HERMES

High Energy Rapid Modular Ensemble of Satellites

DM pre-qualification activities

Yuri evangelista – INAF-IAPS

Demonstration Model (DM) - #1
Subsystem level tests (DA + PCB mock-ups)
Qualification levels

Protoflight Model (PFM) - #1
Satellite level tests (PL + SVM)
Protoflight levels

Flight Models (FM) - #5
Satellite level tests (PL + SVM)
Acceptance

Demonstration Model (DM) - #1
Subsystem level tests (DA + PCB mock-ups)
Qualification levels

Protoflight Model (PFM) - #1
Satellite level tests (PL + SVM)
Protoflight levels

Flight Models (FM) - #5
Satellite level tests (PL + SVM)
Acceptance

Demonstration Model (DM) - #1

Subsystem level tests (DA + PCB mock-ups)

Qualification levels

Mechanical tests of most critical items/processes

Detector assembly

- FEM analysis of static and dynamic loads
- Random vibration test
- Thermal ambient cycling

Optical Filter

- Burst pressure test

Radiation analysis/tests of most critical items

Electronic stack

- Radiation analysis for “known” components (i.e. Cyclone V FPGA)
- Radiation tests of most sensitive, untested, components (e.g. HV DC-DC converter, others?)

Demonstration Model (DM) - #1

Subsystem level tests (DA + PCB mock-ups)

Qualification levels

Mechanical tests of most critical items/processes

Detector assembly

- FEM analysis of static and dynamic loads – RP slides
- Random vibration test – RP slides
- Thermal ambient cycling

Optical Filter

- Burst pressure test

Radiation analysis/tests of most critical items

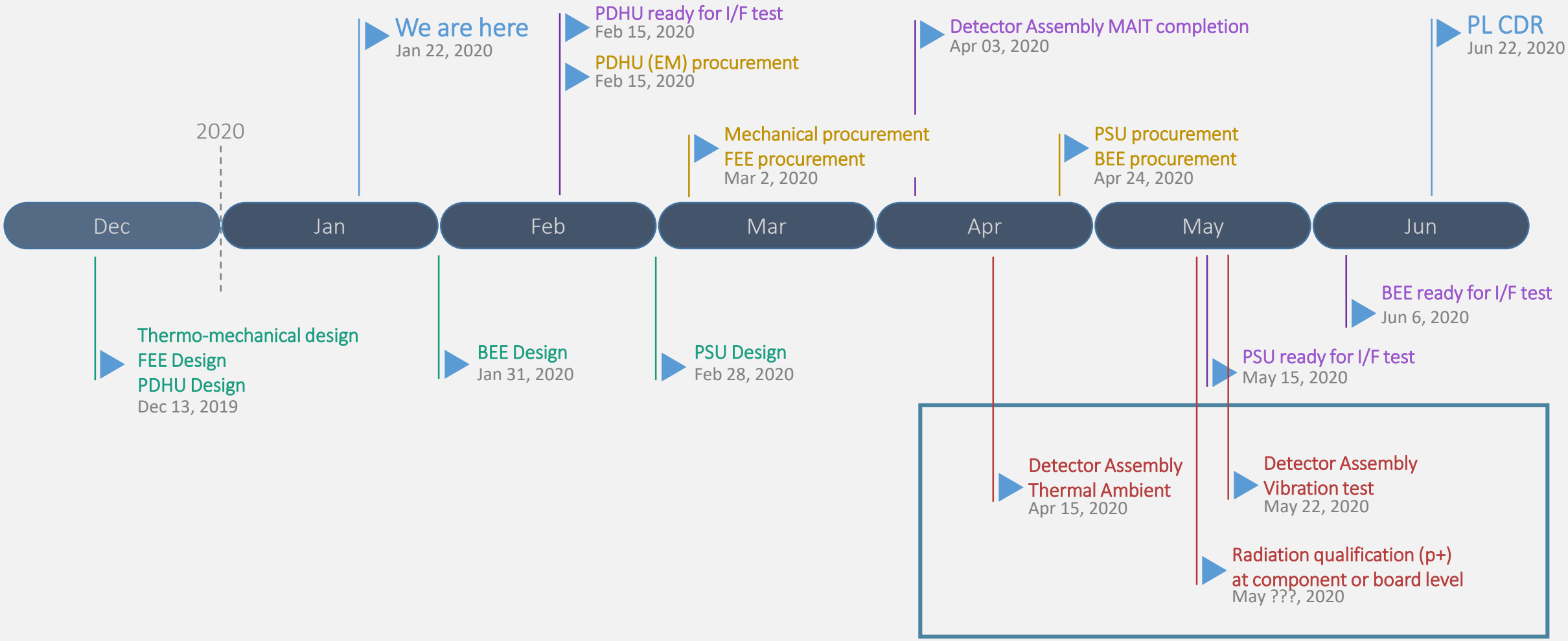
Electronic stack

- Radiation analysis for “known” components (i.e. Cyclone V FPGA)
- Radiation tests of most sensitive, untested, components (e.g. HV DC-DC converter, others?)

HERMES SCHEDULE

PRE-QUALIFICATION

HERMES
High Energy Rapid Modular Ensemble of Satellites



Assembly, integration and test plan (AITP)

A.1 DRD identification

A.1.1 Purpose and objective

The assembly integration and test plan is the master plan for the product AIT process. It describes the complete AIT process and demonstrates together with the verification plan how the requirements are verified by inspection and test.

It contains the overall AIT activities and the related verification tools (GSE and facilities), the involved documentation, the AIT management and organization. It also contains the AIT schedule.

It is one of the major inputs to the project schedule and is used to provide the customer a basis for review and evaluation of the effectiveness of the AIT programme and its proposed elements.

An AITP is prepared for the different verification levels covering in detail the AIT activities at that level and outlining the necessary lower level aspects.

The AITP is complementary to the verification plan. It takes into account the test standards defined in the Customer requirements.

The availability of the verification plan is a prerequisite to the preparation of the AITP.

A.2 Expected response

A.2.1 Scope and content

<1> Introduction

a. The AITP shall contain a description of the purpose, objective, content and the reason prompting its preparation.

b. Any open issue, assumption and constraint relevant to this document shall be stated and described.

<2> Applicable and reference documents

a. The AITP shall list the applicable and reference documents in support to the generation of the document.

<3> Definitions and abbreviations

a. The AITP shall list the applicable dictionary or glossary and the meaning of specific terms or abbreviations utilized in the document.

<4> Product presentation

a. The AITP shall briefly describe the selected models and their built status with reference to the verification plan (see ECSS-E-ST-10-02).

<5> Assembly, integration and test programme

a. The AITP shall document the AIT activities and associated planning.

b. The AITP shall include test matrix(ces) that link the various tests with the test specifications, test procedures, test blocks and hardware model.

c. Assembly, integration and test programmes including inspections, should be detailed through dedicated activity sheets.

d. Activity sheets shall include descriptions of the activity including the tools and GSE to be used, the expected duration of the activity, and the relevant safety or operational constraints.

e. The sequencing of activities should be presented as flow charts.

<6> GSE and AIT facilities

a. The AITP shall list and describe the GSE, test software and AIT facilities to be used.

b. The AITP shall describe the logistics and list the major transportations.

<7> AIT documentation

a. The AITP shall describe the AIT documents to be produced and their content.

<8> Organization and management

a. The AITP shall describe the responsibility and management tools applicable to the described AIT process with reference to ECSS-E-ST-10-02.

b. The AITP shall describe the responsibilities within the project team, the relation to product assurance, quality control and configuration control (tasks with respect to AIT) as well as the responsibility sharing with external partners.

NOTE Tasks with respect to AIT include for example, anomaly handling, change control, safety, and cleanliness.

c. The planned reviews and the identified responsibilities shall be stated.

<9> AIT schedule

a. The AITP shall provide the AIT schedule as reference.

Test specification

A.3 Expected response

A.3.1 Scope and content

<1> Introduction

a. The TSPE shall contain a description of the purpose, objective, content and the reason prompting its preparation.

b. Any open issue, assumption and constraint relevant to this document shall be stated and described.

<2> Applicable and reference documents

a. The TSPE shall list the applicable and reference documents in support to the generation of the document.

<3> Definitions and abbreviations

a. The TSPE shall list the applicable dictionary or glossary and the meaning of specific terms or abbreviations utilized in the document.

<4> Requirements to be verified

a. The TSPE shall list the requirements to be verified (extracted from the VCD) in the specific test and provides traceability where in the test the requirement is covered.

<5> Test approach and test requirements

a. The TSPE shall summarize the approach to the test activity and the associated requirements as well as the prerequisites to start the test.

<6> Test description

a. The TSPE shall summarize the configuration of the item under test, the test set-up, the necessary GSE, the test tools, the test conditions and the applicable constraints.

<7> Test facility

a. The TSPE shall describe the applicable test facility requirements together with the instrumentation and measurement accuracy, data acquisition and test space segment equipment to be used.

<8> Test sequence

a. The TSPE shall describe the test activity flow and the associated requirements.

b. When constraints are identified on activities sequence, the TSPE shall specify them including necessary timely information between test steps.

<9> Pass/fail criteria

a. The TSPE shall list the test pass/fail criteria, including their tolerance, in relation to the inputs and output.

b. In the TSPE, the error budgets and the confidence levels with which the tolerance is to be met shall be specified.

<10> Test documentation

a. The TSPE shall list the requirements for the involved documentation, including test procedure, test report and PA and QA records.

<11> Test organization

a. The TSPE shall describe the overall test responsibilities, participants to be involved and the schedule outline.

NOTE Participation list is often limited to organisation and not individual name.

A.3.2 Special remarks

None.

Test procedure

C.2 Expected response

C.2.1 Scope and contents

<1> Introduction

a. The TPRO shall contain a description of the purpose, objective, content and the reason prompting its preparation.

b. Any open issue, assumption and constraint relevant to this document shall be stated and described.

<2> Applicable and reference documents

a. The TPRO shall list the applicable and reference documents in support to the generation of the document.

<3> Definitions and abbreviations

a. The TPRO shall list the applicable dictionary or glossary and the meaning of specific terms or abbreviations utilized in the document.

<4> Requirements mapping w.r.t. the TSPE

a. The TPRO shall provide a mapping matrix to the TSPE giving traceability towards the test requirement.

<5> Item under test

a. The TPRO shall describe the item under test configuration, including any reference to the relevant test configuration list, and any deviation from the specified standard.

b. The software version of the item under test shall be identified.

<6> Test set-up

a. The TPRO shall describe the test set-up to be used.

<7> GSE and test tools required

a. The TPRO shall identify the GSE and test tools to be used in the test activity including test script(s), test software and database(s) versioning number.

<8> Test instrumentation

a. The TPRO shall identify the test instrumentation, with measurement accuracy, to be used, including fixtures.

<9> Test facility

a. The TPRO shall identify the applicable test facility and any data handling system.

<10> Test conditions

a. The TPRO shall list the applicable standards, the applicable test conditions, in terms of levels, duration and tolerances, and the test data acquisition and reduction.

<11> Documentation

a. The TPRO shall describe how the applicable documentation is used to support the test activity.

<12> Participants

a. The TPRO shall list the allocation of responsibilities and resources.

<13> Test constraints and operations

a. The TPRO shall identify special, safety and hazard conditions, operational constraints, rules for test management relating to changes in procedure, failures, reporting and signing off procedure.

b. The TPRO shall describe QA and PA aspects applicable to the test.

c. The TPRO shall contain a placeholder for identifying:

1. procedure variations, together with justification, and
2. anomalies.

<14> Step-by-step procedure

a. The TPRO shall provide detailed instructions, including expected results, with tolerances, pass/fail criteria, and identification of specific steps to be witnessed by QA personnel.

b. The step-by-step instructions may be organized in specific tables.

c. When the procedure is automated, the listing of the automated procedure shall be documented to a level allowing consistency check with the TPRO and the TPSE.

C.2.2 Special remarks

None.

So, what we need?

- Test schedule
- Requirements to be verified
- Test set-up definition/description
- Test facilities
- Fail/pass criteria (and func. test description)
- GSE/tools
- Anticipated procurement of needed items!
- Test conditions
- Step-by-step procedure

UUT DATA : Model Item C.I.			
STEP n°	**TEST SEQUENCE**	**EXPECTED VALUE**	**MEASURED VALUE**
3.1.	Verify that the DSU is switched off and not operative	OK	
3.2.	Set the thermal chamber temperature to +70°C with 2°C/min slope	OK	
3.3.	Wait for TRP stabilization (gradient on TRP less than 1°C/hr observed for 1 hour)	OK	
3.4.	Record the temperatures of the monitored components	70°C ± 2°C	
3.5.	Verify that the EGSE active loads setup has been done according to Table 6-1	OK	
3.6.	Set the input voltage to 32V	OK	
3.7.	Switch on the DSU and check the current consumption on the EGSE power supply display	0.7 A ± 0.2 A	
3.8.	Upload the ASW V1.0 RC2 via serial interface	OK	
3.9.	Check the current consumption on the EGSE power supply display	0.65 A ± 0.2 A	
3.10.	Record the temperatures of the monitored components	T < 90°C	

Task Name	Start	Finish	Duration
Payload DM	**Mon 01/07/19**	**Mon 15/06/20**	**234 days?**
Payload DM design	**Mon 01/07/19**	**Fri 28/02/20**	**164 days?**
Thermo-Mechanical Design	Thu 01/08/19	Thu 05/12/19	91 days
FEE Design	Mon 01/07/19	Thu 12/12/19	119 days
BEE Design	Mon 01/07/19	Fri 28/02/20	164 days
PSU Design	Mon 01/07/19	Fri 28/02/20	164 days
PDHU Design	Mon 01/07/19	Thu 05/12/19	114 days?
Payload DM procurement	**Fri 06/12/19**	**Thu 30/04/20**	**90 days?**
Thermo/mechanical item procurement	Fri 06/12/19	Fri 28/02/20	10 wks
Detector/FEE procurement	Fri 13/12/19	Fri 28/02/20	9 wks
BEE procurement	Mon 02/03/20	Thu 30/04/20	8 wks
PSU procurement	Mon 02/03/20	Thu 30/04/20	8 wks
PDHU procurement	Fri 06/12/19	Fri 14/02/20	8 wks
BEE board ready for SC-PL I/F test	Thu 11/06/20	Thu 11/06/20	0 days
PSU board ready for SC-PL I/F test	Fri 22/05/20	Fri 22/05/20	0 days
PDHU board ready for SC-PL I/F test	Mon 17/02/20	Mon 17/02/20	0 days
DM MAIT	**Mon 02/03/20**	**Mon 15/06/20**	**70 days**
Detector assembly MAIT	Mon 02/03/20	Fri 03/04/20	5 wks
Electronic stack MAIT	Mon 04/05/20	Fri 15/05/20	2 wks
Intergation	Mon 18/05/20	Fri 29/05/20	2 wks
Test	Mon 01/06/20	Mon 15/06/20	2 wks
DM Environmental tests	**Tue 21/04/20**	**Fri 05/06/20**	**32 days**
Detector Assembly Thermal cycling	Tue 21/04/20	Mon 27/04/20	1 wk
Thermal Cycling functional tests & test report	Tue 28/04/20	Tue 05/05/20	1 wk
Detector Assembly Vibration	Fri 15/05/20	Thu 28/05/20	2 wks
Vibration functional tests & test report	Fri 29/05/20	Fri 05/06/20	1 wk
Radiation Tests (components/boards)	Wed 20/05/20	Tue 02/06/20	2 wks
Payload CDR	Mon 22/06/20	Mon 22/06/20	0 days

Table 5-2: Space segment equipment - Qualification test levels and duration

No	Test	Levels	Duration	Number of applications	NOTES
1	**Life**	Expected environment and maximum operational load	For duration and cycles: For mechanisms, apply ECSS-E-ST-33-01 Table 4-3 For batteries, apply ECSS-E-ST-20	1 test	
2	**Static load**	KQ x Limit Load The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	As needed to record data (10 seconds minimum)	Worst combined load cases	Worst combined load cases are determined by analysis
3	**Spin**	$\sqrt{KQ}$ x spin rate The qualification factor KQ is given in ECSS-E-ST-32-10	As specified by the project	1 test	
4	**Transient**	KQ x Limit Load The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	As needed to record data	As specified	
5	**Random vibration**	Maximum expected spectrum +3 dB on PSD values If margins higher than 3 dB are specified by the Launcher Authority, they apply.	2 minutes	On each of 3 orthogonal axes	
6	**Acoustic**	Maximum expected acoustic spectrum +3 dB If margins higher than 3 dB are specified by the Launcher Authority, they apply	2 minutes	1 test	
7	**Sinusoidal vibration**	KQ x Limit Load Spectrum The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	sweep at 2 Oct/min, 5 Hz - 140 Hz	On each of 3 orthogonal axes	

Table 5-2: Space segment equipment - Qualification test levels and duration

No	Test	Levels	Duration	Number of applications	NOTES
1	**Life**	Expected environment and maximum operational load	For duration and cycles: For mechanisms, apply ECSS-E-ST-33-01 Table 4-3 For batteries, apply ECSS-E-ST-20	1 test	
2	**Static load**	KQ x Limit Load The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	As needed to record data (10 seconds minimum)	Worst combined load cases	Worst combined load cases are determined by analysis
3	**Spin**	$\sqrt{KQ}$ x spin rate The qualification factor KQ is given in ECSS-E-ST-32-10	As specified by the project	1 test	
4	**Transient**	KQ x Limit Load The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	As needed to record data	As specified	
5	**Random vibration**	Maximum expected spectrum +3 dB on PSD values If margins higher than 3 dB are specified by the Launcher Authority, they apply.	2 minutes	On each of 3 orthogonal axes	
6	**Acoustic**	Maximum expected acoustic spectrum +3 dB If margins higher than 3 dB are specified by the Launcher Authority, they apply	2 minutes	1 test	
7	**Sinusoidal vibration**	KQ x Limit Load Spectrum The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	sweep at 2 Oct/min, 5 Hz - 140 Hz	On each of 3 orthogonal axes	

No	Test	Levels	Duration	Number of applications	NOTES
15	**Thermal vacuum**	$T^{Q}_{max}\|_{Op/NOp} = T^{A}_{max}\|_{Op/NOp} + 5^{\circ}C$ $T^{Q}_{min}\|_{Op/NOp} = T^{A}_{min}\|_{Op/NOp} - 5^{\circ}C$ Lower qualification margin than +/-5 °C may be used for temperature below -170 °C. Higher qualification margin than +/- 5 °C may be used for temperature above 120 °C.	8 cycles or 1 or more cycles if combined with ambient cycles (See note 2) For solar panels, 10 cycles	1 test	Note 1: Thermal vacuum and thermal ambient tests are both performed for space segment equipment that operate under a non-vacuum environment after having been exposed to vacuum. Note 2: Number of cycles and operating condition in Vacuum and Ambient will be selected based on mission profile.
16	**Thermal ambient**	$T^{Q}_{max}\|_{Op/NOp} = T^{A}_{max}\|_{Op/NOp} + 5^{\circ}C$ $T^{Q}_{min}\|_{Op/NOp} = T^{A}_{min}\|_{Op/NOp} - 5^{\circ}C$ Lower qualification margin than +/-5 °C may be used for temperature below -170 °C. Higher qualification margin than +/-5 °C may be used for temperature above 120 °C.	8 cycles (See note 2) or 8 cycles minus the number of cycles performed during the vacuum test	1 test	Note 1: Ambient pressure depends on the type of mission (i.e. Mars mission, Venus mission) Note 2: Thermal Ambient test without vacuum test is applicable only to space segment equipment that operate under a non-vacuum environment during their entire lifetime. In assessing this, depressurisation failure should be considered.

VEGA-C quasi-static load design limits

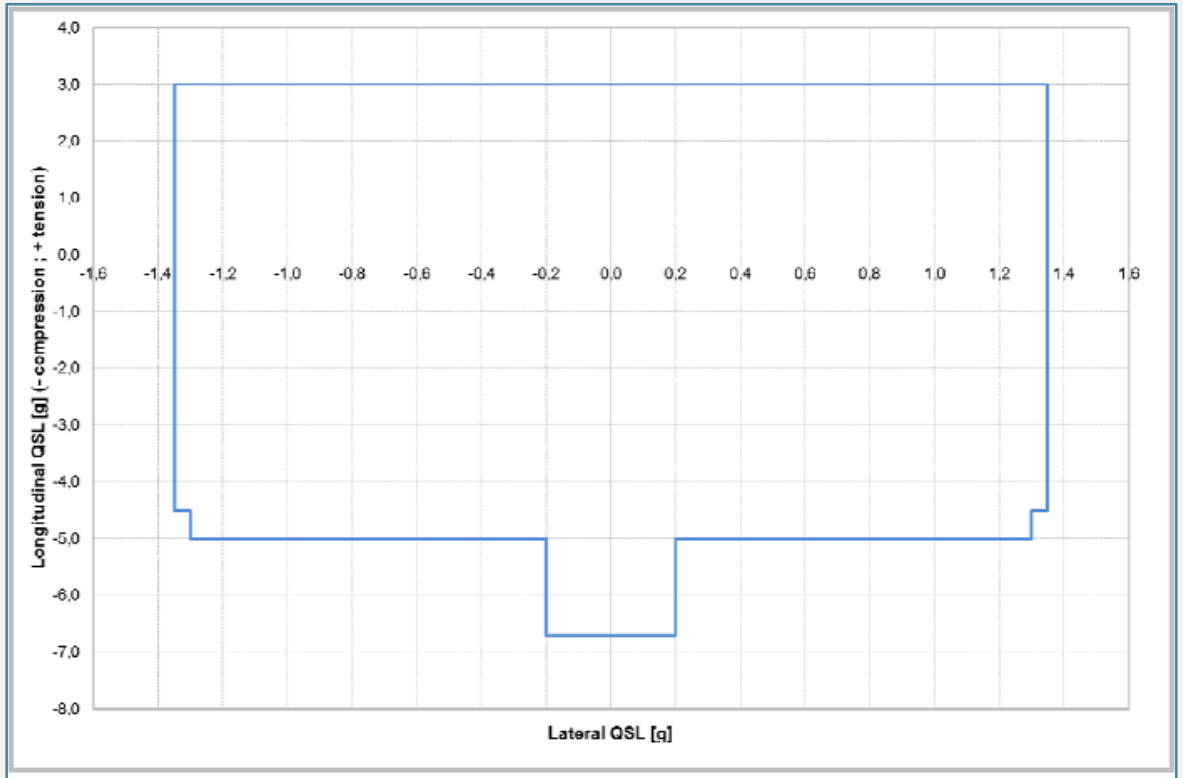


Figure 3.2.1.1.a – Spacecraft design limit load factors for single launch configuration

Soyuz quasi-static load design limits

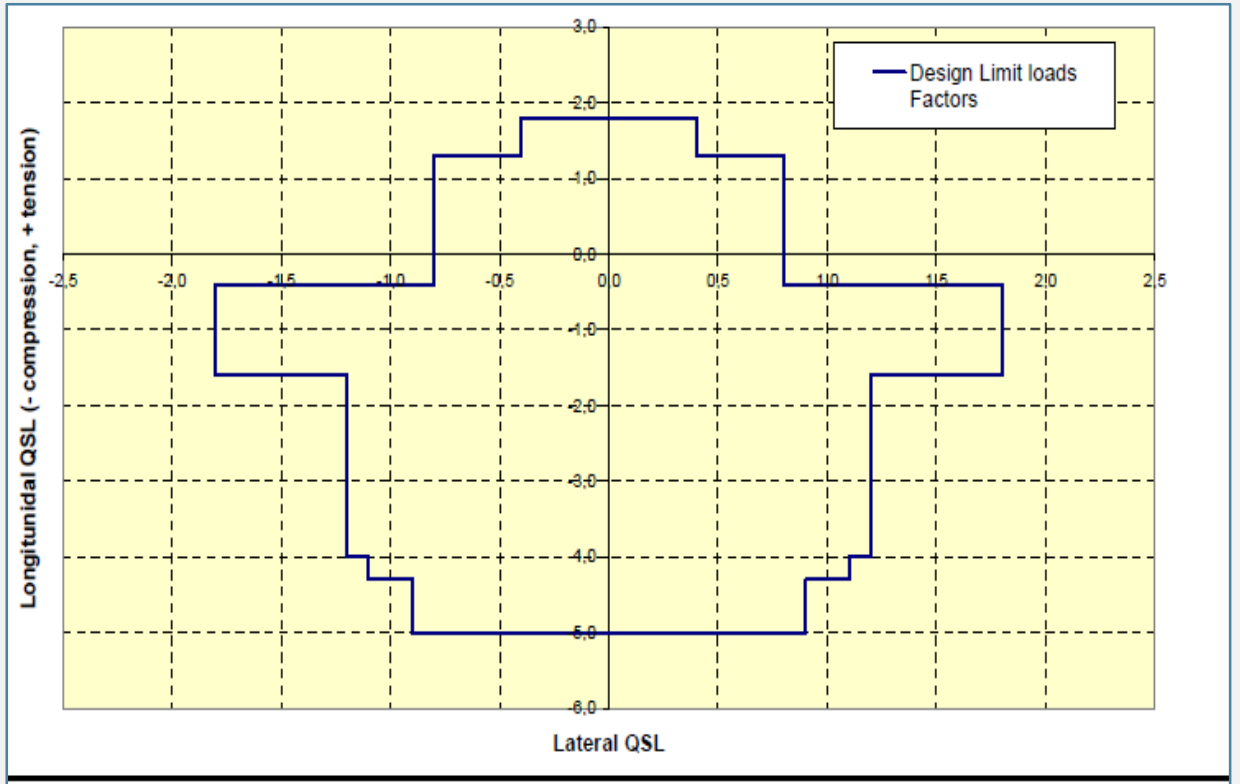
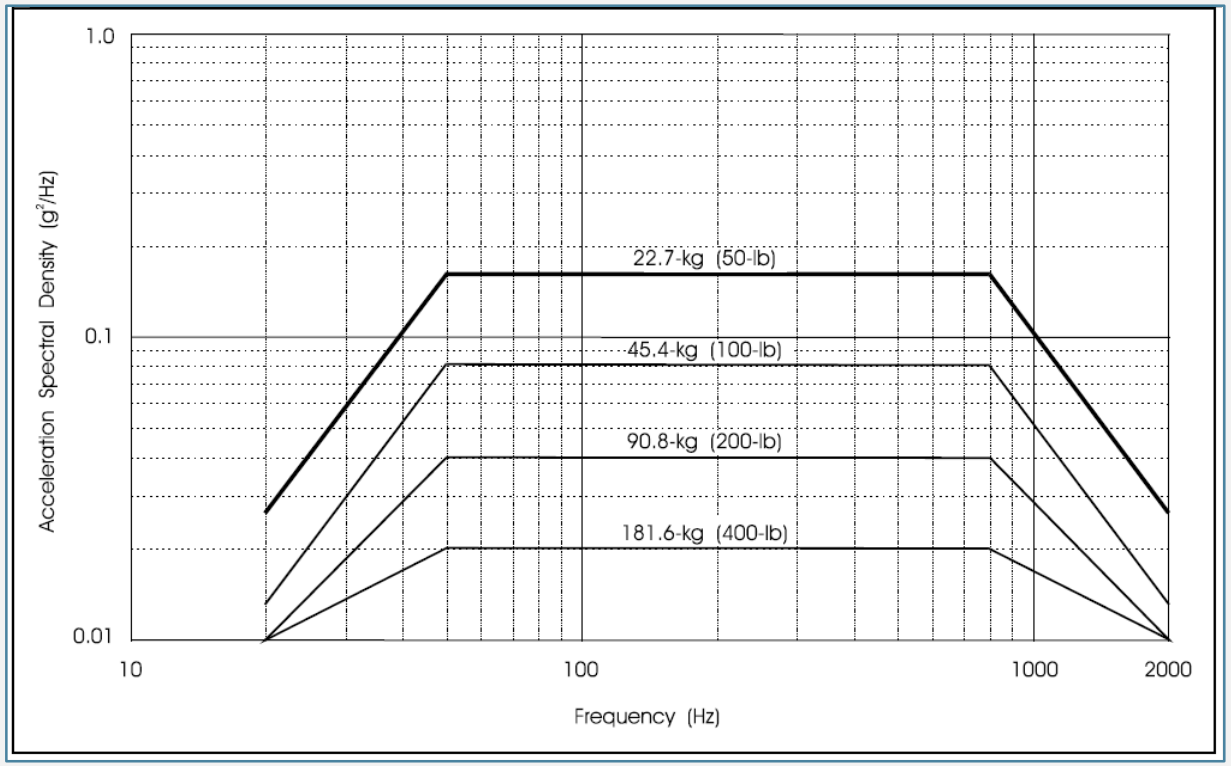


Figure 3.2.1a – Spacecraft design limit load factors

GEVS random vibration test levels



Frequency (Hz)	ASD Level (g^2/Hz)	
	Qualification	Acceptance
20 20-50 50-800 800-2000 2000	0.026 +6 dB/oct 0.16 -6 dB/oct 0.026	0.013 +6 dB/oct 0.08 -6 dB/oct 0.013
Overall	14.1 G_{rms}	10.0 G_{rms}

Soyuz random vibration environment

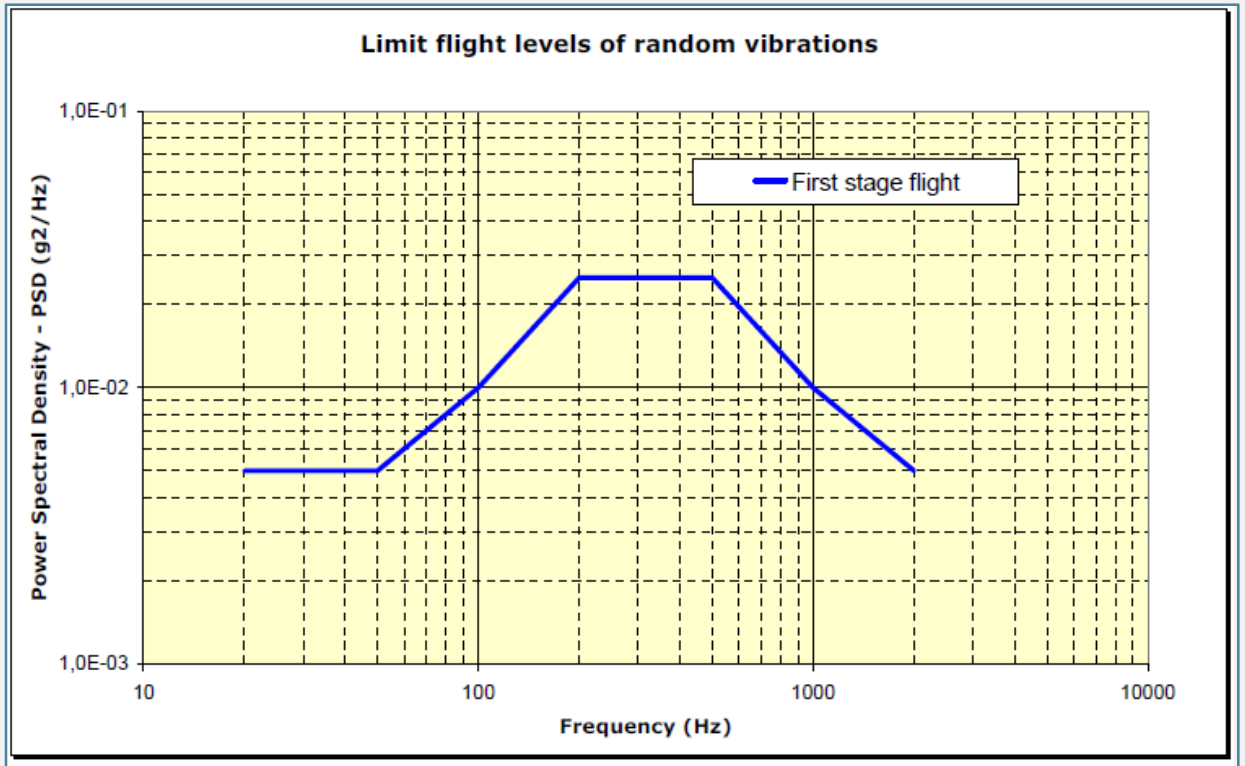


Figure 3.2.5a – Random vibration at spacecraft base (first stage flight)

VEGA fairing pressure profile

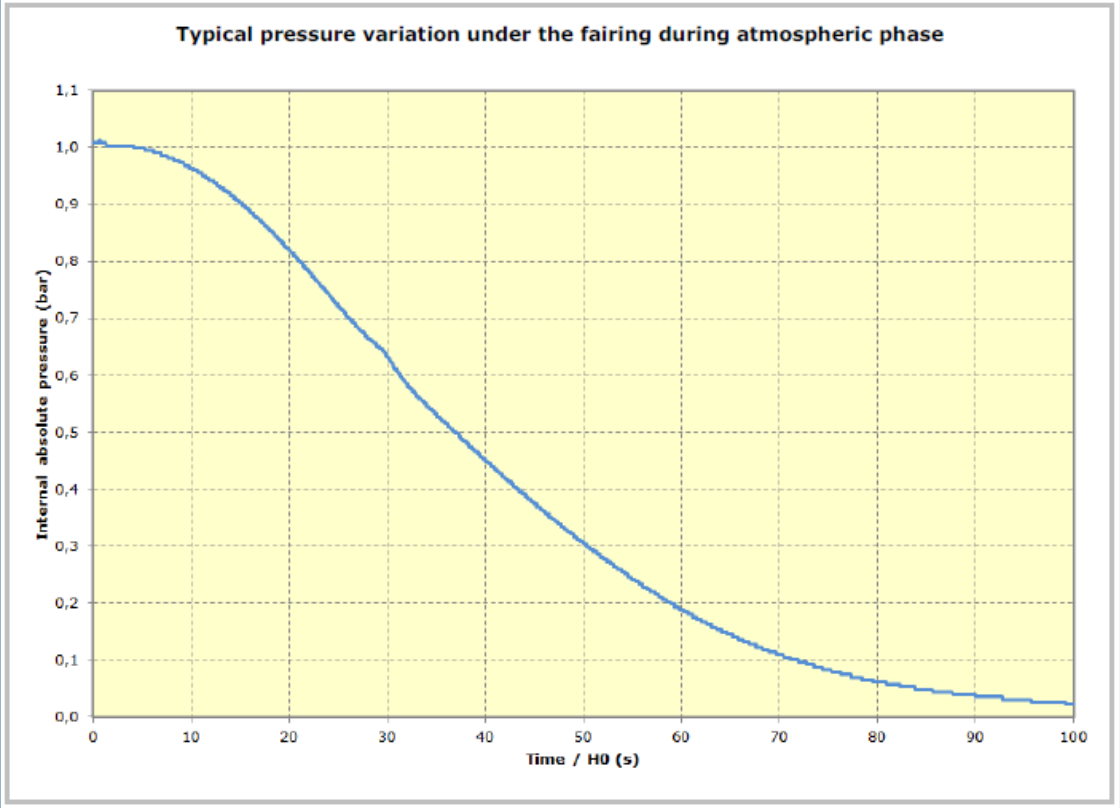


Figure 3.2.8.2a – Typical pressure variation under the fairing during atmospheric phase

Soyuz fairing pressure profile

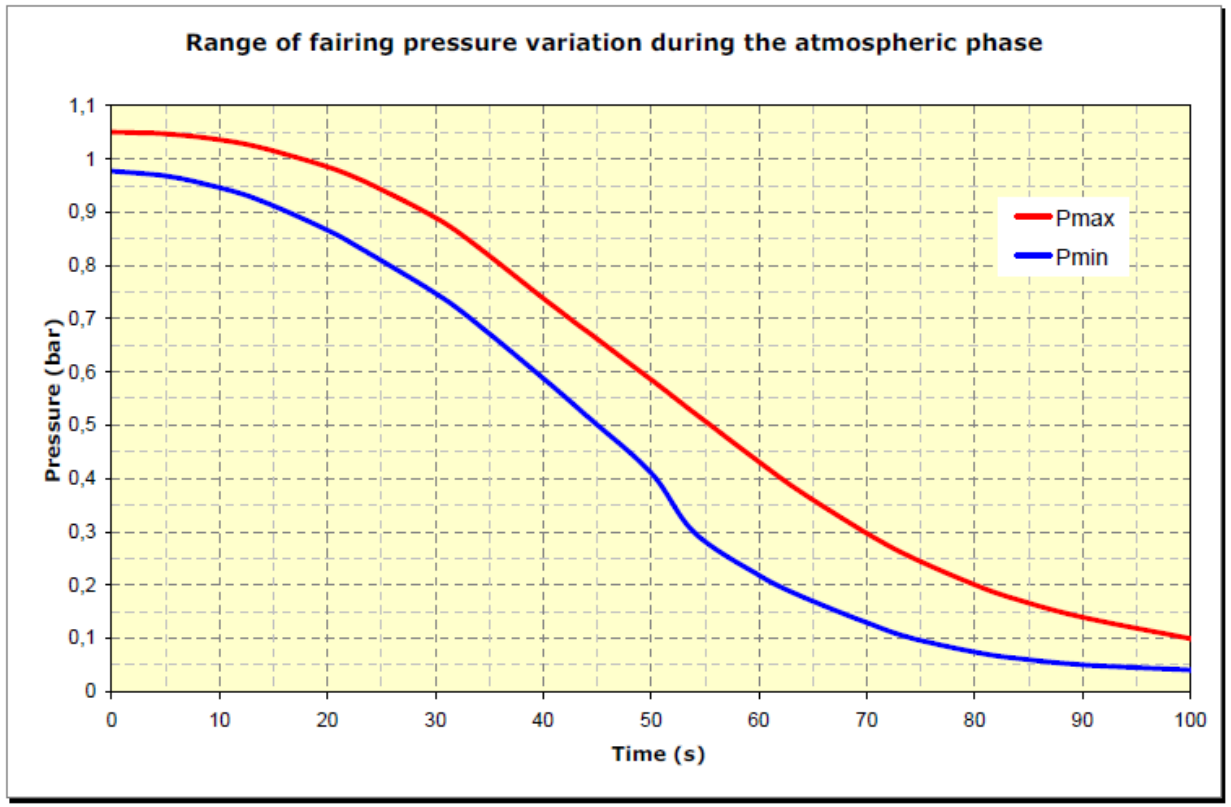


Figure 3.2.8.2a - Pressure variation under the Fairing during atmospheric phase

Bottom line:

- **Vibration and quasi static loads levels to be defined.**

Baseline GEVS, but to be verified compatibility of PL design by means of FEM simulations/analysis.

- **Pressure profile similar for most common launcher**

Optical Filter test can be performed using worst conditions

- **Thermal testing**

DM AIT schedule doesn’t allow for integrated PL to be tested before CDR
DM detector assembly can be tested in Climatic Chamber @ IAPS (Thermal ambient) using:

  - levels/durations defined in ECSS-E-ST-10-03C and (8 cycles, 5° C margin)
  - HERMES non-operative temperature requirement → HERMES-PHYS-R-005: -40° C ÷ +80° C

PL most critical components for radiation damage/SEE

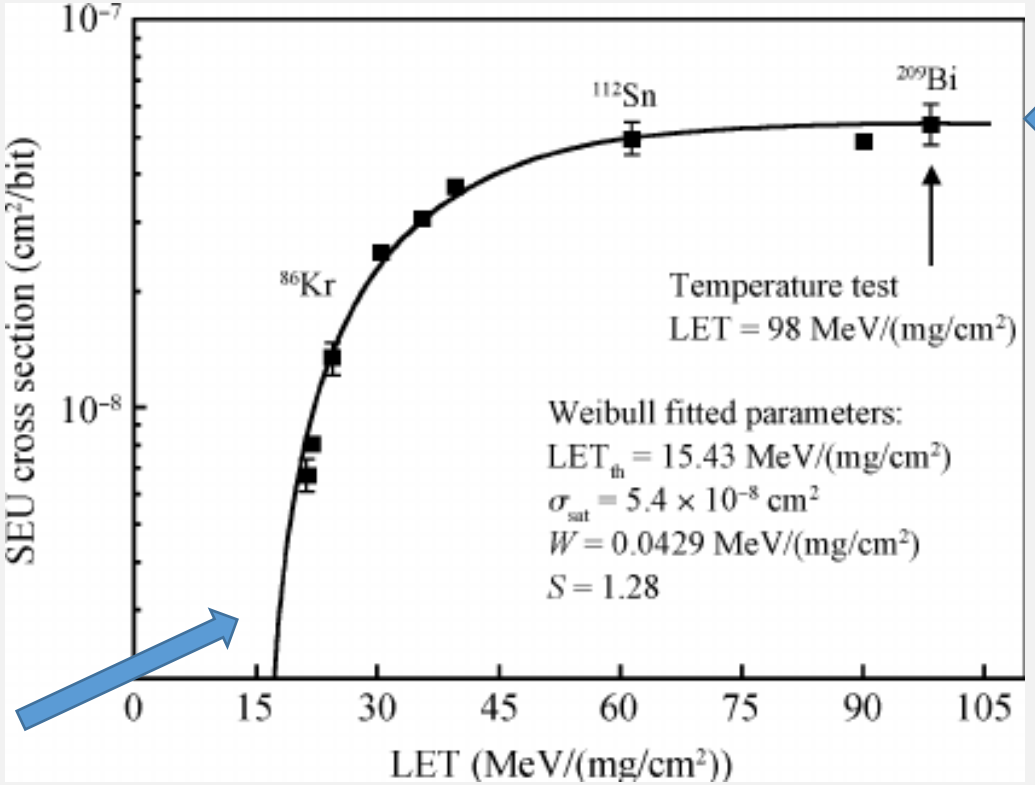
- **SDD detectors**
- **LYRA ASICs**
- **Latch-up transistor on FEE**
- **Cyclone V FPGA**
- **SA.45s CSAC**
- **ADCs**
- **HV DC-DC converters**
- **…**

PL most critical components for radiation damage/SEE

SDD detectors	NIEL and CCE for LOFT, flown on NICER, irradiated for HERMES @ TIFPA, TID to be performed for eXTP (but negligible by analysis)
LYRA ASICs	Radiation hard technology (AMS 0.35), TID to be performed on VEGA, latch-up protected on-board
Latch-up transistor on FEE	Qualification status/radiation hardness not known (?)
Cyclone V FPGA	Tested for SEU/SEL with protons (Qingyu Chen, IEEE, 2019). SEL immune (but protected on board), redundant memory, low (<1/month) SEU rate in LEO, can be reconfigured regularly.
SA.45s CSAC	Radiation tolerant up to 20 krad. SEL, SEU tested up to 64MeV-cm^2/mg
ADCs	Qualification status/radiation hardness not known (?)
HV DC-DC converters	Qualification status/radiation hardness not known
…	…

Probability of a **Single Event Upset** for an electronic component, as a function of the energy deposited by a heavy ion

Cross section:
probability to have a SEU



Saturation effect

Threshold effect

LET: Linear Energy Transfer
LET = -1/ρ × dE/dx
usually measured in
[MeV cm^2 mg^{-1}]

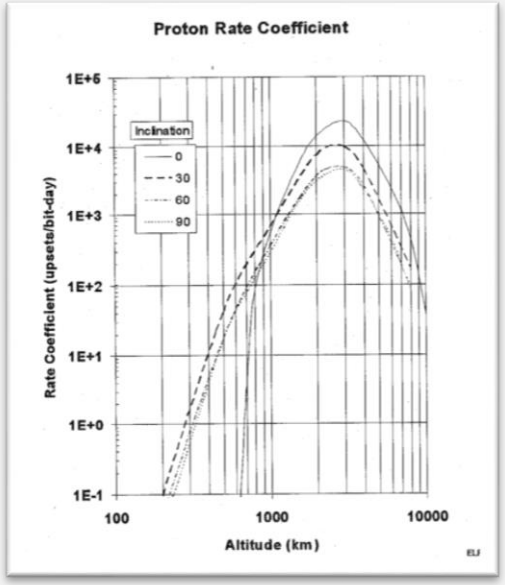
For proton irradiation the behavior is similar, but different probabilities and thresholds

$$FOM = \frac{\sigma_{HL}}{L_{0.25}^2}\left[\frac{(MeV/mg/cm^2)^2}{cm^2}\right]$$

Figure of Merit (FOM) parameter:
depends on threshold LET and saturation cross section for heavy ions (Petersen 1998)

For **protons**: FOM = $4.5 \times 10^4 \times \sigma_P$ (i.e. depends only on saturation cross-section for protons)
In this way, measurements with heavy ions can be put in relation with measurement using protons

Upset rate for a given orbit: R (upsets/bit/day) = C × FOM



Rate coefficient C will depend on the orbit (altitude, inclination)
(tabulated values)

Bottom line:
if you measure SEU saturation cross section for protons,
you can estimate the foreseen SEU rate in orbit for your component
(a proton beam with >50–100 MeV energy is needed)
Best practices in ESCIES_25100 document
(beam energy, fluxes btw. 10^5–10^8 pr/cm^2/s)

To do list:

- Analyze the full PL electrical BOM (FEE, BEE, PSU) identifying all the most critical components
- Search for radiation data/test in the Cumulative Index (1992-today) of IEEE Radiation Effects Data Workshop (RADW)
- Plan radiation tests for critical/unknown components:
  - Use of protons for SEU/SEL is possible (and easier than heavy ions)
  - Tests performed at TIFPA? (test planning!)
  - Estimate environmental conditions, so to define proton flux and fluences to be used
  - Build dedicated test breadboards (few components need to be tested) or perform test at board level (several components need testing)?