# PHASES OF AN ESA HARDWARE PROJECT EXPLAINED

(What is it that the engineers are up to really?)

Vicki Cripps, 2018-05-23

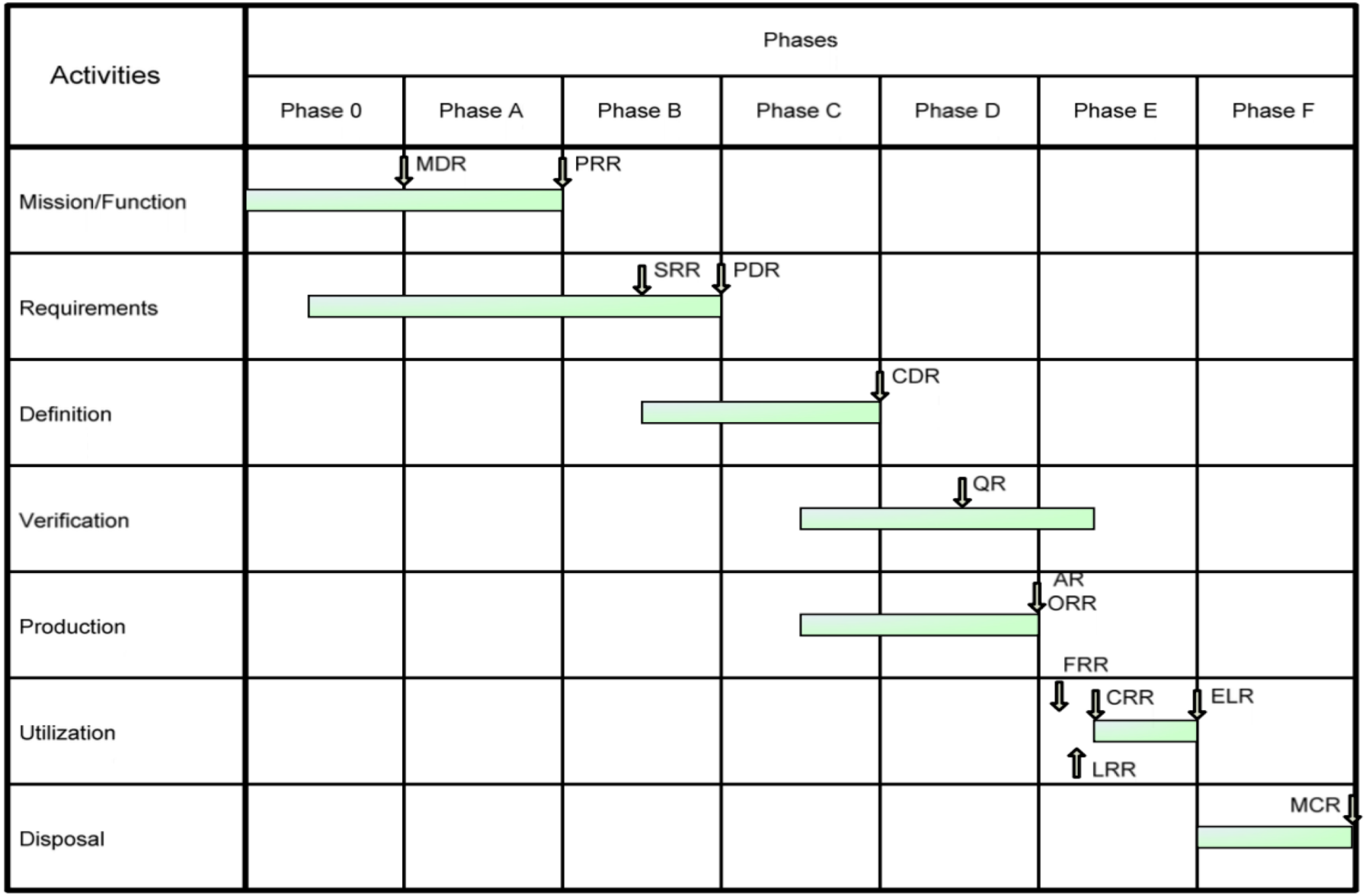
# Overview

- European standards system - ECSS
- Phases of a project, including reviews
- Requirements and their verification
- Hardware models
- Qualification and acceptance testing
- Problems along the way

# ECSS

- ECSS – European Cooperation for Space Standardisation
- ecss.nl
- Members: Italian, German, French, British, Dutch, and Norwegian Space Agencies; ESA; Eurospace (industry)
- Associate member – Canadian Space Agency
- 127 standards and 52 handbooks on management, engineering, product assurance, and sustainability (space debris)
- Not to be confused with ESCC, European Space Components Coordination, specification system for space qualified electronics components

# Project phases: ECSS-M-ST-10C



# Project phases: 0 and A

- Phase 0: Mission Definition
  - Identify the mission needs, science performance goals, safety and operations constraints
  - Create initial technical requirements specification
  - Finished after the Mission Definition Review (MDR)

- Phase A: Mission Feasibility
  - Production of initial technical designs, management plan, system engineering plan, product assurance plan
  - Assess feasibility – implementation, programmatic, cost, operations, organisation, production, maintenance, disposal, etc.
  - Assess risks
  - Release final technical requirements specification
  - Finished after the Preliminary Requirements Review (PRR)

# Requirements and compliance

- Requirement writing is a skill! Requirements should be:
  - understandable, readable independently, and unambiguous
  - verifiable (can be demonstrated)

- Listed in the Experiment Interface Document – Part A (EID-A), largely derived from ECSS
  - For JUICE, we (now) have 1287 requirements to follow
  - Plus 10+ other ‘sub’-requirements documents (science, Airbus)

- Response from the instruments via the EID-B (and matrix)
  - State if compliant, non-compliant, partially compliant or not applicable, with justification
  - Where non- or partially compliant, write a Request for Deviation explaining why, which must be approved by ESA and the Prime
  - List our requirements towards the spacecraft or other instruments

# Requirement examples

- A good JUICE requirement:

*The PI shall ensure that the unit identification code is composed of the following three parts:*

  - *3 to 4 characters for instrument identification, (e.g. RPWI)*
  - *3 characters for unit identification, (e.g. Digital Processing Unit, DPU)*
  - *2 characters for model identification ( ST for Structural Thermal Model, EM for Engineering Model, QM for Qualification Model, FM for Flight Model, FS for Flight Spare Model, PF for Proto-flight Model)*
  - *PTI [Product Tree Identification] number (to be provided by Spacecraft Prime).*

- A bad JUICE requirement:

*Appropriate provisions for their control shall be defined for facilities and procedures, and their implementation shall be verified.*

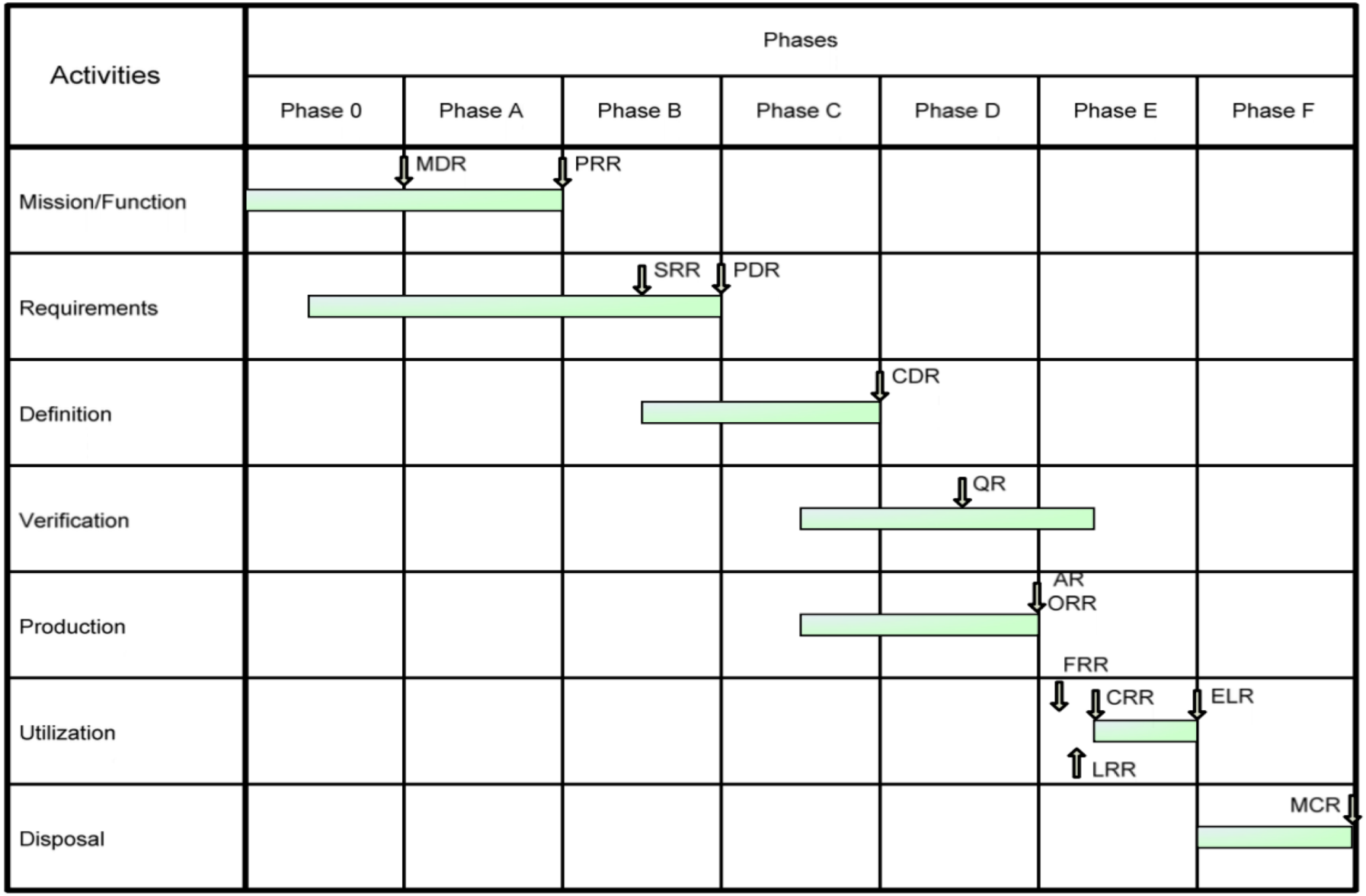
# Requirement verification

- Verification methods
  - Test (‘Test is best’)
  - Inspection
  - Analysis
  - Review of design (check the drawings, or written documentation)

- Verification levels
  - Spacecraft level
  - System level ( = instrument level, RPWI for JUICE)
  - Unit level (e.g. electronics box: EBOX)
  - Sub-unit level (e.g. HF circuit board within the EBOX)

- One requirement can have several verifications at different levels – all need to be documented (now using OpenProject)

# Project phases: ECSS-M-ST-10C



# Phase B and Reviews

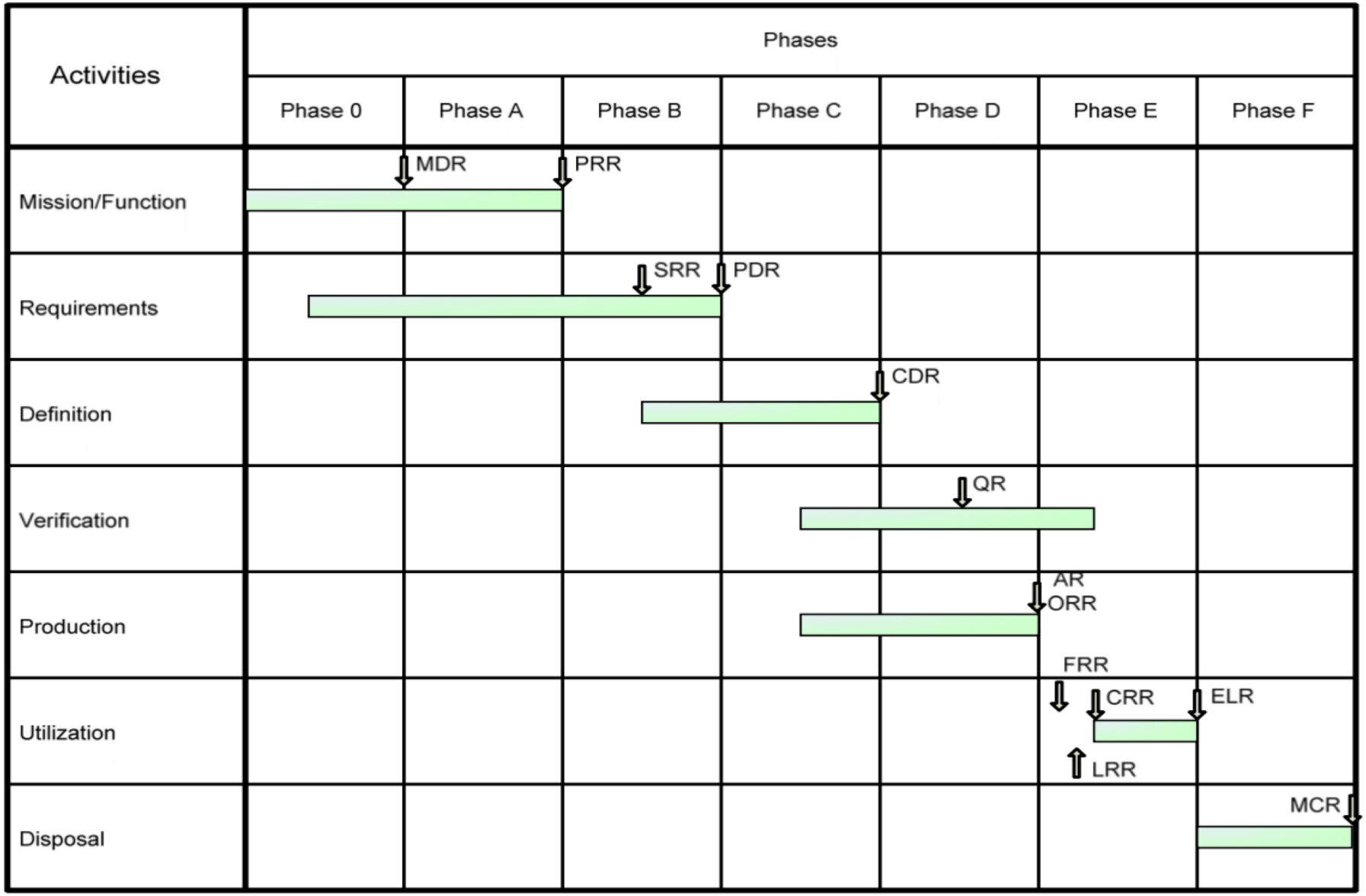
- Phase B – Preliminary Definition
  - Finalise plans, decide on hardware models, define schedule
  - Trade-off studies to decide on preferred solutions
  - Develop design, start procurement of long-lead items (some electronic components have lead times of over 1 year)
  - Spacecraft side – Systems Requirements Review
  - Finished after the Preliminary Design Review (PDR)

- Review process (over 2-3 months)
  - Deliver the datapack
  - Receive Review Item Discrepancies (RIDs) – comments and questions to answer in advance
  - Have a ‘colocation’ meeting, decide on resulting actions
  - For JUICE we issued over 120 documents and models for PDR, and received 241 RIDs

# Problems so far – the 'Prime' schedule

- The 'Prime' – the industry contactor responsible for the spacecraft and all its sub-systems
  - ESA's new way of thinking – in Phase A, have two!
  - For JUICE: Airbus (Astrium) vs. Thales Alenia Space
  - For THOR: Airbus vs. OHB
  - Reviews and meetings duplicated to respect confidentiality
  - Selection made at the end of Phase A
  - Once selected, tender process begins for all the sub-contractors
  - SRR in Phase B – 'paperwork' exercise, only after this that the real engineering work begins
  - By the end of Phase B, the instrument designs should be relatively mature (for THOR, significant detail was expected during Phase A)
  - Requirements for the instruments should be fixed, but the Prime hasn't really started yet

# Project phases: ECSS-M-ST-10C



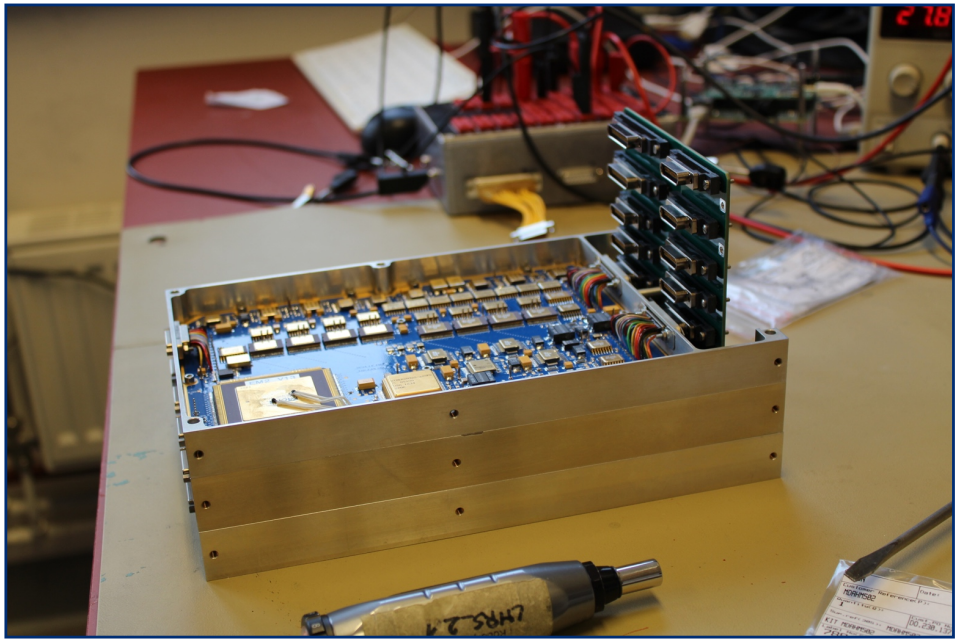
# Phase C

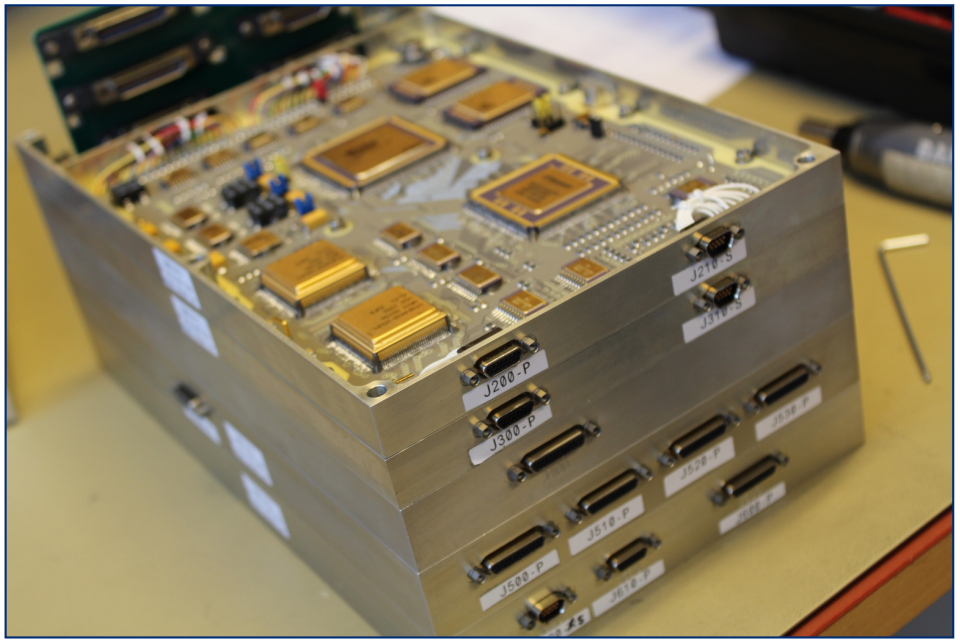
- Phase C – Detailed Definition
  - Finalise the design
  - Detailed definition of interfaces
  - Build engineering models
  - Development testing
  - Planning for assembly, integration, verification and testing (AIV/T)
  - Start writing the User Manual
  - Finished after the Critical Design Review (CDR)
- For JUICE, CDR datapack delivery 15th June
- CDR process has been running since November 2017 at unit level

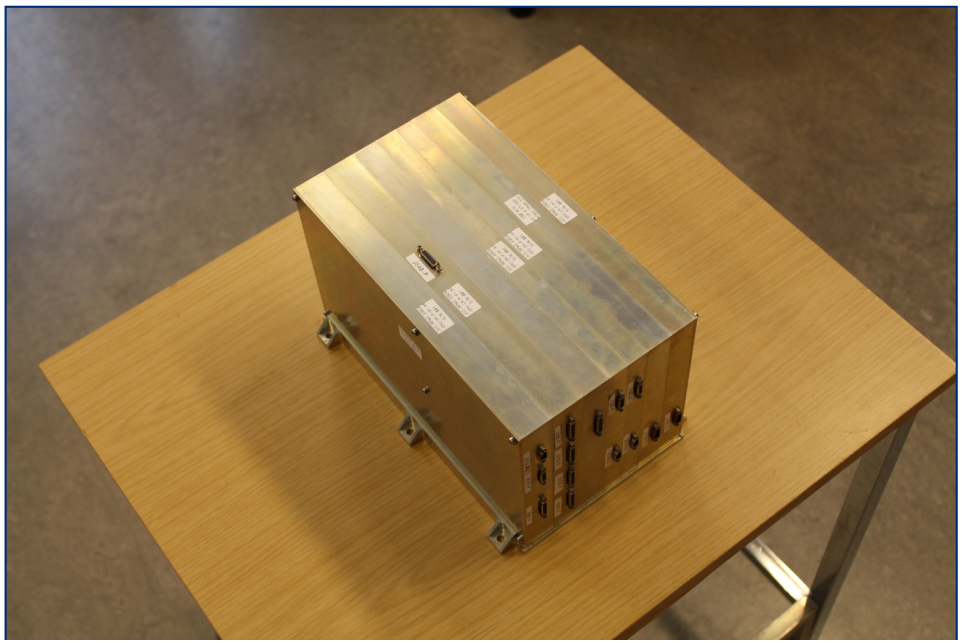
# Hardware Models

| Model | Representativeness |
|---|---|
| Breadboard (BBM) | Test model, cheap, partial models |
| Engineering (EM) | Close to the flight, cheaper parts, less functionality |
| Structural – Thermal (STM) | Same mass and power dissipation |
| Qualification (QM) | Identical to flight |
| Flight (FM) | Full functionality, qualified parts, materials and processes |
| Spare (FS) | Identical to flight / spares kit |
| Protoflight (PFM) | Full functionality, qualified parts, materials and processes |
| Engineering Qualification (EQM) | Close to flight, cheaper parts, full functionality |

# JUICE EM EBOX





# Typical test programme

| Physical | Structural | Thermal | Electrical |
|---|---|---|---|
| Visual inspection | Shock* | Thermal vacuum | Functional and performance |
| Dimensions check | Sine vibration | Thermal balance | Calibration |
| Physical properties | Random vibration | | Grounding, bonding and isolation |
| Deployment | | | EMC |
| Strip-down inspection | | | ESD* |
| | | | Magnetic cleanliness |

* Can be destructive

# Test levels and durations

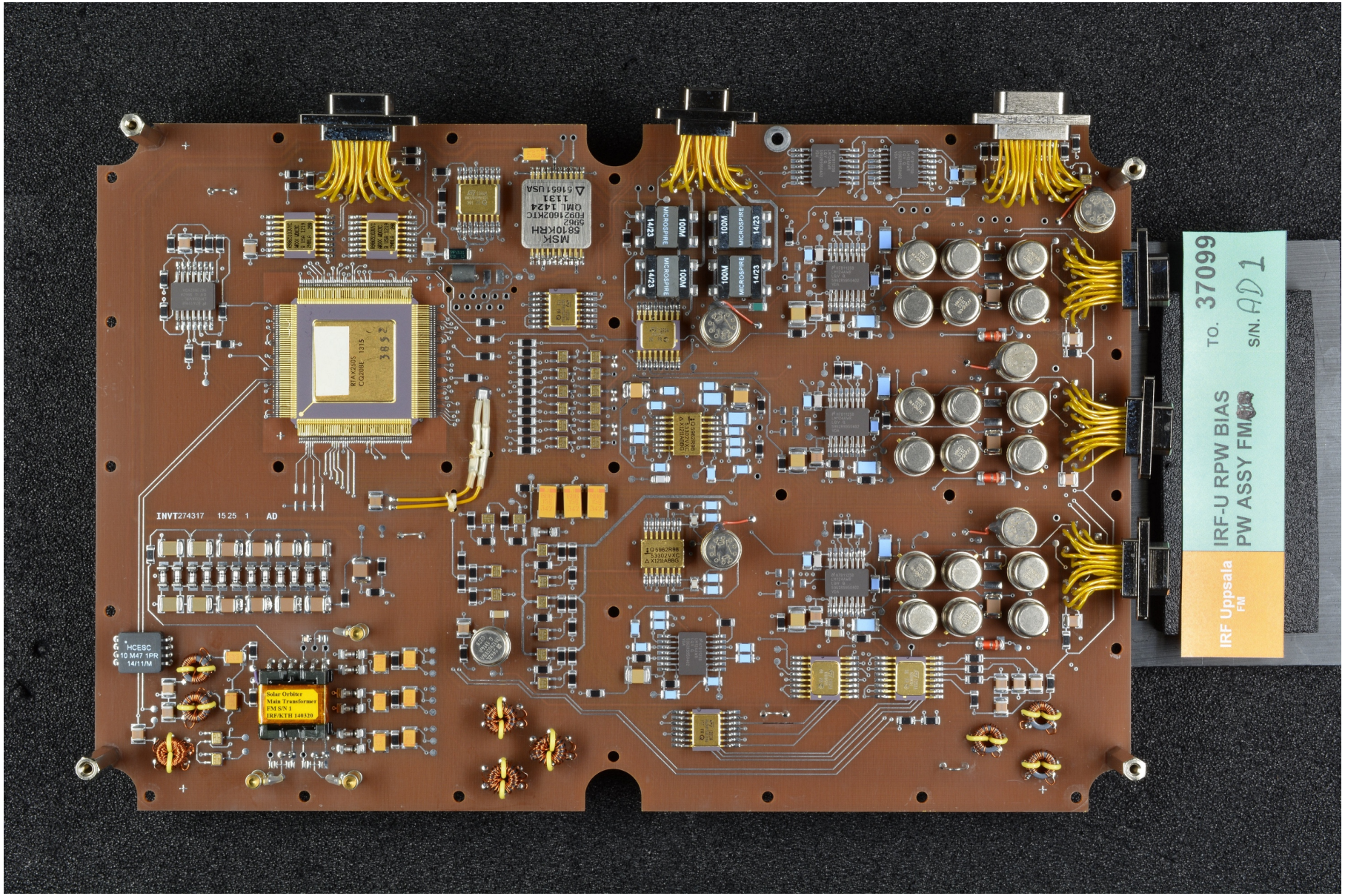
- Acceptance tests
  - Want to check the hardware can survive but still function fully
  - Don’t want to break anything
  - E.g. thermal vacuum tests:
    - Maximum design temp + 5ºC
    - Minimum design temp - 5ºC
    - 4 cycles

- Qualification tests
  - Want to stress the hardware
  - It doesn’t matter as much if it breaks
  - E.g. thermal vacuum tests:
    - Maximum acceptance temp + 5ºC
    - Minimum acceptance temp - 5ºC
    - 8 cycles

# Hardware model testing

| Model | Main use | Qualification test levels | Acceptance test levels |
|---|---|---|---|
| Breadboard (BBM) | Development testing | No | No |
| Engineering (EM) | Test as much as you can | No | No |
| Structural – thermal (STM) | Confirm mechanical and thermal analysis | Yes | No |
| Qualification (QM) | Check design survives | Yes | No |
| Flight (FM) | Go to space ☺ | No | Yes |
| Spare (FS) | Reserve | No | Yes |
| Protoflight (PFM) | Go to space with more risk | Qualification levels and acceptance durations (usually) | |
| Engineering Qualification (EQM) | Check design survives (cheaper and quicker) | Yes | No |

# Solar Orbiter – RPW BIAS FM (top)



# Hardware models: reality

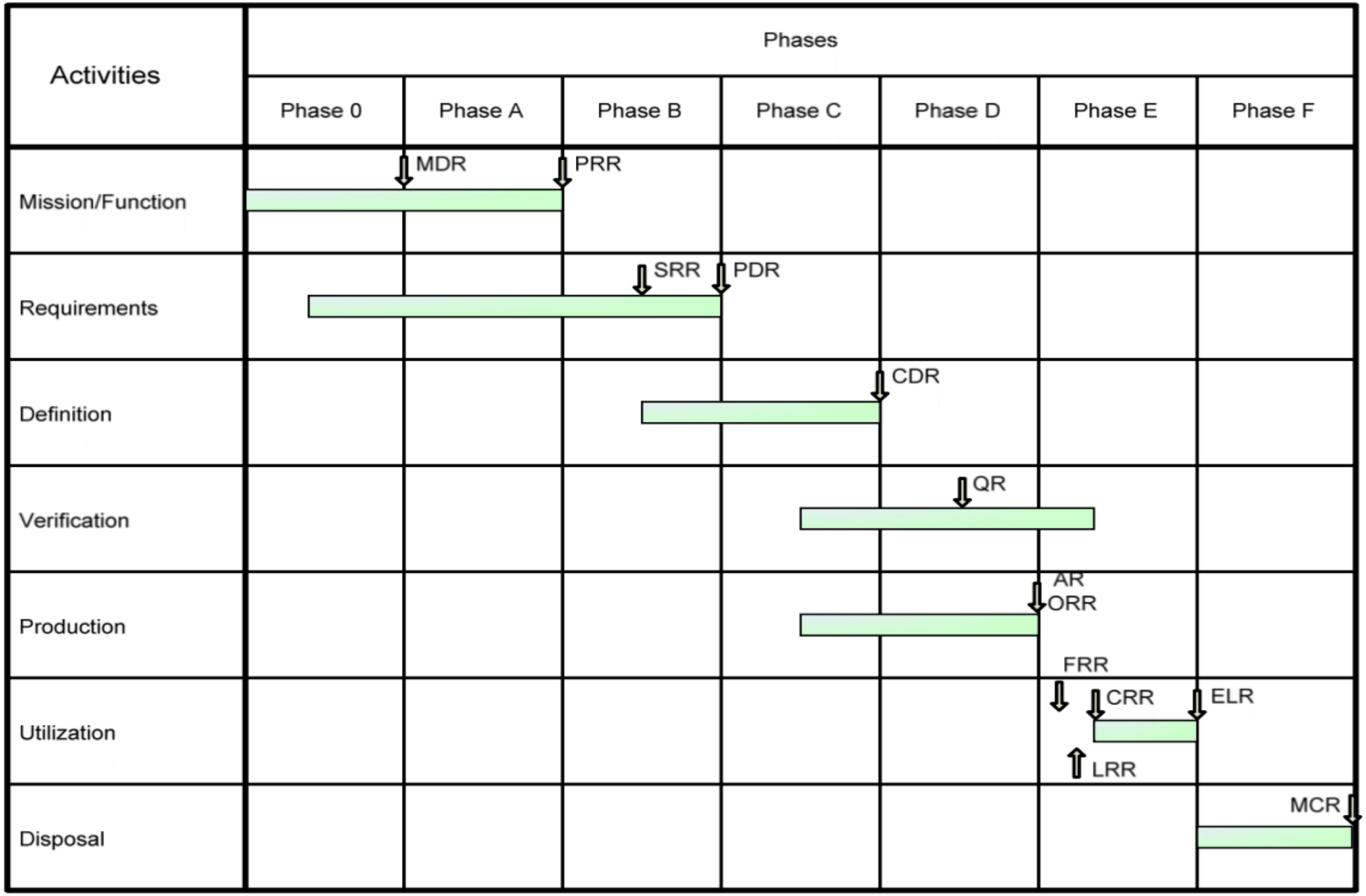
- Forced to change plans

- Solar Orbiter:
  - 8 models in total
  - 5 variants of EM, including ‘EM+’ and ‘pre-EQM’
  - No vibration test done before the flight Main Electronics Box

- JUICE:
  - Electronic components delayed
  - Change from QM / FM approach to PFM for many units
  - STM EBOX will not be tested before we have to give the go-ahead to start the PFM manufacturing

- Rosetta
  - Which model is actually flying?

# Project phases: ECSS-M-ST-10C



# Phase D

- Phase D – Qualification / verification and production
  - Build qualification hardware
  - Complete qualification testing and verification activities
  - Hold Qualification Review (QR)
  - Build flight hardware
  - Complete acceptance testing and authorise delivery
  - Finished after the Flight Acceptance Review (FAR) and Operational Readiness Review (ORR)

- Extra reviews!
  - Manufacturing Readiness Review (MRR)
  - Test Specification Review (TSR)
  - Test Readiness Review (TRR)
  - Post Test Review (PTR)
  - Delivery Review Board (DRB) ……..

# More problems

- Qualification
  - Qualify at the lowest level possible
  - Purchase space-qualified components and materials (long lead time, expensive)
  - Testing of individual samples and assemblies
  - Processes e.g. soldering
  - Often overlaps with building the flight hardware
  - Accept the risk and hope for the best!

- System designed for industry
  - Extremely manpower heavy
  - Reviews are payment milestones
  - Changes cost money
  - Can be difficult to talk to the right person
  - (Anyone want to / can help on JUICE!?)

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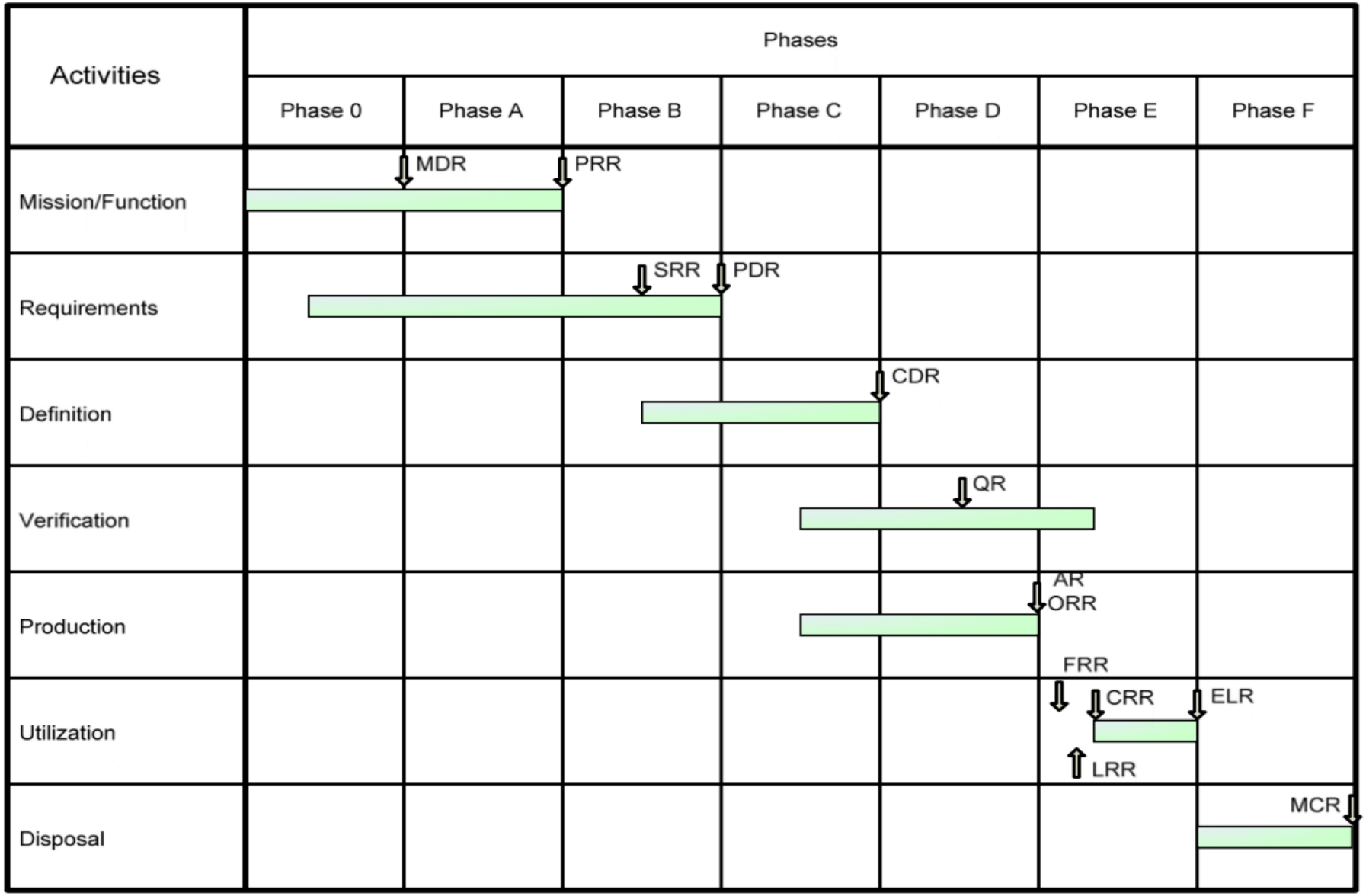
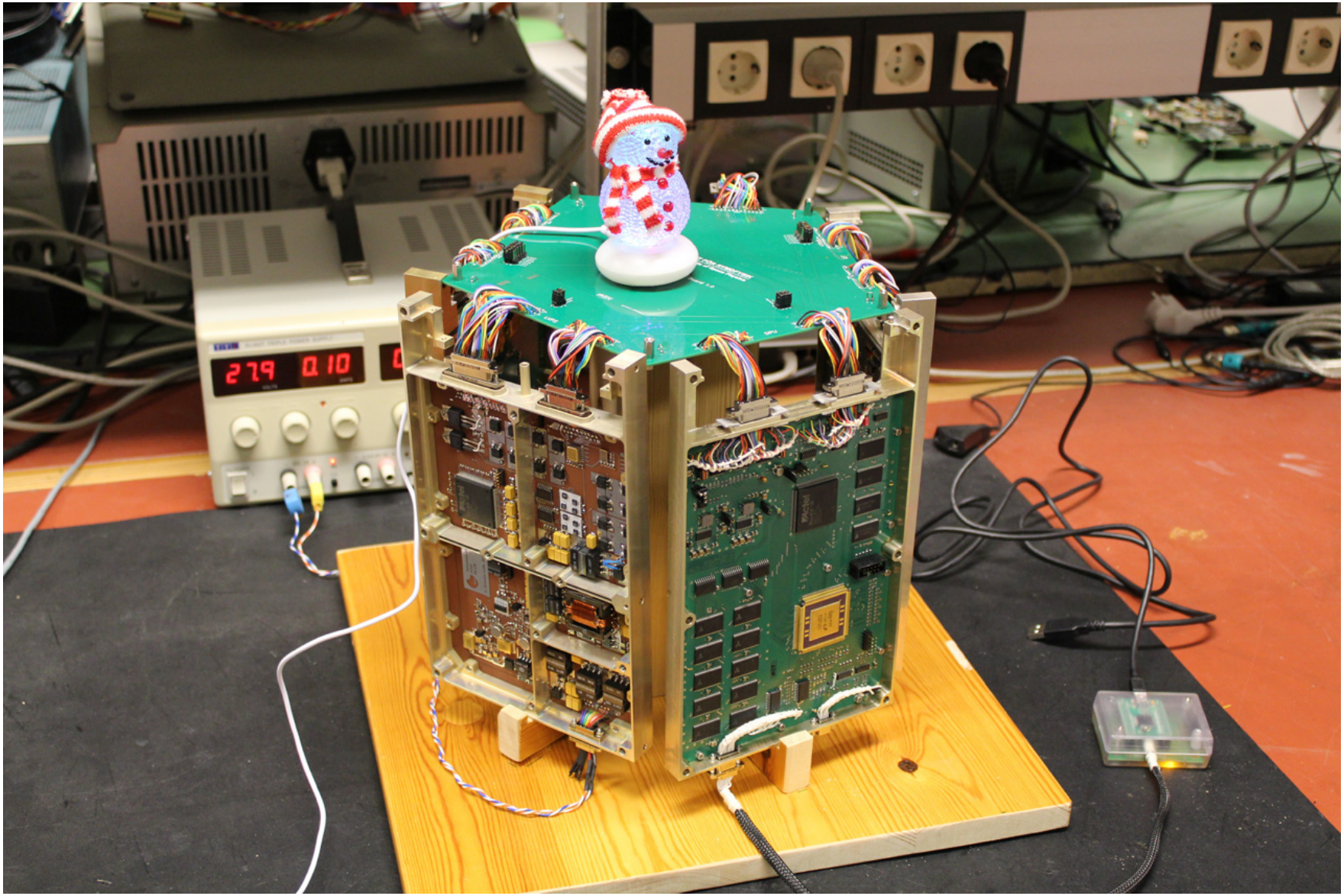


# Phases E and F

- Phase E – Operations and utilisation
  - Flight Readiness Review (FRR)
  - Launch Readiness Review (LRR) and launch
  - Commissioning and Commissioning Result Review (CRR)
  - Operation
  - Ground segment activities
  - Finished after End of Life Review (ELR)

- Phase F – Disposal
  - Finished after Mission Close-out Review (MCR)

# JUICE Christmas tree




Thank you

Questions