N93-26979

POWER TECHNOLOGY DIVISION

AEROSPACE TECHNOLOGY DIRECTORATE

NASA Lewis Research Center

NUCLEAR PROPULSION

TECHNICAL INTERCHANGE MEETING

OCTOBER 20-23, 1992

RADIATOR TECHNOLOGY

ALBERT J. JUHASZ

OCTOBER 21, 1992

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HIGH CAPACITY POWER

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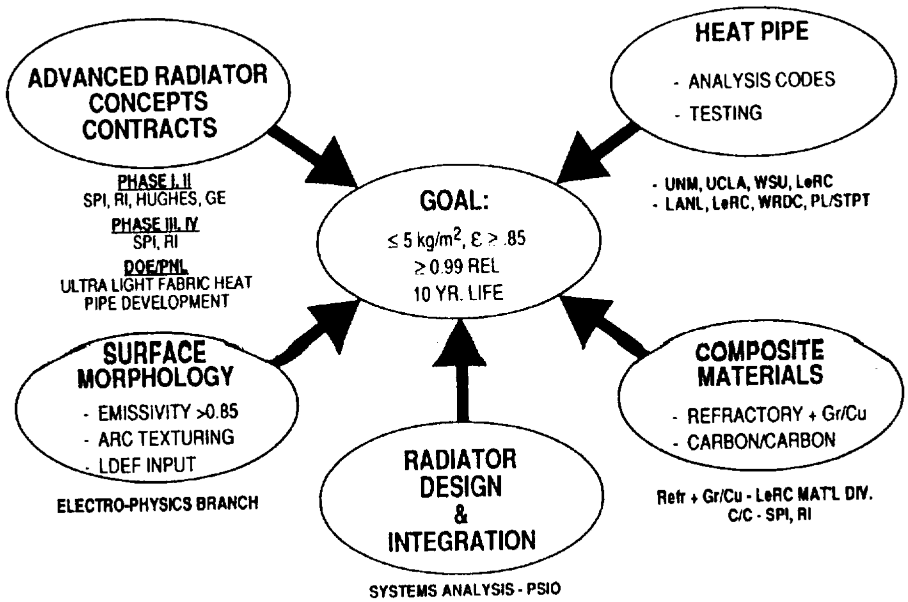
CSTI HIGH CAPACITY POWER - THERMAL MANAGEMENT
PROJECT ELEMENTS



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EXTERNAL PROGRAM SUPPORT FOR FY92

FUNDING SOURCE/AMOUNT	FOCUSED TASK
1. NASA PHASE I SBIR (50 K)	R&D ON HEAT PIPE WORKING FLUID ALTERNATIVES TO Hg (500K - 700K) CANDIDATES: SULFUR-IODINE; ORGANICS
2. AIR FORCE PL/STPT (50 K)	HEAT PIPE CODE DEVELOPMENT - WSU & VALIDATION
3. SDIO (30 K)	HEAT PIPE CODE DEVELOPMENT - UNM & VALIDATION
4. NEP PROGRAM (40 K)	HIGH CONDUCTIVITY FIN DEVELOPMENT VIA INTEGRAL WOVEN FIBER APPROACH
(36 K)	ALTERNATE HEAT PIPE WORKING FLUIDS RESEARCH FOR 500K - 700K RANGE

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SP-100
ADVANCED RADIATOR CONCEPTS PROJECT

ADVANCED RADIATOR CONCEPTS
PROJECT OBJECTIVES

- **IDENTIFY ADVANCED SPACE RADIATOR CONCEPTS TO MEET THE FOLLOWING REQUIREMENTS**
  - TECHNICAL GOALS
    - **SPECIFIC MASS OF 5 kg/m^2; EMISSIVITY ≥ 0.85**
    - **0.99 RELIABILITY**
    - **10 YEAR LIFE**
  - APPLICATIONS
    - **RADIATORS SIZED FOR POWER SYSTEMS WITH A 2.5 MWt HEAT SOURCE**
      - THERMOELECTRIC POWER SYSTEM AT 875 K (Area = 106 m^2, $Qr = 2.4\ MW_t$; P = 100 kWe)
      - STIRLING ENGINE POWER SYSTEM AT 600 K (Area = 335 m^2; $Qr = 1.7\ MW_t$; P = 800 kWe)
- **DEVELOP THE TECHNOLOGY NEEDED FOR THE IDENTIFIED CONCEPTS BY:**
  JANUARY 1992 (ORIGINAL PLAN)
  JUNE 1993 (NEW PLAN)

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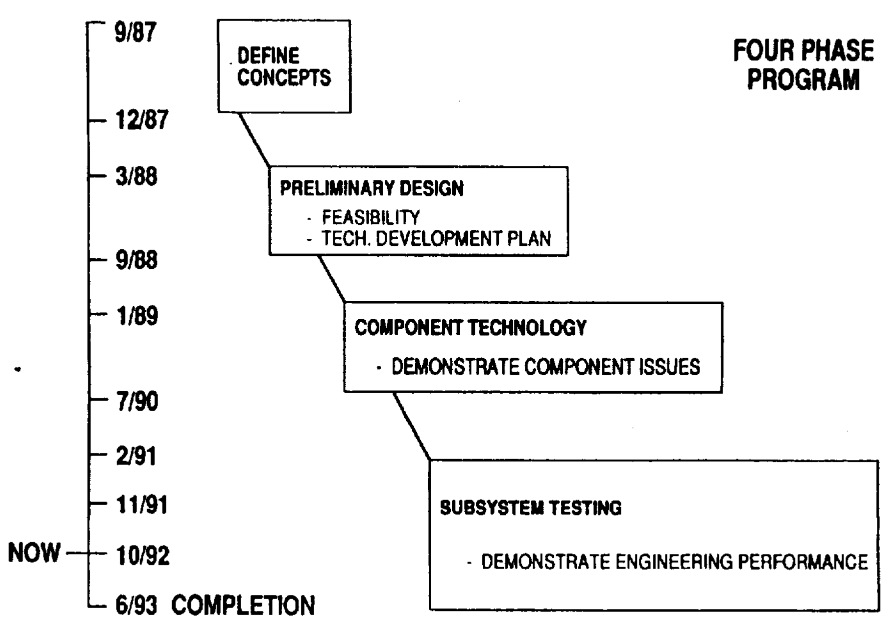
ADVANCED RADIATOR CONCEPTS
PROJECT FLOW CHART



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ADVANCED RADIATOR CONCEPTS
ROCKWELL APPROACH

- TWO-SIDED FLAT PLATE RADIATOR PANELS
- MONOLITHIC C-C PIPE CONSTRUCTION
- EFFORT EMPHASIZING MATERIALS; GEOMETRY SECONDARY
- TECHNOLOGY IMPACT
    - INTEGRAL C-C PIPE/FIN CONSTRUCTION
    - CVD METAL LINED C-C TUBES
- BRAZE DEVELOPMENT FOR METAL LINED C-C TUBES
    - C-C COMPOSITE HEAT PIPE FABRICATION & TESTING

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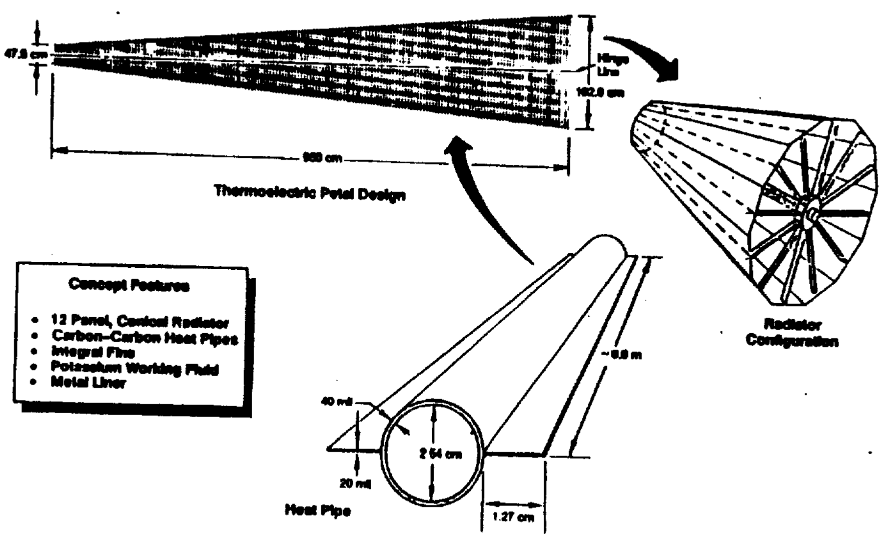
SP–100 Advanced Radiator Concept



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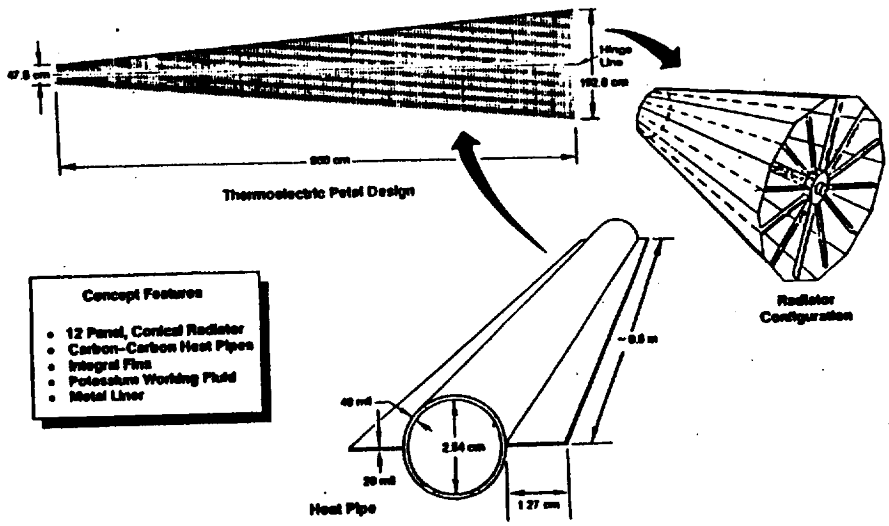
SP-100 Advanced Radiator Concept



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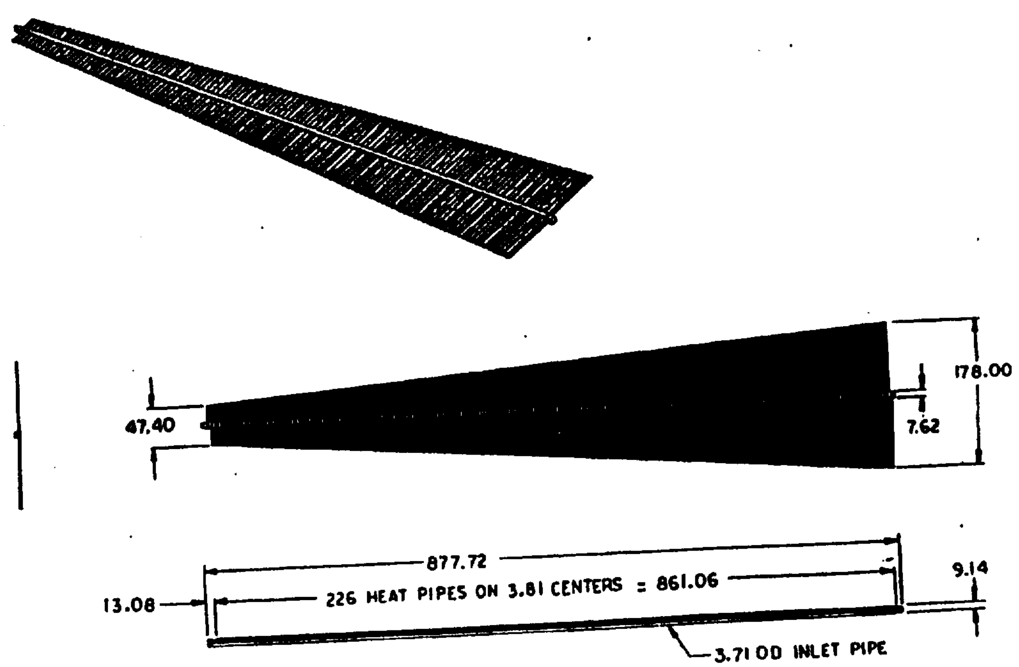
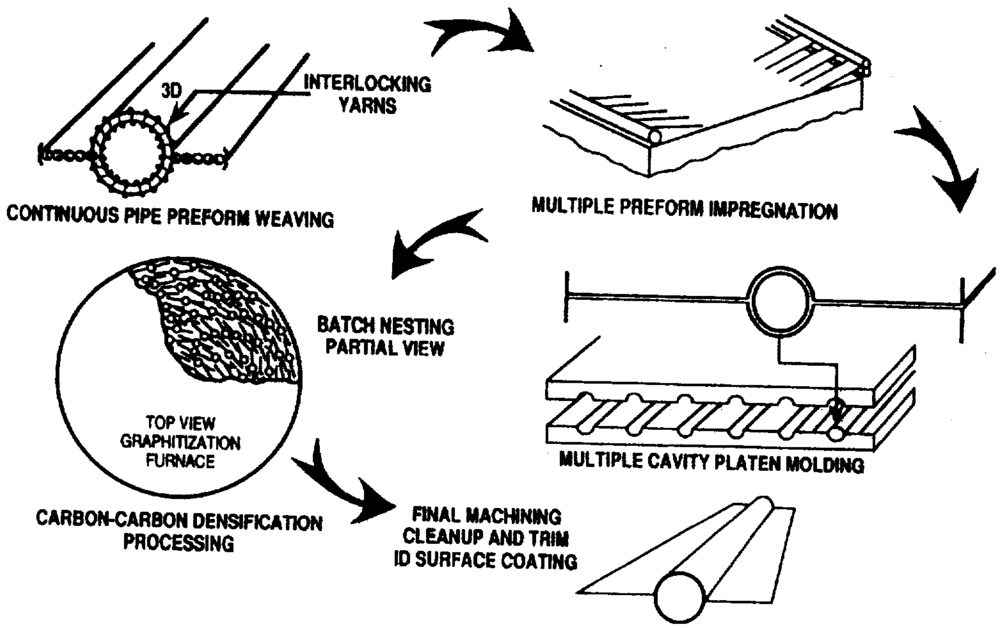


RADIATOR WITHOUT BUMPER ARMOR

ARC - ROCKWELL CONCEPT



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Criteria for Selection of Braze Alloys

- Brazing temperature (generally 22-28K above T_L) must be above maximum operating temperature (875K) of heat pipe to ensure in-service life
- Braze alloy compatibility with carbon-carbon substrate & thin-metallic liner
- Good wettability of carbon-carbon & metallic liner
- Longevity & stability

7 Commercial Braze Alloys Evaluated

Alloy	Composition (wt %)	Foil Thickness (in.)	$T_{liquids}$ (°K)	T_{braze} (°K)
Copper ABA	92.7 Cu/3 Si/2 Al/2.25 Ti	0.002	1297	1311
Silver ABA	Bal Ag/5 Cu/1.25 Ti/1Al	0.002	1185	1200
Palcusil 15	65 Ag/20 Cu/15 Pd	0.002	1173	1186
Gapasil 9	82 Ag/9 Pd/2 Ga	0.002	1153	1178
Ticusil 70	68.8 Ag/26.7 Cu/4.5 Ti	0.002	1123	1144
Cusil ABA	65 Ag/30 Cu/2 Ti	0.002	1078	1100
Cusil	70 Ag/28 Cu	0.002	1053	1075

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7 Commercial Braze Alloys Evaluated With CP-Ti

Alloy	Success	Failure	General Observations
Copper ABA		X	Braze alloy dissolved CP-Ti sheet
Palcusil 15		X	Limited wettability of C-C
Silver ABA	X		Good wetting of both C-C & CP-Ti
Gapasil 9		X	Limited bonding to C-C
Cusil ABA	X		Good adhesion to both C-C & CP-Ti
Cusil	X		Good intimate contact between surfaces
Ticusil 70		X	Good bonding but Ti interface eroded

Braze Alloy Used With Nb-1% Zr

(Nb-1% Zr sheet thickness = 0.001 in.)

Braze Alloy	Success	Failure	Observations
Silver ABA	X		Good wetting & adhesion
Cusil ABA	X		Good wetting & adhesion

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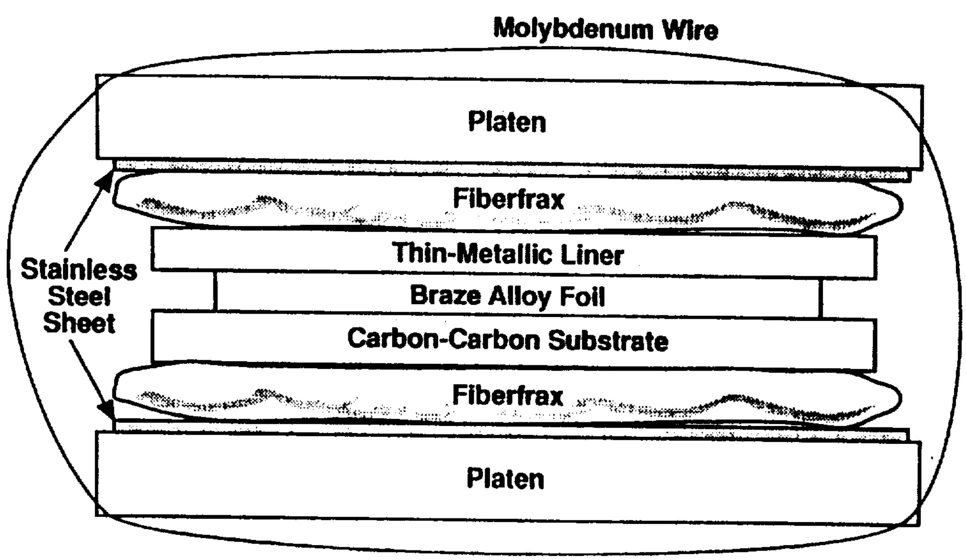
Illustration of Braze Test Fixture



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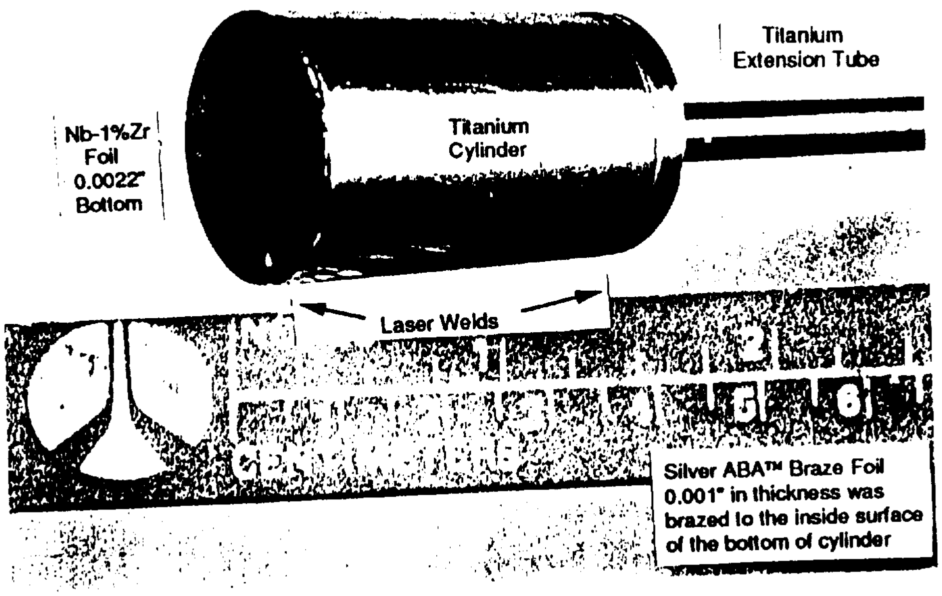
LIQUID POTASSIUM MATERIAL COMPATIBILITY TEST SPECIMEN



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ROCKWELL ADVANCED RADIATOR CONCEPTS
FY 1992 ACCOMPLISHMENTS

SUCCESSFULLY DEMONSTRATED THE ABILITY TO FABRICATE A METAL LINED C-C HEAT PIPE WITH INTEGRAL FINS

- CARBON-CARBON TUBE FABRICATION
  - COMPLETED FABRICATION OF EIGHT FEET OF T-300 C-C TUBE WITH INTEGRAL WOVEN FINS
  - INITIATED WEAVING OF C-C PREFORM USING ONLY HIGH THERMAL CONDUCTIVITY P95-WG FIBERS AND ALL PITCH DENSIFICATION

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ROCKWELL ADVANCED RADIATOR CONCEPTS
FY 1992 ACCOMPLISHMENTS

- **LINER FABRICATION**
  - COMPLETED FABRICATION OF Nb-1%Zr LINER TUBES WITH INTEGRAL EVAPORATOR SECTION VIA UNISKAN (PNL) METHOD
  - COMPLETED FABRICATION OF ALTERNATE LINERS (Nb-1%Zr AND Ti) BY DEEP-DRAW/CHEMICAL ETCHING TECHNIQUE
- **HEAT PIPE FABRICATION**
  - SUCCESSFULLY WELDED Nb-1%Zr END CAPS WITH FILL TUBES TO EVAPORATOR (~20 mil) AND CONDENSER (~3 mil)
  - SUCCESSFULLY FABRICATED PERFORATED FOIL WICK MATERIAL AND ESTABLISHED WELD PARAMETERS
  - SUCCESSFULLY DEMONSTRATED BRAZING OF A THIN METAL LINER INTO A FINNED C-C TUBE

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ROCKWELL ADVANCED RADIATOR CONCEPTS
FY 1992 ACCOMPLISHMENTS

- **HEAT PIPE FABRICATION** (Continued)
  - SUCCESSFULLY DEMONSTRATED THE ABILITY TO UNIFORMLY CVD COAT THE INSIDE OF A 12 INCH TUBE
  - SUCCESSFULLY DEMONSTRATED THE ABILITY TO COT AND MACHINE THE TUBE CUSP AREA CREATING A SMOOTH TUBE INTERIOR
  - SUCCESSFULLY DEMONSTRATED THE BRAZING OF A THIN METAL LINER INTO A C-C TUBE
- **GENERAL**
  - COMPLETED COUPON AND TUBE THERMAL CONDUCTIVITY TESTS
  - COMPLETED 30, 60, AND 180 DAY THERMAL DIFFUSION TESTS - Nb-1%Zr SAMPLES SHOW NO CARBON OR BRAZE DIFFUSION, Ti SAMPLES SHOW BRAZE DIFFUSION INTO LINER
  - UPDATED SP-100 HEAT REJECTION DESIGN INCORPORATING C-C HEAT PIPE CONCEPT

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ROCKWELL FY 93 TASKS

- FABRICATE METAL LINED C-C HEAT PIPE WITH INTEGRAL FINS FOR SP-100 (820 K) RADIATOR
  - INSTALL ANNULAR FOIL WICK
  - PERFORM POTASSIUM FILL-PURGE OPERATION
- PERFORM HEAT PIPE TESTING AT SIMULATED SP-100 HEAT REJECTION CONDITIONS

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LeRC C-C AND COMPOSITE MATERIALS PROGRAM FOR SPACE RADIATORS

IN-HOUSE	- Gr/CU COMPOSITES FOR HEAT PIPE FINS (Gr/Al COMPOSITES BEING DEVELOPED UNDER WRDC CONTRACTS)
	- ARC TEXTURING FOR EMISSIVITY ENHANCEMENT
CONTRACTS	- ARC (ADVANCED RADIATOR CONCEPTS)
SPI-SAN JOSE, CA	- VGCF (VAPOR GROWN CARBON FIBER) MATERIAL FOR VERY HIGH SPECIFIC CONDUCTIVITY HEAT PIPE FINS
RI - CANOGA PARK, CA	- C-C TUBE WITH INTEGRAL WOVEN FINS AND INTERNAL METALLIC LINERS FOR POTASSIUM HEAT PIPES
PNL - (PACIFIC NORTHWEST LABS) - RICHLAND, WA	- LIGHTWEIGHT FLEXIBLE CERAMIC FIBER HEAT PIPES WITH METAL FOIL LINERS

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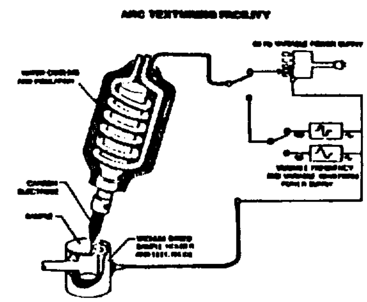
ADVANCED RADIATOR SURFACES

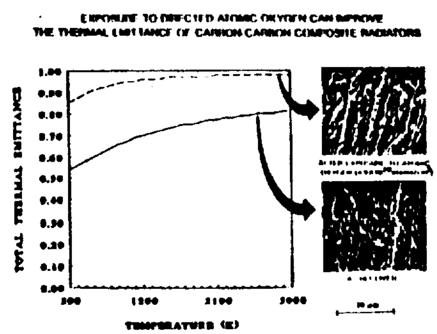


OBJECTIVE: DEVELOP DURABLE, HIGH TEMPERATURE, HIGH EMITTANCE RADIATOR SURFACES

ACCOMPLISHMENTS:

DEMO EMITTANCE >.85 @ 500K FOR TYPICAL RADIATOR MATERIALS
PRELIMINARY DATA ON ATOMIC OXYGEN

STATUS: ON GOING



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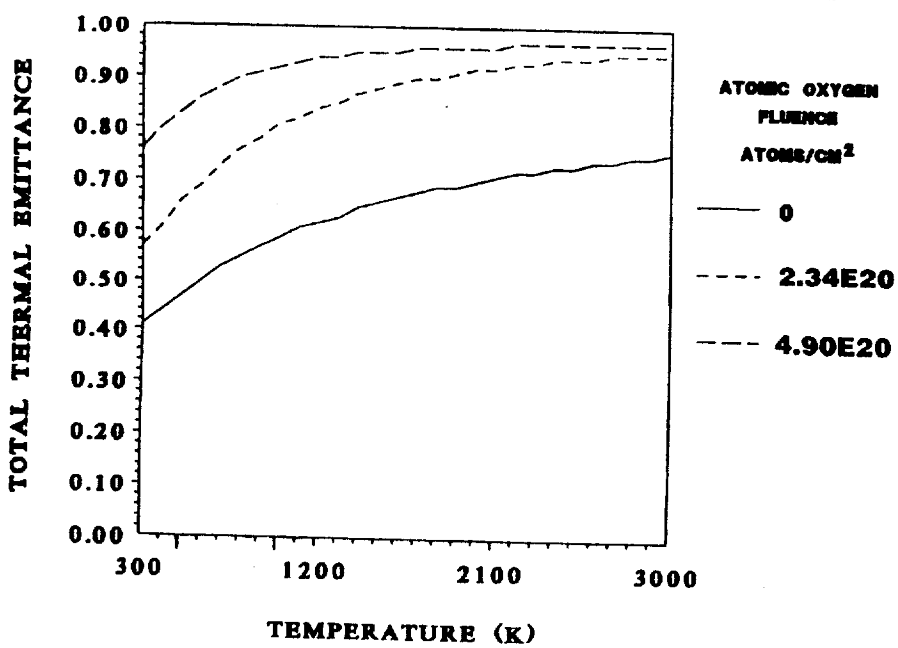
EMITTANCE VS TEMP. FOR ROCKETDYNE C741C C-C COMPOSITE WITH A/O FLUENCE



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- RADIATOR DESIGN & INTEGRATION

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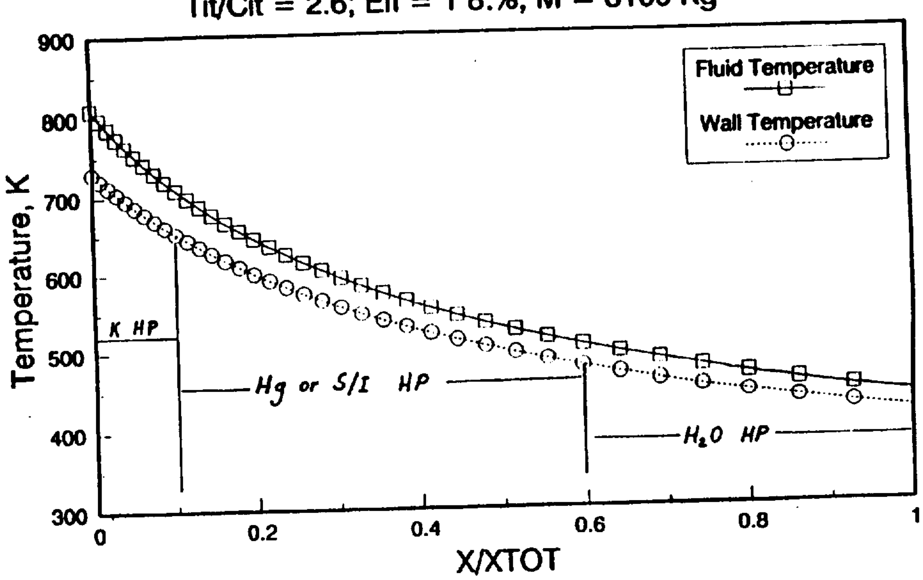
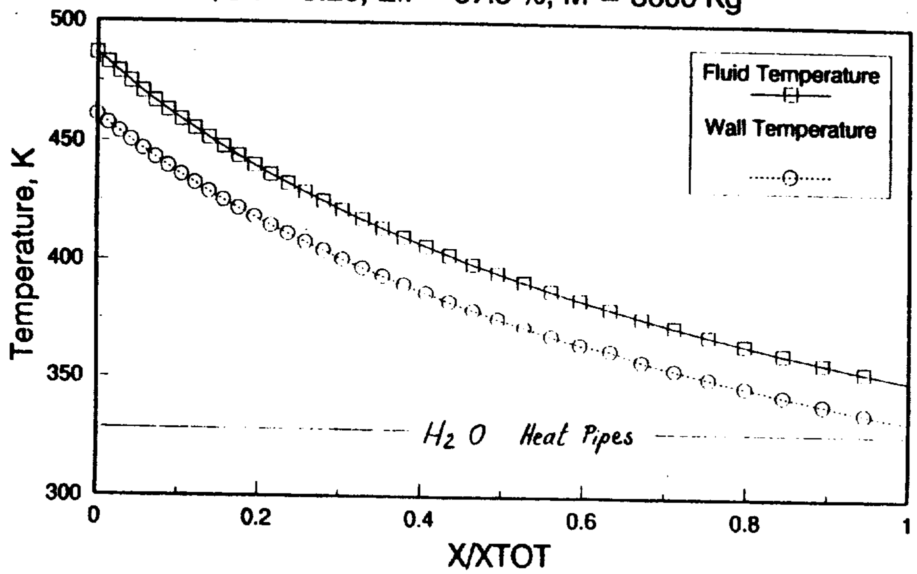
100 kWe CBC Radiator

Tit = 1140 K; Pr = 2.7; ERG = 0; A = 130 m^2

Tit/Cit = 2.6; Eff = 1 8.%; M = 3100 Kg



100 kWe CBC Radiator
Tit = 1140 K; Pr = 1.85; ERG = 95%; A = 184 m^2
Tit/Cit = 3.26; Eff = 37.5 %; M = 3600 Kg



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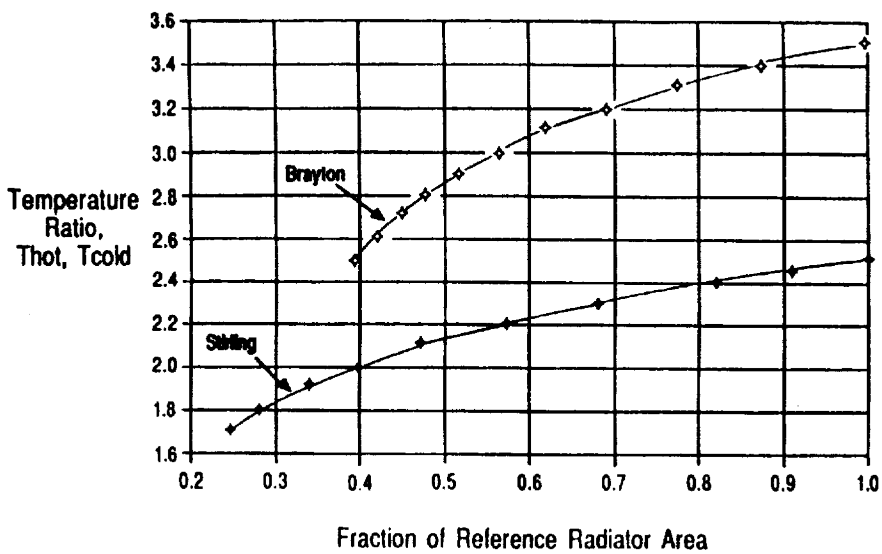
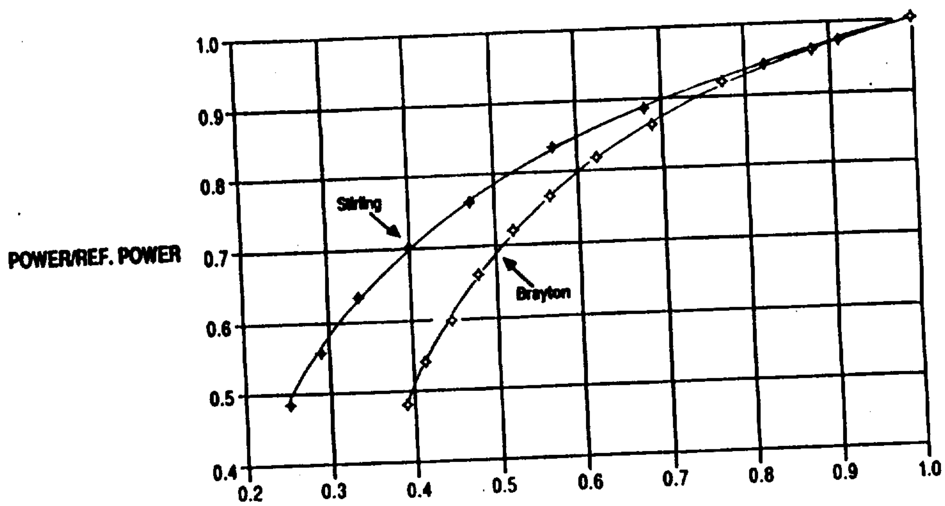
EFFECT OF REDUCTION IN RAD. AREA ON STIRLING & BRAYTON TEMP. RATIOS
(Constant Heat Rejection, Thot = 1050 K, Sink Temp. = 250 K)



EFFECT OF REDUCTION IN RAD. AREA ON STIRLING AND BRAYTON POWER

(Constant Heat Rejection, Thot = 1050 K, Sink Temp. = 250 K)



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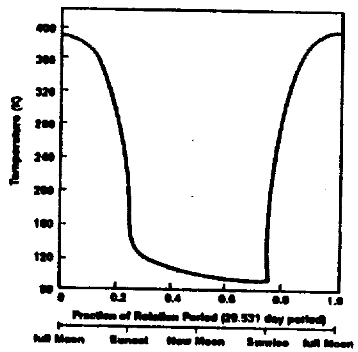
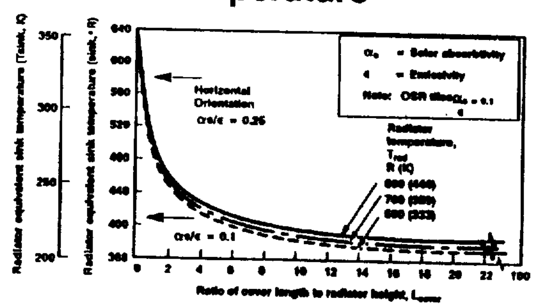
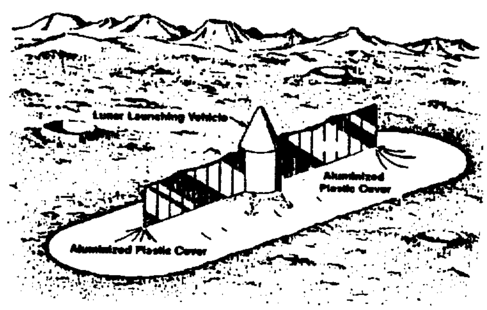
ARC TECHNOLOGY POTENTIAL APPLICATIONS

- NUCLEAR POWERED LUNAR BASE
  - SP-100 OR DERIVATIVE
  - MW TO MULTI MW POWER OUTPUT
- SOLAR DYNAMIC POWER SYSTEM FOR LUNAR BASE
  - IN-SITU (REGOLITH) THERMAL STORAGE
  - 25 TO 100 kWe POWER PLANT
- GEO BASED COMMUNICATIONS SATELLITE
  - SD PCS - 3 TO 5 kWe
- NUCLEAR ELECTRIC PROPULSION
  - 10 MWe CLASS PCS: TI, LMR, TE OR CBC

Lunar Surface Sink Temperature







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NEP POWER SYSTEM HEAT REJECTION

TEMPERATURE RANGES OF INTEREST

POWER SYSTEM CANDIDATES		PEAK CYCLE TEMP (K)	HEAT REJECTION TEMP (K)
IN CORE THERMIONIC	- TI	2200	1000
LM RANKINE	- LMR	1450	950
THERMOELECTRIC - SP100	- TE	1300	850
CLOSED CYCLE BRAYTON	- CBC	1500	320 - 800
STIRLING FPSE	- ST	1300	550 - 600
		1050	450
		900	400

NEP POWER SYSTEM RADIATOR TECHNOLOGIES

POWER SYSTEMS (10 MWe)		$q_R \cdot P (1-\eta/\eta)$ HEAT REJECTED MWt	RADIATOR PARAMETERS TEMP K	AREA m^2	TECHNOLOGY	kg/m^2	kg/kWt
THERMIONIC	$\eta_t = .15$	57.0	1000	1600	SS/Na HP	10	0.2
LIQUID METAL RANKINE	$\eta_t = .18$	45.5	950	1230	SS/Na HP	10	0.3
THERMOELECTRIC	$\eta_t = .05$	190.0	850	7600	Ti/K HP	5	0.2
CLOSED BRAYTON	$\eta_t = .30$	23.3	400 - 800	4800	Ti/K HP C-C/K HP C-C/H_2O HP	4	0.8
STIRLING - FPSE	$\eta_t = .30$ $= .33$	23.0 20.0	600 450	3500 11200	SS/Hg HP C-C H_2O HP Li/NaK LOOP	10 2 5	0.9

JEC90-007.4

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NEP POWER SYSTEM RADIATOR TECHNOLOGIES THRUSTS

POWER SYSTEMS (10 MWe)		HEAT REJECTED MWt	RADIATOR TECHNOLOGIES TEMP K	NEAR TERM	MID TERM	FAR TERM
THERMIONIC	$\eta_t = .15$ $\eta_t = .20$	57.0 40.0	1000 1050	SS/Na HP 10 kg/m^2	CC/Na HP * 5 kg/m^2	LSR, Fiber HP 2 kg/m^2
LIQUID METAL RANKINE	$\eta_t = .18$	45.5	950	10 kg/m^2 SS/Na HP	5.0 kg/m^2 C-C/Na HP	2 kg/m^2 LSR, Electrostatic 3 kg/m^2
THERMOELECTRIC	$\eta_t = .05$	190.0	850	9 kg/m^2 Nb Zr/K HP	5.0kg/m^2 Ti-SiC/K HP	C-C HP 3 kg/m^2
CLOSED BRAYTON	$\eta_t = .30$	23.3	800 - 400	10 - 15 kg/m^2 MP Loop Mixed HP	Mixed HP Ti, C-C 5 kg/m^2	Fiber Fabric/H_2O 1-2 kg/m^2
STIRLING - FPSE	$\eta_t = .33$	20.0	500 - 450	10 kg/m^2 MP Loop Hg HP	Li-NaK Loop 5 kg/m^2	Fiber Fabric/H_2O 1-2 kg/m^2

* ALL C-C HEAT PIPES HAVE INTERNAL COATING COMPATIBLE WITH WORKING FLUID

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THERMAL MANAGEMENT
BASELINE BUDGET

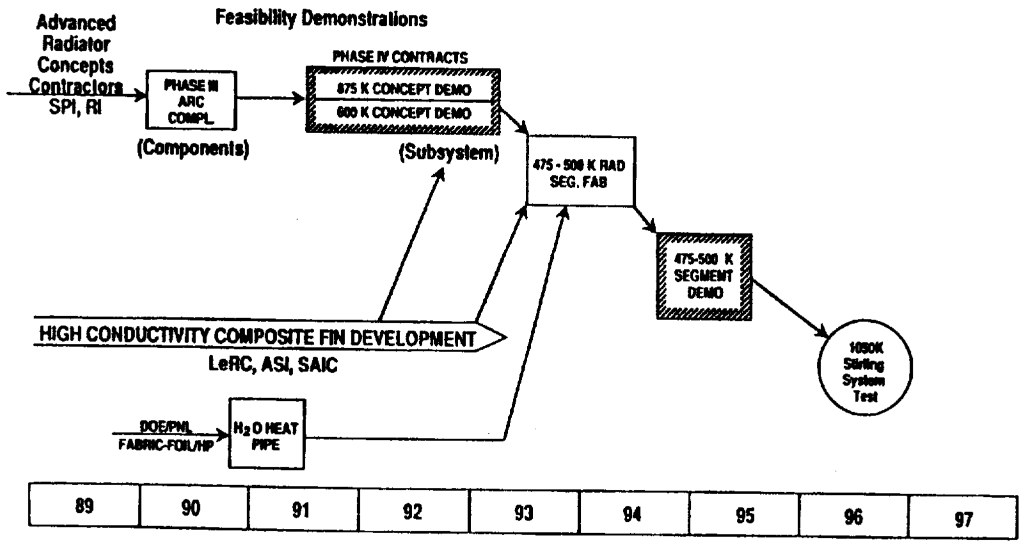

Figure 9

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CONCLUDING REMARKS

- PROGRAM ON TIME AND WITHIN BUDGET
- PROGRAM BROADLY COORDINATED WITH OTHER PROGRAMS THROUGHOUT THE THERMAL MANAGEMENT COMMUNITY
- CSTI/HCP TM PROGRAM $\equiv$ SP-100 TM PROGRAM
- TECHNOLOGY BEING DEVELOPED HAS BROAD APPLICATION
  - SP-100
  - SOLAR DYNAMIC
  - LUNAR/MARS INITIATIVE

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