quality control of those activities.

Refer to ECSS-E-ST-10-03 for more details.

5.2.3. Activities for each model

For each model, the I&T management is the same:

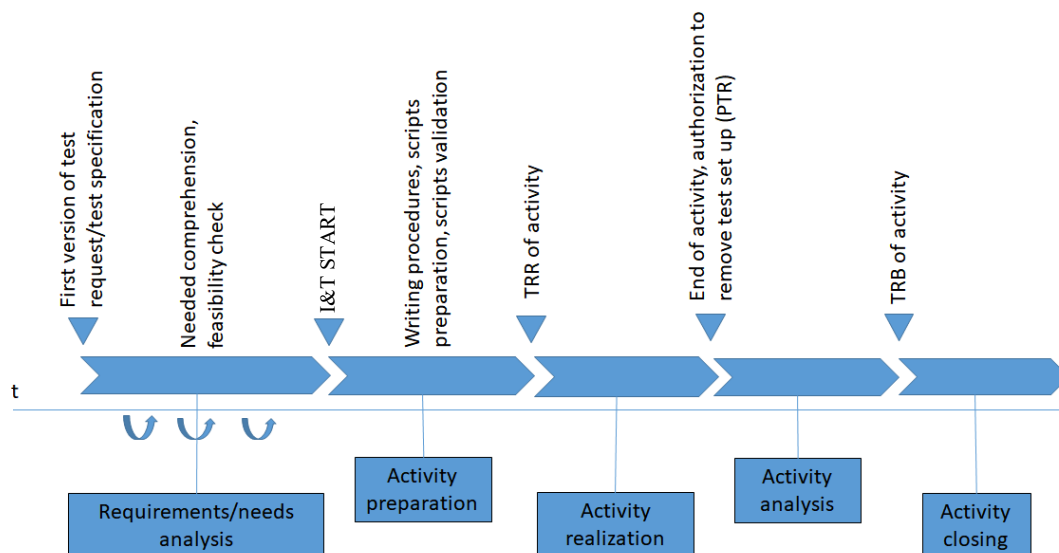


Figure 6: Activities workflow

5.2.4. Incoming inspection for I&T

An incoming inspection performed by I&T shall achieve the handover completion at IRAP side. Sometimes, few delivery acceptance topics are expected to be closed during the incoming at IRAP.

The incoming inspection is described in the PA plan [AD 2].



5.3. I&T Risk management

5.3.1. Risk evaluation

The major risks linked to the activities described in the procedures can be anticipated during TRR meetings.

During these meetings, all the concerned people participate in the risk assessment like system engineer, I&T engineering, I&T manager, equipment or subsystem managers, architects and QA. It can be done prior to TRR through System risk management routines lead by the Project manager.

5.3.2. Actions for risk mitigation

During the Test Requests (“Demandes d’essai”) review sessions, actions will be taken between all stakeholders to adapt the test to keep the objectives of the requested test at reduced risk in I&T.

During the reviews of procedures, each time a major risk is identified, an action must be defined to reduce this risk. These actions will be carried out upstream or during the “at risk” classified activity. The I&T QA must ensure that these actions are carried out and achieved correctly. To do this, a QA Key Point with dedicated operator will be included in the integration procedures.

The human risks identified for iESA I&T, considered as Major, are:

- Risk of anoxia (nitrogen) during environmental tests
- Risk of Electrification during High Voltage electronic board tests

The material risks identified for iESA I&T, considered as Major, are:

- Risk of contamination of CEMs
- Risk of mechanical issue of the Analyzer and connections with EBOX
- Torsional fragility and crushing of the wired inserts
- Risk due to High Voltage threat

More globally, refer to Risk Analysis Assessment driven by PA Management.

Refer to FMEA document ref. HelioS-AN-20220-IRAP-158 V1.0 [RD 3]

Refer to CIL ref. HelioS-LI-20200-IRAP-173 V1.0 [RD 4].

6. I&T DOCUMENTATION

6.1. Documentation diagram

The documentation organization is described in the diagram below. All documents produced by the project shall be reviewed and approved by both Project & PA Managers and Architect as necessary.

The recommended method for the preparation of these documents are defined within PA plan [AD2].

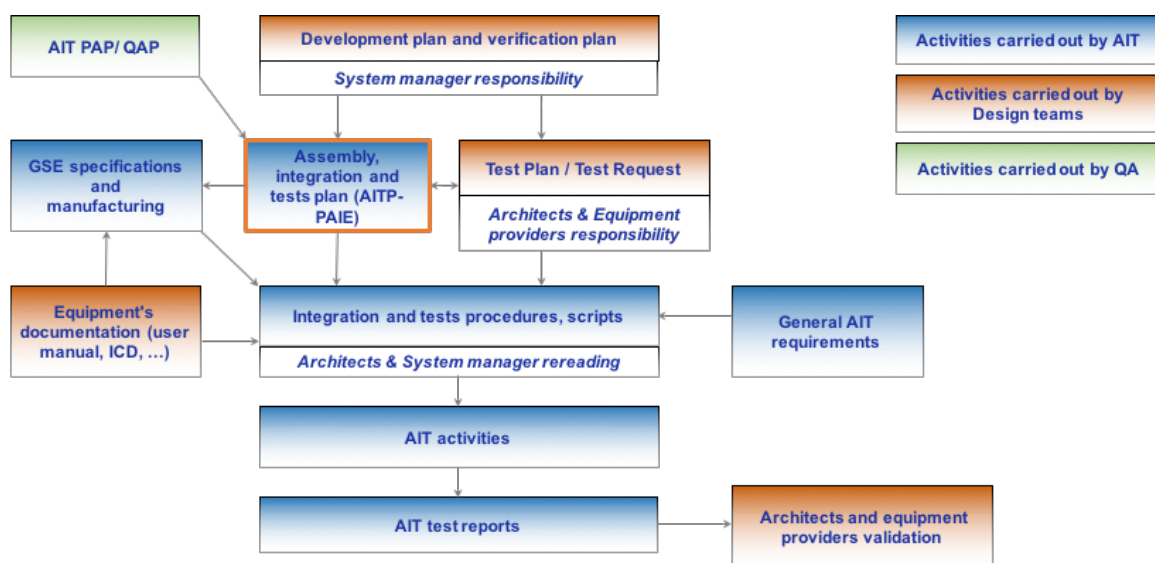


Figure 7: I&T documentation diagram

All documents described above, except scripts and investigation test reports, are written and checked in the sDrive tool.

The following process will be followed for each model.

Refer to iESA Documentation Management Plan ref. HelioS-MG-20100-IRAP-125 V1.0 [RD 5]

6.2. Specification documentation for Tests

6.2.1. Test Specifications or Test Plans

Test Specifications / Test Plans are provided by architects and/or System Manager. They answer the Verification Matrix considered as the one entry document from the project.



They are used by the I&T team to:

- Analyse its feasibility (I&T constraints considered)
- Optimize the test sequence
- Develop basic specifics ground means (test-aid that are not the responsibility of instrument team like Break Out Box)
- Write test procedures and scripts

Each Test Specification / Test Plan contains tests sheets (for health check, functional test, performance test, ...) that include:

- Purpose of the test
- Initial and final configurations
- Method and steps
- Measured parameters, measurement precision
- Expected values, success criteria
- Environment, constraints

Test Specifications / Test Plans could have impact on design, so it needs to be discussed early! Regular meetings are necessary if the requested tests are complex.

6.2.2. Test Request (Demande d'essai)

Test Requests are outside the general framework of documents described above. These requests may come from:

- Treatment of "non-compliance"
- Specific needs for confirmation of a performance of an equipment/ functional channel/other need which it is not possible to identify before.

In that case, it is possible to request other tests by writing a Test Request (TR). This TR is validated by System Manager and then subjected to the I&T Manager to include it in the I&T planning.

Test Request is generated through a JIRA ticket for the I&T.

6.3. Operational documents

6.3.1. Integration and Test Procedures

Integration & test procedures are written by I&T team. Consistency between procedures and Test Specification / Test Plan should be checked. Each procedure is approved by PA. All procedures should be analyzed before their implementation to identify "critical" or "at risk" operations.

For these operations, risk reduction actions may be required.

They contain at least the following information:

- The identification of the iESA sub-system to be tested
- The identification of the system configuration
- The purpose of the procedure
- The initial configuration



- The final configuration
- Description of the GSE and measuring equipment
- People in charge of the execution and their responsibilities
- The applicable documents
- Environmental conditions and safety
- The criteria for success or failure

6.3.2. AS-RUN

The procedure run is called an As-run. Each time the procedure is run, an As-run is created. Each As-run has a unique identifier.

So, an as-run is the document completed by the I&T team during the I&T activities. Each as-run must be run from an already approved procedure.

Once the As-run is completed, the as-run is duly signed.

6.3.3. PRAS (Special Activity Procedure)

This combined Procedure/AS RUN is unique and is not to be run twice. Therefore, the format is a little bit different from the integration and test procedure described above. PRAS is performed each time one or more non-planned tasks are identified before performing the job. For example, this should be identified during a TRR or at the very beginning of an I&T activity.

A template for iESA is in progress.

6.3.4. Log-book & Historical Records

Historical Records will be established at the beginning of the activities and maintained current up to delivery to trace as extensively as possible the operations related to the fabrication & qualification of equipment.

In addition, a configuration list will be kept up to date to reflect the as-built status at any point of time. The QA representative or the I&T team shall keep the logbook updated.

A logbook will be constituted and kept up to date for each activity. iESA I&T will track all activities in the logbook. Usually, Logbook is using the Excel format.

6.3.5. Non-conformities report (NCR)

The NCR will be written in JIRA tool as stated in the PA Plan [AD2].

6.4. Test Reports

At the end of tests, the I&T team send the raw telemetries, if necessary, the tele-command logbook and the completed as-run, which contains at least:

- The synthesis of the results and their analysis if applicable
- The effective configuration of the EUT
- The deviations in the procedure
- The list of anomalies



- The test duration
- The environmental conditions (Temperature, hygrometry, Pressure for TVAC tests...)

7. GROUND SUPPORT EQUIPMENT

GSE will be used for assembly activities, integration and test activities, handling, transport, and storage. Some GSE will be specific to a model, some will be used for different models. In that case, depending on the mean, they can be ordered in multiple copies or not.

7.1. FACILITIES

7.1.1. Cleanrooms

The iESA instrument I&T activities will be performed in several cleanrooms at IRAP. IRAP has five clean rooms and several grey zones for instrument assembly at its disposal.

IRAP main clean room has the following characteristics:

- Number of ISO 7 classroom: 1
- Cleanliness: 10 000
- Temperature: 21°C +/-2°C
- Humidity: 50 % +/-10%

- Number of ISO 8 classroom: 4
- Cleanliness: 100 000 (with 3 work zones of ISO5)
- Temperature: 21°C +/-2°
- Humidity: 50 % +/-10%



7.1.2. CEMs Characterization test facility

IRAP has developed a CEM test facility for the PAS instrument on Solar Orbiter. This test facility will be used for the characterization of iESA CEMs.

7.1.3. Instrument Calibration test facility

Instrument calibration is a crucial stage of the development and I&T procedures. The calibration process is performed at IRAP in a large vacuum chamber using a realistic charged particle beam.

The calibration procedure consists of three main parts:

- Characterization of the detectors (CEMs), and critical parts like UV suppression systems, etc...
- Sensor calibration to verify its absolute and relative responses; make comparisons with numerical simulations results and numerical models.
- Full instrument functional test when the flight-mode operating instrument is checked under real particle beam conditions.

CALIPSO 1 has been developed and commissioned for the calibration of the Flight Spare of Solar Orbiter PAS.



CALIPSO 1 has been fully operational since the end of 2017. The PAS of Solar Orbiter spare model was calibrated with this equipment.

It has been adapted to the needs of iESA for the prototype and will be updated to the following model soon (to be ready with EM and PFM models).

The CALIPSO 1 (CALibration d'Instru-
ments Particules et Service d'Observation)
test facility at IRAP consists of:

- A large calibration vacuum chamber
- An electron gun
- An ion gun
- Smaller diagnosis instrumentation

CALIPSO 1



7.1.4. Test Facilities

➤ **Thermal vacuum TV/TB test facility**

The used facility must:

- Simulate and control the space environmental conditions of an instrument in flight, mainly in terms of vacuum and thermal properties
- Allow to control the instrument during thermal vacuum

The test facility is in a clean room of class ISO 7.

The setup includes:

- A vacuum chamber
- A pump system (primary + secondary)
- A plate at the interior
- A control/command system of the pumping and temperature regulations

Technical figures:

Pressure in the chamber:	10 ⁻⁷ mbar
Temperature range	173K (-100°C) to 373K (100°C)
Cooling system	Liquid nitrogen
Number of independent regulated thermal sinks	TBD
Ø chamber	100 cm mini
Height chamber	100 cm mini
Number of temperature probe channels	50
Precision 4-wires PT100 probes	0,1 °C

- ➔ All the thermal vacuum validation / qualification tests on the different parts or models of iESA will be performed with this chamber.



➤ **BAKEOUT facility**

The Bake out installation is in an air-conditioned test room equipped with a mobile laminar flow hood (ISO 5).

The BAKEOUT installation must have the following purposes:

- Outgas components under vacuum within the temperature range [21; 160] °C
- Measure the outgas level using a TQCM microbalance, in conformity with the norms ECSS-Q-TM-70-01C of ESA and ASTM-E595 of the NASA.

The installation contains:

- A vacuum chamber (parallelepiped) with a minimum volume of about 50 L
 - o The chamber can be equipped with multiple shelves.
 - o The back part contains the essential part of the junctions (pumping, cryogenic cold trap @9K, TQCM balance and electric cable feed through).
- A pumping system (primary + secondary) build out of:
 - o A primary pumping group, dry, with a Roots level
 - o A turbo molecular pump
- A 2 stages Cryo generator
- Multiple security devices for heating of which one autonomous system based on a contact opening thermostat.
- A control/command system for the pumping, temperature regulations during heating and TQCM microbalance steering (real time analysis of success criteria)

➔ The bake-out of the iESA EBOX will be performed in this chamber type.

7.1.5. Mechanical Test Facilities

To validate the mechanical environment several facilities will be used:

- Shaker for vibrations and Shock test bench



7.1.6. EMC Test Facilities

To perform the EMC test, an anechoic chamber is needed, with standard EMC tools (network analyzer, spectrum analyzer, antenna, amplifier, ...).

Test	Test method
Bonding measurements	As applicable
Conducted emission on (secondary) power lines – time domain, in different operating modes (incl. detector ON)	Current emission on power lines with oscilloscope (differential mode, range 30 Hz - 20MHz)
Conducted emission on signal lines	Current and voltage emission on signal lines (differential mode, range 30 Hz – 20 MHz)
Conducted susceptibility on (secondary) power lines – time domain	Noise/signal injection on each individual secondary supply line (differential mode, range 30 Hz – 20 MHz)

7.2. SPECIFIC MEANS

7.2.1. MGSE (Mechanical Ground Support Equipment)

- Mechanical interface baseplate for iESA vibrations campaigns
- Mechanical interface baseplate for iESA shock campaigns

7.2.2. Thermal and/or vacuum GSE

- Mechanical interface baseplate for iESA CEM characterization in CALIPSO.
- Mechanical interface baseplate for iESA instrument calibration in CALIPSO 1.
- Mechanical interface baseplate for iESA thermal vacuum tests campaigns in TV/TB chamber.

7.2.3. EGSE (Electrical Ground Support Equipment)

The EGSE for iESA Instrument, developed at IRAP will be realized to fulfil the following tasks to support:

- 1) Tests at iESA integrated instrument before the integration in the S/C
- 2) Alignment, testing and calibration of iESA. This setup shall be used during the complete iESA integration and performances tests
- 3) Mother board (Big) to perform tests with boards on the workbench (non-integrated yet)

7.2.4. Software GSE

- SGSE developed for sequencer (HelioSwarm Studio)
- SpaceWire Mk4 module (USB ↔ SpW)
- FPGA module (simulator)



7.2.5. Transportation Container

Instrument will be shipped in dedicated container with temperature, hygrometry and shock detectors, and filled with N2 or sealed into double sterile bag with N2 environment as necessary.

- 1 container dedicated for STM

➔ Refurbishing from a previous instrument project (expected from DORN project)

The iESA Instrument will be mounted on a baseplate. This baseplate will be rigid to preserve the devices shape but will be damped thanks to an appropriate damping system.

The maximum accelerations will not exceed ± 10 g at the devices level on the baseplate

The Figure 7 describes the electrical connection to the ground during transportation and at the opening of the iESA container.

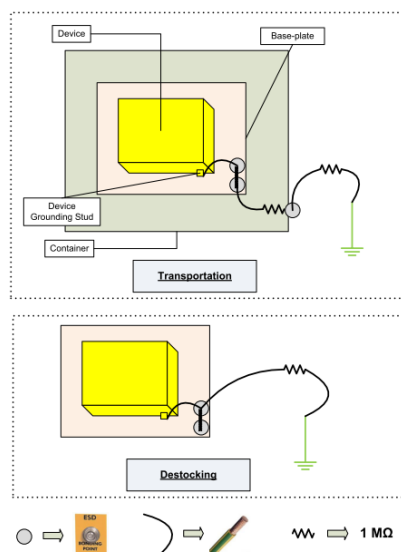


Figure 8 - iESA container Electrical connection



- 1 container for EM model
 - ➔ For all the tests campaigns
- 1 container for PFM model
 - ➔ Delivered to NG

7.2.6. Miscellaneous equipment

- Test-Aids Harnesses

Specific harness dedicated to the tests must be foreseen if they aren't defined in the Electrical ICD document. They will be provided by the Electronics team. Specific harnesses are **TBD**.

- Integration tooling

Screwdrivers with appropriate torque tightening are available at IRAP cleanrooms to assemble the iESA mechanical parts.

The screwdrivers torque is controlled with a calibrated Torque Wrench Line Checker from 0.1 up to 20 N.m.

- Handling devices

For the integration of the top Hat, CEMs and EBOX for EM and FM models.

- Connectors Savers & Protecting connector plugs
- Break out boxes



8. I&T ACTIVITIES PLANNING

8.1. Project schedule

Schedule is managed at project level. I&T Manager is participating in reviewing the schedule with the complete project team. During the I&T phases, engagement of resources and means may be very dynamic, in that way schedule information is challenged very often. In case of NCR during I&T that could impact any kind of reconfiguration or rearrangement, dedicated review can be set in place.

The project planning is reviewed regularly and is a very useful help in decision for I&T forecast.

8.2. I&T Resources engagement vs Activities

To manage correctly the resources that could intervene on several locations, for different I&T skills and especially with mobility of staff, it has been identified that a dedicated tool (simple and easy to follow) must be set in place.

This tool should be useful during I&T weekly meetings as a reminder for staff to organize the 2-3 coming weeks.

I&T WEEKLY MEETING			Week -
Participants			
IRAP XXX XXX XXX XXX	LAB XXX XXX	EXTERNAL ORGANIZATIONS XXX XXX	API/AQ XXX XXX XXX
Architects, Designers and Specialists XXX - EMC XXX - Thermal XXX - Mechanics XXX - EMC XXX - Science		Other participants	
What happened last week (Wk-1)			
Green flags Red flags 			
Forecast AIT/V			
Activities Wk+1	Activities Wk+2	Activities Wk+3	
TRR, TRB, KIP, MIP	TRR, TRB, KIP, MIP	TRR, TRB, KIP, MIP	
Documents in preparation	Documents in preparation	Documents in preparation	
Procurement status	Procurement status	Procurement status	
HR QA AIT/V SPE	HR QA AIT/V SPE	HR QA AIT/V SPE	

Figure 9: Weekly meeting template

Example of a practical tool in Excel with upcoming days in the background and movable “post-it” to adjust according to the activity and the available resources.

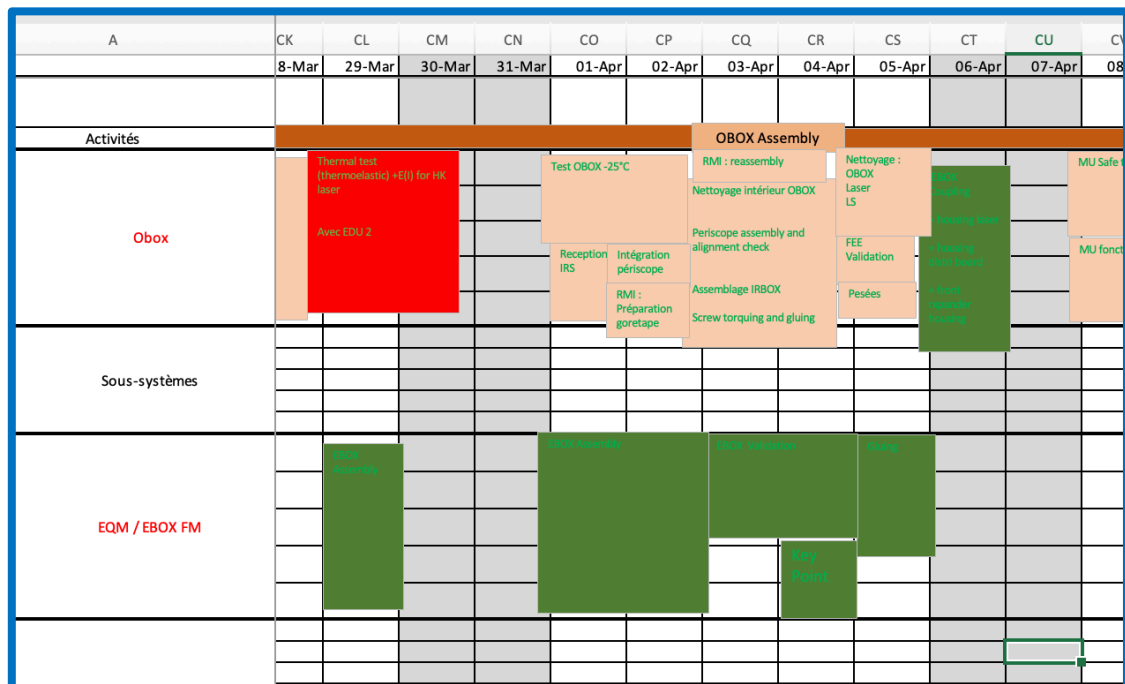


Figure 10: Excel tool for I&T activities within the current week



9. I&T IESA PRELIMINARY FLOW CHART

The I&T flow chart describes all activities that will be performed on iESA project. All these activities are identified with reference numbers and summarized in Activities Sheets.

The requested input, output, success criteria, objective of activities, environmental conditions and more generally all the elements involved are identified in the tests request.

All activities are deployed under a sequence of tasks. Each task must be described.

The flow is punctuated with usual milestones like TRR/TRB (BT/CRE) and dedicated QA ones (MIP/KIP/specific inspections).

Flow charts are developed for I&T activities related to the iESA instrument. Those flow charts are under the responsibility of IRAP I&T and released in coherence with the PAIE.

All the sub-units are tracked in the IRAP flow chart as they are part of the same process. The few specific actions for each sub-unit will be clearly identifiable.

As the iESA flow chart has many elements, it has been divided by models (STM, EM, PFM) for a better understanding.

The global philosophy for PFM Acceptance is as follows:

- LVPS Acceptance (prior or at the time of DRB)
- FPGA Acceptance (prior or at the time of DRB)
- FEE Acceptance (prior or at the time of DRB)
- HVPS & Mother board acceptance
- CEM Characterization / Selection
- EBOX Acceptance
- Top hat coupling and Alignment
- iESA Calibration / Performance
- Final iESA instrument Acceptance

For STM/ EM activities, flow chart is constantly improving with models.

Flow chart dedicated to PFM should be rearranged after CDR because PFM Acceptance activities should be led in different way.

Time and Resources (effort) in the following flows must be increased by 20% average to maintain an acceptable safety margin.



9.1. STM

N°	Activities
iESA-P1100	Pre-requisite activities <i>Pre-fit check of Top-hat analyzer has been done</i> <i>Dummy boards (with necessary component) have been procured and pre-assembled</i> <i>CEM Holder and Base plates already checked</i> <i>Treatment on parts already done (SurTec passivation)</i>
iESA-P1110	CEM integration – Holder assembly <i>Selection of CEM for STM already done</i>
iESA-P1120	CEM Holder assembly test before STM Qualif. campaign <i>Included installation and checks in CALIPSO</i> <i>Included CEM results analysis for STM go ahead</i>
iESA-P1130	STM Integration (with thermal and mechanical instrumentation) <i>Alignment included</i>
iESA-P1140	STM Vib & Shock tests (without MLI)
iESA-P1150	STM Thermal tests (without MLI) <i>Thermal Balance</i>
iESA-P1160	De-integration of STM, instrumentation removal, CEM Holder removal
iESA-P1170	CEM Holder assembly test after STM Qualif. Campaign <i>Included installation and checks in CALIPSO</i> <i>Included CEM results and trend monitoring (comparison with test performed before STM sequence)</i>
TOTAL	TASK EFFORT and CRITICAL PATH (35 days TBD)

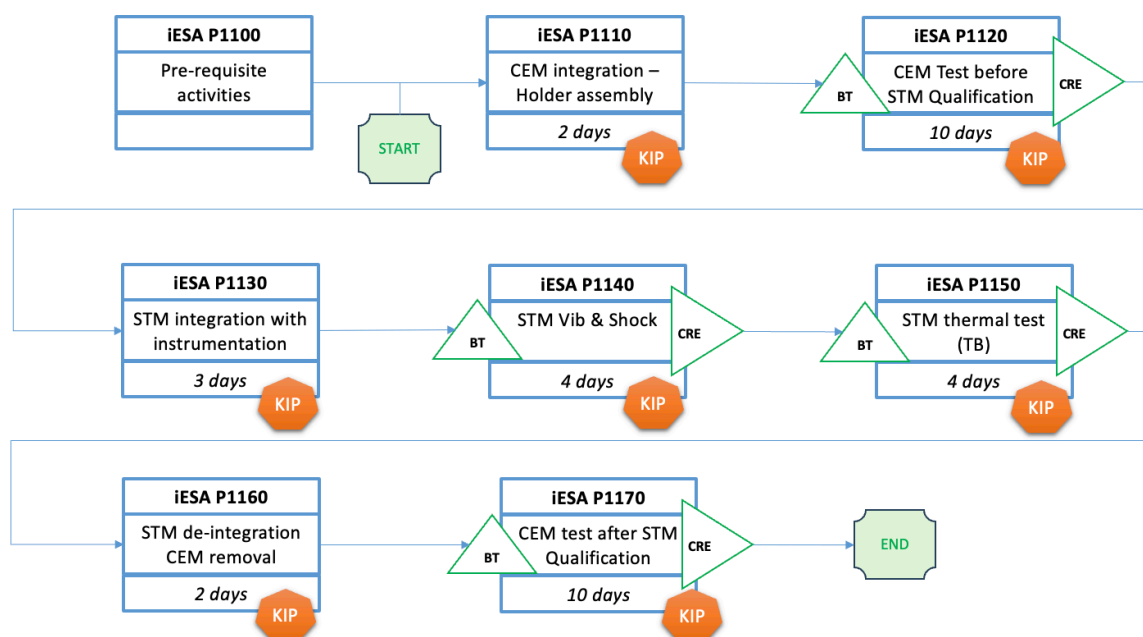


Figure 11: Flow chart for STM activities



9.2. EM

N°	Activities
iESA-P2100	Prerequisite activities <ul style="list-style-type: none"> - LVPS Board received/inspected & test accepted, cleaned/outgassed - PR-FPGA board (with code) received/inspected & test accepted, cleaned/outgassed - FEE Board received/inspected & test accepted, cleaned/outgassed - Mother board inspected/tested/cleaned/outgassed - HVPS board inspected/tested/cleaned/outgassed - Selected CEM for EM already characterized, ISO 5 - Top hat mechanically integrated, aligned (before integration on EBOX) - HV Harness already provisioned (continuity/insulation) / outgassed
iESA-P2110	CEM Holder assembly and health check, ISO 5 <i>Included installation and checks in CALIPSO</i> <i>Included CEM results analysis for EM go ahead</i>
iESA-P2120	Progressive Integration of boards step by step and electrical checks
iESA-P2130	EBOX test without CEM
iESA-P2140	FEE removal from EBOX and CEM integration on FEE
iESA-P2150	EBOX final integration and test with CEM in vacuum
iESA-P2160_1	Coupling Top-hat analyzer with EBOX and test in safe mode <i>Alignment check</i> <i>Reduced functional check in safe mode</i> <i>Outgassing the iESA instrument (Bakeout)</i>
iESA-P2160_2	iESA instrument test (vacuum) Functional check
iESA-P2170	Calibration of iESA EM <i>Before/After Health test / RFT/ FFT</i>
iESA-P2180	EMC test sequence <i>Before/After Health test / RFT/ FFT</i>
iESA-P2190	Post calibration retrofit and test <i>De-assembly + Retrofit + Re-assembly with NP-FPGA and test</i> <i>Before/After Health test / RFT/ FFT</i>
TOTAL	TASK EFFORT and CRITICAL PATH (total 115 days TBD) <ul style="list-style-type: none"> • I&T before CALIBRATION 45 days • CALIBRATION sequence 50 days TBD • EMC tests 10 days TBD • Post-calibration I&T 10 days

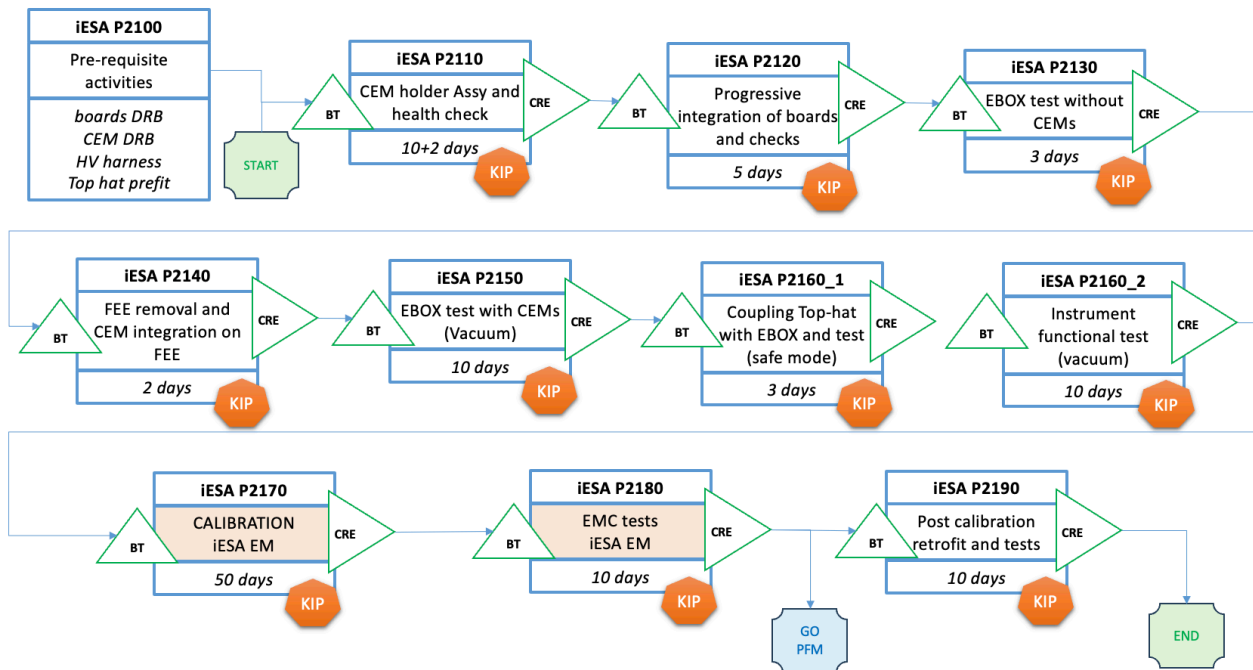


Figure 12: Flow chart for EM activities



9.3. PFM

N°	Activities
iESA-P31XX	To be achieved prior to CDR