MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Ciclo de Palestras Sobre Controle Térmico de Satélites

Radiadores Espaciais

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Divisão de Mecânica Espacial e Controle - DMC

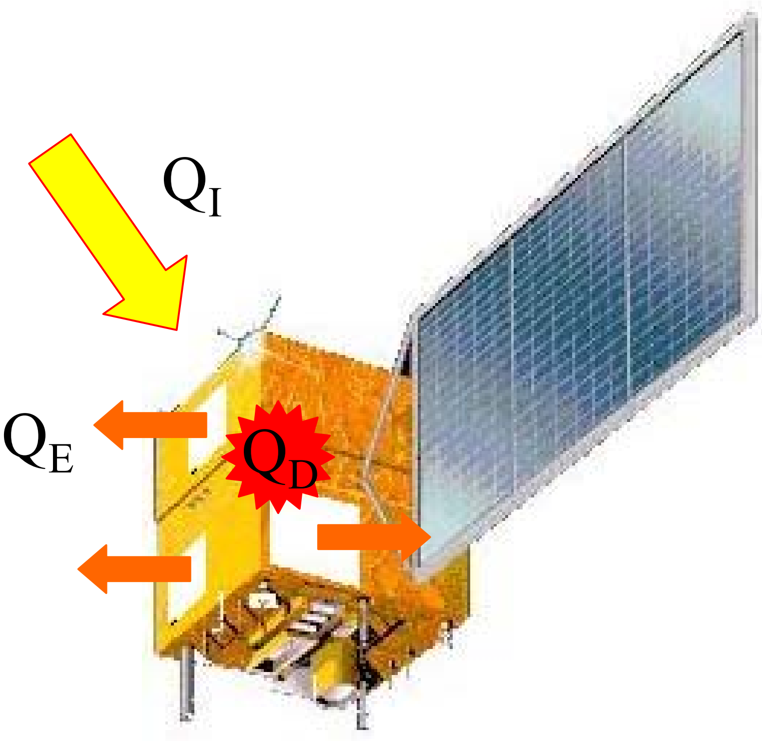
Balanço Térmico Global no Satélite

$$\varepsilon \, A_{eff} \, \sigma \, T_S^4 = \alpha \, A_{eff} \, Q_I + Q_D$$

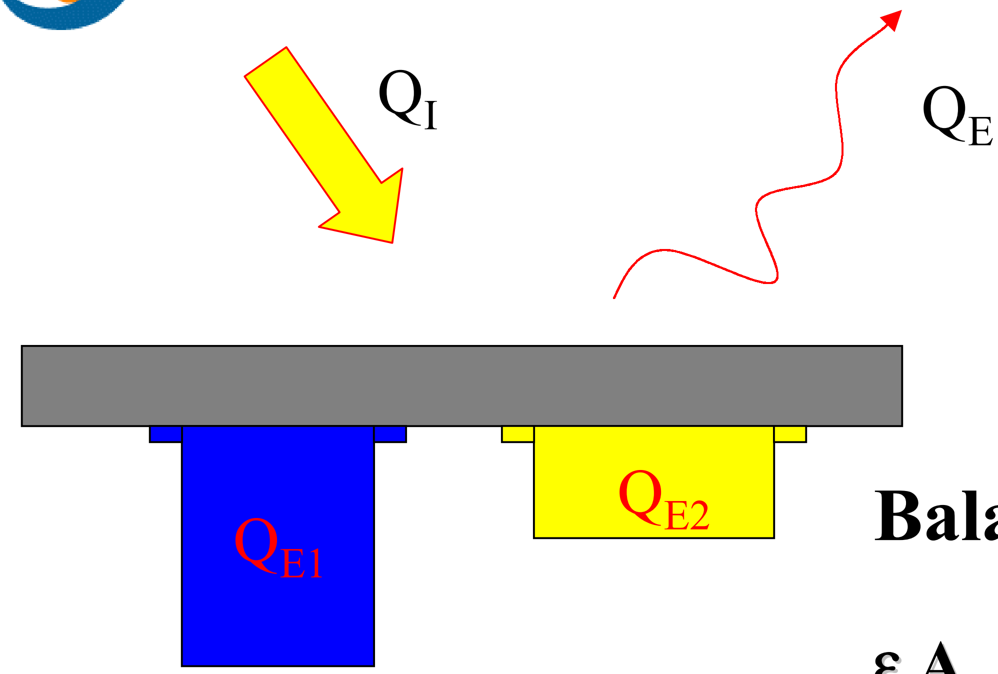
Calor emitido pelo satélite

Calor externo absorvido pelo satélite

Calor dissipado internamente ao satélite



⇨ O Calor excedente em um satélite é rejeitado para o espaço por meio de radiadores.

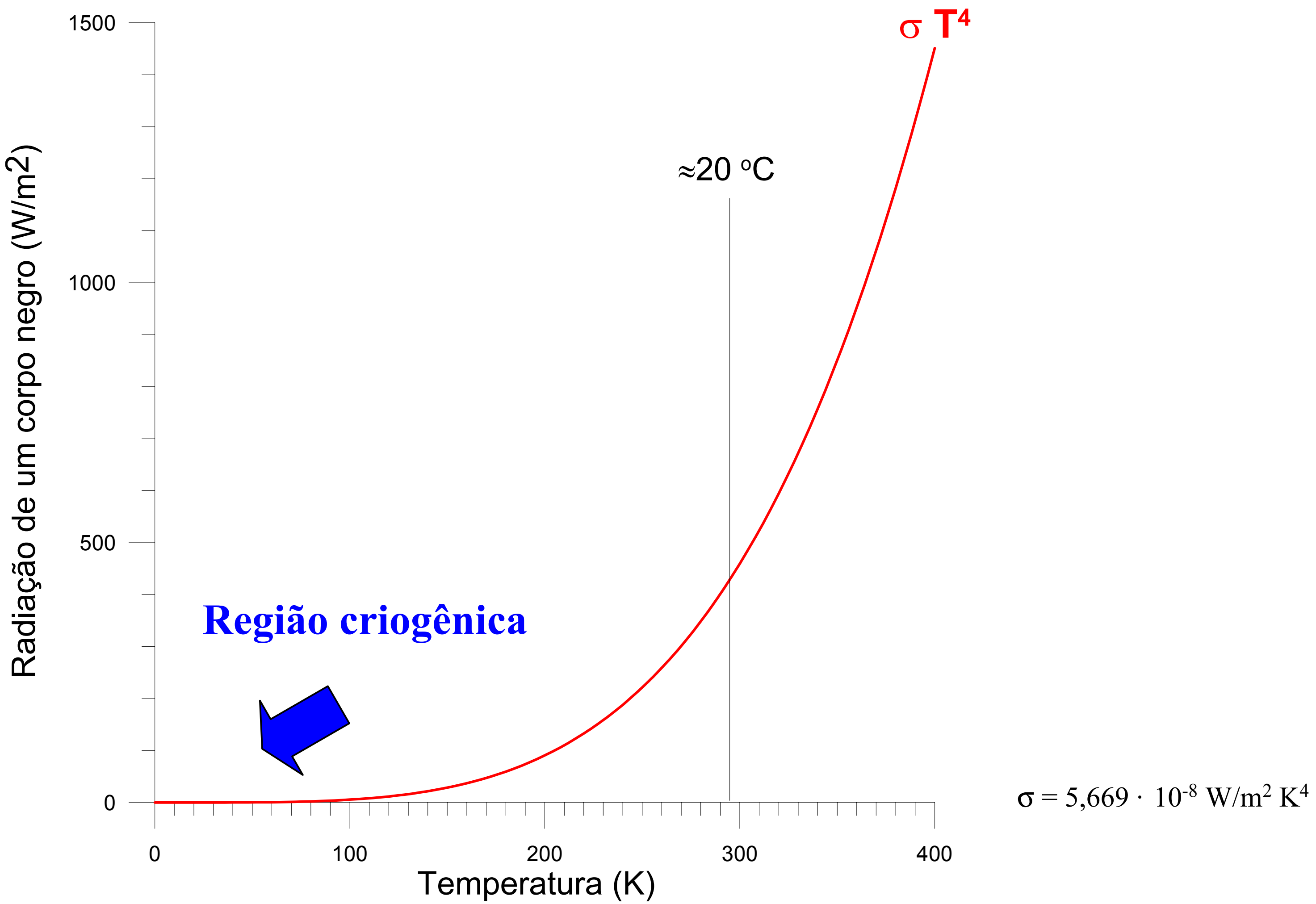


Balanço Térmico no Radiador

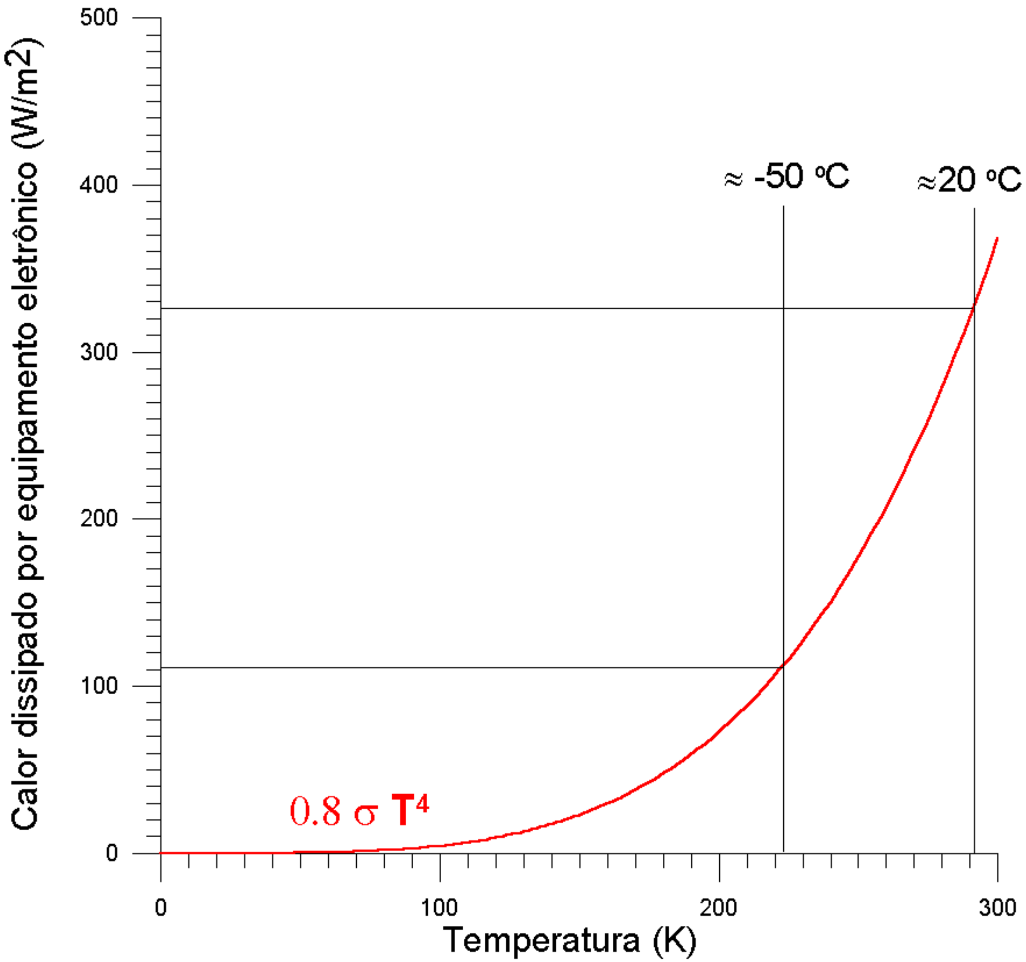
$$\varepsilon A_{rad} \sigma T_{rad}^4 = \alpha A_{rad} Q_I + Q_{E1+E2}$$

- Radiadores apresentam geralmente uma baixa relação α/ε.
- Em geral $\alpha < 0{,}2$ e $\varepsilon > 0{,}8$.

- A quantidade de calor emitida por um radiador é fortemente dependente da temperatura do mesmo: $\varepsilon A_{rad} \sigma T_{rad}^4$



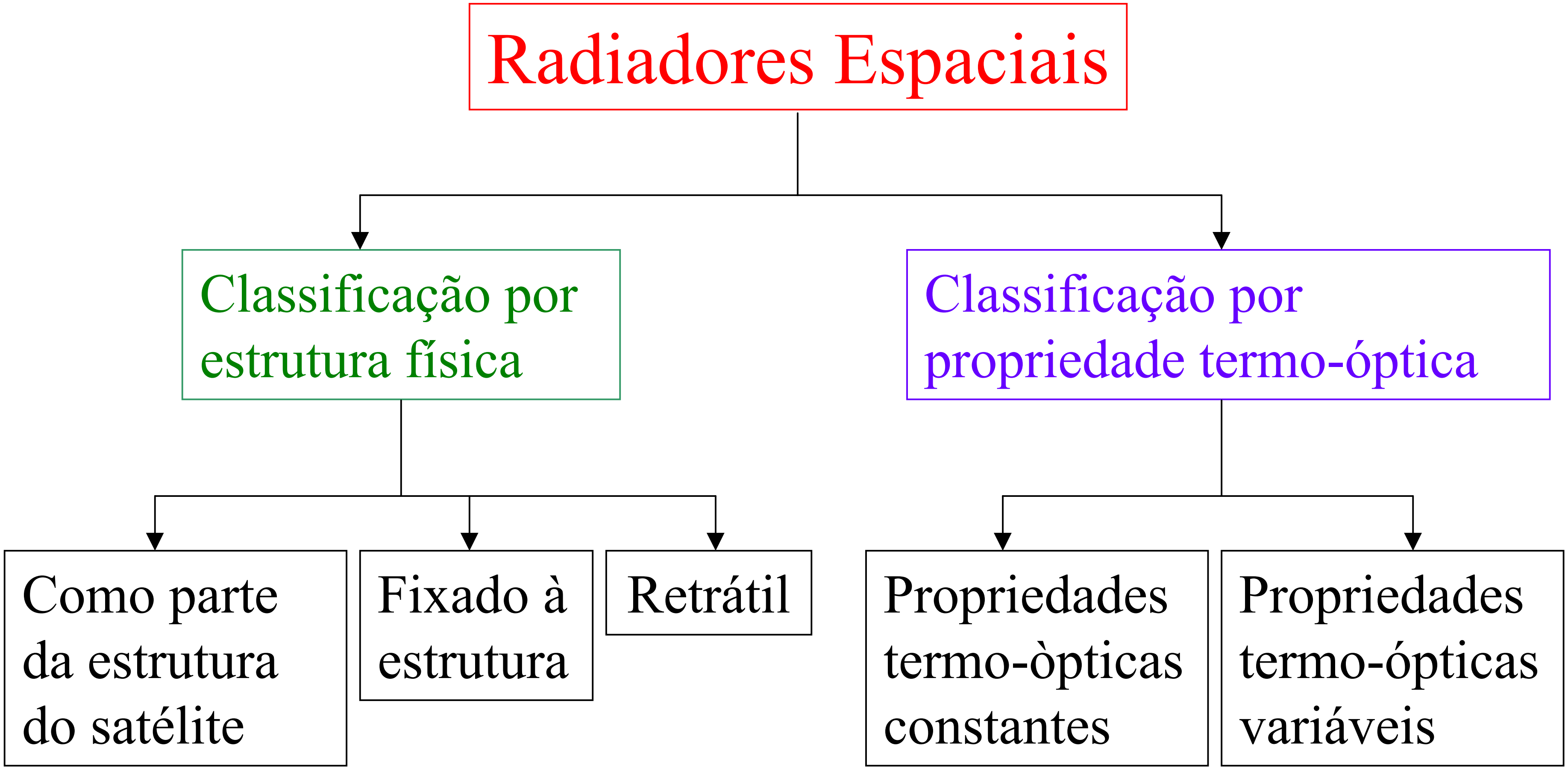
- Tipicamente os radiadores rejeitam de 110 a 325 W/m^2 de calor dissipado pelos equipamentos eletrônicos.



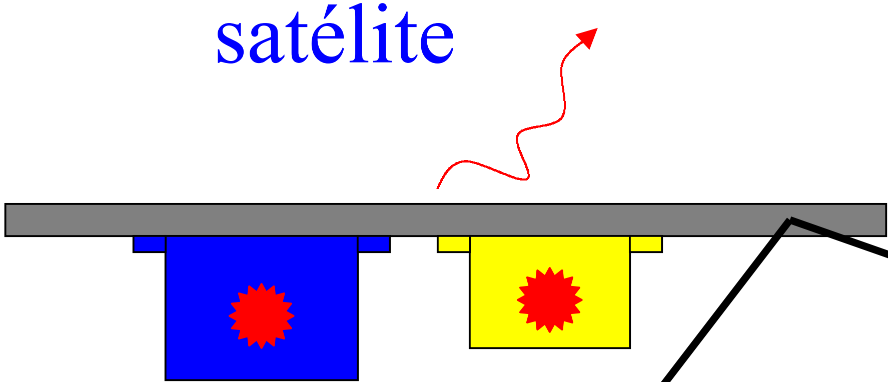
- A temperatura máxima e mínima de operação do radiador não pode comprometer os requisitos de temperatura dos equipamentos à ele acoplados.

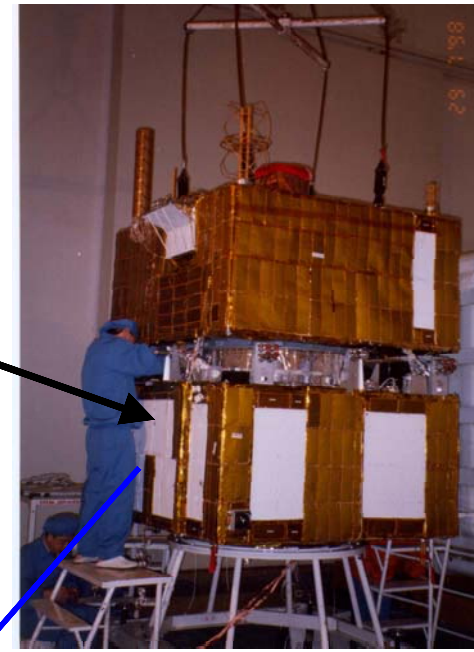
- Tipicamente opera-se no intervalo $5 \leq T_{rad} \leq 40$ ºC.

- Radiadores criogênicos operam a temperaturas bem abaixo do intervalo acima (ver apresentação do Valeri a seguir).


Radiadores Espaciais
Classificação por estrutura física
Classificação por propriedade termo-óptica
Como parte da estrutura do satélite
Fixado à estrutura
Retrátil
Propriedades termo-òpticas constantes
Propriedades termo-ópticas variáveis

→ Radiador é parte integrante da estrutura do satélite





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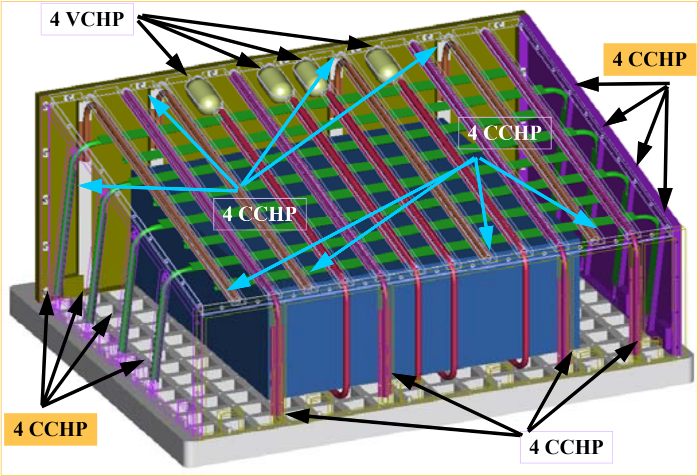
Painel das baterias

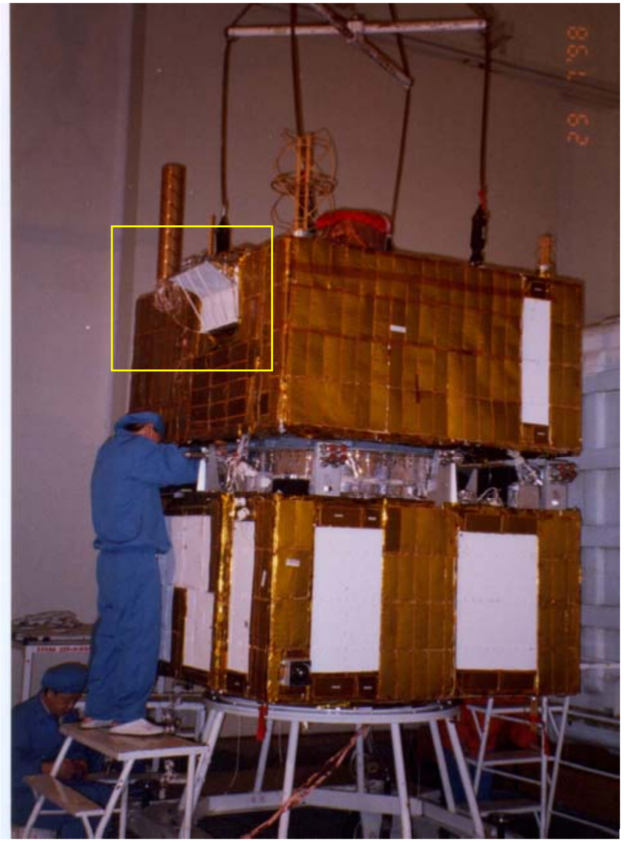
Painel BDR/Shunt com HPs imbutidos

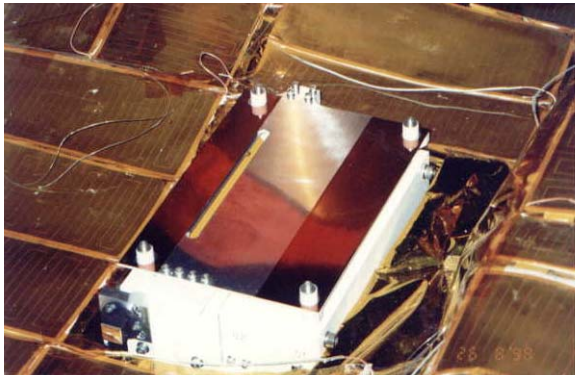
→ Fixado à estrutura



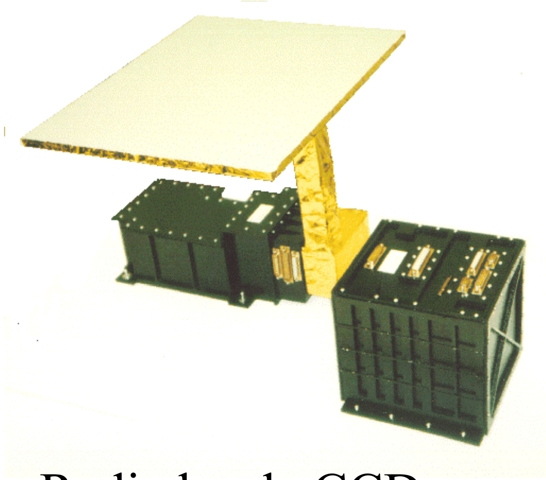
Radiador do ExPS

CBERS - FM1





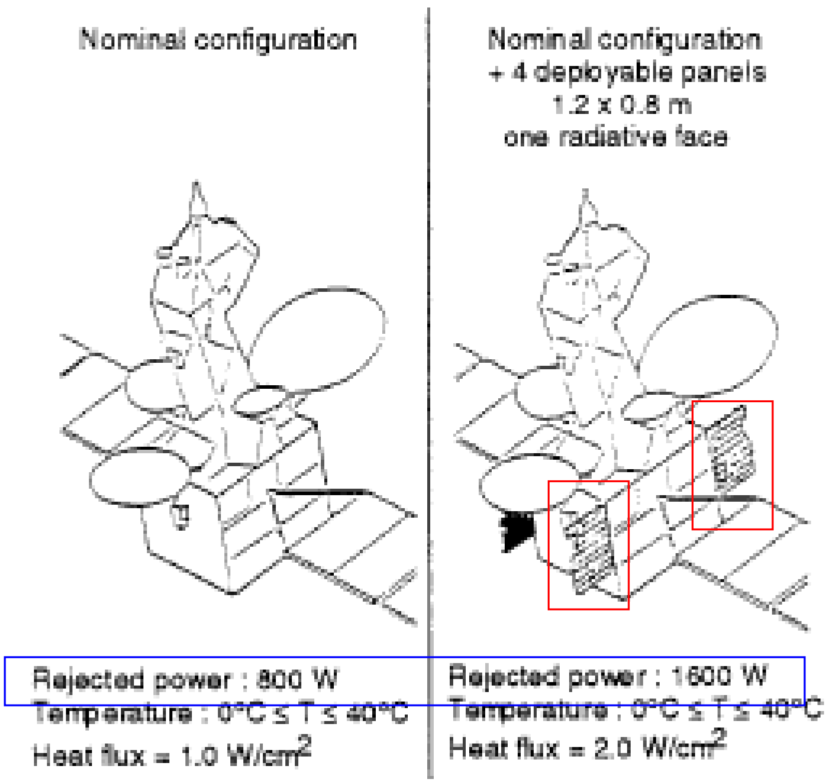
Radiador do WFI
CBERS - FM1

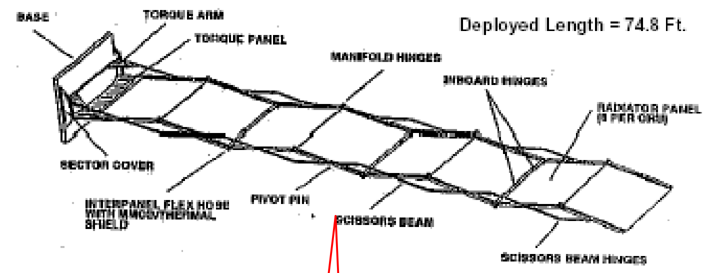


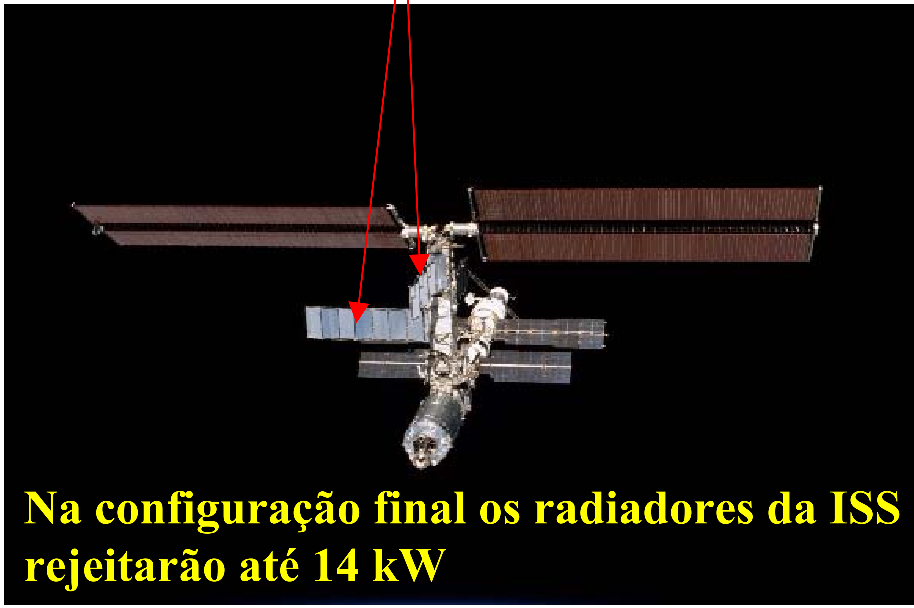
Radiador da CCD
do FUSE

→ Radiadores Retráteis

- Radiadores retráteis surgem da necessidade de um aumento significativo da área de rejeição de calor.

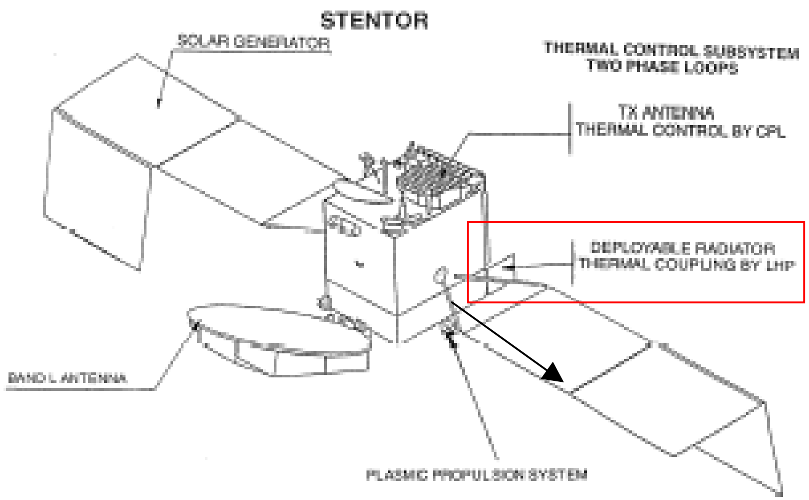






Radiadores Retráteis (cont.)

Satellite de Télécommunications pour Expérimenter les Nouvelles Technologies en Orbite



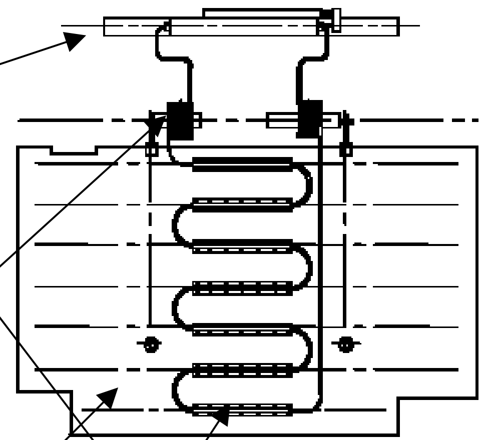
- one LHP (no redundancy)
- evaporator heat load ranging from 150 to 600 watts
- qualification temperature up to +85°C at the evaporator heat input interface
- static head of 2 m
- heat flux density up to 4 W/cm²
- « turnkey » start-ups with radiator panel temperatures as low as -50°C
- operational lifetime 15 years
- deployment capability from 90° to 180°
- mass 13 kg maximum

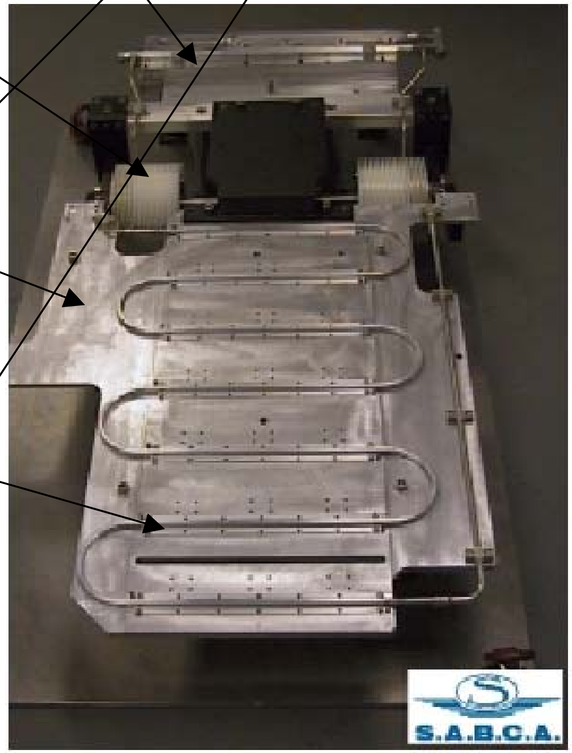
Evaporador do LHP

Linhas flexíveis helicoidais

Radiador com HPs imbutidos

Condensador do LHP





Radiadores Retráteis (cont.)

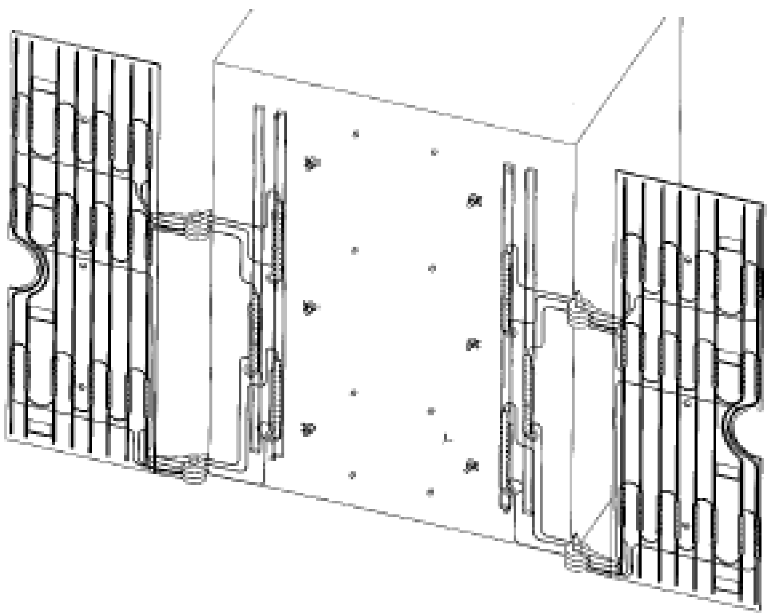


Figure 13 : 1300 W three-LHP DR derived from STENTOR baseline design

- Two LHPs (hot redundancy) tolerating single point failure
- Loop heat transfer capability up to 1200 watts
- Evaporator heat input interface qualification temperature up to +85°C
- Static head of 2 m
- Heat flux density up to 5 W/cm²
- Freeze-tolerant DR (condenser, isolator and radiator panel)
- Operational lifetime 15 years
- Deployment capability up to 180°

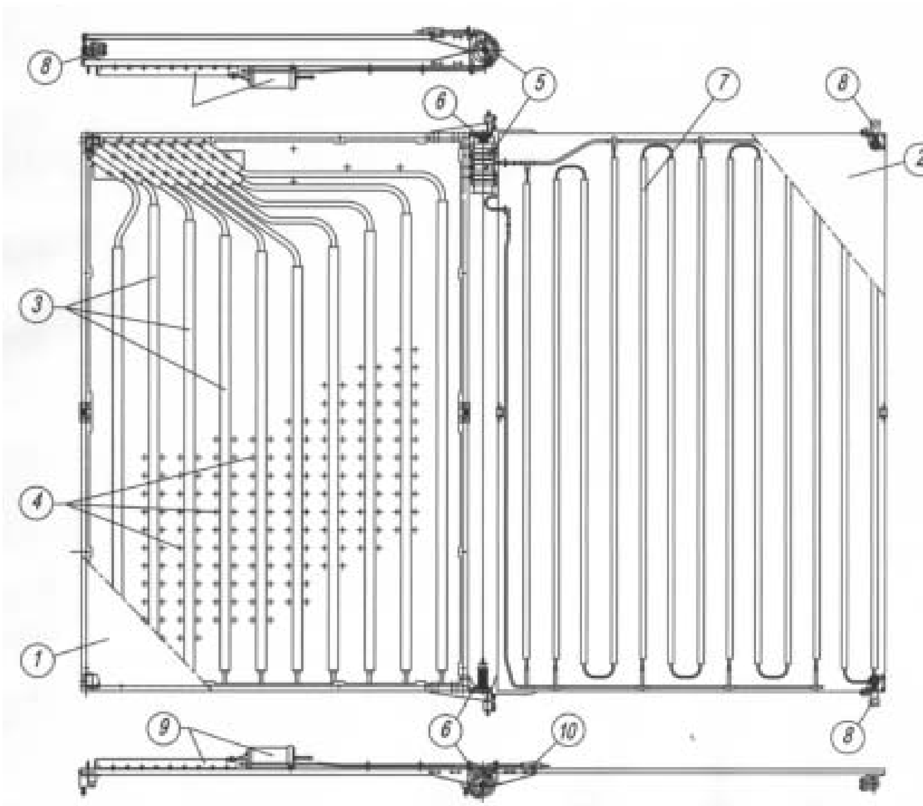
	STENTOR design	DELPHRAD design
Rejected heat (W)	380	400
DR Mass (kg)	13	9.5
Rejected heat / surface (W/m²)	340	355
DR mass / rejected heat (kg/kW)	34	24

Radiadores Retráteis (cont.)

1500 W Deployable Radiator with Loop Heat Pipe

K. Goncharov, A. Orlov and A. Tarabrin
Lavochkin Association

M. Gottero, V. Perotto, S. Tavera and G. P. Zoppo
Alenia Spazio S.p.A.



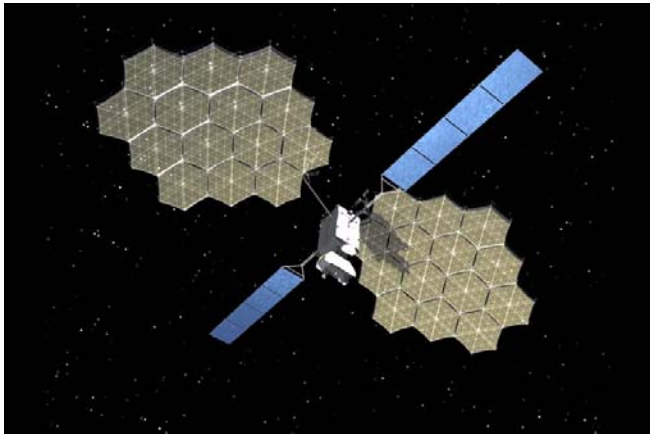
- transferred heat power is from 10 to 1500 W;
- The heat input to the internal (fixed) panel is applied to eighth zones; the total area of the heaters does not exceed 1/10 of the panel area. The internal panel average temperature is from –20 to +60 [°C] at heat load of 10W ÷ 1500W, correspondingly, and the heat sink temperature of 100 K;
- The thermal resistance of the LHP at maximum heat load (Q_{max} = 1500W) and maximum temperature of +60°C is less than 0.007 [K/W];
- The maximum thermal resistance of the whole Deployable Radiator under the same conditions is less than 0.013 (K/W) (temperature difference between contact surface of payload imitators and average temperature of radiating surface at heat power of 1500W is less than 20°C). Thermal resistance value includes AGHPS and LHP thermal resistance, thermal resistance of AGHP/LHP interface, thermal resistance of radiator sheet. In more details calculated and experimental values of thermal resistance are presented in paper [7].

Radiadores Retráteis (cont.)

Development of Loop Heat Pipe Deployable Radiator for Use on Engineering Test Satellite VIII (ETS-VIII)

Hiroaki Ishikawa, Akira Yao, Teturou Ogushi and Seiji Haga
Mitsubishi Electric Corporation (MELCO)

Akihiro Miyasaka and Hiroyuki Noda
National Space Development Agency of Japan (NASDA)



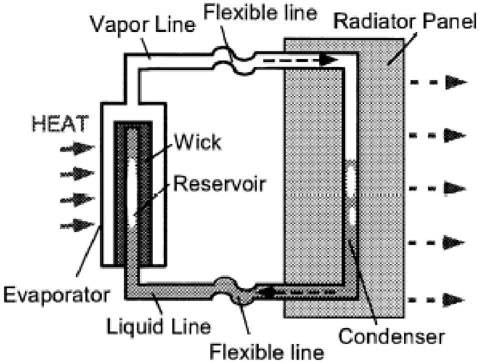


Figure 1 Schematic of Loop Heat Pipe(LHP)

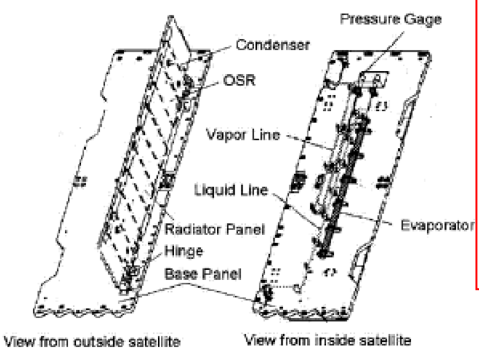
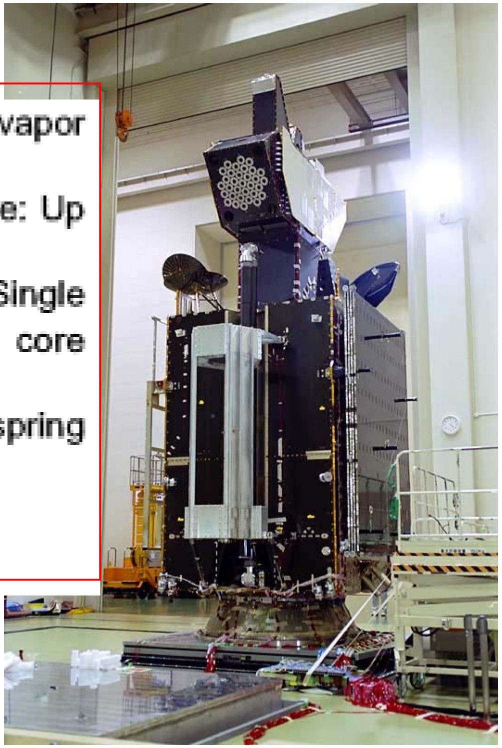
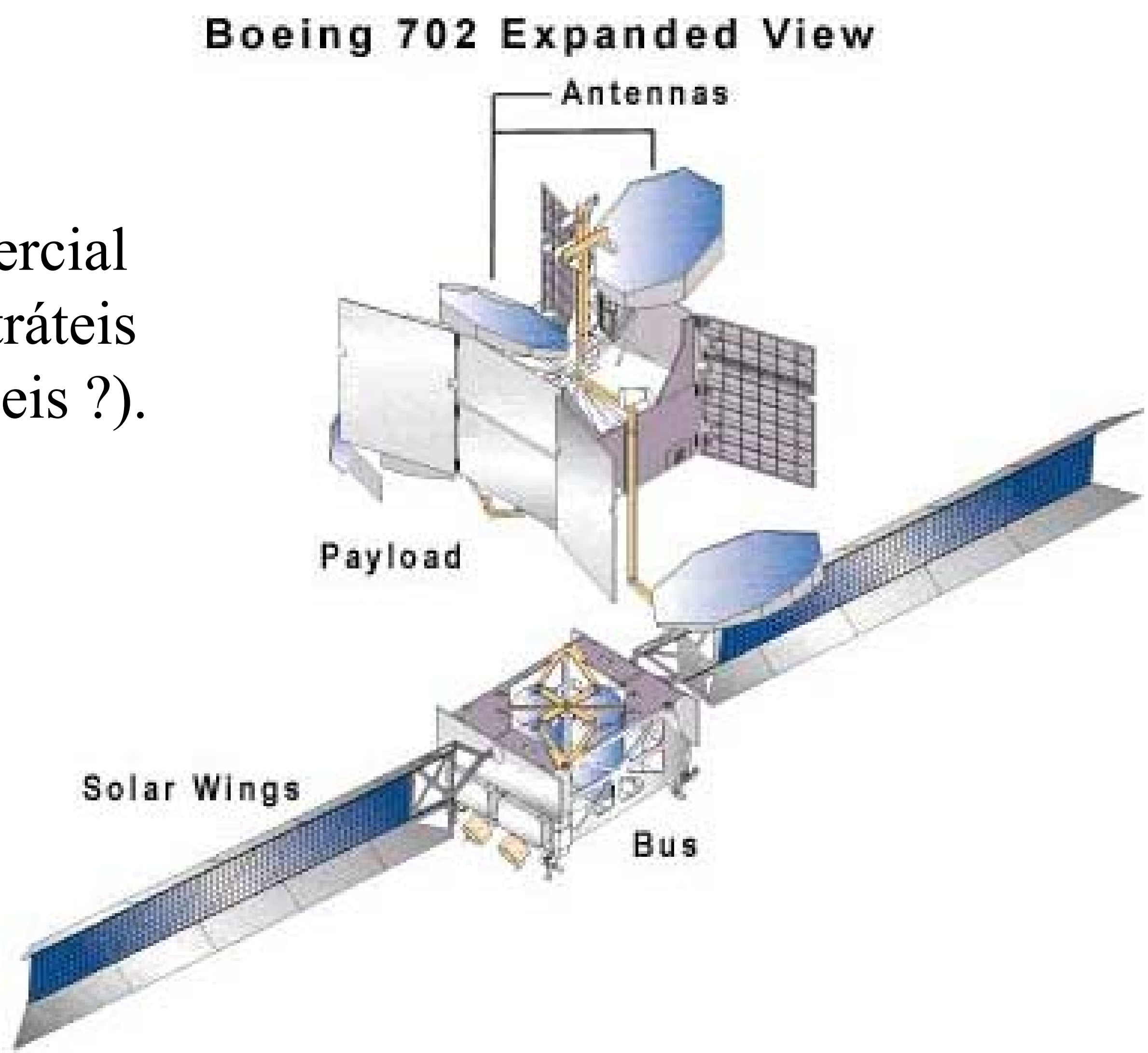


Figure 2 Schematic of Deployable Radiator for ETS-VIII

*Evaporator heat load: Up to 1000watts (at vapor temperature -5~+65°C.
*Evaporator Input interface qualification temperature: Up to +85°C
*Radiator Panel: 1800×490mm Single panel, Single sided OSR coating, CFRP face-skin, Honeycomb core radiator panel
*Heat rejection capability: Up to 400watts in spring equinox
*Deployment Angle: 90°
*Total Weight: 18.7kg

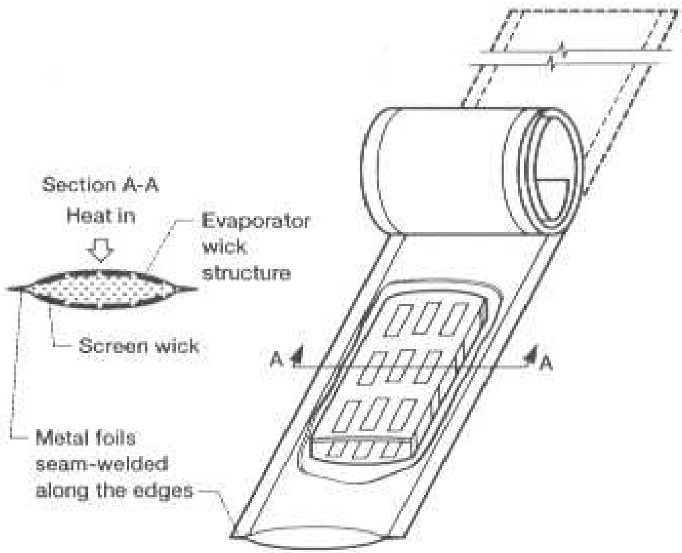


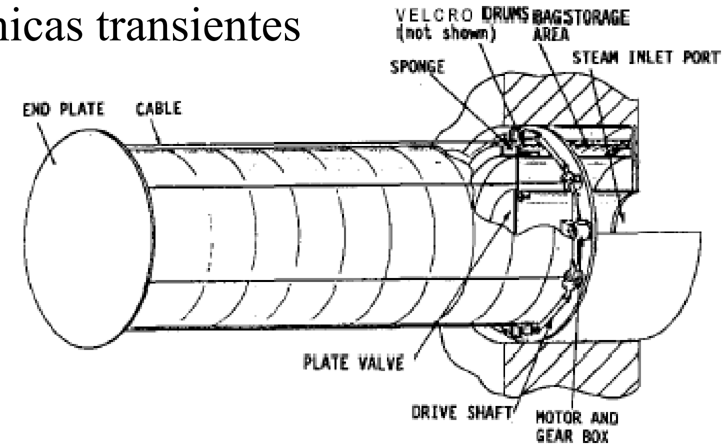
Primeiro satélite comercial que usa radiadores retráteis com LHP (HPs flexíveis ?).

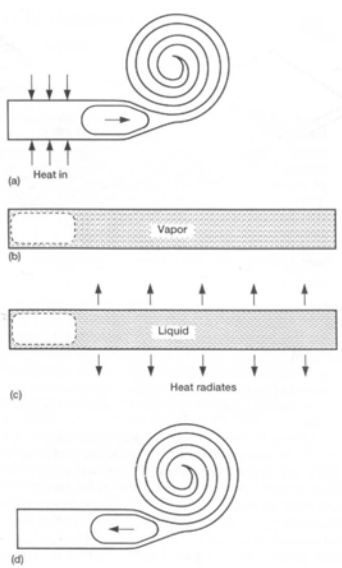


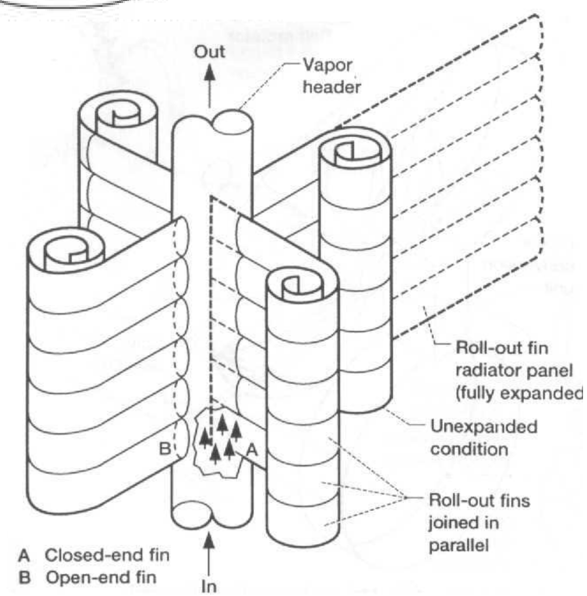
Radiadores Retráteis (cont.)

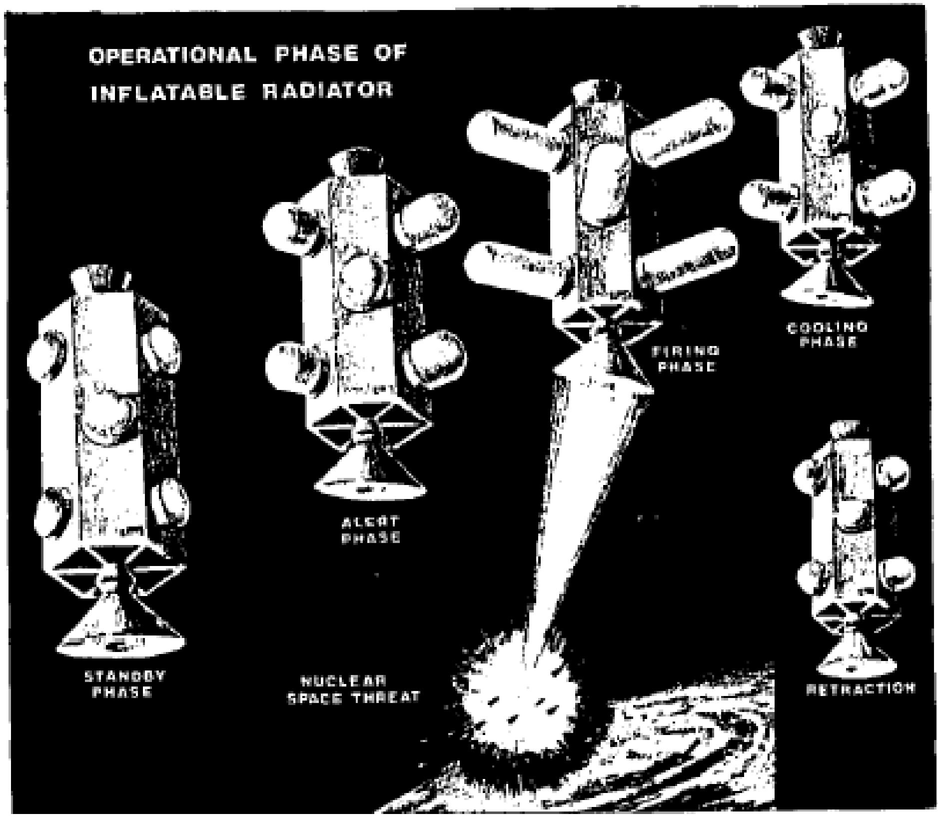
– **Radiadores Infláveis**: Dissipação de grandes cargas térmicas transientes









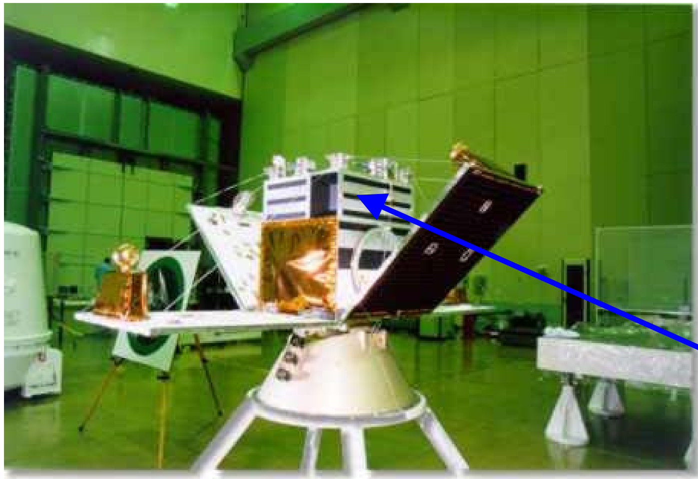


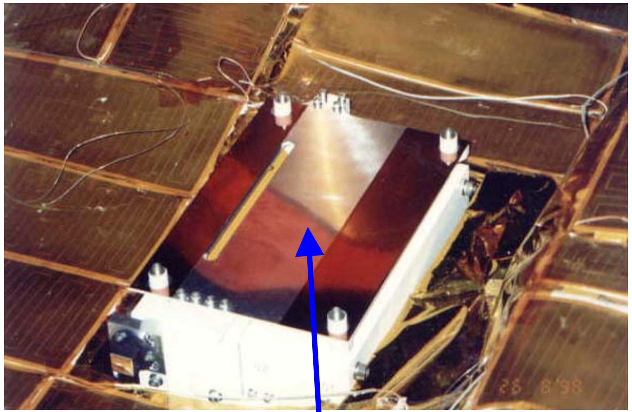
→ Radiadores Com Propriedades Termo-Ópticas Constantes

- Normalmente os radiadores são projetados com uma determinada relação α/ε que se manteria constante ao longo da vida útil do satélite (o valor desta relação só varia pela degradação das propriedades termo-ópticas).

- Diferentes coberturas podem ser usadas conjuntamente sobre a superfície de um radiador para obter-se uma determinada propriedade *efetiva*.

SACI-1





Radiador do WFI
CBERS - FM1

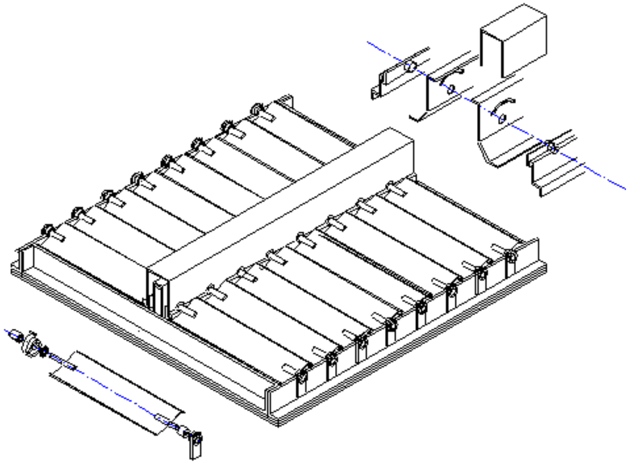
Radiadores com um "mosaico" de coberturas

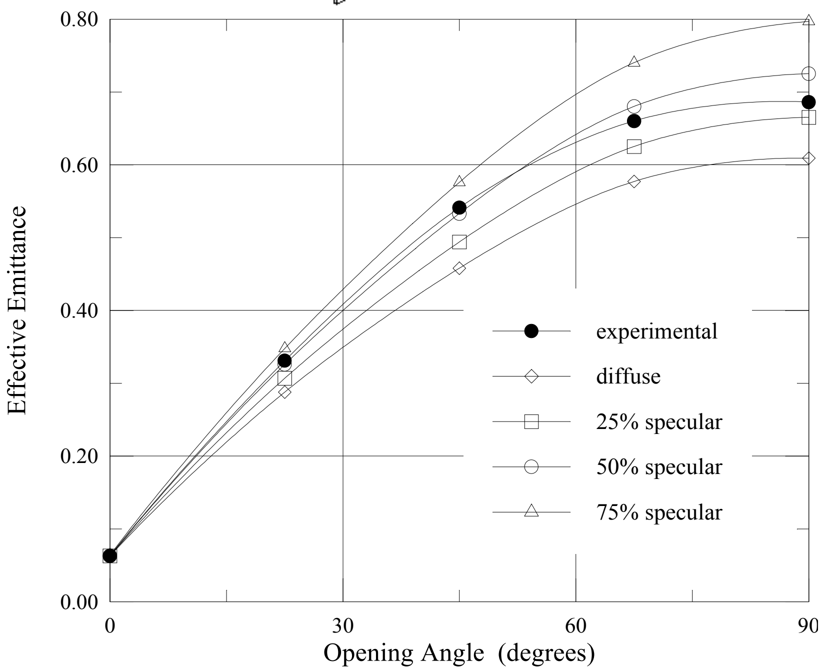
Radiadores com Propriedades termo-ópticas variáveis

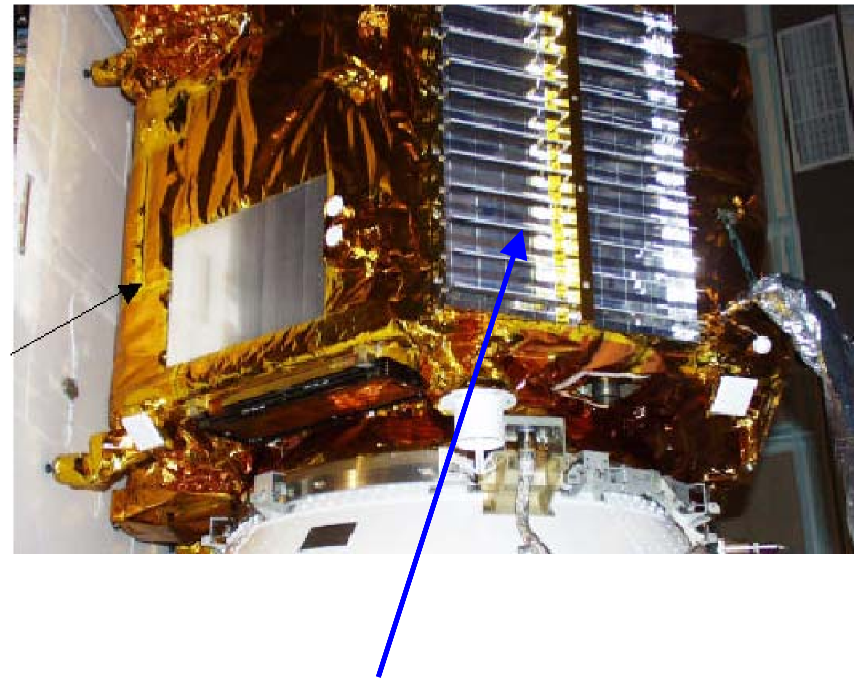
- Mudança da emissividade efetiva pela variação da visada da área de radiação para o espaço.
  - Venezianas mecânicas convencionais.
  - Venezianas com palhetas de matérial bi-metálico ou com memória de forma
- Mudança da emissividade do material que cobre o radiador.
  - Thermochromics.
  - Electrochromics.
- Outros.

Radiadores Com Propriedades Termo-Ópticas Variáveis (cont.)

- Venezianas mecânicas tradicionais.



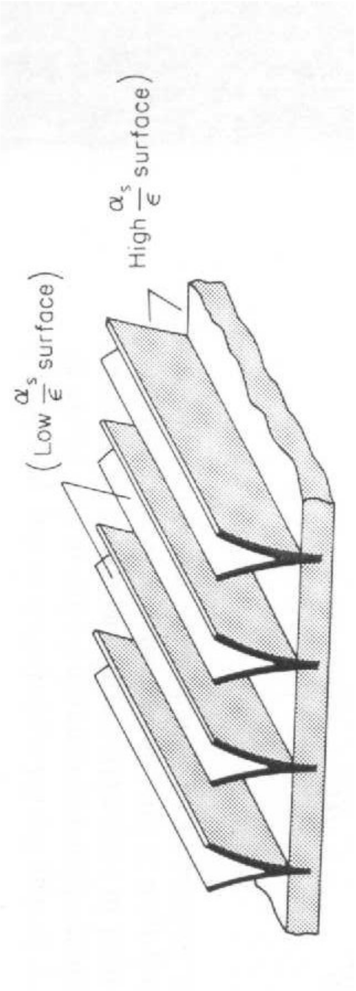


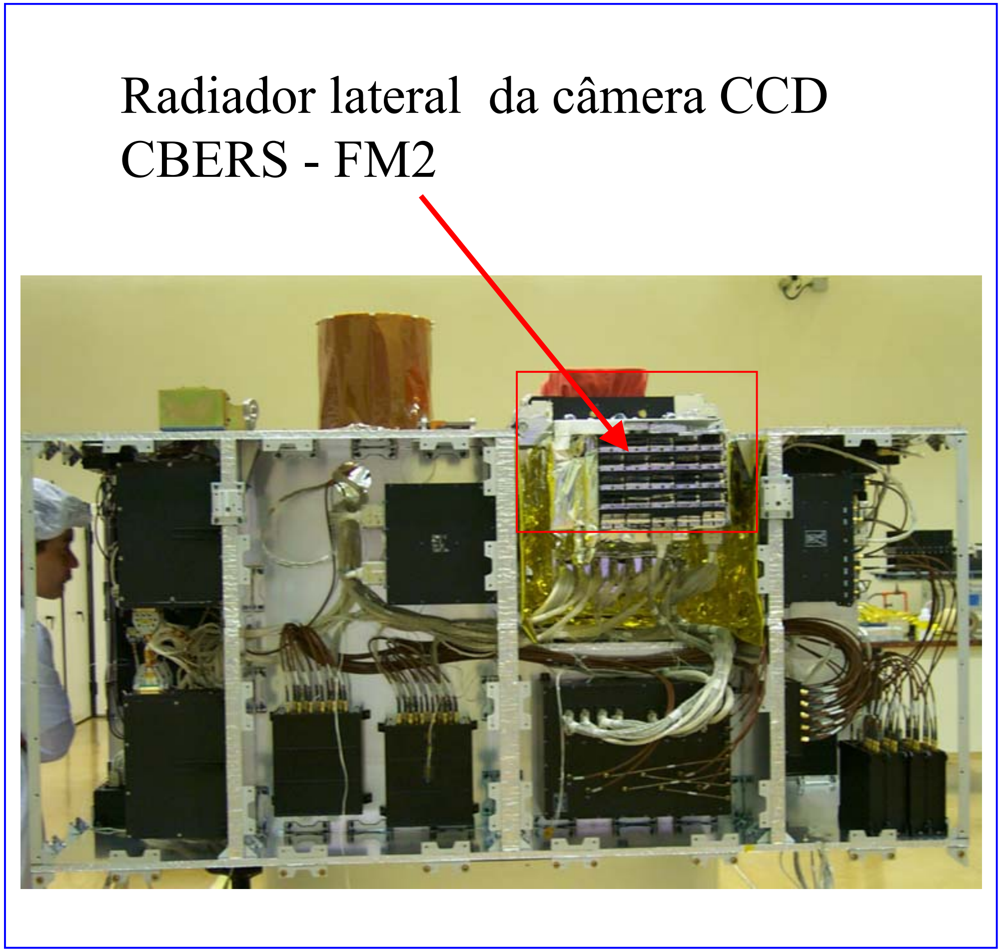


Venezianas sobre radiador do painel das baterias no satélite EO-1

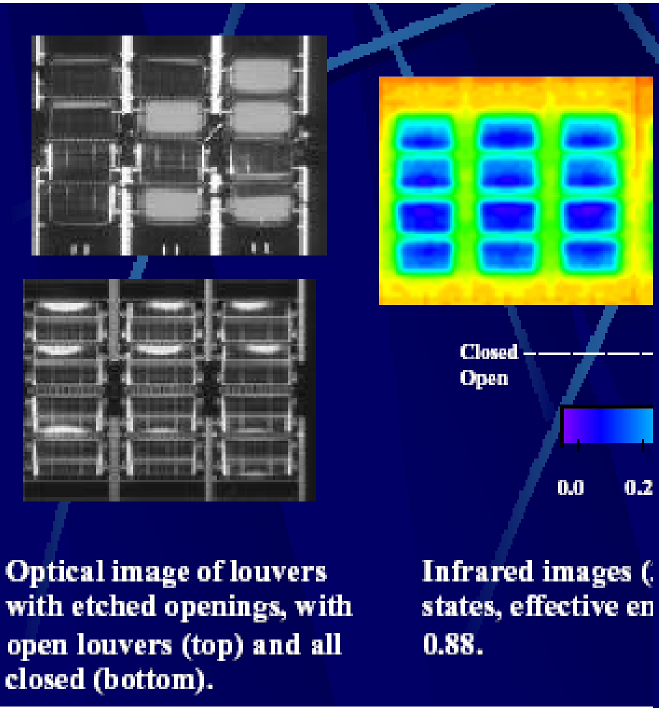
Radiadores Com Propriedades Termo-Ópticas Variáveis (cont.)

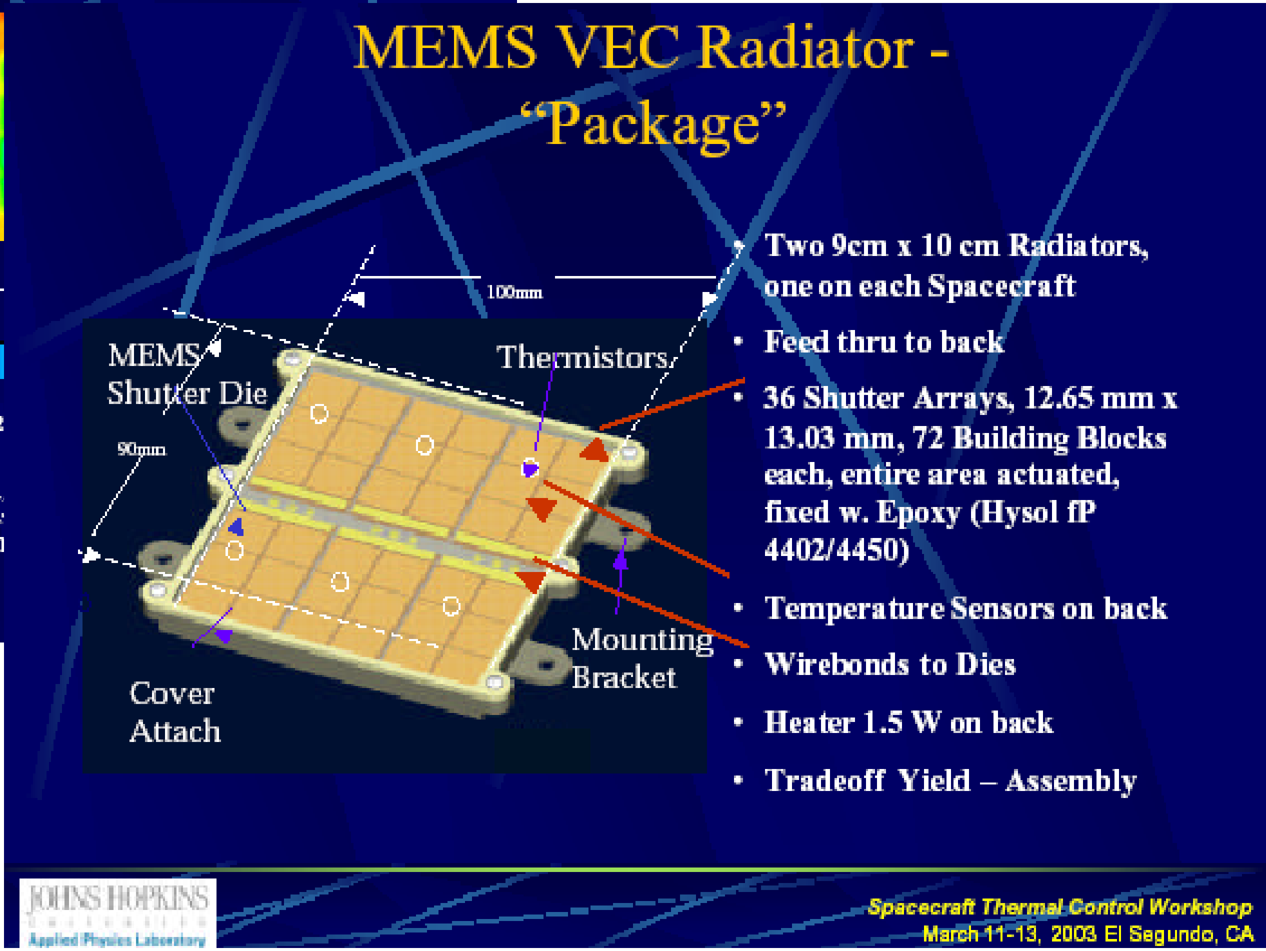
- Venezianas com palhetas em material bi-metálico ou de memória de forma .





- Micro venezianas: milhares de micro-venezianas (6 - 150 μm) são acionadas eletrostáticamente (40 V).





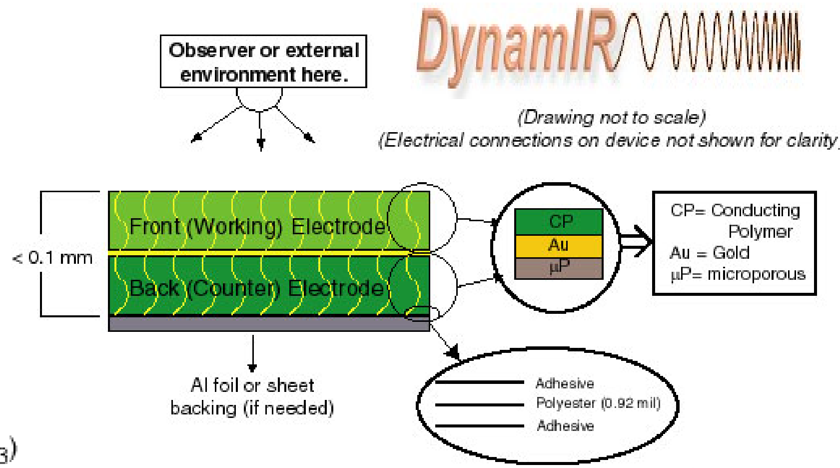
Experimento no satélite tecnológico ST5 a ser lançado em 2004.

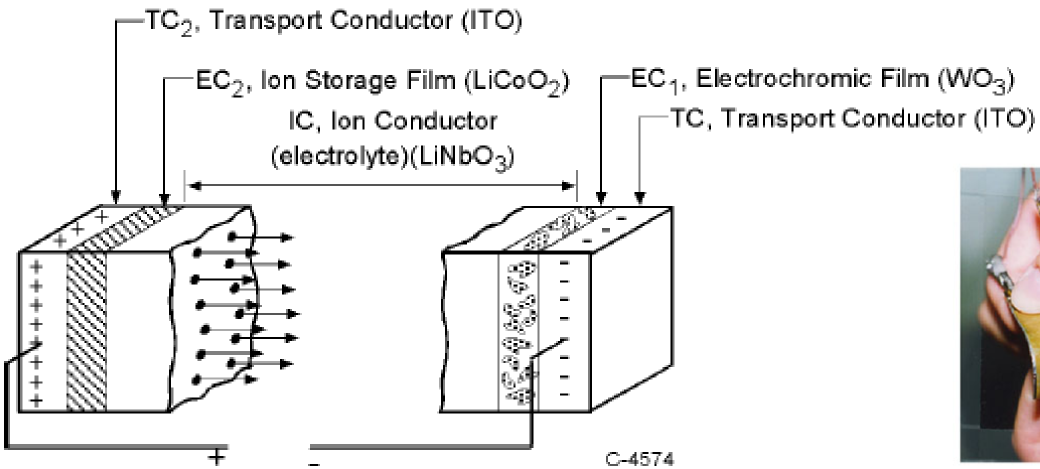
- Electrochromics

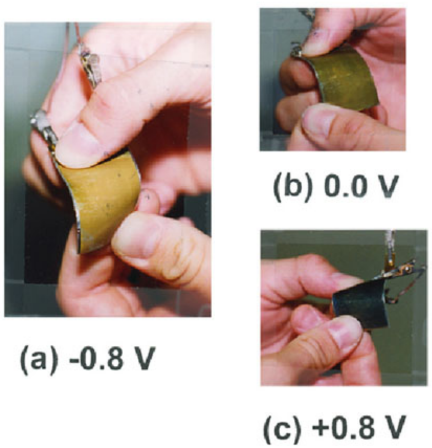
  – Determinados materiais ("compostos") podem mudar sua transmissividade quando submetidos à uma diferença de potêncial (< 5 V) .

  – Mudança de propriedade ótica se dá por meio da aplicação de uma DDP transiente .

  – Radiador pode ser construido depositando o material sobre uma superfície com alto ε .



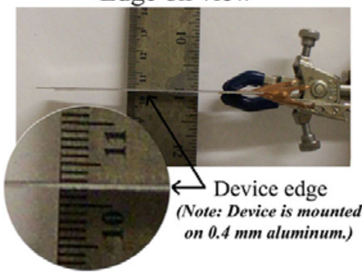




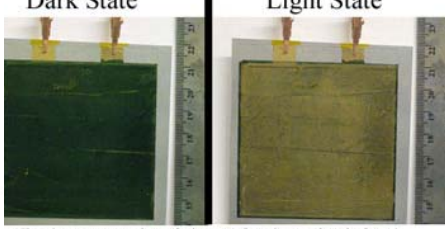
Bending/Flexing has no effect on device function.

(All pictures are raw data and are not modified in any way.)

Edge on view



Dark State Light State



(Device mounted on 0.4 mm aluminum backplate.)

Experimento no satélite tecnológico ST5 a ser lançado em 2004.

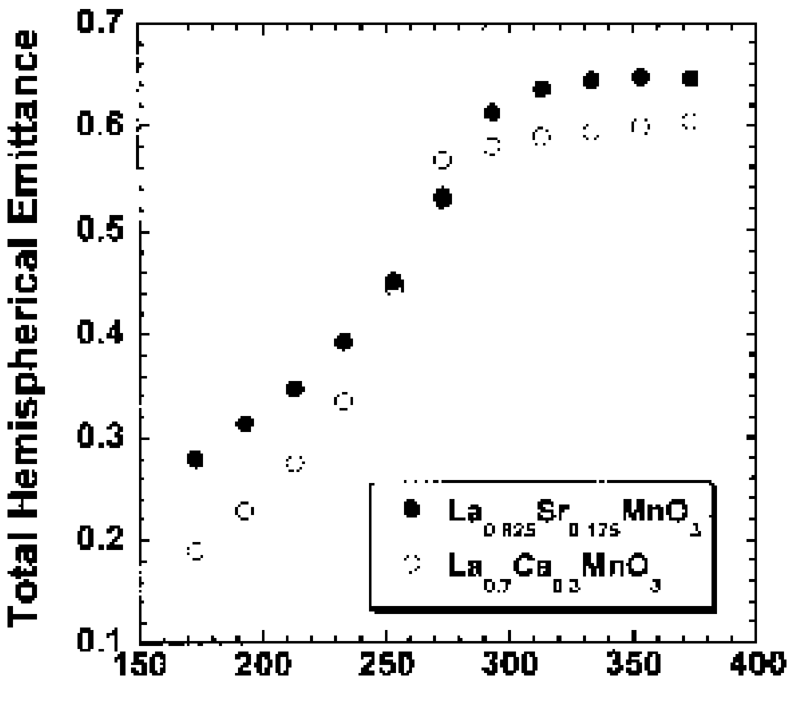
- Thermochromics

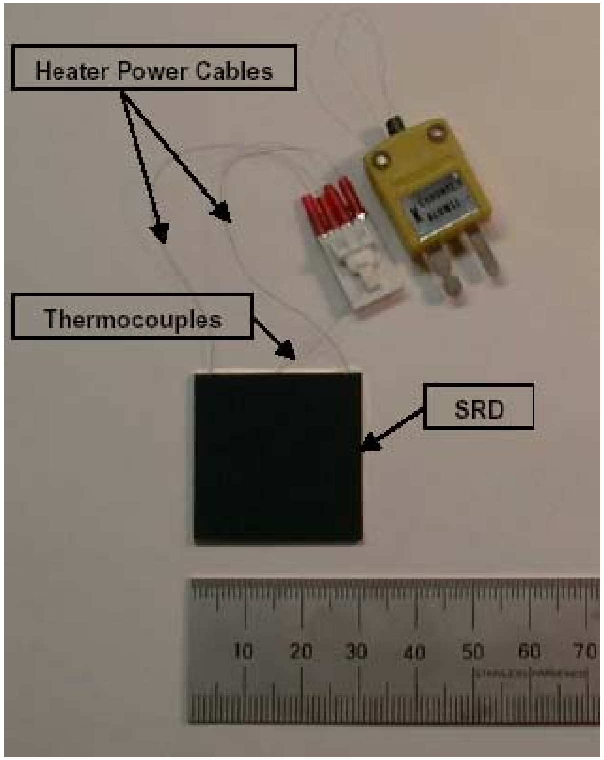
– Determinados materiais sofre uma mudança na propriedade termo-óptica com a temperatura.

– Radiador seria construido fixando diversas pastilhas deste material sobre sua superfície .

– Não há degradação das PTO devido à irradiação UV, por prótons ou elétrons.

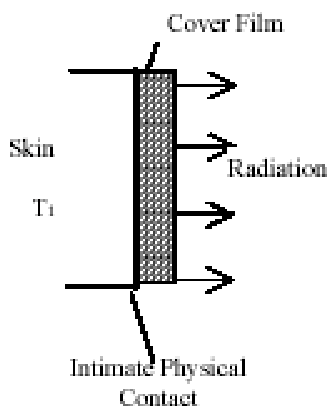
– Problema: alto valor de α (0.84-0.9).

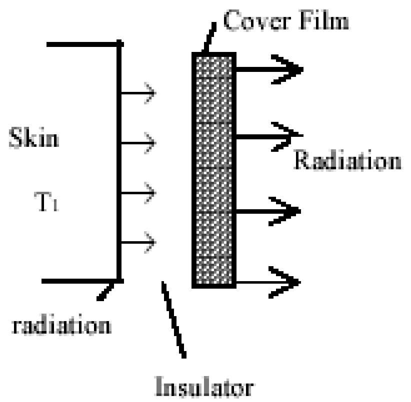


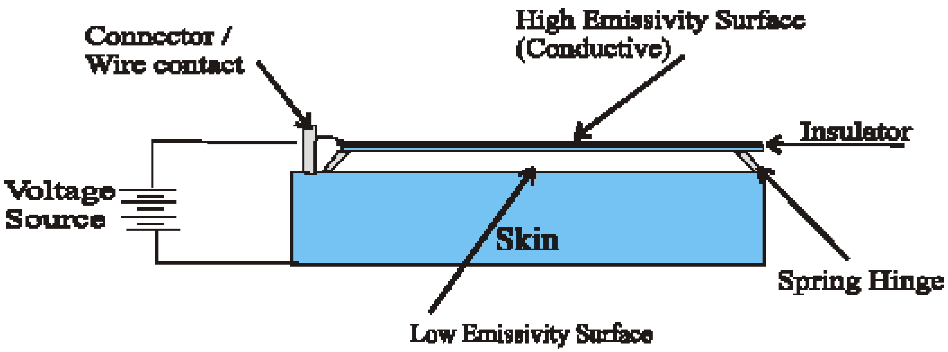


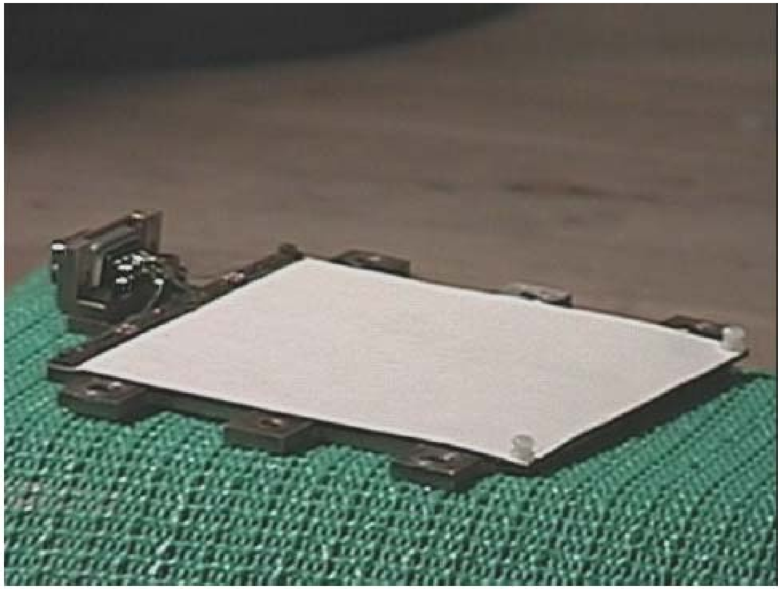
Smart Radiation Device

Radiador "eletrostático": 200 - 500 V





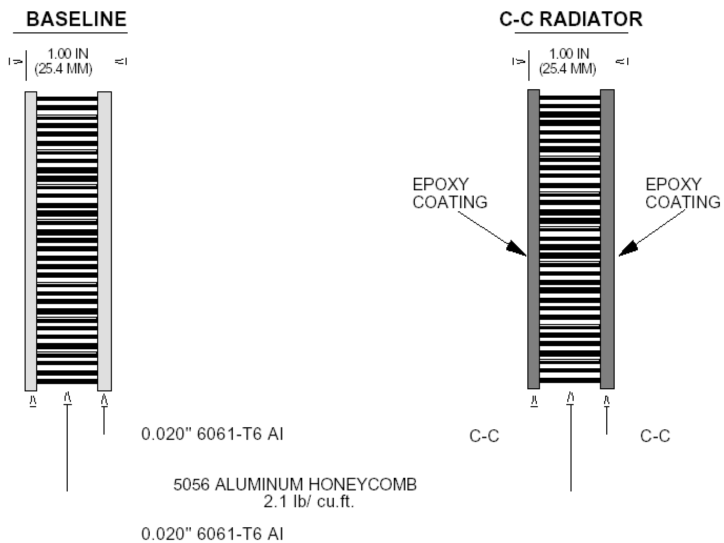




Experimento no satélite tecnológico ST5 a ser lançado em 2004.

→ Radiadores Carbono-Carbono

– Materiais C-C (fibra e matriz em Carbono) oferecem maior eficiência térmica, razão rigidez/massa, "tailorability" e estabilidade dimensional que o aluminio.



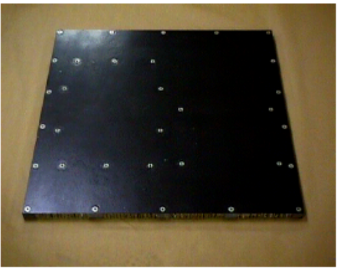


Figure 1.1
Carbon-Carbon Panel Internal Surface

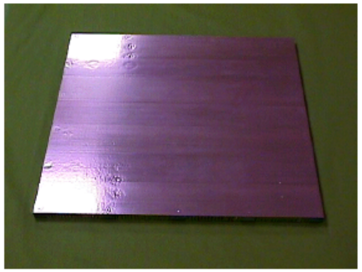
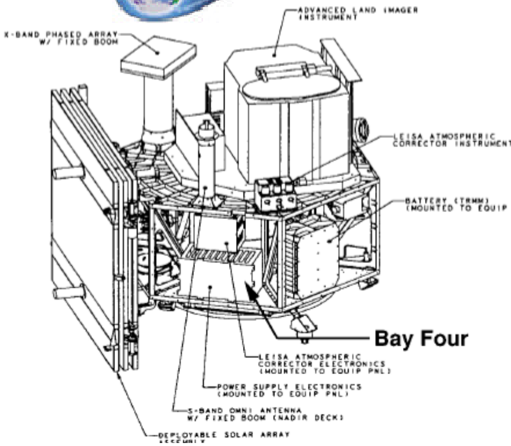
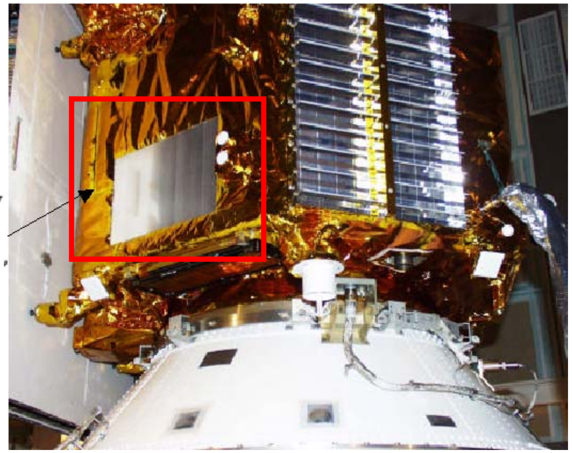


Figure 1.2
Carbon-Carbon Panel External Surface

EO-1





	Pre-Flight / Experimental	Flight Analysis
K (horizontal)	230 W/m-K	295 W/m-K
K (vertical)	230 W/m-K	208 W/m-K
K (z direction)	30 W/m-K	30 W/m-K

LESSONS LEARNED

- C-C Radiator was a success and proved that the technology can work to reduce Spacecraft weight
- C-C has a niche, especially for high temperatures
- C-C still needs further development (my opinion)
  - Reduction in fabrication time and cost - high conductivity "traditional" composites are more competitive
  - CTE Interface issues with heat pipes
- Redundancy a good idea - we flew the spare panel

- Radiador com face-sheets e Honeycomb de C-C.

ULTRACOR INC.
Specialty Core Materials

	Ultracor C-C H/C Panel	P-120 Facesheets Al. H/C	Aluminum Facesheets Al. H/C	Aluminum Plate
Thermal Conductivity (in plane) (W/mK)	350	275	180	180
Density (g/cc)	0.27	0.2	0.3	2.7
Specific Thermal Conductivity (W-cm3/mK-g)	1296	1375	600	66
Thermal Conductivity in Z-direction (W/mK)	65	20	10	180
Specific Thermal Conductivity (W-cm3/mK-g) In Z	241	100	33	66

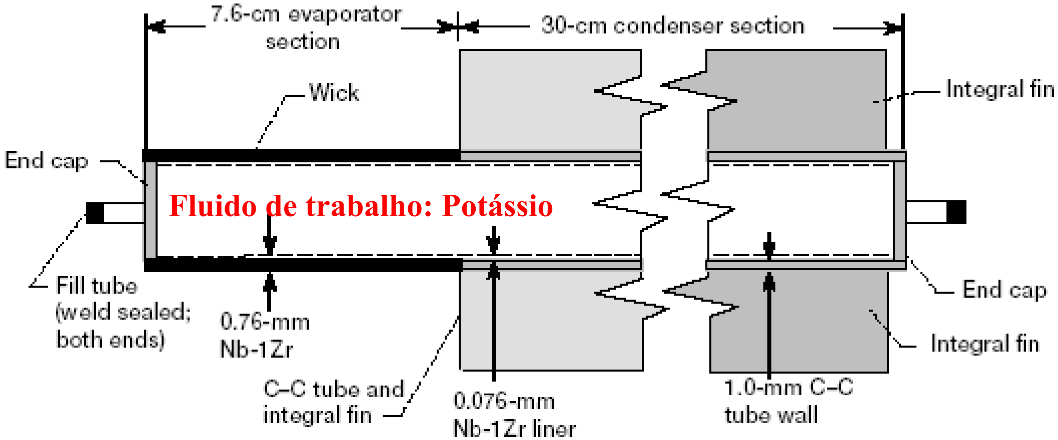
Dados do EO-1 facesheets CC - HC Al

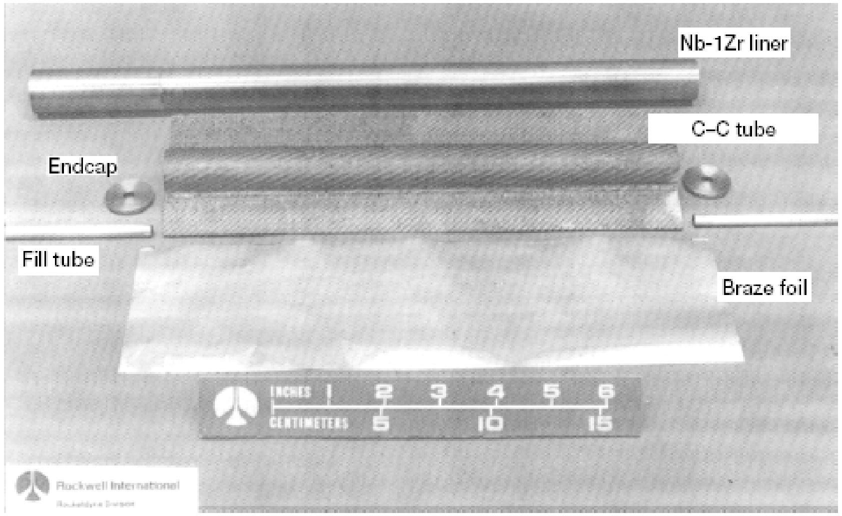
	Pre-Flight / Experimental	Flight Analysis
K (horizontal)	230 W/m-K	295 W/m-K
K (vertical)	230 W/m-K	208 W/m-K
K (z direction)	30 W/m-K	30 W/m-K

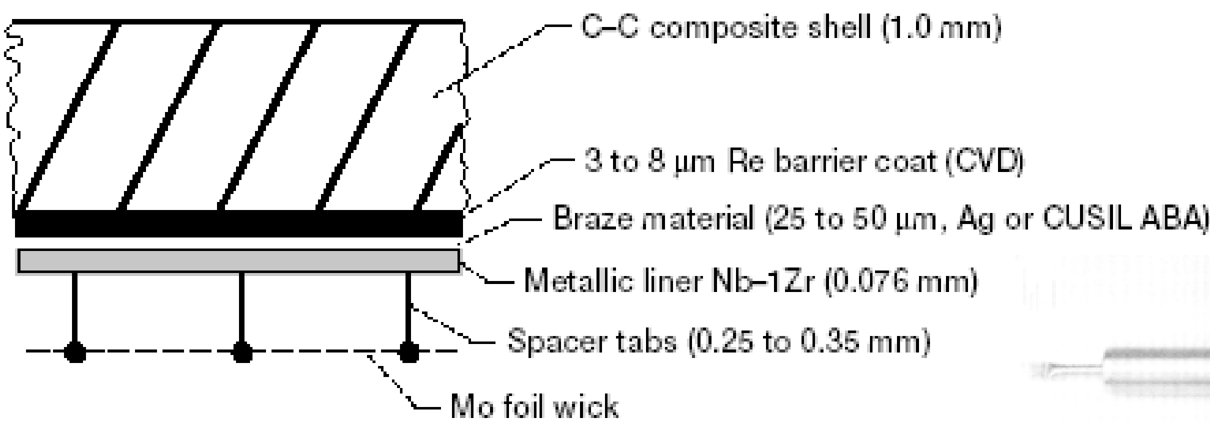
Radiadores Carbono-Carbono (Cont.)

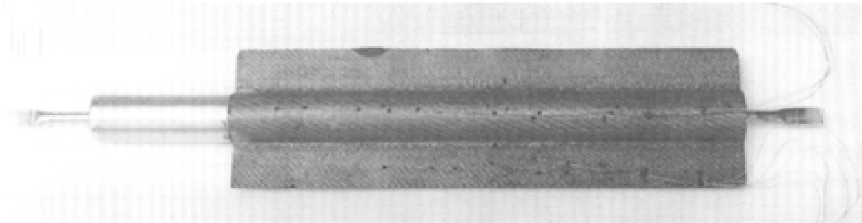
- Radiador C-C com HPs (C-C) para sistemas com alta dissipação de potência.

Glenn Research Center



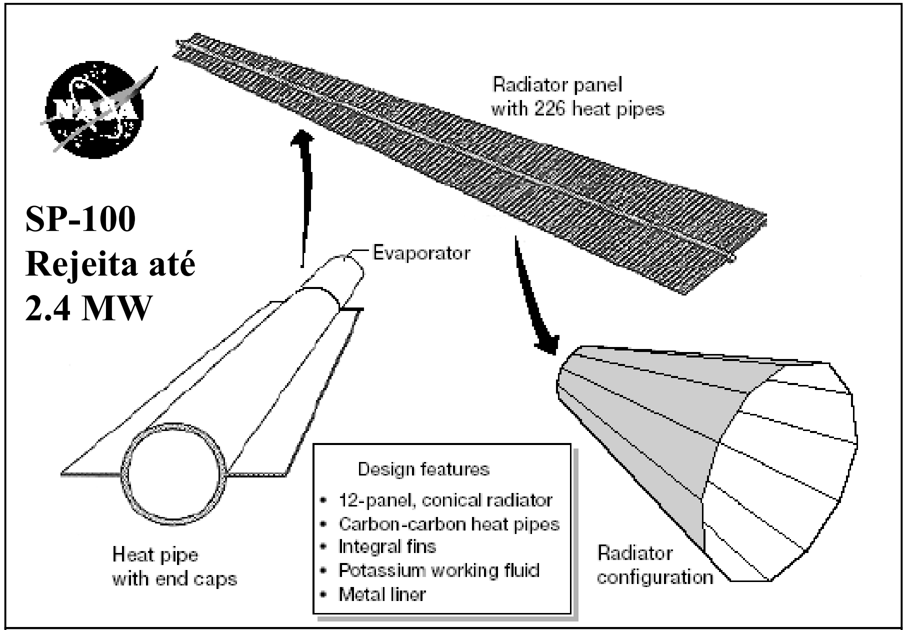




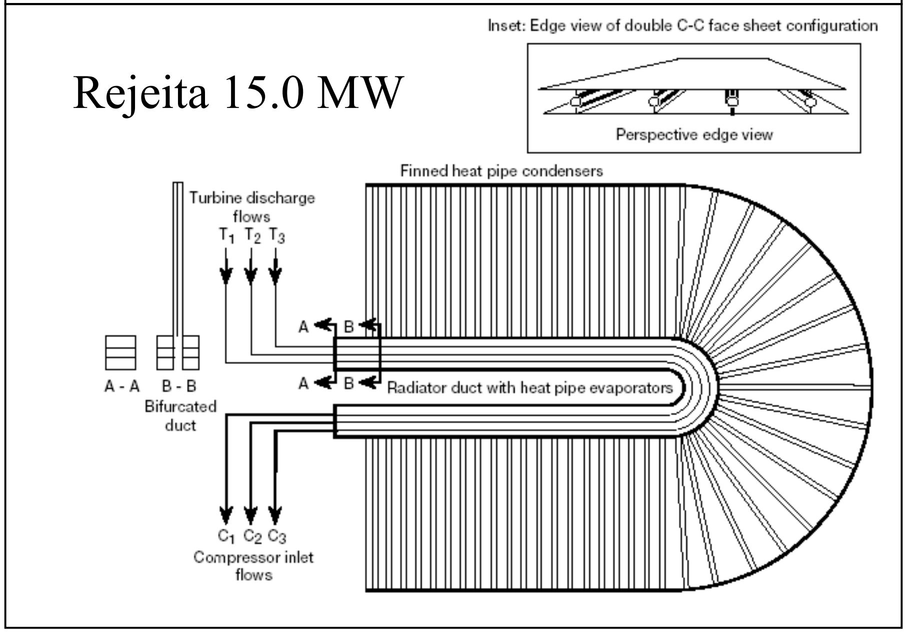


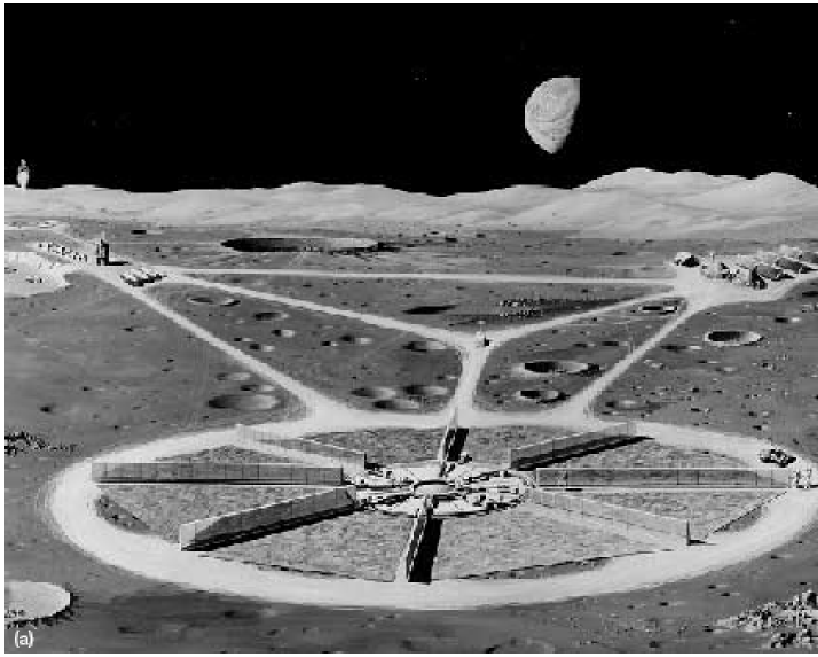
Radiadores Carbono-Carbono (Cont.)

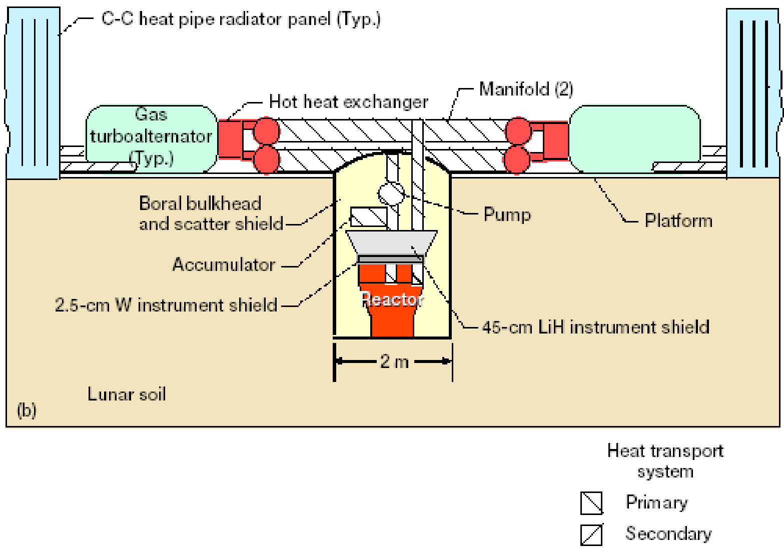
SP-100 Rejeita até 2.4 MW



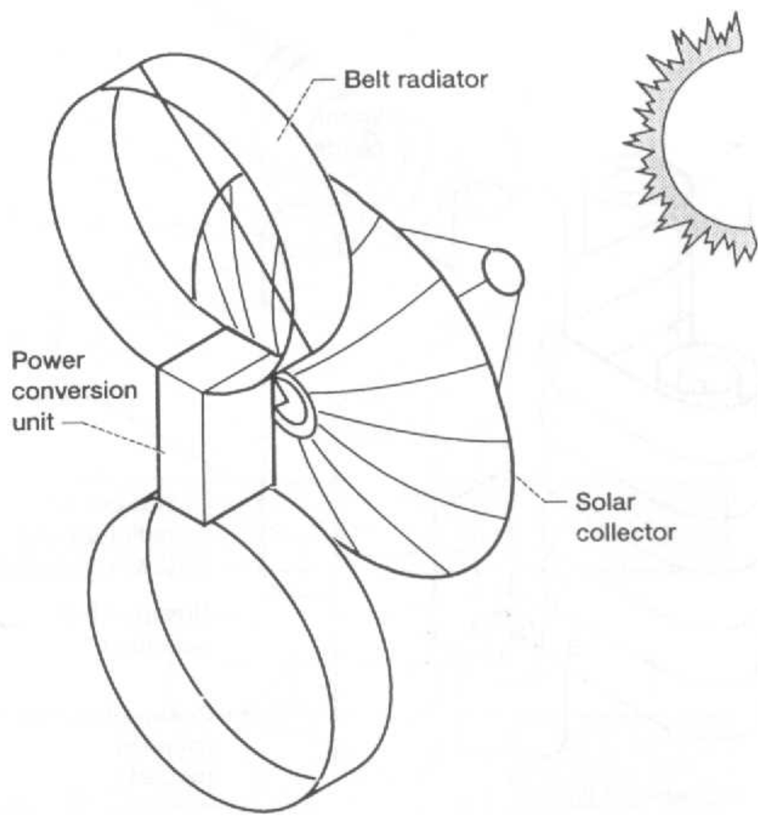
Rejeita 15.0 MW



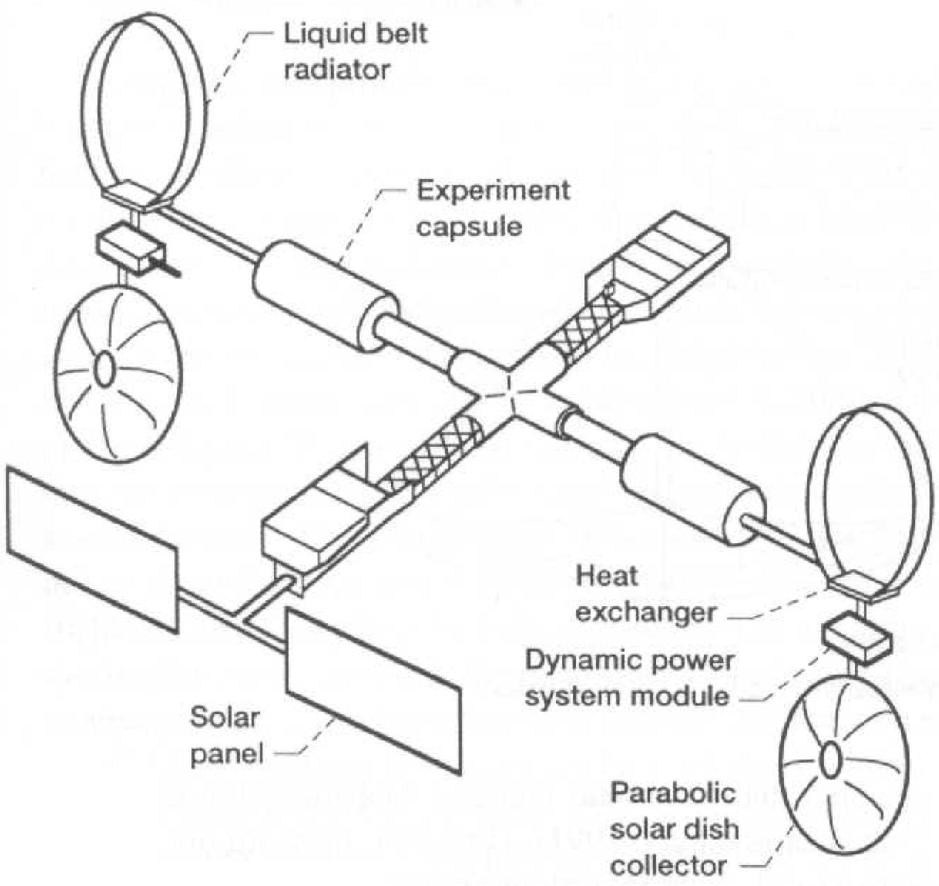




→ Outras Concepções Avançadas Para Sistemas de Alta Dissipação

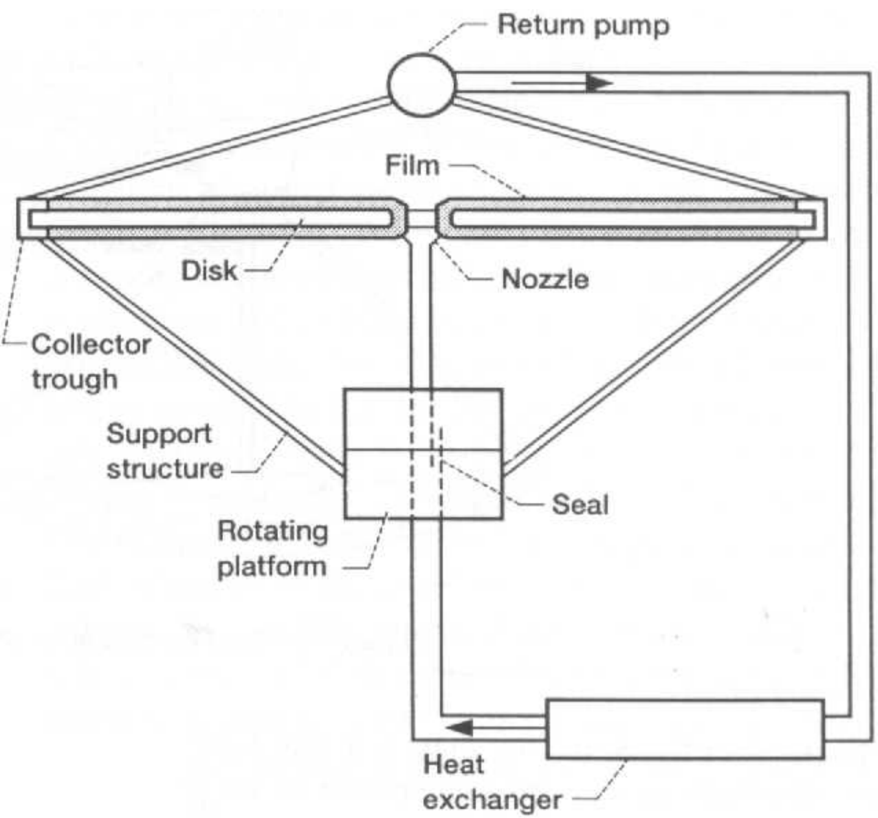


Moving-belt radiator

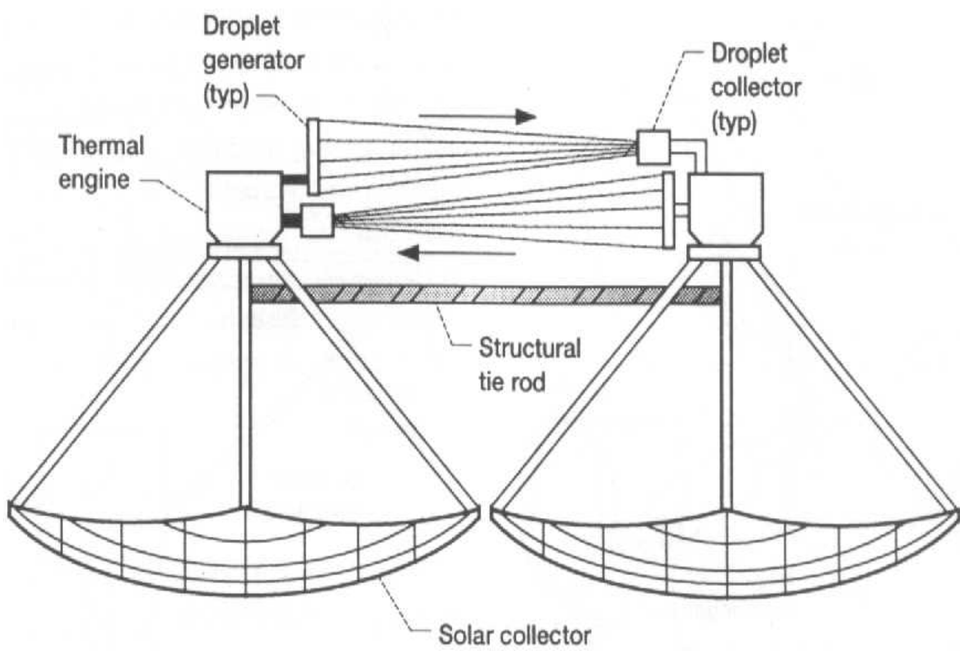


Liquid-belt radiator

Outras concepções vançadas para sistemas de alta dissipação (Cont.)



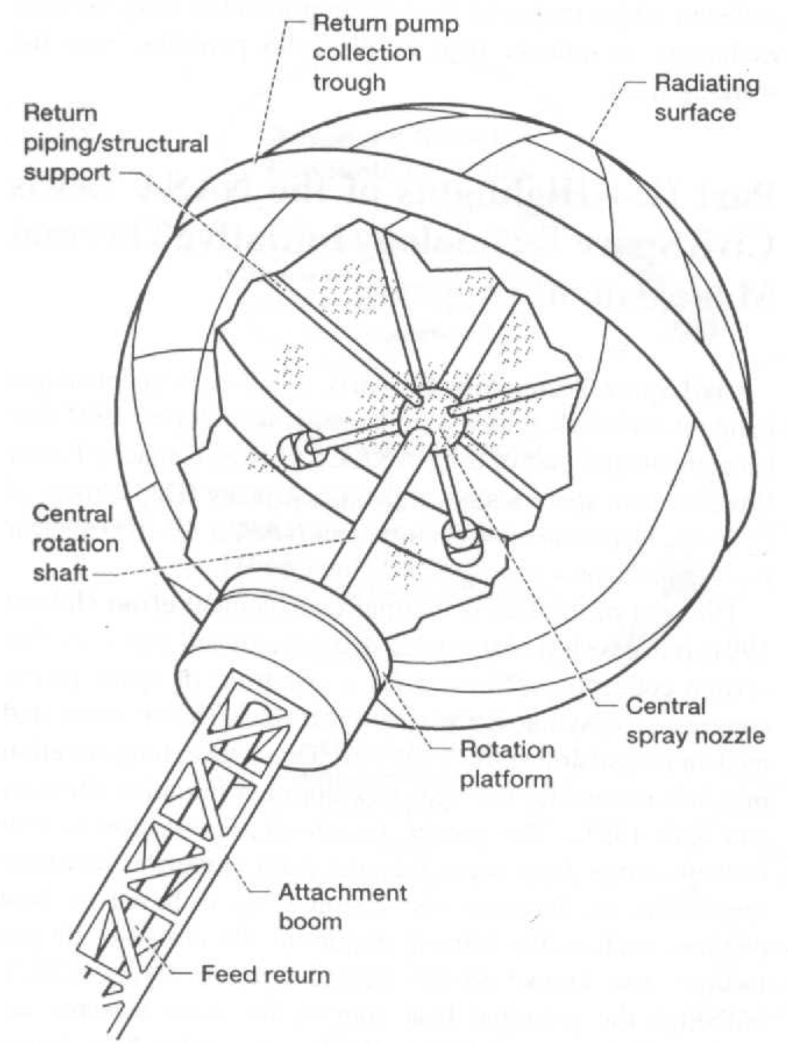
Rotating film radiator

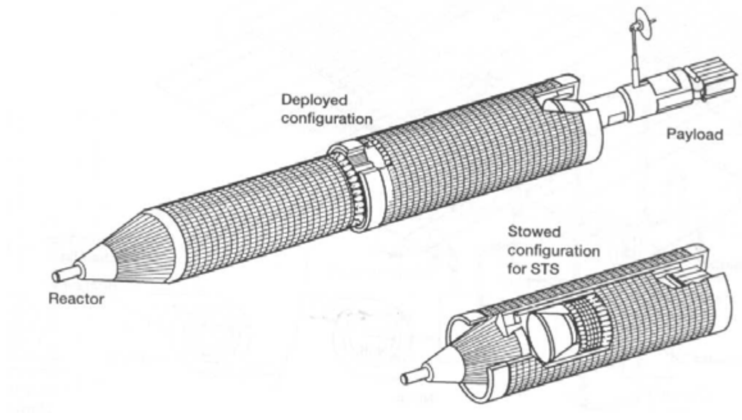


Liquid droplet radiator

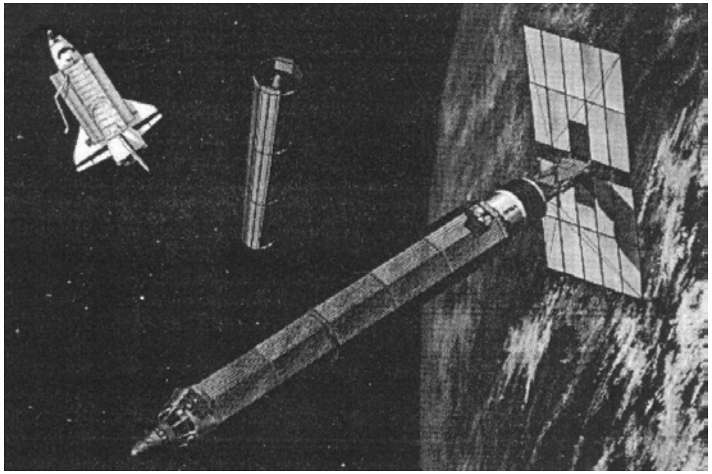
Conceito similar, mas com partículas sólidas: Curie Point Radiator.

Outras concepções vançadas para sistemas de alta dissipação (Cont.)





Telescoping radiator (K HPs)



Rotating bubble-membrane radiator

Folding panel radiator (Li/NaK loops)

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