



Ciclo de Palestras Sobre Controle Térmico de Satélites

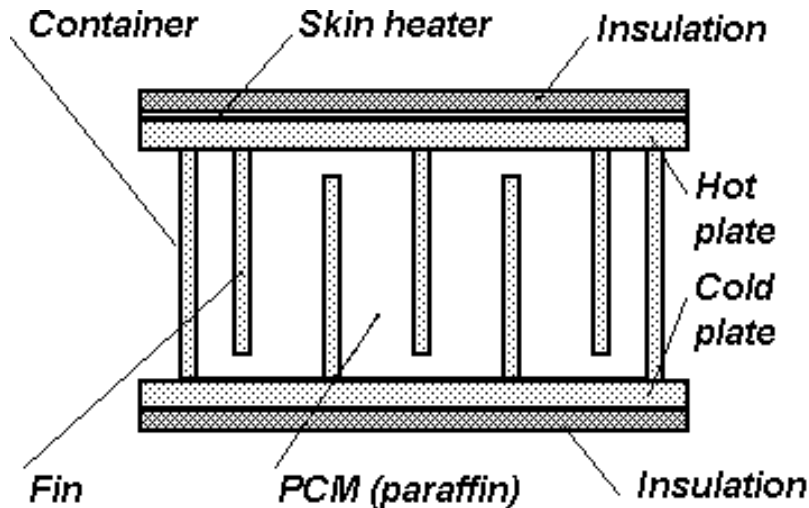
Capacitor térmico

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Divisão de Mecânica Espacial e Controle - DMC

INPE-2003

Capacitor térmico com PCM



Funções térmicas:

- Redução da amplitude de temperatura do equipamento funcionando em modo cíclico
- Prevenção de super-aquecimento para todos os modos transientes
- Prevenção de sub-resfriamento para todos os modos transientes

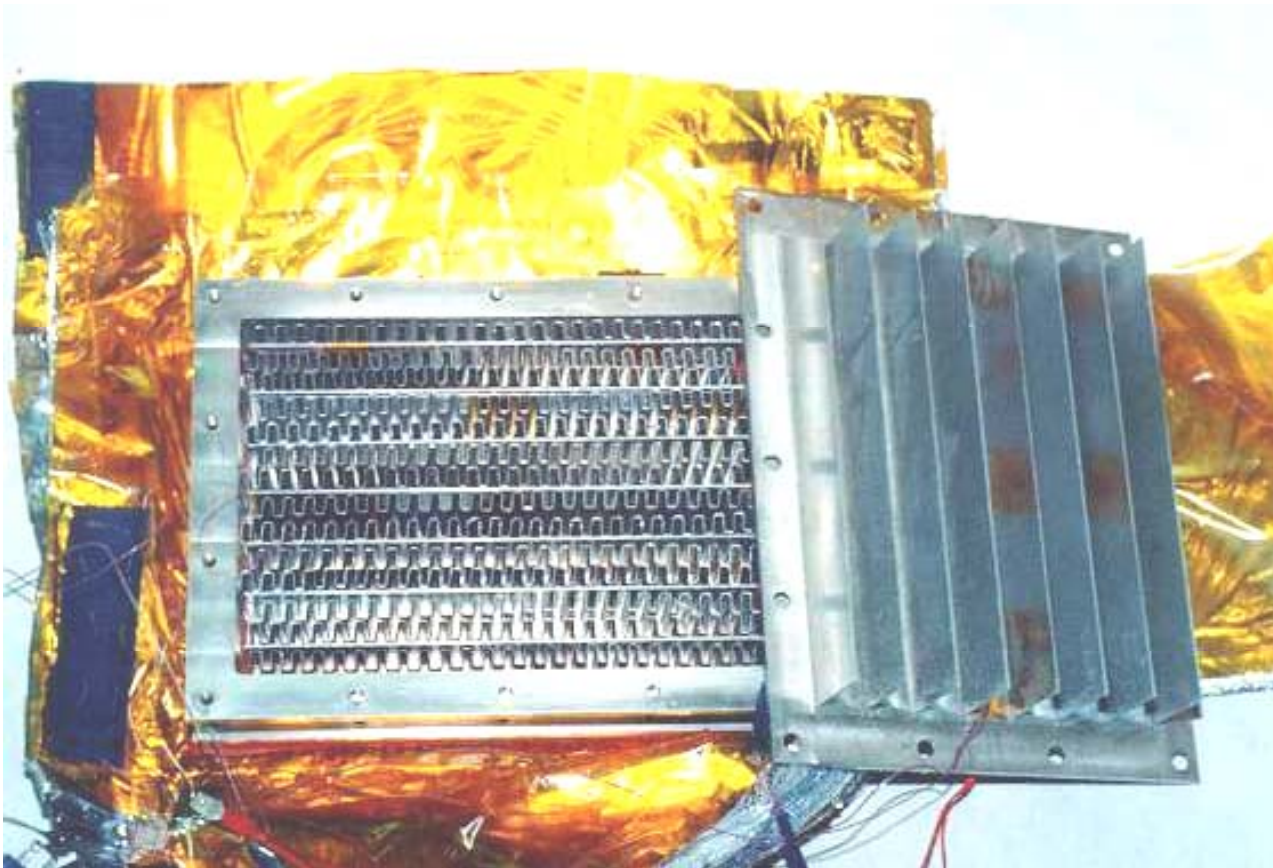
PCM: Material de mudança de fase (Phase Change Material)

Propriedades do PCM

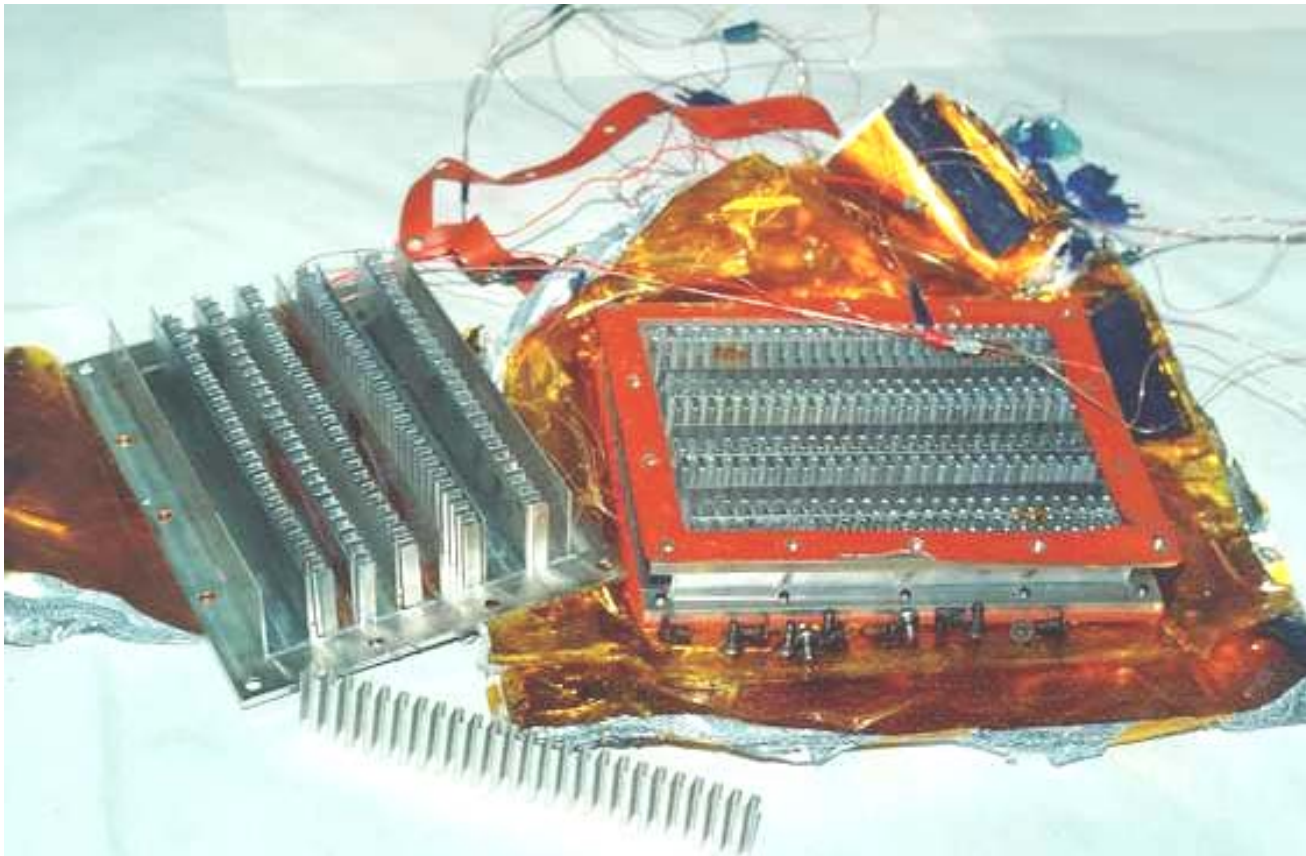
Table 1. Properties of selected PCM [form Hale, Hoover and O'Neill, 1971]

Name	Formula	Melting point, °C	Latent heat, kJ/kg	Specific heat, kJ/kg	Conductivity, W/m ⁰ C	Density, (solid/liquid) kg/m ³
n-Tetradecane	C ₁₄ H ₃₀	5,5	228,0	-	-	- / 771
n-Pentadecane	C ₁₅ H ₃₂	10	205	-	-	- / 768
n-Hexadecane	C ₁₆ H ₃₄	16,7	237,1	2,11	0.15	835 / 774
n-Heptadecane	C ₁₇ H ₃₆	21.7	213	-	-	- / 778
n-Octadecane	C ₁₈ H ₃₈	28,0	243,0	2,16	0,15	814 / 774
n-Eicosane	C ₂₀ H ₄₂	36,7	247,0	2,21	0,15	856 / 778
n-Heneicosane	C ₂₁ H ₄₄	40,2	200	-	-	- / 756
n-Decosane	C ₂₂ H ₄₆	44,0	249	-	-	- / 763
n-Tricosane	C ₂₃ H ₄₈	47,5	232	-	-	- / 764
Polyethylene Glycol 600	H(OCH ₂ CH ₂) _n OH	20-25	146,0	2,26	0,16	-
Acetic acid	CH ₃ COOH	16,7	187,0	2,04	0,18	1215 / 1050
Lithium nitrate trihydrate	LiNO ₃ ·3H ₂ O	29,9 (s/cooling up to 0°C)	296,0	-	-	1550 / 1430

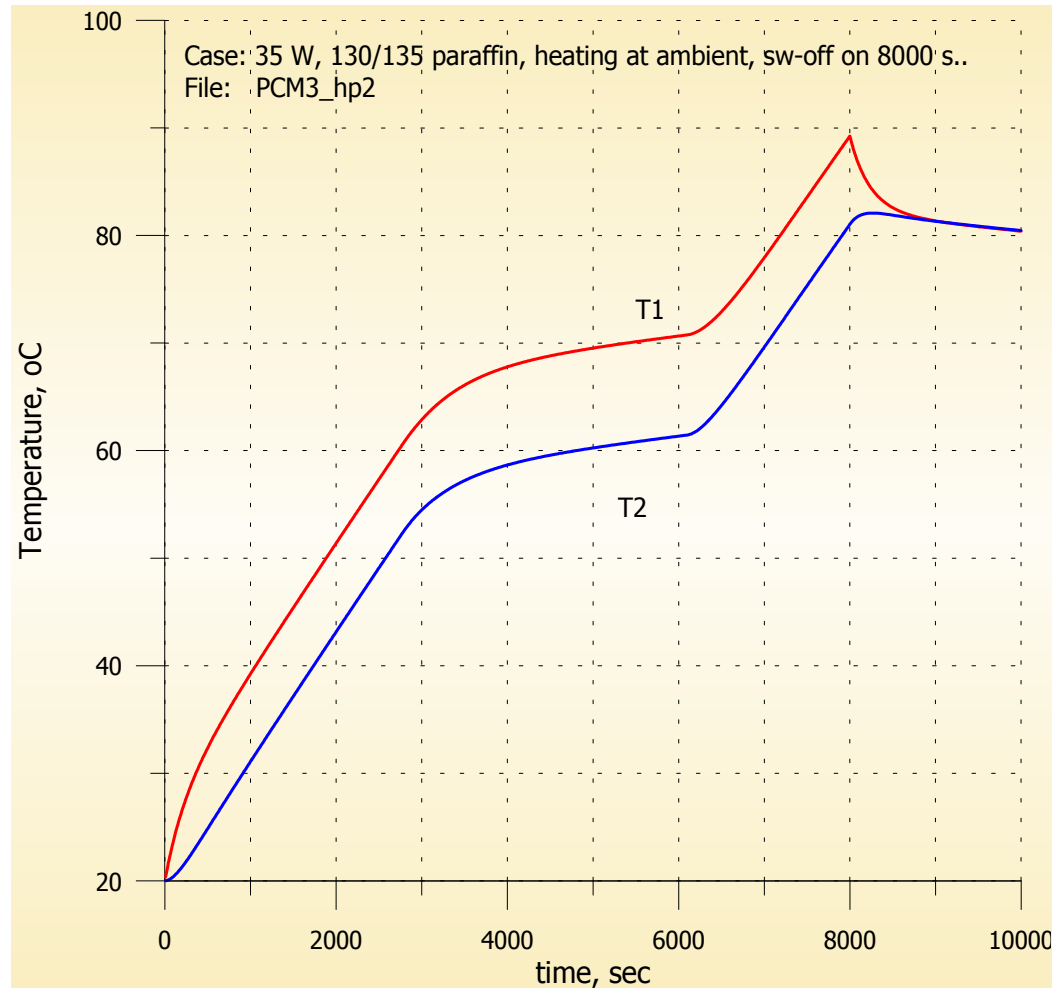
Protótipo PCM-1 de 570 ml (INPE/DMC)



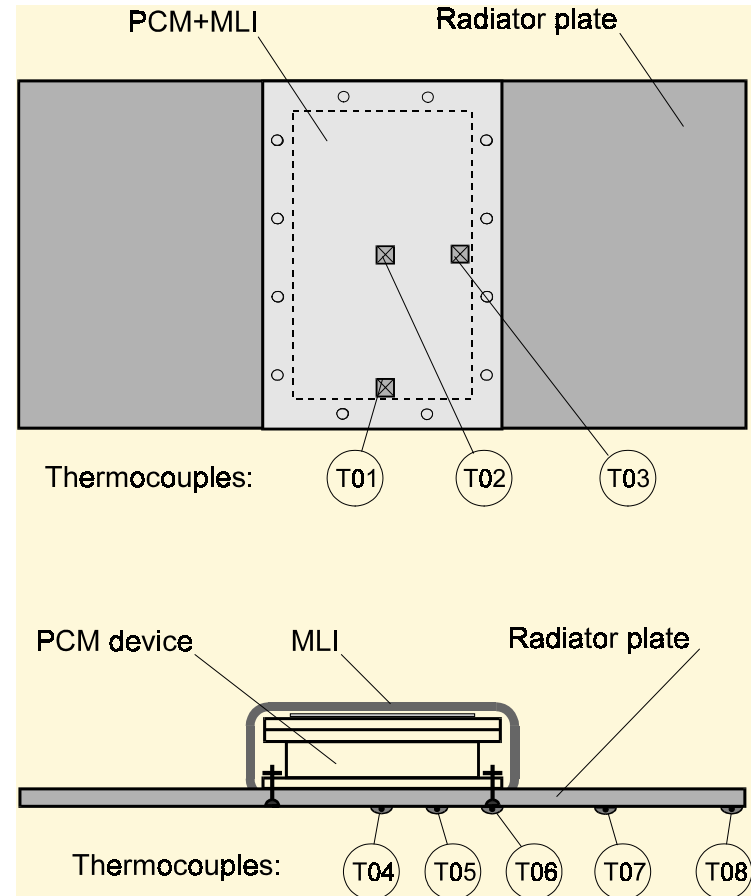
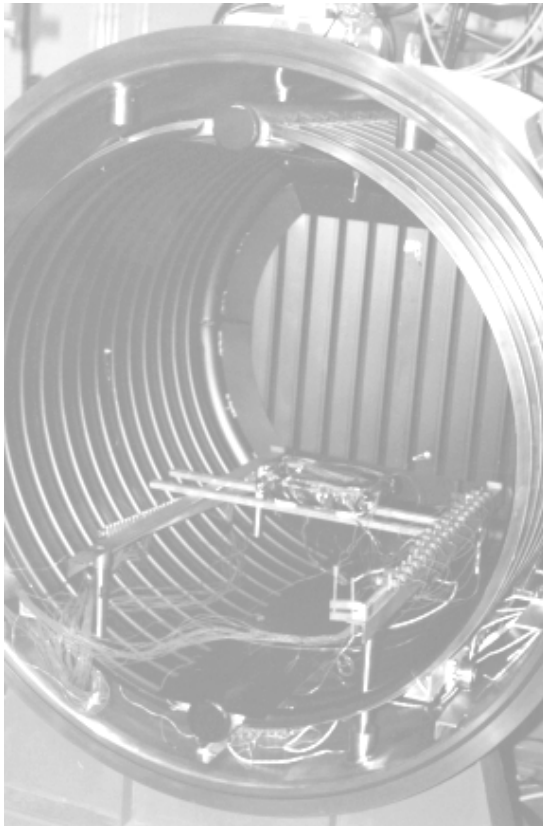
Protótipo PCM-1 de 570 ml



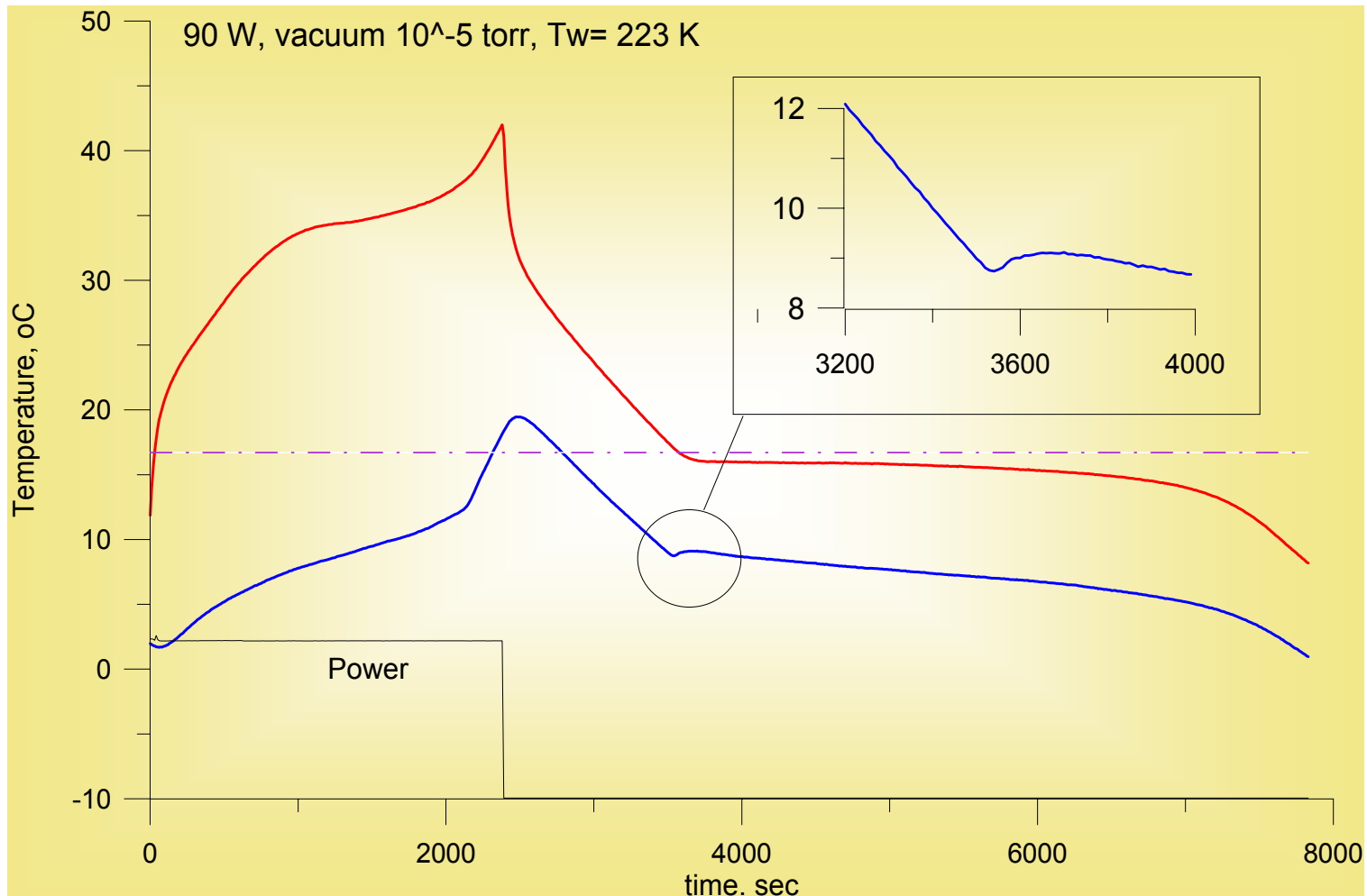
PCM-1: Teste ambiental de aquecimento com parafina 130/135 .



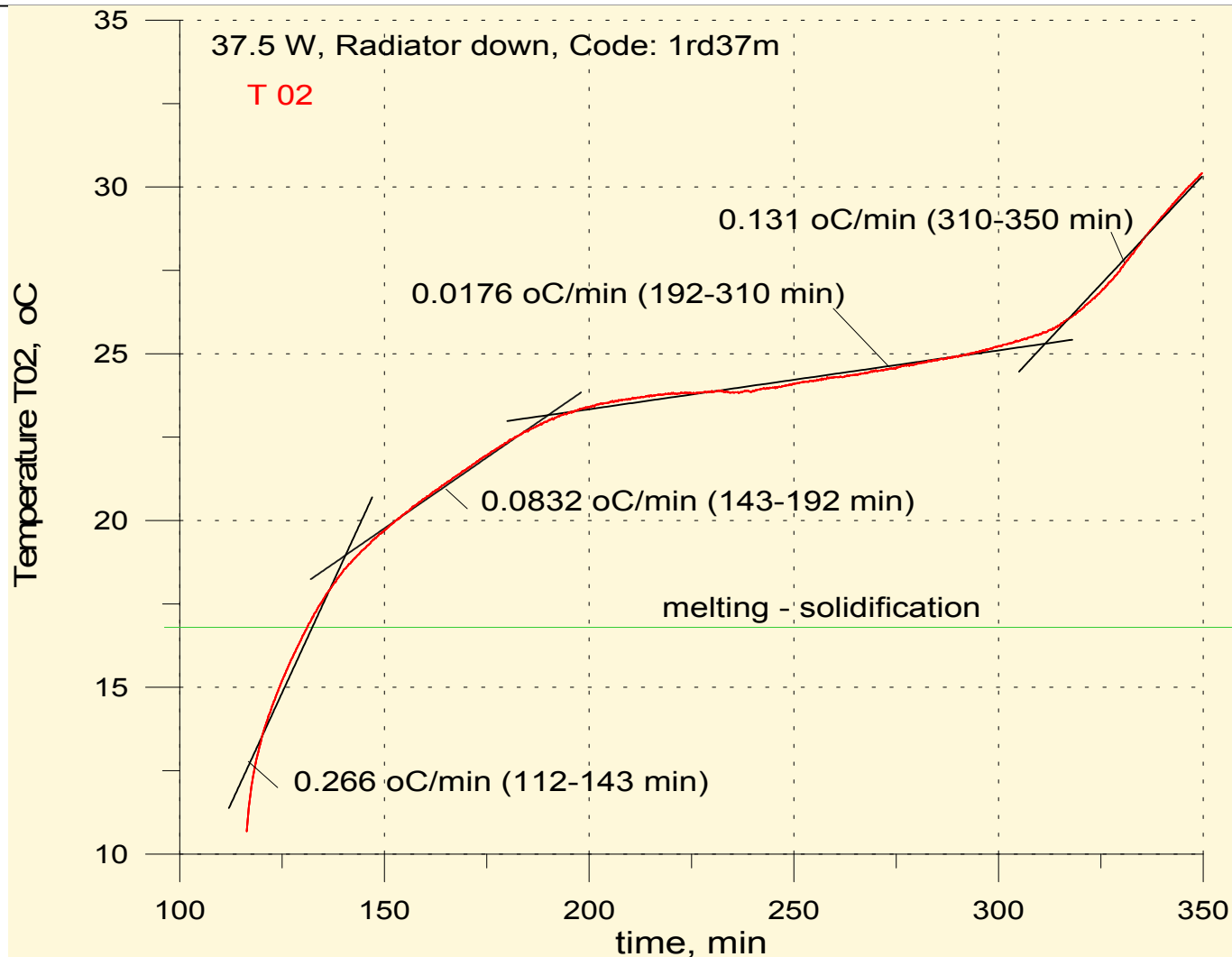
PCM-1: Teste em vácuo com um radiador acoplado.



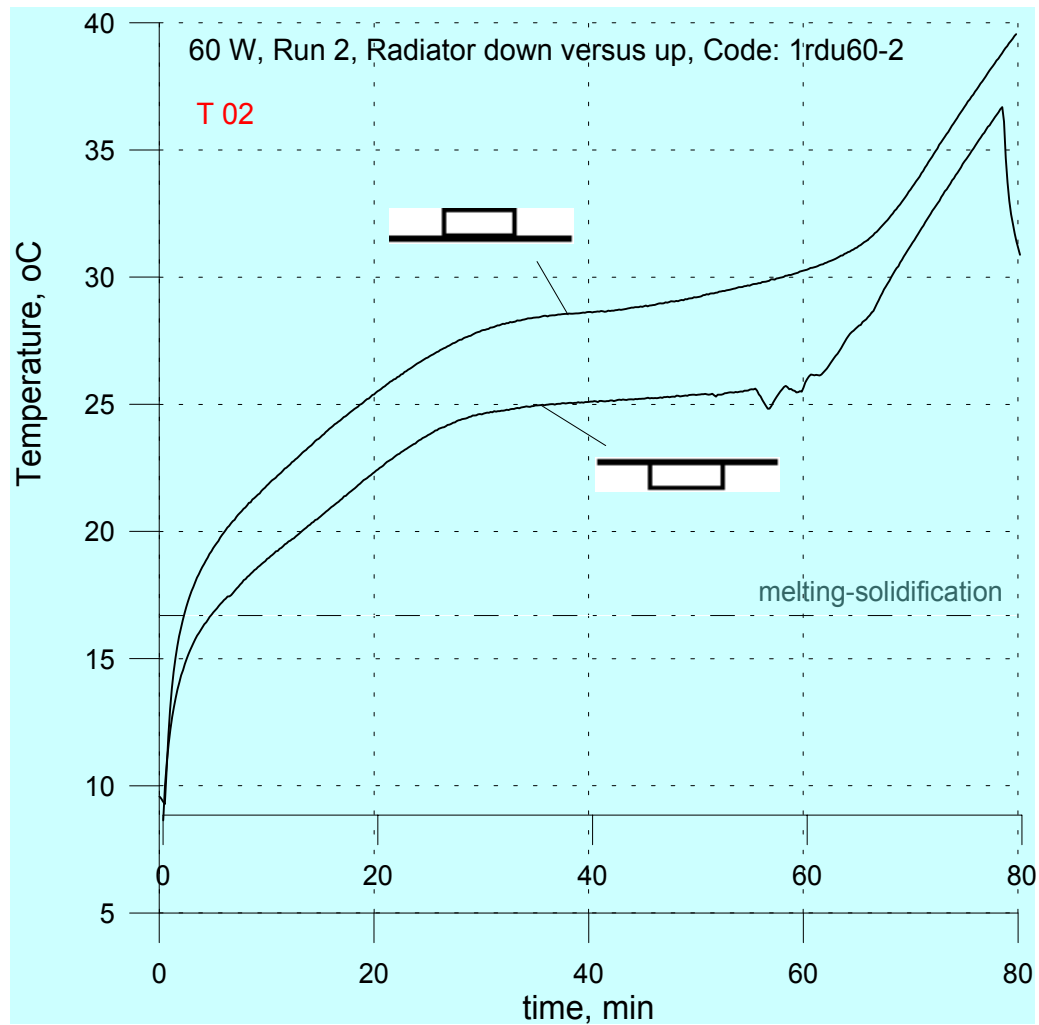
PCM-1: Teste em vácuo com n-hexadecano.



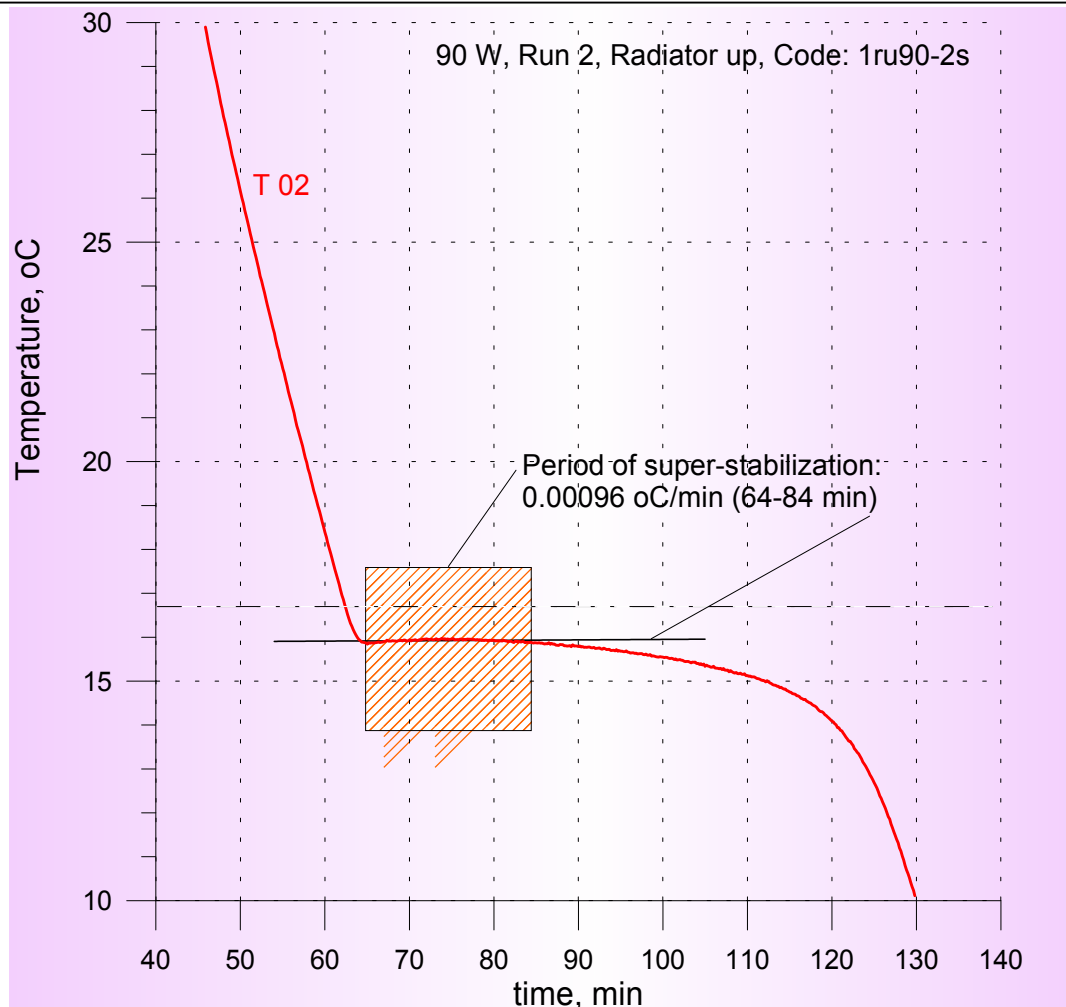
PCM-1: Fases de estabilização durante aquecimento.



PCM-1: Influência da distribuição interna de cavidades



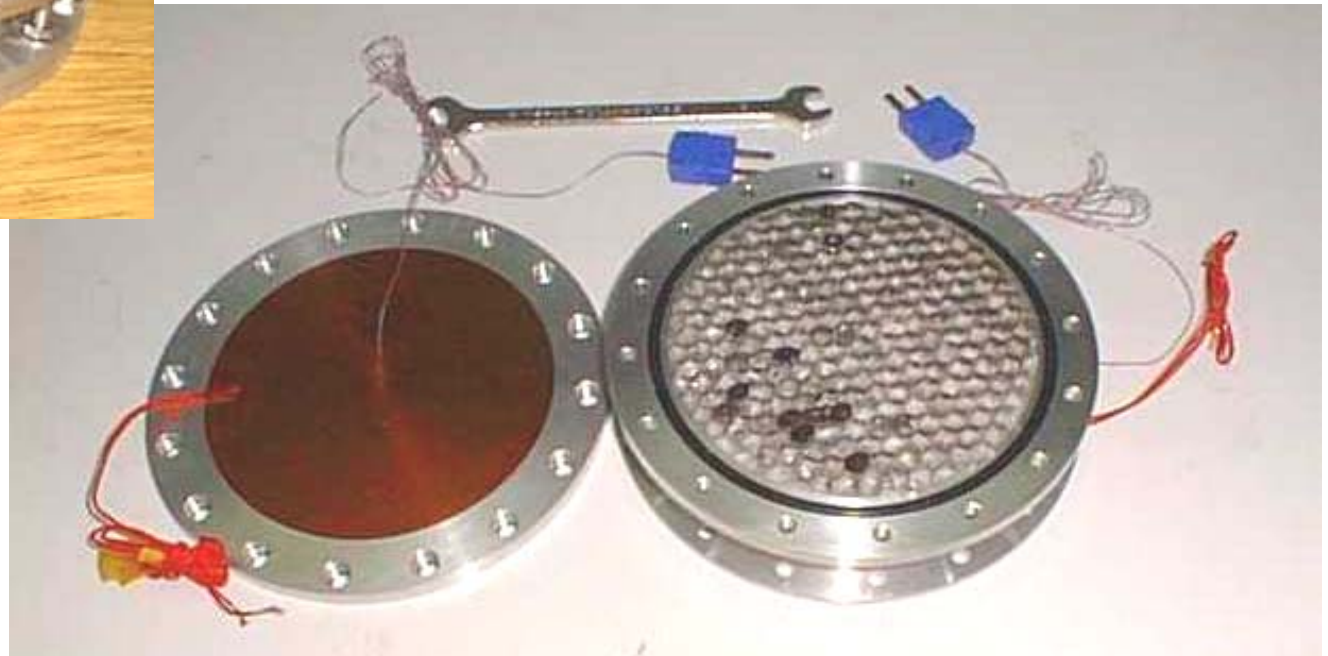
PCM-1: Efeito de super-estabilidade após início da solidificação.



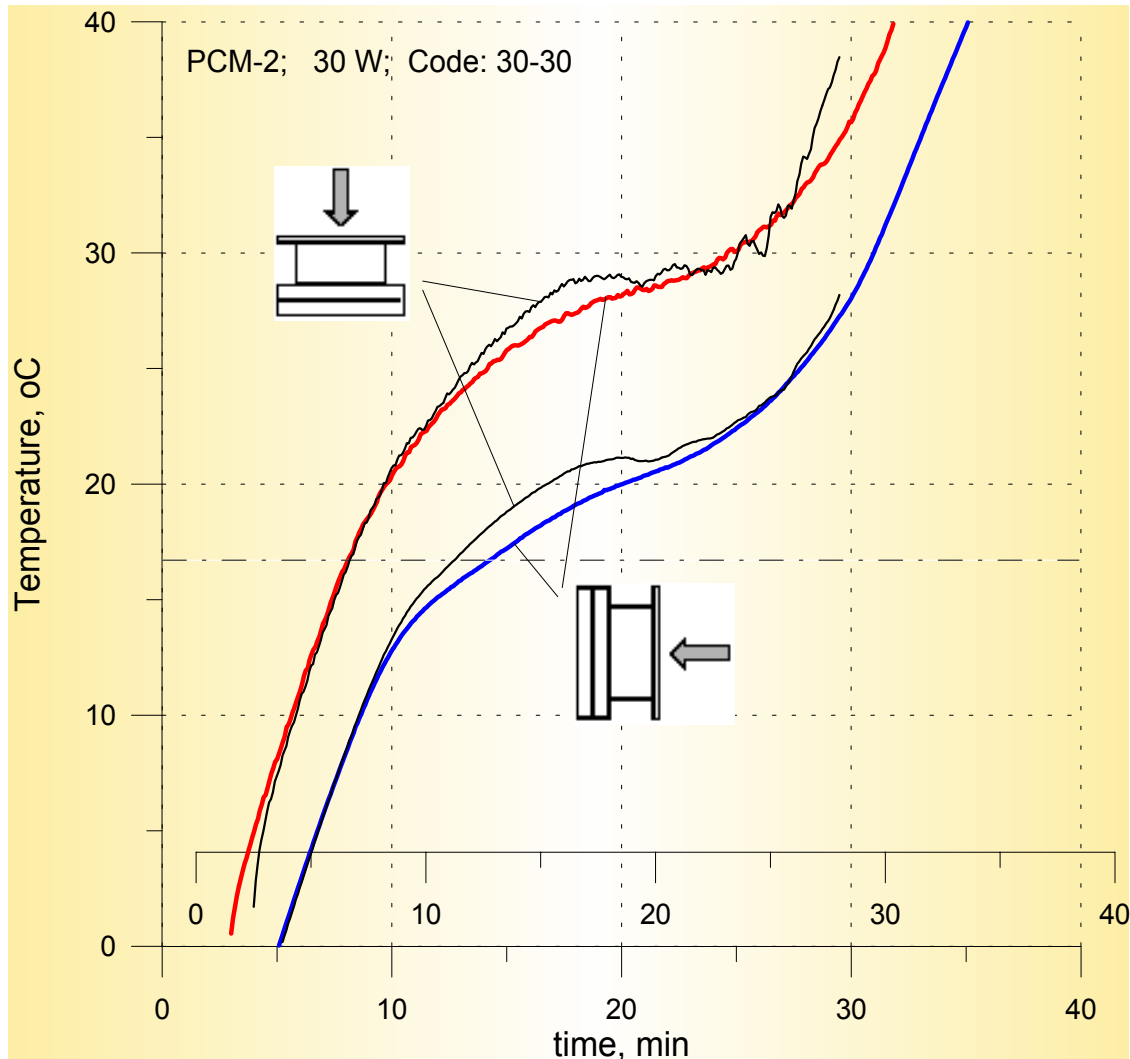
Protótipo PCM-2: de 120 ml, com n-eicosane ou n-hexadecane



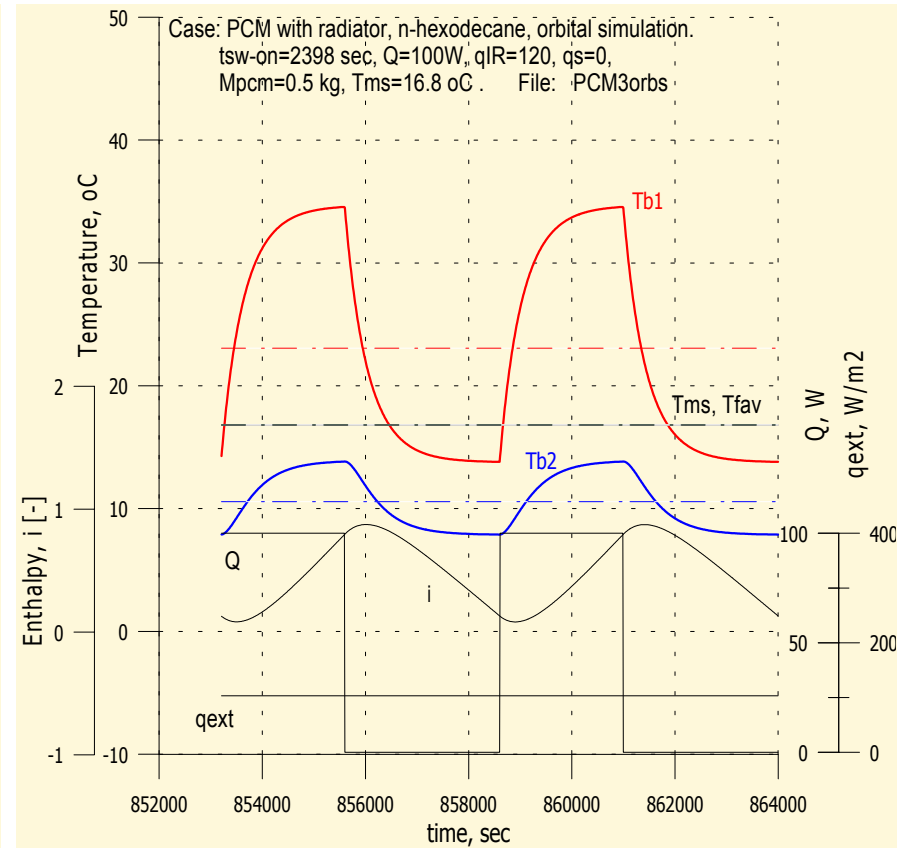
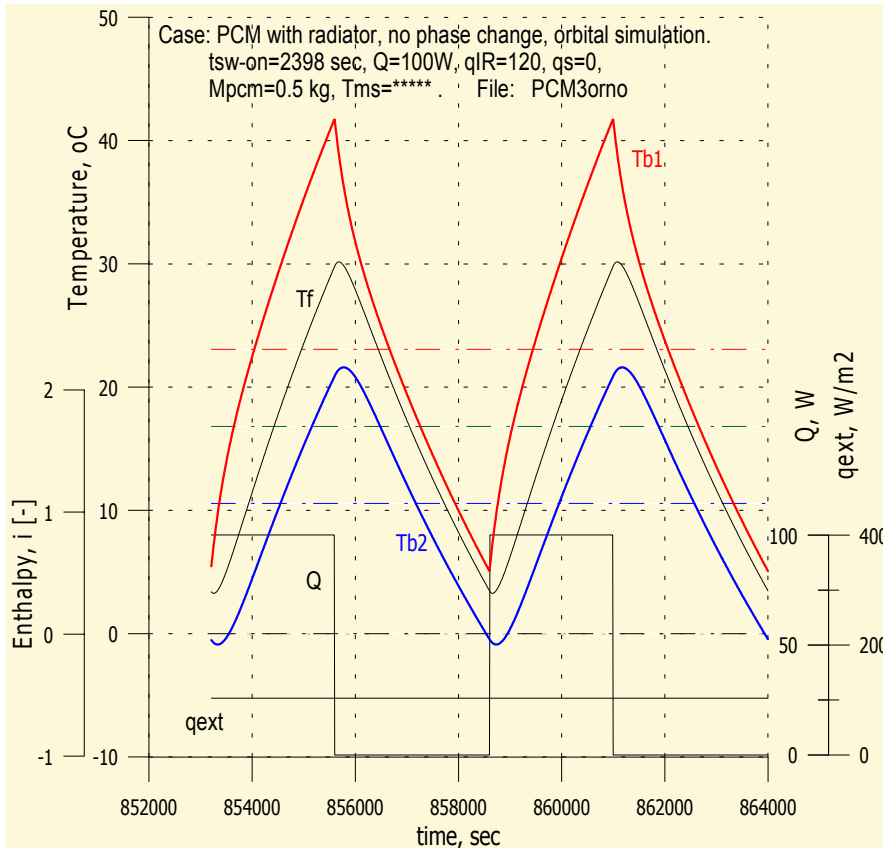
Com estrutura de honeycomb



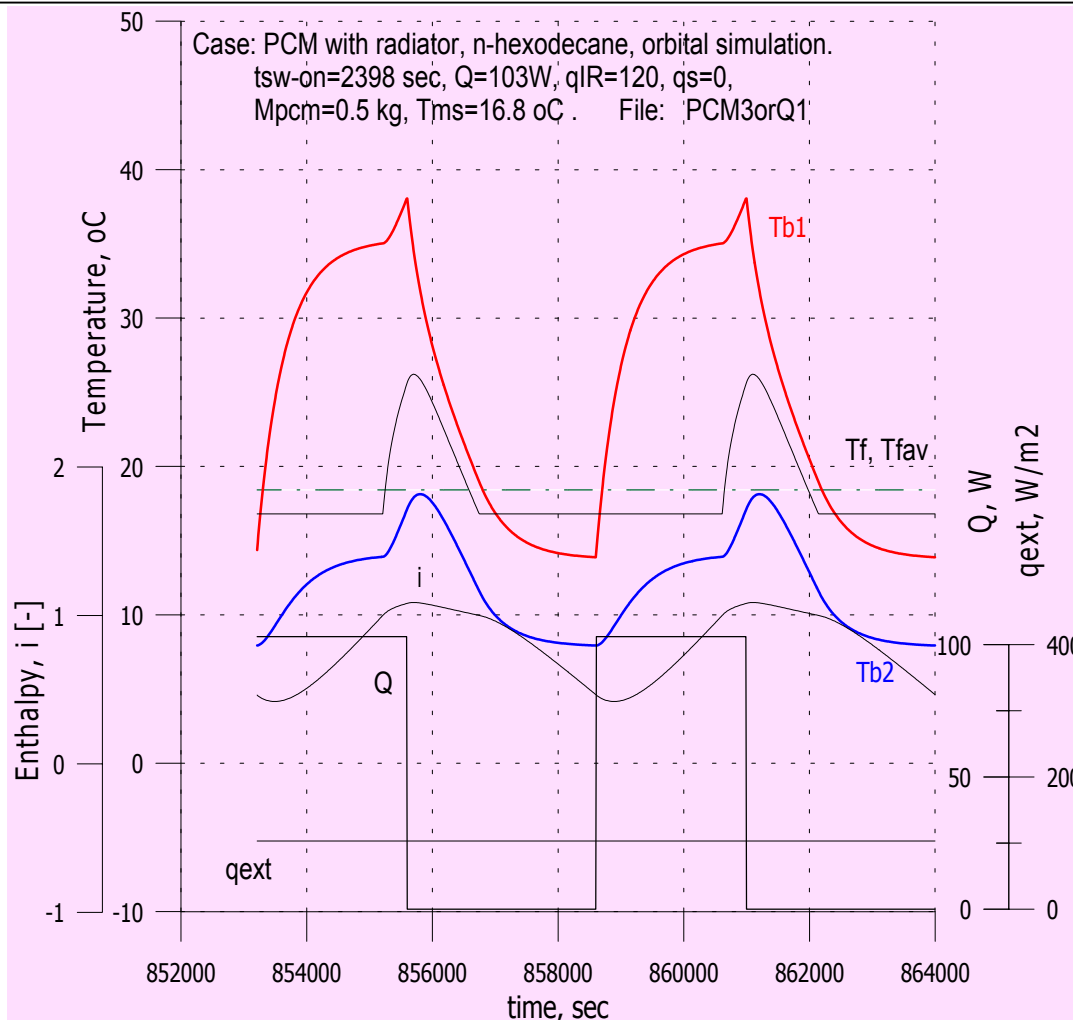
PCM-2: Influência de gravidade



Resultados de simulação numérica: redução de amplitude



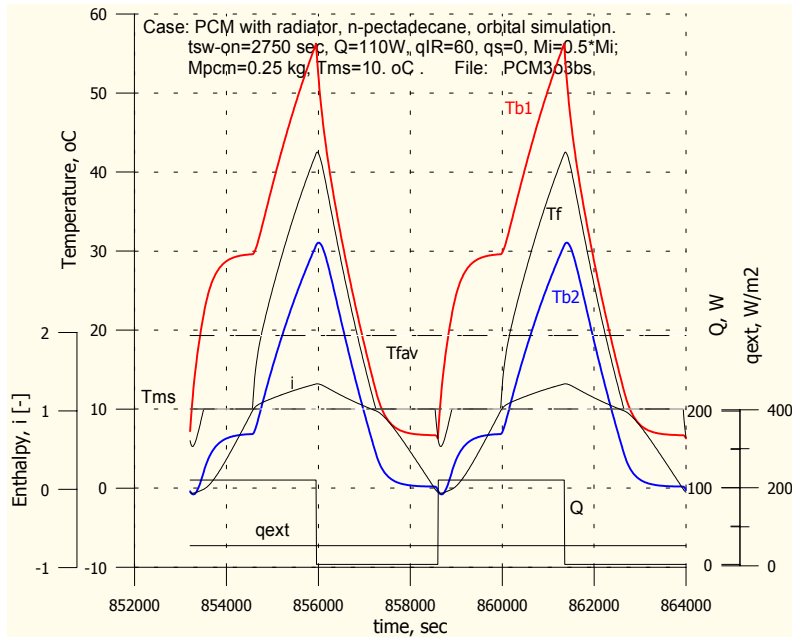
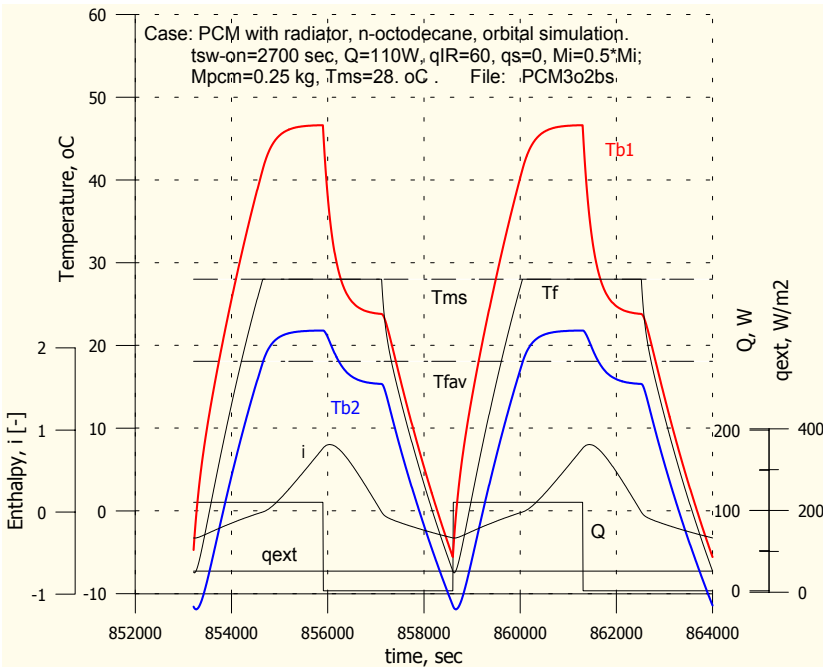
Caso de redução de amplitude: alta sensibilidade a variações de fluxo de calor aplicado



$$K_+ (\delta \bar{S} | \delta \bar{Q}_{\max}) = \frac{\delta S}{S} \frac{Q_{\max}}{\delta Q_{\max}} = 5.46$$

$$K_- (\delta \bar{S} | \delta \bar{Q}_{\max}) = \frac{\delta S}{S} \frac{Q_{\max}}{\delta Q_{\max}} = -5.65$$

Casos de prevenção de super-aquecimento ou sub-resfriamento

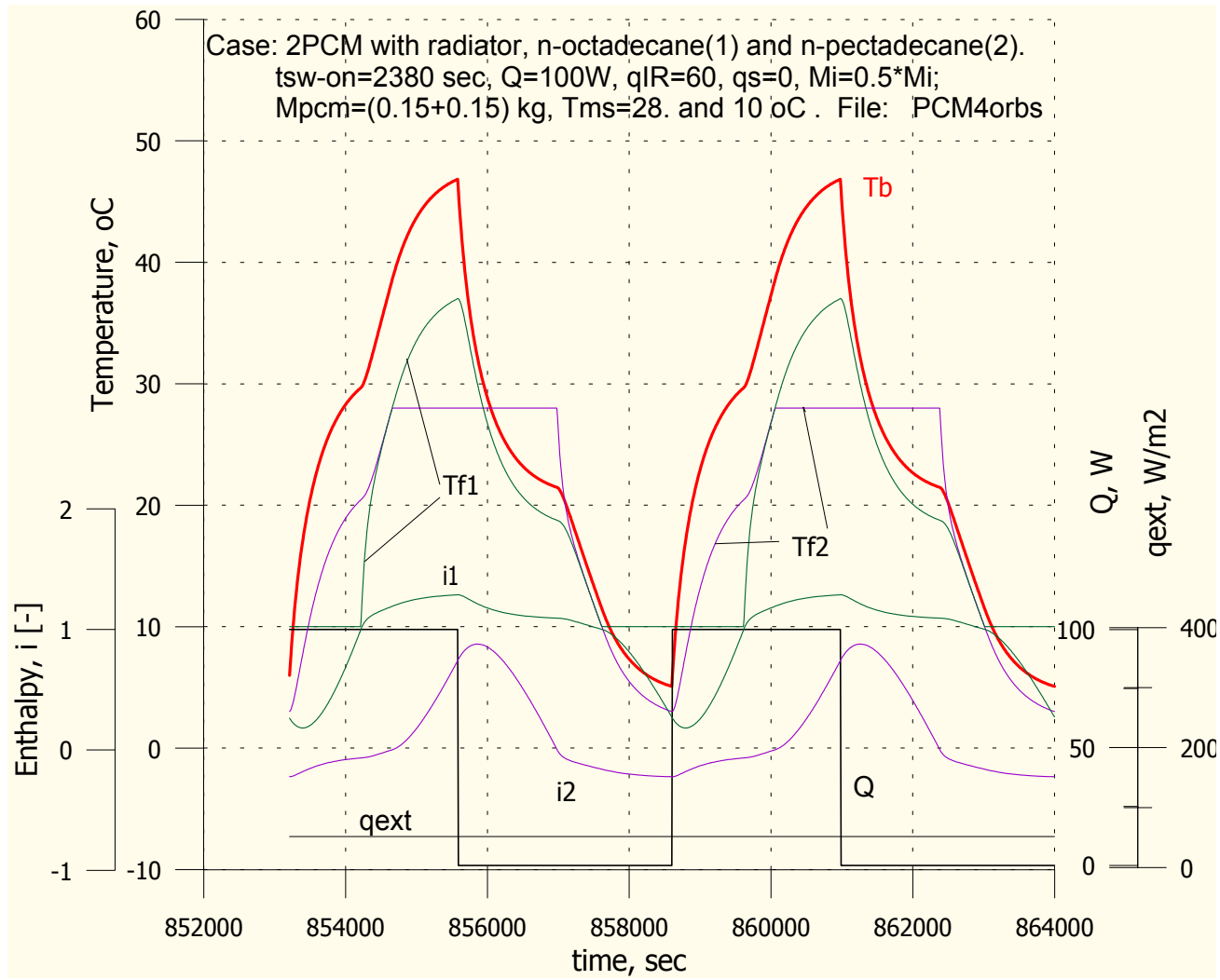


Baixa sensibilidade a variações de fluxo de calor

$$K_+ (\delta \bar{S} | \delta \bar{Q}_{\max}) = \frac{\delta S}{S} \frac{Q_{\max}}{\delta Q_{\max}} = 1.94$$

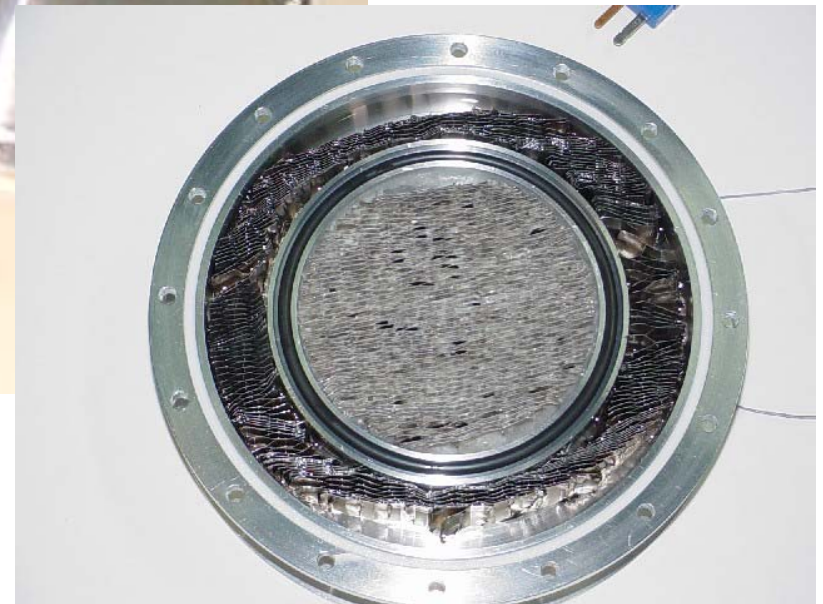
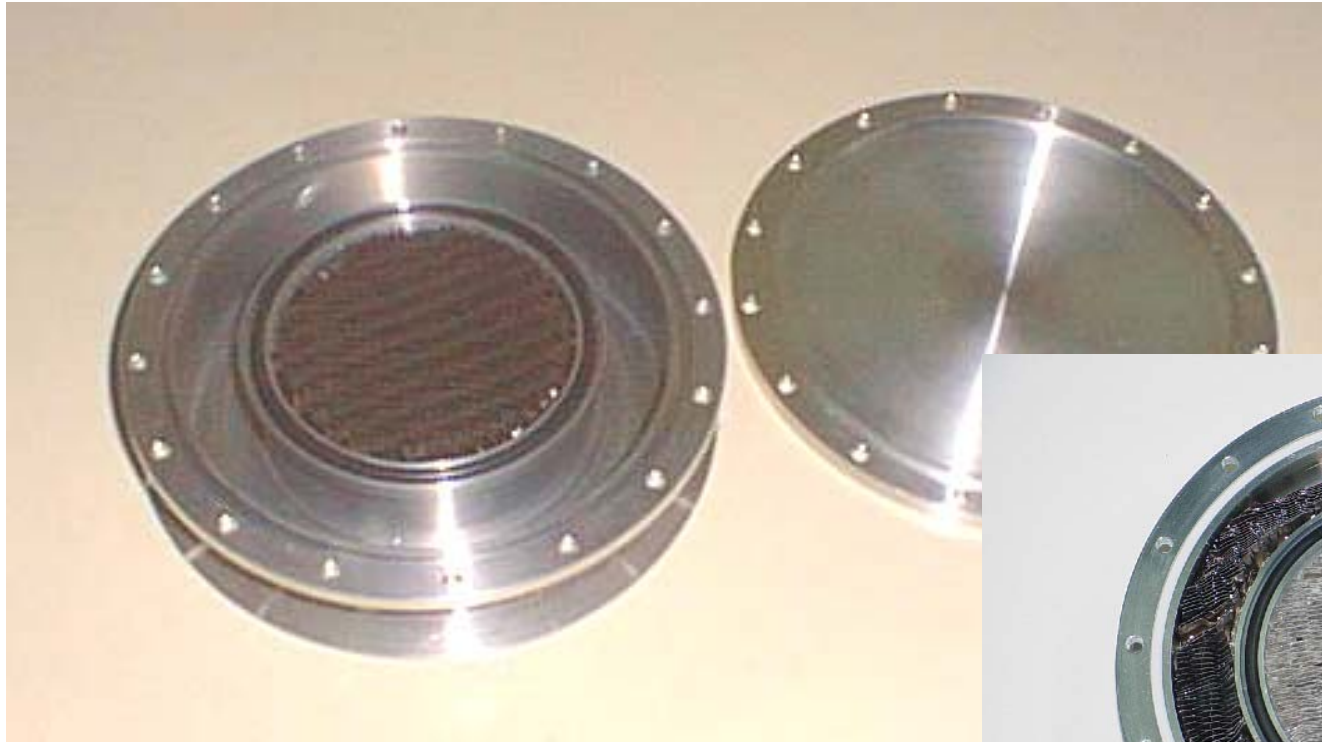
$$K_- (\delta \bar{S} | \delta \bar{Q}_{\max}) = \frac{\delta S}{S} \frac{Q_{\max}}{\delta Q_{\max}} = 1.17$$

Concepção de um capacitor com dois volumes

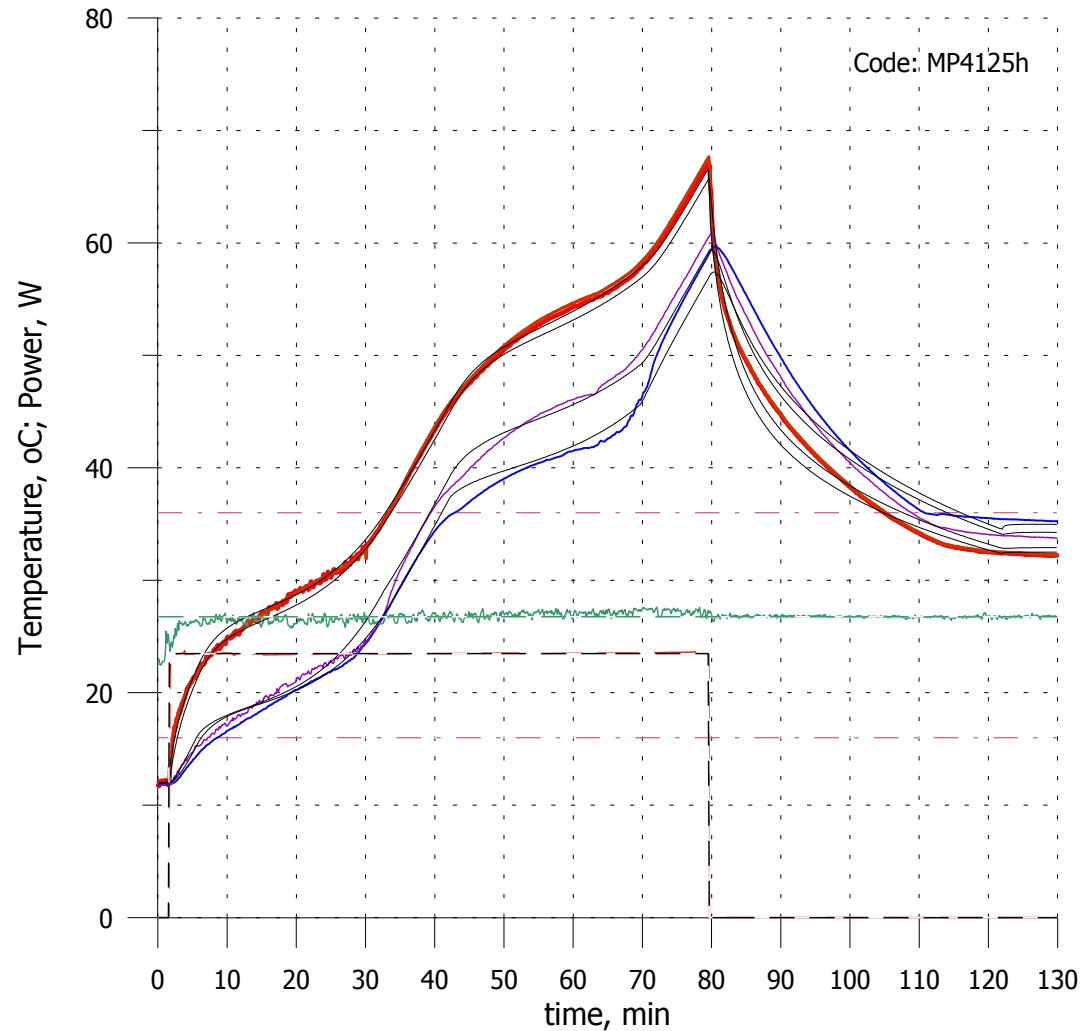
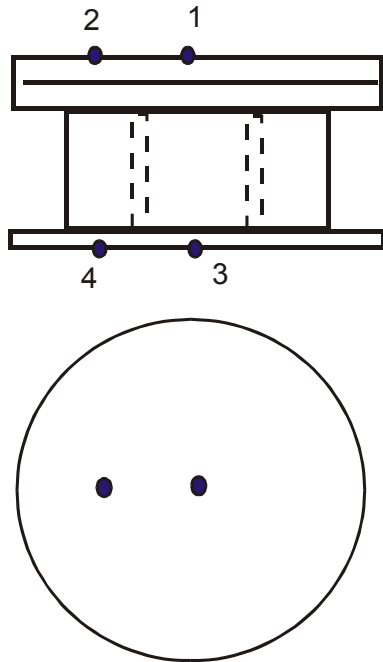


Protótipo PCM -3

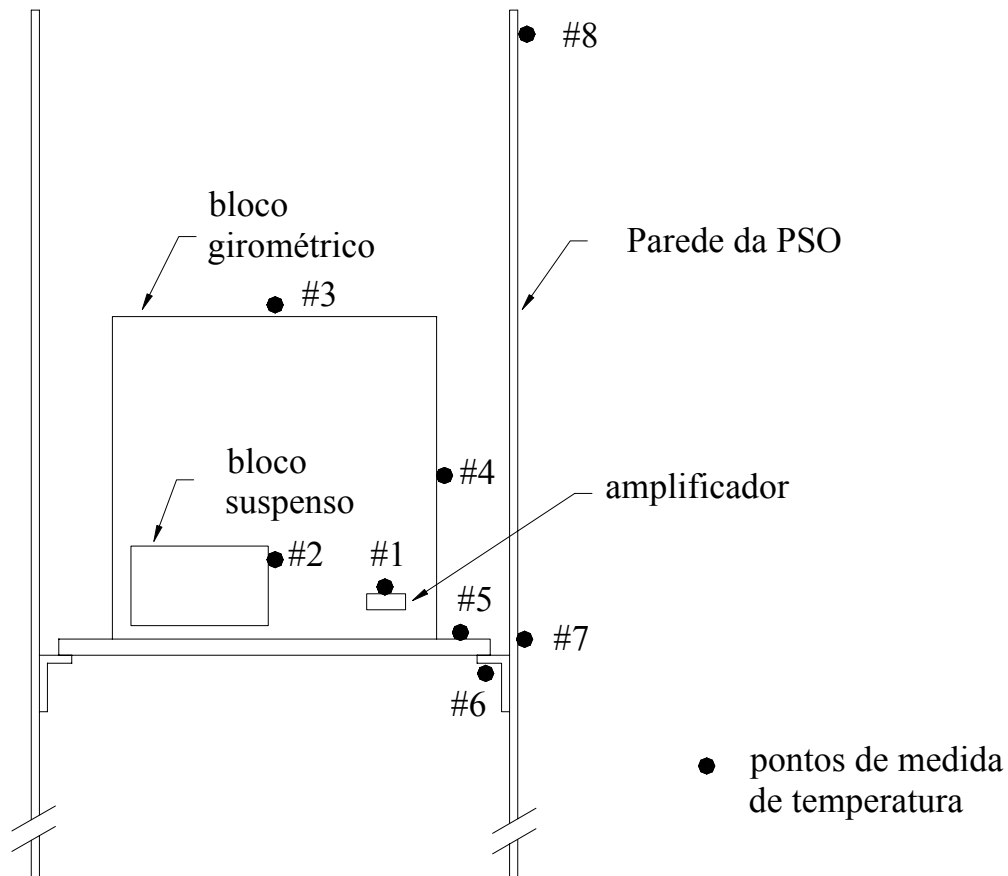
de 150+170 ml de n-pectadecane e n-octodecane



Capacitor térmico de 2 volumes: teste

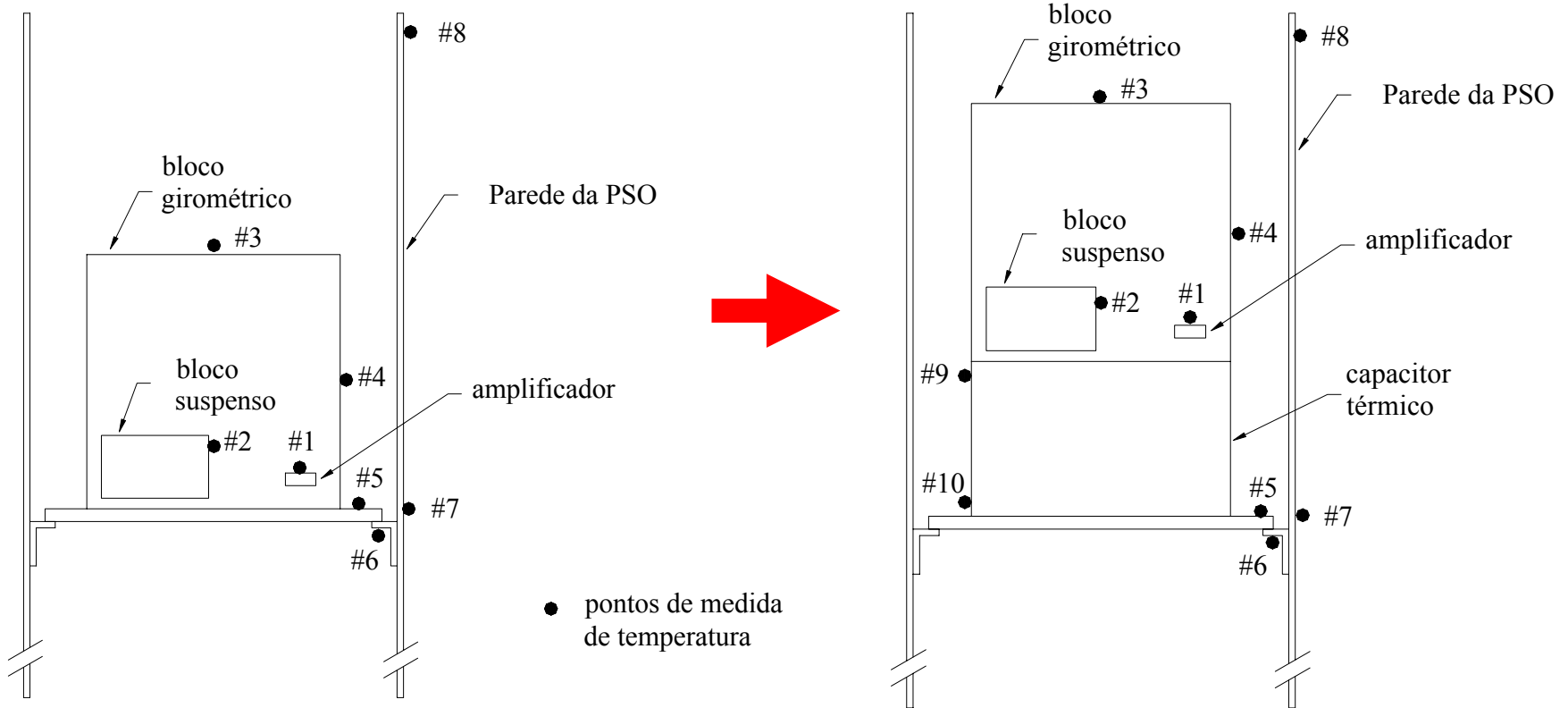


PSO – Plataforma Sub-Orbital

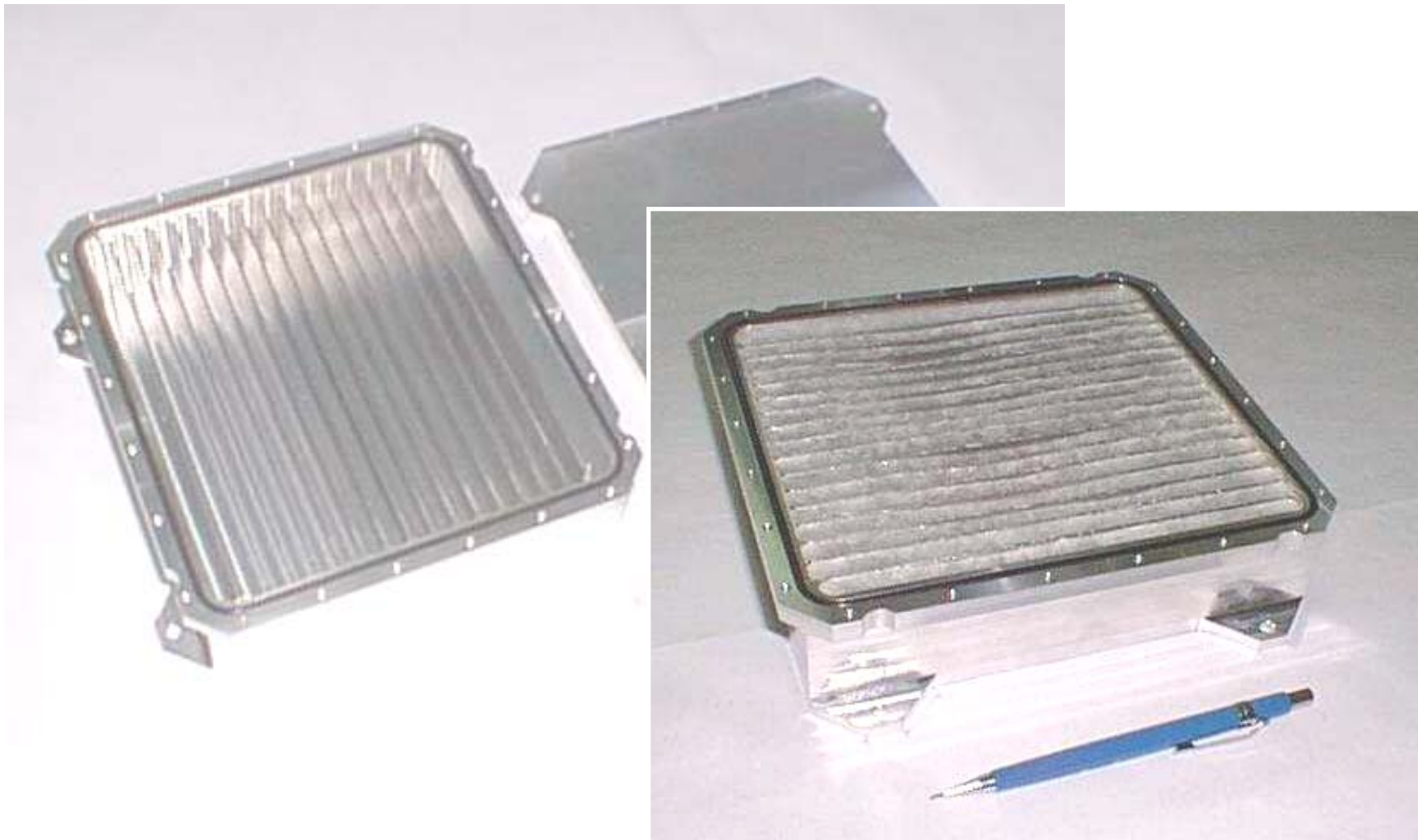


Plataforma Sub-Orbital

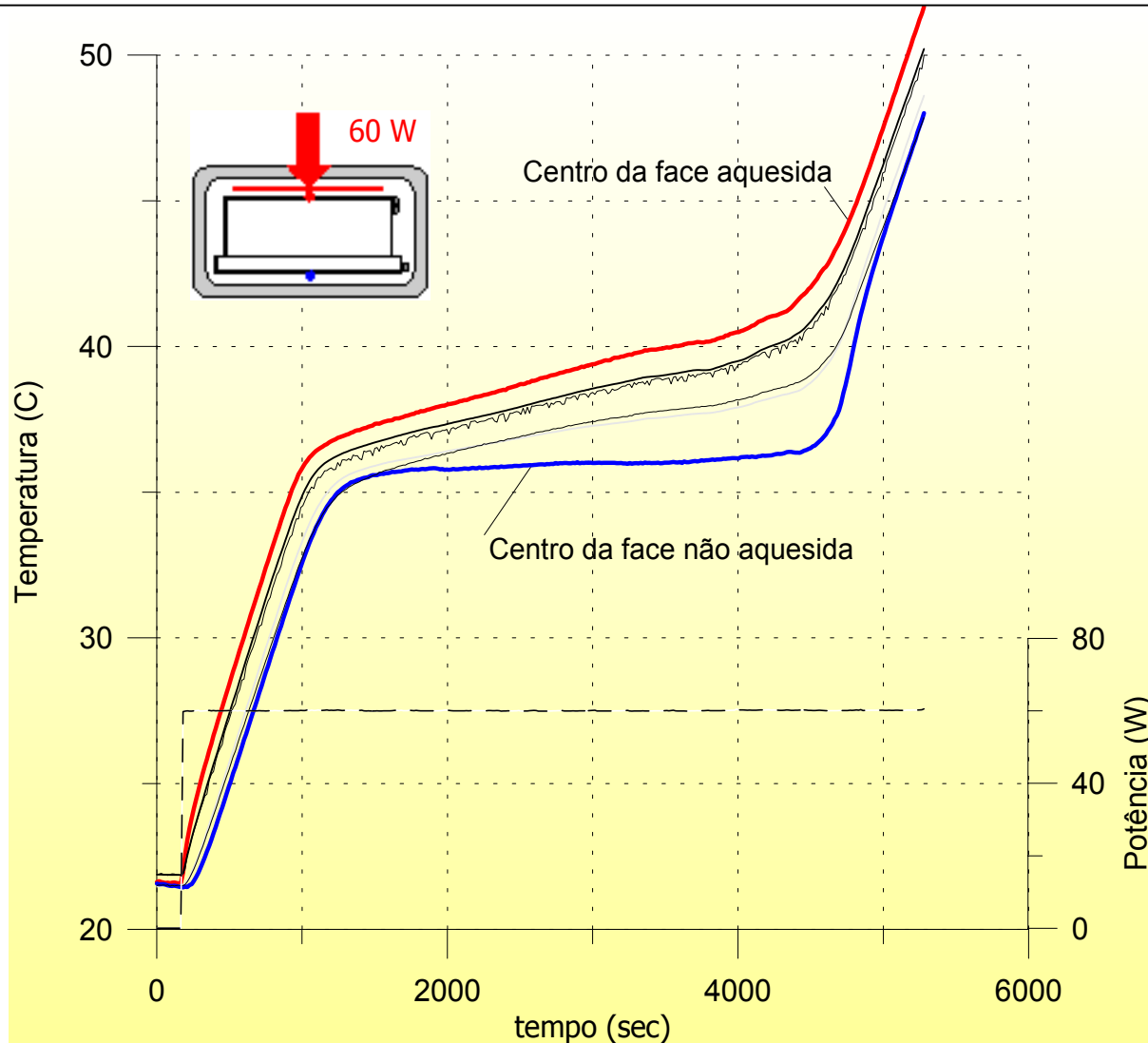
Aplicação do capacitor térmico



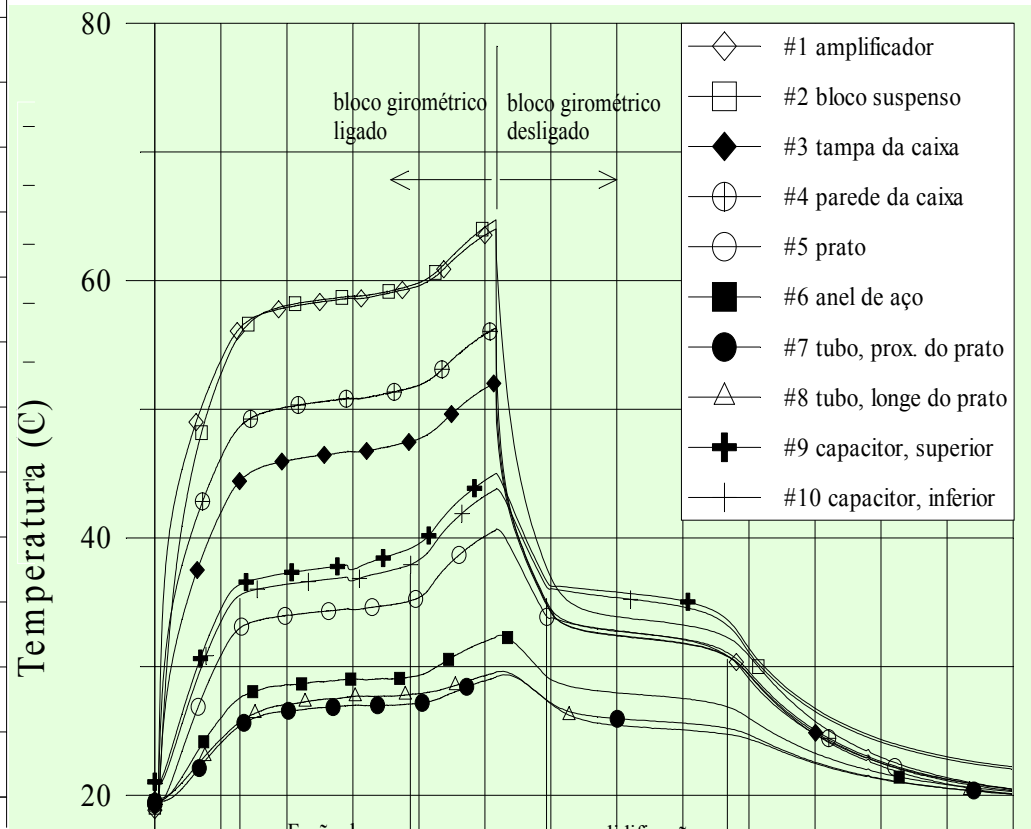
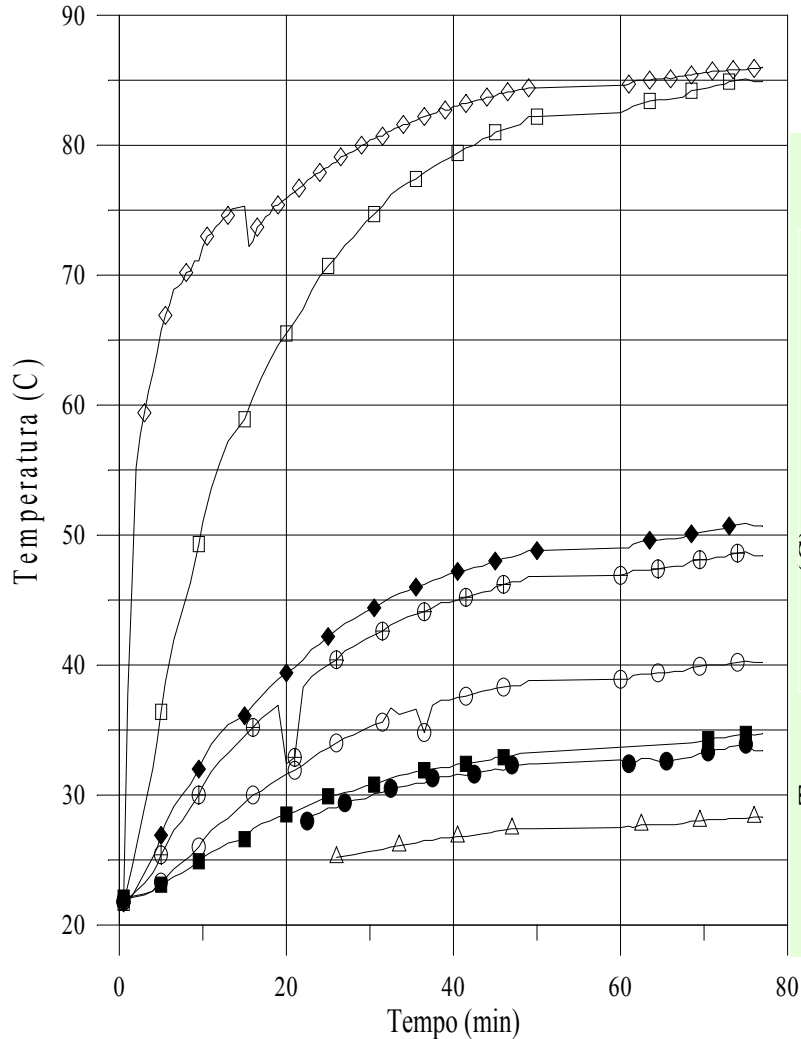
Plataforma Sub-Orbital: Capacitor de 1100 ml



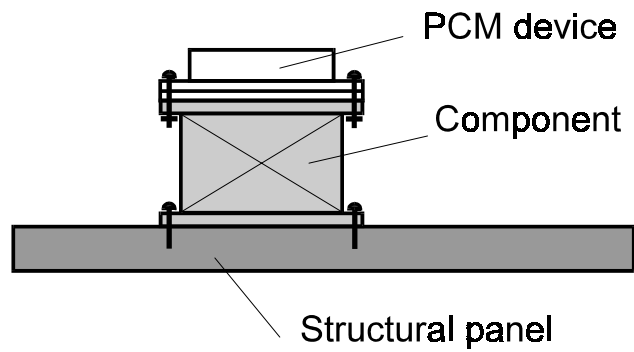
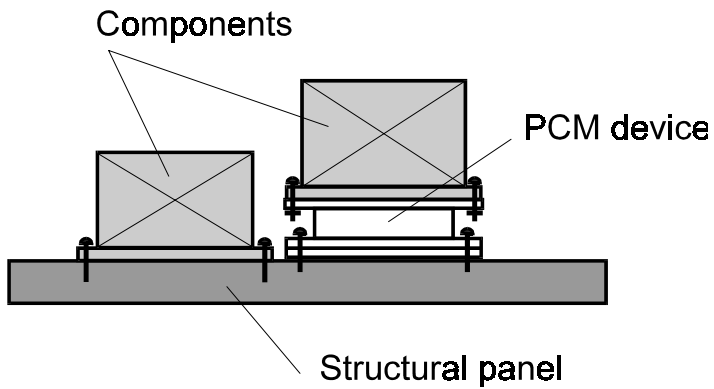
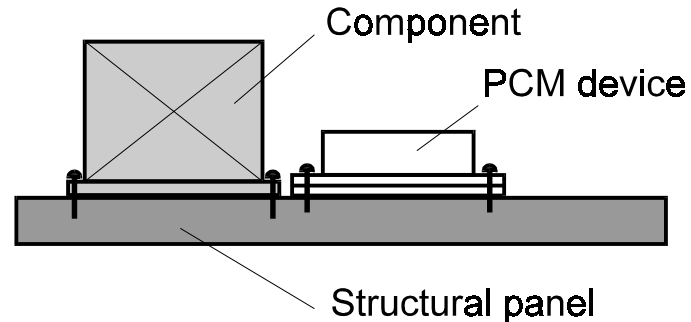
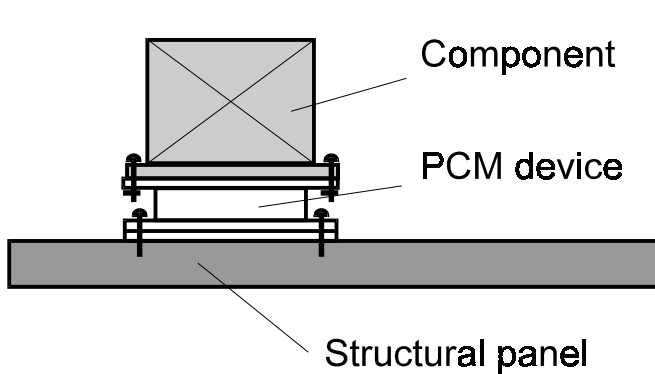
PSO: Teste do capacitor - 60 W



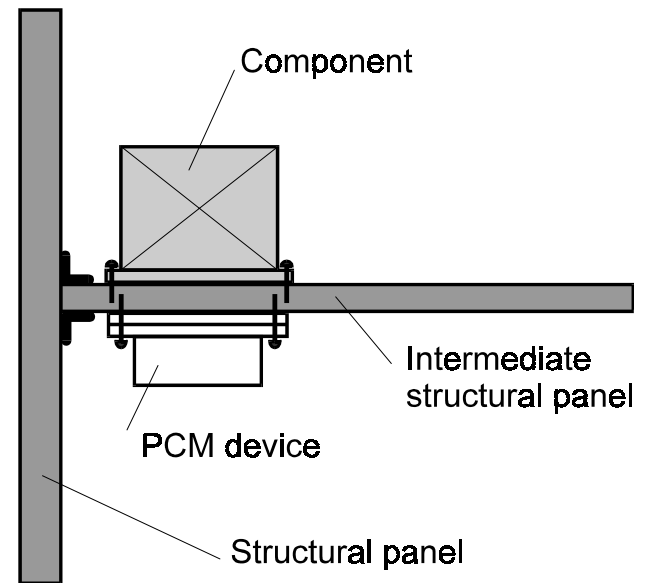
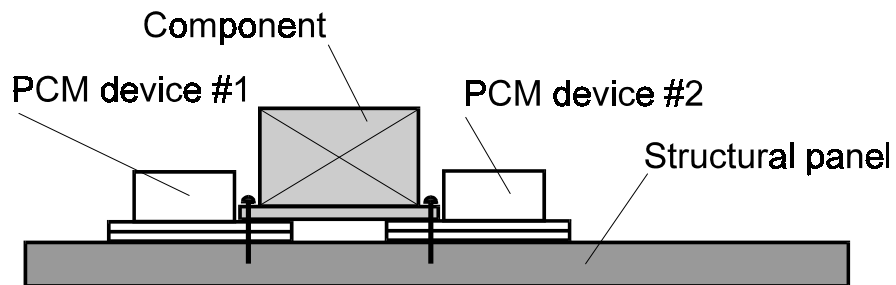
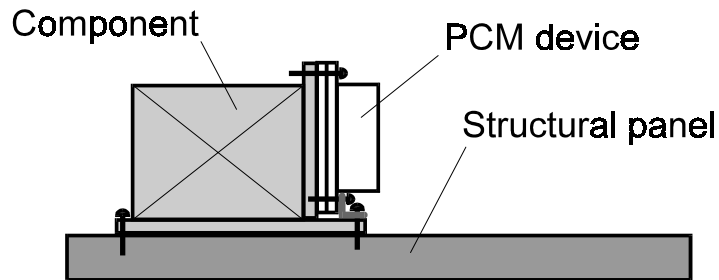
PSO: Testes sem e com o capacitor



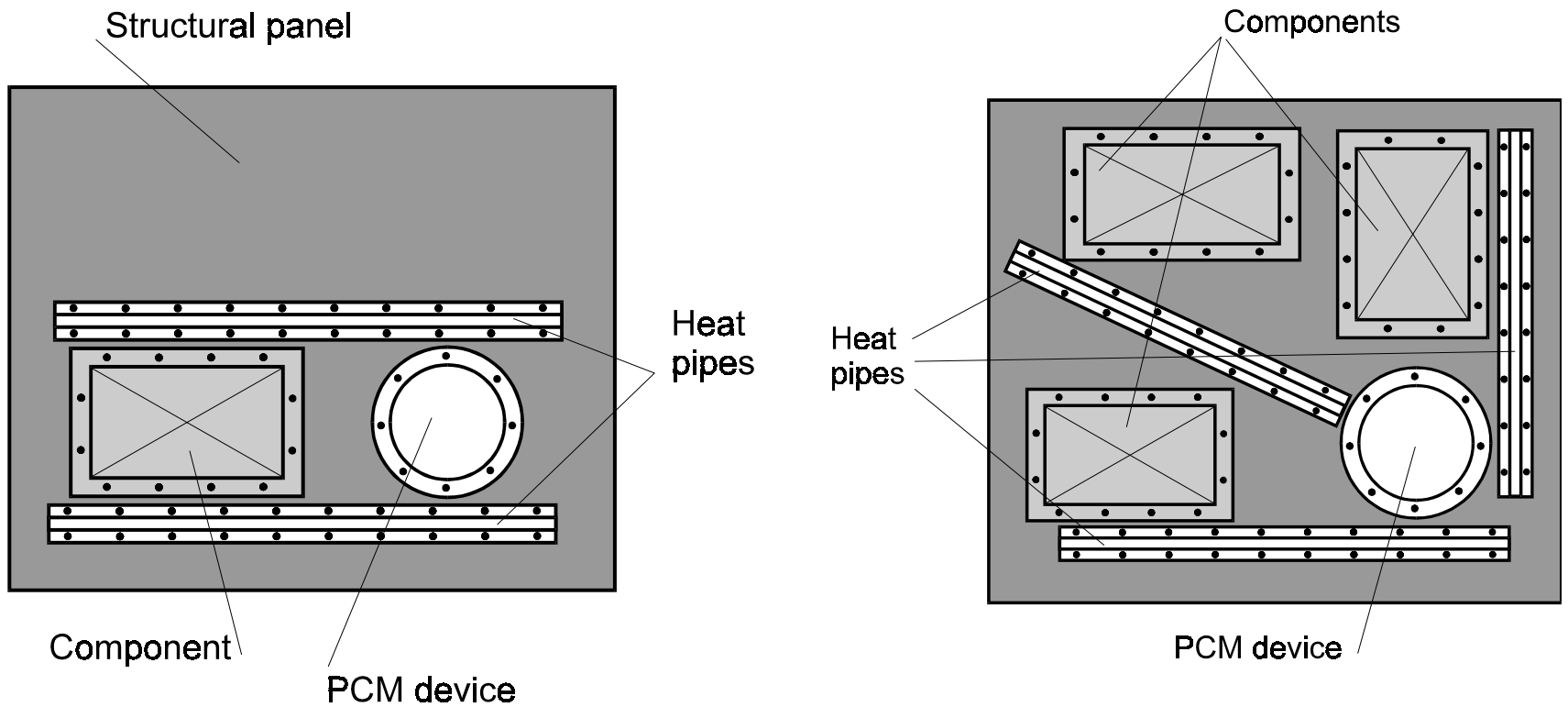
PCM: Aplicações possíveis para satélites



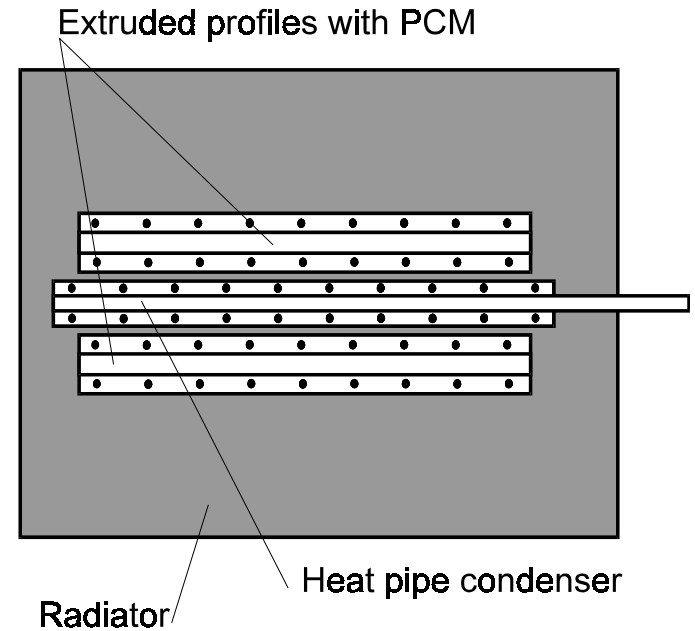
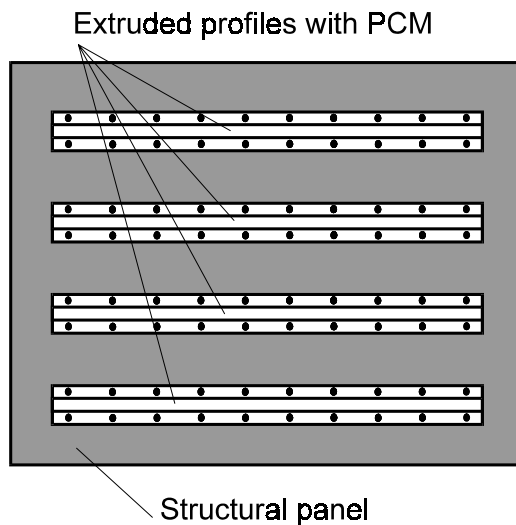
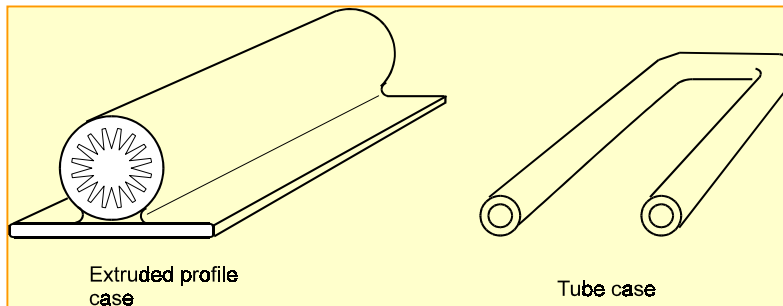
PCM: Aplicações possíveis para satélites



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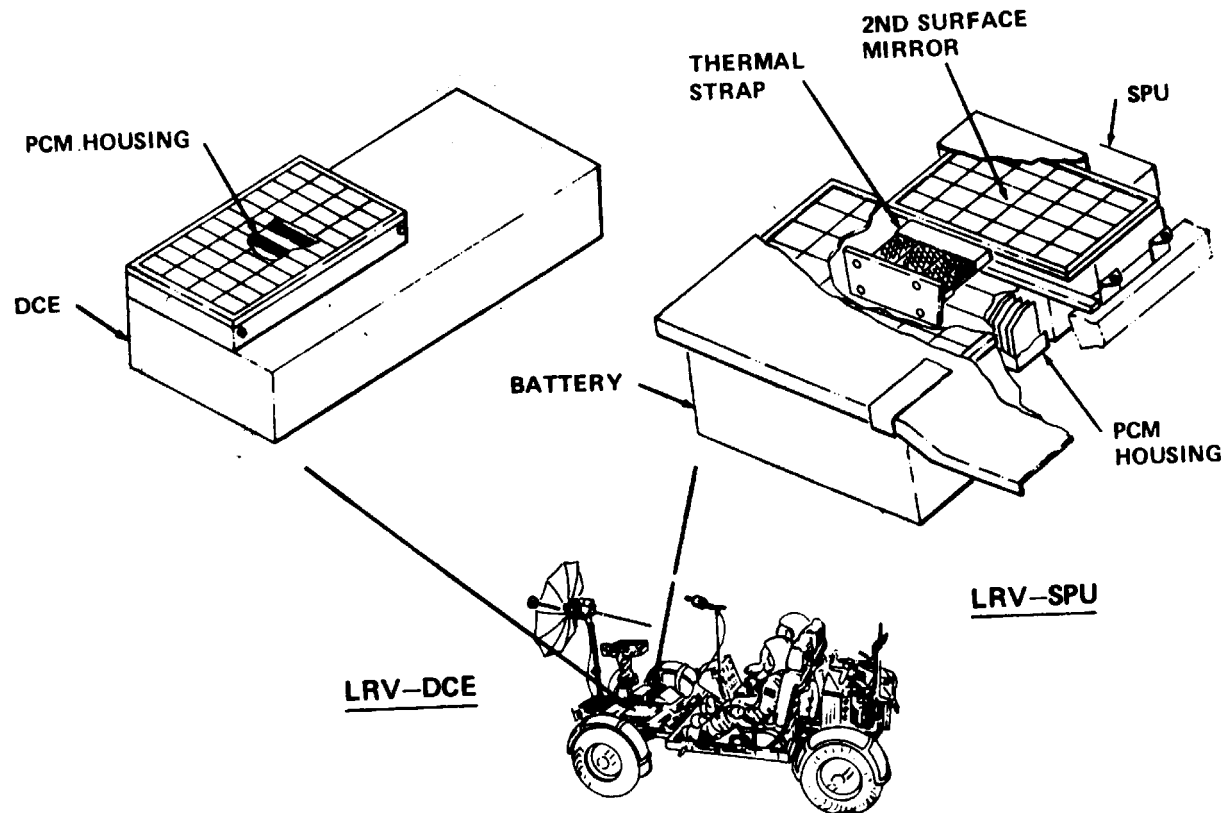


PCM: Aplicações possíveis para satélites



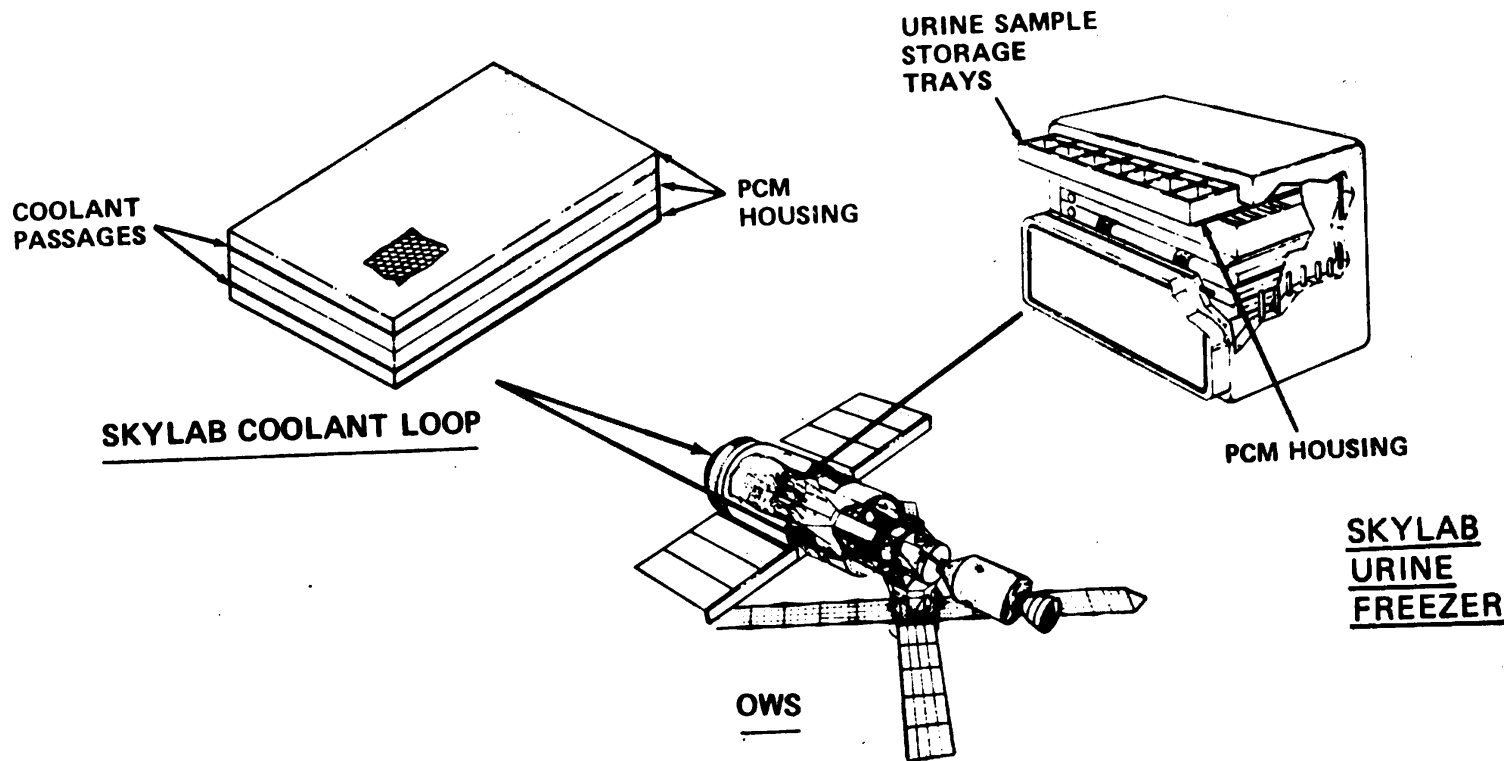
Aplicações de PCM

Estabilização térmica de unidades DCE e SPU em LRV



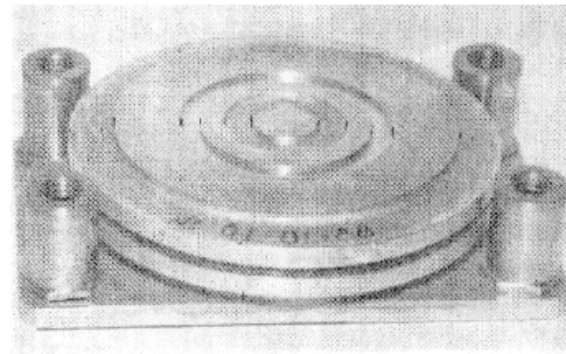
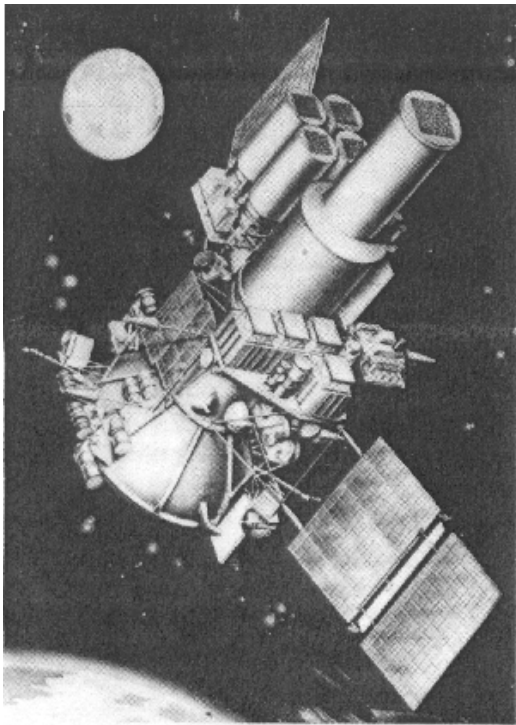
Aplicações de PCM

PCM em Skylab



Aplicações de PCM

“Switch” de PCM em experimento LHP no Granat



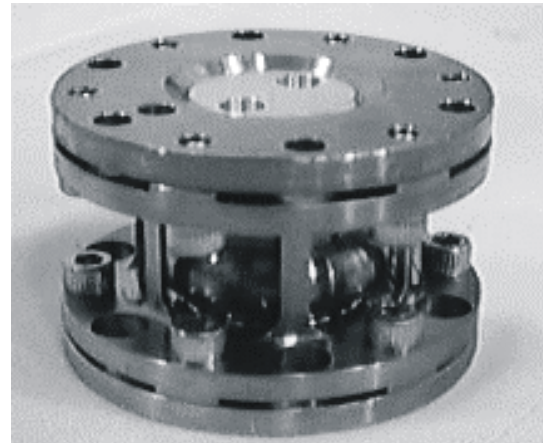
Capacitores térmicos: aplicações

Heat Switch

Starsys PCM plunger

Passive switch

100 g; 1.5" dia.



T. Knowles, Energy Science Laboratories, Inc; 2003 Spacecraft Thermal Control Workshop

Capacitores térmicos: aplicações

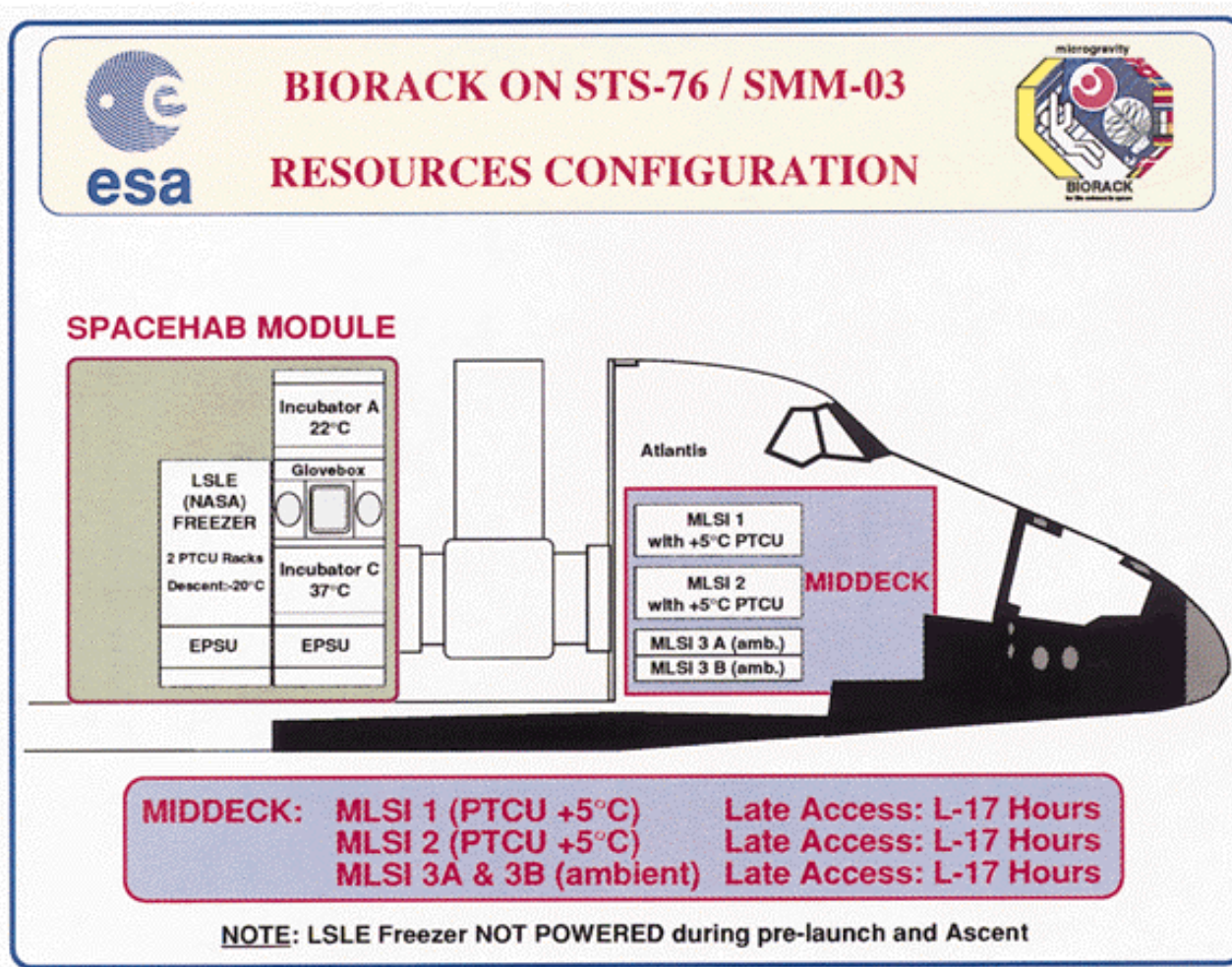
TEB – Thermal Engineering Branch of GSFC/NASA

Phase Change Thermal Storage

- Vegetation Canopy Lidar
Spacecraft (VCL)
- PCM (hexadecane) in 5
honeycomb panels
- absorbs peak heat from 4 lasers
- Isothermal Blackbody Targets
(room temp)
 - MODIS ground demo
calibration target; +/- 0.1°C

<http://mscweb.gsfc.nasa.gov/545web/Technology.html>

Capacitores térmicos: aplicações



<http://esapub.esrin.esa.it/microgra/micrv10n2/images/briv10n2f3.gif>

Capacitores térmicos

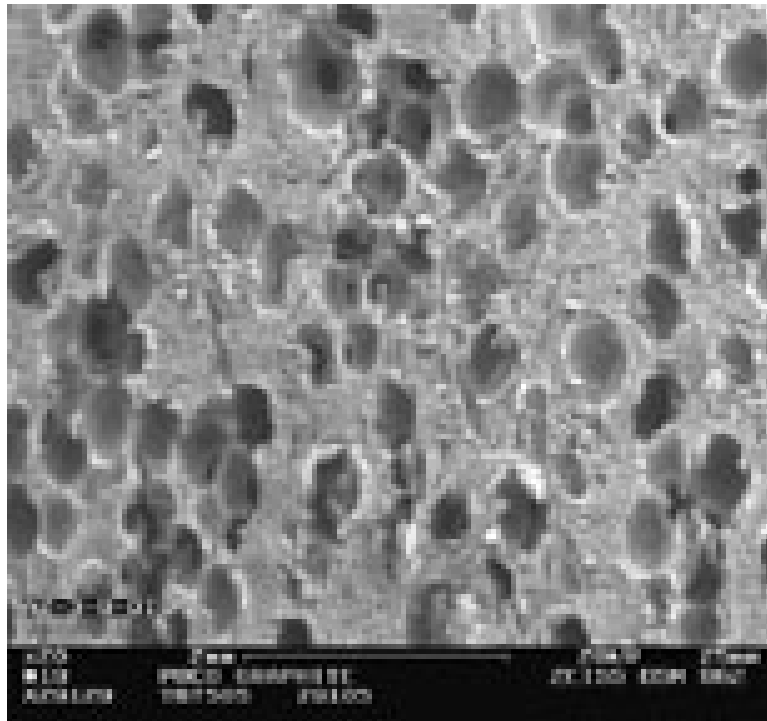
**Energy Science Laboratories,
Inc. (ESLI)**

ESLI's paraffin based heatsinks can be designed to operate at or near 5, 18, 28, 37, 44, 55, or 61 °C. Non-paraffin based designs are also available for cryogenic or high temperature applications. ESLI's PCM composite heatsinks have been space flight tested on the Space Shuttle (STS-95) aboard the CRYOTSU experiment module, and will fly aboard NASA's Vegetation Canopy LIDAR experiment in 2000



www.esli.com

Capacitores térmicos: uso de grafite



Typical Material Properties*

AVERAGE

Density	0.9 g/cc
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Compressive Strength	855 psi
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THERMAL CONDUCTIVITY

Out of Plane	245 W/mK
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In Plane	70 W/mK
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Total Porosity	61%
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Open Porosity (% of total)	95%
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Average Pore Diameter	350 microns
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CTE

TEMPERATURE RANGE	In-Plane AVG	Out-of-Plane AVG
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323 to 423°K/50 to 150°C	1.02	-1.07
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423 to 573°K/150 to 300°C	1.91	-0.02
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573 to 873°K/300 to 600°C	2.64	0.73
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873 to 1073°K/600 to 800°C	3.26	1.31
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Values in ppm/°K or ppm/°C

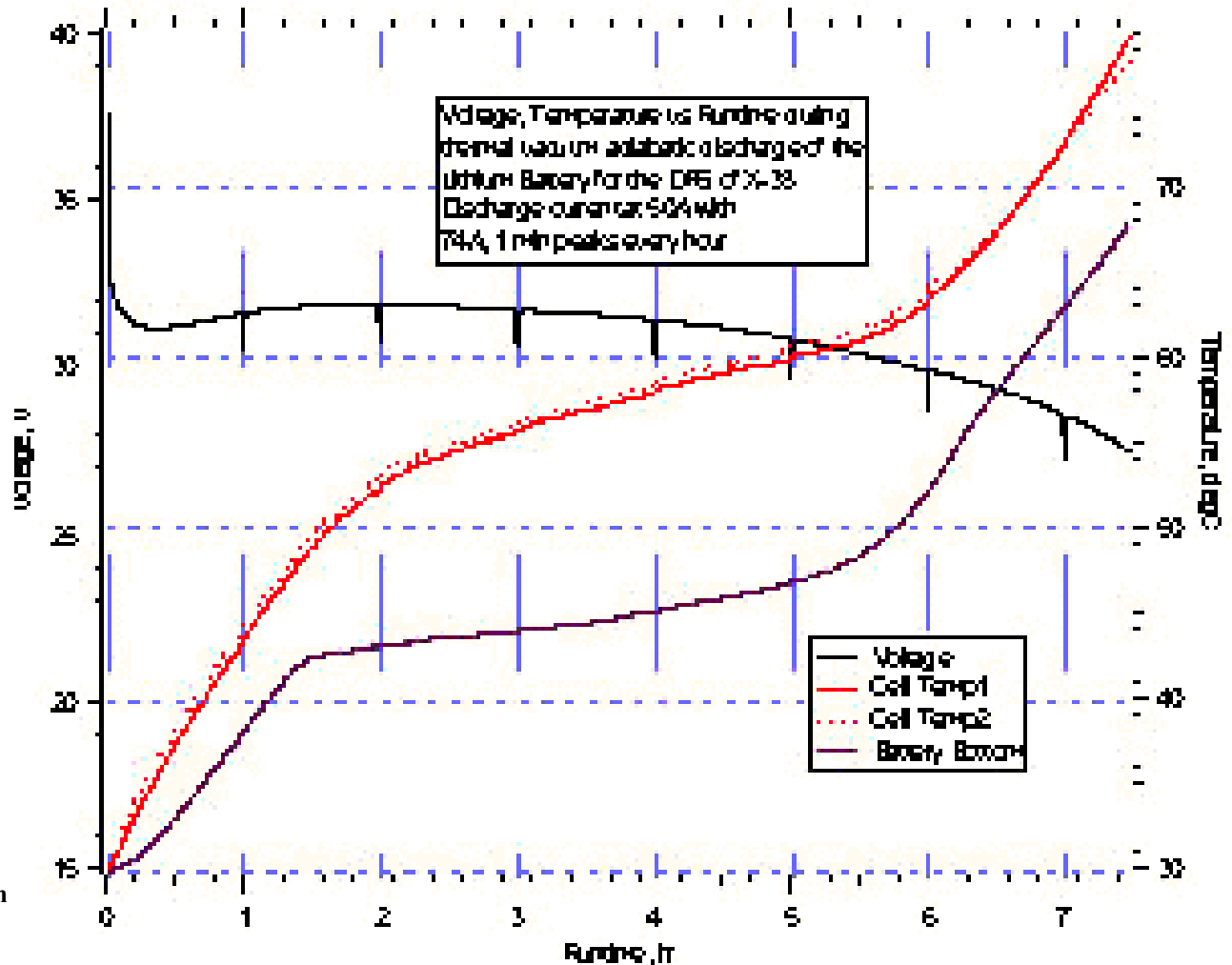
*Developmental stage material, properties may vary.

<http://www.pocothermal.com/html/whatis2.html#>

<http://www.poco.com/>

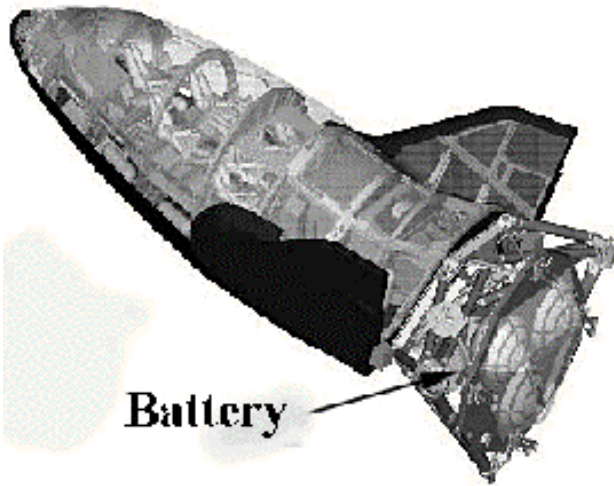
Capacitores térmicos: aplicação para X-38

Qualification test data showing the thermal performance of the batteries with their heat sink shows that the heat absorbed by the melting wax properly maintains battery temperature in the 50 to 60 °C range for performance and safety. The data suggests that the wax took four hours from onset to completely melt.

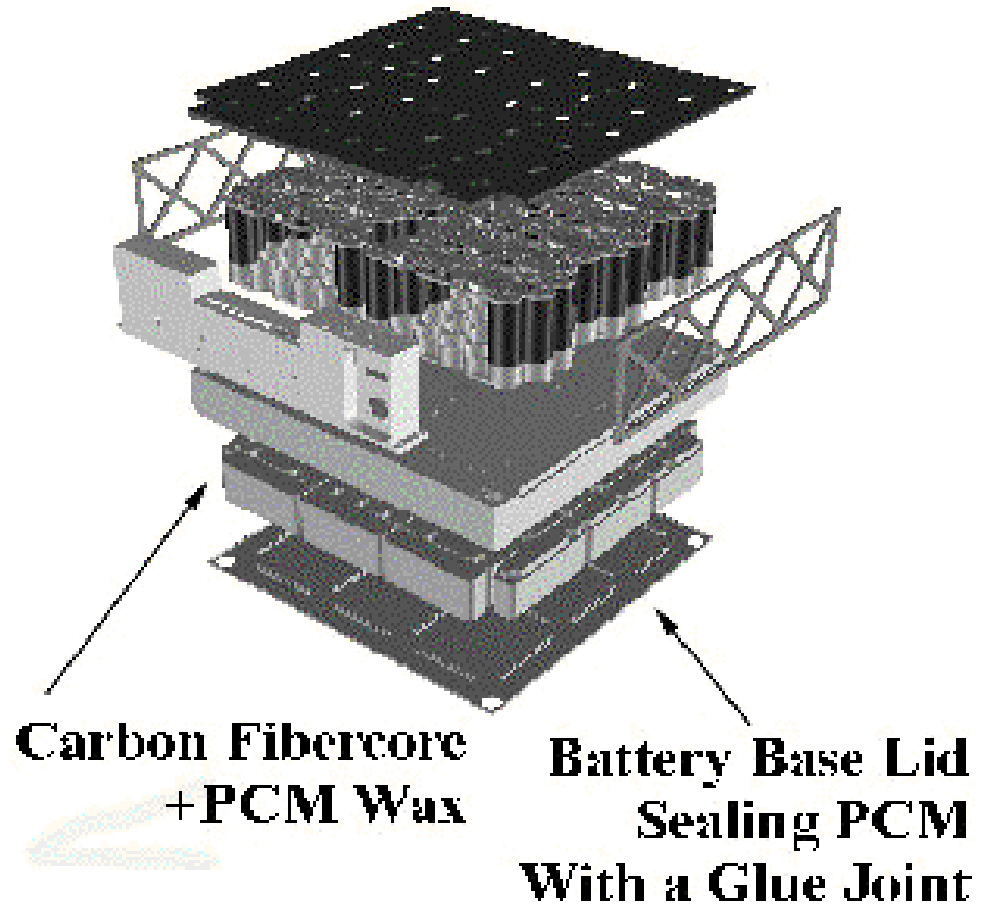


http://www.batteriesdigest.com/x_38.htm

Capacitor térmico no X-38



Lithium- manganese dioxide primary batteries which provide all initial vehicle power including a ctivation of rockets for re-entry



http://www.batteriesdigest.com/x_38.htm

Technology: Energy Sciences Laboratories