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The Solution Crystallisation Diagnostics Facility, a European Facility for Microgravity Research on Structures from Solutions on Board the ISS

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Abstract: Orbital weightless conditions have been shown to yield better and larger crystals. The Solution Crystallization Diagnostics Facility (SCDF) is a third generation instrument developed by ESA and dedicated to the observation and study with advanced diagnostics nucleation and crystallisation processes of molecules from solutions on board the International Space Station. The SCDF is intended to be used for studies of proteins and large biomolecules, and more generally of any kind of molecules growing from solutions, using the powerful set of diagnostics means available in the SCDF platform. Several protein crystallisation reactors have been developed to study protein and macro-biomolecules assembling sequences. An experiment assembly devoted to the study of formation of zeolites is under study and other dedicated experiment assemblies are considered for future development. Ground models of the SCDF have been developed with similar capabilities to allow scientists to train with the reactors, experiment assemblies and diagnostics available in the SCDF.

keyword: Microgravity, Proteins, Solutions, Diagnostics.

1 Introduction

Perfect crystals of macromolecules are needed to reveal structural information necessary for the understanding of their functions. Weightless conditions encountered during orbital space flights have been shown to yield better and larger crystals. The facilities and instruments used so far to grow crystals in space have mostly focused on the growing of crystals for post-flight analysis, and less on the understanding of phenomena associated to the crystallisation processes.

The Solution Crystallization Diagnostics Facility (SCDF) is an instrument developed by EADS under a contract of the European Space Agency (ESA) to observe and study with advanced diagnostics nucleation and crystallisation processes of molecules from solutions in long duration microgravity as obtained on board the International Space Station (ISS). The SCDF development started in 1997 under the name of 'Protein Crystallisation Diagnostics Facility' (PCDF) due to the initial approach of developing a third generation instrument for studying protein crystallisation processes after several successful flights of a previous instrument, the 'Advanced Protein Crystallisation Facility' (APCF). The word 'protein' appearing in the name of the APCF and PCDF facilities stems from the fact that early crystallisation experiments were conducted mainly on protein solutions; it is only in the last few years that other biological macromolecules and other structures developing from solutions were also regularly studied in space microgravity.

The SCDF is intended to be used not only for proteins and large biomolecules, but also any kind of molecules growing from solutions, using the powerful set of diagnostics means available in the SCDF platform. Several protein crystallisation reactors have been developed to study protein and macro-biomolecules assembling sequences. An experiment assembly devoted to the study of formation of zeolites is under study. Other dedicated experiment assemblies are envisaged depending on the interest of the scientific community.

Ground models of the SCDF have been developed with similar capabilities to allow scientists to train with the reactors, experiment assemblies and diagnostics available in the SCDF.

This paper will introduce the historical background of previous similar facilities, the SCDF concept and design for development, including the crystallization reactors and the Zeolite Experiment Assembly, and the overall operation scenario.

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2 History

The microgravity environment available during orbital space flights offers conditions in which gravity driven effects such as convection and sedimentation are strongly reduced. These effects result on earth in disturbances and non-diffusive material transport. The unique microgravity environment is stated to be an important parameter for exploration of crystal growth [Giegé, Drenth, Ducruix, McPherson and Saenger (1995)]. The most often quoted reason for performing protein crystallisation experiments in microgravity is the need to obtain larger and more perfect crystals that allow a better resolution when using X-ray diffraction to determine the crystal structure.

Since the early eighties, several thousands of crystallisation experiments were performed in space on board NASA's Shuttle during Spacelab or Spacehab missions, on board automatic platforms like the European Retrievable Carrier (EURECA) platform, or on board the Russian Mir Space Station.

In the late eighties, the Advanced Protein Crystallisation Facility (APCF), a second generation instrument for biological macromolecules crystallisation experiments, was developed by a consortium of European companies led by the German company DASA-Dornier (presently EADS) under an ESA contract. Two identical APCF flight units accommodated each 48 reactors using three crystallisation methods: hanging drop, free interface diffusion, and dialysis [Snyder, Fuhrmann and Walter (1991); Bosch, Lautenschlager, Potthast and Stapelmann (1992)]. Ten reactors were observed with a CCD camera for recording motions or growth of forming crystals [Chayen, Snell, Helliwell and Zagalsky (1997); Carotenuto, Sica, Sorrentino and Zagari (1997)].

Since 1993, the APCF has flown seven times in space in Mid-deck Lockers on NASA Shuttle missions and on the ISS: Spacehab-1 (1993), Second International Microgravity Laboratory Spacelab (IML-2, 1994), Second United States Microgravity Laboratory Spacelab (USML-2, 1995), Life and Microgravity Spacelab (LMS, 1996), Spacehab/STS-95 (1998), US laboratory on ISS (2001), and Spacehab/STS-107 (2003). The APCF was the first ESA microgravity facility to fly on the International Space Station, installed in the US Laboratory module [Stapelmann, Smolik, Lautenschlager, Lork and Pletser (2001)]. The model flown on STS-107 was tragically destroyed and samples could not be retrieved for post-flight analysis. Results of some the 426 crystallisation experiments performed in total [Helliwell, Boggon, Pletser, Bosch, Fritzsch, Lautenschlager, Potthast and Stapelmann (1998)], were published [Sica, Sorrentino, Mazzarella, Carotenuto, Raia, Marino, Rossi and Zagari (1997); Snyder (1997); Downey (1998); Esposito, Sica, Sorrentino, Berisio, Carotenuto, Giordano, Raia, Rossi, Lamzin, Wilson and Zagari (1998)]. Their impact on the better understanding of the crystallisation process and the parameters governing crystal quality were assessed [Vergara, Lorber, Zagari and Giegé (2003); Lappa (2003); Lappa, Piccolo and Carotenuto, (2003); Vergara, Lorber, Sauter, Giegé and Zagari (2005); Lappa (2005); Wakayama, Yin and Qi (2005)].

Between some of the early flights, new features were added to the APCF. A Mach-Zehnder interferometer was added before the Spacelab LMS mission to enable, in 5 of the 48 reactors, the observation of the crystal growth process as well as the measure of changes in the refraction index, which relate to concentration gradients caused by diffusion or residual convection in the protein chamber [Stapelmann, Smolik, Lautenschlager, Lork, Pletser (2001); Otalora, Garcia-Ruiz (1998)]. New reactors were developed for the Spacehab/STS-95 mission. These were reactors with extended protein chambers that exploit the self-optimisation feature of the counter-diffusion technique [Garcia-Ruiz and Moreno (1994); Otalora, Garcia-Ruiz and Moreno (1996); Garcia-Ruiz and Moreno (1996)] and reactors enabling observation along two orthogonal directions so as to monitor the motion of freely growing protein crystals throughout the volume of the chamber.

With these capabilities, the APCF enabled to address some of the questions relating to the relevance of microgravity protein crystallisation, in addition to the approach generally adopted with other facilities that is limited to solely post-flight analysis of crystals. Based on the experience acquired with the APCF, a group of scientists expressed the need for a new instrument better tailored for future research on biological macromolecules, focusing on the understanding and characterisation of the optimum conditions of crystallisation and crystal growth processes with advanced diagnostics. A Science Team set-up by ESA reviewed the crystallogenesis of biological macromolecules [Giegé, Drenth, Ducruix, McPherson and Saenger (1995)]. Based on this review, ESA initiated the definition by this Science Team of the sci-

entific requirements for the design and development of a next generation instrument, the Protein Crystallisation Diagnostics Facility (PCDF). Further developments were initiated to accommodate other experimental solution configurations, such as zeolites [Kirschhock, Kremer, Jacobs, Pletser, Minster, Kassel, Preud'homme and Martens (2004)].

3 SCDF Concept and Design

3.1 SCDF concept

The SCDF is a multi-user experimental instrument capable of providing in-depth knowledge and understanding of the nucleation and growth process of macromolecules under microgravity.

SCDF protein reactors use the batch and dialysis crystallisation methods and have the capability of being individually controlled for process temperature and solution composition and/or concentration.

SCDF diagnostics include a high-resolution video system coupled with a microscope, interferometers and a dynamic light scattering system. SCDF diagnostics can be extended in the future to include the capability of osmometry and pH-metry to quantify the changes in physico-chemical parameters of the solution during crystallisation.

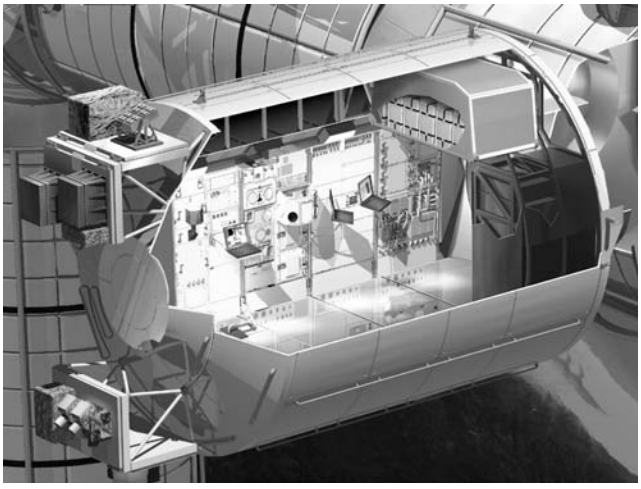

Figure 1 : View of Columbus Laboratory with some of the ESA developed instrument racks. The European Drawer Rack is at the extreme right (ESA/Ducros).

On board the European Columbus Laboratory module (see Fig. 1) to be docked to the ISS, the European Drawer Rack, a multi-user rack developed by ESA (see Fig. 2), will accommodate three drawers (approximately 43x35x60 cm) and four lockers (approximately 43x25x50 cm) [Reibaldi, Manieri, Mundorf, Nasca and Koenig (2000)]. The latter are compatible with the Shuttle mid-deck to transport experiment samples requiring a powered controlled environment from the ground up to the station and back.

Figure 2 : View of the European Drawer Rack with the SCDF electronic unit integrated as a drawer (top middle, right side) and the process unit integrated as a locker (bottom middle, right side) (ESA/Ducros).

3.2 SCDF overall design

The SCDF consists mainly of two parts: an electronic unit accommodating all controls for the performance of experiments, and a process unit, including the process chamber with experiment assemblies in which reactors with experiment solutions will be flown, and additional control electronics.

The electronic unit will be accommodated in a drawer,

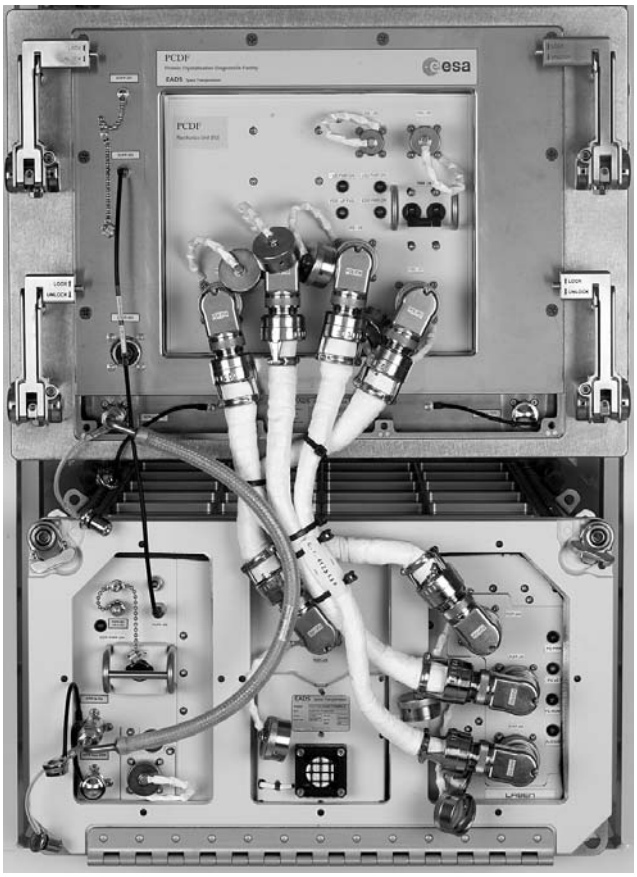

Figure 3 : View of the SCDF electronic (top) and process (bottom) units (EADS).

Table 1 : SCDF protein reactors characteristics

Reactors	Dialysis	XL Dialysis	Batch
Reactor:			
- number	4 (*)	4	4
- material	quartz glass	quartz glass	quartz glass
- envelope (mm)	48x40x101	101x40x44	90x40x65
Volumes:			
- protein (µl)	50, 130, 300	1100	4.3 - 7.3
- buffer (ml)	3 - 5	3 - 5	n/a
- reservoir (ml)	1 (2x)	1 (2x)	1.5 (2x)
Injection:			
- speed (µl/s)	≈ 8	≈ 8	≈ 8
- accuracy (µl)	± 5	± 5	± 5
Stirrer:			
- frequency (Hz)	≈ 1	≈ 1	≈ 1
- rotation	CW-CCW	CW-CCW	CW-CCW
Temperature range (°C):			
• stowage launch/transfer			
in proc. chber	6 - 30	6 - 30	6 - 30
• in-orbit operation			
- in proc. chber	14 - 30	14 - 30	14 - 30
- in reactor	4 - 40	4 - 40	4 - 40
Temperature:			
- sensor	PT100	PT100	PT100
- stability (°C)	± 0.1	± 0.1	± 0.1
- ramps	1°C/h -1°C/d	1°C/h -1°C/d	1°C/h -1°C/d

(*) possibility of installing a 90° scattering channel instead of the Mach-Zehnder Interferometer if only three reactors (instead of four) in the process chamber
Note: CW: Clockwise; CCW: Counter-Clockwise; d: day

while the process unit will be flown in a locker (see Fig. 3), and both will be accommodated in the European Drawer Rack. The process unit will also be used to transport and stow the experiment solutions in a controlled temperature environment in the Shuttle mid-deck, before and after in-orbit processing.

The electronic unit drawer houses first, the Power and Data Electronics, which is the main electronic unit including a power unit, a central processor unit, a control electronics and an optical and video controller unit; and second, the Light Scattering Unit which controls the light scattering equipment. Both units are cooled down by a cold plate that uses the rack moderate temperature water loop of the European Drawer Rack.

The process unit locker includes the process chamber (see Fig. 4), a sort of temperature controlled incubator accommodating four experiment assemblies containing the reactors, each of which can be individually controlled for temperature. The process unit design allows the temperature of the process chamber to be controlled between 6 and 30 ˚ C in the stowage phase in the Shuttle mid-deck during launch, transportation and transfer, and between 14 and 30 ˚ C in the operating phase in orbit when installed in the European Drawer Rack. This provides a first level of temperature control.

3.3 SCDF experiment assemblies and diagnostics

Four experiment assemblies, each housing either a crystallisation reactor or possibly a zeolite reactor, are installed in the process chamber (see Fig. 4 and Tab. 1).

Experiment assemblies include the protein reactor temperature control systems with Peltier elements to individually maintain and modify the protein reactor temperature between –10 ˚ C and +10 ˚ C with respect to the process chamber temperature, that is between a minimum of

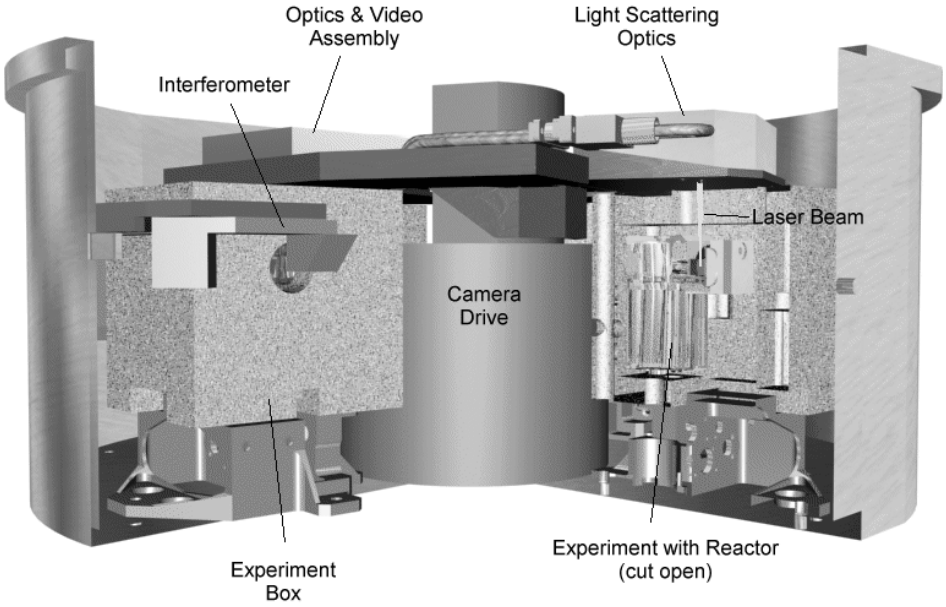

Figure 4 : View of the SCDF process chamber in the process unit showing the experiment boxes and the diagnostics (EADS).

4 ° C and a maximum of 40 ° C, with specified temperature ramps, from 1 ° C per hour to 1 ° C per day. This provides a second level of temperature control. Experiment assemblies also accommodate drive systems for individual injection of solutions in the protein reactor and a rotating stirrer, allowing modification of the composition of the solution to be processed. Individual process controls for temperature and concentration allow several cycles of crystallisation of solutions to be performed.

The protein reactors (see Fig. 5) are made of quartz glass and have four chambers: two reservoirs, a buffer and a protein volume where the crystallisation takes place.

Three types of protein reactors are envisaged that will use either the dialysis or the batch crystallisation method: dialysis reactors with three different protein volumes (300 μl, 130 μl, 50 μl); extended length dialysis reactors with a protein volume of 1.1 ml; and batch reactors with a protein volume of 4.3 ml. Reactors are also fitted with temperature sensors that allow monitoring of the reactor condition and the feedback control of the heating/cooling systems.

The zeolite experiment assembly (ZEA, see Fig. 6 and Tab. 2) will accommodate three chambers filled with different experiment solutions, i.e. an observation chamber having an initial volume of one ml and two reservoir volume of one ml each, an injection system that allows to transfer sample liquids from the reservoirs into the observation chamber which would then have a final volume of three ml. A stirring mechanism allows to mix the different solutions in the observation chamber. A pressure compensation system and a thermal control system keep the experiment sample at an autogenous pressure corresponding to the ambient temperature, with a maximum temperature of 40 ° C. Due to the harsh environment of typical zeolite solutions (pH from 1 to 13) all internal

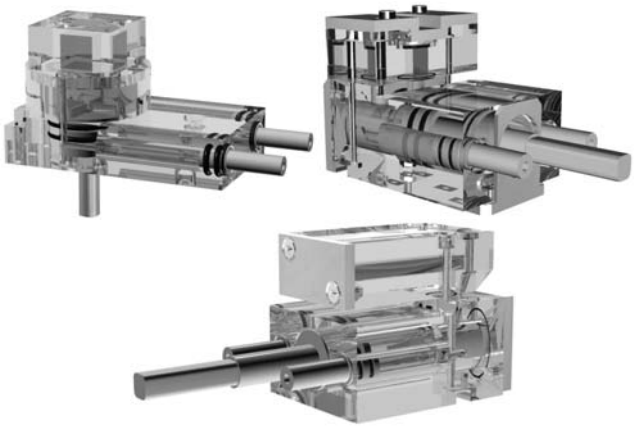

Figure 5 : SCDF protein batch reactor (top left), dialysis (top right), and extended length dialysis (bottom) (EADS)

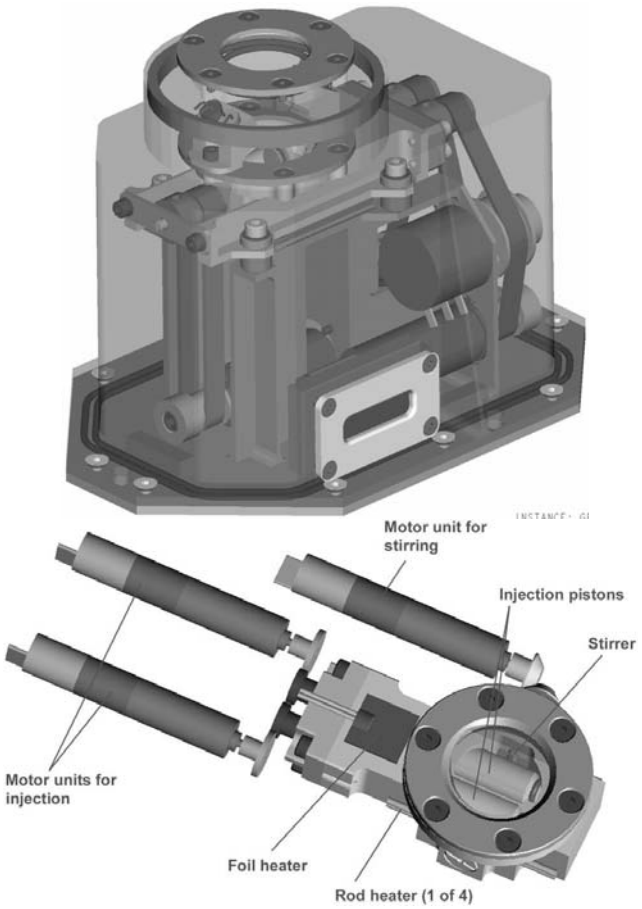

Figure 6 : External view of the ZEA (top) and internal subsystems (bottom) (Verhaert D.D.)

Table 2 : Zeolite Experiment Assembly characteristics

ZEA:	
- number	1
- material	Inconel
- compatible with pH	1 to 13
- window	sapphire
Volumes:	
- observation chamber (ml)	1 (initial) to 3 (final)
- reservoirs (ml)	1 (2x)
Injection:	
- speed	0.1 ml/min -1 ml/week
- accuracy (µl)	± 5
Stirrer:	
- frequency (Hz)	≈ 1
Temperature range (°C):	
• stowage launch/transfer in process chamber	20 ± 1
• in-orbit operation	
- in process chamber	14 - 30
- in ZEA	4 - 40
Temperature:	
- stability (°C)	± 0.5
- ramps	1°C/min -1°C/day

surfaces in contact with experiment solutions are made of inconel to avoid surface reactions.

Diagnostics are grouped at two different locations, either mounted on a central carrousel (or camera drive, see Fig. 4) in the process chamber, or installed directly in experiment assemblies. Diagnostics include a black and white digital video camera with a wide field of view and a microscope optics, a dynamic light back scattering system, both diagnostics mounted on the carrousel. Diagnostics characteristics are shown in Table 3.

For experiment assemblies with protein reactors, additional diagnostics include a second dynamic light scattering optics at 90 ° (coupled with the dynamic light scattering system on the carousel) or a Mach-Zehnder interferometer (both diagnostics installed optionally in some experiment assemblies). These diagnostics can be configured differently in experiment assemblies depending on the type of protein reactors. Mach-Zehnder interferometers using the phase shift method for increased sensitivity achieved by piezo transducers are installed in two of the four experiment assemblies with dialysis or batch protein reactors. With this phase shift technique, the interferometers are capable of achieving a sub-fringe sensitivity in order to detect very minute changes in the solution refractive index. Instead of the Mach-Zehnder interferometer, another optical system can be mounted on the side of the dialysis reactor allowing the protein volume to be observed with a 90 ° scattering angle, at the cost of removing one experiment assemblies from the process chamber due to mass constraints in the process unit locker. Limitations in the accommodation of diagnostics for the extended length dialysis and batch reactors are due to the larger dimensions of these two types of reactor.

For the zeolite experiment assembly, dedicated diagnostics include an optical turbidity measurement system and dedicated optics for dynamic light back scattering.

All experiment assemblies can be observed by the high resolution video camera either in the wide field of view mode or in the microscope mode, and by the dynamic light back scattering system (scattering angle of $\theta \approx 170$ °). These two diagnostics mounted on the central carrousel allow for the observation in turn of the four ex-

Table 3 : SCDF Diagnostics characteristics

Reactors	Dialysis	XL Dialysis	Batch
Illum. optics	Bright field	Dark field	Dark field
Wide FOV optics:			
- FOV (mm)	10 x 10	20 x 8.35	20.6 x 20.6
- resolution (lp/mm)	25	6	6
Microscope:			
- FOV (mm)	2 x 2	4.12 x 4.12	4.12 x 4.12
- resolution (lp/mm)	120	60	60
Dynamic Light Scattering			
- back scattering	$\theta \approx 170°$	$\theta \approx 170°$	$\theta \approx 170°$
- 90° scattering	optional *	n/a	n/a
Interferometry			
- type	M-Z	n/a	M-Z
- phase shift	by piezo	n/a	by piezo
- resolution (lp/mm)	20	n/a	3
- phase resol. (rms)	$\lambda/100$	n/a	$\lambda/100$
Video camera:			
Black & White CCD, 1000 x 1000 pixels, S/N: 60 dB			

Notes: FOV: Field Of View; M-Z: Mach-Zehnder; lp: line pairs; λ: wavelength

periment assemblies. Optics set-ups of the video and microscope systems are designed differently for experiment assemblies with dialysis and batch protein reactors.

Additional details can be found in [Stapelmann, Bosch, Potthast and Pletser (1997); Pletser, Stapelmann, Potthast and Bosch (1999); Pletser, Minster, Stapelmann, Potthast and Bosch (2000); Pletser, Minster, Bosch, Potthast and Stapelmann (2000a, 2000b, 2001)].

4 Overall SCDF operation scenario

The SCDF is to be operated on board the ISS when installed in the European Drawer Rack. The mode of operations is either automatic by pre-programmed sequences controlled by the SCDF built-in electronics, or remote from the ground by telecommand, or local by an astronaut via a portable computer and/or control interfaces on the SCDF front panel.

The present mission scenario assumes an initial upload of the unpowered electronic unit in the European Drawer Rack during the initial upload flight of ESA's Columbus Laboratory module. The process unit, fitted with the first four experiment assemblies (either only protein reactors of the batch or dialysis type or protein reactors and a zeolite experiment assembly), is sent to the ISS as a powered locker in the Shuttle mid-deck for a first mission increment, presently foreseen to be three months, although it could be longer. After shuttle docking to the Station, astronauts will remove the process unit from the Shuttle mid-deck locker, transport and install it in a Station locker in the European Drawer Rack.

While the electronic unit will stay on board the Station for a long duration, typically two to three years, in a dormant unpowered mode when not in use, the process unit will be flown back and forth from ground to orbit and used for the transportation of experiment samples (upload flights) and space grown products, crystals and/or zeolites (download flights). Between consecutive up and down flights of the process unit, experiment assemblies can be exchanged on the ground, close to the Shuttle launch and landing facility at NASA's Kennedy Space Centre. In view of the foreseeable scarcity of future Shuttle flights, other scenarios for upload are presently envisaged with other space carriers.

After harvesting the space grown crystals and/or zeolites in a temperature controlled ground laboratory, the experiment assemblies are emptied, cleaned and prepared for a next flight or exchanged for other type of protein reactors (dialysis or batch) or zeolite experiment assemblies.

Video images, including microscope images and interferograms, will be processed and compressed in the European Drawer Rack video system and either down linked to the ground control station or stored in the video storage subsystem for later down loading. The video images and scientific data (temperatures, light scattering information, positions and statuses of the camera, optics, motors, etc.) are either stored on board or down linked to the control ground station depending on the down linking capabilities at that time. The amount of data down linked will depend on other instruments and facilities to be operated in the European Drawer Rack and on the downlink capabilities of the Columbus Laboratory and the ISS. In view of the share with other instrumentation and of the potential scarcity of command and data up and down traffic, the specific experiment scenarios will need to be optimised to make the best use of the available resources.

Data and video will then be distributed from the receiving ground control station via satellite and/or ground network to scientists either in User Space Operation Centres in Europe, or at a Facility Responsible Centre dedicated to SCDF or to the European Drawer Rack in Europe, or at their home base (laboratory or home institution).

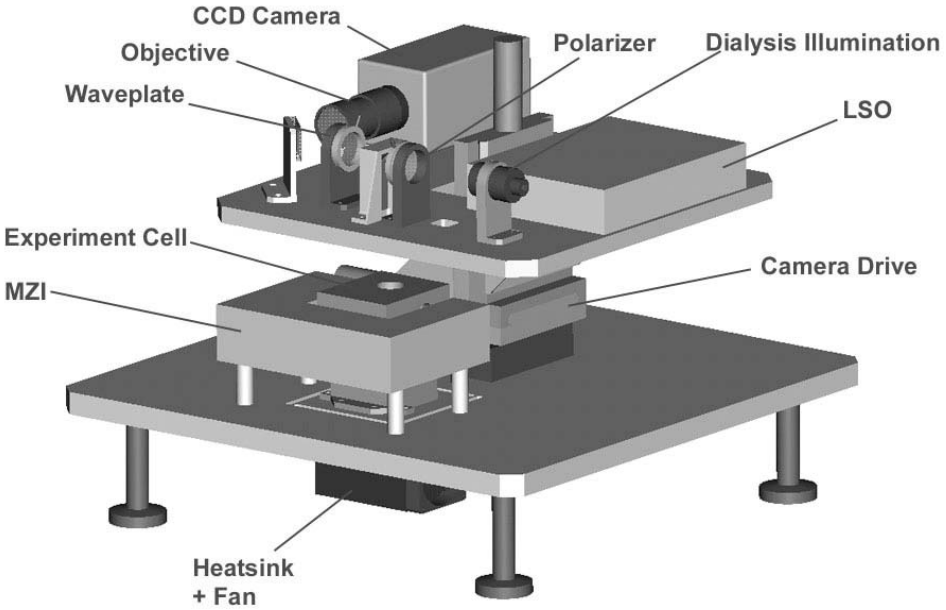

Figure 7 : Sketch of the SCDF Laboratory Model (Verhaert)

Data will be received and treated (e.g. compressed video signal will be decompressed) and displayed on monitors to support scientist decisions on how to proceed with the on-going experiment. Additional image treatment of video images and interferograms can be foreseen at this centre.

Presently, the Belgian User Support and Operations Centre (B-USOC), located in Brussels, Belgium, has been nominated the Facility Responsible Centre dedicated to SCDF.

5 SCDF Ground Models

Several scientific ground models have been developed to prepare for the use of SCDF by scientists and are presently available at the B-USOC. The general features of these models are summarized in Table 4.

5.1 The Non Invasive Back Scattering instrument

The Non Invasive Back Scattering (NIBS) instrument is a commercially available diagnostic instrument [ALV, http://www.nibshpps.de] from the German company ALV procured by ESA and similar to the light scattering equipment that is installed in the SCDF. The NIBS instrument, including the diagnostic tool and the supporting controls and data treatment algorithms, is available for use by scientists to build up experience in using this new and powerful diagnostic means to prepare for the use of SCDF. The NIBS instrument is available for an as wide utilisation as possible to allow the largest number of experimenter teams to train and prepare for this SCDF diagnostic means.

5.2 The SCDF Laboratory Model

The SCDF Laboratory Model is designed around an experiment box, including the reactor, similar to the SCDF flight experiment boxes, but with commercially available thermal control systems and optical diagnostics (see Fig. 7).

Although these are simplified as compared with the SCDF flight design, they are sufficiently similar to enable meaningful experimentation. This laboratory model is intended for scientists to conduct ground crystallisation experiments in identical reactors and experiment assemblies that will fly on SCDF, giving them the opportunity to build up experience with the geometry and size of SCDF reactors and experiment boxes.

5.3 The SCDF Science Reference Model

The SCDF Science Reference Model is designed around four experiment boxes, with thermal control and optical systems similar to the SCDF flight ones, but with commercially available video camera and other controls (see

Table 4 : SCDF Models philosophy

Models	Reactor / Expt Box	Thermal control / Optical diagnost.	Video camera / Other controls	Remarks
Non-Invasive Back Scattering (NIBS)	Scientists' own	Only light scattering diagnostic	n/a	• Commercial instrument (ALV) • Already available and in use • Similar to SCDF back scattering unit • Incl. diagnostic, controls, data treat. algorithms • To prepare Scientists to use this SCDF diagnostic
Laboratory Model (Lab. M.)	1 reactor Similar to Flight Model	Commercially procured	Simplified w.r.t. Flight Model Commercially procured	• Sufficiently similar for meaningful science • Scientists to conduct ground experiments in same reactors as SCDF • Scientists to build up experience with SCDF reactor geometry and size
Science Reference Model (SRM)	4 reactors Similar to Flight Model	Similar to Flight Model	Simplified w.r.t. Flight Model Commercially procured	• Sufficiently similar for same science as SCDF • Scientists to conduct ground experiments in same reactors and using same diagnostics (all) as SCDF • Scientists to conduct reference experiments on ground similarly to SCDF Flight Model
Ground Model (GM)	4 reactors Similar to Flight Model	Similar to Flight Model	Similar to Flight Model	• Foreseen to upgrade the Engineering Model to similarity level of Flight Model • "Twin brother" of Flight Model w.r.t. performance / operations • Used for: - mission related ground technical reference tests - rehearse full experiment scenarios - ground experiments (to a certain extent)

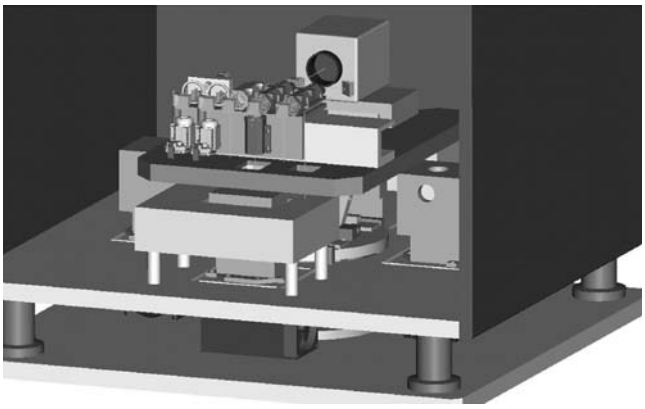

Figure 8 : Close up view of the process chamber of the SCDF Science Reference Model (Verhaert)

Figure 9 : The SCDF Science Reference Model assembly with (from left to right) the SRM unit, its control electronic, cooling support unit and data acquisition system (Verhaert)

Figs. 8 and 9). Although the latter are also simplified with respect to the SCDF ones, their similarity allows representative experimentation.

This Science Reference Model is intended for scientists to conduct SCDF-like experiments on ground using the same reactors, experiment assemblies and optical systems that will fly on SCDF, giving them the possibility to prepare experiments serving as reference to those that will be executed in orbit, in particular to obtain experience with using the optical diagnostics in order to observe nucleation and crystallisation processes on ground before conducting similar experiments in orbit. The Science Reference Model can be used also to conduct

ground crystallisation experiments in parallel and similar to the ones in orbit to complement the results obtained in orbit and to determine whether potentially different behaviour may be observed or different results may be obtained.

5.4 The SCDF Ground Model

In the course of the SCDF development contract, a first full model of the SCDF, called the engineering model, including the electronic and the process units, has been developed in the frame of the main SCDF development contract. This engineering model was used as a development model to improve technical design details and to conduct development tests, in order to prepare for the manufacturing of the flight model. The SCDF flight model has been developed, tested, accepted and integrated in EDR, the engineering model has now become the SCDF ground model. This model is the twin brother of the SCDF flight model that will fly in space with respect to performance and operations. It will be used, either integrated in the ground model of the European Drawer Rack, or in the SCDF ground support equipment, for mission related ground technical reference tests and to rehearse full experiment scenarios. It can also be used to a certain extent for ground crystallisation experiments.

6 Conclusions

The SCDF is a new instrument to study in situ nucleation and crystallisation processes of biological macromolecules and of other molecular configuration growing from solutions in a microgravity environment on board the International Space Station. The SCDF is primarily conceived for in situ observation and control of nucleation and growth processes in microgravity. Nevertheless, the post-flight analysis of products, crystals or zeolites, brought back to ground may add structural information to be correlated with these flight data.

Optimal scientific utilisation of this new facility is expected to be attained with collaborative projects involving scientists with complementary expertise. To support this approach, ESA has developed two additional ground scientific models, the Laboratory Model and the Science Reference Model, to help the international investigator community to prepare their investigations with the SCDF instrument on board the International Space Station.

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ALV: Non Invasive Back Scattering, Sub-mm Particle Sizing, http://www.nibshpps.de

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