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European Physiology Module: an operational concept in constant evolution

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Abstract

The European Physiology Module (EPM) is one of the International Standard Payload Rack (ISPR) in the Columbus of the ISS since 2008. It is operated by CADMOS in Toulouse, France, a control center with the purpose to manage the coordination with all involved parties, especially the Columbus Flight Control team in Munich, Germany to ensure successful operations.

It was initially designed to host human physiology-related experiments such as CARDIOLAB and MEEMM. Its operational concept has changed throughout the years to adapt to the new actors and new goals. The arrival of Plasma Kristall-4 (PK-4), an experiment installed in 2014 to study plasma particles interaction in microgravity paved the way. PK-4 is today one of the longest running experiments onboard the ISS, with 20 successful scientific campaigns and one of the few Russian-European experiment onboard ISS. In 2018, the installation of a commercial payload named ICE Cubes Facility revolutionized the EPM operational concept. The installation of ICE Cubes into the EPM rack required the implementation of a whole new operational concept that allowed for a 24/7 on-call support to keep the rack active. ANITA-2, a payload that analyses the composition of the air inside the ISS, has been installed in 2023. This new payload has now joined the community of continuously powered payloads in the EPM and showed that a 15 years old concept can evolve to meet the goals of today and tomorrow.

In order to support the new operational concept of the EPM, new monitoring tools have been introduced. One can find a 24/7 running automated phone call support triggered by EPM live telemetry and also an EPM remote monitoring terminal to monitor EPM telemetry.

This versatility is still evolving with future payloads coming up in the future, such as Atmoflow, an experiment aiming at studying the dynamics of the Earth's atmosphere. Each time a new payload is incorporated into the EPM, its operational concept has to be revisited to guarantee its sustainability.

Additionally, it is worth mentioning the EPM laptop as a critical component of the EPM operational concept allowing the downlink of files using direct EPM commanding via the CCSDS protocol as opposed to a Remote Desktop Protocol connection.

EPM and its various payloads inside have been developed by numerous parties in the aerospace industry – CNES, OHB, Spacewire, Airbus, DLR, etc… – according to scientific requirements defined in coordination with ESA by the different research institutions and universities throughout Europe and the world.

Keywords: Operational concept, ISS, Columbus, EPM, Unattended OPS, experiments.

Acronyms/Abbreviations

ANalyzing InterferomeTer for Ambiant air (ANITA-2)
Centre d'Aide au Développement et Mission aux Opérations Spatiales (CADMOS)
Consultative Committee for Space Data Systems (CCSDS)
Cardiolab (CDL)
Crew Health Care Support (CHeCS)
Centre National d'Etudes Spatiales (CNES)
Columbus Orbital Laboratory (COL)
COL Control Center (COL-CC)
Columbus Payload Laptop (COL PL Laptop)
Control & Video Unit (CVU)
Data Service Subsystem (DaSS)
Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Dose Distribution inside ISS (DOSIS)
European Astronaut Center (EAC)
European Physiology Module (EPM)
European Space Agency (ESA)
Facility Control Computer (FCC)
Flight Control Team (FCT)
Flight Model (FM)
Gravitational References for Sensorimotor Performance (GRASP)
Health & State (H&S)
Housekeeping (HK)

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Human Research Facility (HRF)
Joint Operations Interface Procedure (JOIP)
International Commercial Experiment (ICE)
ICE Cubes Facility (ICF)
ICE Cubes Mission Control Center (ICMCC)
Inter Console Note (ICN)
id este (*i.e.*)
Ishikawajima-Harima Heavy Industries Co. Ltd., Tokyo (IHI)
International Space Station (ISS)
International Standard Payload Rack (ISPR)
Local Area Network (LAN)
LapTop Unit (LTU)
Media Access Control (MAC)
Muscle Atrophy Research and Exercise System (MARES)
Multi Electrode EEG Mapping Module (MEEMM)
Military Standard 1553 (MIL-STD-1553)
Man Machine Interface (MMI)
Multi-Purpose Computer and Communication (MPCC)
Operating System (OS)
Otto Hydraulik Bremen (OHB)
Payload Developer (PD)
Power Distribution Unit (PDU)
Plasma Kristall 4 (PK-4)
Principal Investigator (PI)
Remote Desktop Protocol (RDP)
Serial Line standard (RS485)
Science Module (SM)
Science Module Support Computer (SMSC)
Standard Utility Panel (SUP)
Tera Bytes (TB)
Transmission Control Protocol (TCP)
Telemetry/Telecommand (TM/TC)
Utility Interface Panel (UIP)
Right or Left Utility Distribution Panel (R/LUDP)
User Support Operations Center (USOC)
Video Cabin Assembly (VCA)
Virtual Machine (VM)

1. Introduction

1.1. CADMOS interactions within the ISS teams

The CADMOS operators, located in Toulouse, France, is involved in the ISS operations as a focal point between the PDs, the PIs and the Columbus Flight Control Team and serves ultimately as the leaders into preparing the operations of a certain payload or experiment and to be the responsible in real-time operations for this payload inside the ISS. CADMOS is described as a User Support Operations Center (USOC), part of whole operations community in Europe among around six other USOCs spread among Europe: in France, Germany, Switzerland, Belgium or Spain. CADMOS is working closely with Payload Developers during the development phase of the payload and even more closely during the operations since ultimately the owner the payload is the PD. CADMOS has the responsibility to follow the preparation phase of a payload in order to make sure it can be reasonably operated inside the ISS knowing all the different technical, operational and legal constraints. All the payloads CADMOS is responsible of are ordered by ESA.

CADMOS is also working with Principal Investigators, scientists receiving the data afterwards, during real-time operations to make sure that the science data collected and generated are viable and serve the science purpose. During the preparation phase it is also important for CADMOS to be involved in the science preparation to make sure that the creation of data and especially the downlink of a huge amount of data is realistic knowing the different constraints.

At the end CADMOS is working with Columbus Flight Control Team for the upstream preparation of various operational products in order to have an orderly execution in real-time for the payload. Additionally, in real-time CADMOS is working in the console with different parties from COL and ESA for the good flow of execution of any payload activities, it can involve using ground commanding to the ISS and telemetry from the ISS or any astronaut action or both.

Ultimately CADMOS is working to archive all the data (scientific and others) generated during the execution of an experiment for its sustainability.

1.2. European Physiology Module: a payload operated by CADMOS

The European Physiology Module is operated by CADMOS since the beginning of launch of COL in 2008. The EPM is an element of the ESA Microgravity Facilities for Columbus program; it is designed to operate on-orbit within the Columbus Module of the International Space Station (ISS) and to be compatible with the Columbus Module launch

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environment. The EPM has been developed by OHB System. EPM rack is located in the so-called position Aft 3 of COL, sometimes abbreviated to COL1A3. EPM hosts a number of Science Modules (SM) providing support for experiment executions in different branches of the Human Physiology. The EPM modular design allows to add up to 8 Science Modules on-orbit to tailor the EPM configuration to the experiment protocol and scientific requirements.

Figure 1 below is a view of the EPM FM inside COL in June 2023.

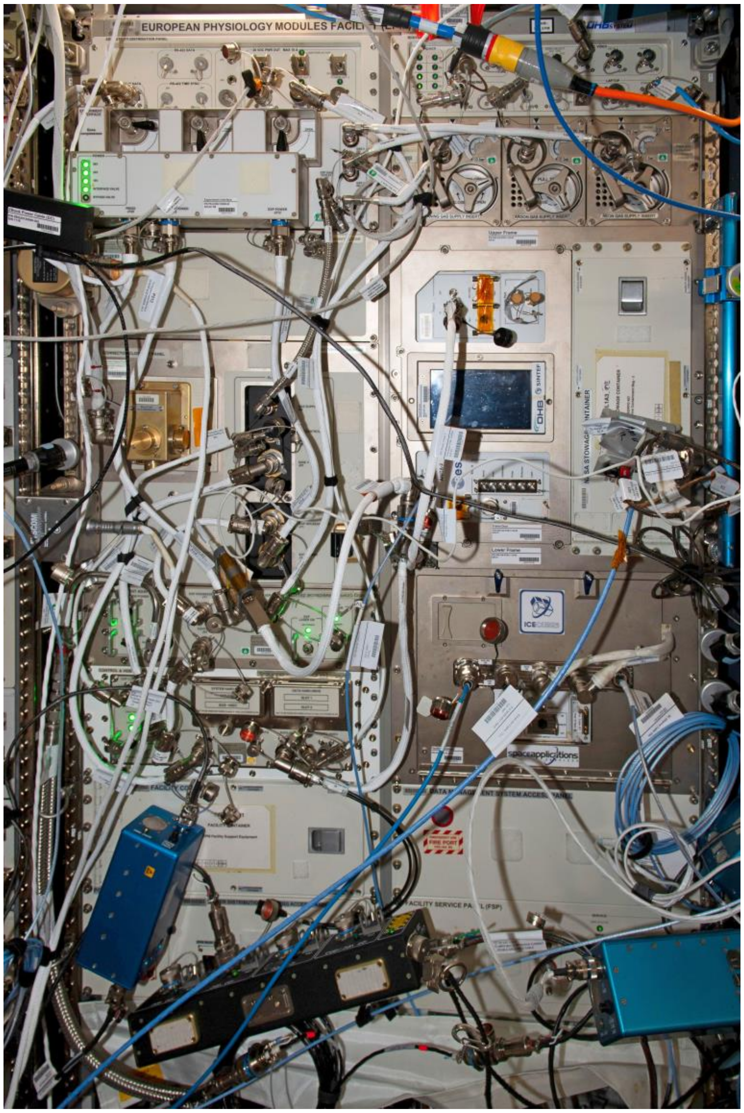

Figure 1: European Physiology Module Flight Model inside COL in June 2023 – it contains several experiments such as PK-4, ICE Cubes Facility and ANITA-2 ©NASA/ESA

This payload rack was initially designed to host physiology experiment, hence its name including Physiology, but evolved through time to welcome a various type of experiment. To name a few of those: Cardiolab, Multi Electrode EEG Mapping Module, Plasma Kristall 4, ICE Cubes Facility, ANITA-2 and is also a support to DOSIS, ECHO or GRIP and GRASP experiment. EPM is composed of two main computers called Facility Control Computer, the main interface between EPM and COL and the Science Module Support Computer which is the main interface between the SMs inside EPM and the Facility Control Computer. It also has an EPM laptop, that became an EPM Virtual Machine in 2021, to help astronaut inside the station to exchange data gathered on-board then for an EPM operator to be able to downlink those generated data to the ground for instance and to ultimately share those data to the scientific community.

EPM follows the ISPR concept inside ISS (vs Express Rack standard) and can potentially receive the following resources from COL: power at 120 Volts and up to 10 Amps, data connection via LAN and MIL-STD-1553 bus, water

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cooling, nitrogen and vacuum as outlined in Figure 2. It is worth mentioning that there is a direct connection between the smoke detector inside ISS, which is considered as isolated from the COL cabin air and the vital layer of data from COL, allowing for a robust surveillance of the smoke detection at any moment inside EPM when the rack is active.

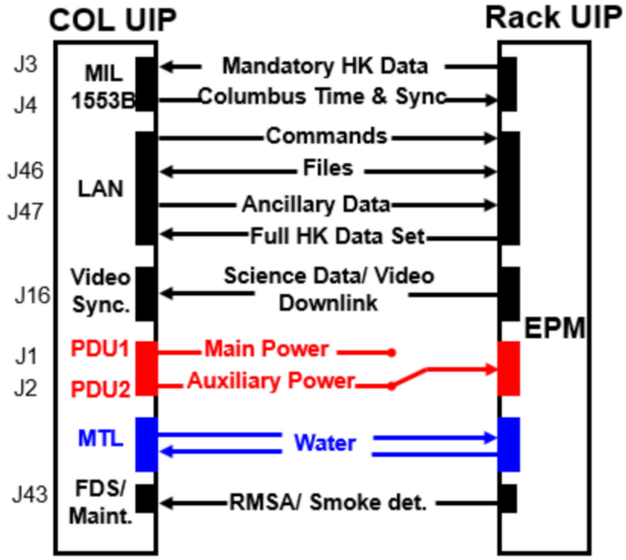

Figure 2: Interfaces between COL and EPM

EPM is a rack that can host payloads inside it. It has eight active positions for so-called SM and can provide to its hosted payloads the following resources: 28V current, air cooling, data connection via RS485 or Ethernet and Video downlink via a multiplexer. The purpose is to provide a plug & play interface for any experiment that wishes to follow the 6 post IHI ISPR standard in order to meet the maximum possible space for SMs. Ultimately the SMs or Stand-alone payload could also take the advantage to directly towards the Left or Right Utility Distribution Panels (LUDP/RUDP) on the rack front of EPM in order to receive 28V current, LAN interface, and a video input outlet to redirect for instance an internal video towards the ground.

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2. Legacy: EPM early days in Columbus

2.1. Description of the first EPM configuration (EPM-1)

In its launch configuration, EPM was accommodated with two SMs (or Class-2 payloads) and a stowage container:

CARDIOLAB	A science module developed by CNES/DLR for performing scientific studies about how the cardiovascular system (CARDIOvascular LABoratory) adapts under microgravity conditions
MEEMM	An ESA funded Multi-Electrode Electroencephalogram Mapping Module for recording and processing advanced EEG/EMG signals for brain and neurology research. MEEMM records electrophysiological signals generated by brain or muscle activity.
NASA stowage container	Container used to stow NASA Human Research Facility (HRF) instruments. Among the instruments launched in the NASA stowage container is the ESA developed HandGrip Dynamometer (HGD), Pinch Force Dynamometer (PFD) and the HRF Urine Collection Kit (UCK). EPM project responsibility is limited to the accommodation of the stowage container within EPM. Instructions for operations related to the HRF stowage items are not part of EPM operations.

The EPM was also provided with a dedicated laptop (LapTop Unit or LTU) that was connected to the EPM rack when the rack was active. The LTU (usually deployed in Columbus in the rack front of EPM) was used as the man-machine interface (MMI) for experiment and facility control. It could be used either by the crew in Columbus or by the ground operator at CADMOS remotely.

This configuration allowed conducting experiments in the following fields:
- Cardiovascular: regulation of arterial pressure and heart rate; measurement of blood volume and its distribution; distribution of liquids in the organism, etc.
- Neurosciences: neuro-vestibular control of posture; sensorimotor coordination of balance and ambulation; study of sleep patterns, electroencephalogram and evoked potentials, etc.
- **Muscle:** recording of muscular activity during exercise sessions (by means of electromyography).

The intended scientific scenarios for physiological studies carried out in Columbus included interactions of EPM with collocated facilities, such as the HRF rack or other ISS equipment. EPM provides commands and data interfaces as well as the exchange of small biological samples such as blood, urine and saliva samples.

The launch configuration (EPM-1) is depicted in Figure 3.

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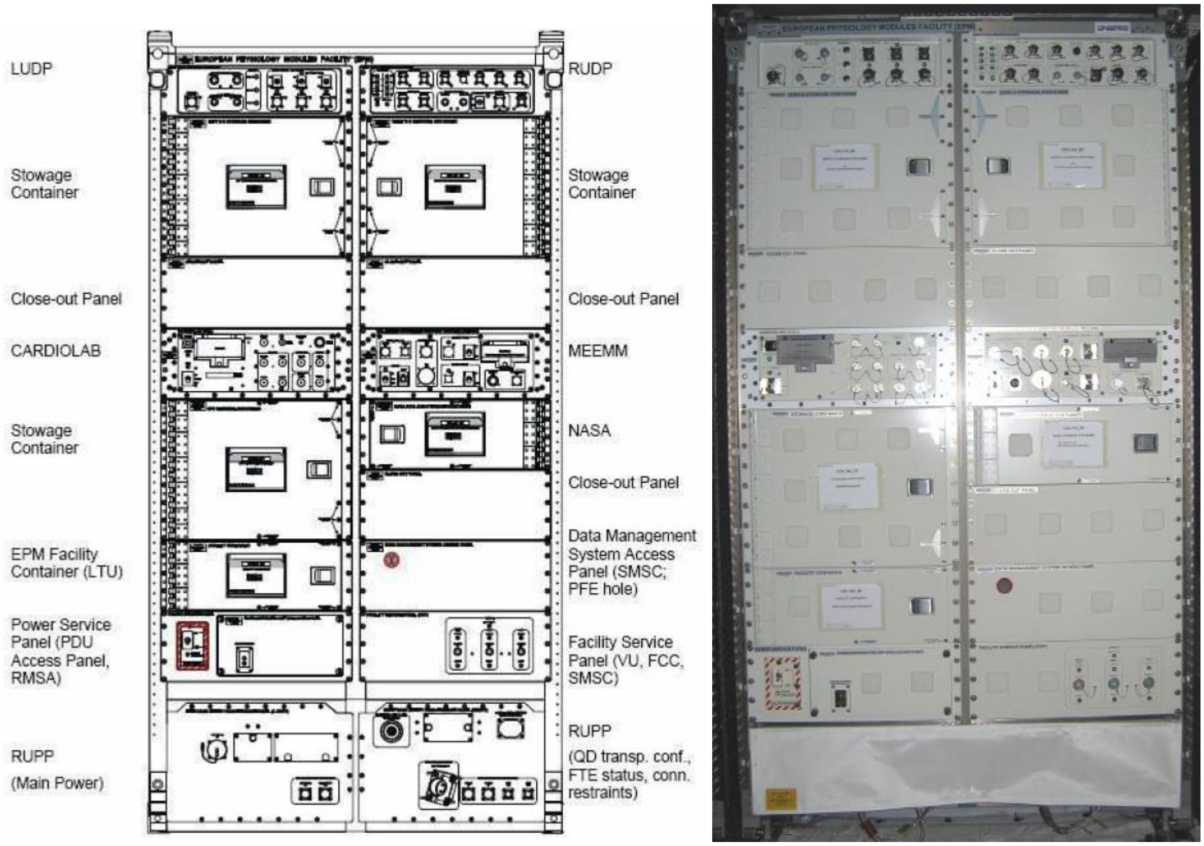

Figure 3. EPM-1 configuration baseline ©OHB/NASA/ESA

2.2. On-orbit commissioning of EPM

The on orbit Commissioning activities were aimed to prepare the EPM facility for the operations after the launch and the rack relocation in its operative position, and to verify that the launch loads have not adversely affected its functionalities and performance. The activities performed during the commissioning were the following:

- EPM relocation from launch to on-orbit location
- EPM setup (removal of the mechanical launch fixations and installation of several items in the facility)
- EPM activation and checkout (EPM activation and checkout of the facility in standby mode, test of the interfaces to the Columbus and to ground)
- EPM checkout (functional tests of the EPM subsystems)
- EPM Laptop setup, activation and stowage
- EPM CDL activation and checkout
- EPM MEEMM activation and checkout

The above listed operations were conducted on February 16th, 2008, both by the astronauts on board of the ISS and by the operators at CADMOS. EPM was one of the first payload to be turned ON in Columbus. The astronaut involvement was mandatory for the mechanical setup, and was only desired for the other activities. In fact, EPM has been designed to be operated remotely, i.e. all the activities requiring commanding and monitoring capabilities can be performed by ground only.

The only other activities performed during the year 2008 were to check the good health of the rack (in June and August).

2.3. MEEMM and CDL operations

After the EPM rack commissioning phase, the experimental phase of MEEMM and CDL was able to start.

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The experiment flow for MEEMM and CDL is based on a maximum of automated procedures (with ground monitoring and control activities) to reduce crew time involvement. For EPM, crew involvement can be either as the test subject but also as assistant/operator. An experiment session consists of a succession of standardized phases:

A. Experiment Configuration/initialization phase:

- Initialization phase (crew and ground activities):
  - Prepared the needed material to be used during the session
  - Equip the subject with sensor and/or stressor device according to procedure
  - Verify the overall configuration
  - Parameter setup (if necessary)
- Verification phase (depending of the equipment used):
  - Assess and adjust the quality of the physiological signals and the status of devices (crew)

B. Experimentation phase (for stationary sessions):

- Experiment execution
  - The MMI provides displays for experiment control, real-time sub-modules control, and monitoring of physiological data
  - The central unit provides real-time synchronized time stamp and storage of data from the submodules
  - Real-time telemetry (if needed)
- Data transfer phase:
  - Transfer of all data recorded by CDL sub-modules to the CDL central unit for storage in the central storage media. For MEEMM, the signals/data are stored directly on the central unit
  - Mandatory for CDL ambulatory sessions / could be used in the same way for stationary sessions
  - When data have been transfer from remote instruments to the central units, then the data transfer to ground (if needed) can be done by ground

C. Experiment De-configuration

- Disassembly (crew and ground):
  - Shutdown of SM and EPM (ground)
  - Stowage of EPM Laptop and used devices (crew)

The specificities of MEEMM was that the signal was acquired by dedicated electrodes fixed on the test subject. The electrodes for brain investigation were integrated in a flexible cap. For the cap measurements, the injection of gel into the electrodes was necessary to ensure a good contact to the skin. Then, the first amplification steps for the small signals were performed in a headbox close to the test subject. From the headbox, the signals were transferred to the rack mounted MEEMM Main unit for further amplification, processing and storage.

The specificities of Cardiolab is that it is composed of a main unit, integrated in EPM, and submodules or instruments that are stowed items. Most of the Cardiolab scientific functions are provided by rack-external sensor and stressor devices that can be operated in the cabin. These instruments can be connected to the EPM rack via the Cardiolab main unit front panel, by a direct interface (serial line) to the EPM Laptop. Some instruments are completely autonomous, others require power supply from EPM.

MEEMM first activities were held on January 21st, 2009 and Cardiolab on February 9th, 2009. MEEMM and CDL have been used for several years, until March 2013 for MEEMM and April 2015 for CDL main unit. Several protocols were tested, implying the usage of EPM for 2 to 3 days in a raw, a dozen of time per year, for 2 to 14 hours of daily usage. Autonomous instruments from the CDL experiment have been used after 2015 and are still used today. Their operational concept can include the use of EPM to download data via the Laptop, or be completely independent from EPM.

MEEMM and Cardiolab main units were initially certified for a 10 years operational life, which have been extended in 2016 to "Unlimited (ISS End of Life)". After several years being unused, MEEMM and CDL main units have been decommissioned and trashed in the frame of ANITA-2 installation in 2023, see following section 7.

In parallel to the first experiment executions of MEEMM and CDL, a new payload has been installed in Columbus and required recurrent operations on EPM: Dose Distribution inside ISS (DOSIS).

2.4. DOSIS

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DOSIS has been installed and connected to EPM in 2009. The scientific objectives of DOSIS are:

- to measure radiation field parameters such as absorbed dose and particle fluence as well as dose equivalent at different locations inside the ISS, using passive and active radiation measurement devices.
- to refine radiation transport calculations through realistic shielding distributions of the ISS
- to assess the radiation exposure of the astronauts working on board

The DOSIS experiment is composed of:

- the DOSIS main box, located at EPM Utility Interface Panel (UIP, on EPM deck side) level and powered via Columbus Standard Utility Panel (SUP). It is also connected to EPM RUDP via LAN cable for data transfer. The main box includes two DOSTEL (Dosimetry Telescopes): two active radiation detectors oriented 90° to each other
- a DOSIS Triple Detector Package (TDP) attached to the DOSIS Main Box with Velcro (passive hardware)
- Ten DOSIS Passive Detectors Packages (PDP), spread over Columbus cabin but not linked to EPM uploaded with some vehicles twice a year and staying on board only for a couple of months to be later downloaded and analyzed.

The configuration of DOSIS installed on EPM is shown in Figure 4.

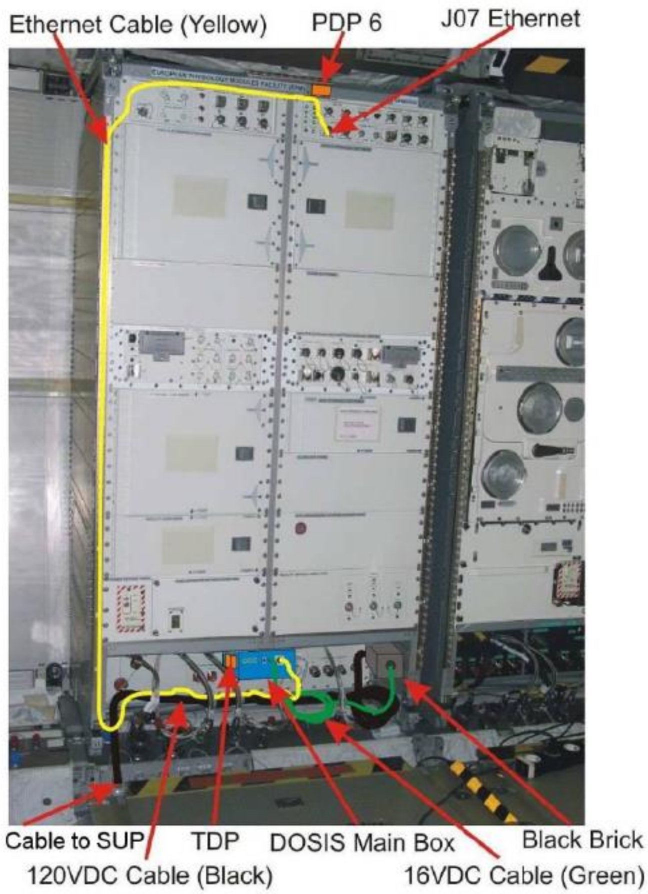

Figure 4. DOSIS main box configuration on EPM ©EADS

The operational concept of the active part of DOSIS is that the DOSTELs are gathering data, transferring them to the DOSIS main box. The data can then be transferred to ground through EPM via a LAN connection by CADMOS OPS using commanding who finally share the data with MUSC, the USOC responsible of DOSIS located in Cologne, Germany. Such downlinks are performed every month since the very first one on July, 31st 2009.

There has been a pause between mid-2011 and mid-2012, during which a new version of DOSIS, DOSIS-3D has been uploaded and installed. The new version of DOSIS works since the first downlink made on June 6th, 2012.

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From its installation, DOSTEL-1 made 3803 days of science data and DOSTEL-2 made 4467 days of science data, which data have all been downlinked through EPM by CADMOS.

All in all, from 2008 to mid-2014 EPM was ON between 20 and 30 days per year, including the maintenances necessary to check the rack good health, the software update on the rack, on the EPM laptop on the and anomaly handling.

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3. First Evolution: arrival of plasma experiment named PK-4

3.1. Experiment overview and scientific objectives

The first big evolution of the EPM rack took place in 2014, with the installation of the Plasma Kristall-4 (PK-4) experiment during Increment 42. PK-4 is an experiment for investigating complex plasmas developed by OHB. A complex plasma is a plasma that contains electrons, ions a neutral gas and micro particles or dust grains (that's why it is also referred to as dusty plasma). The installation of PK-4 generated a new EPM configuration called EPM-2 as for instance Cardiolab module that moved to the right side of EPM to let PK4 occupy the whole left side of EPM, as described in Figure 5.

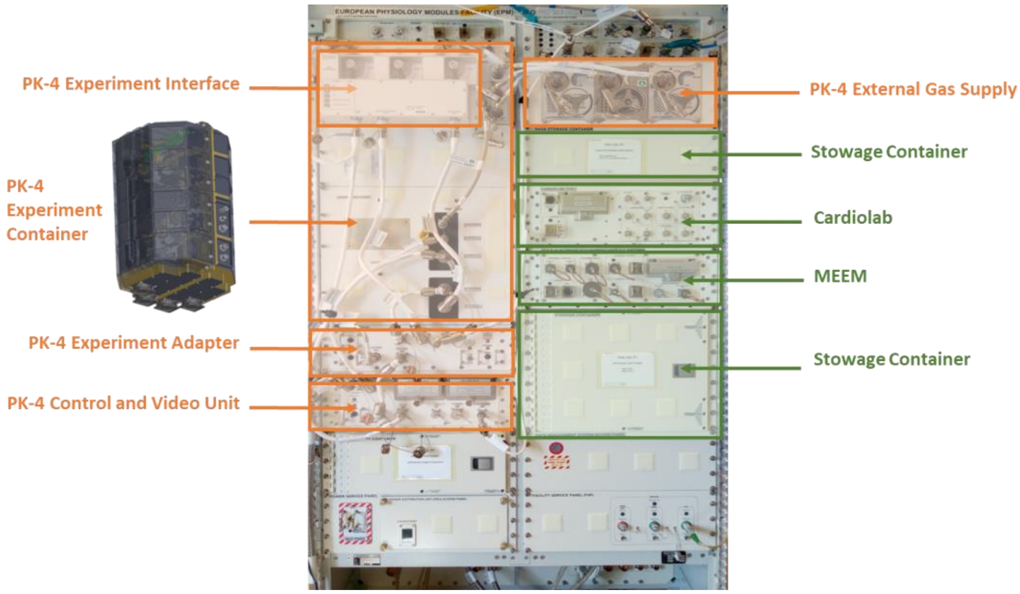

Figure 5: EPM-2 Rack configuration after PK-4 Experiment installation

PK-4 has not been conceived to perform a specific experiment, but as a platform enabling the possibility to execute a large variety of experiments related to complex plasmas comprising the study of their microscopic properties (e.g. charging of particles, fundamental interactions between particles, agglomeration and particle growth), macroscopic properties (viscosity, equations of state, lane formation or self-organization) and generic properties of classical many-body systems.

The PK-4 Experiment Facility is composed of an Experiment Container (containing the plasma chamber, the vacuum system and all the subsystems required to perform the scientific experiments), an Experiment Adapter (providing mechanical, electrical and venting interfaces between PK-4 and the EPM rack), the Control and Video Unit (that provides the communication services between the experiment and the rack and serves as storage of all the data generated during experiment sessions) and the External Gas Supply (consisting of 3 gas bottles containing argon, neon and a mixture of argon and oxygen).

In 2017, a problematic leakage caused by an improper closing of one of the gas valves was detected on PK-4. This was resolved via the installation in July 2018 of an additional module known as the Experiment Interface. This module contains a gas flow controller and 3 external manual shut-off valves.

3.2. Operational concept

A typical science campaign lasts 8 days of continuous 24/7 operations, comprising the preparation of the system for the science runs, the execution of the science itself and the post-processing of the generated data. During this time, the operator on console is continuously commanding the EPM and PK-4. Figure 6 represents a high level overview of a PK-4 science campaign flowchart:

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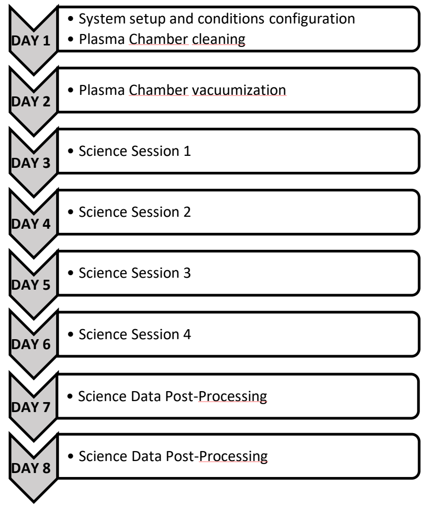

Figure 6: PK-4 Campaign flowchart

3.3. Resources utilization

Prior a PK-4 science session starts, a vacuum needs to be created in the plasma chamber to put the system in the optimal conditions for science. To do so, the experiment needs to be connected to the so called Columbus Ventline interface via an external flexhose (this line allows the venting into space of the gases used by the different racks in the Columbus module). With the help of a turbo-molecular pump (and after 36h of continuous pumping), the desired pressure of ~10^{-5} bar is reached. Up to our days, PK-4 is the only payload in the EPM exploiting the connexion to the Columbus Ventline.

The video recorded during each PK-4 science run is also displayed in a video monitor on-board the ISS, that is deployed by crew specifically for the PK-4 campaign. The video is broadcasted using one of the Video Cabin Assemblies (VCA) available in Columbus. This can serve for two purposes:

a) It gives the possibility for PK4 PIs on ground to follow via the on-board camera the execution of activities on this videos monitor.
b) It gives also the possibility for a crew to be able to follow the execution of a script, during the first fifteen campaigns, it was recurrent for some scientific scripts that the crew had to perform so-called 'particle catch' since it was time sensitive for science purpose, ground had too much latency and only crew was able to perform a correct catch via EPM commanding on the EPM laptop. CADMOS operator would be enabled to talk directly to the crew on-board to guide them for a more efficient science execution. Starting from campaign 16, PK4 PIs managed to enhance their scientific script in order for ground to execute them remotely without crew assistance.

Additionally, the EPM High Rate Data and Video downlink resources are specifically booked during a PK-4 campaign since they are required to obtain live video of the internal experiment cameras and to share it with the Principal Investigator (PI) following the science campaign.

The most notable resource utilized during a PK-4 is probably the so-called crew time. Each PK-4 campaign requires between 5 and 8 hours of crew support, consisting of activities such as installing the video monitor, opening/closing the external manual shut-off valves to perform the different gas exchanges or checking that the camera is active and pointed towards PK4/EPM. On top of that, and due to the high amount of commands sent and being potentially time-sensitive while science is being executed, CADMOS is enabled for block commanding, which means that commands are not announced on the dedicated communication loop.

3.4. 10 years of PK-4 operations

PK-4 was designed and certified to be operational until effectively the end of the ISS, except for the so called Pressure Release Valves contained inside each Gas Bottle Assembly in the External Gas Supply module (i.e. 6 valves in total), which were certified for 10 years of operations. The high yield of science results of PK-4 motivated the

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approval of a life extension activity of these pressure relief valves in October 2024, to ensure the continuation of PK-4 operations.

The PK-4 life extension activities consisted in the deinstallation of each Gas Supply Assembly and its partial disassembly, to reach each pressure relief valve. With the aid of a hand pump, a pressure sensor and a dedicated software, each individual valve could be triggered open and tested, confirming that they were still functional as expected. Since the PK-4 gas hoses had to be disconnected to enable the manipulation of the Gas Supply Assemblies, the activity was followed by a complete PK-4 leak check. This recertification campaign was performed by a Russian Crew member during over 10 hours of crew time, and supported by CADMOS from ground.

Since its installation in the EPM rack, PK-4 has enabled the execution of 20 successful science campaigns extending over 10 years and with the recertification activities completed successfully, it is expected to perform at least 5 additional campaigns (at a rate of 3 per year during 2 years).

The histogram below in Figure 7 shows the number of PK-4 campaigns executed per year since 2014 (including commissioning and various maintenance/recertification activities):

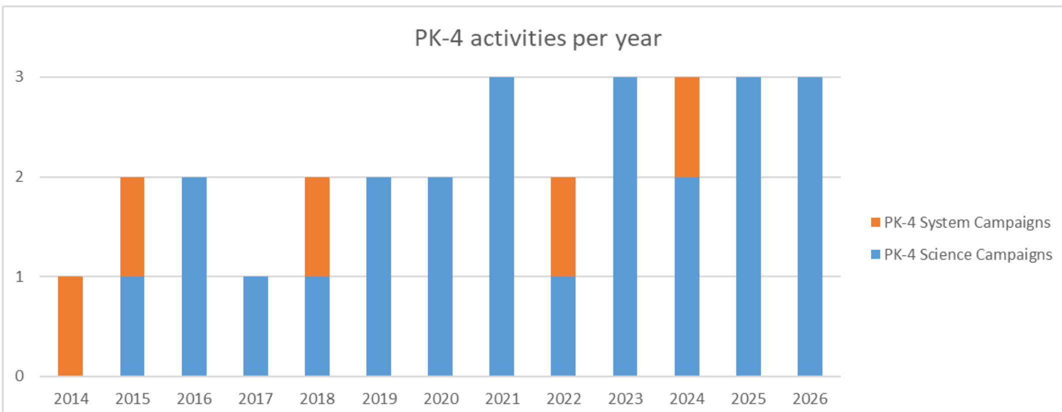

Figure 7: Histogram of PK-4 activities since its installation in 2014

Where the PK-4 System Campaigns correspond to the following activities:

- 2014 → PK-4 Installation and Check Out
- 2015 → PK-4 Commissioning
- 2018 → PK-4 Experiment Interface installation
- 2022 → PK-4 CVU motherboard repair
- 2024 → PK-4 Pressure Relief Valves Recertification Campaign

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4. Second Evolution: Installation of ICE Cubes Facility

4.1. Installation of ICE Cubes and impact towards EPM operational concept

In June 5th, 2018, a new payload has been installed inside EPM: International Commercial Experiment (ICE) Cubes. It was the first commercially oriented payload in Columbus. It consists of a framework that can accommodate in up to 20 cube-shaped containers, placed in the ICE Cubes facility (ICF, see Figure 8) and operated by the private company Space Applications Services. The ICF is designed as an integrated payload, harnessing resources from the EPM (TM/TC via the MIL-STD-1553 Bus, Power 28 VDC, air cooling via forced air ventilation and smoke detection) and distributing it to the different Cubes according to their needs. The exact number, size and content of those cubes vary depending on the missions and scientific needs. Cubes can be as small as 1U, up to 4U, and can contain various experiments like a kaleidoscope or an investigation to study the coalescence of droplets of different liquids. Batches of new cubes are uploaded regularly since then and installed in EPM for the duration of their mission. Interventions by crew are mainly necessary for Cubes installation/de-installation.

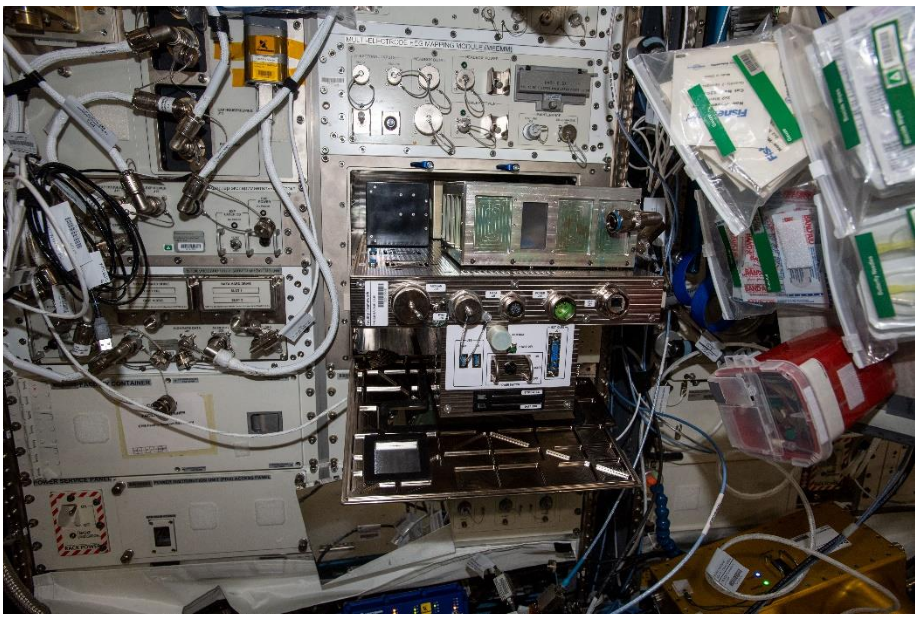

Figure 8: The ICF integrated inside EPM, with the front door open and a 4U cube installed ©NASA/ESA

The ICE Cubes concept is mostly ensured by the use of MPCC, providing near real time TM/TC capabilities to the ICE Cubes Mission Control Center (ICMCC) and its customers. CADMOS is only receiving limited telemetry (temperature, current and voltage) to monitor the good health of the payload on a high-level and can only power it ON or OFF. Hence, CADMOS is only in charge of the ICF interface with EPM, but does not manage the cubes.

Compared to the payload previously integrated inside EPM and presented in sections 2 and 3, ICE Cubes operations require continuous resources from the EPM rack. While before ICE Cubes the EPM rack was maximum kept ON for a week during PK-4 campaigns, with at least one CADMOS OPS and one CADMOS GC on console the whole time of the activities to monitor the payload and the ground segment, starting from mid-2018 EPM was needed to remain active for extended period of time (several months in a row). Due to limited human resources in the Columbus project, ESA requested EPM to be operated unattended by CADMOS and a new concept had to be put in place.

As EPM has not been designed to be operated 24/7 nor left unattended, the EPM Payload Developer put some conditions on this new concept:

- EPM status needs to be monitored whenever the rack is left unattended
- EPM cannot stays un-monitored by CADMOS OPS for more than 12 hours
- EPM status needs to be checked at least once per working day by CADMOS OPS

The main objective of the EPM unattended ops concept is to keep the responsibility of the EPM monitoring within CADMOS, as much as possible. As such, tools have been set up to ensure proper monitoring of the on-going operations

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and notification of the on-call CADMOS OPS in case of anomaly. This tool is called the EPM Remote Monitoring System, based on the EPM Data Externalization. This has been a common work between CADMOS and OHB, the EPM PD. The deployment of such tools has been facilitated by the absence of EPM rooted caution and warning event on-board the ISS.

4.2. Introduction of 24/7 on-call support implementation

The idea behind the deployment of the Remote Monitoring System is to prevent CADMOS operators from a 24/7 on console duty. Since the end of the ICE Cubes commissioning in August 2018, during which CADMOS provided the usual on-console support during office hours, no 24/7 CADMOS support on console has no more been ensured for ICE Cubes daily operations.
CADMOS is working on a best effort basis to ensure ICE Cubes mission success and science objectives completion, taking a special care to keep its rack up and running for its own good and the one of its other hosted payloads.

4.2.1. On-call team

In order to set up the EPM unattended operation, the following set-up has been put in place: a dedicated team has been trained to become the EPM unattended OPS team. All the members are already certified EPM operator. A minimum of 5 persons is needed to cover a year of unattended operations. It was decided to split the responsibility each week to a different operator, from Monday to next Monday (or next working day in case of banking holidays). As per contract, the on-duty OPS shall be reachable 24/7 during his/her on-duty week and shall be able to reach console in maximum 2 hours if requested. The on-duty OPS is on site 8/5 and on-call the rest of the time.
The EPM unattended OPS team is backed-up by the EPM operator lead at CADMOS as needed, the EPM PD at OHB System and the CADMOS ground segment expert teams (as Ground Controller and Operational Maintenance), only during working days and office hours.

The EPM unattended OPS team is due to comply with the work regulations. Some examples among others:
- No more than 10h of shift in a raw, and exceptionally 12h, taking into account the travel from and back home.
- Have 35 hours weekly break every 7 days and a 11 hours daily break.
- Use a triggering device when working alone in the control room facility if one is somehow falling.

The EPM on-call team has the following hardware at its disposition:
- Two phones dedicated to EPM unattended OPS that receives phone calls from the automated EPM monitoring tool when there is an anomaly. Only one is used at a time and provided to the COL FCT, but the second one is always available in case of contingencies.
- Professional phones: this gives the on-call person a back-up in case the prime phone shall be turned OFF for whatever reason.
- Three laptops dedicated to receive EPM telemetry remotely from home. Only one is used at a time, but the others are always available in case of contingencies. In order to have data externalization at home, a fixed IP is needed at home.

4.2.2. Daily check

Before the installation of ICE Cubes inside EPM, CADMOS managed its operations by having at least one operator on console during the execution of an EPM activity. For those standard operations, more personnel might be needed depending on the complexity and sensitivity of the operation such as PK-4. Some experiments require CADMOS to perform commanding of EPM (DOSIS, etc.) while others consist in providing support to the crew and COL-CC in performing experiments.

The introduction of the 24/7 on-call support did not have any impact on these standard operations, with one exception. The Remote Monitoring System is now always active, but only used by the CADMOS OPS on-duty to monitor EPM while the console is unmanned. Hence, a daily check on working day has been put in place to ensure that EPM is left in a good configuration by the CADMOS OPS that has performed his/her operations on EPM, before leaving console and transferring the responsibility of monitoring to the CADMOS OPS on-call. Thr daily check contains the following steps:

a) Check EPM and ICE Cubes Telemetry

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b) Check monitoring system is working (good health of the ground segment, including data externalization and monitoring system), more details are given on the tools in section 4.6.
c) Check the maintenance status on COL-CC side that might impact the ground connection between CADMOS and COL-CC.
d) Preventive actions to prevent ground segment issues (CCSDS log compression in EPM console) and EPM logs are sent to EPM PD on a weekly basis.
e) Report nominal status (or not) of the daily check to the relevant positions.

4.3. Anomaly handling

EPM does not have internal rack telemetry that utilizes Caution & Warning Bits. Following Cautions are associated with EPM but are formally Columbus System related to smoke detection or fan status inside EPM and shall be responded in coordination with Col-CC and CADMOS:

- EPM – Smoke Detector Fail
- EPM – Smoke Detector Lens Contamination
- EPM – Smoke Detector Active BIT Fail
- EPM – Fan Failure

In case some of the responses require a power cycle of EPM, it is agreed (with no harm to EPM) that Col-CC hard shutdown EPM if on-call OPS is not on console to perform a graceful shutdown when needed. On-duty EPM operator will be alerted of the operation by Col-CC and will assess if a reactivation is possible.

The EPM rack has an internal alarm system that monitors EPM Health & Status. Whenever a parameter value is off-range or when a command is sent in a non-correct mode, the system triggers an alert message that can be analyzed by the EPM Remote Monitoring System to warn the on-duty operator. When an alarm is received by the on-duty operator, she/he analyzes the origin of the anomaly using the EPM telemetry received remotely and decides whether any troubleshooting steps are required. If needed, CADMOS OPS can come on console to take the possible corrective actions. Recurrent anomalies are known to happen on any payloads and therefore also EPM. By experience, EPM is likely to trigger some of those anomalies when operated continuously on a long period of time. Most of the recurrent anomalies of EPM are well identified and understood. They can usually be treated on next working day, without an intervention of the on-duty OPS on site.

The response time for CADMOS OPS to take any action when an alert is received will be provided on a best effort basis and will depend on the criticality of the situation. Nevertheless, CADMOS will guaranty a maximum reaction time of 12 hours to cover the worst case scenario when EPM remote monitoring system will fail during the night and allow for having 11 hours of daily rest as per French regulation laws.

4.4. Unexpected discoveries and updates

As it was the first time EPM was kept ON for such a long time, new anomalies have been discovered on a payload already operated for ten years. Among those, we can mention:

- Housekeeping value higher/lower than the highest/lowest limit: these anomalies were only sporadic before ICE Cubes, and were then received almost daily afterwards. It appears to be most of the time glitches in the telemetry. While in the first months CADMOS OPS came on console every time to investigate the issue, they are now recurrent anomalies that do not need to be reported since the status come back to nominal automatically.
- More globally, before ICE Cubes there was six recurrent anomalies linked exclusively to EPM, five more were added afterwards.
- The reset of the SMSC clock every 11d 13h 41mn has been discovered. It was an unknown behavior of SMSC which implies an automatic reset of the SMSC. The discovery has been made thanks to the periodic EPM log transfer to and analysis by EPM PD. Currently a preventive reboot of the SMSC is performed weekly to prevent this anomaly from happening.

As the daily check was always performed on console before COVID and the remote office development, this period offered the possibility for discussing this requirement and now the on-call operator has the possibility to perform the daily check either from home (calling console directly on the phone) or from console at CADMOS.

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4.5. *Critical cubes impact*

Some cubes inside ICE Cubes have strong scientific constraints and do not allow EPM to be powered OFF due to science loss. This comes in contradiction with the fact that from PD inputs, EPM cannot stay un-monitored by CADMOS for more than 12 hours.

The situation has been encountered during the 2020 Christmas break, when there was a major anomaly that prevented Ku-band communication for almost three days between ISS and ground. When CADMOS OPS asked to power off EPM as per current documentation as no TM was received for more than 12 hours, the request has been rejected by the COL FCT due to the installed cube which was a critical one and will have induce a science loss. It was possible for Col-CC to have a very high-level surveillance of EPM via S-band telemetry to cover the loss of monitoring capability from CADMOS, and later on a clear concept has been defined, as follow.

- The period during which Col-CC could take over the EPM monitoring in case of contingency is pre-coordinated with the ESA manager. Such monitoring cannot be applied out of this timeframe and is only applicable during critical ICE Cubes science.
- Several off-nominal cases have been identified and transmitted to the involved parties. In each scenario, it is explained: the impact on the monitoring, the actions to solve the anomaly, the responsible for anomaly resolution, the estimated duration for recovery and the risk mitigation.
- A dedicated display on Col-CC side with basic EPM Health and Status data, validated by EPM PD, has been created for them to follow the pre-coordinated EPM parameters on a daily basis. In case an off-nominal value arises, then the on-call EPM operator should be informed and will indicated if required actions are needed.
- Initially, the EPM ground segment was not designed to receive the EPM Health & Status telemetry that were only part of the S-band packets. Afterwards, an additional work has been performed on the processed parameters to be able to receive at CADMOS high-level overview of EPM TM from S-band packets.
- In the very worst case neither CADMOS nor STRATOS can monitor EPM, crew procedures have been worked to allow the crew to perform a daily check of EPM thanks to the EPM laptop.

4.6. *Monitoring tools*

In order to achieve EPM unattended operations, CADMOS has installed an automated notification tool relying on the EPM TM Data Externalization tool, developed by OHB, allowing a remote user to monitor EPM telemetry. A data monitoring system from CNES called Sygale was adapted to CADMOS needs in order to support the remote monitoring of EPM.
OHB EPM monitoring solution in 2018 forwards to syslog the following events (see Figure 9):

· EPM Messages with error flags.
· EPM HK TM with anomaly flag.
· Network connection between EPM link server and reception of EPM TM via DAG.

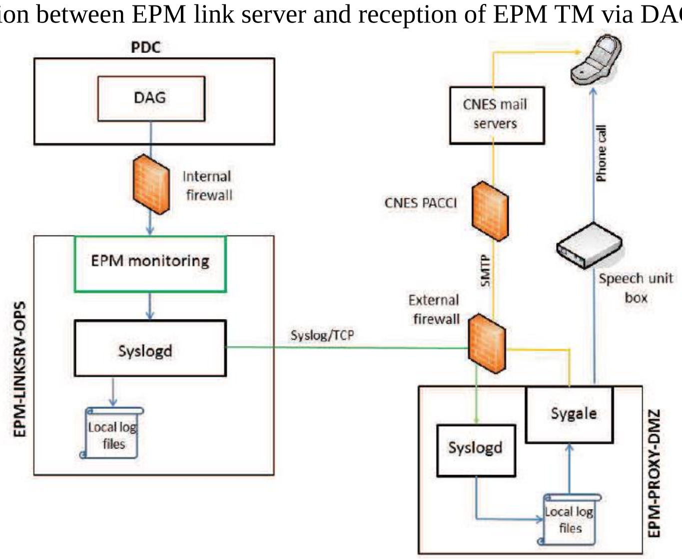

Figure 9: Remote monitoring concept ©CNES

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A blacklist has been configured to ignore specific EPM flag not required by OPS team (like EDAC failures). A whitelist has been configured to add specific informative flag message that would be required by OPS team (like telemetry back to its nominal range). The alerts to be forwarded to the on-call operator are preselected in accordance with CADMOS and OHB expertise with EPM. Alerts are then transmitted using syslog over TCP protocol to prevent loss of packets. The network link is also monitored and a phone call is triggered if it is somehow failed. The logs that go through the patterns are generating analert which is forwarded:

- By a phone call to 2 dedicated phones (using voice modem called Speech Unit)
- By email to a generic operational address

In case of an alert, on-duty operator can further analyze the problem by using a laptop installed with Data Externalization solution receiving EPM telemetry. This laptop is hosting a virtual machine with OHB EPM Control Panel software: no TC can be sent but all EPM telemetry can be analyzed using this way. To make sure the EPM remote monitoring system is up and running, it also sends a "Heartbeat" every hour under the shape of an email to the on-duty EPM OPS. If the heartbeat stops or is inconsistent, the operator will take actions to assess the ground segment problematic. Very recently a new CNES tool has replaced Sygale and is called CAD-ALERT. This tool provides an updated interface with the usage of the Yamcs ground segment introduced for EPM in 2022.

The unattended OPS concept is restricted to ICE Cubes (not applicable when PK-4 is active for example).

4.7. A new challenge for ICE Cubes and EPM: Laplace

Since late 2020 a new project is in development for ICE Cubes called Laplace. Laplace is a microgravity experiment addressing planetary science, more specifically focusing on the study of dust particles. The objective of Laplace is to shed light onto the question of how planets form in protoplanetary disks. In a broader context, the scientific objectives of Laplace are the study of dust-dust, dust-gas and dust-light and agglomerate interactions.

The Laplace Insert will be inserted into the ICF Container, and replace the ICF Framework for the duration of the Laplace mission. The operational concept of Laplace is derivate from the ICE Cubes one. However, the Laplace Insert is more complex than a standard Experiment Cube and requires additional interfaces, resources, and coordination:

- During the experiment runs, Laplace will need more power than its location on EPM can deliver. Hence, a power cable will bring additional power from the EPM LUDP to Laplace (same way as for PK4). Due to this specific configuration, PK4 and Laplace cannot run in parallel otherwise the incoming LUDP outlet would trip.
- During the experiment runs, Laplace will need venting and nitrogen from COL. The venting will be provided through the vacuum line of the COL1A3 UIP. It is to be noticed that it will be the first time Nitrogen and Vacuum of COL1A3 UIP will be used.
- The use of the vacuum line for venting and the intensive use of both vacuum and ventline lines for several payloads raised lots of engineering topics and coordination issues to allow each payload to perform its science when desired. Other payloads inside COL will need to use the vacuum line and it is important that the usage of the vacuum line from one payload does not jeopardize the science of another.

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5. Stand-Alone payloads using EPM as a support: GRIP & GRASP, Myotones, ECHO, MARES, Easy-Motion

A lot of other payloads were interested about a unique and very useful feature of EPM: to be able to downlink data using basic TM/TC from EPM. This feature may seem easy but is not so straight-forward and not so spread among payload racks. Therefore, some payloads, often physiology experiment because CADMOS was also responsible of them, wanted to have this advantage to collect data straight after operations. For physiology experiment it was particularly interesting since data was collected on a specific device, then connected to EPM laptop – more details in Section 6 – via USB connection and ultimately data are simply downloaded to ground via basic commanding.

Myotones was a stand-alone physiology (SAP) experiment with the purpose to study the muscular evolution in weightlessness for a long-time duration mission.

ECHO is a SAP physiology experiment performing echography measurement in space with the difficulty of having the astronaut being the operator and subject on ground while having PIs remotely helping the crew to take the best echography measurement as possible.

MARES was a rack installed in COL and was used from 2015 to 2019 to carry out research on musculo-skeletal, biomechanical, neuromuscular and neurological physiology, to study the effect of microgravity on the human being, and to evaluate the efficiency of the countermeasures against space environment-induced physiological effects. It can also be used to evaluate the performance of exercise tests protocols.

The three payloads were following the same approach: they are SAP and experiments measuring scientific data and generating data. After the measurement on the crew, the stand-alone devices were plugged to the EPM laptop via USB connection and the according data were downloaded to ground using EPM commanding towards CADMOS. Those physiology data are then encrypted and shared to the dedicated scientific community. This operational concept was heavily used in an efficient way through several years. Figure 10 presents a very high-level schematic of the EPM laptop concept downloading physiology data.

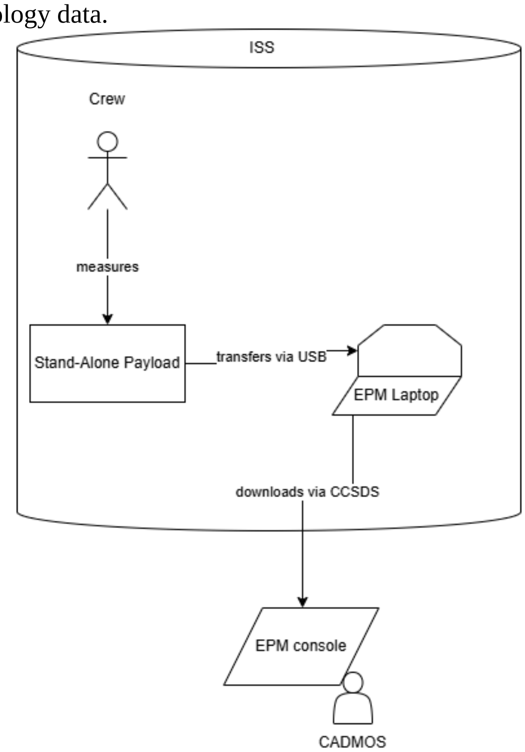

Figure 10. Schematic of a data transfer using EPM commands for a stand-alone payload

Another specific example is the GRIP experiment which was a mix between a SAP being installed inside COL using the EPM interfaces for the LAN data and a 120V power provision. A set of GRIP TM/TC was added to the EPM library in order to command the payload and after the measurement, scientific data were downloaded to ground via EPM console. The purpose of the GRIP experiment was to carry out research on dexterous manipulation in weightlessness through time. It helped to study the long-term adaptation of grip-force, the effect of weight versus mass, the optimization of movement kinematics and dynamics and the evolution the grip force during controlled collisions.

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Last example of a payload supported by EPM was Easy-Motion. This stand-alone payload had a very specific usage since it needed to be charged at a certain voltage and one solution was to be plugged to the PK-4 experiment, powered for the sole purpose to charge Easy-Motion experiment.

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6. Evolution of EPM Laptop: towards COL Payload Laptop using EPM Virtual Machine

As slightly described in the previous sections, an important feature of the EPM is its laptop. In 2008, an EPM laptop was launched with EPM rack and serves as a sub-unit of EPM called LapTop Unit (LTU). At the beginning, the Operating System was installed in a Lenovo T61p laptop as in Figure 11 below using Windows XP. It served as a man-machine interface either for experiment, file transfer or rack manipulation by crew using TM/TC via direct LAN interface towards EPM. There is, as well, the possibility to use TM/TC from ground console to manipulate EPM laptop. LTU of EPM is plugged to EPM to receive power at 28V from the RUDP.

Figure 11: Lenovo T61p laptop © Lenovo Wiki

6.1. Commands via CCSDS for file manipulation and batch file launch

One way to use the EPM laptop from ground is via the CCSDS protocol. Taking advantage of the LAN interface between the laptop and EPM, there is then the possibility to communicate with it from ground. Several useful features are implemented such as:

- Wake-ON Lan: thanks to the LAN connection being always in place even if the laptop is off, there is a possibility to use a Wake-up LAN command with the MAC address of the destination laptop. This way there is the possibility to start the OS of the laptop remotely and without any crew action on board.
- File manipulation: one of the most powerful and useful feature is this one. Being able to simply manipulate files allows for instance, for a crew in the ISS to copy files using external devices and ground console to downlink the file to the ground remotely using TM/TC. This has been heavily used for physiology experiment using stand-alone devices.
- Batch launcher: another powerful command introduced on EPM commanding around 2015 was the batch launcher. This command is able to run a batch file with a specific name in a specific folder, using batch files already uploaded on board inside the EPM Laptop. For instance, there is the possibility to zip folder, take laptop screenshot, among others.
- Shutdown of computer: in the same way as for the Wake-ON LAN, there is the possibility via commanding to shut down the OS and therefore power off the laptop remotely.

All those features allow an independent utilization of the EPM Laptop from ground without any crew action therefore making it very useful.

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6.2. On-board commanding from crew

The LTU offers the capacity to utilize its MMI in order for any crew on-board the ISS to manipulate EPM FM using TM/TC via a direct LAN connection between the LTU and EPM. This scenario can be used in case of contingency if the ground segment is somehow unavailable and there is a time critical activity or a mandatory activity to be performed. This can also be useful in case of repair after an anomaly on the EPM to be able to send low-level basic commanding to FCC (EPM main computer) which can only be done via a serial connection directly between FCC and LTU. Figure 12 presents an excerpt of the EPM MMI interface for the crew – which is highly similar to the one on ground.

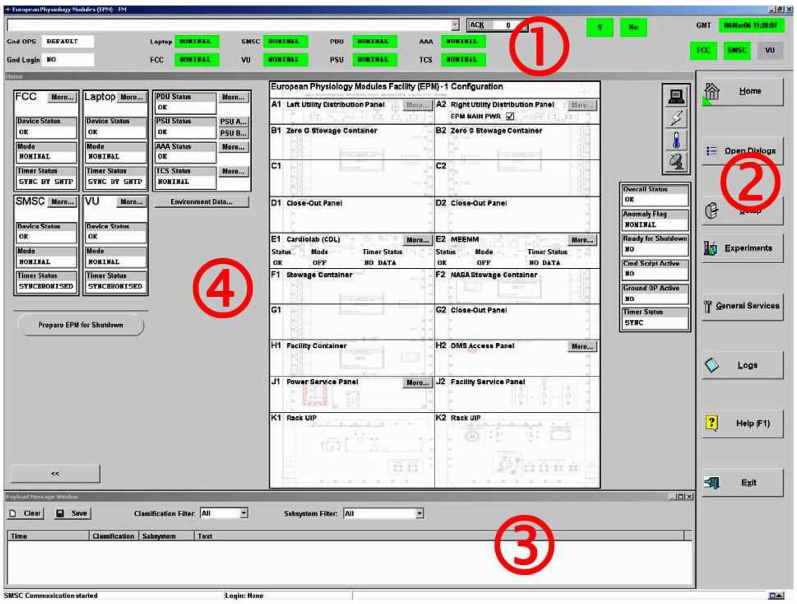

Figure 12: EPM MMI for the crew

The EPM main display is divided into four sections:

1. The Payload Status Area includes the alert bar, which is responsible for displaying alert messages, the current time, the status of the main components of the system, the status of the ground login and the ground communication bands.
2. The Primary Button Panel serves for navigation among the displays.
3. The Payload Message Window indicates messages and alerts from the system.
4. The Workspace Area is the region where displays may be opened. The displays do not cover the other sections.

6.3. Transition to a new laptop: creation of a virtual machine while keeping the same operational concept

As of 2021, ESA transitioned all their laptops on board from the former T61p to the new HP Zbook, see Figure 13. This new laptop is using Windows 10 but the old EPM laptop OS was still using Windows XP therefore the introduction of the EPM Virtual Machine inside the so-called COL Payload Laptop. Its OS would be in Windows 10 and having some specific VM dependent on the payload, in our example an EPM VM in Windows XP.

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Figure 13 : HP ZBook G2

Some reconfiguration was required in order to be iso-concept *i.e.* being able to use the EPM VM from ground-only. The idea was to keep the Wake-ON LAN and the shutdown of the EPM VM OS but this was not possible due to the addition of the COL PL Laptop OS in Windows 10 layer. It was possible to modify the Wake-ON Lan command by using the new MAC address of the new ZBook laptop but the EPM VM has to be started automatically at some point since the EPM can only connect to a certain software launched when EPM VM has started. For that we have introduced a Windows task which is starting automatically the EPM VM at startup of the COL PL Laptop OS. The other way around, a Windows task for shutting down the COL PL Laptop OS when powering off EPM VM was required. By using the same command as before to shut down the EPM laptop, now it would only power off the EPM VM. This new task would be checking every 5 minutes if the EPM VM is still running, if yes, then it will continue to perform the frequent check, if not it would then power off the COL PL Laptop after 5 minutes.

Later on in 2024, for security reason, the EPM finally transitioned to a Windows 10 OS after Windows XP. This operation was transparent with regards to the COL PL Laptop concept and the Windows task were still present to operate the EPM VM remotely from ground.

6.4. In the future: remote desktop connection to the COL Payload Laptop

New discussion arose recently about introducing a Remote Desktop access capacity for the Zbook laptop and therefore being able to access the EPM VM remotely from CADMOS control center using the MPCC, which use another protocol used to communicate with payloads on board the ISS. This feature would allow to have a deported screen of the Zbook laptop and use it from ground as if someone was in front of it. Knowing that currently the usage of the EPM laptop and afterwards EPM VM is done blindly via telecommand and therefore offers less functionalities then having a RDP access. Namely to be able to install or deinstall software from ground, to perform security patch updates from ground or to change the set-up of the virtual machine among others.

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7. Third Evolution: ANITA-2 installation thanks to a mechanical adapter

In March 2023 a new Class-2 payload called ANITA-2 was installed in the EPM. This payload aims at demonstrating the air monitoring capabilities under realistic condition in a space habitat, including the dynamic variation of air contaminants caused by astronaut activities, scientific experiments, degradation of space hardware over time and microbial activity.

ANITA-2 was accommodated in the EPM C2-E2 position. However, due to its dimensions (the payload was originally conceived to be installed in an Express Rack and not in the EPM standard), it could not be accommodated as a typical Science Module (*i.e.* horizontally). Therefore, a mechanical adapter so-called Locker Adapter had to be manufactured, consisting of a dedicated interface with the EPM, capable of receiving both ANITA-2 and the NASA Stowage Container in the above mentioned position as outlined in Figure 14.

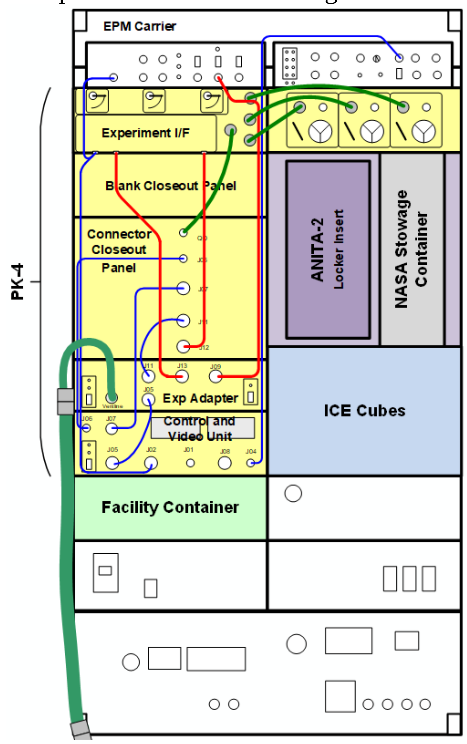

Figure 14: EPM-4 Rack configuration, after installation of ANITA-2

ANITA-2 receives power and cooling resources from the EPM. However, for data exchange and commanding purposes, the payload interfaces directly with COL and the ISS via the so-called MPCC (Multi-Purpose Computer and Communication).

<u>ANITA-2 Operations</u>

The center responsible for ANITA-2 operations is called ECOS and located at the European Astronaut Centre (EAC) in Cologne, Germany. ANITA-2 automatically analyses the air from the Columbus cabin every ten minutes, but it also allows the possibility of manually bringing air from a different ISS module and inserting it into the ANITA-2 facility. This activity, known as a Non-Local Sampling activity, is performed by crew around six times a year usually for a cargo or crew vehicle docking on the ISS performed right after the hatch opening.

Since mid-2024, NASA has acknowledged the interest of using ANITA-2 as an official air analyzer and considers it part of the ISS system called Crew Health Care System (CHeCS). It has now joined ICE Cubes as EPM payloads requiring 24/7 on call support and is now part of the EPM monitoring concept.

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8. Towards the future: Atmoflow

In the upcoming years, the EPM will continue its evolution by replacing the older payloads with new ones. This is the case of Atmoflow, that should be installed in 2027 and will take most of the volume that PK-4 is using today within the rack as depicted in Figure 15.

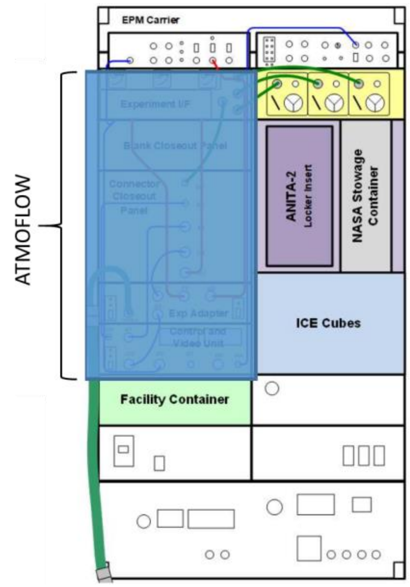

Figure 15: Atmoflow future integration inside EPM

Atmoflow will aim at investigating convective flows in the spherical gap geometry, subject to a central force field. This will be achieved by simulating buoyancy driven convection through a central dielectrophoretic field in the microgravity conditions provided in the ISS environment. Furthermore, the experiment will provide a differential rotation between an inner sphere (representing the planet's surface) and an outer sphere (representing the upper boundary of the planet's atmosphere). This differential rotation, together with the application of lateral temperature boundaries will allow the simulation of a deep planetary atmosphere, as described in Figure 16.

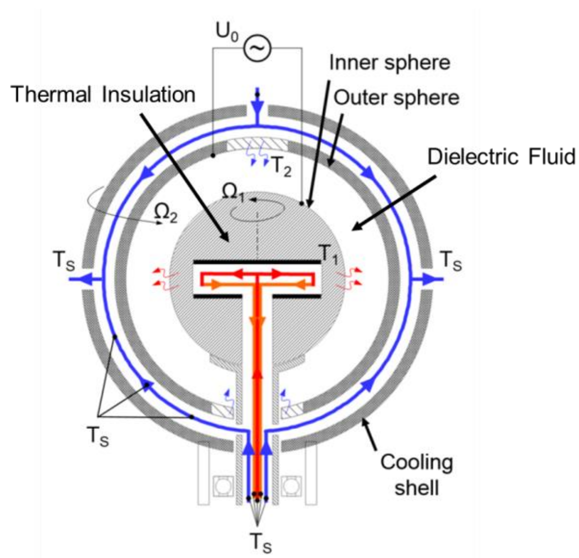

Figure 16: Sketch of experimental concept of AtmoFlow, representing the 2 concentric spheres

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After its commissioning phase, estimated to last around two weeks, Atmoflow will be almost continuously operating for approximately two years, to ensure that all required data points are measured three times. Which will generate over 2000 data points measured in 78 experimental runs (multiple measurements of the same point are required for statistical purposes and representing around 25 TB of data. The commanding and reception of telemetry of Atmoflow will be done both via EPM using CCSDS for the high level manipulation such as power ON/OFF, change of Atmoflow mode, temperature, voltage, current, boolean statuses and also via MPCC for deeper commanding such as science script startup, experimental point set-up, video and images verification. This will make of Atmoflow the first payload hosted in the EPM rack for which CADMOS will be responsible and that will be mainly commanded via MPCC. Therefore, the ground segment ad CADMOS will have to follow up and adapt to this new operational concept.

9. Statistics about EPM operations throughout the years

Throughout time between 2008 and 2025, CADMOS was responsible of EPM operations in COL. In the Table 1 and Figure 17 below, you can find a few data to outline how intensely EPM was operated by CADMOS on console.

Table 1 Relevant data for the EPM operations by CADMOS

	EPM utilization [hours per year]	EPM power cycles	EPM cumulative utilization [hours]
2008	13:26	3	13:26
2009	217:42	32	231:08
2010	87:50	20	318:58
2011	112:27	21	431:25
2012	133:19	27	564:44
2013	121:00	26	685:44
2014	151:12	34	836:56
2015	342:14	29	1179:10
2016	344:43	35	1523:53
2017	246:56	29	1770:49
2018	2644:33	36	4415:22
2019	7280:25	16	11695:47
2020	3691:35	20	15387:22
2021	4419:23	42	19806:45
2022	4171:25	38	23978:10
2023	7552:54	14	31531:04
2024	8001:17	7	39532:21
Total	39532:21	429	

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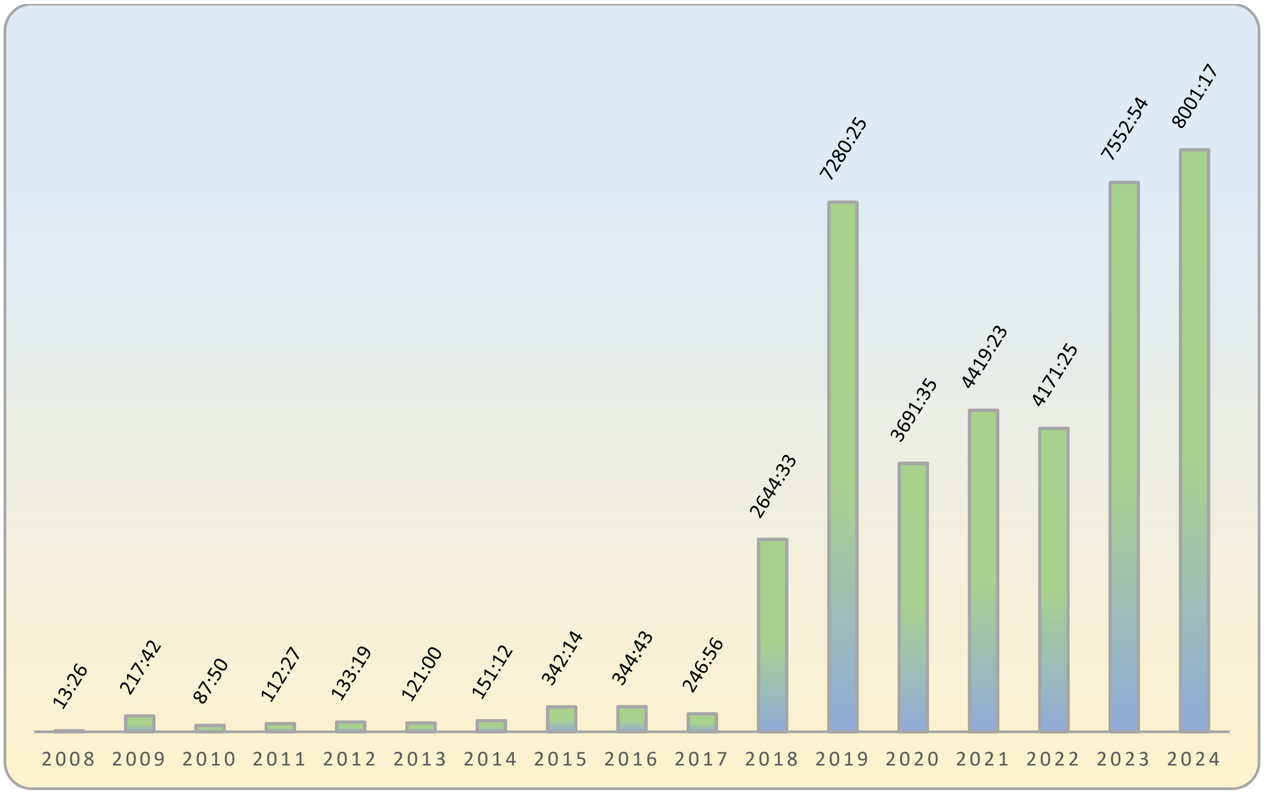

Figure 17: Operation utilization of EPM Flight Model in hours per year

In 2018, ICE Cubes Facility was hosted in EPM and had to run continuously hence the huge difference starting in the middle of this year for the operational utilization. More details about ICF and the change of operational concept is provided in Section 4.

Two huge anomalies respectively on the SMSC in 2020 and the FCC in 2022 lowered the amount of utilization time while creating still a new operational concept for the SMSC failure, whereas it was not possible at all to operate EPM rack while FCC was in failure.

When the SMSC failed in 2020, it rendered impossible for some, and very difficult for others experiments the possibility to control them. Everything inside EPM had to be reassessed to know whether they could be operated without SMSC. At the end, PK4 was not able to be operated at all – possible to power it on but then no solution to receive and send TM/TC; whereas for other payloads such as GRIP and ICE Cubes it was possible to operate them in an off-nominal configuration.

- GRIP: without a SMSC, there was no possibility to send any TC to GRIP payload via CCSDS from ground. Nevertheless, it was possible to plug a laptop including scripts usually started from ground by EPM TC and then crew would be able to start the scripts. Additionally, no GRIP TM is received to ground since it should be passing through SMSC and no time sync are available.
- ICE Cubes: without a SMSC, EPM TM was missing only a couple of parameters on high-level from ICF especially temperatures and booleans parameters giving a quick status. Fortunately, this payload is also connected to MPCC and gives the possibility to ICMCC to operate this payload. The downside of missing the SMSC for ICF was more related to the unattended support of EPM on a 24/7 basis. A certain set of parameters is regulating the surveillance of EPM for unattended ops which should be checked every working day. For the off-nominal situation, it was still possible to keep EPM active with ICF but the parameters to be checked had different values with many errors statuses.
- DOSIS: it was not possible to downlink the created data without a SMSC therefore there was a 6-months loss of science.

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Conclusions

All those discussions allow to conclude on the versatility and always changing operational concept of EPM. Indeed, it was firstly uploaded while being installed in the COL back in the ISS in 2008 with the purpose to serve for physiology experiment as its first two payloads inside it MEEMM and CDL were designed to. After some years, it also helped to support a lot of stand-alone payloads through time such as DOSIS, MARES, ECHO or Myotones. The first change on board inside EPM was the installation of PK4 in 2014 that rearranged the payloads inside it and add a new type of experiment outside of the physiology scope. In 2018, the installation of ICE Cubes Facility totally changed the operational concept of EPM in order to keep it on a 24/7 basis powered. In the future, new payloads such as Laplace installed in ICF will be the first payload inside EPM to use the vacuum and nitrogen and later on in 2027, Atmoflow will be installed instead of PK4 and will need to execute more than two thousand experiments measurements on a daily basis. EPM had a lot of evolution between its early days back in 2008 and nowadays in 2025, mainly regarding its operational concept. A lot of work and energy has been executed on EPM, and there are still a lot of challenges to come!

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