International Thermal System Interoperability Standards (ITSIS)

Baseline – August 2019

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PREFACE

INTERNATIONAL THERMAL SYSTEM INTEROPERABILITY STANDARDS (ITSIS)

The International Thermal System Interoperability Standards (ITSIS) establishes standards for commonality across elements, vehicles, systems and/or components relative to thermal control. The standards specifically address fluids to be employed in active external and internal coolant loops, and coldplates that interface directly to those coolant loops to enable collaborative endeavors utilizing difference spacecraft in deep space.

Configuration control of this document is the responsibility of a Multilateral Coordination Board (MCB). The National Aeronautics and Space Administration (NASA) will maintain the ITSIS under Human Exploration and Operations Mission Directorate (HEOMD) Configuration Management. Any revisions to this document will be approved by the MCB.

Baseline

INTERNATIONAL THERMAL SYSTEM INTEROPERABILITY STANDARDS (ITSIS)

CONCURRENCE

AUGUST 2019

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TABLE OF CONTENTS

PARAGRAPH **PAGE**

1.0 INTRODUCTION 1-1
1.1 PURPOSE AND SCOPE 1-1
1.2 RESPONSIBILITY AND CHANGE AUTHORITY 1-1
2.0 DOCUMENTS 2-1
2.1 APPLICABLE DOCUMENTS 2-1
2.2 REFERENCE DOCUMENTS 2-1
3.0 INTERNATIONAL THERMAL INTEROPERABILITY FLUIDS STANDARD 3-1
3.1 GENERAL 3-1
3.1.1 SYSTEM ARCHITECTURE CONCEPT 3-1
3.1.2 ENGINEERING UNITS OF MEASURE 3-2
3.2 COMMON COOLANT(S) 3-2
3.2.1 TECHNICAL SPECIFICATION 3-2
3.2.2 REGULATIONS 3-3
3.2.3 NON-TOXIC COOLANT(S) 3-3
3.2.4 LIQUID PHASE LEAKAGE LIMITS 3-4
3.2.5 MATERIALS COMPATIBILITY 3-4
4.0 HUMAN EXPLORATION MISSIONS COLDPLATE STANDARD 4-1
4.1 GENERAL 4-1
4.1.1 ITEM DEFINITION 4-1
4.1.2 INTERFACE DESCRIPTION 4-1
4.1.3 INTERFACE RESPONSIBILITIES 4-2
4.1.4 COORDINATE SYSTEM 4-3
4.2 ENVELOPE 4-3
4.3 STRUCTURAL REQUIREMENTS 4-4
4.3.1 STRUCTURAL LOAD DISTRIBUTION 4-4
4.3.1.1 STRUCTURAL LOADS 4-4
4.3.1.2 INTERNAL COLDPLATE MOUNTING TO SUPPORT STRUCTURE, BOLT FORCES 4-5
4.3.1.3 EQUIPMENT MOUNTING LOADS TO INTERNAL COLDPLATES 4-5
4.3.2 WEIGHT 4-5
4.4 MECHANICAL 4-6
4.4.1 COLDPLATE TO SECONDARY SUPPORT STRUCTURE INSTALLATION 4-6
4.4.2 INTERNAL COLDPLATE SURFACE 4-6
4.4.2.1 INTERNAL COLDPLATE LOCAL FLATNESS 4-6
4.4.2.2 INTERNAL COLDPLATE ROUGHNESS 4-6
4.4.2.3 INTERNAL COLDPLATE ENHANCED BONDING SURFACE(S) 4-7
4.4.3 LOCATION AND ORIENTATION 4-7
4.5 HOLES 4-7
4.5.1 MOUNTED EQUIPMENT ONTO INTERNAL COLDPLATES 4-7
4.5.1.1 SUPPORT STRUCTURE 4-8
4.5.1.2 FASTENERS 4-8
4.5.2 INTERFACING EQUIPMENT TO EXTERNAL COLDPLATES 4-8

4.5.2.1 SUPPORT STRUCTURE....4-8
4.5.2.2 FASTENERS....4-8
4.5.3 INTERNAL COLDPLATE BONDING REQUIREMENTS....4-8
4.6 INTERNAL COLDPLATE THERMAL PERFORMANCE....4-9
4.6.1 HEAT REMOVAL CAPACITY....4-9
4.7 EXTERNAL COLDPLATE THERMAL PERFORMANCE....4-9
4.7.1 HEAT REMOVAL CAPACITY....4-9
4.8 FLUID INTERFACES....4-10
4.8.1 OPERATING FLUID CHARACTERISTICS....4-10
4.8.2 EXTERNAL LEAKAGE....4-10
4.8.3 FLUID CONNECTORS....4-10
4.9 COLDPLATE ELECTRICAL INTERFACES....4-10
4.9.1 INTERNAL COLDPLATE BONDING....4-10
5.0 OPERATIONAL ENVIRONMENTS....5-1
5.1.1 CONDENSATION CONTROL....5-1
6.0 VERIFICATION AND TESTING....6-1
6.1 PROVISION OF COOLANT TEST DATA....6-1
7.0 FUTURE TOPICS FOR POSSIBLE STANDARDIZATION....7-1

APPENDIX

APPENDIX A - ACRONYMS AND ABBREVIATIONS....A-1
APPENDIX B - GLOSSARY....B-1
APPENDIX C - OPEN WORK....C-1

TABLE

TABLE 4.2-1 STANDARD INTERNAL COLDPLATE SIZES....4-4
TABLE C-1 TO BE DETERMINED ITEMS....C-1
TABLE C-2 TO BE RESOLVED ISSUES....C-1

1.0 INTRODUCTION

This International Thermal System Interoperability Standards (ITSIS) is the result of a collaboration by the International Space Station (ISS) membership to establish interoperable interfaces, terminology, techniques, and environments to facilitate collaborative endeavors of space exploration in cis-Lunar and deep space environments. These standards are available for international and commercial partnerships.

Standards that are established and internationally recognized have been selected where possible to enable a variety of providers. Increasing commonality among providers while decreasing unique configurations has the potential to reduce the traditional barriers in space exploration: overall mass and volume required to execute a mission. Standardizing interfaces reduces the scope of the development effort.

The information within this document represents a set of parameters, which if accommodated in the system architecture, support greater efficiencies, promote cost savings, and increase the probability of mission success. These standards are not intended to specify system details needed for implementation nor do they dictate design features behind the interface; specific requirements will be defined in unique documents.

1.1 PURPOSE AND SCOPE

All spacecraft require a thermal management system to maintain a tolerable thermal environment for the spacecraft crew and/or equipment. The purpose of this document is to state standards for when common fluids are employed in active external and internal coolant loops and agreed-to requirements for coldplates that interface directly to those coolant loops. Future revisions of the document will incorporate any additional content for deep space missions that is not already included. This standard supports reliability and commonality for cooling systems that work across elements, when there is agreement to utilize common coolant(s). This document also provides basic, common design parameters to allow developers to independently develop and/or provide compatible coldplates.

1.2 RESPONSIBILITY AND CHANGE AUTHORITY

Any proposed changes to this standard by the participating partners of this agreement shall be brought forward to the ITSIS working group for review.

Configuration control of this document is the responsibility of the Multilateral Coordination Board (MCB). The National Aeronautics and Space Administration (NASA) will maintain the ITSIS under Human Exploration and Operations Mission Directorate (HEOMD) Configuration Management. Any revisions to this document will be approved by the MCB.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, or other special publications. The documents listed in this paragraph are applicable to the extent specified herein.

None

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document. These reference documents may or may not be specifically cited within the text of this document.

JSC 20584	Spacecraft Maximum Allowable Concentrations for Airborne Contaminants
SSP 30219	Space Station Reference Coordinate Systems
SSP 41172	Qualification and Acceptance Environmental Test Requirements
SSP 57000	Pressurized Payloads Interface Requirements Document

3.0 INTERNATIONAL THERMAL INTEROPERABILITY FLUIDS STANDARD

3.1 GENERAL

The goal of establishing standards is to maximize the success of future human spaceflight missions conducted as international and commercial partnerships. The ability of components, systems, or vehicles delivered from multiple sources to work together as an effective system is important to the success of actual missions. Good collaboration can make technology development and system maturation more efficient, by sharing the lessons learned and failures that drive requirements. Using standard assumptions can also make development more efficient by making tests conducted by one partner relevant and valid to multiple partners.

This section of the document considers when there is use of a common coolant(s), which would be agreed to across the international partnerships for implementation in thermal systems of future mission flight vehicles and ground support hardware. Note that candidate fluids should be those with historical precedence/flight experience and/or coolants that are currently or planned to be extensively tested with data, testing results, analyses, etc. to be provided to/shared with all agencies; this is necessary due to issues with materials compatibility, proprietary considerations, specific additives, etc. Additionally, any biocides or other additives should be included in a shared database and testing programs. These programs should be openly discussed between the fluid provider and element/module provider and consideration must be given to simulating/testing accurately with the in-space cabin environment as this can affect the chemistry of the coolant(s) over time.

3.1.1 SYSTEM ARCHITECTURE CONCEPT

The thermal control system is designed to maintain the overall vehicle(s)/module(s) within thermal limits as required for the crew and equipment during all phases of the mission; this includes rejecting the waste heat from the vehicle(s)/module(s), maintaining hardware within its specified temperature limits, and controlling the crew cabin environment to maintain the walls above the dew point. Coolant loops are used to transfer heat energy from vehicle/module components/subsystems to radiators for overall rejection and/or to transport the excess heat to equipment or a spacecraft region needing additional heat energy for operation. The thermal control system must be a robust design that can operate over a range of heat loads in external environments ranging from the cold of deep space to the warm environment that results from full sun on one side of the vehicle plus albedo and planetary infrared radiation.

This standards document has been prepared to support future exploration missions, and is not limited to a specific mission or space vehicle(s) architecture. However, to provide a framework and common understanding, this standard was developed for permanently attached spacecraft elements. The overall thermal system can be assumed to be servicing one or more physically connecting vehicles and/or modules, with human occupants and powered equipment located internally and externally. It is assumed that the vehicles/modules each have individual active thermal control systems, but may contain the same coolant(s) for commonality. Internal and/or external loops may also be cross-strapped/connected-together. This document only addresses the coolants for the active flowing loops; passive thermal components/hardware that contain internal coolant fluids such as heat pipes are not controlled by this document.

This standards document does not currently consider vehicle(s)/module(s) dormancy periods, very high-power vehicle systems (i.e., nuclear), all elements of the thermal system (e.g., does not address all hardware components such as pumps and heat exchangers, or avionics), design for redundancy, failure tolerance or corrective action(s) for off-nominal cases, layout or specific architecture of the thermal system components, operational details such as heat load distribution with the modules, spacesuit thermal control, or performance degradation over time.

3.1.2 ENGINEERING UNITS OF MEASURE

All dimensions are in International System of Units (SI units) (metric).

In some sections of this document, measurements are shown in English units as reference only. In addition, prefixes are added to the metric unit in some cases to be compliant with industry standards and/or to ease understanding by the reader.

3.2 COMMON COOLANT(S)

THERM-001: Coolant(s) selected for use in the active thermal control system shall be common across all space vehicles with coolant loops that are interfacing/connected across the modules or elements; this excludes visiting/temporarily docked space vehicles or elements.

THERM-002: The specific coolant(s) and formulation shall be agreed to by all partner space agencies.

Rationale: Coolants that are common/shared across modules or elements must be identical, including any additives, to ensure compatibility and operability in each module/element. The decision to implement "cross-strapping" (where fluid lines/pipes are connected or joined physically across spacecraft modules/elements) will depend on the architecture of the space vehicle/modules, and the need or intended capability to service more than one vehicle/module using the cooling system of another vehicle/module. An example would be for the case of radiator failure on one or more vehicle/module. If implemented, the fluids that are shared/utilized across modules/elements must have identical chemical and physical properties.

3.2.1 TECHNICAL SPECIFICATION

THERM-003: The supplier of the selected coolant(s) shall provide verification that the fluid(s) meets the technical specification used for procurement to ensure identical chemical composition, including any additives, and identical fluid/physical properties.

Rationale: The properties and compatibility issues associated with thermal coolants are often determined by additives and other details of the formulation that are not obvious by simply describing the primary fluid (e.g., propylene glycol). The recommendation to satisfy this requirement is to use a common vendor that all partner space agencies/partners agree to. It is acceptable to procure an alternate coolant(s) and/or obtain the coolant(s) from an alternate vendor(s) if it meets the technical specification used for procurement, and is documented in a separate verification assessment to that specification. Note this would include matching the properties of additives.

3.2.2 REGULATIONS

THERM-004: The selected coolant(s) shall meet and sustain the regulations of all government and local environmental agencies per the requirements specified for the country(ies) of usage. Note this should also include pre-negotiation and arrangement of pickup and transport of waste or used fluids to an authorized treatment, storage and/or disposal vendor(s)

Rationale: The nature of coolants requires strict regulation of their handling and transport to ensure environmental and safety requirements are satisfied.

3.2.3 NON-TOXIC COOLANT(S)

THERM-005: For any coolant that is used within a spacecraft habitable volume, review and approval for use shall be obtained via the NASA Johnson Space Center (JSC) Toxicology Group.

THERM-006: In addition, to protect personnel during ground operations, safety precautions and procedures shall be enforced to ensure the maximum exposure limit established by the supplier/manufacturer is not exceeded.

THERM-007: All fluid systems that are within the habitable volume in space shall provide means to limit leakage of the coolant(s).The standard approach is to ensure compliance with JSC 20584, Spacecraft Maximum Allowable Concentrations for Airborne Contaminants. If the fluid(s) is not specified in JSC-20584, then use of the fluid(s) shall comply with guidelines as determined and provided by the JSC Toxicology Group.

THERM-008: In dual loop systems, when the external fluid is toxic and is maintained at a higher pressure than the internal fluid, design and/or operational controls shall be provided to ensure the introduction of the external fluid into the habitable volume does not exceed safety limits.

Rationale: Due to the nature of coolants, measures must be taken to control hazards associated with leakage or exposure to crew/personnel. The JSC Toxicology Group establishes the unique guidelines for safe and acceptable levels of individual chemical contaminants in spacecraft air, known as the Spacecraft Maximum Allowable Concentrations (SMAC)s. In addition, suppliers/manufacturers have established exposure limits to ensure protection of personnel health. As an example, measures must be taken to ensure exposure to the fluid(s) does not exceed the established limits during ground servicing, such as filling the thermal system with coolant, sampling, etc.

3.2.4 LIQUID PHASE LEAKAGE LIMITS

THERM-009: Thermal control components/systems shall provide means to limit coolant leakage or other release for nominal operations (i.e., resupply, sampling or component replacement) and off-nominal events (e.g., component failure).

THERM-010: For coolants that are within the habitable volume, leakage limits are determined based on several different criteria – maximum crew exposure limits, free liquid limits and trace contaminant control limits. The lowest of these limits shall be used to establish the leakage limit specification.

Rationale: Due to the nature of coolants, liquid phase leakage and exposure to personnel must be precluded for protection of personnel health.

3.2.5 MATERIALS COMPATIBILITY

THERM-011: For implementation in future space vehicles/modules, the agency/partner responsible for providing specific thermal Ground Support Equipment (GSE) and/or flight hardware shall verify that the system/subsystem materials exposed to the coolant(s) are compatible. Data on compatibility of materials should be shared by each agency/partner when it is obtained via vendors, testing, etc.

Rationale: The coolant(s) must be compatible with all of the GSE and/or flight hardware materials to avoid degradation or other anomalies that may affect performance.

4.0 HUMAN EXPLORATION MISSIONS COLDPLATE STANDARD

4.1 GENERAL

This section of the document is focused on the physical and fluid interfaces of coldplates to be employed in future flight vehicles. The content herein drives commonality in the design, sizing, fabrication, performance, etc. This document does not address the complete thermal system to be incorporated in future space vehicles, and does not reference other components that may be employed in that system such as heat exchangers, pumps, etc.

4.1.1 ITEM DEFINITION

For the purposes of this standard, each coldplate represents an assembly forming either a contact-type or radiative-type heat exchanger. Note that it is expected that all internal coldplates will be contact-type. External coldplates will be radiative-type, similar to coldplates employed on the ISS, or alternatively will be a customized, contact-type coldplate. Each coldplate will provide for thermal control of electronics and/or other interfacing equipment. It is likely that each coldplate will have single flow-through passages with heat acquisition and transport on one or both sides. Standard operation will enable heat transfer to the fluid in the interfacing coolant loop. While the coldplates will operate with a range of coolant flow rates, it is expected that the internal coolant loop will maintain the localized coldplate temperature above the cabin dew point. Multiple sizes of coldplates will be employed for vehicle(s)/module(s) to accommodate internal and external equipment. Further, the intent is to consider a wide range of sizes with at least one size/designed coldplate that could be employed for common equipment rack-equivalents (e.g., rack, pallet) located within the vehicle(s)/module(s).

4.1.2 INTERFACE DESCRIPTION

Coldplates have both physical and fluid interfaces. The physical interfaces for coldplates include the structural mounting surfaces/attachment points and associated hardware.

Internal and external coldplates will be mounted/attached to secondary support structure using bolts, and non-transferable to alternate locations within or external to the vehicle(s)/module(s). The fluid interfaces include the connection point(s) and any associated hardware to connect the flow passages to the external coolant loop(s), to allow unimpeded flow of coolant through the coldplate.

THERM-012: The internal equipment to be cooled shall be mounted to the coldplate flat surface(s) with bolts, or alternatively secured flush to the flat surface by mounting with bolts to the secondary support structure. The fluid interfaces include the connection point(s) and any associated hardware to connect the flow passages to the coolant loop(s), to allow unimpeded flow of coolant through the coldplate.

THERM-013: The external coldplates shall have fins on the cooling surface(s) which will mesh with fins that are on the equipment to be cooled; once the equipment is installed, there is radiative heat transfer between the equipment fins and the colder coldplate fins. Alternatively, the external coldplates shall have a flat cooling surface(s) which will be flush-mounted/precision matched to the baseplate of the equipment to be cooled; once the equipment is installed, there is heat transfer between the equipment baseplate and the colder coldplate surface(s).

THERM-014: The external coldplates shall accommodate robotic and/or Extravehicular Activity (EVA) attachment or replacement of the interfacing equipment, which may include provision for alignment guides, robotic and/or suit-compatible grasps or handles, visual alignment labels, attachment/locking hardware, mechanisms for soft-dock and/or hard-stop, etc.

Rationale: The described interface is primarily based on heritage of the ISS coldplates and those currently in development for new vehicles/modules (e.g., Orion).

4.1.3 INTERFACE RESPONSIBILITIES

Section 4.0 of this document is written with the intent of providing standards for coldplate assemblies which will be directly connected to the coolant loop(s) of future module/vehicle(s).

THERM-015: The providers of the interfacing secondary support structure(s), fasteners for surface mounting of equipment, connecting tubing, insulation, sensors, cabling/electrical lines, and any other items not mentioned in Section 4.1.2, or within this document, shall ensure those interfacing items are compatible with coldplates meeting the standards outlined herein.

Future vehicles may utilize modules and rack-equivalents (e.g., rack, pallet) like those used on the ISS, and in this case integration of coldplates to the rack-equivalent(s) or other secondary structure should be completed by the module/vehicle integrator or provider.

THERM-016: In addition, future vehicles may utilize Orbital Replacement Units (ORU)s for replacement or trade out of equipment externally, and again the module/vehicle integrator or provider shall ensure that the ORU hardware and its interface are compatible with external coldplates meeting the standards outlined herein.

Rationale: It is the responsibility of the module/vehicle integrator to ensure all interfacing items from the module/vehicle-side are compatible with coldplates that comply with this standards document.

4.1.4 COORDINATE SYSTEM

THERM-017: A coordinate system shall be agreed to and utilized, such as that defined in SSP 30219, Space Station Reference Coordinate System for body-fixed systems.

Rationale: ISS experience has demonstrated the need to establish a set of coordinate systems to be used for implementation of internal and external hardware; this may preclude issues by establishing a common orientation framework.

4.2 ENVELOPE

A number of coldplate sizes are provisioned to accommodate a range of equipment interface requirements. While most coldplates are intended for cooling equipment internal to the pressurized vehicle(s)/module(s), some coldplates will be implemented for external applications.

THERM-018: The standardized internal coldplate sizes given in Table 4.2-1, Standard Internal Coldplate Sizes, shall be used in future vehicles/modules.

THERM-019: While there would be various part numbers depending on the agency(ies), contractor(s), etc., the designators shown shall be added to the end of the part number(s) for consistency in designating size and location.

TABLE 4.2-1 STANDARD INTERNAL COLDPLATE SIZES

COLDPLATE Designator	Heat Transfer Area (contact area) in width of the plate (inlet/outlet ports) vs. length (mm x mm)	REFERENCE: Heat Transfer Area (contact area) converted to English Units (in x in) +/- 0.1	Minimum Edge to Edge Coldplate Area in width of the plate (inlet/outlet ports) vs. length (mm x mm)	Maximum Weight (dry) (kg)
-IC1	88 x 158	3.5 x 6.2	138 x 208	0.6
-IC2	158 x 228	6.2 x 9	208 x 278	1.05
-IC3	158 x 368	6.2 x 14.5	208 x 418	1.43
-IC4	158 x 438	6.2 x 17.2	208 x 488	1.64
-IC5	228 x 88	9 x 3.5	278 x 138	0.76
-IC6	228 x 158	9 x 6.2	278 x 208	1.05
-IC7	228 x 298	9 x 11.7	278 x 348	1.6
-IC8	228 x 368	9 x 14.5	278 x 418	1.89
-IC9	228 x 508	9 x 20	278 x 558	2.47
-IC10	298 x 228	11.7 x 9	348 x 278	1.67
-IC11	710 x 452	28 x 17.8	760 x 502	11

Note 1: The dimensions address the heat transfer surface(s) where equipment would be mounted and the minimum edge to edge size with a minimum of 25 mm beyond the equipment mounting area on all sides measured from the center of the outermost mounting holes; the thickness of the coldplate(s) is not included.

Note 2: The dimensions shown do not include the tube stubs or any other protrusion(s) beyond the edges of the coldplate.

Note 3: The designators indicate “I” for “internal”, “C” for “coldplate” and a numerical designator to distinguish the coldplates based on overall dimensions/size.

Note 4: The dimensions for the heat transfer area are shown in English units as reference only, as the engineering units of measure are given in Section 4.1.5.

Note 5: The –IC11 coldplate is assumed for common equipment rack-equivalents.

There is no equivalent table for external coldplates as these will be customized to accommodate the equipment to be interfaced, similar to the external ORUs on the ISS. Note that Table 4.2-1, Standard Internal Coldplate Sizes, is not intended to preclude the use of custom-sized internal coldplates in special cases or if needed; a waiver must be requested and approved by the appropriate program board(s).

Rationale: This section specifies a range of standard coldplate sizes based primarily on ISS experience.

4.3 STRUCTURAL REQUIREMENTS

4.3.1 STRUCTURAL LOAD DISTRIBUTION

4.3.1.1 STRUCTURAL LOADS

The structural loads that will be imparted to the coldplates will be dependent on the launch vehicle(s). It is expected that the maximum loads transmitted would occur during launch combined with ascent vibration, and additionally that these would be the worst-case loads imparted over the course of the mission(s).

THERM-020: The coldplates shall be designed for the maximum axial and lateral loads specified for the launch/mission vehicle(s).

It is assumed that the coldplates are completely supported by secondary structure, and the loads will be evenly distributed among the coldplate attach points. Alternatively, coldplates might be placed between equipment and support structure (where equipment is not fastened to the coldplate, but to the underlying supporting structure), and in this case additional structural interfaces between the coldplate and secondary structure, and coldplate and equipment, will be added as needed.

4.3.1.2 INTERNAL COLDPLATE MOUNTING TO SUPPORT STRUCTURE, BOLT FORCES

THERM-021: The maximum mounting bolt torque for all internal coldplates is 9 Newton meter (Nm).

As stated previously, external coldplates will be customized to accommodate the equipment to be interfaced, similar to the external ORUs on the ISS. Maximum mounting bolt torque for all external coldplates will be specified in lower level documents.

4.3.1.3 EQUIPMENT MOUNTING LOADS TO INTERNAL COLDPLATES

Equipment mounting refers to items to be attached/interfaced to the internal coldplate surface(s) to provide conductive cooling.

THERM-022: The maximum mounting bolt torque for attached equipment to internal coldplates shall be less than the torque strength values for an unpressurized suit or bare hand, for a 5th percentile female.

Rationale: This section bounds the loads and forces expected to be exerted on the coldplates during nominal mission operations. Specified values were selected based primarily on ranges of human ability and ISS experience. Torque strength values may be obtained from SSP 57000, Pressurized Payloads Interface Requirements Document, or alternative requirements specified in lower level program documentation.

4.3.2 WEIGHT

THERM-023: Coldplates shall not exceed the maximum dry weights as specified in Table 4.2-1, Standard Internal Coldplate Sizes.

Rationale: Specified values are based primarily on ISS experience.

4.4 MECHANICAL

4.4.1 COLDPLATE TO SECONDARY SUPPORT STRUCTURE INSTALLATION

THERM-024: Internal coldplates shall provide mounting holes along the edges.

THERM-025: The spacing of the mounting holes for internal coldplates will be matched to the mounting surface, but shall be no closer than 0.04 meters (m) (40 millimeters (mm)) apart. The holes shall accommodate bolts, which will be specified in lower level documents.

THERM-026: The internal coldplates shall be mounted to the secondary support structure using a sufficient number of mounting holes such that the structural load distributions stated in Section 4.3.1 are not exceeded.

THERM-027: External coldplates shall provide mounting holes along the edges, and the holes will be matched to the mounting surface. As stated previously, external coldplates will be customized to accommodate the equipment to be interfaced, similar to the external ORUs on the ISS. The spacing of the mounting holes and sizing to accommodate selected bolts will be specified in lower level documents.

THERM-028: The external coldplates shall be mounted to the secondary support structure using a sufficient number of mounting holes such that the structural load distributions stated in Section 4.3.1 are not exceeded.

Rationale: To standardize the interface, details are provided for a bolt hole pattern and interface requirements to secure coldplates to secondary support structure.

4.4.2 INTERNAL COLDPLATE SURFACE

THERM-029: All internal coldplate, active heat transfer area/surface(s) shall be stainless steel material.

4.4.2.1 INTERNAL COLDPLATE LOCAL FLATNESS

THERM-030: The local flatness on each internal coldplate equipment mounting side(s) shall be 0.01 centimeter (cm)/cm with an overall flatness of 0.05 cm/cm. The flatness is measured in the fully restrained and supported condition.

4.4.2.2 INTERNAL COLDPLATE ROUGHNESS

THERM-031: Coldplate mounting/conductive surfaces shall have a surface finish with a maximum roughness of 6.3 micro-m Root Mean Square (RMS).

4.4.2.3 INTERNAL COLDPLATE ENHANCED BONDING SURFACE(S)

THERM-032: The internal coldplates shall provide a stainless-steel bonding surface at the interface between the coldplate and the mounted equipment/item(s).

THERM-033: Any material used for significantly enhanced thermal conductivity at the interface shall be evaluated for compliance with the program's design and construction standards for materials and processes, as specified in lower level documents.

THERM-034: The selected material shall allow mounted hardware to be released and replaced without degradation to the interface material itself, for initial mounting and to support later repair and/or replacement.

THERM-035: In addition, use of an interface material between the coldplate and hardware mounted thereon shall not degrade the quality of the electrical bond per Sections 4.9.1 and 4.9.2.

Rationale: The mounting surface of the coldplate is critical to the overall performance. The described interface is based on experience with ISS and other spaceflight hardware.

4.4.3 LOCATION AND ORIENTATION

The internal coldplates will be mounted throughout the pressurized areas of future vehicle/module(s). It is also possible for coldplates to be mounted externally, to provide cooling for external equipment/systems.

THERM-036: Coldplates shall be preferentially located and oriented such that the crew and/or cameras can inspect the fluid connectors by simply removing the applicable close-out panel or via unimpeded visualization with another access point.

Rationale: For planned replacement or maintenance of hardware, or in the case of an off-nominal condition, visualization of the connectors is required. ISS experience has demonstrated that coolant leaks are possible and that it is important to be able to access and visually verify the condition of the fluid lines and connections

4.5 HOLES

4.5.1 MOUNTED EQUIPMENT ONTO INTERNAL COLDPLATES

THERM-037: The internal coldplate interface surface(s) shall contain through holes (6.4 mm) for mounting equipment to the coldplate. The through holes shall be located and spaced in a 70 mm x 70 mm grid pattern.

4.5.1.1 SUPPORT STRUCTURE

THERM-038: The internal coldplate support structure shall provide mounting holes to accommodate capture bolts in compliance with Section 4.4.1, and to ensure non-interference with the coldplate mounting hole pattern described in Section 4.5.1.

4.5.1.2 FASTENERS

THERM-039: The coldplates shall be mounted/installed onto the secondary support structure with capture bolts. The part number of the bolts will be specified in lower level documents.

Rationale: Details on the mounting, including the grid pattern, are needed to ensure standardization and allow equipment to be mounted at any coldplate location.

4.5.2 INTERFACING EQUIPMENT TO EXTERNAL COLDPLATES

THERM-040: For cooling an external replaceable ORU(s), the external coldplate interface surface(s) shall include radiative fins to mesh with fins on the equipment to be cooled, or alternatively shall be a customized, contact-type coldplate.

4.5.2.1 SUPPORT STRUCTURE

THERM-041: The coldplate support structure shall provide mounting holes to accommodate capture bolts to allow attachment to external secondary support structure, including non-interference with the radiative fins and other protrusions/hardware on the interfacing equipment to be cooled.

4.5.2.2 FASTENERS

THERM-042: The coldplates shall be mounted/installed onto the secondary support structure with captured bolts. The part number of the bolts will be specified in lower level documents.

Rationale: Details on the mounting interface are needed to ensure standardization and allow equipment to be mounted securely. This section provides standards based primarily on ISS experience and development of other space vehicles (e.g., Orion Service Module).

4.5.3 INTERNAL COLDPLATE BONDING REQUIREMENTS

THERM-043: The coldplates shall meet the agreed-to bonding and grounding standards from the installed equipment to the secondary support structure through the conductive contact surface.

THERM-044: Non-conductive materials shall not be applied to this surface.

Rationale: Attachment of equipment to the coldplate surface must be designed to avoid electrical static charge build-up and provide the capacity to conduct safely any fault current that may be imposed on it.

4.6 INTERNAL COLDPLATE THERMAL PERFORMANCE

THERM-045: When activated for the mission, coldplates internal to the vehicles/modules shall operate while being exposed to the cabin atmospheric conditions.

4.6.1 HEAT REMOVAL CAPACITY

THERM-046: The heat flux requirement is given as the average the coldplate shall remove. The coldplates specified in Table 4.2-1, Standard Internal Coldplate Sizes, must have a capability to provide/cool an average of 1 Watt (W)/cm^2.

Rationale: This section states the coldplate(s) must operate effectively and provides performance parameters based on expected state-of-the-art. The heat flux requirement is the minimum the coldplate shall remove and the maximum that a mounted component shall impose.

4.7 EXTERNAL COLDPLATE THERMAL PERFORMANCE

THERM-047: When activated for the mission, coldplates external to the vehicles/modules shall operate while being exposed to the environmental conditions.

4.7.1 HEAT REMOVAL CAPACITY

The heat flux should be specified as the average and maximum the coldplate shall remove. The maximum value also denotes the maximum flux that an ORU can impart to the radiative interface. As stated previously, external coldplates will be customized to accommodate the equipment to be interfaced, similar to the external ORUs on the ISS. The heat flux requirements for all external coldplates will be specified in lower level documents.

Rationale: This section states the coldplate(s) must operate effectively in the external mission environment and that specific performance parameters will be provided in lower level documents.

4.8 FLUID INTERFACES

4.8.1 OPERATING FLUID CHARACTERISTICS

The operating fluid media for coldplates located externally on the vehicle/module(s) will be specified in lower level documents.

The operating fluid media for coldplates located internally in the vehicle/module(s) will be specified in lower level documents.

4.8.2 EXTERNAL LEAKAGE

THERM-048: The external leakage of the coldplates shall be verified at the Maximum Design Pressure (MDP). This approach will be similar to what is implemented for the ISS program; refer to SSP 41172, Qualification and Acceptance Environmental Test Requirements.

4.8.3 FLUID CONNECTORS

THERM-049: The coldplates located internal and external to the vehicle/module(s) shall be fabricated with tube stubs for connection to the internal/external coolant loop(s). It is assumed that all coldplates will be positioned and then the fluid connections will be permanently attached in place.

Rationale: Details on the fluid interface are needed to ensure standardization and allow equipment to be mounted securely. This section provides standards based primarily on ISS experience and development of other space vehicles (e.g., Orion Service Module).The selected internal and external fluid media will be specified in lower level documents.

4.9 COLDPLATE ELECTRICAL INTERFACES

4.9.1 INTERNAL COLDPLATE BONDING

THERM-050: Internal coldplates shall meet the agreed-to bonding and grounding standards to interface with the vehicle mounting structure as defined in lower level program documentation.

4.9.2 EXTERNAL COLDPLATE BONDING

THERM-051: External coldplates shall meet the agreed-to bonding and grounding standards to interface with the vehicle mounting structure as defined in lower level program documentation.

Rationale: Mounting of equipment to the coldplate surface and/or attachment of the coldplate itself to the vehicle/module support structure needs to be designed to avoid electrical static charge build-up and provide the capacity to conduct safely any fault current that may be imposed on it. Bonding requirements are specified based on the intended use, including specification of electrical hardware that will be mounted to the interface.

5.0 OPERATIONAL ENVIRONMENTS

THERM-052: When the thermal control system is activated and operated in the planned mission location(s)/environment(s), the coolant and coldplates internal to the vehicles/modules shall operate while being exposed to the cabin atmospheric conditions.

THERM-053: When the thermal control system is activated and operated in the planned mission location(s)/environment(s), the coolant and coldplates located externally on the vehicles/modules shall operate while being exposed to the environmental conditions.

5.1.1 CONDENSATION CONTROL

THERM-054: The thermal control system shall operate in conjunction with the Environmental Control and Life Support System (ECLSS) to prevent condensation.

Rationale: This section states the coldplate(s) must operate effectively in its local environment. In addition, the thermal control system, working in conjunction with the ECLSS, must preclude condensation.

6.0 VERIFICATION AND TESTING

It is the responsibility of the spacecraft developer to perform verification and validation. The majority of the standards will be verified using a combination of interface/compatibility testing, integrated end-to-end testing and analysis at the subsystem and system level.

The following provides guidance on early test methods for verification.

The detailed flow down of the interface standards and corresponding verification requirements will be captured in program requirements and lower level documents. The requirements listed in Sections 3.0 and 4.0 will typically be verified through the rollup of subsequent verifications of lower level allocated and derived technical requirements and analysis of integrated designs. These will be traced through bidirectional traceability matrices in the lower level requirements.

The majority of the requirements will be verified using a combination of interface/compatibility testing, integrated end-to-end testing and analysis at the subsystem and system level. When test or analysis of the individual elements is not adequate to show compliance at an integrated level, additional test or analysis will be performed. Because the performance of the thermal system is directly related to the operational environment(s), testing in simulated conditions (such as in a vacuum chamber(s)) is typically required. Consideration must also be given to operations in zero gravity, and/or other gravity levels such as during ascent, on descent and for planetary surface operations. In addition, extended duration testing (i.e., life testing) may be required to verify coolant chemical stability, performance, etc. for the intended operational life of the thermal control system.

Results of testing and associated analyses provide critical data and recommendations to inform the design process. After major design reviews or other key milestones, like the completion of integrated testing, engineers should iterate back through the mission requirements set, mission environmental parameters, system design, and developed models to make updates or optimize. The Thermal Control System (TCS) matures as the spacecraft design progresses and concludes with a full certification program prior to flight.

Verification and testing should be completed as early in the design cycle as is reasonable. Consideration must be given for programmatic constraints (e.g., budget, manufacturing capability), but also priority for having relevant supporting performance data and validated models for major design events and other program milestones. The specifics of the verification program will be captured in verification and validation documentation.

6.1 PROVISION OF COOLANT TEST DATA

As stated previously in Section 3.1, candidate coolants must have historical precedence/flight experience and/or must be currently or planned to be extensively tested. Data, testing results, analyses, etc. should be provided to/shared with all agencies; this is necessary due to issues with materials compatibility, proprietary considerations, specific additives, etc. Additionally, any biocides or other additives must be specified and included in the database and testing programs, and consideration must be given to simulating/testing accurately with the in-space cabin environment as this can affect the chemistry of the coolant(s) over time.

It is the responsibility of the agency(ies)/partner(s) completing the coolant(s) testing and analyses, and determining the methods, procedures, operations, etc. to provide/share all associated data and information with all participating agencies/partners.

7.0 FUTURE TOPICS FOR POSSIBLE STANDARDIZATION

- External coldplate interface details per updates to the International External Robotic Interoperability Standards (IERIS) (e.g. external ORUs)
- Inclusion of other key thermal system components (e.g., heat exchangers, radiators)
- Inclusion of fluid connectors (e.g., quick disconnects)
- Requirement(s) that preclude the TCS hardware from contaminating the coolant fluid(s) with chemicals or via leeching, etc.
- Future revisions of this document may include additions and/or modifications to the standards for missions beyond cislunar space, such as standards for treatment/handling of dust in planetary environments

APPENDIX A - ACRONYMS AND ABBREVIATIONS

cm	centimeter
ECLSS	Environmental Control and Life Support System
e.g.	exempli gratia (for example)
EVA	Extravehicular Activity
GSE	Ground Support Equipment
HEOMD	Human Exploration and Operations Mission Directorate
i.e.	id est (that is)
IERIS	International External Robotic Interoperability Standards
ISS	International Space Station
ITSIS	International Thermal System Interoperability Standards
JSC	Johnson Space Center
kg	kilogram
m	meter
MCB	Multilateral Coordination Board
MDP	Maximum Design Pressure
mm	millimeter
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
Nm	Newton meter
ORU	Orbital Replacement Unit
REV	Revision
RMS	Root Mean Square
SMAC	Spacecraft Maximum Allowable Concentration
SSP	Space Station Program
TBD	To Be Determined
TBR	To Be Resolved
TCS	Thermal Control System
vs.	versus
W	Watt

APPENDIX B - GLOSSARY

CAPTURE BOLTS

Reference to fasteners designed or used in conjunction with material(s) or part(s) to resist loosening under vibrations and torque; examples include using a locking nut or insert, or an adhesive to secure the fastener in place

CROSS-STRAPPED

Reference to fluid lines/pipes that are connected or joined physically across spacecraft modules/elements

APPENDIX C - OPEN WORK

Table C-1 lists the specific To Be Determined (TBD) items in the document that are not yet known. The TBD is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBD item is numbered based on the section where the first occurrence of the item is located as the first digit and a consecutive number as the second digit (e.g., <TBD 4-1> would be the first undetermined item assigned in Section 4 of the document). As each TBD is solved, the updated text is inserted in each place that the TBD appears in the document and the item is removed from this table. As new TBD items are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBDs will not be renumbered.

TABLE C-1 TO BE DETERMINED ITEMS

TBD	Section	Description

Table C-2 lists the specific To Be Resolved (TBR) issues in the document that are not yet known. The TBR is inserted as a placeholder wherever the required data is needed and is formatted in bold type within brackets. The TBR issue is numbered based on the section where the first occurrence of the issue is located as the first digit and a consecutive number as the second digit (i.e., <TBR 4-1> is the first unresolved issue assigned in Section 4 of the document). As each TBR is resolved, the updated text is inserted in each place that the TBR appears in the document and the issue is removed from this table. As new TBR issues are assigned, they will be added to this list in accordance with the above described numbering scheme. Original TBRs will not be renumbered.

TABLE C-2 TO BE RESOLVED ISSUES

TBR	Section	Description