TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP

POWER SYSTEM TECHNOLOGY DISCIPLINE

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TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

TECHNOLOGY DISCIPLINE SUMMARY FOR *POWER SYSTEM*

- **SUBSTANTIAL BENEFITS IDENTIFIED FOR ADVANCED TECHNOLOGY**

GENERATION

- **PHOTOVOLTAIC PLANAR AND CONCENTRATOR ARRAYS**
  - REDUCED AREA (2x) AND REDUCED COSTS (RECURRING AND RESUPPLY)
  - 2x MASS REDUCTION WITH BETTER PACKING DENSITY AND PERFORMANCE
- **NON-SOLAR OPTION**
  - NON-PLUTONIUM ISOTOPE DYNAMIC SYSTEM REDUCES ORIENTATION AND MISSION CONSTRAINTS

STORAGE

- **LONG LIVED NI/H_2 BATTERIES**
  - MORE THAN 2x INCREASE IN CYCLE LIFE REDUCES RESUPPLY COSTS
- **TEST BED FOR HEI REGENERATIVE FUEL CELL WITH SYNERGISTIC SSF BENEFITS**
  - VALIDATES HEI TECHNOLOGY PLUS PROVIDING CONTINGENCY OR SAFE HAVEN POWER

DISTRIBUTION

- **AC FOR GROWTH**
  - HYBRID AC/DC SYSTEM
- **INCREASED AUTONOMY**
  - FREES CREW TIME FOR OPERATIONS, INCREASES SAFETY AND RELIABILITY

- **SSF SYSTEM TRADES SHOULD BE CONDUCTED TO EVALUATE RISKS/BENEFITS OF TECHNOLOGY OPTIONS SOON**

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POWER GENERATION *POWER GENERATION SUBSYSTEM*

ADVANCED PHOTOVOLTAIC ARRAY DEVELOPMENT

BACKGROUND

SCOPE - DEMONSTRATE ADVANCED SOLAR ARRAY LEVEL 5 TECHNOLOGY (PLANAR AND CONCENTRATOR) FOR SSF GROWTH.

OBJECTIVES - DEVELOP AND DEMONSTRATE ADVANCED SOLAR ARRAY OPTIONS WITH ≥50% IMPROVEMENT IN W/m^2 OVER BASELINE SOLAR ARRAY AND W/kg PERFORMANCE GREATER THAN BASELINE SOLAR ARRAY.

REQUIREMENTS/ RATIONALE - 100 kW NEEDED FOR EVOLUTIONARY SPACE STATION. SIGNIFICANT W/m^2 PERFORMANCE IMPROVEMENT REQUIRED TO REDUCE DRAG. CONCENTRATOR ARRAYS HAVE POTENTIAL FOR SUBSTANTIAL COST REDUCTIONS AND EFFICIENCY INCREASES. DOD INVESTMENT IN GaAs/Ge CAN BE USED TO PROVIDE HIGH PERFORMANCE PLANAR OPTION.

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ADVANCED PHOTOVOLTAIC ARRAY DEVELOPMENT

PROGRAM PLAN

APPROACH -

- FOR PLANAR ARRAY: PILOT PRODUCTION OF 19% 8x8 GaAs/Ge CELL TECHNOLOGY (OR TANDEM CELL), FAB, ASSEMBLE AND TEST PANEL COUPONS.
- FOR CONCENTRATOR ARRAY: DEVELOP LIGHTWEIGHT OPTICS, AND 25% CONCENTRATOR CELL. DESIGN, FAB, ASSEMBLE, AND TEST PANEL LEVEL HARDWARE.

DELIVERABLES -

- PRODUCTION READY 19% GaAs/Ge CELLS (OR EQUIVALENT) FOR ADVANCED PLANAR CONCENTRATOR OPTICS/25% CELL, DEMONSTRATE PANEL.

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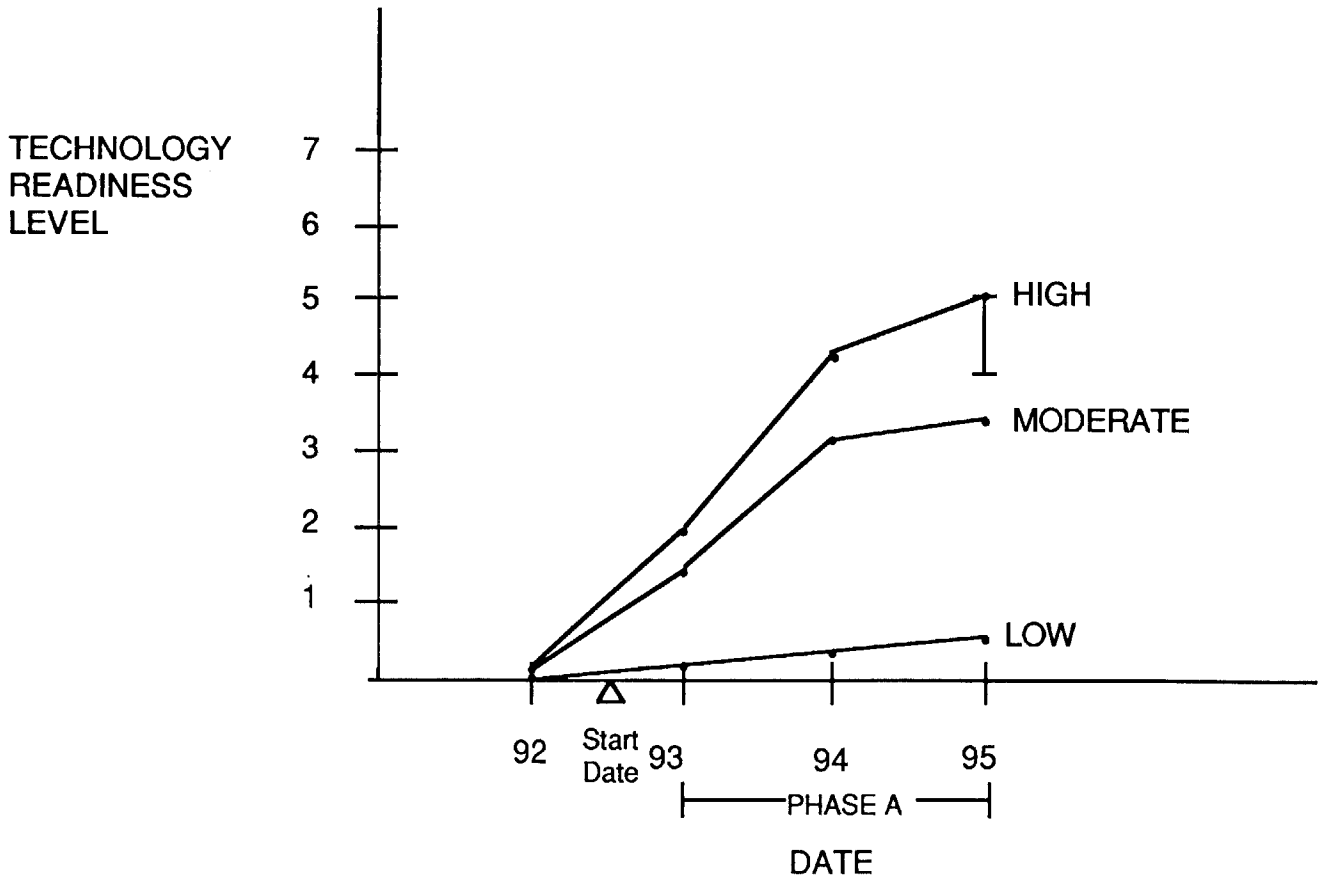
POWER GENERATION

POWER GENERATION SUBSYSTEM

ADVANCED PHOTOVOLTAIC ARRAY DEVELOPMENT

TECHNOLOGY ASSESSMENT



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POWER SYSTEM *POWER GENERATION SUBSYSTEM*

SOLAR DYNAMIC TECHNOLOGY

BACKGROUND

SCOPE - PERFORM TECHNOLOGY DEMONSTRATIONS TO OBTAIN IMPROVEMENTS OVER CURRENT SSF DESIGN*
- LOWER WEIGHT
- LOWER LAUNCH VOLUME
- IMPROVED OPERATIONAL CAPABILITY
- IMPROVED RELIABILITY

OBJECTIVES - INCREASE SSF SOLAR DYNAMIC SPECIFIC POWER BY 100% (W/kg)
- 50% Wt REDUCTION IN HEAT RECEIVERS, CONCENTRATOR AND RADIATOR
- PCU PERFORMANCE IMPROVEMENTS

REQUIREMENTS/ RATIONALE - SUPPORT 175 kW HEI SSF WITH IMPROVED POWER SYSTEM
- LOWER WEIGHT, LAUNCH VOLUME AND COST

AN ALTERNATIVE, SUNLIGHT INDEPENDENT POWER OPTION WAS SURFACED THAT WILL REDUCE CONSTRAINTS ON SSF ORIENTATION AND FLIGHT HARDWARE

*IT IS ASSUMED THAT THE SSF PROGRAM OFFICE WILL IMPLEMENT THE SD DEVELOPMENT PROGRAM

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POWER SYSTEM *POWER GENERATION SUBSYSTEM*

SOLAR DYNAMIC TECHNOLOGY

PROGRAM PLAN

APPROACH -

- DEFINE LIGHTWEIGHT SYSTEM DESIGN, PERFORM CONFIGURATION TRADE STUDIES
- FABRICATE AND TEST SUBSCALE SUBSYSTEM ELEMENTS- (CONCENTRATOR SEGMENT, RECEIVER, RADIATOR) TO ASSESS DESIGN VALIDITY AND POTENTIAL MASS SAVINGS, LONGEVITY
- INTEGRATE COMPONENTS TO DETERMINE SYSTEM SENSITIVITIES
- ASSESS FEASIBILITY/TECHNICAL/POLITICAL ISSUES IN NON-PLUTONIUM ISOTOPE/DYNAMIC/CONVERSION SYSTEM FOR SSF

DELIVERABLES -

- SUBSCALE CONCENTRATOR SEGMENTS, RECEIVER, RADIATOR TESTED AT APPROPRIATE SCALE
- LOWER LEVEL ASSEMBLIES
- FEASIBILITY STUDY OF NON-PLUTONIUM FUELED ISOTOPE/DYNAMIC CONVERSION SYSTEM

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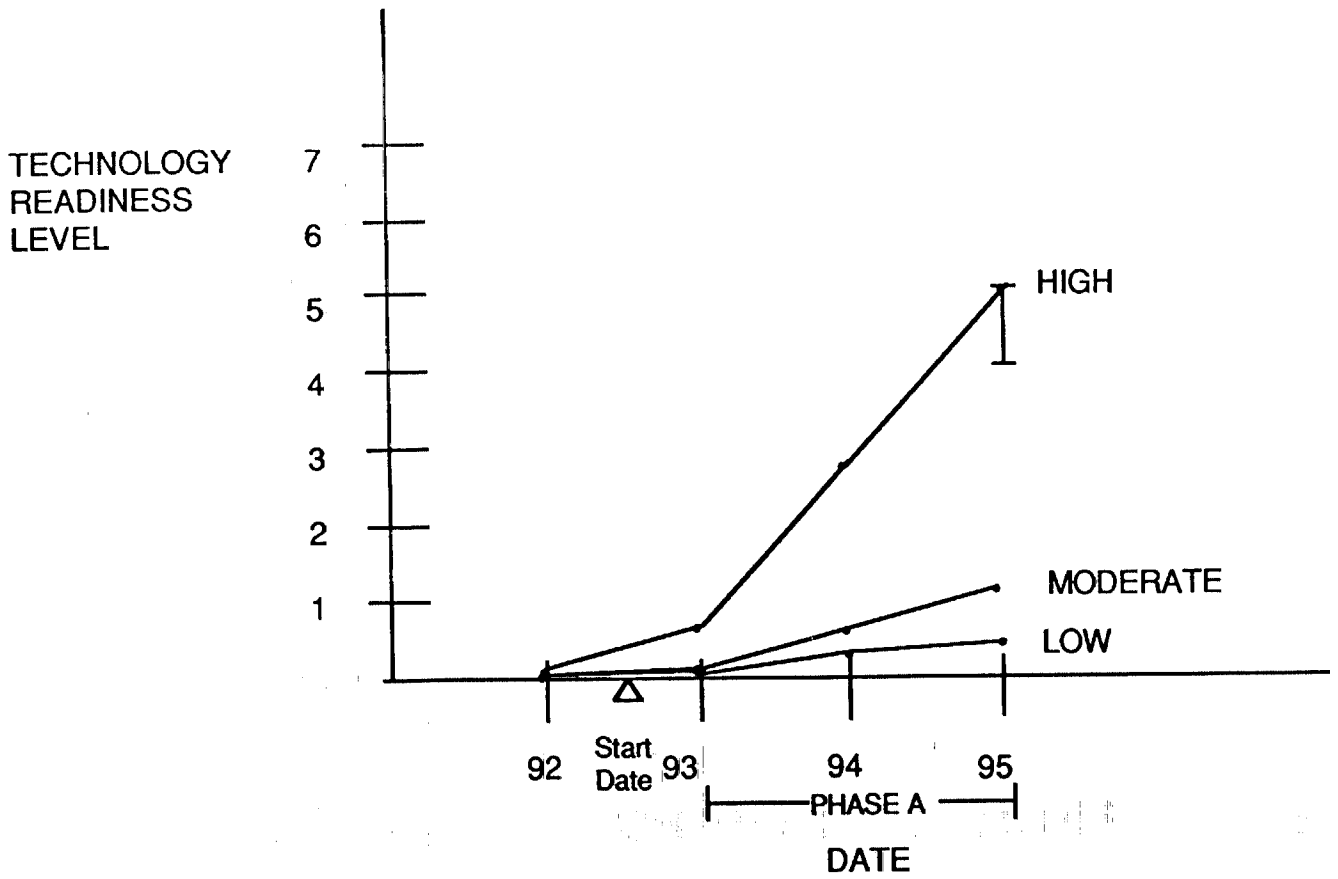
POWER GENERATION SUBSYSTEM

SOLAR DYNAMIC TECHNOLOGY

TECHNOLOGY ASSESSMENT



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POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

ADVANCED Ni/H_2 BATTERY TECHNOLOGY

BACKGROUND

SCOPE - VALIDATE Ni/H_2 BATTERY TECHNOLOGY FOR EXTENDED LIFE, IMPROVED ENERGY DENSITY

OBJECTIVES - REDUCE LIFE CYCLE COST BY INCREASING CYCLE LIFE BY AT LEAST 2X (10 yr 60,000 CYCLES), IMPROVE ENERGY DENSITY BY 20% AND INCREASE DoD CAPABILITY BY 150%

REQUIREMENTS/ RATIONALE - PRESENT Ni/H_2 BATTERIES ARE PLANNED FOR REPLACEMENT AFTER ABOUT 3.5+ YEARS, LIFE IMPROVEMENTS WOULD SUBSTANTICALLY REDUCE COSTS. INCREASING SSF POWER TO 100 kW BY 2000 AND 125 kW BY 2002 AND ULTIMATELY TO 175 kW WOULD BE ENHANCED BY LIGHTER WEIGHT LONGER LIVED BATTERIES

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POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

ADVANCED Ni/H_2 BATTERY TECHNOLOGY

PROGRAM PLAN

APPROACH -

- COMPONENT LEVEL TESTING OF ELECTRODE DESIGN, COMPOSITION AND PROCESSING
- FLIGHT TYPE CELL TESTING AND TECHNOLOGY VALIDATION
- BATTERY DESIGN IMPACT EVALUATION

DELIVERABLES -

- 320 Ni/H_2 CELLS (81 AH)
- BATTERY DESIGN IMPACT EVALUATION
- TEST DOCUMENTATION

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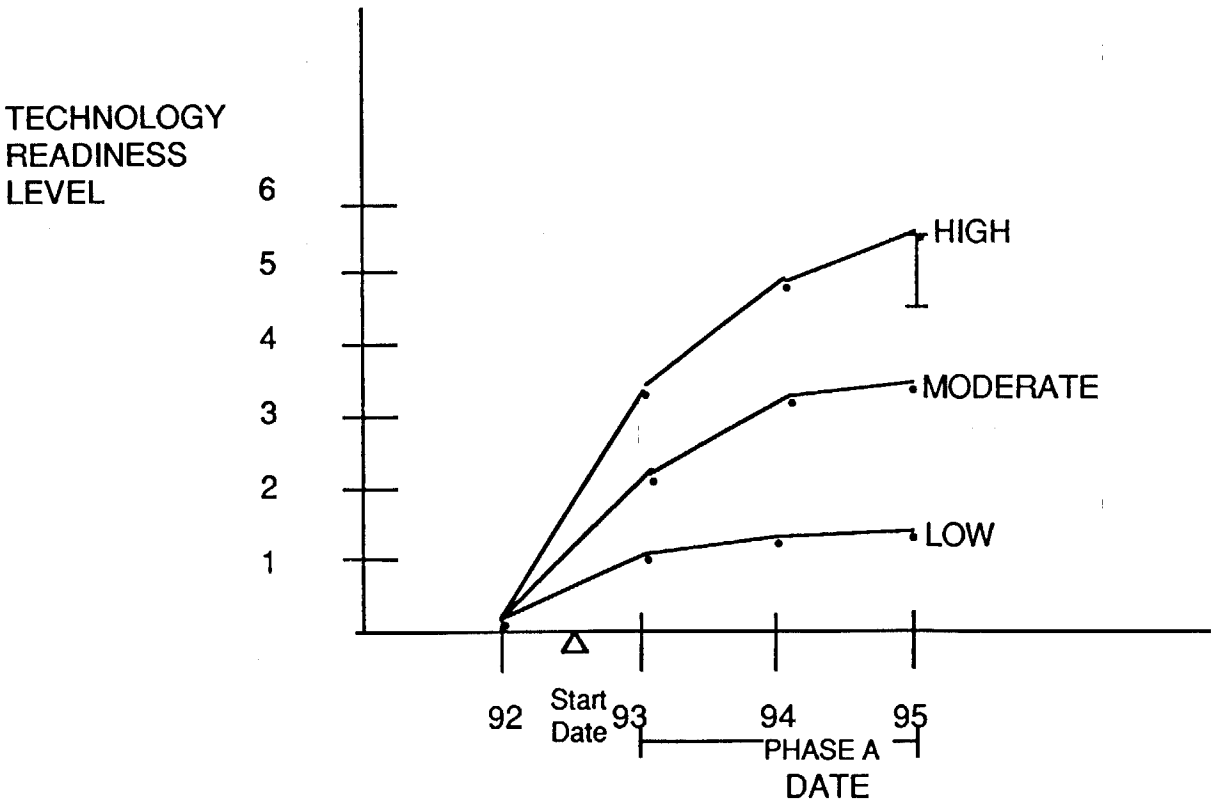
POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

ADVANCED Ni/H_2 BATTERY TECHNOLOGY

TECHNOLOGY ASSESSMENT



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POWER SYSTEM *ENERGY STORAGE SUBSYSTEM*

REGENERATIVE FUEL CELL (RFC) DEMONSTRATION

BACKGROUND

SCOPE - DEMONSTRATE HEI RFC BREADBOARD AND ESTABLISH USEFULNESS FOR SSF.

OBJECTIVES -
- VALIDATE RFC TECHNOLOGY DEVELOPED FOR HUMAN EXPLORATION INITIATIVE (HEI),
- ALSO OFFERS SSF CONTINGENCY BY STORING UNUSED ENERGY,
- PROVIDES POTENTIAL INCREASE IN EMERGENCY, CONTINGENCY, PEAKING, OR SAFE HAVEN POWER.

REQUIREMENTS/ RATIONALE - SSF PROVIDES WORST CASE TESTING OF HEI RFC TECHNOLOGY; WILL PRCVIDE DESIGN CONFIRMATION REDUCING RISK TO HEI. TAPER CHARGING AND LOAD FACTOR ON SSF MAY PROVIDE UNUSED POWER FOR THIS TEST. MAY PROVIDE 200-1000 kW HRS FOR SAFE HAVEN, CONTINGENCY, PEAKING OR EMERGENCIES.

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM

ENERGY STORAGE SUBSYSTEM

REGENERATIVE FUEL CELL (RFC) DEMONSTRATION

PROGRAM PLAN

APPROACH -

- DEVELOP 10 kW LONG LIFE FUEL CELL (20,000 HRS)
- DEVELOP HIGH PRESSURE ZERO 'G' ELECTROLYSIS UNIT (20 kW, 20,000 HR LIFE)
- DEVELOP PASSIVE INTERACTION COMPONENTS (TANKS, CONTROLS . . . . .)
- DEMONSTRATE 2000 HOUR TEST OF SSF, LUNAR PROFILES

DELIVERABLES -

- BREADBOARD SYSTEM, LIFE TESTED READY FOR INTEGRATION INTO SSF EXPERIMENT
- TEST DATA

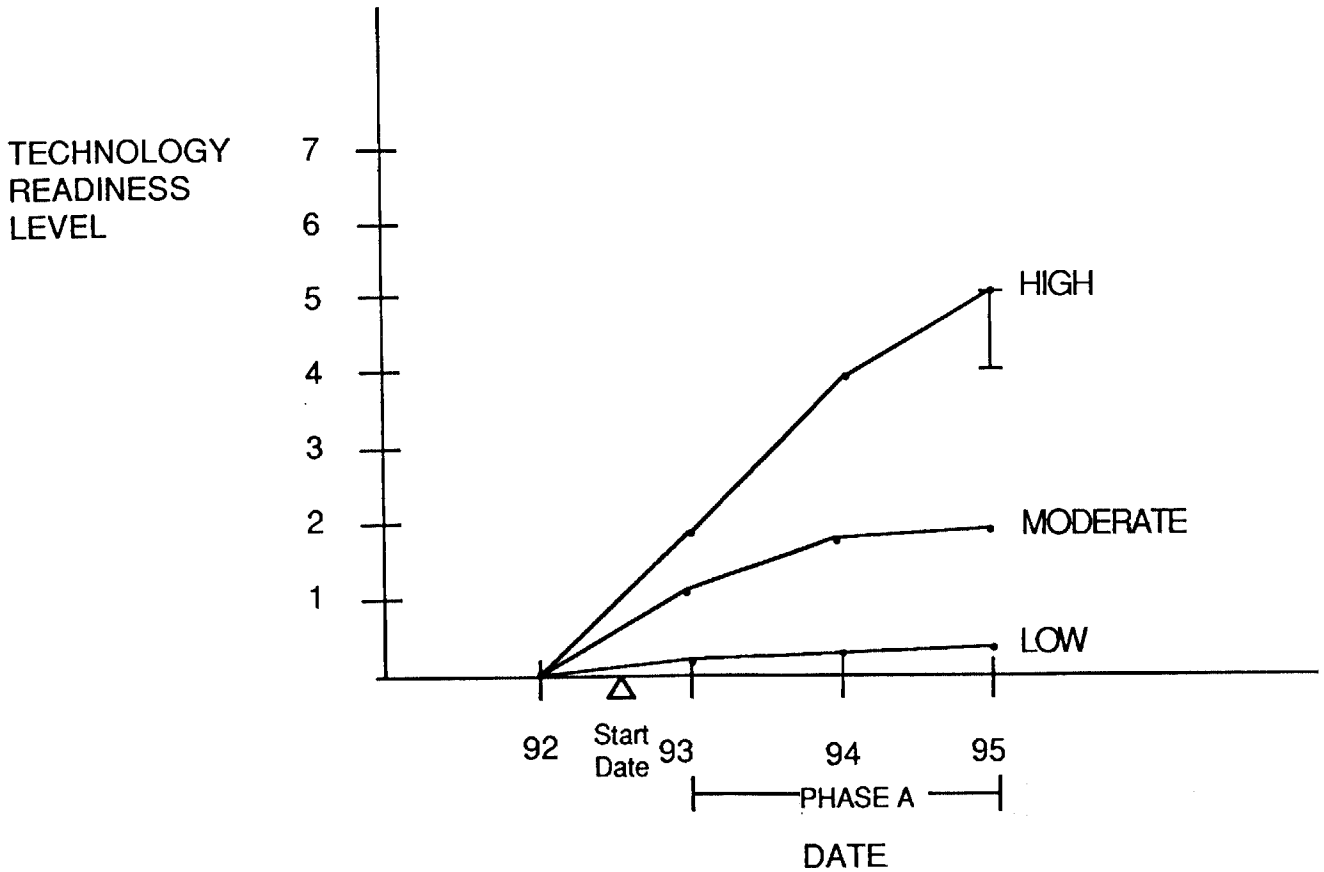
TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

POWER SYSTEM

ENERGY STORAGE SUBSYSTEM

REGENERATIVE FUEL CELL (RFC) DEMONSTRATION

TECHNOLOGY ASSESSMENT



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POWER SYSTEM *POWER DISTRIBUTION*

POWER MANAGEMENT TECHNOLOGY

BACKGROUND

SCOPE - PROVIDE POWER MANAGEMENT SYSTEM TECHNOLOGIES FOR POWER NEEDED TO SUPPORT HEI & OTHER SSF NEEDS

OBJECTIVES - GROW PMAD CAPABILITY TO 175 kW WITH ALLOWANCE FOR FURTHER GROWTH AND AUGMENT IOC STATION POWER. USE STATION AS PROTOTYPE FOR HEI PMAD

REQUIREMENTS/ RATIONALE -

- SAFETY/BUILT-IN TEST/AUTOMATED NDE
- MEET ALL HEI NEEDS
- AUTOMATE TO REDUCE CREW TIME & DOWN LINK TRAFFIC
- COMPATIBLE WITH IOC DC SYSTEM
- REDUCE LIFE CYCLE COSTS

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POWER SYSTEM *POWER DISTRIBUTION*

POWER MANAGEMENT TECHNOLOGY

PROGRAM PLAN

APPROACH -

- PERFORM TRADE STUDY FOR SSF GROWTH AND REVELANCE TO HEI REQUIREMENTS
- ENSURE AUGMENTATION MEETS LUNAR BASE PMAD RQMTS
- DEVELOP CRITICAL COMPONENTS (AC & DC), SENSORS AND NON-DESTRUCTIVE DIAGNOSTICS
- DEMONSTRATE TECHNOLOGY & RESOLVE SYSTEMS ISSUES ON TEST BED(S)

DELIVERABLES -

- STUDY RESULTS AND RECOMMENDATIONS
- HOOKS & SCARS ON SSF (e.g., ROLL RING REQ.)
- FLIGHT PROTOTYPE COMPONENTS
- TEST BED DEMONSTRATION

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POWER SYSTEM *POWER DISTRIBUTION*

POWER MANAGEMENT TECHNOLOGY

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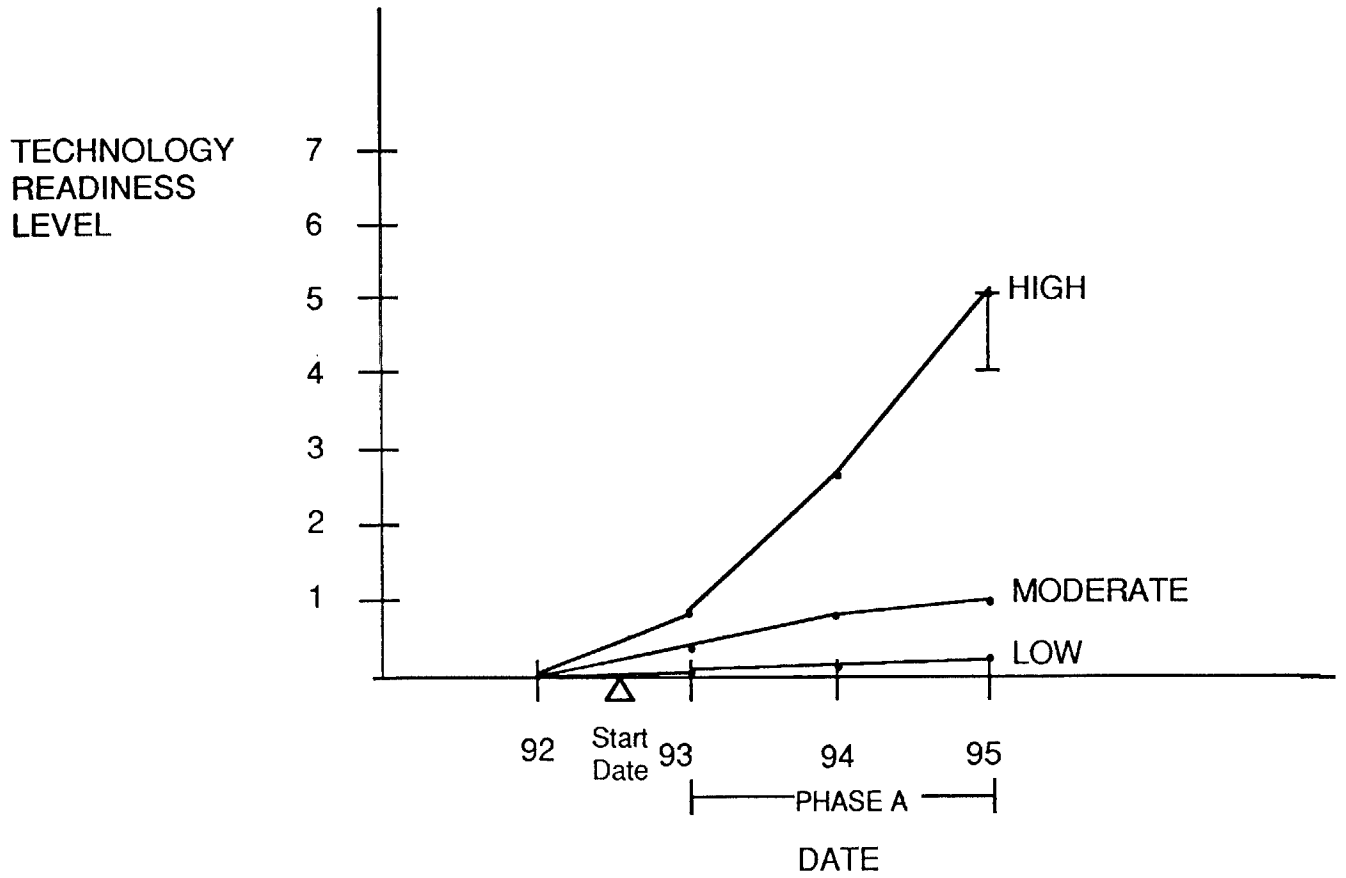

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POWER SYSTEM *POWER DISTRIBUTION*

ELECTRICAL POWER SYSTEM AUTOMATION

BACKGROUND

SCOPE - DEVELOP TECHNOLOGY FOR REAL-TIME PMAD AUTOMATION

OBJECTIVES - DEVELOP AI FOR EVENTUAL ONBOARD POWER OPS/MAINTENANCE INCLUDING FAULT IDENTIFICATION, ISOLATION AND POWER ALLOCATION

REQUIREMENTS/ RATIONALE
- ENABLE SUFFICIENT CREW AVAILABILITY FOR TRANSPORT NODE OPERATIONS
- SIGNIFICANT INCREASE IN SAFETY & RELIABILITY
- IMPROVED RESOURCE UTILIZATION PROVIDING ADDITIONAL POWER FOR ONBOARD EXPERIMENTS
- PROOF-OF-CONCEPT DEMONSTRATION TEST BED

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POWER SYSTEM *POWER DISTRIBUTION*

ELECTRICAL POWER SYSTEM AUTOMATION

PROGRAM PLAN

APPROACH -

- FORMAL REQUIREMENTS DEFINITION
- DEVELOP COOPERATING EXPERT SYSTEMS TECHNOLOGY
- MIGRATE INTELLIGENCE TO LOWER LEVELS
- DEVELOP NEEDED SMART SENSORS/SWITCHES
- CONFIRM PREDICTIVE FAULT MANAGEMENT
- LEVERAGE EXISTING SSF TEST BEDS
- DEVELOP V&V PROCEDURES FOR AI

DELIVERABLES -

- SOFTWARE (HEURISTICS, RULES, ETC.)
- SENSOR/SWITCH HARDWARE
- PROOF-OF-CONCEPT DEMONSTRATION TEST BED

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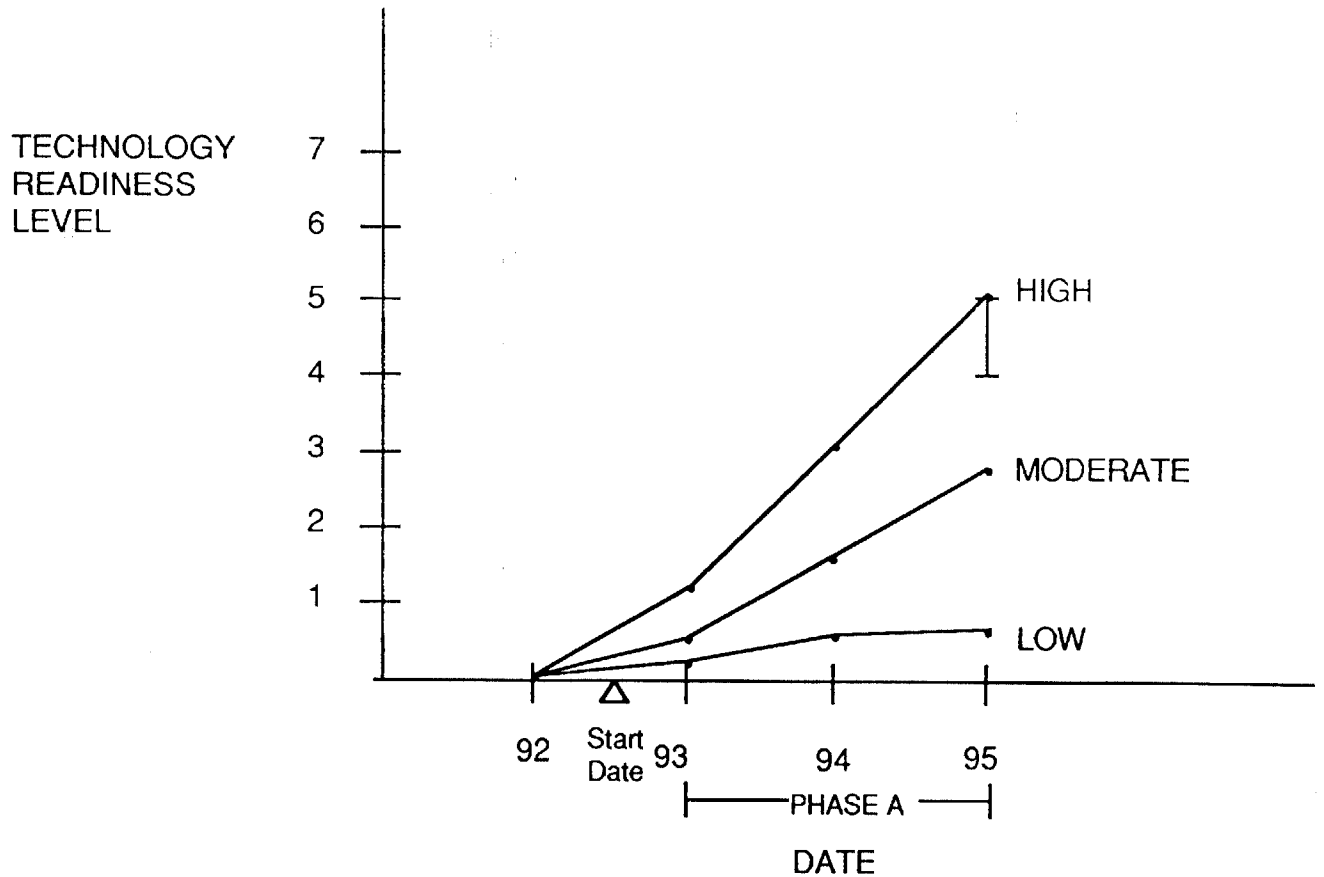

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RECOMMENDATIONS/ISSUES FOR POWER SYSTEM

- **EXTENSIVE SSF SYSTEM TRADE-STUDIES TO QUANTIFY BENEFITS/RISKS OF TECHNOLOGY OPTIONS**
  - FIRM REQUIREMENTS NEEDED
  - CLEAR CUT CRITERIA FOR DECISION MAKING LCC vs INITIAL COST vs PROGRAMMATIC FUNDING PROFILE
  - ASSESS DESIRABILITY OF MULTIPLE POWER SOURCES
  - ASSESS ALL IDENTIFIED OPTIONS PLUS OTHERS
  - INCLUDE AC vs DC DISTRIBUTION ASSESSMENT FOR GROWTH
- **NEED MORE UNIFORM APPROACH TO AUTOMATION AND V & V ACROSS SSF**

TECHNOLOGY FOR SPACE STATION EVOLUTION -A WORKSHOP

SSF SUPPORT OF HEI - ISSUES/AC-DC POWER DISTRIBUTION

RECOMMENDATIONS/ISSUES FOR POWER SYSTEM

RECOMMENDATION: USE AC TO DISTRIBUTE 100 kW HEI POWER AUGMENTATION

BENEFITS:

- **HIGHER EFFICIENCY**
- **LOWER WEIGHT**
- **SAFER**
  - RELIABLE FAULT INTERRUPTION (HARDWARE PROTECTION)
  - EASIER SOFT FAULT DETECTION (FIRE & THERMAL DAMAGE)
  - PRACTICAL GROUND FAULT DETECTION (CREW SAFETY)
  - NO PERSISTENT ARCS
  - GREATER SYSTEM STABILITY (NO COUPLING OF MULTIPLE DC-DC CONVERTERS)
- **EASIER GROUNDING ISOLATION (GROUND POINTS CANNOT BE ISOLATED IN DC SYS)**
- **GREATER FLEXIBILITY & GROWTH CAPABILITY**
  - CHANNELIZATION NOT REQUIRED
  - EASY COMBINATION OF MULTIPLE GENERATORS
  - EASY MULTIPLE FEEDS TO LARGE OR CRITICAL LOADS
- **GREATER IMPROVED STATUS TO OPERATORS & CONTROL SYSTEM - BETTER SENSORS**

HEI REQUIREMENTS DIFFERENT THAN R&D STATION:

- **LOADS DIFFERENT - LARGER, MOTORS, ATTACHED VEHICLES, ETC.**
- **MORE PEAK LOADS, VARIABLE POINT OF DEMAND**
- **AC GENERATION (?) - SD**
- **TEST BED FOR HEI POWER SYSTEMS**

ISSUES:

- **FREQUENCY - SD GENERATION (1200 Hz), HIGH FREQUENCY (20 kHz), OTHER (400 Hz)**
- **CUT OVER POWER POINT - PMC (37.5 kW), AC (75 kW)**
- **AUGMENTATION OF EXISTING MODULE POWER**
- **DC vs AC SECONDARY DISTRIBUTION FOR NEW MODULES**