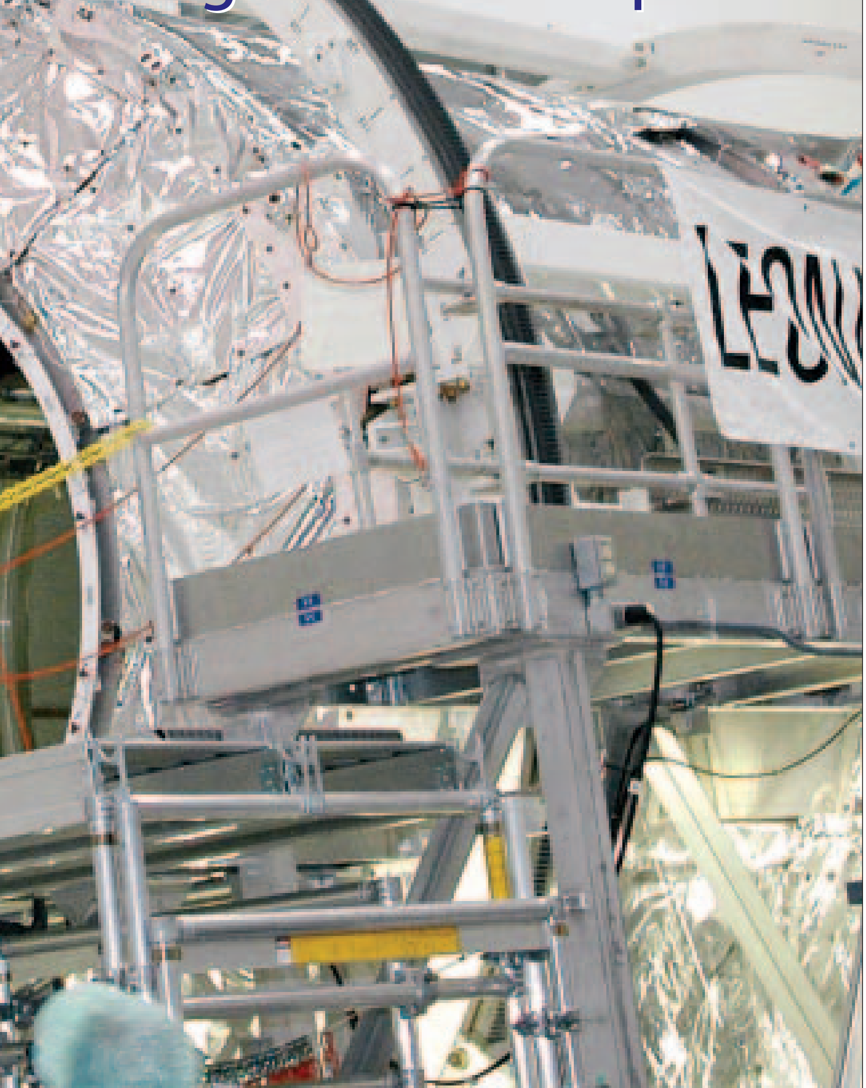
MELFI
Ready for Science

MELFI is loaded into its carrier module ready for launch aboard the Space Shuttle on 4 July 2006



ESA's –80°C Freezer Begins Work in Space

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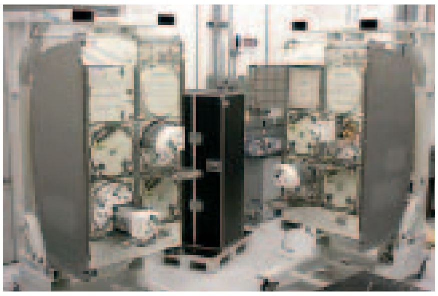
After a 4-year wait, ESA's 'MELFI' freezer rack is now installed and working in the International Space Station (ISS). It provides researchers with a unique cold-storage facility important, for example, for biology and human physiology investigations. Originally designed for frequent return trips, a major shift in Station requirements meant that a major effort had to be made before launch aboard Shuttle mission STS-121 in July to prepare it for permanent residence in space. The first science samples have been successfully frozen, before the first European samples were added in September.

Introduction

The 'Minus Eighty-degree Laboratory Freezer for ISS' (MELFI) allows the fast-freezing and storage of life sciences and biological samples aboard the International Space Station. Developed by ESA on behalf of NASA and the Japan Aerospace and Exploration Agency (JAXA) under various bilateral barter agreements, the Agency has delivered three flight units to NASA and one to JAXA. A flight-standard Engineering Model, a Training Model



FU1 (left) and FU2 at the Florida launch site

with simulation capabilities and a Laboratory Ground Model are installed at NASA's Johnson Space Center (JSC) in Houston and have been used extensively by the ground and space crews to prepare for utilisation. In addition, ESA is providing spares and sustaining engineering to maintain all MELFI hardware for up to 10 years of operations.

The prime contractor is EADS-Astrium in Toulouse (F), with main subcontractors:

- L'Air Liquide (F), for the core cooling system;
- Linde (D), for the cold-volume chain;
- Kayser-Threde (D), for the electrical system and some rack components;
- ETEL (CH), for the motor and motor-drive electronics;
- DAMEC (DK), for the utilisation concept and hardware.

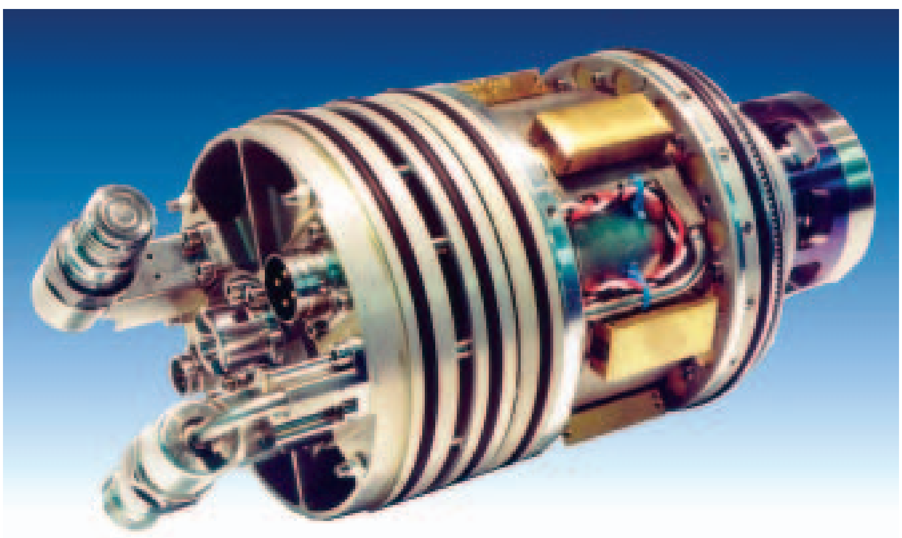
Brief Description

The samples are stored in four identical Dewar enclosures. Each Dewar can be set to cool to below three different temperatures: –80ºC, –26ºC and +4ºC. The centralised cooling system is based on a reverse Brayton cycle using very pure nitrogen as the working fluid. The basic machine was developed under ESA's Technology Research Programme (TRP), and then modified to satisfy MELFI's specific and stringent requirements. The Brayton expander and compressor wheels are mounted on the same shaft, running at up to 96 000 rpm. At that speed, the system produces 90 W of cooling power at –97ºC.

The cooling distribution to the Dewars is via vacuum-insulated nitrogen lines running from the machine. A distribution valve on each Dewar stabilises the temperature within the required range by modulating the cold nitrogen flow. The valves can also isolate each Dewar independently, shutting down one or more enclosures when the storage capacity is not needed.

Within the Dewars, trays and boxes accommodate basic samples shapes. Users can design their own accommodation hardware, based on defined interface requirements and their cooling needs. MELFI is a 'contact freezer' to allow selection of the cooling speed. For fast cooling, the samples must be held against the Dewar trays and have a large, conductive surface. Conversely, samples requiring slow cooling need small, isolating interface surfaces.

A single Brayton machine provides cooling for MELFI

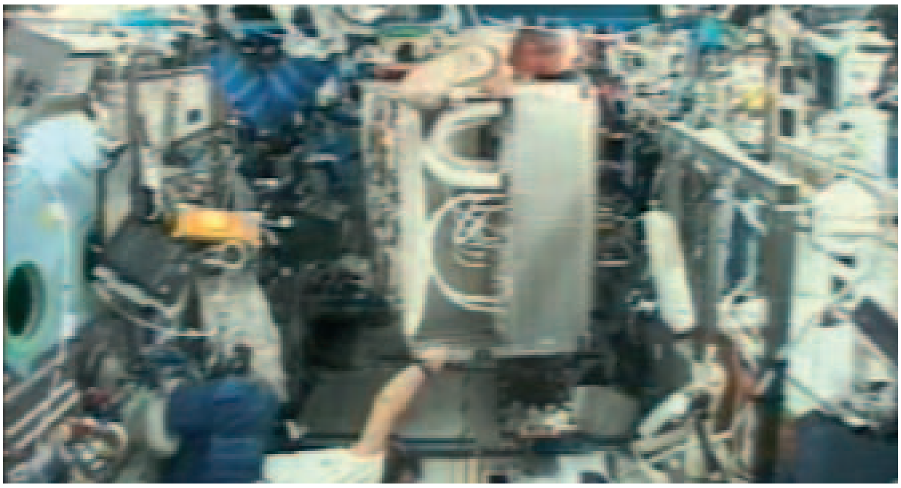


MELFI begins its journey to the ISS

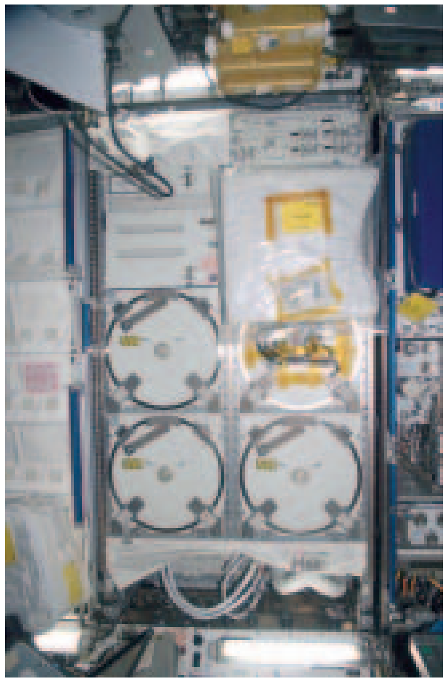
MELFI's cooling system provides a quite remarkable performance. It can cool about 300 litres in 2 days to less than –90ºC using only 900 W and hold it there with less than 800 W. It also meets the Station's stringent noise requirements (less than 40 dB). For comparison, similar systems on Earth use about double the power with noise levels around 60 dB (100 times higher), and could never handle 15 Shuttle launches!

The first MELFI flight unit (FU-1) was ready in October 2002 for a planned flight on Shuttle in March 2003. However, the *Columbia* disaster in February 2003 halted all launches for several years. FU-1 had to be deintegrated from its Multi-Purpose Logistics Module (MPLM) host and maintained for the next 3 years. This work included simple routine maintenance, such as briefly running the system and changing the operating fluids, and a more extensive effort to increase the time it can spend in orbit.

In fact, the change in the Station logistics scenario meant that MELFI's



MELFI is carefully manoeuvred into position in Destiny



...and ready for use

baseline utilisation had to be modified. The original plan was to cycle the three MELFI units between orbit and Earth, with ground maintenance shorter than 2 years between missions. The plan now is to launch only two MELFIs before the Shuttle retires in 2010 – and keep them in space.

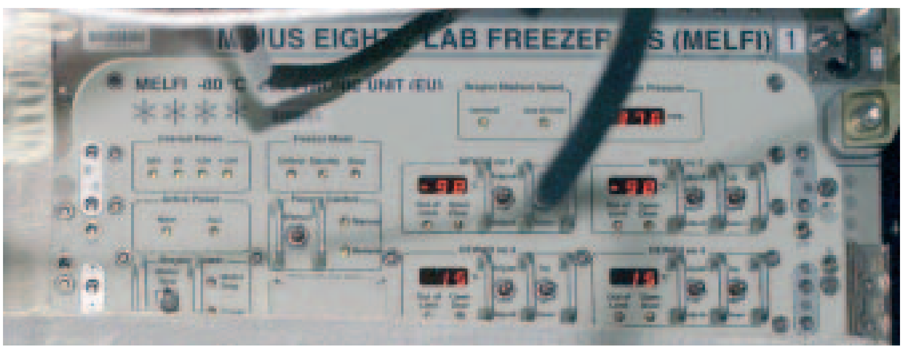
At NASA's request, ESA assessed this proposal. The study showed that MELFI's very robust design will allow it to remain in space, with additional maintenance using dedicated tools and spares provided by European industry. The consequences for the Station's work schedule have still to be discussed and agreed between the two agencies.

This has also changed how the samples are delivered to Earth. The original scenario used MELFI as a transportation freezer, up/ downloading frozen materials and processed samples every 3–12 months. But given the far fewer Shuttle flights now and the retirement in 2010, a new route for cooled samples needs to be found. At the moment, the only possibilities are the Shuttle's small middeck freezers (such as Merlin), or thermal bags lined with phase-change materials (PCMs). Of course, the middeck freezer path will be lost with Shuttle's retirement. And the thermal bags can hold the required temperature for only a few hours.

This problem of returning hardware and, in particular, experiments results from the Station is probably the most critical for using the ISS to its full potential.

ESA has studied retrievable capsules and freezers that could fit in them. This includes both active freezers and passive, long-term storage containers. However, the lack of funding and support from the stakeholders has so far prevented their procurement.

The control panel shows the two active Dewars at –98ºC; the others remain at the ambient +15ºC



Into Orbit

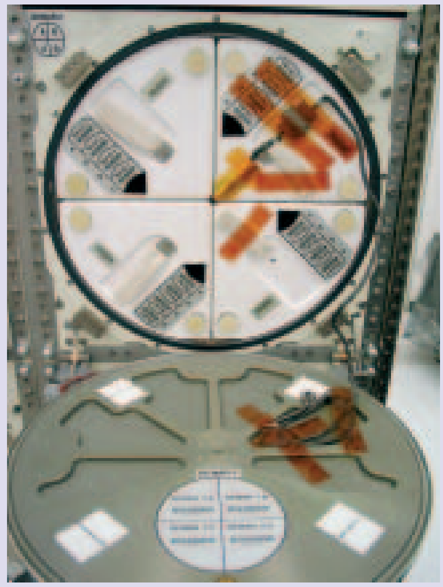
STS-121 delivered tonnes of equipment and supplies to the ISS following docking on 6 July, including MELFI FU-1. After attaching MPLM to the Station using Shuttle's robotic arm, the transfer of racks and supplies could begin. MELFI's move was particularly interesting because it is one of the largest and heaviest payload racks aboard the Station. Commander Pavel Vinogradov and Flight Engineers Jeff Williams and Thomas Reiter had to move the bulky item with great care through the ISS to its final position in the Destiny laboratory. There was always the risk of damage to the rack itself and to the many items stored en route.

Once all the connectors were locked, the rack was powered up on 19 July and commissioning began. First, there was a general check-out of all the subsystems, and then the 'MELFI On-Orbit Cooling Experiment' (MOOCE) began to test performance.

Starting up the cooling machine was particularly important. It was qualified on the ground for up to 15 launches and retrievals, but its behaviour after a real

Jeff Williams removes the frozen 5 ml MOOCE sample

MOOCE sample frozen in the ground model



MOOCE hardware installed on Dewar-2

launch and in weightlessness was somewhat uncertain. A very careful procedure was thus followed, commanded remotely by ground operators.

Much to their relief, all went smoothly and the various speed steps were all taken flawlessly up to the maximum 96 000 rpm. This was followed by individual activation of all the Dewar valves. The full functionality of the cold system had now been demonstrated. In particular, Dewar-2 reached –97°C in about 12 hours.

MOOCE

MOOCE has now measured MELFI's cooling characteristics in orbit. The main reason behind it is the need expressed by some scientists to cool samples very quickly from ambient temperature in order to avoid damage to tissue or cell structures.

The experiment hardware was defined by the ESA Project staff and designed and manufactured at ESTEC, within the Thermal Control Section of the Directorate of Technical & Quality Management. The hardware was qualified at ESTEC and extensively tested at NASA's Kennedy Space Center launch site to verify its behaviour with the Station's data-acquisition systems. Cooling-speed reference tests were performed on the ground for later comparison with on-orbit runs.

The Station crew began configuring the MOOCE hardware on 20 July. A slight problem arose when the computer was switched on and the procedure initiated, but a complete blank screen appeared. Since the complete data stream, including video, was available on Earth, the ground team could see what was happening and could help the crew very efficiently in troubleshooting. This allowed the problem to be solved in less than half an hour; the experiment was started by inserting the first sample.

There were no other mishaps and all the planned runs were completed in about a week. All the data were downloaded for evaluation and correlation with the ground data and analytical models.

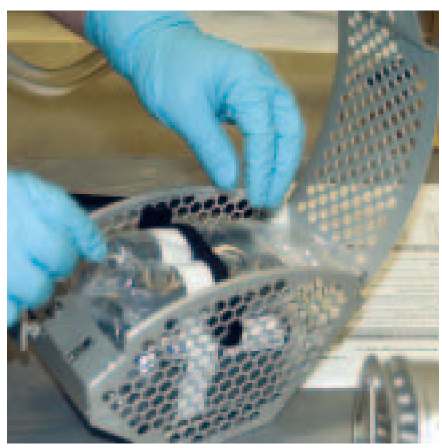
Complete analysis requires at least 3 months, but some preliminary conclusions can be drawn at the time of writing (September 2006). As expected, there are differences in the cooling times. The on-orbit curves show a slower rate, owing to the lack of natural convection, but there are also differences between the various runs. Those differences are most probably due to the way in which the samples were inserted into the freezer, and to the design of the packaging.

ESA will provide NASA and the user community with the '1 *g*-to-0 *g* tool" correlated with the on-orbit data. Users will be able to design different sample packaging, test them in the MELFI Engineering Model and predict the on-orbit performance.

First Samples

Given the positive results from the commissioning phase, NASA decided to activate another Dewar at the lowest temperature to prepare for the first insertion of science samples. 'Passive

ICEPAC inserted in a MELFI storage box



Jeff Williams inserts the POEMS sample container into Dewar-2: the first operational user of MELFI

Observatories for Experimental Microbial Systems' (POEMS), a US experiment devoted to microbial research, had the honour of being the first real sample cooled in Dewar-2, while a number of PCM packages were accommodated in Dewar-1.

These PCM packs (ICEPAC©) are essential for downloading processed samples to Earth. They were developed by NASA for the various temperature levels and require a long time for cooling, owing to their very high thermal inertia.

The thermal bags are filled with the ICEPACs just before insertion into the Shuttle middeck lockers before reentry. A large number of ICEPACs have to be used in order to stay safely within the allowed temperature range for up to 2 days. The bags are removed immediately upon opening of the Shuttle hatch as 'early retrieval' payloads. Logistics were developed by NASA, with some Ground Support Equipment provided by ESA, to ensure the specimens are delivered to the scientists in the best possible conditions.

The first European experiments to profit from MELFI were the SAMPLE, IMMUNO and CARD physiology experiments in September 2006. In the meantime, another ESA facility launched on STS-121, the European Modular Cultivation System (EMCS), completed commissioning in August and began operations in September with the TROPI plant experiment. TROPI then became a guest of MELFI in the autumn and will profit from the return route, together with IMMUNO and CARD, on STS-116 in December 2006.

MELFI FU-2 will be launched in 2008 and installed in Japan's Kibo module.

Conclusion

MELFI was a very challenging development for European industry. The advanced technology of the Brayton machine and its cold box required a great deal of resourcefulness. Highly dedicated engineers in the companies and ESA spent months on designing, manufacturing and verifying all the elements of the cold chain and developing the sophisticated control software to command them. The results, however, show that it was all definitely well worth the effort. Once again, European industry has shown its capability for being highly innovative and producing world-class payloads for science.

In order to get the full benefit from MELFI, it is important to capitalise on the technologies and to provide the Station and the science community with more transportation freezers and passive containers to be used after the Shuttle's retirement and for the Exploration programmes to come. Indeed, life sciences research is of paramount importance for ensuring human health and performance on these exploration missions.

MELFI may be operating in orbit for a very long time. With a robust logistics system for up/downloading samples, it will help scientists to get the best samples they need for making advances in life sciences for space and ground applications.

Acknowledgements

Thanks must be made to all the individuals who have contributed to the success of the MELFI. The authors wish to thank the development companies (EADS-Astrium, L'Air Liquide, Kayser-Threde, LINDE, ETEL, CRYSA, DAMEC) and their staff, NASA Project staff and ESA D/HME, D/TEC and D/RES staff for their invaluable support over many years.

More information about MELFI and its use on-orbit will be posted at http://spaceflight.esa.int/users after the MOOCE data are fully evaluated