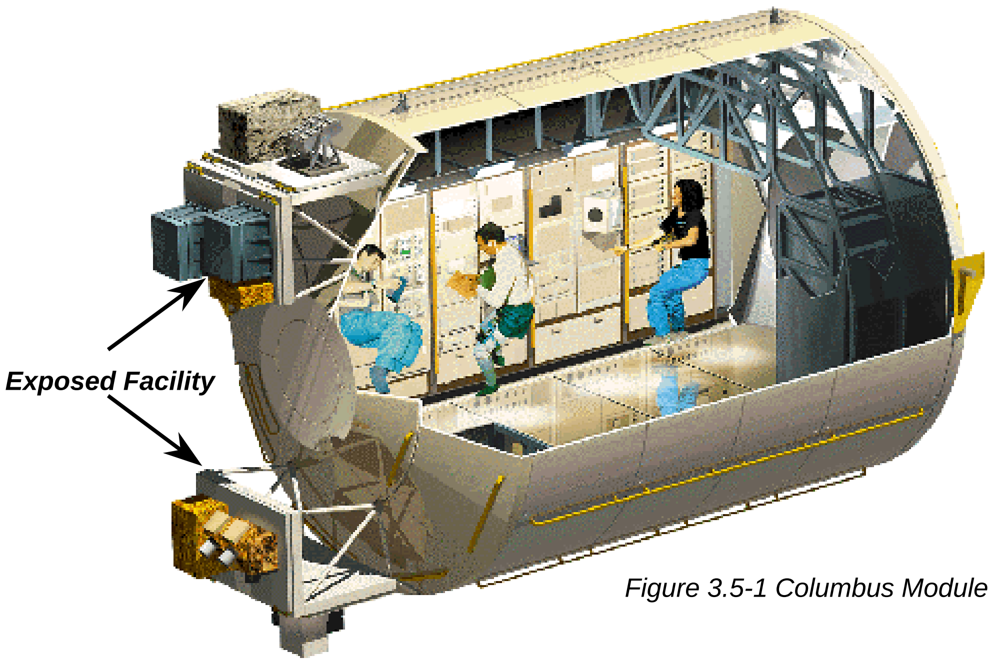

Figure 3.5-1 Columbus Module

support, thermal conditioning, power, video, data services and other accommodations provided for JEM-EF payloads are covered below in Section 5.3.7.

In addition to the PM and EF, the JEM has an Experiment Logistics Module-Pressurized Section (ELM-PS) to serve as a pressurized passive storage and carrier module for stowage of research supplies, spare hardware and internal user payloads. There is also the un-pressurized Experiment Logistics Module-Exposed Section (ELM-ES) which is a storage and carrier module for spare external hardware and user payloads.

3.5 Columbus Module

The *Columbus* module will be contributed to ISS by ESA (Figure 3.5-1). Its internal configuration provides for a total of 10 ISPRs for research payloads with 5 ISPRs allocated to NASA under NASA-ESA resource sharing agreements. To achieve cost benefits the basic *Columbus* design is based on the Multi-Purpose Logistics Module (MPLM), a transport module provided to the ISS program by Agenzia Spaziale Italiana (ASI), the Italian Space Agency.

Columbus is designed as a general-purpose laboratory to support ESA-defined scientific disciplines in the areas of materials and fluid sciences, life sciences and technology development. As part of its Microgravity Facilities for *Columbus* Program, ESA is developing five multi-user laboratories in the fields of Biology, Human Physiology, Materials, and Fluid Science that will be provided to European scientists. These facilities are nominally slated to occupy ESA's space in *Columbus*, but location swaps with facilities in the modules belonging to the other International Partners, particularly the U.S., may occur in response to operational considerations.

An Exposed Payload Facility is planned for *Columbus*. It will consist of two separate support structures attached to the *Columbus* Pressurized Module end cone in the zenith and nadir positions (Fig. 3.5-1). NASA-ESA resource sharing agreements allocate 50% of the resources at these locations to NASA, and additional details on the payload accommodations at these sites are given in Section 5.3.7.

3.6 Russian Segment

The Russian segment is slated to have two research modules to support research payloads generated by Russian researchers. The segment will have power, data, and other systems separate from the rest of the ISS.

4. The ISS Environment

4.1 Orbital Parameters and Modes of Operation

The ISS has a nearly circular orbit with an altitude range of 350-460 km (189-248 n mi) and an inclination of 51.6° to the equator. As shown in Figure 4.1-1, the Station's orbit causes it to reach a maximum of

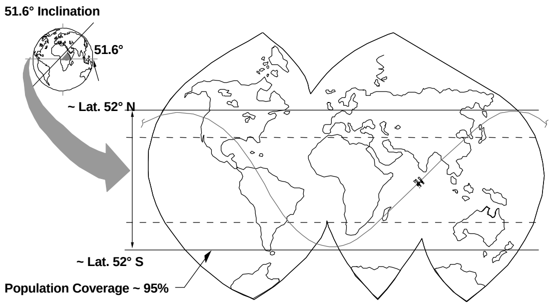

Figure 4.1-1. ISS orbital inclination and groundtrack

52° in north and south latitude, such that it flies over 85% of the globe and 95% of the Earth's population.

The description of the Station's flight attitude (orientation relative to the plane of its orbit) is referenced to local-vertical/local-horizontal (LVLH) axes that are fixed with respect to the Station's near-circular orbit (i.e., *not* to the physical Station). The LVLH origin is at the Station's center-of-mass; the z-axis points radially toward the Earth's center (or toward the *nadir* direction), the x-axis points along the orbital velocity vector (the *ram* direction, with *wake* being opposite), and the y-axis completes the right-handed triad. The flight attitude of the Station is then described using a second, Station-fixed, coordinate system whose orientation relative to LVLH is specified using the Eulerian angles of yaw, pitch and roll. Several Station-fixed coordination systems are defined. The most widely used is the Space Station Reference Coordinate System, shown in Figure 4.1-2, in which the positive *x*-axis points along the axis of the U.S. Lab away from the Zarya and Service Modules; the positive *y*-axis points starboard along the main truss, and positive *z* completes a right-handed coordinate system.

Between flight 5A, when payloads will first be carried, and flight 12A, there are two main flight attitudes for ISS: normal XVV (station *x*-axis toward the velocity vector) and XPOP (station *x*-axis perpendicular to the orbit plane). The XVV mode is airplane-like, *x* forward, *z* down, and *y* ("right wing") level. For integrated systems design reasons (thermal, power, communications, etc.) XVV is required to be ±15° roll/yaw, and +10 to -20° pitch with respect to LVLH.

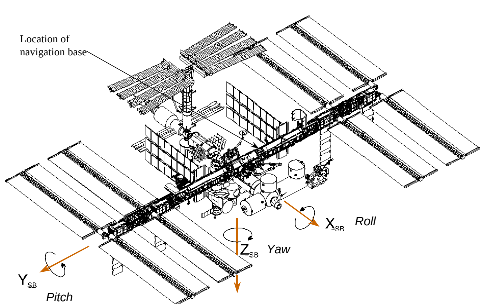

Figure 4.1-2. Space Station Reference Coordinate System

Until flight 12A, when additional solar arrays are installed, there is insufficient power generation in XVV when the sun β angle (angle between the sunline and the orbit normal) exceeds either 37° or 52° (depending on the stage of assembly), making it necessary to fly in the XPOP orientation. The ISS orbit plane regresses about the earth's rotational pole at about 6 °/day relative to the sun, so the station alternates between a couple weeks in XVV and a couple of weeks in XPOP for almost two years, until flight 12A finally makes that unnecessary.

The ISS will be operated according to a number of specific modes, each of which has a specified set of conditions and capabilities (Table 4.1-1). Some familiarity of the ISS User with these modes is important because, although most modes support research payload operations at some level, there are others for which payload operations may be sharply curtailed or discontinued. Among the modes summarized in Table 4.1-1 are Microgravity and Standard modes, which are the primary modes of operation for research. During Microgravity mode the Station must be operated so as to meet a stringent set of requirements for its microgravity environment. This partly involves maintaining an XVV attitude by non-propulsive means, along with other operational constraints. More details on ISS microgravity requirements are provided in the next section. Standard mode has many identical capabilities to Microgravity mode, and provides full support for research payloads. However, Standard mode allows a number of activities that could result in the microgravity environment specifications being exceeded, such as control of the Station attitude by propulsive means.

In addition to Microgravity and Standard modes, Reboost mode is necessary because the Station's large cross-section and low altitude causes its orbit to decay due to atmospheric drag at an average rate of 0.2 km/day (0.1 n mi/day). Thus, a periodic reboost using on-board thrusters must be carried out approximately every 10 to 45 days. The Reboost period itself requires 1-2 orbits (1.5 - 3 hours) and represents an assured, but temporary, interruption in the maintenance of the Station's microgravity specification.

Table 4.1-1. ISS Modes of Operation

Standard	• Represents core operations when tended or preparing to support human presence • Provides "shirt sleeve" environment • Internal and external operations supported, monitored and controlled
Reboost	• Used to obtain additional altitude while maintaining a habitable environment *and* supporting internal and external user payload operations • Altitude controlled propulsively
Microgravity	• Consists of capabilities required for microgravity research by user payloads in a habitable environment • *Does not* include effects of crew activity, but *does* include effects of crew equipment (e.g., exercise devices)
Survival	• Initiated upon command or when a warning of imminent threat (e.g., loss of attitude control, loss of thermal conditioning, available power out-of-range) is not acknowledged by the on-orbit crew, the Orbiter crew, or the ground • Autonomously attempts to correct the threatening condition and provides keep-alive utilities to Station's crew/core systems • *Precludes support or commanding of external or internal operations*
Proximity Operations	• Provides capabilities related to supporting safe operations with other vehicles while maintaining a habitable environment and supporting internal and external user payload operations • Vehicle is actively determining and controlling attitude nonpropulsively
Assured Safe Crew Return	• Provides mitigation capability for life threatening illness, unrecoverable loss of Station habitability, or extended problem requiring resupply/servicing, which is prevented from occurring due to launch problems • Consists of actions, operations and functions necessary to safely populate the Crew Return Vehicle (CRV), separate the CRV, return the CRV to earth, and egress the CRV upon recovery on the ground
External Operations	• Utilizes functionality related to supporting Station-based external operations while maintaining a habitable environment and supporting internal and external payload operations • Vehicle actively determining and controlling its attitude non-propulsively

4.2 Microgravity

Inside an orbiting spacecraft a "microgravity" environment exists in which the acceleration of objects and persons relative to their surroundings is reduced to the level of micro g's (9.8×10^{-6} m s^{-2}). The acceleration environment is "microgravity" and not "zero gravity" due to two principal classes of residual accelerations. The first of these is quasi-steady acceleration, whose magnitude and direction varies relatively slowly, on the timescale of greater than 100 seconds, and whose cause lies largely in the very small aerodynamic drag experienced by the spacecraft as well in gravity gradient effects. On top of quasi-steady accelerations, the structural and acoustic vibrations due to the mechanical systems in the spacecraft produce vibratory accelerations, whose magnitudes and directions are oscillatory over a spectrum of frequencies from 0.01 to 300 Hz.

The levels of both quasi-steady and vibratory accelerations on ISS are of interest to microgravity researchers whose investigations cover the effects of reduced gravity on a large range of physical, chemical and biological phenomena. For this reason, the ISS has been designed, is being built, and will be operated to meet a set of requirements for both its quasi-steady and vibratory microgravity environment. The requirements specify not only allowable levels of acceleration, but also where on the Station and for how long such acceleration limits must be obeyed.

4.2.1 Quasi-steady Requirements

Accelerations are considered quasi-steady if at least 95% of their power lies below 0.01 Hz as measured over a 5400-second period (the approximate time of one orbit). Quasi-steady acceleration is present largely for two reasons. The first is aerodynamic drag that the Station experiences due to the residual atmosphere at low earth orbit. This drag causes the Station to lose altitude, and somewhat paradoxically, causes it to accelerate along its orbital velocity vector. The second contribution comes from gravity gradient: the fact that any point not exactly at the Station's center mass wants to follow its own orbit. Such points, however, because they are physically part of the Station are subject to accelerations from the structural forces that keep them attached to the Station as it orbits.

The drag, gravity gradient and other secondary effects can be incorporated into calculations that reveal the quasi-steady acceleration magnitude as a function of coordinate position relative to the Station's center of mass. The results take the form of coaxial elliptical cylinders of equal acceleration that are aligned along the Station's orbital velocity vector. Figure 4.2.1-1 is a view along the *y* axis in the Space Station Reference Coordinate System, showing where the various

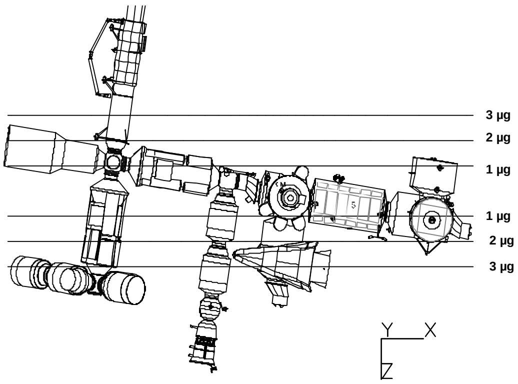

Figure 4.2.1-1. ISS quasi-steady microgravity environment

Station elements lie relative to a planar section through the cylinders for flight in XVV attitude. Note that the U.S. Lab lies principally within the 1 µg contours, with some racks between the 1 and 2 µg contours.

The calculations for the ISS quasi-steady acceleration environment can be compared to a set of formal design requirements which state that *50 percent of the ISPR locations within the U.S. Lab, Columbus and the JEM must be have quasi-steady accelerations below 1 ug for periods of 30 continuous days a total of 6 times per year*. The operation of the Station in Microgravity Mode is designed to produce these 30-day intervals. The quasi-steady acceleration vector has an additional directional stability requirement stating that the *component perpendicular to the vector's orbital average must be less than or equal to 0.2 mg*. To meet this requirement the Station's attitude must be controlled during orbit so that it maintains a constant position relative to the LVLH axes.

4.2.2 Vibratory Requirements

The requirements for the vibratory microgravity environment on ISS are defined in terms of a "spectrum" of allowed root-mean-square (RMS) acceleration as a function of vibrational frequency from 0.01 Hz to 300 Hz. The total vibrational level experienced by the station arises from the combined effects of the payload and vehicle systems. The vibratory microgravity requirements are therefore defined using an RMS acceleration vs. frequency curve for the allowed contribution to the total system vibration by the vehicle alone, with a separate curve for the allowed contribution by the entire complement of payload systems. These two curves are shown in Figure 4.2.2-1. The total allowed system vibration is the root-sum-square of the payload and vehicle values and at the scale of Figure 4.2.2-1 would plot just slightly above the vehicle curve.

Similar to the quasi-steady microgravity regime, the vibratory acceleration levels given by Figure 4.2.2-1 must apply at 50 percent of the ISPR locations within the U.S. Lab, *Columbus* and the JEM, for at least 30 continuous days, 6 times per year (i.e., during Microgravity Mode).

During ISS development the contribution of the ISS vehicle systems, without payloads, to the total system vibration is assessed analytically using a computationally intensive set of finite-element and statistical energy models. A fundamental aspect of the results of these models has been to show that, without some type of mechanically active vibration-damping system, the vibration levels at all ISPR locations would exceed the Figure 4.2.2-1 requirements. As a result an Active Rack Isolation System (ARIS) was designed to isolate selected ISPRs from Station vibrations while at the same time holding them in place in their rack bays. Additional details on the ARIS are provided in Section 5.3.2 below.

Calculation and modeling of the contribution of payload systems to the total system vibratory environment is also being implemented, but is at a technically less-advanced stage. Nevertheless, the fact that a payload complement vibratory requirement exists at all should be noted by any investigator considering developing a payload for ISS, because the requirement has implications for placing constraints on how much vibration an individual payload can produce. A scheme to manage the vibration contributions of individual payloads so that the total payload complement does not exceed the requirement is presently under development

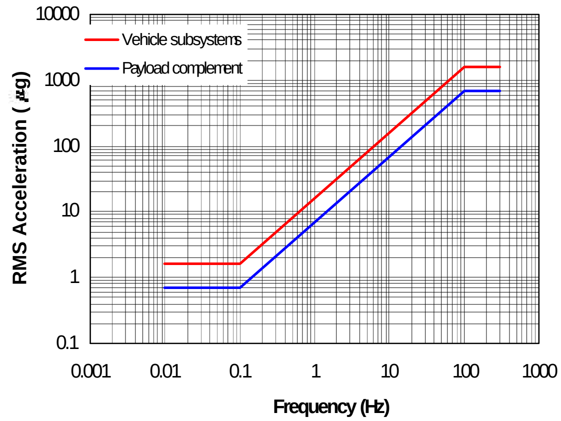

Figure 4.2.2-1 ISS Vibratory Microgravity Requirements

4.2.3 Microgravity Acceleration Measurement

The Space Acceleration Measurement System-II (SAMS-II) and the Microgravity Acceleration Measurement System (MAMS) will measure the quasi-steady (MAMS) and vibratory (MAMS and SAMS-II) microgravity environment on board ISS. The data will assist ISS Users with correlating microgravity-sensitive experimental results with the ISS microgravity environment. The Principal Investigator Microgravity Services (PIMS) project at NASA's Glenn Research Center will analyze the SAMS and MAMS data and provide the results to principal investigators, the ISS program and other investigators. Further information on PIMS and ISS microgravity measurement can be found on the PIMS website (Appendix B).

4.3 Internal Environment Control and Monitoring

The nominal atmosphere onboard the ISS is an Earth-normal 101.4 kPa (14.7 psia) with 21% oxygen and 78% nitrogen. Pressure is maintained between 97.9 – 102.7 kPa (14.2 - 14.9 psia), with a minimum pressure of 95.8 kPa (13.9 psia). Oxygen partial pressure is maintained in the range of 19.3 - 23.4 kPa (2.8 - 3.4 psia). The relative humidity is maintained between 25% and 70%. The medical operations requirement, and the ISS specification, for CO_2 level is a 24-hour average of 0.7% or less, although a 24-hour average exposure as high as 1% is allowable during crew exchanges. The ISS program has agreed to maintain the cabin CO_2 level to 0.37% (with the goal of reaching 0.3%) for two 90-day periods each year. Modeling has shown that with two U.S.- and one Russian-segment CO_2 scrubbers a level closer to 0.2% can be expected.

4.4 External Environment Control and Monitoring

The ISS external environment is the space natural environment as modified by the presence of the ISS and its related operations. The natural environment is defined as that which would exist if the ISS were not in orbit. The natural environment includes neutral atmosphere, plasma, charged particle radiation, electromagnetic radiation, meteoroids, space debris, magnetic field, and gravitational field.

The ISS itself produces a variety of modifications to its external environment. Among these are changes to the gaseous and particulate environment, which are of concern because they can result in surface contamination and change the environment for imaging and sensing space and the earth. Controls on these effects for the ISS Program include the specification that ISS contamination sources will contribute no more than 1×10^{14} molecular-cm^{-2} to the molecular column density along any unobstructed line of sight, and produce no more than 1×10^{-6} g-cm^{-2}-yr^{-1} total deposition on sampling surfaces at 300°K. Contamination requirements directed specifically at effects on attached payloads and the ISS vehicle by other attached payloads specify that an attached payload shall not deposit material at a rate greater than 5×10^{-15} gm/cm^2/sec on other attached payloads and 1×10^{-15} gm/cm^2/sec on ISS vehicle elements. There will be instruments attached at or near external payload sites to monitor these contamination rates.

5. Accommodations for Research on ISS

This section provides a detailed overview of the general and specific resources for research payloads on ISS. This includes station-wide resources such as power and data that affect all users, whether associated with the U.S. or non-U.S. IP communities. For specific research facilities, however, the discussion covers in detail only those areas of ISS to which U.S. investigators will have direct access. Indirect access to facilities controlled by the IP research communities is possible if U.S. researchers are part of co-investigator teams with IP researchers. For this reason a brief outline of the IP facilities is also provided.

5.1 Resource Allocation

Each of the ISS International Partners is allocated a share of Station resources in proportion to their contribution to the program. The resulting allocation scheme is detailed in Table 5.1-1. Within this overall allocation framework additional shifting of resources can occur based on bilateral agreements that allow IPs and countries to trade resources and responsibilities. Internally, IPs use their own mechanisms to apportion space and research capability to their scientific, technological, and commercial interests. To coordinate their research and resources trades, the IPs have established bi- and multilateral working groups.

In exchange for providing the bulk of the Station infra-structure and lift capability, the United States is allocated 97.7% of the space in its own U.S. Lab module plus 46.7% of the European *Columbus* and

Japanese JEM pressurized laboratory space. This is equivalent to 13 ISPRs in the U.S. Lab, and 5 ISPRs each in both the JEM and *Columbus*. The CAM holds 4 ISPRs also allocated to the U.S., yielding a Station-wide number of 27 ISPRs for U.S. research, 5 for the Europeans and 5 for Japan. In addition to its four attached payload sites on the ISS truss, the U.S. program will have use of 50% of the external attached payload space being provided on the JEM-EF and *Columbus*. No allocation of resources for the Russian Space Agency is included in Table 5.1-1 because with the exception of crew time, RSA retains 100% of the resources and accommodations it provides.

In addition to outright trading of resources and responsibilities, cooperative development agreements are also possible, whereby a facility or piece of equipment is developed jointly by two (or more) IPs with the understanding that both will share access to the final product. A significant fraction of the research-specific facilities and equipment described below, which are under nominal access to U.S. researchers, are being developed in this way.

Table 5.1-1. ISS Partner Allocation

	NASA	CSA	ESA	NASDA
	Percent (%)			
Utilization Capabilities / User Accommodations				
NASA Lab Module *Destiny* - *Annual Avg Rack Locations (DRE)*	97.7	2.3		
NASA CAM - *Annual Avg Rack Locations (DRE)*	97.7	2.3		
NASA Truss Payload Accommodations - *Annual Avg Truss Attach Points (AP)*	97.7	2.3		
ESA Columbus Module - *Annual Avg Rack Locations (DRE)* - *Annual Avg COF Attach Points (AP)*	46.7	2.3	51.0	
Japanese Experiment Module (JEM) - *Annual Avg Rack Locations (DRE)* - *Annual Avg JEM-EF Attach Points (AP)*	46.7	2.3		51.0
Utilization Resources				
Resources: - *Annual Avg Power (kW)* - *Annual Total Crew Time (hours) (non-Russian)*	76.6	2.3	8.3	12.8
Rights to Purchase Supporting Services				
Space Station Launch & Return Services - *Press/Unpress Upmass (kg)* - *Press/Unpress Downmass (kg)* - *Press Volume/ Press Down Volume (DRE)*	76.6	2.3	8.3	12.8
Communications Data Transmission Capacity - *Annual Avg Downlink (Mbps)*	76.6	2.3	8.3	12.8

DRE = Double Rack Equivalent

5.2 Station-wide Resources

5.2.1 Power

Station power at assembly complete will be generated from four sets of solar arrays on the Integrated Truss Structure. The arrays rotate on two axes to track the sun. The lack of a third axis does reduce power generation during high solar β angles as discussed above, but this does not cause operational limitations to payloads after flight 12A. At assembly complete 26 kW minimum continuous and 30 kW average power and thermal conditioning will be provided to payloads during Standard and Microgravity modes. An additional 2.5 kW of power is provided to operate ISS systems that support payload operations. During various other operating modes, payloads receive a minimum of 6.5 kW of continuous power.

5.2.2 Payload Data Handling and Communication

To transfer research data and video to the ISS User, the Station provides an onboard command and data distribution network associated with a forward and return antenna communication. A 72 kbps S-band forward link is used to send commands for payloads, while a 150 Mbps Ku-band system is used for the payload downlink. Data onboard are distributed from the payloads to an automated payload switch (APS).

Three types of connections are available for this distribution, either directly or indirectly: 1) a MIL-STD-1553B Payload Bus (through a Payload Multiplexer/Demultiplexer), 2) an 802.3 Ethernet, or 3) a fiber-optic High-Rate Data Link (HRDL). The APS distributes the data to a high rate modem for distribution to the Ku-band system. The Assembly Complete orbital coverage for the Ku-band system is approximately 45%. However, several initiatives are in place to increase this orbital coverage to continuous availability. Included in the data rate at Assembly Complete are four compressed channels of video downlink, and three channels of video uplink. The Payload Multiplexer/Demultiplexer provides 300 megabytes of nonvolatile mass storage for payloads. A 216-gigabit communications outage recorder is provided to record research data during loss of signal with the communication system. Video onboard is distributed from the payload to one of several switches. Each switch routes the signal to a recorder or monitor, or distributes it to the downlink. Three video compression units will be on board (one each in the U.S. Lab, JEM, and *Columbus*) to allow video to be downlinked simultaneously with the research data.

5.2.3 Thermal Management

Thermal radiators are positioned on the Integrated Truss Structure. These radiators are oriented using rotary joints to keep them parallel to the sun's rays so as to keep them from receiving external heat inputs, and to keep them oriented toward space to allow radiation of heat. Using H_2O internally, the radiators pick up heat from the ISS through the environmental control system, which then transfers that heat to the radiators using NH_4 as the active heat transfer fluid.

5.2.4 Payload Stowage

Whereas the major items of hardware planned for orbital flight on the ISS can be specifically "slotted" at uniquely suitable locations on the vehicle, generic stowage space is required for the small, loose pieces of hardware and consumables that must support a crewed space vehicle. Stowage considerations encompass not just time on orbit, but transport to and from orbit as well. Because stowage is optimized for the entire Station system, instances may result in which research stowage is not immediately adjacent to a User's experiment.

The majority of stowage on ISS is accommodated by ISPR-size racks that provide compartmentalized storage. The types of stowage racks currently being developed are the Resupply Stowage Rack (RSR), the Zero-G Stowage Rack (ZSR), and the Resupply Stowage Platform (RSP). The RSR has a capacity of 1.1 m^3 (37.5 ft^3) and stows miscellaneous small items or loose cargo by means of a group of lockers of various sizes. These locker assemblies, made with doors and latches, are configured to accept individual stowage trays, and are bolted into the rack structure. Stowage trays are the basic containers for transportation to orbit and for on-orbit stowage of internal cargo for the ISS. If a given RSR is used only in the transportation phase, contents of the trays may be removed and stowed in the appropriate modules. The stowage trays are modular and interchangeable to support a variety of cargo types.

The ZSR is a lightweight, on-orbit stowage restraint system. The ZSR comprises two elements: a collapsible shell and a fabric insert. The shell is an aluminum frame that provides a standardized interface to the insert. The fabric inserts can be configured to carry sub-containers that include the stowage trays mentioned above, as well as various types and sizes of soft-sided cargo bags. The 1.2 m^3 (42.8 ft^3) ZSR is not designed to transport cargo during launch and landing phases.

The RSP is a re-supply/stowage carrier system for transporting ambient pressurized cargo to and from the ISS. It can transport the same types of soft-sided cargo bags and other sub-containers as the ZSR.

5.2.5 Crew Resources

When assembly is complete, the crew will work an 8-hour day Monday through Friday, and a 4-hour day on Saturday. Sundays are planned as crew rest days, although required essential payload maintenance activities, such as care and feeding of biological specimens, will take place. A total of 160 crew-hours per week will be available for research purposes at Assembly Complete. This number assumes the nominal crew size of seven. These hours must be apportioned among all science, technology, and commercial investigations on board the Station. The remaining crew hours will be devoted to Station maintenance, EVA, command and control, and other Station vehicle housekeeping functions as necessary. Additional hours for payload operations may be available, based on the burden of ISS vehicle requirements.

5.2.6 Crew Health Care System

To support the medical needs of crewmembers during ISS assembly and operations, NASA has developed the Crew Health Care System (CHeCS). CHeCS consists of three primary elements: 1) the Health Maintenance System for providing medical care, 2) the Environmental Health System for monitoring the internal environment of the ISS, and 3) the Countermeasures System, which provides hardware and procedures for crew member exercise to minimize the effects of spaceflight on the body.

The Health Maintenance System includes a defibrillator, an ambulatory medical pack, a respiratory support pack, an advanced life support pack, a crew medical restraint system, and a crew containment protection kit.

The Environmental Health System will assess toxicology, water quality, microbiology, and the radiation environments. To accomplish this, the toxicology system includes a volatile organic analyzer, a compound-specific analyzer for combustion products, and a compound-specific analyzer for hydrazine. A water sampler and archiver and total organic carbon analyzer will enable crewmembers to assess water quality. A surface sampler kit, a water microbiology kit, and a microbial air sampler will enable microbiology assessments. Finally, the radiation environment will be monitored with an extravehicular/intravehicular charged particle directional spectrometer, a tissue equivalent proportional counter, and a variety of dosimeters placed throughout the Station.

The Countermeasures System will consist initially of a treadmill equipped with a vibration isolation and stabilization system and a medical computer.

The primary purpose of CHeCS is to provide for and monitor the well being of the astronauts while in orbit but components of CHeCS occasionally may be used to support life sciences research on ISS if that use does not interfere with CHeCS' primary purpose. Similarly, CHeCS may require occasional use of research equipment for periodic assessment of crew health.

5.3 Generic NASA Accommodations for Research Payloads

5.3.1 International Standard Payload Rack

To support efficient integration and interchangeability of payload hardware — and to maximize joint research among investigators using this multinational facility — the ISS program has adopted the International Standard Payload Rack (ISPR). The 37 ISPR slots for science payloads on ISS provide a common set of interfaces regardless of location. Nonstandard services are also provided at selected locations to support specific payload requirements.

Each NASA ISPR provides 1.6 m^3 (55.5 ft^3) of internal volume. The rack weighs 104 kg (230 lbm) and can accommodate an additional 700 kg (1543 lbm) of payload equipment. The rack has internal mounting provisions to allow attachment of secondary structure. The ISPRs will be outfitted with a thin center post to accommodate sub-rack-sized payloads, such as the 48.3 cm (19 in) Spacelab Standard Interface Rack (SIR) Drawer or the Space Shuttle Middeck Locker. Utility pass-through ports are located on each side to allow cables to be run between Racks. Module attachment points are provided at the top of the rack and via pivot points at the bottom of the Rack. The pivot points support installation and maintenance. Tracks on the exterior front posts allow mounting of payload equipment and laptop computers. Additional adapters on the ISPRs are provided for ground handling. Japan has developed an ISPR with interfaces and capabilities that are nearly identical to NASA's.

Power. The standard power interfaces for the 37 ISPRs consist of a 3 kW power feed and a 1.2 kW auxiliary feed. The power interface voltage will range from 114.5 to 126 Vdc. Prime power is fed to the ISPRs via 8-gauge wiring. The modules provide the switching and circuit protection using 25-A remote power controllers. The auxiliary power feed is distributed on 12-gauge lines. At selected ISPR locations (5 in *Destiny*, 5 in *Columbus*, and 4 in the JEM), a 6 kW power capability is distributed on 4 gauge wiring along with 1.2 kW auxiliary feed. At three locations within the U.S. Lab, prime and redundant 6 kW power feeds are provided to support operation of 12 kW payloads

Thermal Management. A moderate-temperature water loop is provided via a 1.3 cm (0.5 in) line with a quick-disconnect to each ISPR at an inlet temperature range of 16-24 °C (61-75 °F). The water is circulated through heat exchangers and stainless steel cold plates to allow thermal conditioning of the internal payload hardware. The water flow is controlled within the U.S. Lab and the JEM to optimize the heat rejection efficiencies of the system. The maximum return water temperature is 49 °C (120 °F). Inside a payload rack, an avionics air/heat exchanger assembly can be connected to the loop to remove up to 1200 W by circulating air. At selected locations in the U.S. Lab (9 ISPRs) and the JEM (5 ISPRs), a low-temperature water loop (0.6-10 °C or 33-50 °F) is provided via a 1.3 cm (0.5 in) line with a quick-disconnect. The maximum return temperature on this loop is 21 °C (70 °F). A pressure drop of 40 kPa (5.8 psid) is allowed across the inlet and outlet of both water loop interfaces. Payloads can also dissipate small amounts of heat into the cabin air. Depending on the temperature conditions set by the crew, a minimum of 500 W can be dissipated into both the U.S. Lab and *Columbus* (complement of all payloads within the module). Negotiations are underway with Japan on the allowable heat dissipation into the JEM.

Command and Data Handling. The standard interfaces to the ISPRs include a MIL-STD-1553B Payload Bus that uses twisted shielded wire pairs and a high rate data link via optical fibers. Commands to the payloads from the ground, crew, and onboard automated procedures are delivered via this 1553B connection as are health, status, safety, and ancillary data types. Each payload location is allowed one remote terminal on the bus. Payload display and controls via 12 laptop ports are supported in the three modules (4 in the U.S. Lab, 4 in the *Columbus*, and 4 in the JEM). A timing signal is available to the payloads at 1 Hz with an accuracy of ± 5.0 ms with respect to the onboard time source over the 1553 bus.

Each ISPR is provided 2 fibers that connect to an input and output port on the APS for distribution of up to 100 Mbps of data between racks or for downlinking via the Ku-band system. Within the JEM, two additional fibers support downlinking research data through the JEM Interorbit Communication System (ICS). An 802.3 Ethernet local area network is distributed to the ISPR locations within the U.S. Lab, JEM, and *Columbus* for telemetry, file transfer, and laptop communications. The Ethernet's 10Base-T architecture allows up to 10 Mbps of data transfer to multiple ISPR locations. The Ethernet commonality of this interface across the 37 ISPRs is presently under definition.

Video. The standard video interface to the ISPRs within the U.S. Lab and *Columbus* is comprised of fiber optic lines using an EIA-RS-170A optical pulse frequency modulated video signal. Fibers are used to support video to and from the ISPR payload. A synchronization and control signal is also provided to the ISPR in accordance with EIA-RS-170A. The video distribution to the JEM is via twisted shielded wire pairs. A video card can be used inside the payload racks to convert the optical video/sync signals to electrical baseband NTSC EIA-RS-170A video/sync. The video signals from the ISPRs are sent to switches that allow distribution to onboard monitors, one of seven video tape recorders, or to the video baseband signal processor to allow distribution to the ground via the Ku-band.

Vacuum Exhaust System (Waste Gas). All of the laboratory modules contain the plumbing to support a waste gas exhaust system that is vented to space. A 2.5 cm (1 in) diameter gas line connected to this exhaust system is provided at each of the ISPR locations. The pressure allowed into the waste gas line is 275.8 kPa (40 psia). The temperature of the exhaust waste gas is allowed to be between 15.6-45 °C (60-113 °F). The waste gas system can reach pressures of 1×10^{-3} torr (1.9×10^{-5} psia) in less than two hours for a single payload volume of 100 liters (3.5 ft^3) at an initial pressure of 101.4 kPa (14.7 psia). The waste gas system is a shared and scheduled resource that can only be operated at one ISPR location within each module at a time. This requirement is to prevent cross contamination of payloads and incompatible mixtures of waste gas constituents. The types of waste gas constituents allowed must be compatible with the wetted materials of the module waste gas system.

Vacuum Resource. At selected locations within the U.S. Lab (9 ISPRs), JEM-PM (4 ISPRs), and *Columbus* (8 ISPRs), a 2.5 cm (1 in) vacuum resource line is provide via a quick-disconnect for those payloads requiring a vacuum environment. Each module contains the plumbing to produce this vacuum resource by connection to space. The vacuum is provided at a pressure of 10^{-3} torr (1.9×10^{-5} psia). Multiple payload locations may be connected to the vacuum resource at a time.

Nitrogen. A 0.95 cm (0.375 in) nitrogen line via a quick disconnect is provided as a standard service to all 37 ISPRs. The nitrogen is provided between 15.6-45 °C (60-113 °F) at a pressure of 517-827 kPa (75-120 psia). The flow rates to payloads will be up to 0.9 kg (0.2 lbm) per minute. Each payload will incorporate a valve to control the flow of nitrogen.

Carbon Dioxide, Argon, and Helium. As a non-standard interface, carbon dioxide, argon, and helium are provided to selected ISPR locations in the JEM. These gases are provided via a 0.95 cm (0.375 in) line with a quick-disconnect. The nominal pressure range of these gases is 517-786 kPa (75-114 psia) when a single ISPR is being operated. The maximum design pressure of the line is 1379 kPa (200 psia).

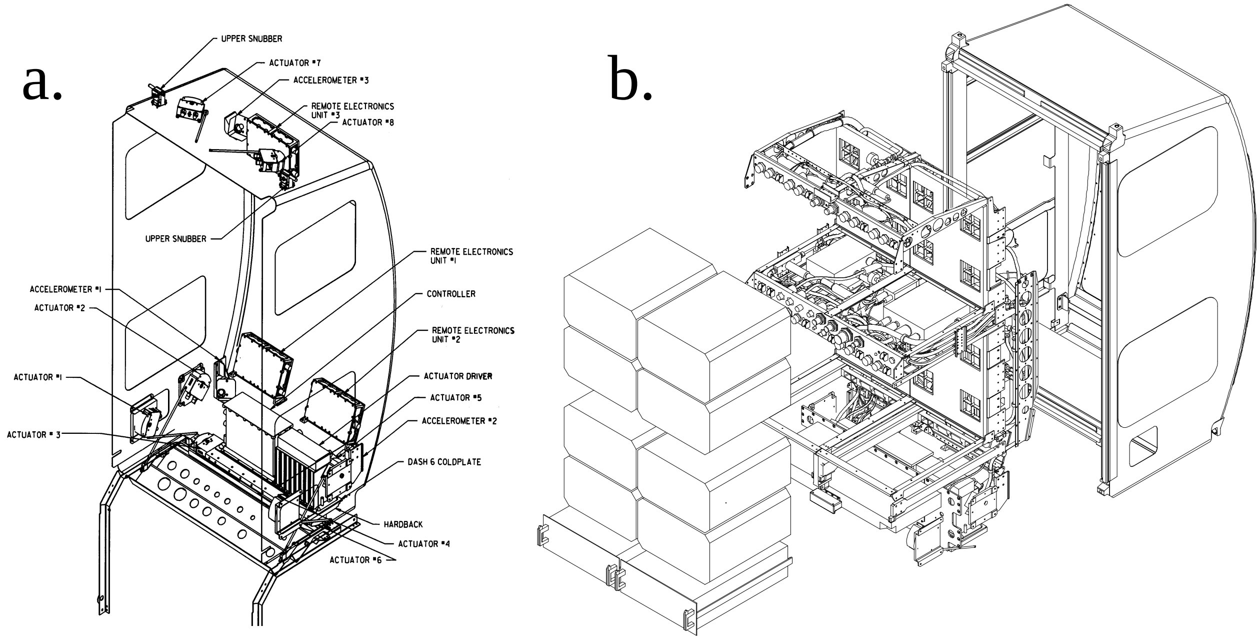

Figure 5.3-1. (a) ARIS components attached to an ISPR, (b) EXPRESS rack with 8 Mid-Deck Lockers

5.3.2 Active Rack Isolation System

The Active Rack Isolation System (ARIS) is designed to isolate payload racks from vibration such that the on-rack environment will meet the system vibratory specifications shown in Figure 4.2.2-1. The ARIS is an active electromechanical damping system attached to an ISPR that senses the vibratory environment with accelerometers, then damps it by introducing a compensating force. The ARIS components reside both inside and outside the ISPR (Fig. 5.3-1a).

Currently, eleven ARIS-equipped racks are planned for investigator use and several locations in *Destiny* and *Columbus* accommodate ARIS-equipped racks. The ARIS is currently under development and its system capabilities will be determined as part of an on-orbit ISS microgravity characterization experiment during the 6A-7A.1 time interval.

5.3.3 Sub-Rack Accommodations and EXPRESS Rack

The accommodations for research on ISS are designed to give a User the option of using what amount to "central facilities" for conducting their research, or developing their own experimental equipment from scratch. The central facilities option is discussed below in Section 5.4, which covers Facility-Class Payloads. If no central facility meets a given investigator's requirements, they can consider building "investigation-specific" equipment that is unique to their needs. Such equipment will typically be allocated a sub-portion of an ISPR based on a unit of space called a Mid-deck Locker Equivalent (MLE). This unit has dimensions roughly based on the Space Shuttle's Mid-deck Storage Locker (MDL), which has an internal 0.06 m^3 (2.0 ft^3) volume and approximate dimensions of 43.2 cm (17 in) width $\times$ 50.8 cm (20 in) depth $\times$ 25.4 cm (10 in) height. Equipment that is built around the MLE size-concept is typically referred to as a sub-rack payload.

In designing ISS to accommodate sub-rack payloads it became apparent that several advantages would be obtained if investigators building MLE-based equipment were provided with host racks with a standardized set of interfaces. Based on this the EXPRESS rack concept was born. EXPRESS stands for EXpedite the PRocessing of Experiments to the Space Station. The purpose of the EXPRESS Rack is to allow quick (i.e., less than one year) and simple integration of payloads into the ISS. The EXPRESS Rack contains standard interfaces within an ISPR configuration to allow payloads quick and standard access to ISS resources. The EXPRESS Rack offers structural support hardware, power conversion and distribution equipment, data and video equipment, nitrogen and vacuum exhaust distribution hardware, and thermal support equipment.

Whereas an EXPRESS Rack can be accommodated at any ISPR location on the ISS, it typically will be installed in a 3-kW ISPR location. The EXPRESS Rack configuration shown in Figure 5.3-1b accommodates eight MLE-payloads in two areas of four lockers each, and two 4-Panel Unit (PU) drawers. This layout can accommodate single or multiple MLE-style lockers.

MLE payloads are bolted to the EXPRESS Rack backplate, which is attached to the rear posts of the ISPR. MLE payloads interface to resources (power, commands/telemetry, water cooling, waste gas venting, and GN_2) via connection on the front face of the payload. Cooling is provided via passive radiation and heat exchange to the cabin environment, forced avionics air cooling via rear interfaces with the Rack avionics air loop, or water cooling. Drawer payloads interface at the rear for power, data, and avionics air.

The payload complement within an EXPRESS Rack receives a combined total of 2 kW at 28 Vdc for power and 2 kW heat rejection (air and water cooling combined). The EXPRESS Rack includes an Avionics Air Assembly (AAA) to provide forced air cooling. This assembly has a limited capability that must be shared by all payloads within the rack. Adequate air flow rate should be provided by the payload developer with an internal fan or equivalent. Use of cabin air cooling is restricted for EXPRESS Rack payloads due to Fire Detection and Suppression concerns and restricted heat dissipation allocation for racks in the ISS. The EXPRESS Rack interface to the moderate temperature water loop and the forced air cooling are common/shared resources and must be evaluated as an integrated subsystem to ensure that the heat loads are equally accommodated by the particular system. Each EXPRESS Rack includes one payload connection for vacuum exhaust and one connection for nitrogen distribution.

Some EXPRESS Racks will use ARIS to reduce acceleration disturbance. The EXPRESS Rack with ARIS has two connectors on the lower connector panel where second generation Space Acceleration Measurement System (SAMS-II) Remote Triaxial Sensors can be connected for the purpose of measuring the acceleration environment within the EXPRESS Rack.

A sub-rack payload destined for an EXPRESS Rack (an EXPRESS payload) can be transported to the ISS in the orbiter middeck, in an inactive EXPRESS Rack in the Multi-Purpose Logistics Module (MPLM), or in an EXPRESS transportation rack in the MPLM. Passive EXPRESS payloads are transported to the ISS in the MPLM, either in an inactive EXPRESS Rack or in an inactive EXPRESS transportation rack. An EXPRESS payload that must be active during ascent/descent or must have late or early access may be integrated into the space shuttle orbiter mid-deck. An EXPRESS rack payload can be transported from the ISS to the ground with the same options for launch.

5.3.4 Nadir Research Window

The Nadir Research Window is positioned in the U.S. Lab module such that in normal XVV attitude it will point toward nadir. The window design has a three-pane configuration, with an outer 1 cm (0.38 in) thick debris pane, a 3.2 cm (1.25 in) redundant pressure pane, and a 3.2 cm (1.25 in) primary pressure pane (see Figure 5.3.4-1). In addition, in the U.S. Lab interior a removable scratch pane will be mounted over the primary pressure pane to protect the pane from debris within the window volume prior to the installation of the Window Observational Research Facility (WORF). The debris and pressure panes are made out of fused silica, with a 50.8 cm clear aperture, and will have an optical wavefront error of 1/10 of a wave over 12.7 cm, with a reference wavelength of 632.8 nm. Using this window, it will be possible to use up to 20-cm optics without image degradation from window-induced wavefront error. Although ground resolution is difficult to estimate because of differing conditions of target contrast, atmospheric haze and shimmering, and spacecraft motion, the 20-cm optics used in the WORF may, under optimum conditions, be able to distinguish ground objects as small as 1-3 m (3.3-9.8 ft). The window panes will have an anti-reflection coating designed to minimize signal loss due to reflections between adjacent panes. This coating provides a wavelength transmittance through the window that favors the visible wavelengths, although it has reasonable transmittance in the near UV and infrared.

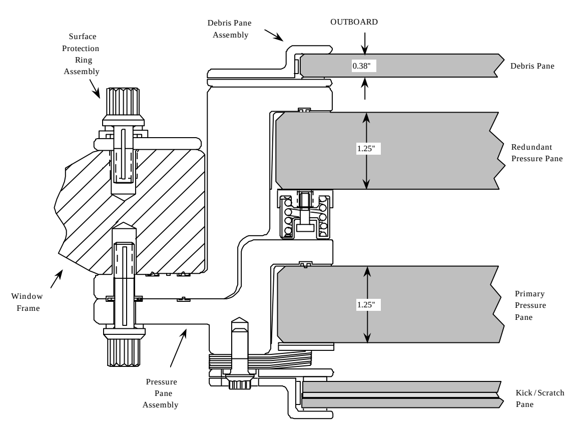

Figure 5.3.4-1. Nadir window cross-sectional view

Table 5.3.5-1. Laboratory and Station Support Equipment	
Laboratory Support Equipment	
Description	**Flight Available**
Refrigerated Centrifuge	Post AC
Digital Thermometer	UF-1
Incubator	UF-3
Micro Mass Measurement Device	UF-5
Small Mass Measurement Device	UF-5
Compound Microscope	UF-3
Dissecting Microscope	UF-3
Passive Dosimeter	5A.1
Quick/Snap Freezer	UF-7
Cryo Storage Freezer	UF-7
Minus Eighty-degree Laboratory Freezer (MELFI)	UF-1
Station Support Equipment	
Bar Code Reader	UF-1
Battery Charger	UF-1
ISS General Purpose Video Camera	TBD
Film Still Cameras	7A.1
Digital Still Camera	7A.1
Cleaning Equipment	6A
DC Power Supply	UF-1
Digital Recording Oscilloscope, Digital Multimeter, pH Meter, and Digital Thermometer (Combined)	7A.1
Function/Sweep Generator	UF-1
General Purpose IVA Tools	2A
Maintenance Work Area	7A.1
Portable Utility Light	TBD
Crew Refrigerator/Freezer	UF-1
Restraints and Mobility Aids	UF-1
Utility Outlet Panel	TBD
Fluid System Servicer	TBD

5.3.5 Laboratory and Station Support Equipment

Lab Support Equipment (LSE) and Station Support Equipment (SSE) comprise the general-purpose equipment and tool items developed to support ISS maintenance and payload operations. (The distinction between LSE and SSE relates mainly to where the equipment originates from within the ISS Program.) A significant fraction of this equipment exists to support research, and consists of the sorts of basic equipment such as pH meters and microscopes that would be found in a typical ground-based research lab. The availability of specific pieces of LSE and SSE is linked to the assembly sequence such that pieces will become available to researchers at different stages of Station assembly. A list of the LSE and SEE items and the flight after which they will be available is provided in Table 5.3.5-1. The laboratory freezer systems provided as part of the LSE complement are of particular interest to the Life Sciences researchers and are described separately below.

Cryofreezer System. The Cryogenic Freezer System will consist of two complementary units, the Cryogenic Storage Freezer and the Quick/Snap Freezer. The Cryogenic Storage Freezer will maintain samples at or below -183 °C (-297.4 °F) throughout a mission life cycle. It will be used to preserve plant and animal cell fine anatomy, ultrastructure and genetic material. It will provide a cryogenic storage environment both on orbit and during transport to and from the ground. When used with appropriate ground-support equipment, it will allow samples to be maintained at cryogenic temperatures during transport from the home laboratory on the ground to the Space Station and from the Space Station back to the ground lab. The 35-liter (1.2 ft^3) internal volume of the storage freezer will accommodate 1000 or more 2- to 5- ml (0.1- to 0.3- in^3) sample vials.

The Quick/Snap Freezer is a portable unit to be operated in conjunction with the Cryogenic Storage Freezer. The Quick/Snap Freezer will be used to cool all samples before they are inserted into the storage freezer and will also provide a means to transport cooled samples between the Life Sciences Glovebox, the X-ray Crystallography Facility, and the Cryogenic Storage Freezer. It will "quick freeze" 2 ml (0.1 in^3) and 5 ml (0.3 in^3) contained samples and ultra-rapidly freeze ("snap freeze") small ($1 \times 2 \times 1$ mm or $0.04 \times 0.08 \times 0.04$ in) tissue samples. The unit will be accessible from within the work volume of the Life Science Glovebox.

Minus Eighty-degree Laboratory Freezer (MELFI). The Minus Eighty-degree Laboratory Freezer for ISS (MELFI) is a low temperature sample cooling and storage unit that will maintain samples below -68 °C (-90.4 °F) throughout a mission life cycle. The MELFI will provide a temperature-controlled volume of not less than 300 liters (10.6 ft^3) in four Dewar-type modules (vacuum-insulated containers). Each Dewar will have a capacity of not less than 75 liters (2.6 ft^3) of internal storage volume. The MELFI is designed to operate optimally at -80 °C (-112 °F), but will have independent activation/deactivation and temperature control for each

Table 5.3.6-1. U.S Attached Payload Resource Accommodations	
U.S. Truss Site (allocation per site)	
Operational Envelope	ref. SSP 57003-Attached Payload Interface Requirements Document
Maximum Payload Height	3.1 m (10 ft)[1]
Mass	4990 kg (11,000 lbm)[1]
Power	3 kW at 113-126 Vdc (shared)[2]
Thermal	passive only
Low Rate Data	by 1553B, <100 kbps (shared)[2]
High-Rate Data	by fiber optic High-Rate Data Link, 95 Mbps (shared)[2]
U.S. EXPRESS Pallet (allocation per pallet)	
Mounting platform dimensions	394 x 229 cm (155 x 90 in)
Total payload mass	1361 kg (3000 lbm)
U.S. EXPRESS Pallet Adapter (per adapter)	
Adapter dimensions and operational envelope	(see Fig. 5.3.6-2)
Payload mass	227 kg (500 lbm)
Power	2.5 kW at 113 Vdc/500 W at 28 Vdc (shared)[2]
Thermal	passive only
Low Rate Experiment Data, Command, Control and Telemetry	by 1553B, < 100 kbps (shared)[2]
High Rate Experiment Data	by fiber optic High-Rate Data Link, 6 Mbps (shared)[2]

[1]Subject to enveloping formulas
[2]Maximum value, represents allocation shared among several payloads.

Dewar, allowing one Dewar to be set at +4 °C (39 °F) and one at –26 °C (-14.8 °F). It will preserve samples that require all biochemical action to be stopped but do not require cryogenic temperatures. Cell culture media, bulk plant material, and blood, urine and fecal samples are examples of the types of items that will be stored in the MELFI. The four Dewars will accommodate a wide variety of sample container sizes and shapes.

5.3.6 U.S. Truss Site Payload Accommodations and EXPRESS Pallet

The available resources and accommodations for U.S. truss-site payloads are summarized in Table 5.3.6-1. Resources are given for a single payload occupying an entire truss-site, which is one option for an ISS User, and also for payload accommodated on an EXPRESS pallet, which is the other option. An EXPRESS pallet occupies an entire truss site using the truss payload attach system. It provides an equally sub-divided attachment surface that will accommodate up to 6 individual payloads (Figure 5.3.6-1). Similar to the EXPRESS rack for internal payloads, the accommodations at each of the 6 payload locations are standardized to provide quick and straightforward payload integration. This is accomplished using a standard EXPRESS Pallet Adapter (ExPA) plate to which the payload is permanently mated prior to launch and which is subsequently locked into place on the pallet by the Special Purpose Dexterous Manipulator on the Station's robotic arm. Power and data distribution to each of the six ExPAs is then provided via blind-mate connectors to the integrated pallet.

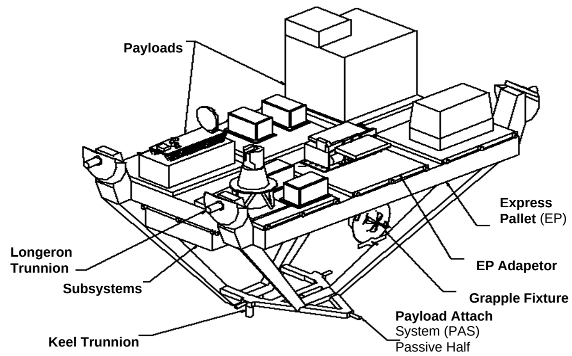

Figure 5.3.6-1. EXPRESS Pallet

The enveloping parameters for the allowed dimensions for payload hardware occupying one entire truss site are somewhat complex and are diagrammed in NASA document SSP 57003-*Attached Payloads Interface Requirements Document*. The allowed payload mass and center of gravity are also enveloped in SSP 57003 and the values in Table 5.3.6-1 are provided as one example of an inter-related set of parameters. For individual EXPRESS pallet adapter payloads the dimensionsal envelope is diagrammed in Figure 5.3.6-2.

The power and data resources supplied to individual attached payloads are subject to sharing with other payloads. Table 5.3.6-1 therefore specifies the maximum power and data resources that an individual payload could receive assuming there were no demands from other attached payloads. Because this is an ideal situation the actual resource is subject to availability and likely to be less than the values listed.

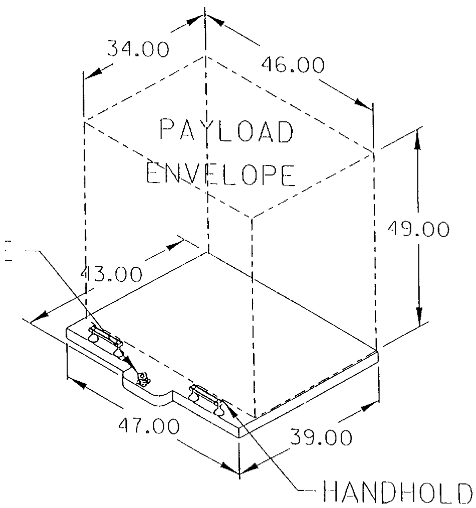

Figure 5.3.6-2. EXPRESS Pallet Adapter (ExPA) payload envelope (dimensions in inches).

Power to individual truss sites is provided by prime and redundant power feeds and is switched and circuit-protected by a 25 A remote power controller. An individual EXPRESS pallet receives all of the power and data resource allocated for its truss-site.

Each truss site is provided one remote terminal on the payload MIL-STD-1553B bus from the payload Multiplexer/De-Multiplexer (MDM) in the U.S. Lab. The bus is used for command, control, system health, and status data. Data downlinks or on-board display can be achieved through connections to the payload MDM. Two high-rate fiber optic data links are provided at each site. The fibers are connected directly into the automated payload switch within the U.S. Lab to allow research data to be downlinked via the Ku-band system or switched to another payload.

For individual ExPA payloads a pallet controller will provide a MIL-STD-1553B bus, RS 422/485 and analog interfaces. It will transmit and receive high rate data on fiber optic interfaces.

For attached payloads whose missions are based on astronomical imaging or Earth remote sensing a knowledge of ISS orbital position, flight attitude and view fields is a consideration. Data on orbital position and flight attitude will be provided to payloads as Broadcast Auxiliary Data on the 1553B bus. Position will be known to within 3000 ft (RMS of *x*, *y* and *z* axes.). Attitude knowledge will be within 3° per axis of roll, pitch and yaw. The fields of view for attached payloads are dependent on payload type and location, with full truss-site payloads having greater lattitude in viewing than ExPA payloads. Viewing in the zenith direction for payloads on nadir-pointing truss sites is not generally possible and vice versa. Viewfields for ExPA payloads depend on the payload's position on the pallet and the relative height of adjacent payloads. Positions provide various combinations of viewing in the nadir, zenith, ram, wake, and Earth-limb directions.

5.3.7 JEM and Columbus Exposed Facility Payload Accommodations

Payload dimension envelopes, masses, fields of view and other resource data for the JEM-EF and the *Columbus* Exposed Payload Facility are listed in Table 5.3.7-1. As shown in Figure 5.3.7-1, the JEM-EF

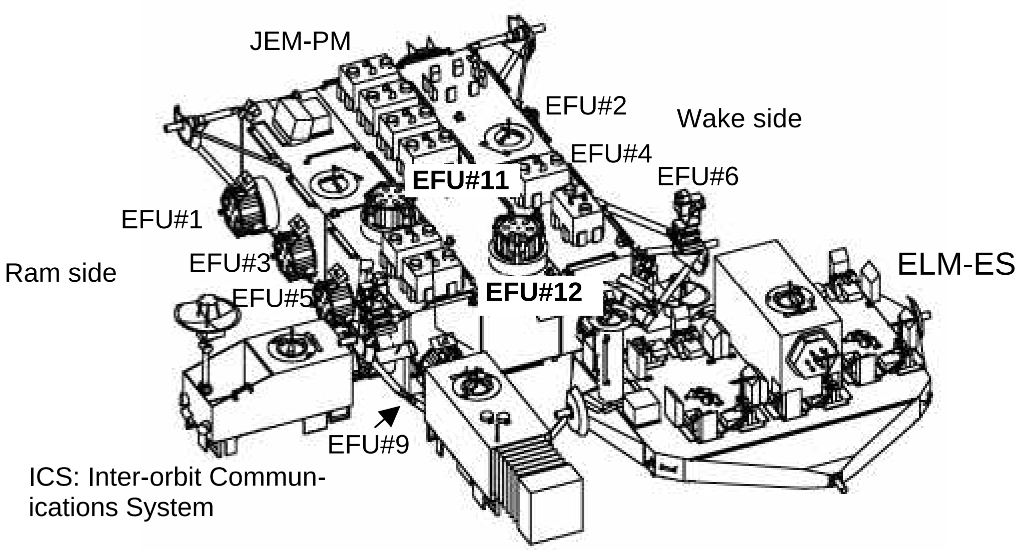

Figure 5.3.7-1 JEM-EF Configuration and JEM-EF Experiment Payload-attached Locations

provides a total of 12 attachment ports called Exposed Facility Units (EFUs) to which space-exposed hardware may be mated using a standard Payload Interface Unit (PIU). It is through the PIU that payloads receive all utilities. A total of 10 EFUs are available for User payloads, the other two being allocated to the ELM-ES, which transports payloads to orbit and stores them when they are not active, and the Interorbit Communication System (ICS). Five of the 10 available EFUs are available for NASA payloads.

In addition to a PIU, each JEM-EF payload must have a Space Shuttle-compatible Grapple Fixture to allow handling of the payload by the JEM Remote Manipulator System (JEM-RMS), a robotic arm system used for the transport and positioning of external user payloads. The JEM-RMS has both a main arm and a fine arm for robotics manipulation and is operated by the crew from within the JEM-PM with the aid of a viewing port. A central capability of the JEM system is the ability to use the airlock in the JEM-PM to robotically transfer payload hardware between the JEM-PM, the EF and the ELM-ES. Due to airlock size constraints this capability is limited to research samples or hardware sub-parts of payloads but does not include entire payloads.

The availability of these resources is not equal at all EFUs. For example, higher masses of 2500 kg can be accommodated at two EFU locations, one on the wake and the other on the port side of the EF. The listed mass values are maximums per site. Power is switched and circuit protected. Each site is provided a moderate temperature non-water fluid (fluorinert) loop for heat rejection. The data and video services are connected back to the U.S. Lab for downlinking and distribution to the Ku-band system or to the ICS.

Columbus Exposed Facility payloads are accommodated on two support structures attached to the outboard end-cone of the module (see Fig. 3.5-1). Payloads will be interfaced to these support structures using ExPAs. Each support structure accommodates one starboard-pointing and either one nadir-pointing or one zenith-pointing ExPA, for a total of four on the module (Fig. 3.5-1). The payload accommodations and resources provided to the *Columbus* Exposed Facility ExPAs are summarized in Table 5.3.7-1.

Table 5.3.7-1. Non-U.S. International Partner Attached Payload Resource Accommodations

JEM Exposed Facility (per EFU)	
Dimension envelope	1.8 x 0.8 x 1.0 m (6 x 2.6 x 3.3 ft)
Mass	500 kg (1,100 lbm)/2500 kg (5500 lbm)
Power (main)	3 kW at 113-126 Vdc (shared)[1]
Power (keep alive)	100 W feed
Thermal (active)	by circulating fluid (fluorinert) loop, 3 kW
Thermal (passive)	by conduction through PIU, 7 kW
Low Rate Experiment Data, Command, Control and Telemetry	by 1553B bus, < 100 kpbs (shared)[1]
High Rate Experiment Data	by FDDI optical fibers, 43 Mbps
Ethernet	by 802.3 protocol, 10 Mbps (shared)[1]
Experiment Video	by twin-axial cable, using EIA-RS-170A protocol.
Fields of view	zenith-ram-wake-port (2 sites); zenith-nadir-ram (3); zenith-nadir-ram-port (1); zenith-nadir-wake (4)
Columbus EXPRESS Pallet Adapters (per adapter)	
Payload dimension envelope	(see Fig. 5.3.6-2)
Payload mass	227 kg (500 lbm)
Power	2.5 kW at 120 Vdc (shared)[1]
Thermal	passive only
Low rate experiment data, command, control and telemetry	by 1553B bus, **<**100 kpbs (shared)[1]
High-rate data	by extension of Columbus video/data link, 32 Mbps
Ethernet	by 802.3 protocol, 10 Mbps (shared)[1]
Fields of view	all except nadir (1); all except zenith (1); all except port with partial nadir/zenith (2)

[1]Maximum value, represents allocation shared among other payloads.

5.4 Multi-User Facilities: The Facility-Class Payload Concept

The ISS central research facilities are being developed and managed as a special category of payloads

Table 5.4-1. ISS Facility-Class Payloads					
Facility Name	**Facility Type, (Rack Number) Research Function**	**Research Organization**	**Developing Organization (Location)**	**Location on ISS**	**Integration Flight(s)**
HRF	Rack-level, (2), +stowed equipment Effects of microgravity on humans	OLMSA, Life Sciences Division	NASA Life Sciences RPO (JSC)	Columbus	5A.1, 12A.1
GBF	Rack-level, (3), +centrifuge rotor Effects of gravity on biological systems	OLMSA, Life Sciences Division	NASA Space Station Biological Research Project (NASA ARC)	CAM	UF-7
BRF	Rack-level, (1) Protein crystallization, cell culture and biochemical studies	OLMSA, Microgravity Research Division	NASA MRPO Biotechnology Science Discipline	JEM-PM	AC
MSRF	Rack-level, (3) Materials science and materials processing investigations	OLMSA, Microgravity Research Division	NASA/ESA MRPO Materials Science Diciplline	U.S. Lab	UF-3, AC
FCF	Rack-level, (3) Combustion science and fluid physics investigations	OLMSA, Microgravity Research Division	NASA MRPO Fluids/Combustion Science Disciplines	U.S. Lab	UF-3, UF-5, AC
LTMPF	Exposed facility Low-temperature physics investigations under microgravity	OLMSA, Microgravity Research Division	NASA MRPO Fundamental Physics Discipline (NASA JPL)	JEM-EF	HTV2
MSG	Rack-level, (1) Enclosed volume for chemical and biological studies under microgravity	OLMSA, Microgravity Research Division	NASA/ESA MRPO Glovebox Program	Columbus	UF-1
XCF	Rack-level, (1) Single crystal growth and structure determination	OLMSA, Space Utilization & Product Development	NASA MRPO Space Product Development	U.S. Lab	UF-5
AHSTF	Rack-level, (1) Test-bed for supporting technologies for long duration human spaceflight	OLMSA/Office of Spaceflight (joint)	NASA Microgravity/ Spaceflight (Code U/M)	JEM	16A
WORF	Rack-level, (1), uses nadir window Earth observation by various imaging systems	OLMSA,Offices of Spaceflight, Earth Sciences, and other government agencies	ISS Payloads Office (JSC-OZ)	U.S. Lab	UF-2
APCF	Sub-rack, single MLE Protein screening under temperature-controlled conditions		ESA/NASA	Columbus	7A.1
EMCS	Sub-rack Plant growth and development studies under variable gravity	OLMSA, Microgravity Research Division	ESA/NASA	U.S. Lab	UF-3

known as facility-class payloads, which are intended to form a key part of the Station's research infrastructure. Facility-class payloads are fundamentally multi-user in nature. Rather than originating with an individual investigator, facility-class payloads are being designed and developed by several NASA organizations, in some cases under cooperative development and barter agreements with IP organizations. Funding and oversight of the ISS facility-class payload program is managed through the ISS Payloads Office at JSC.

In keeping with promoting experimental flexibility for the ISS, a number of facility-class payloads have modular designs that allow investigators to design investigation-specific components uniquely suited to a particular experimental need. Access to the ISS facility-class research infrastructure is open to the U.S. and International Partner scientific community through competition.

Table 5.4-1 summarizes the array of facility-class payloads currently under development for ISS. The Table designates a facility type as "rack-level" if it

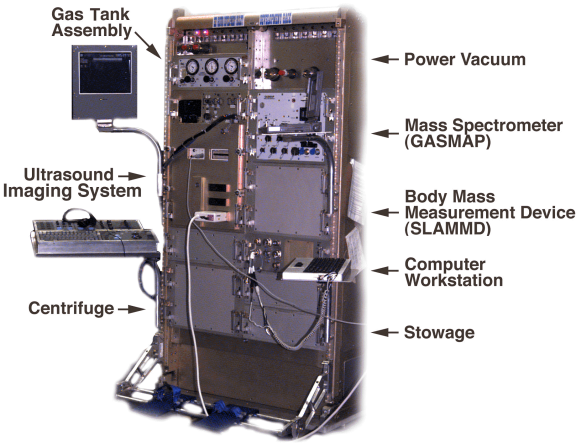

Figure 5.4-1 HRF Rack 1

consists of one or more fully integrated racks. Basic information is included on the NASA or IP research and support organizations to which the facilities are linked. The Integration Flight column lists the flights that will bring major components of the facility to the Station. (In this column the AC designation denotes a facility that will be available at Assembly Complete, but whose actual integration flight is too late in the Assembly Sequence to define at this time.)

Many facility-class payload projects have associated websites and these are listed in Appendix B.

5.4.1 Human Research Facility

The Human Research Facility (HRF) supports life sciences investigations on ISS that seek to understand the physiological and psychological changes in humans due to space flight. Investigations will be of two broad types: basic research that uses microgravity and other unique aspects of the ISS environment to address fundamental scientific questions regarding human physiology, and strategic research defined by NASA to solve problems associated with human adaptation to spaceflight. The latter may involve, for example, developing countermeasures to mitigate the detrimental effects of long-term exposure to microgravity.

HRF will consist of items mounted on two racks based on the EXPRESS design (HRF Racks 1 and 2), as well as separate equipment kept in stowage and brought out as needed. A photographic diagram of HRF Rack 1, highlighting the type and location of its major components, is shown in Figure 5.4-1. HRF Rack 1 will be the first of the facility-class payloads launched to ISS, on flight 5A.1. HRF Rack 2 will be added later, sometime around flight 12A.1. An important feature of both racks is that they are outfitted with Standard Interface Rack (SIR) interfaces for individual subrack components of research equipment. The SIR interface provides standardized slides and slide guides for the mechanical interface between a subrack unit and the HRF rack. It provides blind mating of power and data connectors when a subrack unit is slid into the HRF rack. The SIR interface permits simple installation of a SIR-equipped drawer in any position in the HRF rack, exchange of one drawer for another and movement from one rack to another.

The major pieces of research equipment in HRF Rack 1 are an Ultrasound/Doppler system, a metabolic gas analyzer system, a portable computer and a computer workstation for data processing and data communications. A suite of experiment-unique radiation dosimetry equipment will also be stowed in the HRF rack. An extensive list of additional HRF research equipment can be found at:

- ✓ http://lslife.jsc.nasa.gov/

Investigators using HRF will also have access to the complement of equipment in CHeCS, even though the latter is technically part of the vehicle systems and not a research payload. As an example, the ergometer and treadmill, developed by CheCS for countermeasures, may be utilized in HRF exercise experiments.

Investigations that will use the HRF are selected through an established process that includes international solicitation, review and selection via an annual NASA Research Announcement (NRA). The first NRA which included ISS research opportunities was distributed in February 1996 with the result that initial investigators were under contract in 1997. The human research program on ISS uses an experiment definition and development process similar to that used on the Shuttle program and subsequently modified on the NASA/Mir program. In addition to HRF capabilities, the investigators in the program use their own unique hardware, other flight facilities, ancillary flight information and ground systems to accomplish their research objectives.

5.4.2 Gravitational Biology Facility

The ISS will house a suite of biological research specimen support equipment that collectively will constitute the Gravitational Biology Facility (GBF). Housed within the CAM, the GBF supports research on how the space environment affects a broad range of biological systems. The centerpiece of the GBF is

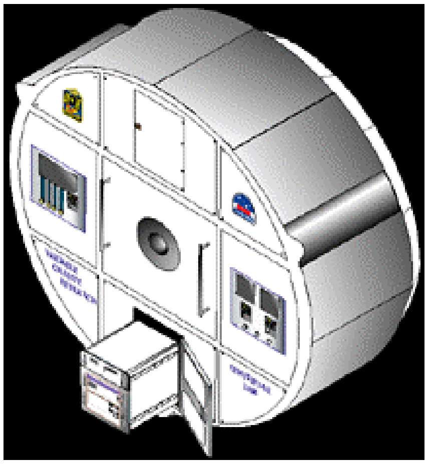

Figure 5.4.2-1. GBF centrifuge

a 2.5 m (8.2 ft) diameter centrifuge, shown in Fig. 5.4.2-1, that accommodates eight biological habitats for maintaining a variety of biospecimen types, from cells to rodents to large plants. To monitor and provide utilities for the habitats when they are outside of the centrifuge, the GBF provides Habitat Holding Racks (HHRs), as well as a Life Sciences Glovebox for transferring specimens without exposing them to the cabin environment.

As the Centrifuge rotates, artificial gravitational forces are produced upon the attached habitats that house various biological specimens. To create a 1.0 *g* acceleration the centrifuge rotates at 28.4 revolutions per minute. Slower rotations produce lower levels of artificial gravity; faster rotations produce higher levels of gravity. Accelerations ranging from 0.01 *g* to 2.0 *g* will permit scientists to compare how differing gravity levels affect the biology of organisms housed in habitats under otherwise identical conditions, thus separating the effects of gravity from other factors in the space environment.

The centrifuge will provide life support resources and electrical power to the habitats as well as data transfer links to ISS systems and to the ground. The hub, or center, around which the Centrifuge rotates provides structural support for the rotating part of the centrifuge, and it provides life support to the specimen habitats.

The Life Science Glovebox will provide a sealed work area in which crew members can perform experimental procedures. Habitats and other science equipment will be attached to the Life Sciences Glovebox in a manner that prevents any exchange of biological material between the cabin and Glovebox or habitat when biospecimens are being transferred into or out of the glovebox. Two crew members will be able to use the Glovebox work volume at the same time by means of gloves that extend into the work volume. The enclosed volume of the Glovebox will be about one half cubic meter (approximately 16 cubic feet). As air circulates through the work space, activated charcoal filters will clean it continuously by adsorbing chemicals that may be present. In addition, a high efficiency air filter will remove particles and aerosols.

Two HHRs provide the structural, mechanical, environmental, and communications support for the biospecimen habitats. The HHRs will provide life support resources and electrical power to the habitats and other scientific equipment, as well as data links to ISS systems and to the ground. Each HHR, as well as the Life Sciences Glovebox and the centrifuge rotor, is outfitted to accommodate SIR drawer payloads. Each habitat, in turn, is outfitted as a SIR drawer, permitting simple one-step installation and removal of habitats and other science equipment. Thus, a habitat may quickly and simply be exchanged from one HHR to another or transferred to and from the Life Sciences Glovebox or the centrifuge rotor. Experiment data can be transferred from the Station to NASA's Ames Research Center and then relayed to scientists at their institutions and laboratories. The data links also make it possible for operators on the ground or astronauts on the Space Station to send commands to the laboratory equipment. This will allow researchers on the ground to monitor and control the environmental and experimental parameters inside the habitats.

Habitats which will be available to researchers include: a Cell Culture Unit for cell and tissue cultures; a Plant Research Unit for small plants; an Egg Incubator for studies in development; an Insect Habitat; an Aquatic Habitat; and an Advanced Animal Habitat for rats and mice. The habitats provide food, water, light, air, humidity and temperature control, and waste management for their inhabitants. In addition to environmental capabilities, the habitats collect, transmit, and receive operational, engineering, and scientific data through their host systems: the Centrifuge, the Life Sciences Glovebox, and the HHRs. In addition to the Habitats the GBF will have an Incubator to provide the capability to grow cells and tissue cultures.

5.4.3 Biotechnology Research Facility

The Biotechnology Research Facility (BRF) will be the primary scientific facility for conducting mammalian cell culture, tissue engineering, biochemical separations and protein crystal growth on ISS. The BRF consists of one rack that provides support services for a variety of sub-rack payload experiments developed by investigators. Facility services include power, thermal management, video signal switching and processing, distribution of research quality gases and bulk 37° C incubation. The BRF will provide a centralized command and data handling interface to the Space Station, as well as some data and video storage.

5.4.4 Fluids And Combustion Facility

The ISS Fluids and Combustion Facility (FCF) is one modular, multi-user, facility designed to accommodate the research needs of the fluid physics and combustion science research communities. The FCF will occupy three powered racks and one stowage rack. The powered racks are called the Fluids Integrated Rack (FIR), Combustion Integrated Rack (CIR), and Shared Accommodations Rack (SAR). The combustion and fluids disciplines share racks and mutually necessary hardware within FCF to dramatically reduce cost and effectively use ISS resources.

The FCF Level 1 performance requirement stipulates that 10 high-quality, complex, fluids and combustion experiments be performed annually within nominal NASA budgetary and ISS resource constraints. It further stipulates that FCF be able to support 80 percent of the fluids and combustion experiments likely to be proposed. FCF can also accommodate up to 20 additional high-quality experiments sponsored by commercial entities and IPs; however, those sponsors must provide the additional funding and ISS resource allocations. Owing to the flexibility of FCF, experiments from disciplines outside of fluids and combustion can also be supported.

FCF incorporates several very advanced imaging systems capable of microscopic to macroscopic imaging at low to very high frame rates and over ultraviolet to infrared wavelengths. Some of these are intensified systems for low light imaging. Some are capable of intelligent, automatic target acquisition, tracking, focusing, and zoom. Payloads located in the FIR, CIR, and SAR can use them. By design, after SAR is on-orbit, other US Lab facilities and payloads can also use them. Other facilities and payloads can share the FCF image storage, analysis, and transmission capabilities (located in the FCF racks) via a small-diameter, temporary, fiber-optic interface cable from the FCF rack to an FCF-provided camera mounted in their rack (their rack must provide 28Volt power to the camera). Up to six FCF cameras can be concurrently operational. Owing to the modular design, users can develop their own unique camera and lens systems relatively cheaply, if necessary, and connect them to the FCF data storage and communication sub-system.

The FIR features a large user-configurable volume for experiments. The volume resembles a laboratory optics bench. An experiment can be built up on the bench from components, or it can be attached as a self-contained package, or a combination. The FIR provides data acquisition and control, sensor interfaces, laser and white light sources, advanced imaging capabilities, power, cooling, and other resources. Equipment can be quickly mounted by astronauts with final positioning by remote control from the FCF Telescience Support Center (TSC, see Section 6.) or from the Principal Investigator (PI) home institution. FIR is designed to be adaptable to nearly any kind of fluids experiment.

The CIR features a 100-liter combustion chamber surrounded by optical and other diagnostic packages including a gas chromatograph. Experiments are conducted in the chamber by remote control from the TSC or PI home institution. The CIR is the only rack on ISS dedicated to combustion experimentation.

The SAR contains shared data storage and computational capabilities. Among other things these allow the PI to analyze large volumes of image data between data point runs to optimize science return. The SAR provides powered storage for scientific samples needing that capability. It provides a sample preparation and FCF maintenance area, as well as active storage of fluids and gases needed for certain types of fluids and combustion experiments. When not being used for the forgoing, it provides a significant volume and optics bench that is configurable for experiments – including mid-deck locker type experiments. These experiments will have the full FCF capability for data acquisition, control, and imaging available to them; hence, they can be less expensive to produce. Experiments are conducted by remote control from the TSC or PI home institution.

5.4.5 Microgravity Sciences Glovebox

The Microgravity Science Glovebox (MSG) is a joint development project between NASA and the European Space Agency (ESA). The double rack unit is a versatile research facility designed to permit the flexibility of crew-manipulated investigations. Its configuration has been planned around the concept of an experimental workstation where a variety of experiments can be installed and operated in a fashion very similar to their operation in a ground-based laboratory. This approach has provided a work area with a comprehensive set of readily accessible laboratory resources to support an investigator-supplied experimental apparatus. Specifically, the facility provides a large enclosed work volume, power, video, photography, vacuum connections, heat rejection, stowage, filtered air, gaseous nitrogen, lighting, airlock access, physical positioning and hold-down attachments, and computer data acquisition and control capabilities.

In consideration of the ambient microgravity operational environment, the work area is enclosed and sealed by a large window, designed to contain potential liquid spillage, loose hardware, or gaseous by-products generated as a result of the experiment's performance. Crew access to the volume and operational manipulation of the experiments is through sealed glove ports. To enhance the value of the crew operation, the communication utilities to the facility have been designed to enable real-time visual and data monitoring of the experimentation by a ground based scientist, along with limited computer control by this scientist. As ISS utilization evolves, the MSG is scheduled to become a major pathfinder for developing and exploiting the scientific advantages of truly enabling the coupling of experimentation in space with an evaluative response from the crew and investigators.

5.4.6 Materials Science Research Facility

The Materials Science Research Facility (MSRF) is a facility to accommodate the current and evolving cadre of peer-reviewed Materials Science investigations which include solidification of metals and alloys, thermophysical properties, polymers, crystal growth studies of semiconductor materials, and research in ceramics and glasses. The facility will provide the apparatus for satisfying near-term and long-range Materials Science Discipline goals and objectives to be accomplished in the microgravity environment of the U.S. Laboratory on the ISS. The types of materials processing that will be accommodated include Bridgman-type directional solidification, solidification and quench, physical vapor transport, solution undercooling, solution crystal growth, and containerless processing.

The MSRF consists of three modular autonomous Materials Science Research Racks (MSRR-1, MSRR-2, and MSRR-3) which will be deployed in phases and will accommodate materials processing furnaces and common subsystems and interfaces required to operate the furnaces. Each MSRR is a stand-alone rack that will use ARIS. Each will be comprised of either on-orbit replaceable Experiment Modules (EMs), Module Inserts (MIs), Investigation-unique Apparatus, and/or Multi-user generic processing apparatus, and will support a wide variety of scientific investigations.

The European Space Agency, the international partner for MSRR-1, will provide the Materials Science Laboratory and associated infrastructure for mounting it inside the ISPR. Materials science capabilities will be accommodated with Module Inserts (MI) to be installed in the MSL. Single sample processing is accomplished using manual sample exchange by a crewmember. A number of Module Inserts, which are on-orbit replaceable, are currently being developed both by NASA and ESA. These MIs will accommodate near-term scientific investigations for the Materials Science Research Program.

MSRR-2/3 configurations will have enhanced capabilities to provide a variety of additional hardware features to meet the current and future anticipated science processing requirements. These capabilities include, but are not limited to, high temperature processing, in-situ optical imaging, real time video, magnetic damping, sample resistance measurement, X-Ray imaging, and Seebeck measurements. The design of the EMs for MSRR-2/3 will be consistent with the developing rack architecture and will incorporate optimum flexibility to support on-orbit maintenance and change-out of key components. The EMs for each of these rack will be designed to be "smart" furnaces and will be comprised of the Furnace Module, Avionics, Control, Support Subsystems, and Automated Multiple Sample Exchange mechanism.

5.4.7 Window Observational Research Facility

Installed over the Nadir Research Window, the Window Observational Research Facility (WORF) provides a means of deploying a variety of payloads for conducting geologic, climatologic, atmospheric, and geographic research. As shown in Figure 4.1-1, the ISS flies over ~85% of the Earth's surface (up to 95% of the Earth's human population), and flies over a given location approximately every three days, with an identical lighting condition every three months. This pattern will provide a tremendous opportunity to observe changes in Earth's surface, oceans and atmosphere on a regular basis.

The WORF design will use existing EXPRESS Rack hardware to minimize both development time and schedule risk. Common EXPRESS hardware will include a Rack Interface Controller box for power and data connection, Avionics Air Assembly fan for air circulation within the rack, rack fire detection, and appropriate avionics to communicate with the ISS data network. The WORF rack will provide mounting for payloads, with access to power at 120 or 28 Vdc , uplink and downlink commands at low and medium data rates, and moderate temperature cooling capability for payloads. The WORF will also include a means of removing condensation from the interior surface of the window and a variety of shields to protect the interior window surface from the impacts from loose tools and hardware being used in the payload area. These shields will still have sufficient optical performance to allow the crew member to see out the window during their use. The interior of the WORF will provide for a non-reflective, light-tight environment both to minimize glare off the window, and to allow use of payloads that will be sensitive to extremely low energy phenomena such as auroras. A shroud attached to the hatch at the front of the rack will allow crew members to work in the WORF without the problems of glare from the U.S. Lab interior.

The payload volume of the WORF is sized to allow the mounting of payloads up to 53.3 cm x 50.8 cm x 76.2 cm (21 in x 20 in x 30 in) with a mass of up to 136.1 kg (300 lbm). This allows the crew to operate up to three instruments in the window at once. The payload volume will provide a standard set of mounting points for payloads to mount instruments and supporting avionics. At present, the WORF will not provide specialized tracking mounts for individual payloads. Investigators requiring special instrument mounts will need to provide them. The WORF will provide mounts for small, hand-held payloads such as film cameras, electronic still cameras and camcorders. This mount will provide for stable mouting for the purposes of crew Earth observations photography. Lastly, the WORF will provide secure stowage for the scratch pane, as well as limited payload stowage.

5.4.8 X-Ray Crystallography Facility

The X-ray Crystallography Facility (XCF) is a comprehensive protein crystal analysis facility that incorporates necessary elements for analyzing complex macromolecular crystals in the microgravity environment. The XCF supports the preparation of crystals for visual evaluation and mounting, sample freezing, and collection of X-ray diffraction data on selected crystals. As part of its resource allocation the XCF will have crystal growth facilities housed in an associated EXPRESS Rack, enabling commercial researchers to grow crystals as well as determine their structures. The integrated capabilities of the XCF enable commercial researchers and scientists to grow samples and obtain structural data on those samples prior to subjecting the crystals to re-entry stress and time-related degradation. Without crew intervention for nominal operations, the proposed system robotically downlinks video of crystal formation to the awaiting scientist. The researcher commands which crystals are to be harvested and prepared for freezing and the X-ray diffraction analysis. The information is stored on board as well as transmitted to the researcher on Earth. The downlinking allows the scientist to review the results and uplink any modifications to the data collection process. An astronaut crew member can provide assistance on a scheduled or 'as available' basis. Data privacy for principal investigators can be provided.

5.4.9 Advanced Human Support Technology Facility

The Advanced Human Support Technology Facility (AHSTF) will serve as a research and development testbed for enabling technologies required by NASA to sustain human life during long duration and deep space missions. Technologies to be developed will support the following fields: Advanced Life Support; Advanced Environmental Monitoring and Control; and Space Human Factors Engineering.

The AHSTF is anticipated to feature the first ISS suite of hardware in support of advanced life support and environmental monitoring. The AHSTF will provide an on-orbit test bed for supporting technologies that enable development of a closed environment life support system applicable to long-duration exploration flights. Nanominiaturization technologies will probably be extensively utilized during this early period of ISS human support technology research, particularly to enhance environmental sensor systems. Detailed hardware parameters for the AHSTF are under development.

5.4.10 Low-Temperature Microgravity Physics Facility

The Low Temperature Microgravity Physics Facility is the first laboratory developed by NASA from the *Fundamental Physics in Space Roadmap* (JPL 400-808, 4/99). The LTMPF Facility Class Payload is a complete low temperature laboratory to be attached to the JEM-EF. There will be two identical facilities, each weighing 500 Kg or less and each supporting two experiments in parallel operations. An advanced superfluid helium Dewar maintains a base temperature pre-selected at between 1.6K to 2.0K for a period of approximately five months.

The Dewar insert is configured to best accommodate two experiments. Typically it consists of two sets of thermal-mechanical platforms called the probes. Attached to each probe are the cells and sensors for each experiment. Each probe can have several stages of isolation platforms with separate temperature regulations on each stage to provide the maximum temperature stability. The total volume for both probes and experiment hardware occupy a cylindrical volume of 19 cm (7.5 in) in diameter and 70 cm (27.6 in) long. The total allocated weight for both sets of experiment hardware attached to the probes (but excluding the probe mass) is 12 Kg or less. Electronics are built on the modular VME chassis with up to 42 slots for standard or custom-built electronic boards that can be reconfigured for each flight. Ultra high-resolution temperature and pressure sensors have been developed based on SQUID (Super-conducting Quantum Interference Devices) magnetometers. There are up to 12 SQUIDs shared between the two experiments. The high-resolution thermometers have demonstrated sub-nano-Kelvin temperature resolution in past space experiments. Other existing measurement techniques include resistance thermometers, precision heaters, capacitance bridges, precision clocks and frequency counters, modular gas handling systems, and optical access capability. An onboard flight computer controls all facility and instrument electronics, all ISS interfaces, command, telemetry, and data storage during on-orbit operations.

Most LTMPF experiments are sensitive to random vibrations, charged particles, and stray magnetic fields. The level of random vibrations at low frequency (< 0.1 Hz) is several micro g rms. A passive vibration isolation system attenuates higher frequency (> 1Hz) vibration inputs from the ISS to below 500 micro g rms. Several layers of magnetic shielding are built into the instrument probe to protect the experiments from on-orbit variations in the magnetic field environment. Vibration and radiation monitors will provide experimenters near real-time data.

The responsibility for developing and testing the experiment hardware and software rests on the principal investigator, who may also choose to delegate the responsibility to a more experienced party including the LTMPF project staff located at NASA’s Jet Propulsion Laboratory (JPL). In addition to general management and science support, JPL will also be responsible for the final integration of experiment hardware to the facility and the engineering activities thereafter. Once on ISS, the experiments simultaneously take data for approximately five months. After cryogen depletion, LTMPF may continue to monitor environments on board the ISS while it awaits return by the Shuttle. Upon return to Earth, the experiments undergo de-integration and inspection at JPL. The facility and some of the experiment hardware are then refurbished for the next set of experiments. Each facility is designed to survive five cycles of testing, launch and landing. Taking turns to launch one facility ever 16 months will provide for up to twenty years of service to experiments that demand an environment of long duration microgravity at low temperature.

5.5 International Partner Research Accommodations

All of the previously described research accommodations, whether developed solely by the U.S. or under cooperative/barter agreements between the U.S. and the other IPs, are directly accessible to U.S.-based researchers. The following sections provide a summary of multi-user research facilities whose programmatic origin gives priority access to researchers based in non-U.S. IP countries.

5.5.1 ESA Accommodations

A complete description of the research accommodations being contributed to ISS by ESA are to be found in the ESA document *The International Space Station: A Guide for European Users* (ESA Publication BR-137). The resources allocated to European users are based on 5 ISPRs in the *Columbus* module and 2 Express Pallet Adapters on the *Columbus* external payload facility. Beyond this allocation, European researchers can gain access to whatever additional resources are being developed under barter or cooperative development agreements between ESA and other IPs.

European multi-user external research facilities for the *Columbus* Exposed Facility remain to be defined. The 5 ISPR locations allocated to ESA inside *Columbus* will be used to support the following facilities:

Biolab. *Biolab* is a single-rack multi-user facility that will support biological research on small plants, small invertebrates, microorganisms, animal cells, and tissue cultures. It will include an incubator equipped with centrifuges in which the preceeding experimental subjects can be subjected to controlled levels of accelerations.

Fluid Science Laboratory. This is a single-rack multi-user facility in which it will be possible to study dynamic phenomena of fluid media in microgravity.

European Physiology Modules. The *European Physiology Module* is a single-rack multi-user facility that will support investigations of respiratory and cardiovascular conditions, hormonal and body fluid shift, bone demineralization and neuroscience. The facility is based on a modular design concept to support diverse experiments.

European Drawer Rack. The *European Drawer Rack* is an ISPR-based holding rack designed to accommodate up to 8 independently-operating sub-rack payloads. The payloads have the option of being accommodated in Middeck Lockers or slightly larger Standard Experiment Drawers.

European Stowage Rack. This is a modular stowage rack designed to accommodate payload equipment and samples in Standard Experiment Drawers and Middeck Lockers. Power, data and thermal control resources are not provided to the stowed items.

5.5.2 NASDA Accommodations

The NASDA research accommodations are summarized in the NASDA publication *Space Station Japanese Experiment Module Multiuser Experiment Facilities Catalog*. The accommodations for Japanese users are based on 5 ISPRs in the JEM pressurized module, and 5 ports on the JEM-EF. Multi-user facilities for Japanese users on the EF remain to be defined, however. The 5 ISPR spaces will consist of three Materials Science Racks and two Life Sciences Racks. Some of the individual multi-user research facilities being developed for these racks are of sub-rack size, so that an individual ISPR may contain more than one facility.

The multi-user research facilities currently under development for Japanese users are as follows:

Gradient Heating Furnace (GHF). The GHF is allocated the entire resources of Materials Science Rack 1 and consists of the Material Processing Unit and Sample Cartridge Automatic Exchange Mechanism. The Material Processing Unit is a zone-type 1600°C (2912 °F) furnace with vacuum capabilities that accepts cartridge-type samples. In order to conserve crew resources on orbit, the sample cartridge is automatically exchanged by the Sample Cartridge Automatic Exchange Mechanism.

Advanced Furnace for microgravity Experiment with X-ray radiography (AFEX). A multi-user image furnace with the capability for in-situ observation using X-ray radiography. A sample placed in the focus of a gold-plated ellipsoidal mirror is heated and melted by radiation from a 1500 W halogen lamp. Alternatively, isothermal heating of samples can be carried out using ceramic heaters placed around the sample. AFEX is allocated the entire resources of Materials Science Rack 2.

Electrostatic Levitation Furnace (ELF). The ELF is a materials research facility that uses electrostatic levitation for containerless sample processing. Laser heating provides for sample heating to temperatures of up to 2000°C (3632 °F) in a gas atmosphere or under vacuum. Observation is provided by a pyrometer, a thermal imaging system and a video camera. The ELF will occupy a sub-rack portion of an ISPR.

Isothermal Furnace (ITF). The ITF is a multipurpose furnace for forming materials and conducting research on solidification and diffusion of melting samples with a uniform temperature profile. Two locations are provided in this facility for addition of user-unique equipment. The ITF will occupy a sub-rack portion of an ISPR.

Cell Biology Experiment Facility (CBEF). The CBEF provides a controlled temperature, humidity and CO_2-level environment for fundamental life sciences research on small plants, animals, cells, tissues and microorganisms. A rotating table can provide g-levels from 0.1 to 2 g for specimens. The CBEF is a sub-rack payload currently slated to share rack space with the Clean Bench.

Clean Bench (CB). Provides a closed workspace for aseptic (glovebox) operations with life sciences and biotechnology materials. All materials entering and leaving the work volume pass through a pretreatment chamber for sterilization if required. The CB is currently pared in an ISPR with the CBEF.

Fluid Physics Experiment Facility (FPEF). Intended to support fluid physics experiments involving phenomena such as Marangoni convection, bubble generation, heat transfer, liquid wettability, combustion and bubble behavior in a moderate temperature environment. The FPEF is currently scheduled to share rack space with the Solution/Protein Crystal Growth Facility and the Image Processing Unit.