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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL SYSTEM TECHNOLOGY DISCIPLINE

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TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR *THERMAL CONTROL*

To support the required evolutionary Space Station capabililites, the thermal control system must accommodate up to a fourfold increase (300 KW) of heat loads. Utilization of the baseline technology to accommodate the growth requirement will significantly impact:

- Radiator deployed area and associated sweeping volume,
- EVA assembly time,
- Orbiter manifesting penalties,
- Orbital and ground operational support, and
- Maintenance and repair operations.

Cost effective growth of the evolutionary thermal control system requires the:

- Heat rejection system size increase be reduced,
- Capability of the heat acquisitions and transport systems be increased,
- System assembly, monitoring and controls be more automated,
- Passive heat rejection techniques be improved, and
- Essential analytical tools be developed.

A comprehensive technology program, which will enable the necessary thermal technologies to meet the Space Station evolution need has been defined with development plans for three different (High, Moderate, and Low) funding levels.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *HEAT REJECTION*

BACKGROUND

SCOPE: A high capacity and long life heat rejection subsystem that will be used to minimize required increase of radiator area, to decrease or eliminate EVA radiator assembly/maintenance time and to reduce radiator launch penalties.

OBJECTIVES: To develop a high capacity and long life heat rejection subsystem which will utilize (1) elevated radiator operating temperature and stable coating properties to maximize the heat flux capability of the radiator, (2) thermal storage to accommodate peak load without additional radiator area, (3) long life and robotic assembly compatible radiator panels to reduce EVA time, and (4) decreased radiator weight and stowage volume to reduce launch penalties.

JUSTIFICATION: The evolutionary heat rejection subsystem must increase its capacity to match increased Station power levels. Utilization of the baseline technology to accommodate the increaed capacity will require a very large radiator area increase which not only will generate significant launch weignt, stowage and EVA assembly time penalties but also result in orbiter docking approach constraints, structural interference with power and/or habitat modules and thermal interference with attached payloads. Furthermore, current coating and insulation materials will degrade with time by atomic oxygen depletion, solar radiation, ionizing radiation and micrometeoroid and debris impacts. With the increased number of radiator panels, maintenance (change out) of the radiator panels will become a major drain of the crew time and productivity. A heat rejection with higher heat flux, longer life and lower weight must be developed to mitigate all these impacts.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL *HEAT REJECTION*

PROGRAM PLAN

APPROACHES:

1. Develop a high density heat storage subsystem for heat loads leveling.
2. Develop a extended-life surface coating to allow for radiator design with begining of life properties.
3. Develop high thermal conductance between thermal bus and radiator panels.
4. Develop a high efficiency heat pump which will significantly increase radiator temperature without incurring a substantial power penalty.
5. Develop a high temperature and high capacity heat pipe to accommodate high temperature radiator operation.
6. Develop higher micrometeoroid/debris tolerant radiator panels to reduce maintenance and repair.
7. Develop robotic radiator assembly techniques with closer tolerance to reduce EVA.
8. Develop a light-weight, high-conductivity and high-strength materials for radiator fin and heat pipe.

DELIVERABLES:

1. Heat rejection technologies that will enable a high capacity (up to 300KW) Space Station heat rejection subsystem with required increase of radiator area minimized, EVA radiator asembly/maintenance time decreased or eliminated and radiator launch penalties reduced.
2. A technology demonstration preprototype which will be used to support DDT&E of the evolutionary Space Station heat rejection subsystem.

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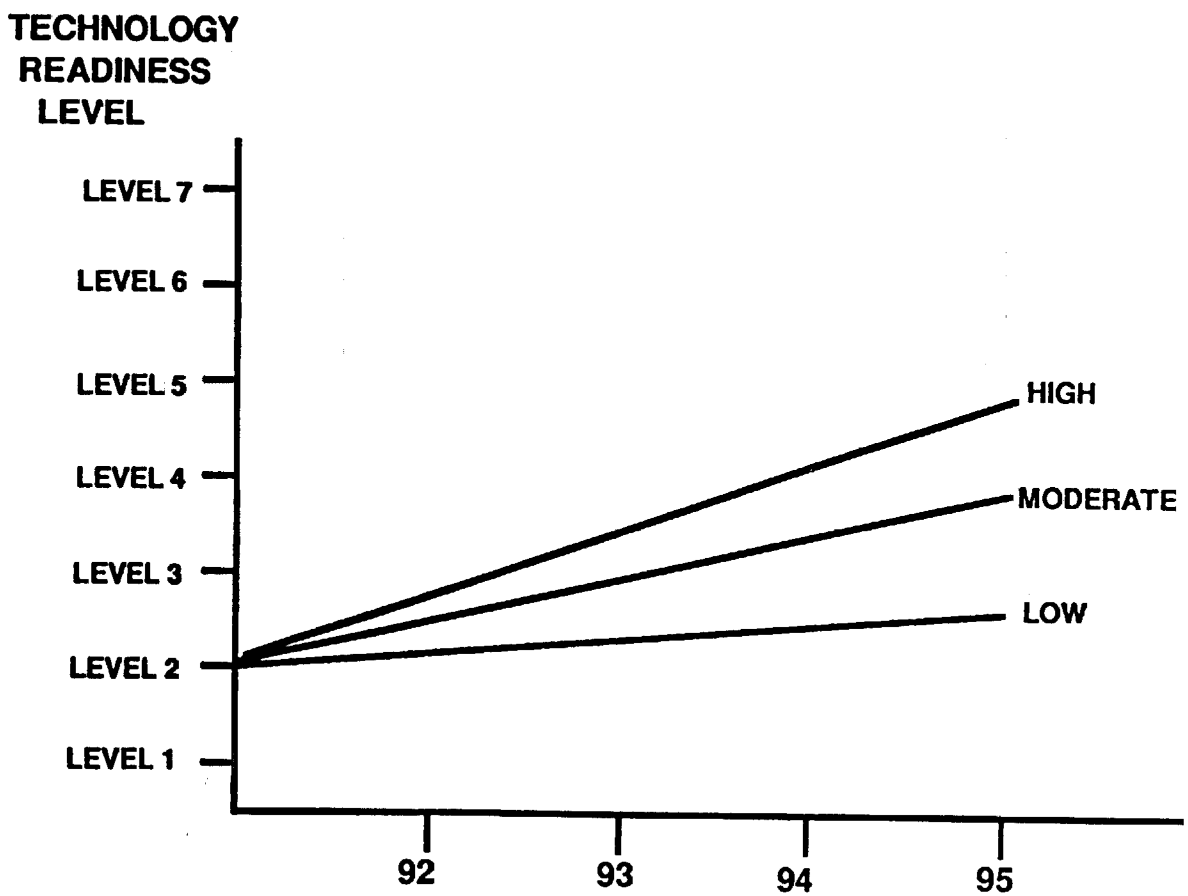
THERMAL CONTROL

HEAT REJECTION

TECHNOLOGY ASSESSMENT



A WORKSHOP

BACKGROUND

SCOPE: A highly efficient and robust 2-phase heat acquisition and transport subsystem which will accommodate incremental growth to a total capacity of 175 KW and/or 300 KW, and will provide active thermal control to attached payloads and service facilities.

OBJECTIVES: To develop a high efficient (in weight, power, EVA assembly time and cost) and robust two-phase flow heat acquisition and transport subsystem which will utilize (1) high heat flux capacity, long life heat exchage devices, (2) efficient active thermal control for attached payloads and service facilities, (3) very low leakage quick disconnects and transport lines, (4) robotic compatible ORU's, and (5) pumps with lower power consumption and longer life.

JUSTIFICATION: The evolutionary heat acquisition and transport subsystem requires a significant increase of the heat exchange devices and complex extensions of the transport lines to provide active thermal control to additinal modules, attached payloads and service facilities. Utilization of the baseline technology to accommodate the growth requirement will impose a very large increase in weight, power and EVA assembly time penalties, as well as potential for intolerable environmental contamination due to ammonia leakage from the increased line length and complexity of plumbing network. A heat acquisition and transport system with higher heat flux, longer life heat exchangers, less leakage lines and quick disconnects must be developed to provide efficient active thermal control to the growth Space Station equipment and payloads.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

PROGRAM PLAN

APPROACHES:

1. Develop high heat flux, low pressure drop heat exchange devices for the two-phase thermal bus evaporators and condensers.
2. Improve materials compatibility of NH3 and H2O heat exchangers.
3. Continue development of payload thermal bus for active cooling of attached payloads and/or service facilities.
4. Develop very low leakage quick disconnects and non-permeating ammonia lines whcih are compatible with robotic assembly.
5. Develop automation and robotics compatibility for other thermal bus ORU's.
6. Develop two-phase flow thermal bus pumps with a lower power consumption and a longer mean time between failures.

DELIVERABLES:

1. Heat acquisition and transport technologies that will enable a highly efficient and robust Space Station therrmal bus.
2. A technology demonstration preprototype which will be used to support DDT&E of the evolutionary Space Station heat acquisition and transport subsystem.

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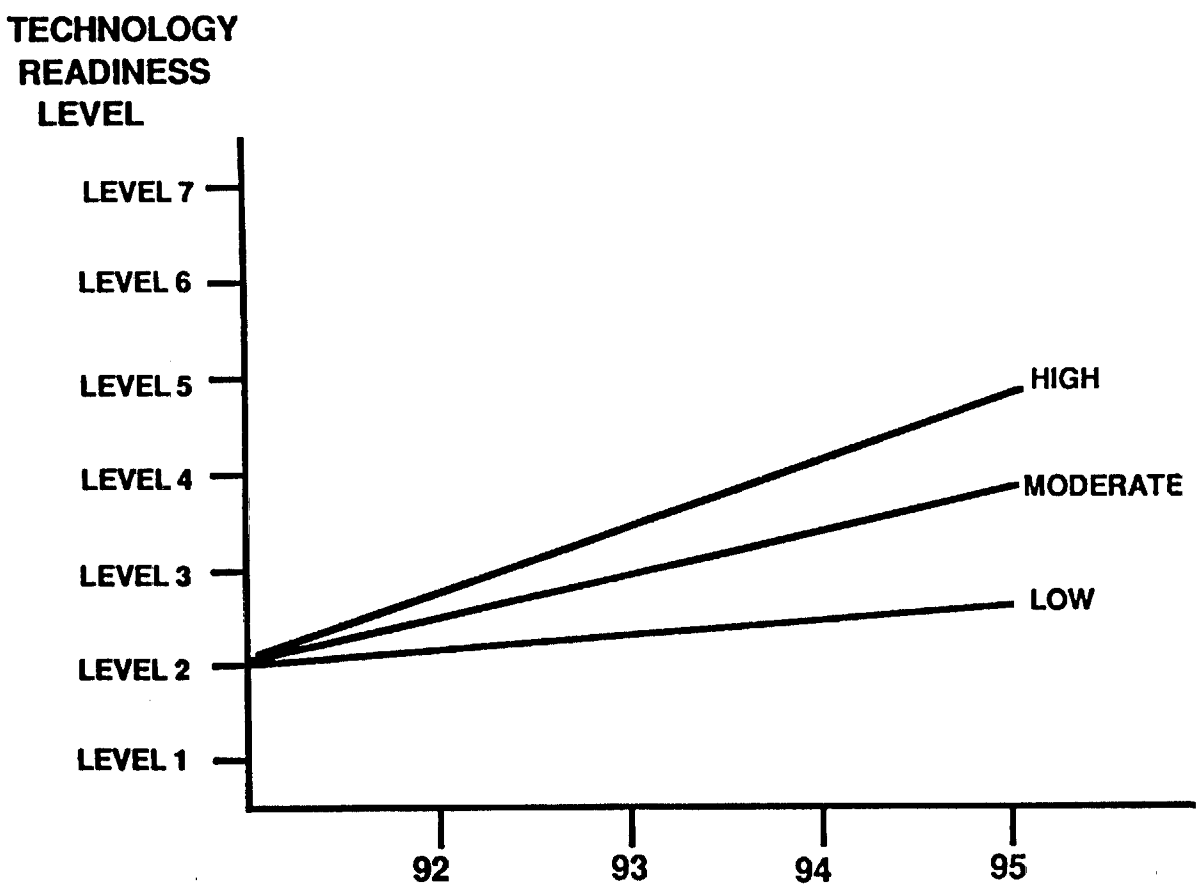
THERMAL CONTROL *HEAT ACQUISITION AND TRANSPORT*

TECHNOLOGY ASSESSMENT



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THERMAL CONTROL *MONITOR ING & CONTROL*

BACKGROUND

SCOPE: A fully automated monitoring and control subsystem which will reduce crew and ground support needed for the operation and failure detection, isolation and recovery (FDIR) of the thermal control system.

OBJECTIVES: To develop a fully automated monitoring control subsystem which will incorporate AI/Expert System technology to perform normal operation control, failure detection, isolation and recovery, system performance trend analysis and predicion of unscheduled maintenance for the thermal system. The monitoring and control subsystem will interface with the crew and ground support through the Space Station Data Management and Operation Management Systems.

JUSTIFICATION: The evolutionary Station thermal control system will have increased complexity with growth in the quantity of hardware components and complexity in system architecture. Utilization of the baseline automatic control techniques to accommodate the growth requirements will result in a significant increase of crew and ground support required for operation and FDIR of the thermal control system. A fully automated thermal control system incorporating AI/Expert System technology will alleviate the required crew and ground support, thus increse productivity and reduce the operational cost of the evolutionary Space Station. Furthermore, the monitoring and control subsystem based on AI/Expert System will be able to perform system trend analysis and predict unscheduled maintenance to prevent failure of aging equipment to increase crew productivity and safety.

PROGRAM PLAN

APPROACHES:

1. Incorporate AI/Expert System technology into monitoring and control of the thermal control system. The thermal control technology community will work hand-in-hand with the AI technology community in this development.
2. Improve instrumentation for measurements of two-phase flow rate and quality and for accurate remote sensing of surface temperatures.
3. Develop reliable automatic leak detection and position identification and isolation techniques.

DELIVERABLES:

1. AI/Expert System based monitoring and control technology which will enable a fully automated monitoring and control subsystem for the evolutionary Space Station thermal control system.
2. A technology demonstration preprototype which will be used to support DDT&E of the monitoring and control subsystem for the evolutionary Space Station thermal control system.

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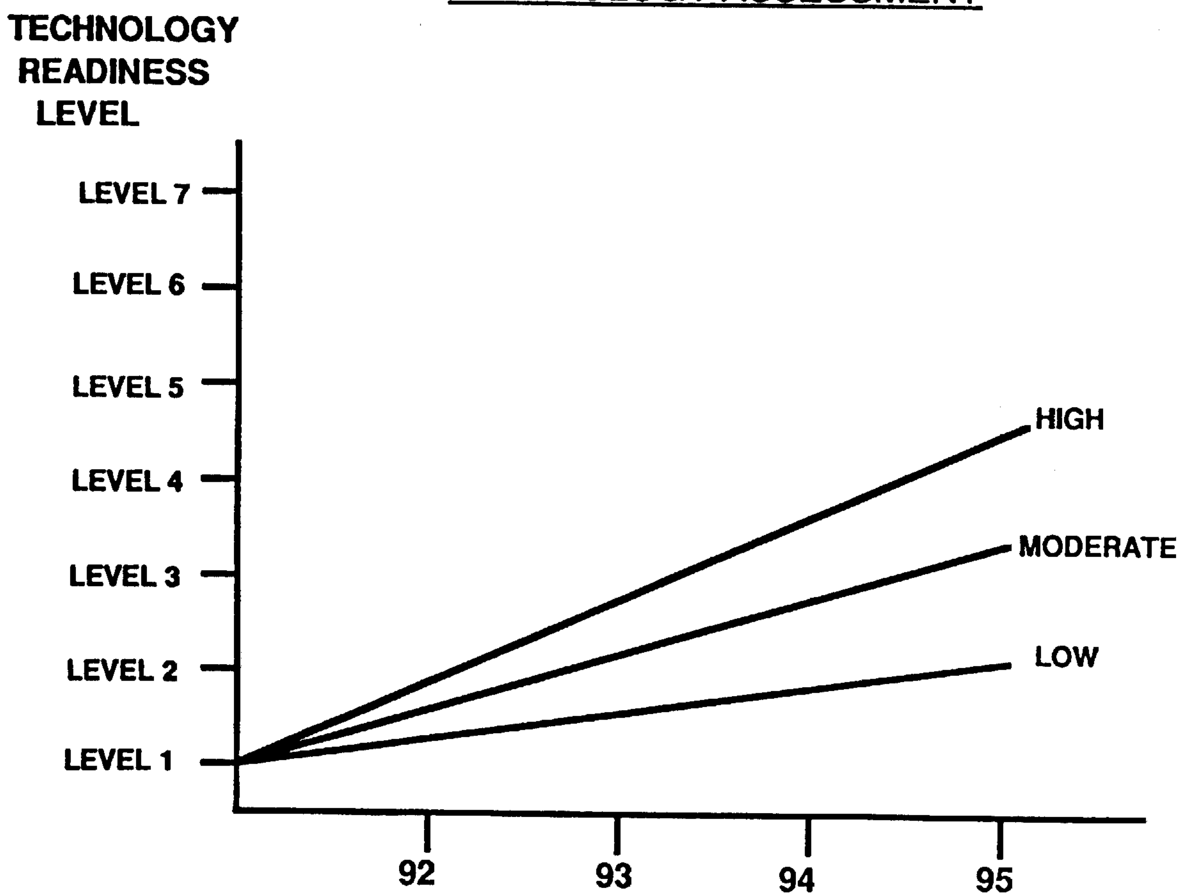
THERMAL CONTROL *MONITORING & CONTROL*

TECHNOLOGY ASSESSMENT



TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL | *PASSIVE THERMAL CONTROL*

BACKGROUND

SCOPE: Passive thermal control devices to accommodate higher passive heat loads and to reduce maintenance and electrical heater requirements.

OBJECTIVES: To develop high capacity passive thermal control techniques such as long-life and high performance surface coating and insulation materials to accommodate higher passive heat loads, and flexible heat pipes for load sharing to reduce heater power consumption.

JUSTIFICATION: The evolutionary Station passive thermal control system must accommodate higher heat loads associated with growth of attached payload requirements. Utilization of the baseline passive control techniques to meet the growth requirements will result in a significant increase of passive radiator area. The increase in area may not be allowed due to interference with the required views to space of the attached payloads. Furthermore, the baseline coating and insulation materials will degrade with time by atomic oxygen depletion, solar radiation, ionizing radiation and micrometeroid/debris impact, longer-life materials are required to reduce the EVA time for refurbishment of passive thermal control components.

PROGRAM PLAN

APPROACHES:

1. Develop coating and insulation materials less sensitive to space environment.
2. Improve surface properties of the coating materials.
3. Develop passive load-sharing techniques , such as flexible, variable conductance heat pipes, for reduction of heater power requirements.

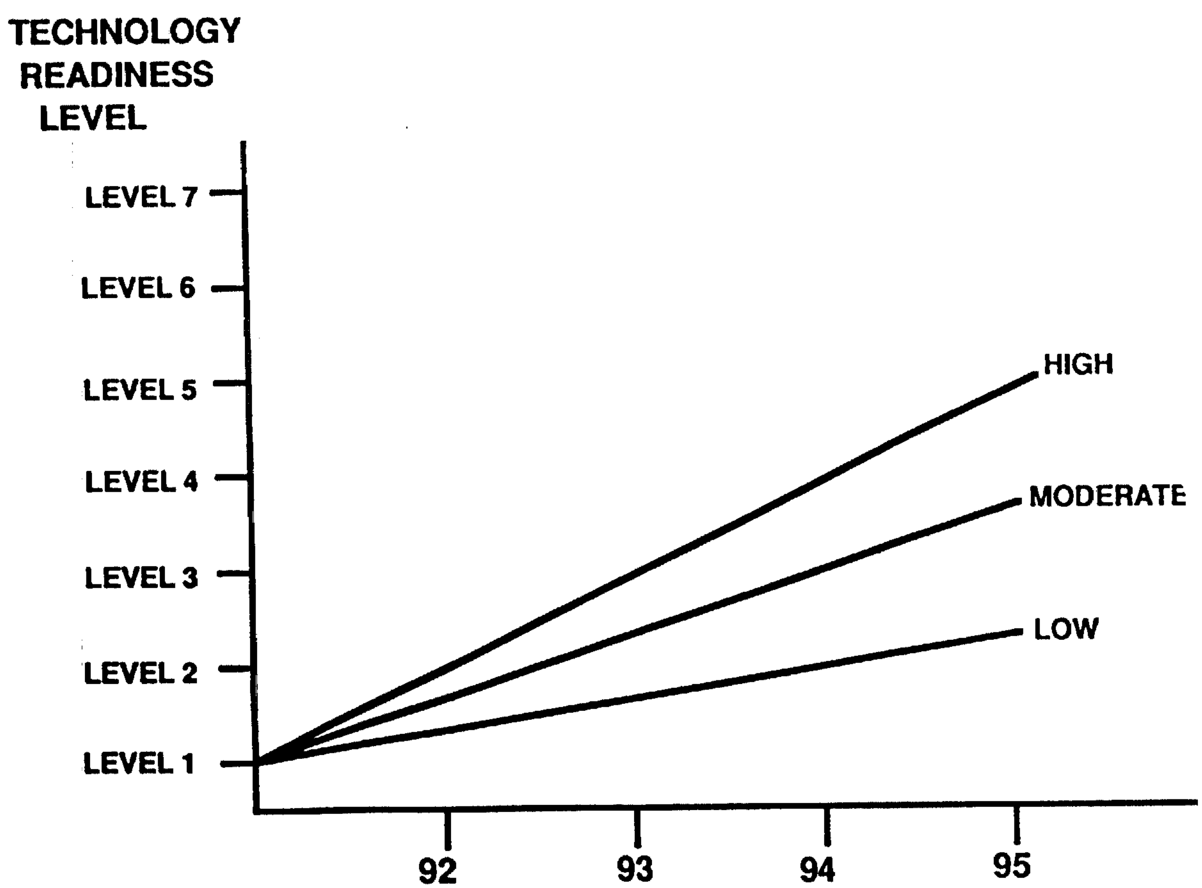
DELIVERABLES:

1. Passive thermal techniques which will accommodate higher heat loads with minimized increase of radiator area, and longer material durability.
2. A technology demonstration preprototype which will be used to support DDT&E of the evolutionary Space Station passsive thermal control.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

THERMAL CONTROL | *PASSIVE THERMAL CONTROL*

TECHNOLOGY ASSESSMENT



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BACKGROUND

SCOPE: A capability to accurately predict performance of growth Space Station thermal control components and system, with analytical tools which have been verified with test data.

OBJECTIVES: To develop fully verified theoretical models and design algorithms which are based on fundamental understanding of two-phase fluid behaviors and heat transfer in microgravity obtained through ground and flight testing. The analysis tools to be developed, enhanced and verified include empirical tools for component/system designs, two-phase flow dynamic simulation tools and integrated system analysis tools.

JUSTIFICATION: Fully verified theoretical models and design algorithms do not exist for two phase fluid flow and associated thermal processes in microgravity, resulting in overly conservative designs for the baseline Space Station thermal control system. Application of the existing analysis tools for the evolutionary thermal control system will incur significant unnecessary weight, power and cost penalties. Development/enhancement of the analytical tools and test verifications of the tools and advanced technology will be the most cost effective way to minimize the conservatism in the design process of the thermal control system.

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THERMAL CONTROL *ANALYSIS AND TEST VERIFICATION*

PROGRAM PLAN

APPROACHES:

1. Establish fundmental understanding of two-phase fluid flow behaviors and heat transfer in zero-gravity through ground and flight experiments.
2. Develop new/enhance existing empirical design tools to increase design confidence. Incoporate AI technology into the design tools.
3. Generate a 3-D analytical simuation tool for two-phase flows in microgravity.
4. Improve existing integrated system analysis tools for design conservatism reduction, DDT&E support and flight techniques development.
5. Create central database by compiling data from a wide range of sources to facilitate accuracy and completeness of analytical process.
6. Integrate evolutionary technology hardware into the existing test beds to minimize testing costs.

DELIVERABLES:

1. A comprehensive set of test verified analytical tools required to enable efficient design, development, test and evaluation of Space Station evolutionary thermal control system.
2. Testing evaluation of evolutionary thermal control technology.

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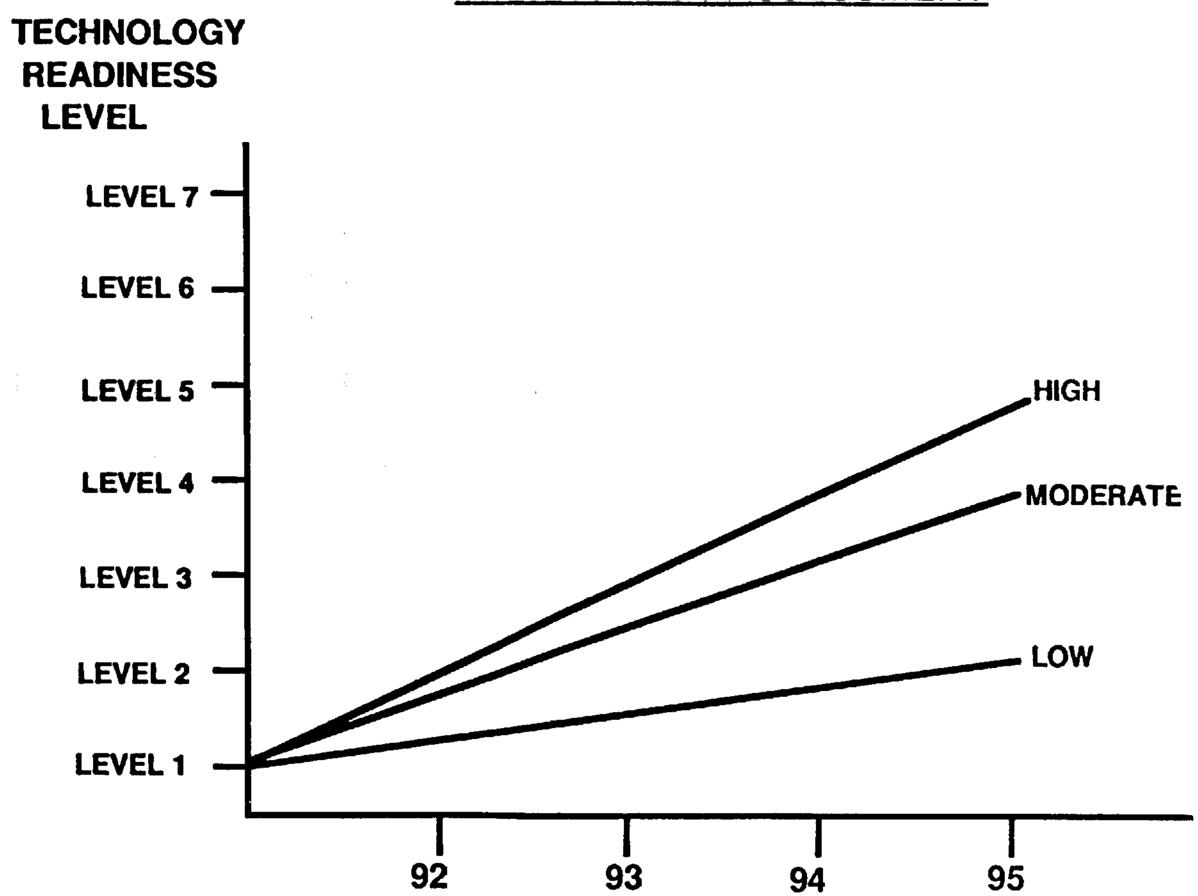
THERMAL CONTROL | *ANALYSIS AND TEST VERIFICATION*

TECHNOLOGY ASSESSMENT



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THERMAL CONTROL

RECOMMENDATIONS

o REDUCE SIZE AND INCREASE LIFE OF GROWTH RADIATOR SYSTEM TO AVOID COSTLY INCREASES ASSOCIATED WITH THE UTILIZATION OF BASELINE TECHNOLOGY

o INCORPORATE AI ROBOTICS TECHNOLOGY INTO THE TCS TO:

- MINIMIZE ORBITAL AND GROUND OPERATION SUPPORT
- INCREASE THE EFFICIENCY OF MAINTENANCE AND REPAIR (E.G., FDIR)
- REDUCE EVA TIME

o DEVELOP ACTIVE THERMAL CONTROL ALTERNATIVES TO ENABLE

- ACTIVE EXTERNAL EQUIPMENT COOLING
- MORE EFFICIENT AND LESS COSTLY HEAT ACQUISITION DEVICES

o INITIATE A MAJOR EFFORT TO DEVELOP AND VALIDATE A COMPREHENSIVE SET OF ANALYTICAL TOOLS TO ENABLE EFFICIENT DESIGN AND EVALUATION OF THE GROWTH THERMAL SYSTEM.

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THERMAL CONTROL

ISSUES

- o UTILIZATION OF BASELINE TECHNOLOGY TO MEET GROWTH STATION REQUIREMENTS WILL RESULT IN COSTLY INCREASES OF:
  - DEPLOYED RADIATOR AREA AND ASSOCIATED SWEEP VOLUME
  - EVA ASSEMBLY TIME
  - ORBITER MANIFESTING PENALTIES (WEIGHT & VOLUME)
  - ORBITAL AND GROUND OPERATIONAL SUPPORT
  - MAINTENANCE AND REPAIR OPERATIONS
- o EXISTING ANALYTICAL TOOLS RESULT IN OVERLY CONSERVATIVE DESIGN (I.E., UNNECESSARY WEIGHT, VOLUME AND POWER PENALTIES)
- o DEPENDENCE ON ONLY PASSIVE COOLING OF ALL EXTERNAL EQUIPMENT WILL NOT BE ADEQUATE FOR GROWTH STATION

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