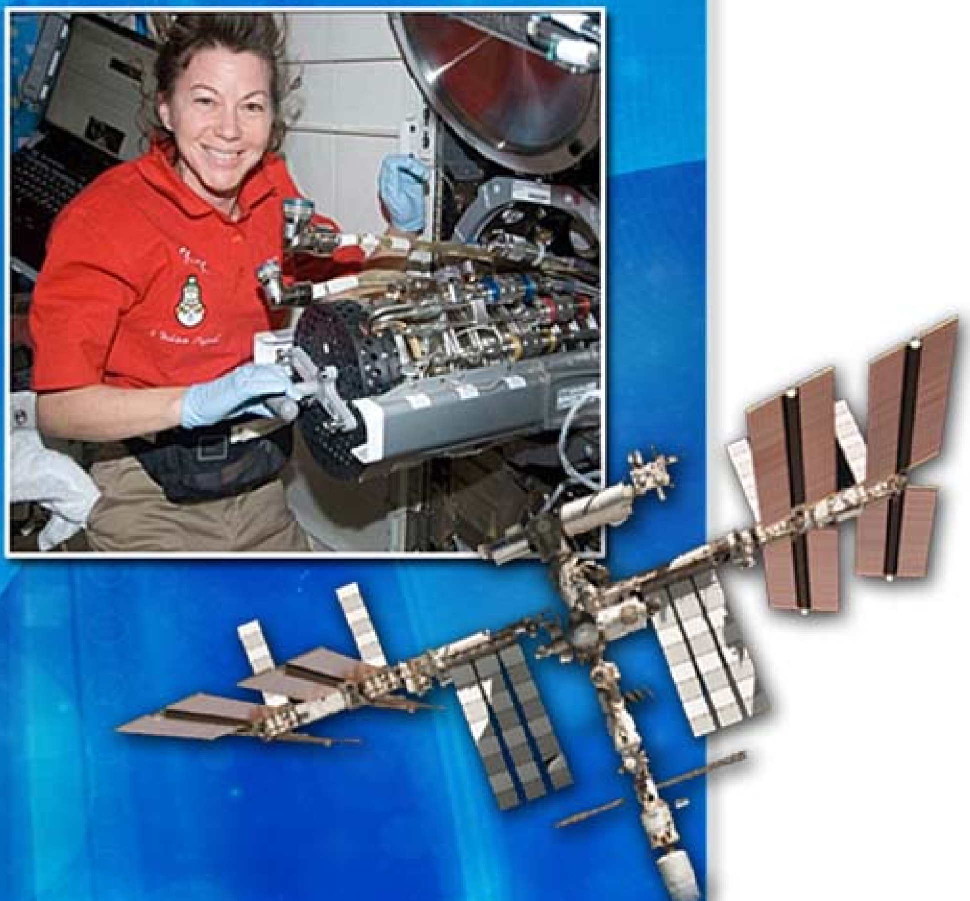
National Aeronautics and Space Administration



Materials Science Research Rack Onboard the International Space Station

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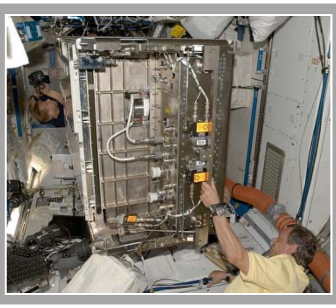
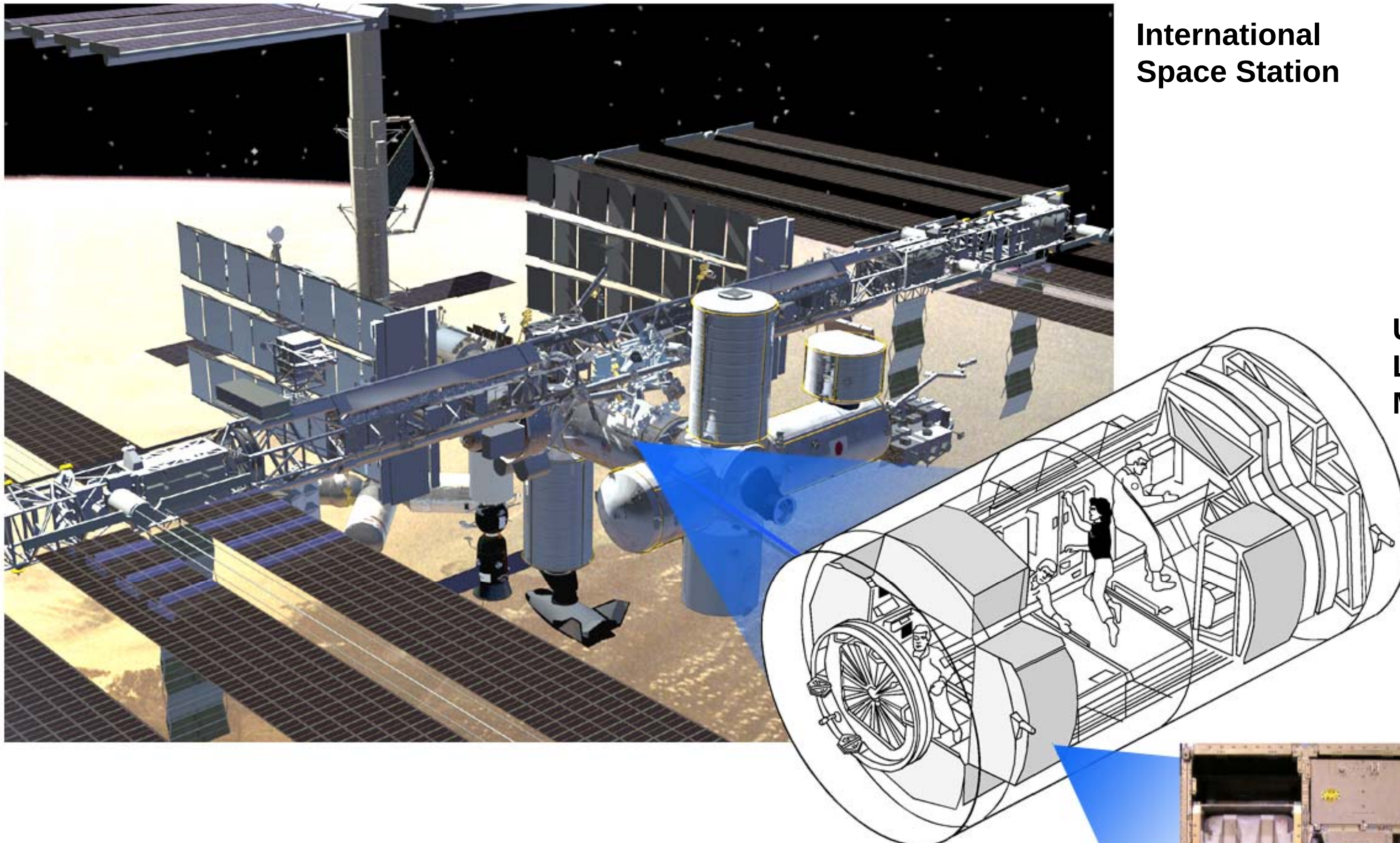
Materials Science Research Rack (MSRR)

- **The Materials Science Research Rack (MSRR) is a highly automated facility developed in a joint venture/partnership between NASA and ESA**
  - Allows for the study of a variety of materials including metals, ceramics, semiconductor crystals, and glasses onboard the International Space Station (ISS)
  - Multi-user facility for high temperature materials science research
  - Launched on STS-128 in August 2009, and is currently installed in the U.S. Destiny Laboratory Module
- **Research goals**
  - Provide means of studying materials processing in space to develop a better understanding of the chemical and physical mechanisms involved
  - Benefit materials science research via the microgravity environment of space where the researcher can better isolate the effects of gravity during solidification on the properties of materials
  - Use the knowledge gained from experiments to make reliable predictions about conditions required on Earth to achieve improved materials

MSRR Location



- MSRR is resident onboard ISS in the U.S. Destiny Laboratory Module in the Lab Overhead 3 position

Integrated Facility Overview

♦ **NASA**

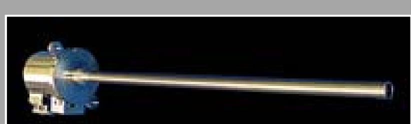
- MSRR Experiment Carrier (EC)
  - – Boeing International Standard Payload Rack (ISPR) with Active Rack Isolation System (ARIS) capability
  - – Rack Support System (RSS) – provides resource allocation to 2 Experiment Modules (Alpha and Beta sides of the rack) and provides access for the EMs to the ISS systems
    - Power
    - Data – 1553 BUS, Payload MDM
    - Video – provides signal and downlinks to ISS internal video system
    - Vacuum access – Vacuum Exhaust System and Vacuum Resource System
    - Thermal environment control - Moderate temperature cooling loop
    - MSRR Payload Laptop Computer
- Stowage – Experiment Module (EM) Alpha
  - – On-orbit stowage for MSFC/ESA-provided tools, spares, Orbital Support Equipment, and Sample Cartridge Assemblies (SCAs)
  - – Scarred with resources/services for an additional Experiment Module for future use

MSRR Flight Unit

Integrated Facility Overview (continued)

♦ ESA

- Materials Science Laboratory (MSL) – Experiment Module Beta
  - Main mode of operation is directional solidification of alloys and semiconductors
  - Supports crystal growth by zone melting or measurement of diffusion coefficients (stationary temperature profiles)
  - Operation of resistance heated Furnace Inserts with up to 8 individually controlled heaters qualified for maximum temperatures of 1400 °C
  - Precise experiment control (temperature profiles and growth speed) with various experiment diagnostics and stimuli (e.g., rotating magnetic field to stir the liquid metal)
- Low Gradient Furnace (LGF)
  - Designed to achieve a well-controlled low or medium thermal gradient inside the sample between one high- and one low-temperature heater zones with an adiabatic zone in-between these 2 heater zones
- Solidification and Quenching Furnace (SQF)
  - Bridgman furnace designed to provide for high gradients typically in the range of 50 - 150 K/cm in the cartridge, consisting of one hot cavity, an exchangeable adiabatic zone, and a water cooled chill block (cooling zone) acting as heat sink
  - Quench capability provided by a rapid displacement of the furnace insert, typically 50 to 100 mm within about 1 second
- Sample Cartridge Assemblies (SCAs)
  - Leak-tight containers for materials samples, sensors for process control & safety, and stimuli
  - LGF-type SCAs and SQF-type SCA qualified for maximum temperatures of 940 °C and 1065 °C, respectively

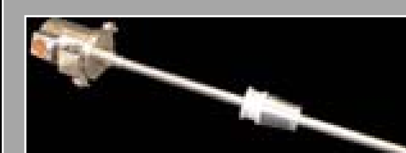


LGF-Type SCA

LGF Flight Model

MSL Flight Model

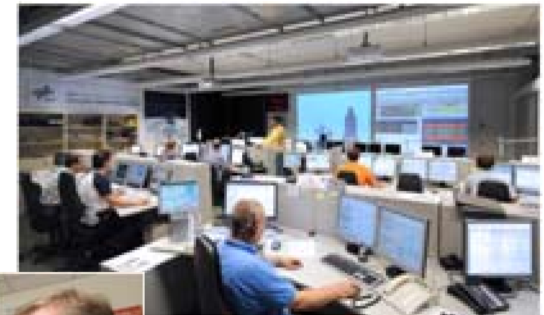
SQF Flight Model



SQF-Type SCA

Basic Operational Concept

- **Furnace Inserts are exchangeable on-orbit**
- **SCAs are installed, one at a time, into the Furnace Insert by a Crew Member**
- **Experiments can be run by automated command via Sample Processing Programs (SPPs), telemetry commands from the ground, or by Crew Member commanding via the MSRR Laptop Computer**
- **Joint MSRR/MSL operations are performed via integrated team approach**
  - MSRR operations team at the Huntsville Operations Support Center (HOSC) in Huntsville, AL
  - MSL operations team at the Microgravity User Support Center (MUSC) at DLR in Cologne, Germany
  - Principal Investigators (PIs) present in HOSC and MUSC control rooms during sample processing; PIs also receive near real-time data at the PI facilities
  - Ground labs available at MUSC and MSFC



MUSC Ground Control Room

HOSC Ground Control Room

MSFC Ground Lab including PRCU

MUSC Ground Lab

Materials Science Research with MSRR/MSL

SETA
Solidification along an Eutectic Path in Ternary Alloys
(ESA Research Program)

Team composed of
Academic Partners from **D, F, B, TR, US**

MICAST
Microstructure Formation in Casting of Technical Alloys under Diffusive and Magnetically Controlled Convective Conditions
(ESA-MAP AO-99-031)

Team composed of
Academic Partners from **D, F, H, CDN, US**
and Industrial Partners

CETSOL
Columnar-to-Equiaxed Transition in Solidification processing
(ESA-MAP AO-99-117)

Team composed of
Academic Partners from **D, F, IRL, US**
and Industrial Partners

METCOMP
Metastable Solidification of Composites: Novel Peritectic Structures and In-situ Composites
(ESA-MAP AO-99-114)

Team composed of
Academic Partners from **D, CH, A, H, US**
and Industrial Partners

Other Researchers

Principal Investigators from **US**

MSRR/MSL Operations – Success Story

- MSRR/MSL have successfully completed over 1300 hours of operational time (as of August 2014)
- On-orbit commissioning was completed Nov 6, 2009
- 12 SCAs were successfully processed November 2009 – April 2010 in the LGF and downloaded on various Shuttle flights
- 17 SCAs were successfully processed January 2011 – August 2014 in the SQF and downloaded on various SpaceX flights
- Preliminary examination of samples indicate that the majority of the desired science objectives have been successfully met
- 1 SCA remains to be processed in the coming months (as of September 2014)

Future Plans

♦ Future SCAs provided by ESA

- Batch 2b SCAs planned for NET 2015
- Batch 3 SCAs planned NET 2018

♦ Future SCAs provided by NASA

- NASA SCA development kicked-off January 2011 to support US PIs and their partners
- The first of these Flight SCAs are being developed for investigations to support research in the areas of crystal growth and liquid phase sintering
- Subsequent investigations are in various stages of development
- NASA SCAs will be qualified for use in the LGF at maximum temperatures of 1250 °C
- US investigations will include a ground test program in order to distinguish the particular effects of the absence of gravity.
- First Flight SCAs planned for 2015, total of approximately 50 units by end of 2018

This facility is available to support additional programs such as the US National Laboratory, Technology Development, NASA and International Research Announcements, ESA application-oriented research programs, and others.