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NIAC
NASA Institute for Advanced Concepts

# A Chameleon Suit to Liberate Human Exploration of Space Environments


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HSSSI


October 30, 2001

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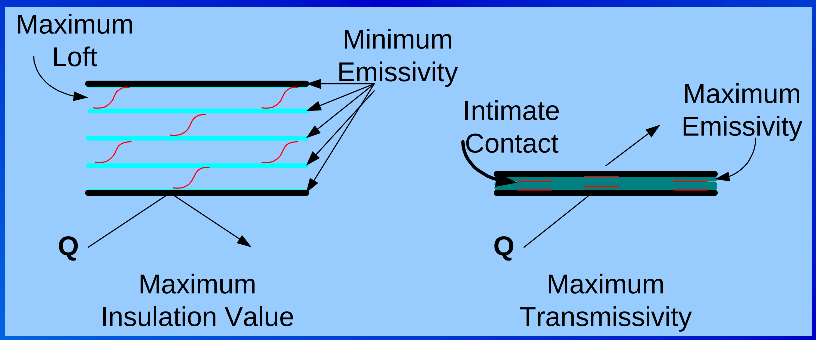
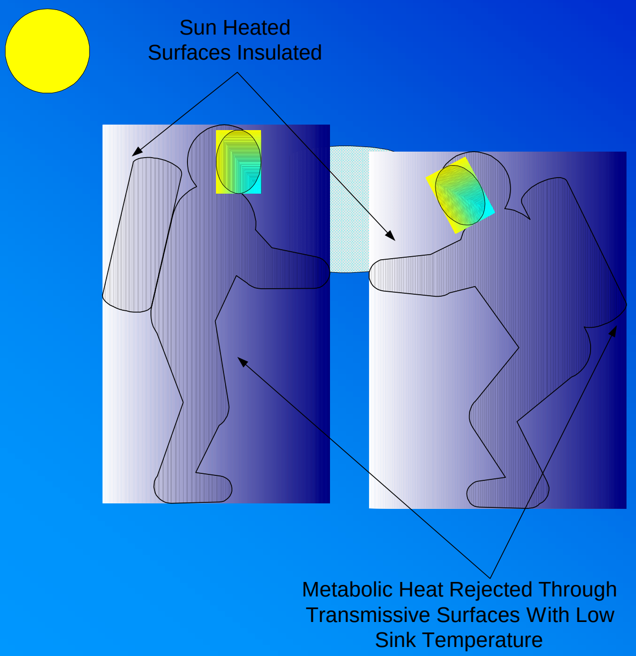
# Concept Summary




- Enabling Waste Heat Rejection From Full Suit Surface Area
- Controlled Suit Heat Transfer
  - Matches metabolic load and environment
  - Layer contact and distance (conduction changes)
  - Layer emissivity
- Eliminate Expendables
- Simpler, Lighter Life Support

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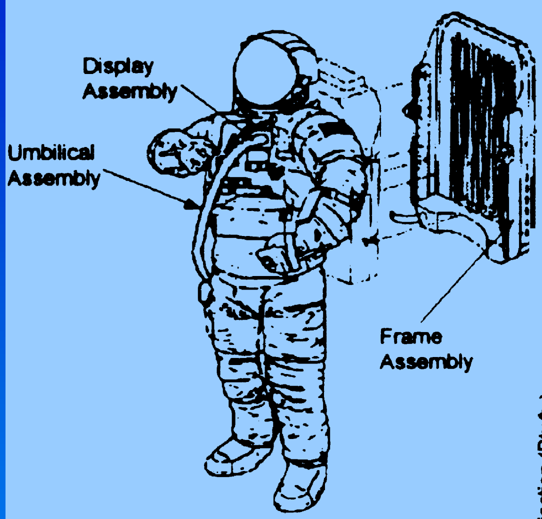
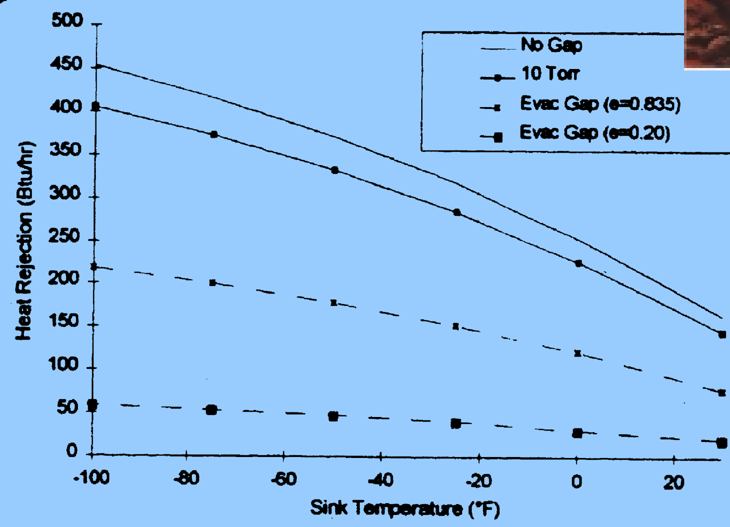
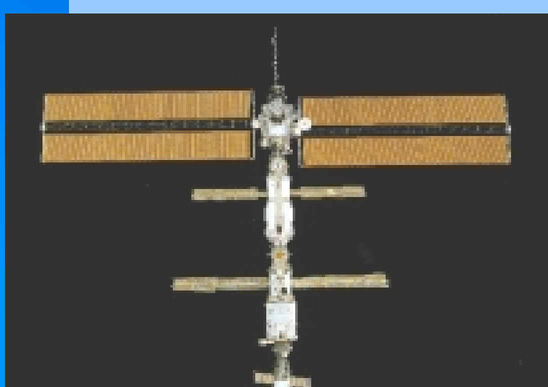
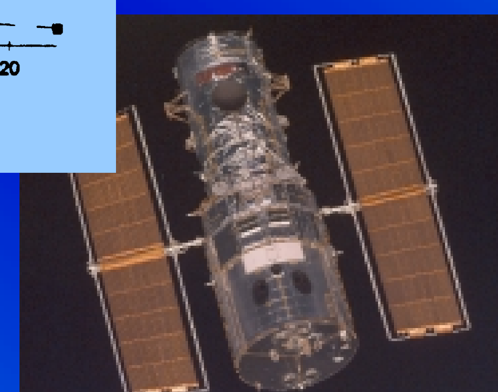
# Mission Needs Addressed





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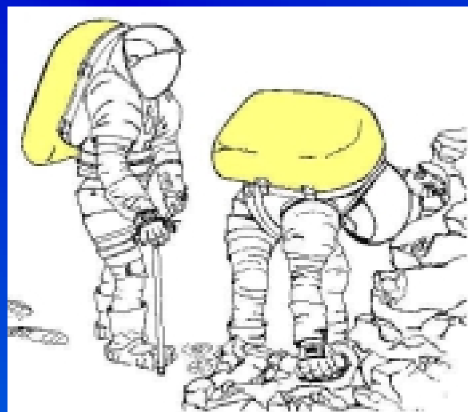
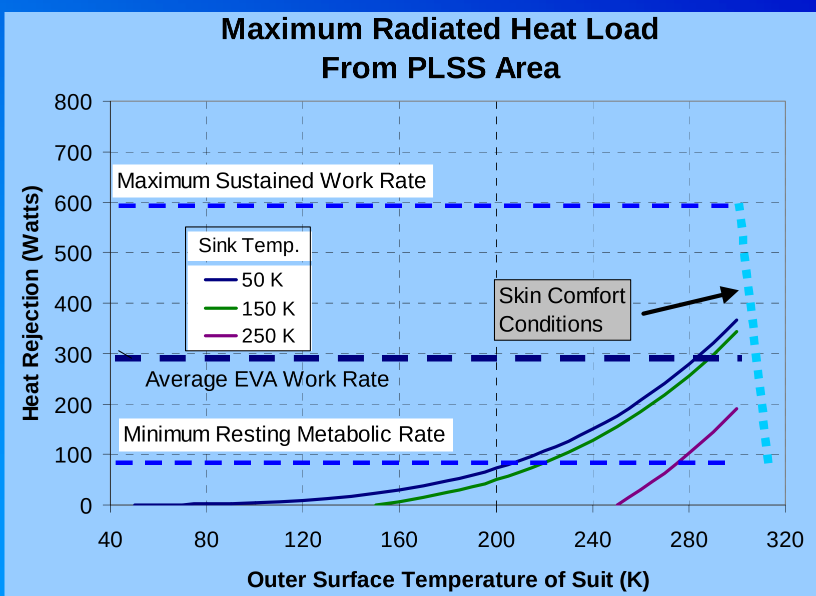
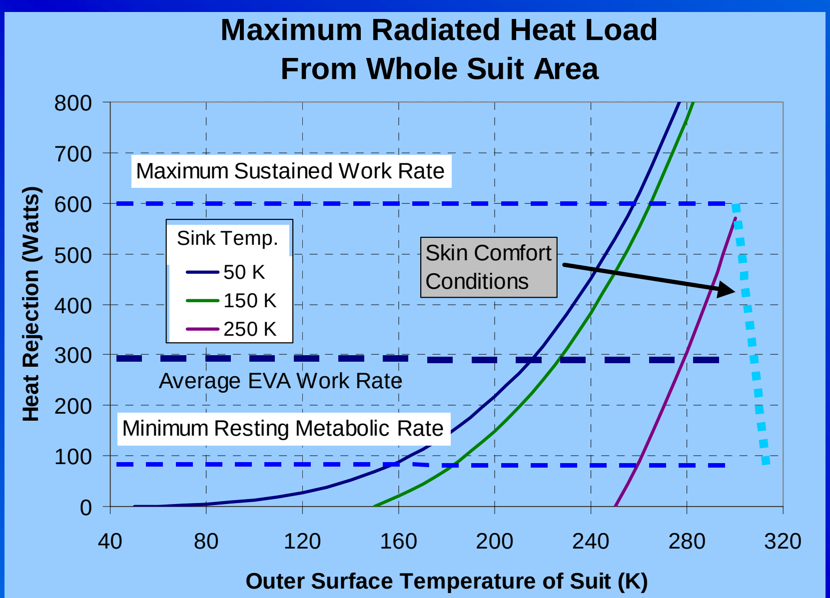
# Performance - Feasibility Assessment





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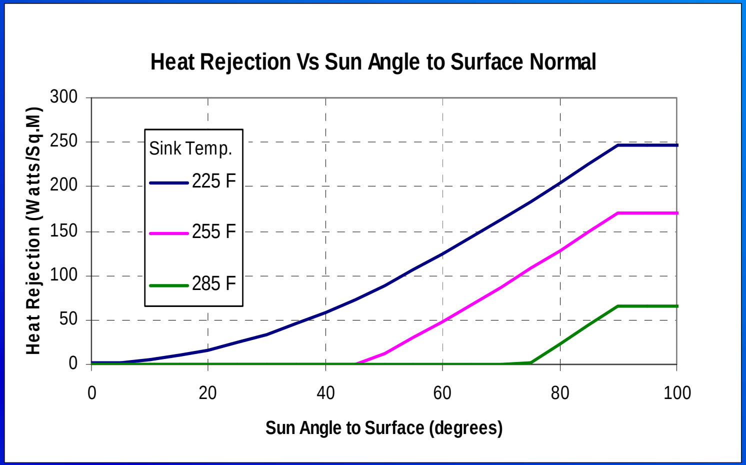
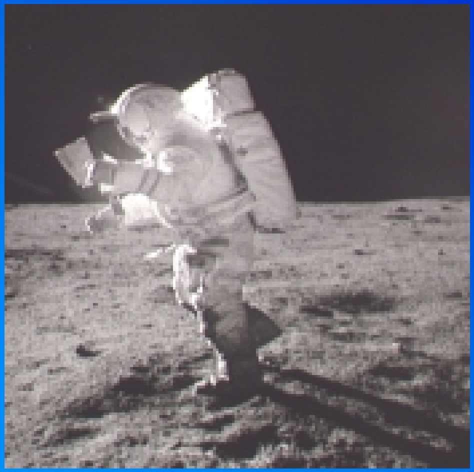
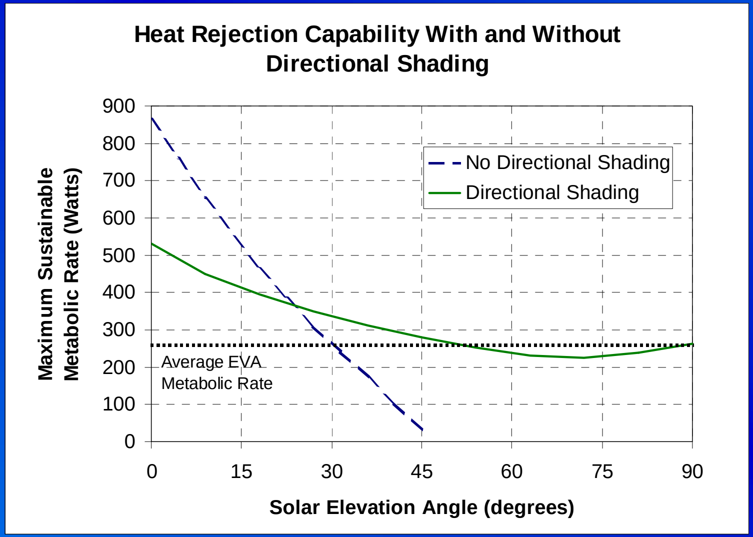
# Performance - Mission Environments & Interactions





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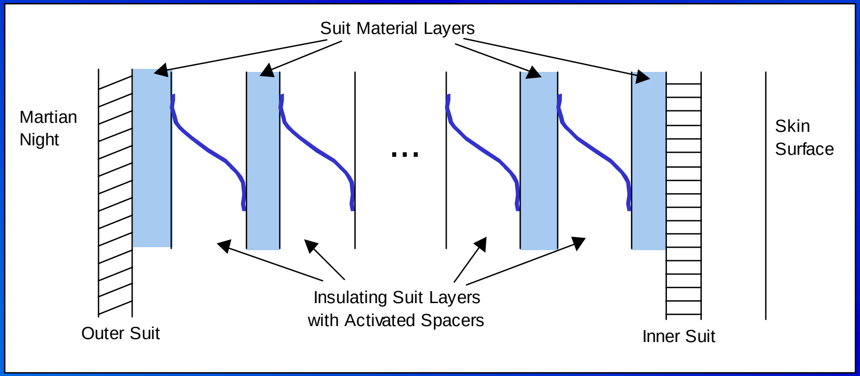
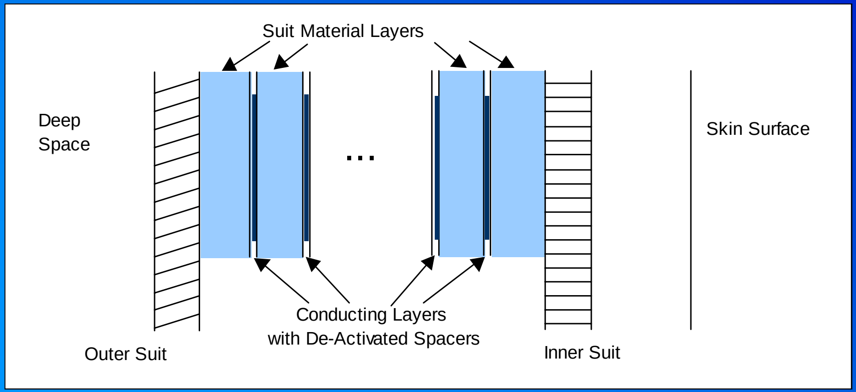
# Performance - System Elements Requirements Derivation




Radiation transport can be limited to acceptable loss for resting conditions in cold environment

## Cold Environment (Mars Night)

- Min Metabolic Rate → 100 W
- Outer Layer Emissivity → 0.85
- Conductivity → 0.96 W/m$^2$-°C
- 6-layer Conductivity→ 0.16 W/m$^2$-°C




Thermal resistance can be minimized to increase radiation transport for hot environment

## Hot and Warm Environments

- Max Metabolic Rate → 600 W
- Emissivity → 0.85
- Conductivity → 300 W/m$^2$-°C
- 6-layer Conductivity→ 50 W/m$^2$-°C

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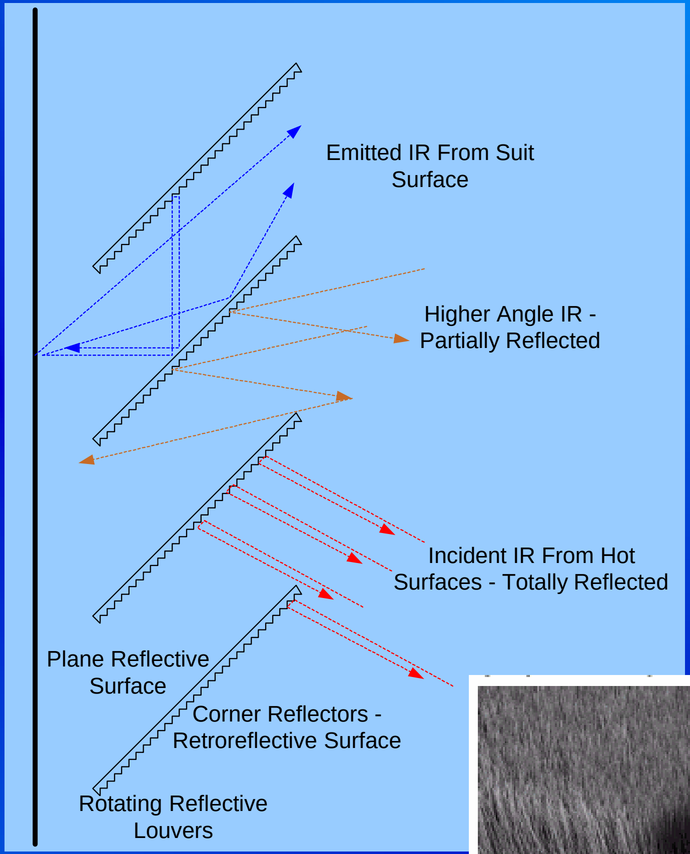
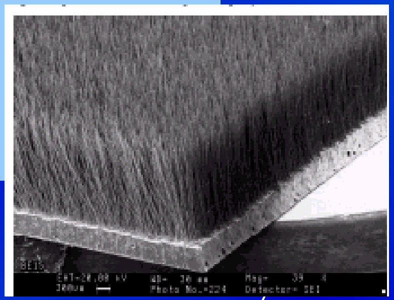
# Concept Evolution, Refinement and Growth Potential

- Conductive Velvet Interlayer Contact
  - Reduced temperature drop to outer surface
- MEMS Directional Shading Louvers
  - Radiative heat rejection in “impossible” environments
- Supplemental Heat Transport
- Micro-Heat Pump Technology



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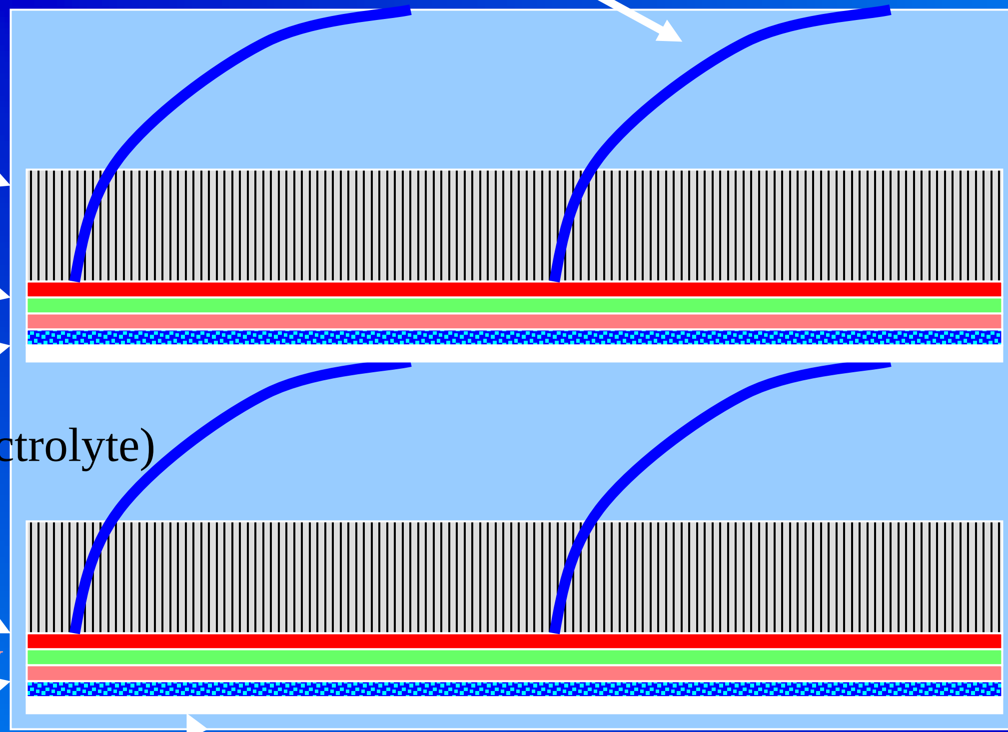
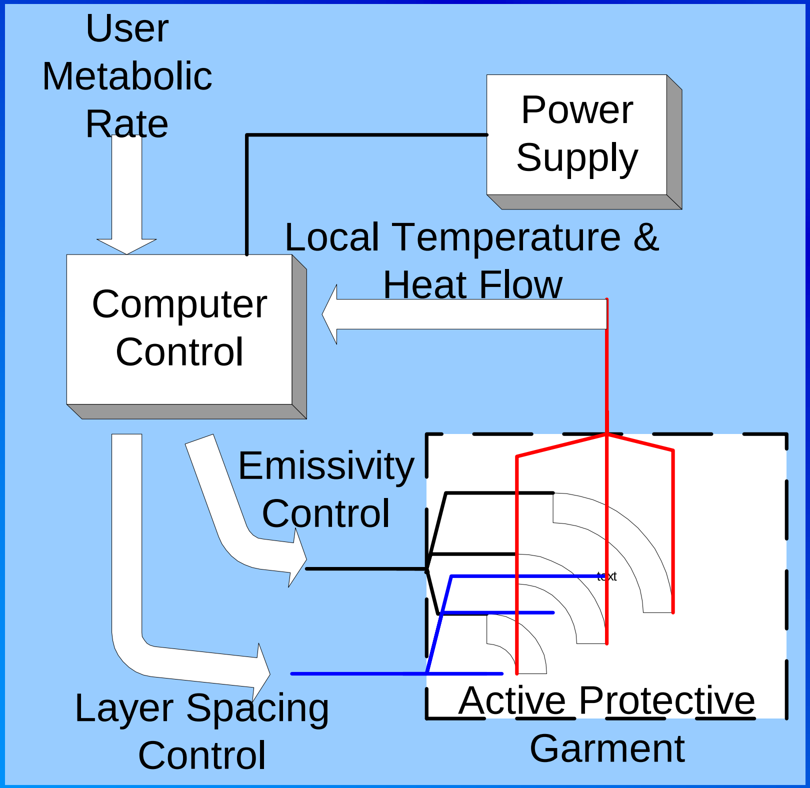
# Chameleon Suit Layer Structure



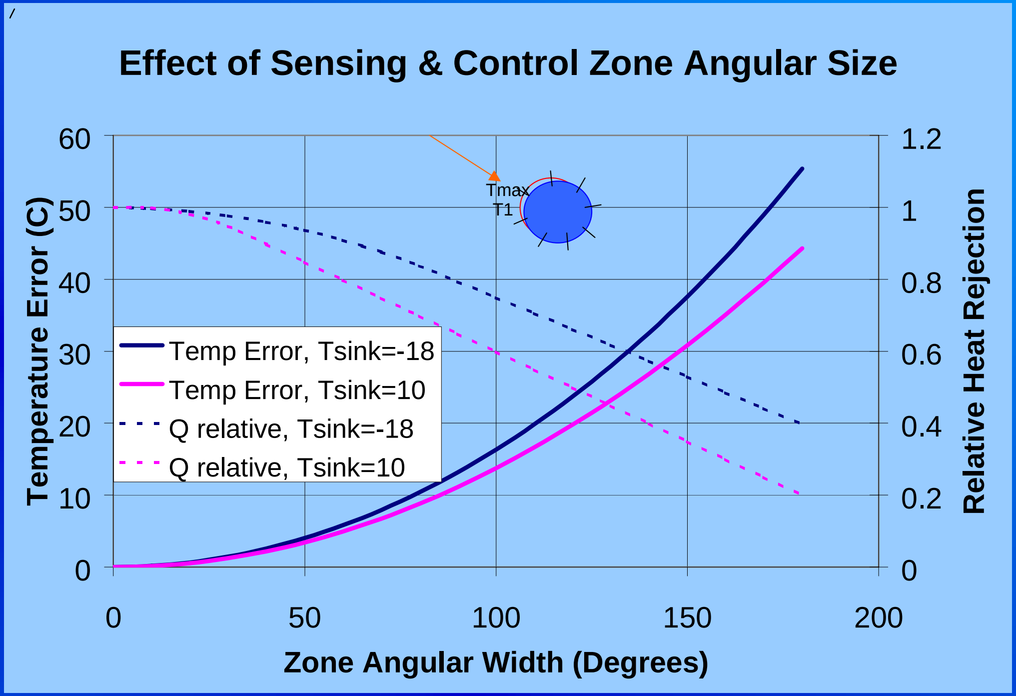
# System Sensing & Control Basics




- Local Temperature & Centralized Metabolic Rate
- Local Temperature is Key
  - Outside surface sets feasibility of heat rejection
  - Inside surface controls comfort
  - Layer delta T gives heat flux
- Metabolic Rate
  - Sets comfort temperature
  - Sets total heat flux

# System Sensing & Control

- System Control Needs
  - Maintain Thermal Comfort
  - Avoid Hot & Cold Touch Temperatures
- Environmental Factors
  - Hot & Cold Extremes
  - Rapid Variation
  - Directional Sources
    - Sun, Hot Surfaces
- Crew Motion
  - Contact Pressure
- Suit Control Zones



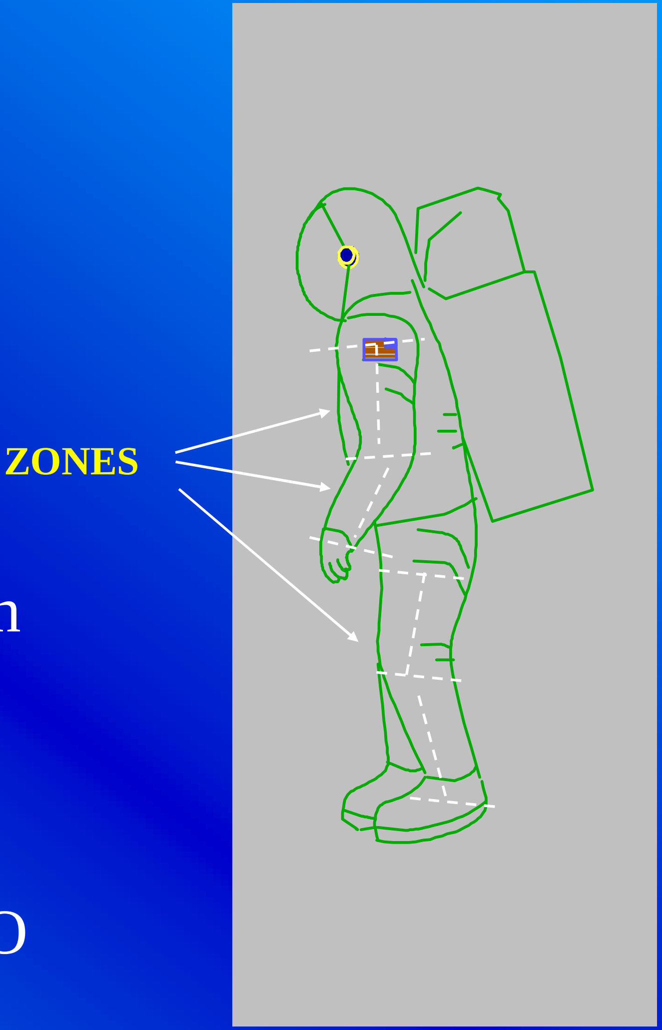

| Control & Sensing Zones | | | Inactive Zones |
|---|---|---|---|
| | | | |
| Head | 11 | | Gloves |
| Torso | 32 | | Elbows |
| Upper Arm | 24 | | Knees |
| Lower Arm | 24 | | Boots |
| Upper Leg | 24 | | |
| Lower Leg | 24 | | |
| Shoulders | 7 | | |
| | | | |
| **Total** | **146** | | |

# Sensing & Control Integration Options

- Driving Factors
  - Robust Control
    - Simple signal and power interfaces
    - Minimize harnesses
    - Redundancy
  - Minimize Heat Leak
  - Minimize Power/Weight/Volume of Control Electronics
- Control Basis
  - Total Heat Rejection
  - Skin Comfort temperature
  - Comfort Indicators
- Architecture Options
  - Centralized
  - Distributed
- Signal Transfer
  - Analog/Sensor inputs
  - Data Bus, Wireless
  - Effector Drivers
  - Power Distribution

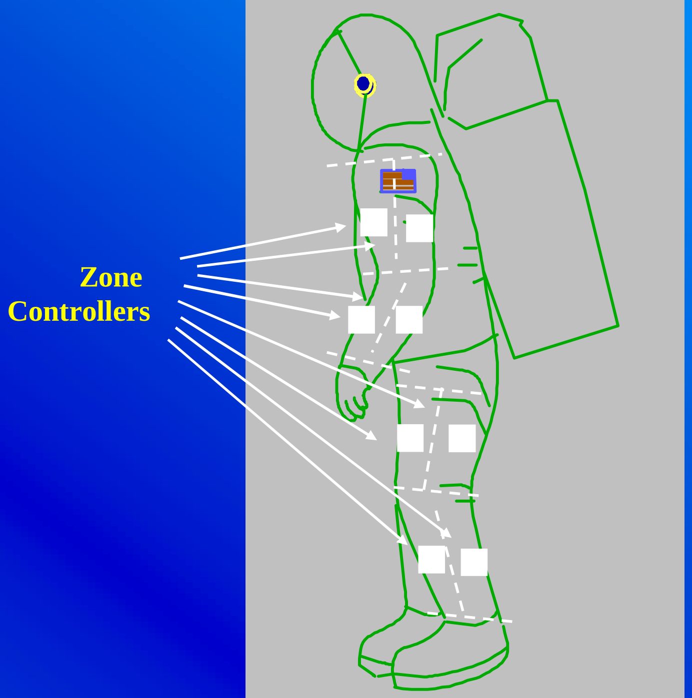
# Control And Feedback

- ~150 Zones, 5 layers => High I/O Count
- Centralized Control Requires Complex Data Transfer, High Data Rates
- Optimal Approaches in Dealing With High I/O Counts Are Based on a Distributed Processing Concept
- Distributed Control Zones for Segments of the Suit Simplify the I/O Requirements



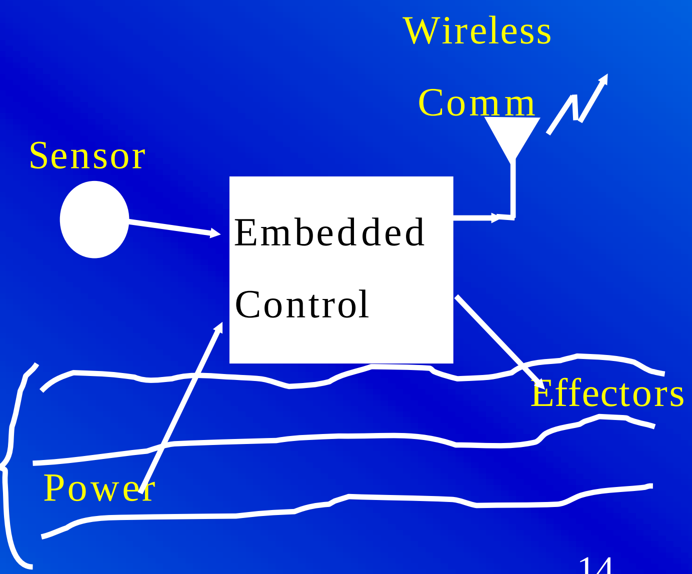
# Control And Feedback Preferred Implementation

- Central Processor
  - Determines metabolic rate
  - Transmits inner wall T targets
  - Receives zone status & wall T
- Networked dedicated zone controllers
  - Receive T targets & local T's
  - Locally send actuator control signals
  - Transmit inner wall T & status
- Signal transmission
  - Wireless IEEE 802.11B protocol
  - Alternate - signals on power lines



# Power Distribution

- Current Technology Harnesses
  - Weight, Reliability, Mobility Impacts
- "Smart" Garment Technology
  - Integrated Power and Signal Distribution
    - Conductors woven in cloth layers
    - Conducting polymer layers
  - Integrated Sensing, Data Terminal, Actuator Control Elements on Chip
- Wireless Data Transmission, Local Control Components
  - Only Power Physically Connects Layers (Thermal Short)
  - Minimum Number of Connections




Fabric Effector Control
and Input Power Layers

# Technology Base Assessment - Development Needs Key Areas

- Variable Geometry Insulation
  - Light weight, flexible biomimetic polymer actuators.
  - Durable and effective felt thermal contact material.
- Controlled Thermal Radiation
  - Effective thermal IR electrochromic polymers with high contrast ratios
  - “Soft” MEMS directional louver implementations.
- “Smart” Garment Sensing and Control Integration
- Cost Effective Integrated Garment Manufacturing

# Variable Geometry Insulation Actuators

- Elongating polymers (MIT)
  - Conductive polymers (PPy, PAN)
  - liquid, gel or solid electrolytes
  - 2% linear , 6% volumetric at ~ 1V
- Bending polymers (UNM)
  - Ionic polymer-metal composites (Nafion-Pt)
  - need to prevent water leakage (encapsulation, better Pt dispersion)
  - complete loop with <3V

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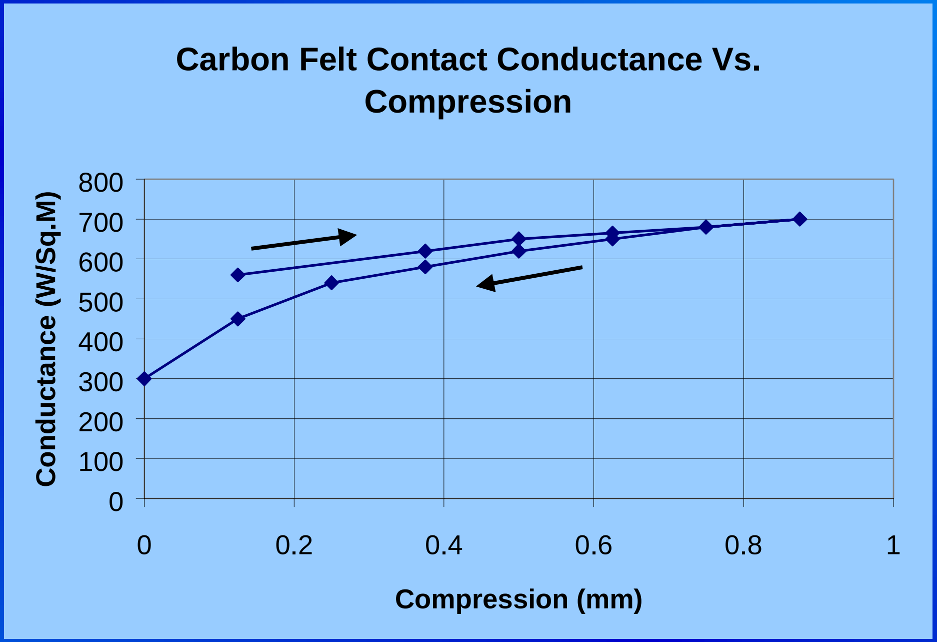
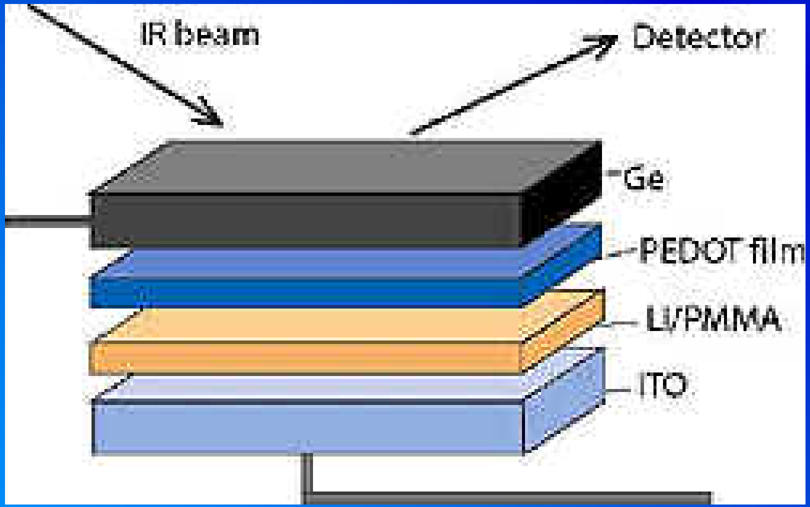
# Interlayer Thermal Contact

- Low Thermal Resistance Is Required
  - High Metabolic Rates
  - Warm Environments
  - Vacuum Conditions
  - Low Contact Pressure
- Carbon Fiber Felts Show Good Performance
- Durability in Application Requires Development



# Electro-emissive Technologies

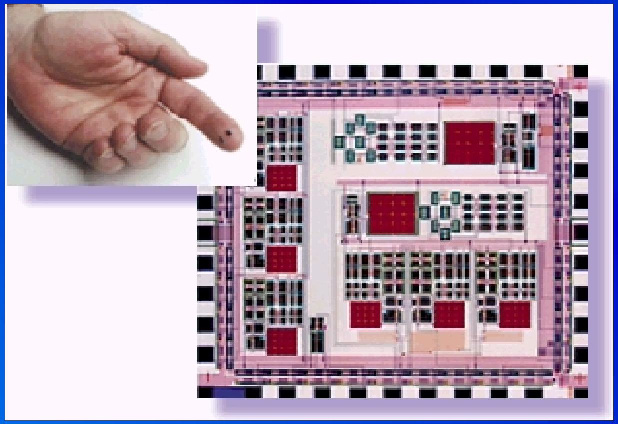


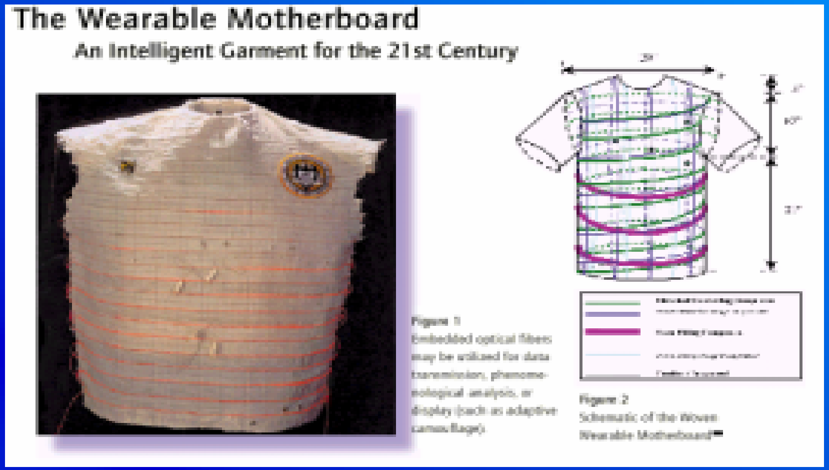

- Most Broadband Infra-red Research Has Been With Inorganic EC Materials ($WO_3$)
- Contrast Ratios > 2:1 in the Thermal IR Shown
- Polymer EC Materials are Under Study by Numerous Investigators
- Much Further Development is Needed

# Directional Shading Louvers

- MEMS Louver Technology is Under Development for Satellite Applications
  - Shown to Provide Effective Emissivity Modulation
  - Options Under Study Include Pivoting Louvers Required for Chameleon Suit Directional Shading
- Louver Size for IR Corner Reflectors is Compatible With Application (~.03 mm deep)
- Major Development Challenges
  - Integration in Flexible Garment
  - Removable Louver Layers

# Sensing & Control Integration






- Systems Embodying the Required Functions Are Being Developed for Many Uses
- Key Challenges Will Be:
  - Space Environment Compatibility
  - Limiting Weight & Maintaining Flexibility With Many Layers

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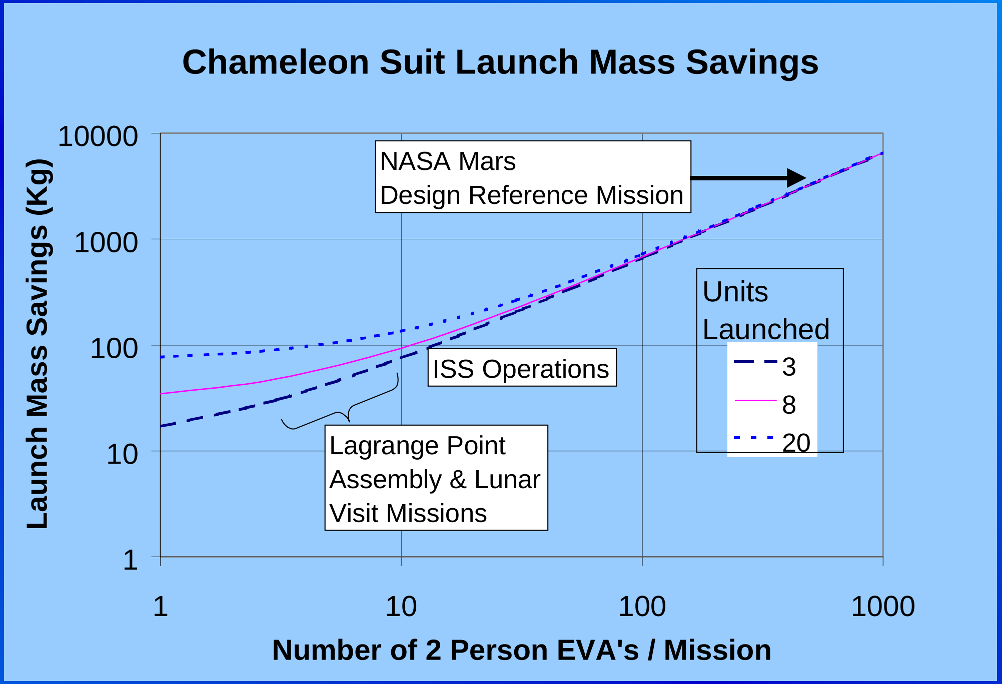
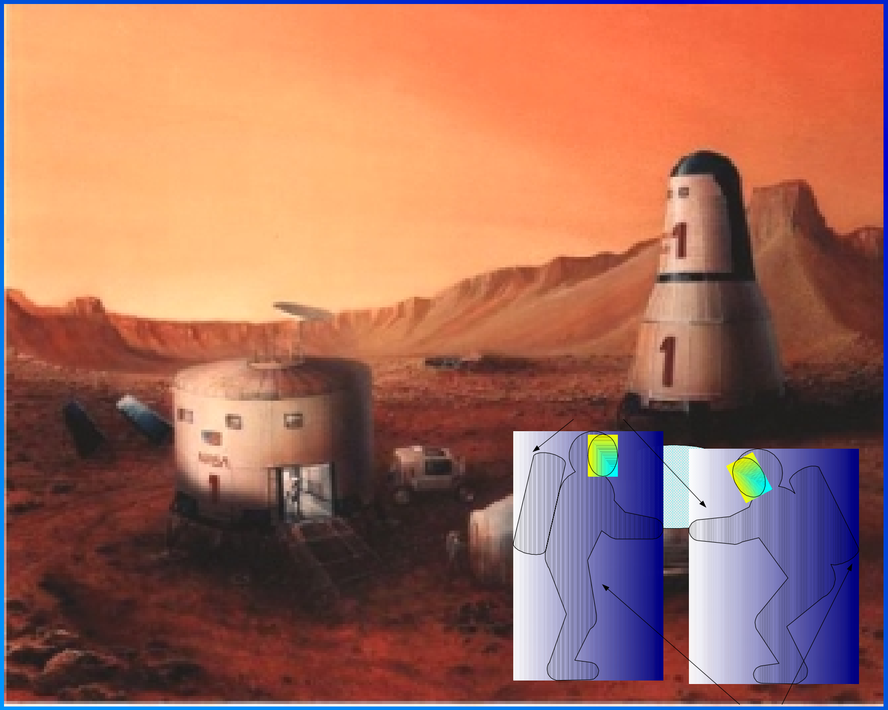
# Mission Benefits Assessment

- Substantial Launch Mass Savings
  - Savings For All Missions
  - EVA Intensive 1000 Day Class Missions Benefit Most
- ~ 3.5 Kg Reduction in EVA Carry Mass
- Capability for Non-Venting Operations in Most Environments
  - Science & Servicing Flexibility



# Summary & Conclusions



- Studying the Chameleon Suit Reveals Many New Challenges
  - None Have Yet Proved Insoluble
- Many Required Technology Advances are Pursued Elsewhere
  - Specific Development and Adaptation Work is Required
- Potential Benefits to NASA are Substantial and Real
  - Further Study Should be Pursued