ECSS-E-HB-31-01 Part 11A
5 December 2011

Space engineering

Thermal design handbook - Part 11: Electrical Heating

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

Foreword

This Handbook is one document of the series of ECSS Documents intended to be used as supporting material for ECSS Standards in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.

The material in this Handbook is a collection of data gathered from many projects and technical journals which provides the reader with description and recommendation on subjects to be considered when performing the work of Thermal design.

The material for the subjects has been collated from research spanning many years, therefore a subject may have been revisited or updated by science and industry.

The material is provided as good background on the subjects of thermal design, the reader is recommended to research whether a subject has been updated further, since the publication of the material contained herein.

This handbook has been prepared by TEC-MT/QR division, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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Scope

In this Part 11, the use of electrical heaters and electrical coolers in spacecraft systems are described.

Electrical thermal control is an efficient and reliable method for attaining and maintaining temperatures. Solid state systems provide for flexibility in control of thermal regulation, they are resistant to shock and vibration and can operate in extreme physical conditions such as high and zero gravity levels. They are also easy to integrate into spacecraft subsystems.

The Thermal design handbook is published in 16 Parts

ECSS-E-HB-31-01 Part 1	Thermal design handbook – Part 1: View factors
ECSS-E-HB-31-01 Part 2	Thermal design handbook – Part 2: Holes, Grooves and Cavities
ECSS-E-HB-31-01 Part 3	Thermal design handbook – Part 3: Spacecraft Surface Temperature
ECSS-E-HB-31-01 Part 4	Thermal design handbook – Part 4: Conductive Heat Transfer
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ECSS-E-HB-31-01 Part 16	Thermal design handbook – Part 16: Thermal Protection System

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References

ECSS-S-ST-00-01	ECSS System - Glossary of terms
ECSS-E-HB-30-09 Part 15	Thermal design handbook – Part 15: Existing Satellites

All other references made to publications in this Part are listed, alphabetically, in the **Bibliography**.

3
Terms, definitions and symbols

3.1 Terms and definitions

For the purpose of this Standard, the terms and definitions given in ECSS-S-ST-00-01 apply.

3.2 Symbols

A	cross sectional area, [m^2]
I	electric current, [A]
L	length of conductive path, [m]
Q	heat transfer rate, [W]
Q_F	fourier effect heat flow, [W]
Q_J	joule heat flow, [W]
Q_P	peltier effect heat flow, [W]
Q_{cd}	conduction loss, [W]
Q_o	operating heat, [W]
Q_p	process heat transfer rate, [W]
Q_r	radiation loss, [W]
Q_{sl}	steady state loss, [W]
Q_w	warm-up power, [W]
R	electrical resistance, [Ω]
T_a	ambient temperature, [K]
T_f	final temperature, [K]
T_i	initial temperature, [K]

T_s	heat sink temperature, [K]
V	voltage, [V]
W	power, [W]
a	neat seebeck coefficient for two dissimilar materials, [W.K^{-1}.A^{-1}]
c_p	specific heat, [J.kg^{-1}.K^{-1}]
h	latent heat of fusion or vaporization, [J.kg^{-1}]
k	thermal conductivity, [W.m^{-1}.K^{-1}]
m	mass of material in each process load, [kg]
q_T	thomson effect heat flow per unit of conductor length, [W.m^{-1}]
t	cycle time for each load, [s]
tw	desired warm-up time, [s]
ΔT	difference of temperature between two junctions formed by dissimilar materials, [K]
ΔV_S	seebeck effect open circuit potential difference, [V]
ε	emissivity of heat sink material
σ	Stefan-Boltzmann constant = 5,6697 x 10^{-8} W.m^{-2}.K^{-4}
τ	Thomson coefficient, [W.K^{-1}.A^{-1}]

Subscripts

c	cool
h	hot
max	maximum

4
Electrical heating

4.1 General

Reliable long-term performance of most spacecraft components takes place at a specified temperature range. The attainment of some temperature range requires, in many instances, the generation of heat within the spacecraft. This involves simply turning up an electrical, chemical or nuclear heater.

When a local uniform heat source or a profiled heating area is needed, electrical heaters can provide it efficiently due to their versatility. Some applications are reported later in this clause.

Electrical heaters are based on Ohm's and Joule's laws.

Ohm's law states that the steady electric current, I, flowing through an electrical conductor is proportional to the constant voltage, V, and to the reciprocal of the electrical resistance of the conductor, R:

$I = V/R$

According to Joule's law, the heat released per unit time, Q, by an electrical current, I, is equal to the square of the electrical current, multiplied by the electrical resistance, R:

$Q = I^2R$

Three parts can be distinguished in an electrical heater:

4.1.1 Conductive element

Made up by a metal alloy with specific properties depending on the use:

- High-strength alloys to carry mechanical stress.
- Non-magnetic materials.
- High temperature-coefficient alloys for self-regulated heaters.

4.1.2 Electrical terminations

Depending on the objectives and operating conditions of the heater, the most widely used options are:

Welded leadwire

Crimped leadwire

High-temperature wire

UL-approved wire

Solder pads

Pins and connectors

Plated through-holes

Integral flex-circuits

Flat foil leads

4.1.3 Electrical insulation

4.1.3.1 Kapton/FEP insulation

For temperature requirements less than 473 K, heaters constructed of Kapton film and FEP Teflon have been qualified (NASA S-311-79) and flight tested for space. The Kapton film used generally is 0,05 x 10^{-3} m thick, with a thermal conductivity of 163 $W.m^{-1}$. It is used either onboard spacecraft or for simulation purposes in ground experiments. It has good flexibility and light weight; it is chemical and radiation resistant (to 10^6 rads) and present low outgassing. See Taylor (1984) [11].

Two types of Kapton laminated heater elements are manufactured:

- Coiled wire is used for resistances up to 620 x $10^4\Omega/m^2$. It withstands severe flexing with repeated installations and removals, because flexing does not bend the wire as it does to a printed circuit.
- Printed circuit Kapton/FEP heater is an etched nickel alloy foil with a clear amber pollyimide insulation. It can be quite complex, with cutouts, void areas, and unusual shapes. Varied watt densities within the same element can be obtained by controlling the pattern.

It is the right choice for flat surfaces because heat is more efficiently transferred and, also, the foil heater can be reproduced with great precision by photographic techniques. This kind of heaters has been widely used in space applications.

Higher watt densities and greater reliability can be obtained with an aluminium foil backing: it spreads heat and eliminates hot spots due to voids in mounting adhesives.

4.1.3.2 Other insulations

Electrical heaters working in hard conditions, like temperatures over 473 K, are sheathed in metal. Alumina insulation is used to encase a spiral-wound or a straight wire resistance element within the sheath. Moisture is removed and the enclosure is helium leak tested. Electrical connections are made through a glass-to-metal seal header.

There are other kinds of foil heaters, with different insulations, but their usefulness in space applications is limited. Nevertheless, they are mentioned here:

- Nomex heaters are used as a low cost alternative to Kapton. It is radiation resistant to 106 rads, but it is not suitable for vacuum.
- Silicone rubber is a fiberglass reinforced elastomer, it may be vulcanized to heat sinks and it is resistant to many chemicals but it is not suitable for vacuum or radiation. It is used for commercial and industrial applications because of its low cost and high temperature rating compared to Kapton.
- Mica heaters are rigid, so they should be factory formed and are clamped to heat sinks with rigid backing plates, or else their layers will separate during warm-up. They can be

used in vacuum after burn in. They can withstand temperatures up to 866 K, and high watt densities, up to 1705 x 10^3 W.m^{-1}.

- Kapton/WA is a clear amber polyimide film with acrylic adhesive. It is chemical and radiation resistant, with low outgassing, low cost and high resistance densities. The only problem is its narrow temperature range that limits applications over 423 K.
- Polyimide glass (Fiberglass reinforced polyimide) heaters have reduced flexibility but they have a temperature range up to 513 K and a potential for high watt densities.
- Optical grade polyester heaters have an 82 % light transmission and could be mounted in windows, lenses or between LCD and backlight, in cockpit displays and handheld terminals, in order to prevent condensation and permit cold weather operation.
- Polyester is a low cost solution for economic fabrication of large heaters.
- Scrim is an open weave fiberglass cloth for lamination inside composite structures.

Temperature range for some insulations, compared to Kapton/FEP, are represented in Figure 4-1.

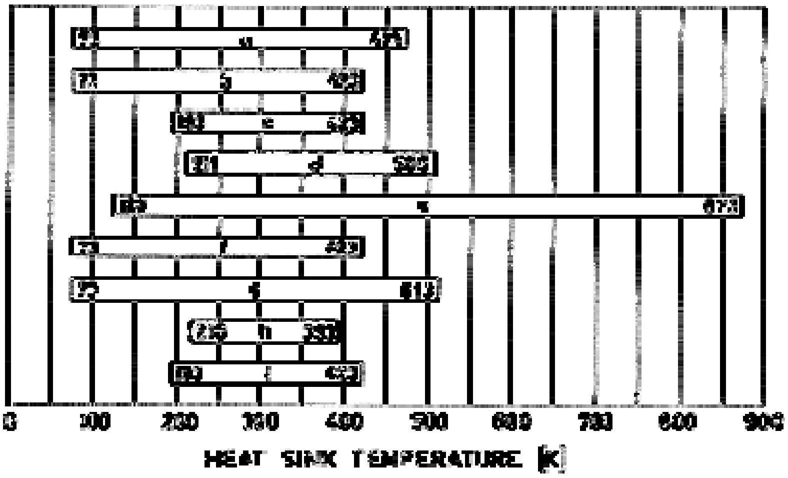


Figure 4-1: Temperature range of thermofoil heaters depending on insulation. From MINCO (1989a) [6]. a) Kapton/FEP, b) Kapton/FEP Al backing, c) Nomex, d) Silicone Rubber, e) Mica, f) Kapton/WA, g) Polyimide Glass, h) Polyester, i) Scrim.

4.1.4 Outgassing

Outgassing in a vacuum environment, in terms of weight loss versus time is an important property in space applications, see Figure 4-2. Essentially the outgassing products are water, carbon monoxide and carbon dioxide. Loss weight in Kapton/FEP is very low, about 1 %, and it occurs during the first few hours of test.

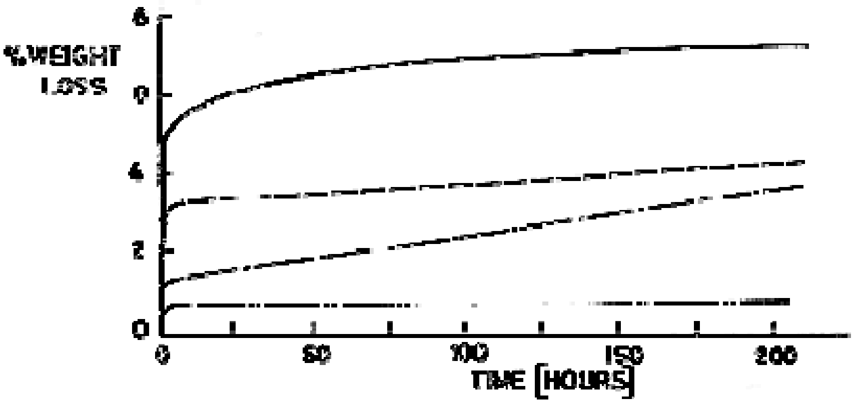


Figure 4-2: Outgassing in a vacuum environment. Weight loss versus time. Temperature 473 K, pressure 4 x 10^{-4} Pa, preconditioning 50 % RH. From MINCO (1973) [5]. ———: Cross-linked polyalkane; — —: Silicone rubber, MIL-W-16878/7; —·—: MIL-W-81044/1; —··—: Kapton, Type HF.

4.2 Space applications

Electrical heaters have had a widespread gamut of uses. Some of them are mentioned in this clause.

4.2.1 Viking spacecraft

Thermostatically controlled electric heaters were used in the lander body to:

- Maintain the propulsion systems over hydrazine freezing point (275 K) and, at the same time, maintain the cavity around the lander body at a relatively low temperature to prevent overheating of the lander internal equipment during the pre-separation checkout operation.

— Accurate temperature control in critical parts of the biology and gas chromatograph/mass spectrometer experiments.

— Pyrolyze Martian soil samples.

— Heat external meteorology instruments and semi-external but insulated cameras.

From Tracey, Morey and Gorman (1978) [12].

4.2.2 Fltsatcom spacecraft

This satellite is essentially a constant power dissipation spacecraft, therefore this dissipation is produced by the electronic units within the spacecraft and sufficient heaters are provided to substitute for each component which might be turned off and maintain temperatures above established minimum levels.

From Reeves (1979) [9].

4.2.3 OTS

Electrical heaters are used as battery heaters, in the Traveling Wave Tube Amplifier as compensation heaters, and in the hydrazine tank, lines and valves, in order to prevent hydrazine from freezing.

See ECSS-E-HB-31-01 Part 15, clause 5.

4.2.4 SPOT

Electrical heaters are used in the thermal control of the satellite platform, propulsion system, batteries compartment, high-resolution visible range instruments, and payload telemetry system.

See ECSS-E-HB-31-01 Part 15, clause 8.

4.2.5 Miscellaneous utilization

- To warm overboard dump valves for liquids (Space Shuttle).
- To keep constant structural temperature on the Space Telescope in order to prevent optical misalignment.
- To maintain the temperature of sensitive gyroscopes and accelerometer guidance platforms.
- To control the temperature of pressure transducers, other electronics components, and infrared reference sources.
- Metal sheathed heaters are used on catalyst beds of hydrazine thruster engines for spacecraft attitude control.
- To prevent condensation on satellites viewing windows.
- To keep solar panels warm at night.
- As shunt resistors, mounted on the skin of a satellite, to dump excess power of overcharged batteries which would otherwise overheat delicate instruments.

From Taylor (1984) [11].

4.3 Power requirement estimation

The design of electrical heaters for space presents one important characteristic: limited power makes calculation of correct wattage become critical.

Calculation and theory cannot substitute for experimentation when accuracy is very important, because they cannot account for all the variables acting upon the system; nevertheless the value obtained with the quick estimation procedure that will be described here (MINCO (1989b) [7]), can be used to obtain a first approximation.

To confirm wattage calculations, a sample heater is placed with the required configuration against an actual or simulated component with thermocouples mounted. The expected environment is reproduced and the voltage varied in order to find either heat-up time or the exact power required for temperature stabilization.

Finite element analysis can handle many problems which resist theoretical or experimental solutions. It is able to simulate extremely fast warm-ups, map thermal gradients across complex shapes, and determine watt density zones for profiled heaters.

When the warm-up heat is much greater than the steady state loss (a common situation) a dual element heater may be a good solution: one high-power element for warm-up and a smaller element for maintenance temperature.

4.3.1 Simplification assumptions

Heat sink, heater and processed material are at a uniform temperature. This is not strictly true, but it is sufficient in a first step.

Convection losses are not considered since satellite applications of electrical heaters happen in vacuum.

For radiant heat transfer, the surrounding environment is a black body at ambient temperature. This is usually a good assumption in large open areas; however, it may not be so good in a small enclosure.

Approximations are chosen to give values higher than the real one, ensuring that heaters will have more than sufficient power for the application. Also, a security factor is recommended.

4.3.2 Conduction losses

In electrical heaters, conductive loss generally refers to leakage through insulation layers or heat sink mounting hardware. Conduction is a function of the temperature difference between the heater and its surroundings,the distance between hot and cool areas, L, and the cross sectional area, A, and conductivity, k, of conductive paths. The conduction loss is given by

$$Q_{cd} = \frac{kA(T_s - T_a)}{L} \qquad [4\text{-}1]$$

4.3.3 Radiation losses

Radiant leakage varies with the temperature difference between the heater and its surroundings, the heater surface area, *A*, and the emissivity of the surfaces radiating and absorbing the heat, ε. Highly reflective foils on the heater surface reduce heat leakage. The radiation loss is given by

$Q_r = \varepsilon A \sigma (T_s^4 – T_a^4)$

where σ is the Stefan-Boltzmann constant.

4.3.4 Process heat requirements

Process heat represents work done by the heater to thermally process (warm, melt or vaporize) some material, other than the heat sink, for example heating hydrazine lines. The process heat is given by

$Q_p = (m/t)[c_p(T_f – T_i) + h]$

where m is the mass processed and t the cycle time for each load.

If the heater merely maintains temperature, the process heat is equal to zero. For continuous processes m/t can be substituted by the mass flow.

4.3.5 Operating heat requirements

It is equal to the sum of steady state losses and process heat. The steady state loss is given by

$Q_{sl} = Q_{cd} + Q_r$

and, thus, the operating heat is

$Q_o = Q_{sl} + Q_p = Q_{cd} + Q_r + Q_p$.

4.3.6 Warm-up heat requirements

It is used to bring the heat sink to the final temperature in the desired time, plus extra heat to compensate for conductive and radiant losses during warm-up. The warm-up power is given by

$$Q_w = \frac{H_w\left(T_f - T_i\right)}{1 - e^{-\alpha}} + H_w\left(T_i - T_a\right) \qquad [4\text{-}2]$$

where

$$H_w = \frac{Q_{sl}}{T_f - T_a} \qquad [4\text{-}3]$$

is the warm-up coefficient (see MINCO (1989b) [7]), and α is a dimensionless coefficient defined by

$$\alpha = \frac{H_w t_w}{m c_p} \qquad [4\text{-}4]$$

where t_w is the desired warm-up time.

4.4 Regulation of electrical heaters

Nearly all heated systems have some type of temperature controller. Unregulated heaters can exhibit large temperature fluctuations when heat demands or ambient temperatures vary.

Often, when the temperature is high, less heating is needed, and when the temperature is low, more is desirable. Heating power can be made to adjust automatically without complicated controls by choosing the temperature coefficient of the heating element material. Alloys used in heaters can have a temperature coefficient of resistance ranging from almost flat to as high as 0,0045 ohms change per ohm resistance per degree Kelvin (see Taylor (1984) [11]).

Nevertheless the performance of a thermal system is improved by the use of sensors and controllers. Some of the most significant improvements are the accuracy of the system to maintain the temperature near the setpoint, the heater life and the power rating.

The thermal switch design, used in the Viking lander body (see clause 4.2.1), could be a good example of a regulation system. The switch consist of a sensor/actuator and a contactor. As the temperature inside the lander decreases, the vapor pressure of the Freon in the actuator drops, the piston moves to one side and the linkage closes the contacts. When the lander temperature increases, the Freon vapor pressure rises, the piston moves to the other side and the linkage opens the contacts. The actuator has a double bellows seal to prevent leakage. The contactor has a soft seat to minimize sensitivity to particulate contamination, and a copper flex foil to provide a high-conductivity flexible heat transfer path for the movable contact.

4.4.1 Temperature sensor

Heater, sensor and heat sink are not at the same temperature. Thermal gradients across the various components cause delays in response time, and, therefore, there could appear overshoots on warm-up and sluggish response to heat demands. In order to minimize these effects, the sensor should be placed near the heater in static systems and near the heat sink in dynamic systems.

Several positioning options for sensors are commercially offered by manufacturers:

- Wirewound resistance thermometers placed in a window into the foil heating element. Both the heater and the sensor are more tightly coupled to the heat sink than to each other, however the sensor is near enough to the heater to prevent overshoot. Resistance thermometers have the advantage of averaging temperatures over an area.
  - Some manufacturers can laminate thermistors or thermocouples inside heater bodies to measure temperature at a single point.
  - Thermal-Ribbon thermometers can be mounted alongside the foil heater or directly over the element.

4.4.2 Temperature controller

4.4.2.1 On/off control

This controller cycles the heater about the setpoint by turning power completely on and off (Figure 4-3). This system is used in thermostats and simple electronic controllers and it has two drawbacks:

- Overshoot on warm-up or on load changes.
- Temperature never settles to the setpoint.

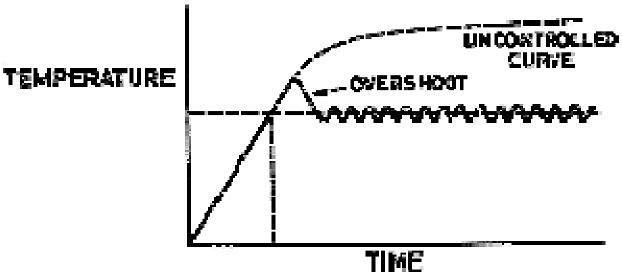


Figure 4-3: On/Off control. Temperature versus Time. From MINCO (1989a) [6].

4.4.2.2 Simple proportional control

The heater is supplied at full power until it enters a zone, called the proportional band, where the controller gradually reduces power until the heater stabilizes at a constant temperature. Unless the heater is perfectly balanced for a "50% on/50% off" duty cycle, its final temperature differs from the setpoint. This is the system "droop" that lies within the proportional band, see Figure 4-4.

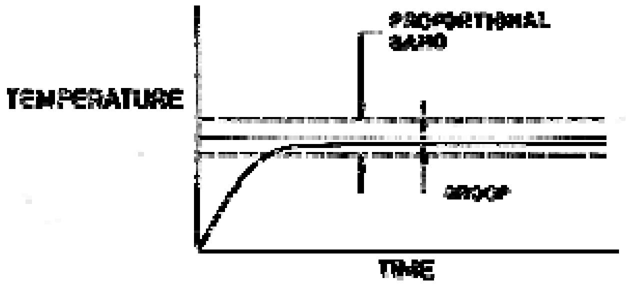


Figure 4-4: Simple proportional control. Temperature versus Time. From MINCO (1989a) [6].

4.4.2.3 PID control

Proportional-Integral-Derivative control improves accuracy in two ways (see MINCO (1989a) [6]): widening the proportional band in relation to the rate of temperature rise to prevent overshoot, and automatically compensating for droop.

4.5 Existing systems

Data on commercially-available thermoelectric devices are presented in this clause. Data are arranged as follows:

1. Manufacturer
2. Commercial Name
3. Standard Insulations
4. General Specifications
5. Shape, Dimensions and Electrical Resistance
6. Attachment
7. Watt densities
8. Leads and/or Wires

4.5.1 Minco Products Inc.

4.5.1.1 Manufacturer

MINCO PRODUCTS, INC.

7300 Commerce Lane

Minneapolis, Minnesota 55432-3177

U.S.A.

TEL: 612 571-3121

FAX: 612 571-0927

4.5.1.2 Commercial name

Thermofoil Heaters.

4.5.1.3 Standard insulations

Kapton/FEP, silicone rubber, Nomex/Epoxy and mica.

4.5.1.4 General specifications

Table 4-1 contains thickness, flexibility, dielectric strength and temperature range of Thermofoil Heaters for the standard insulations.

Table 4-1: Characteristics of MINCO Thermofoil Heaters. From MINCO (1989a) [6]

	Kapton/FEP	Silicone Rubber	Nomex/Epoxy	Mica
Insulation Thickness x 10^5 [m]	2,5/5,1	20,3	2,5/12,7	25,4/50,8
Maximum heater thickness over element x 10^4 [m]	2,54	5,08	4,32	6,35/11,43
Heater flexib. Min. bend radius x 10^4 [m]	7,62	31,75	15,24	RIGID
Dielectric strength [V RMS]	1000	1000	1000	1000/2000
Temperature Range [K]	73 to 473	211 to 508	193 to 423	123 to 873

4.5.1.5 Shape, dimensions and electrical resistance

4.5.1.5.1 Standard heaters

MINCO has a great variety of standard electrical heaters that are summarized in Table 4-2 for Kapton, silicone rubber and Nomex insulations, and in Table 4-3 for mica insulation. The standard Thermofoil heaters have a single uniform element patternedto minimize induction. Only limit values are presented in those tables, to give an idea about the variety of models.

MINCO standard planform shapes are represented in Figure 4-5 for Kapton, silicone rubber and Nomex insulations, and in Figure 4-6 for mica insulation.

Table 4-2: MINCO Standard Thermofoil Heaters. Kapton, silicone rubber and Nomex insulations. From MINCO (1989a) [6]

Type [a]	N [b]	Available resistance [Ω]		Effective area x 10^4 [m^2]	
		min	max	min	max
1	1004	3,3	2341	2,26	948/1120 [d]
2	117	4,3	630	5,10	379
3	122	4,2	713/1317 [c]	7,48	664
4	0	--	--	--	--
5	27	3,6	199/262 [c]	10,0	17,9/55,5 [c]
6	192	3,4	1016/1648 [d]	2,45	735/1006 [d]
7	72	3,7	168/440 [c]	9,35	114/1000 [d]
8	229	4,7	2890	5,61	609/903 [d]
9	30	7,9	243/280 [c]	7,87/3,61 [c]	19
10	53	3,8	200/530 [c]	7,68/0,97 [c]	24
11	84	4,2	670	4,19/3,81 [c]	482

[a] Types correspond to those sketched in Figure 4-5.

[b] Number of heaters quoted in MINCO (1989a) [6].

[c] Only available with Kapton and Nomex insulations.

[d] Only available with silicone rubber insulation.

Table 4-3: MINCO Standard Thermofoil Heaters. Mica Insulation. From MINCO (1989a) [6]

Type [a]	N [b]	Available resistance [Ω]		Effective area x 10^4 [m^2]	
		min	max	min	max
1	14	4,5	106,0	20,6	422,6
2	2	2,0	3,9	7,7	7,7
3	6	11,1	83,4	34,8	377,4

[a] Types corresponds to those sketched in Figure 4-6.

[b] Number of heaters quoted in MINCO (1989a) [6].

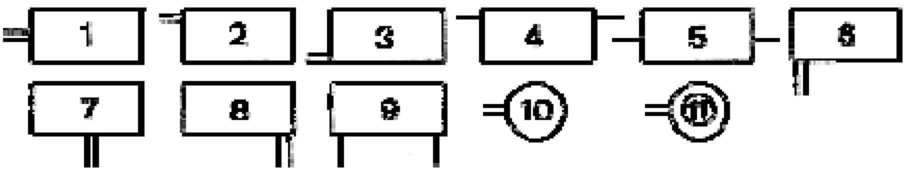
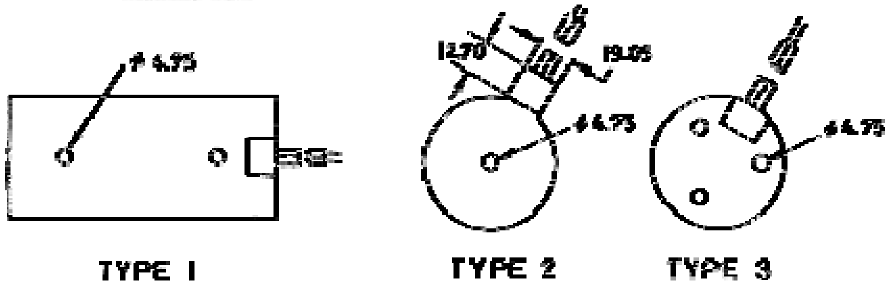


Figure 4-5: Pattem of MINCO Standard. Thermofoil heaters. From MINCO (1989a) [6].



Note: non-si units are used in this figure

Figure 4-6: Pattem of MINCO Mica. Thermofoil heaters. Dimensions in mm. From MINCO (1989a) [6]

4.5.1.5.2 Heater kit

The HK913 heater kit (Figure 4-7 and Table 4-4) contains 14 heating elements that can be arranged in over 1000 combinations. #10 PSA (see clause 4.5.1.6) is included for attachment. It have solder pads instead of lead wires. Insulation is Kapton/FEP and resistance tolerance is ±15%. The complete kit or individual heaters can be ordered.

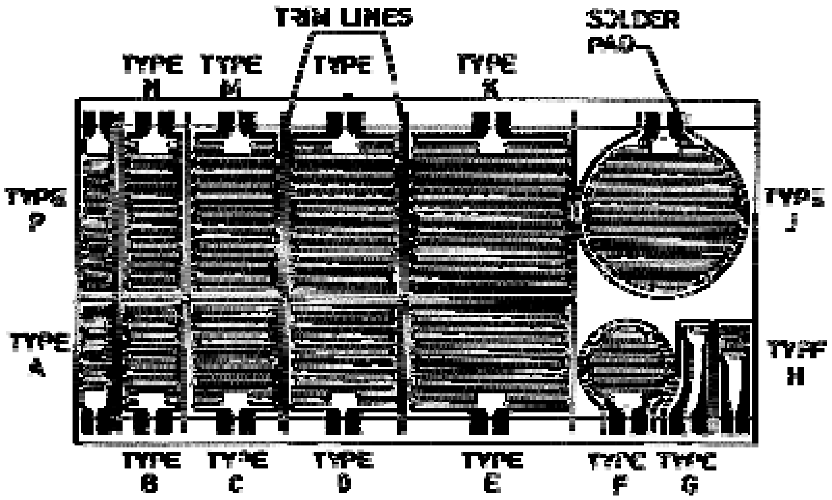


Figure 4-7: Pattem of MINCO. Heater Kit HK913. From MINCO (1989a) [6]

Table 4-4: Area and Electrical Resistance of the Heaters Contained in Minco Heater Kit HK913. From MINCO (1989a) [6]

HEATER [a]	AREA x10^4 [m^2]	RESISTANCE [Ω]	HEATER [a]	AREA x10^4 [m^2]	RESISTANCE [Ω]
A	3,7	40	H	1,3	15
B	7,7	80	J	29,0	275
C	12,0	120	K	36,1	360
D	15,8	160	L	24,2	240
E	23,7	240	M	18,5	180
F	6,7	75	N	12,1	120
G	0,3	5,5	P	6,1	60

[a] Shapes correspond to those sketched in Figure 4-7.

4.5.1.5.3 Custom options for thermofoil heaters

- Intricate geometries with different sizes and shapes can be manufactured by MINCO.
- Profiled elements level out temperature gradients by providing extra heat in the zones where heat loss is greatest.
- Dual layer heaters can be used in order to double resistance densities or effectively cancel induction with mirror elements.
- Dual voltage heaters, with twin elements, are designed to produce the same heat output connected in parallel to 115 V or in series to 230 V.

With dual layer elements, resistances up to 465 x 10^4 Ω.m^{-2} are possible. In single layer elements resistance are within the following limits (MINCO (1989a) [6]):

Heater type	Maximum resistance x 10^{-4} [Ω.m^{-2}]
Kapton/FEP	69,75
Nomex	69,75
Kapton/WA	232,50
Silicone rubber	31,00
Mica	1,78
Thermal-Clear (wire)	186,00

4.5.1.6 Attachment

Mounting methods suggested by MINCO are:

- Clamping: Mica heaters are clamped to heat sinks with rigid backing plates because unsupported ones can separate during warm-up. See Figure 4-8. Other heaters, except silicone rubber, may also be clamped for higher watt density ratings.

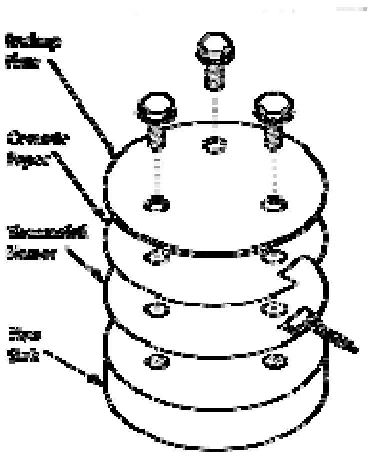


Figure 4-8: Clamping attachment of a MINCO Mica. Thermofoil heater. From MINCO (1989a) [6].

Heater assemblies with bolted, welded and crimped backing plates are provided by MINCO.

— Vulcanization: It is used to bond silicone rubber heaters to mating parts without adhesive. Therefore heat transfer is facilitated, yielding better performance and reliability.

— Films: This category includes #10 and #12 pressure-sensitive adhesives (PSAs), factory applied by MINCO. They present uniform thickness and lack of bubbles. PSAs are easy to apply, nevertheless they have limited temperature ranges. #14 PSA is an adhesive film approved for space/vacuum environments, however it requires a relatively high level of heat and pressure to cure. Ablefilm 550K has a good combination of performance and ease of application, but it carries a high price.

— Liquid Adhesives: RTVs and epoxies work better than PSAs for curved surfaces and higher watt ratings; however they can include air bubbles unless given special handling. Bubbles under the heater cause localized overheating and possible heater burnout. Special techniques such as drawing a vacuum on the adhesive after mixing, or perforating heaters between strands, are recommended for critical aerospace applications. Aluminium backing helps spread heat away from remaining bubbles, and it is therefore recommended if heaters operate near the upper limit of their watt density ratings.

— Shrink Bands and Stretch Tape: Shrink bands and stretch tape secure heaters to cylinders. The adhesive layer between heater and heat sink is eliminated and therefore higher watt densities are allowed. Shrink bands are pre-stretched plastic strips with PSA adhesive on the ends. The band is wrapped around the heater and cylinder and its end is shrunk on place.

A data summary is included below in Table 4-5.

Table 4-5: Characteristics of Adhesives Recommended by MINCO. From MINCO (1989c) [8]

Name	Type	Temperature Range [K]	Kapton	Insulation Silicone Rubber	Nomex	Thermal Cond. [$W.m^{-1}.K^{-1}$]	Material [a] Approvals	Comments
MINCO #10PSA	$5,1x10^{-5}$ m Film	200 to 373	Yes	No	Yes	0,23	NASA-RP-1061 Low outgassing UL recognized	Uniform thickness Easy to apply Flat surfaces only
MINCO #12PSA	$5,1x10^{-5}$ m Film	89 to 477	Yes	Yes	No	0,13		Uniform thickness Easy to apply Slightly curved surfaces
MINCO #14PSA Acrylic Film	$2,54x10^{-5}$ m Film	73 to 422	Yes	No	Yes	0,13	NASA-RP-1061 Low outgassing	Uniform thickness Difficult to apply
ABLEFILM 550K	$7,6x10^{-5}$-$20,3x10^{-5}$ m Film	219 to 423	Yes	No		0,79	NASA-RP-1061 Low outgassing	Uniform thickness Easy to apply Expensive
MINCO #6RTV Cement	1 Part Paste	211 to 508	No	Yes	No	0,21	NASA-RP-1061 UL recognized	High temp. capability
GE 566 RTV	2 Part Paste	158 to 508	Yes	Yes		0,21	NASA-RP-1061 Low outgassing MIL-A-00509	Proper mixing is essential High temp.

Name	Type	Temperature Range [K]	Kapton	Insulation Silicone Rubber	Nomex	Thermal Cond. [W.m^{-1}.K^{-1}]	Material [a] Approvals	Comments
							(salt spray) MIL-A-8623	capability
MINCO #15 Epoxy	2 Part Epoxy	203 to 398	Yes	No	Yes	0,88	NASA-RP-1061 Low outgassing	Easy to use disperser High thermal conductivity
Crest Resin 3135	2 Part Epoxy	78 to 366	Yes	No		0,14	NASA-RP-1061 Low outgassing	Slightly flexible Cryogenic rating
Type 3 Shrink Band	Mylar Shrink Band	200 to 422	Yes	Yes	Yes	N.A.	NASA-RP-1061 Low outgassing UL recognized	Easy to apply Removable Smooth cylinders only
Type 4 Shrink Band	Kapton Shrink Band	200 to 450	Yes	Yes	Yes	N.A.	NASA-RP-1061 Low outgassing UL recognized	Easy to apply Removable Smooth cylinders only
MINCO #20 Stretch Tape	Silicone Rubber Tape	222 to 473	Yes	Yes	Yes	N.A.		Easy to apply Removable Smooth cylinders only

[a] UL: Underwriters Laboratories.

4.5.1.7 Watt densities

See Table 4-6, where the maximum recommended heat output per square meter for different heater types and attachment methods are presented.

Table 4-6: Specifications of MINCO Thermofoil Heaters. From MINCO (1989a) [6]

Heater type and Mounting Method		Temperature Range [K]	Maximum Watt Density x 10^{-3} [$W.m^{-2}$]
Mica	$2{,}54 \times 10^{-4}$ m	123-873	186,0
	$5{,}08 \times 10^{-4}$ m	123-873	139,5
Silicone Rubber	Vulcanized	211-508	108,5
	#20 Stretch Tape	211-473	108,5
	#6 RTV Cement	225-508	65,1
	#12 PSA	211-453	72,8
Kapton	#20 Stretch Tape	225-473	93,0
	#3 Shrink Band	211-423	93,0
	#14 Film	73-423	93,0
	#15 Epoxy	203-398	93,0
	#10 PSA Al backing	218-423	77,5
	#10 PSA	213-373	46,5
Nomex	#20 Stretch Tape	228-423	52,7
	#14 Film	193-423	51,1
	#15 Epoxy	208-398	52,7
	#10 PSA	203-373	40,3

4.5.1.8 Leads and/or wires

Red Teflon insulated lead wires, per MIL-W-16878, stranded, are used in Kapton, Nomex and silicone rubber heaters. See the different types in Table 4-7.

Mica/glass insulated, stranded nickel-clad copper, potted at termination with high temperature cement. See Table 4-8.

Table 4-7: Characteristics of MINCO Lead wires Mounted in Kapton, Nomex and Silicone Rubber Heaters. From MINCO (1989a) [6]

		AWG 30	AWG 26	AWG 24	AWG 20
Current Capacity [A]		3,0	5,0	7,5	13,5
Maximum Heater Thickness over leads x 10^3 [m]	Kapton/FEP	1,27	1,52	1,65	2,16
	Silicone Ruber with PSA	1,78	2,03	2,29	3,05
		2,16	2,41	2,67	3,43
	Nomex/Epoxy	1,65	1,90	2,41	2,92

Table 4-8: Characteristics of MINCO Lead wires mounted in Mica Heaters. From MINCO (1989a) [6]

		AWG 22	AWG 20	AWG 18
Current Capacity [A]		8,0	9,0	11,0
Maximum Heater Thickness over leads x 10^3 [m]	2,5 x 10^{-4} m Mica	3,81	5,08	5,08
	5,1 x 10^{-4} m Mica	4,32	5,59	5,59

4.5.2 Isopad Limited

4.5.2.1 Manufacturer

ISOPAD LIMITED

Isopad House, Shenley Rd.

Borehamwood, Hertfordshire WD/ 1TE.

England

TEL: 01-953 6242

FAX: 01-207 5530

4.5.2.2 Commercial name

Isotape: Factory terminated tracer.

Isotrace: Self limiting tracer.

Unitrace: Cut-to-length tracer.

4.5.2.3 Standard insulations

- ISOTAPE: PTFE insulation of thickness 0,4x10^{-3} m for use up to 300 V (0,5x10^{-3} m for use up to 600 V) plus glass fiber braiding silicone varnished.
- ISOTRACE: Thermoplastic elastomer.
- UNITRACE: Silicone rubber.

4.5.2.4 General specifications

Trace heaters are primarily to be used in earth facilities, because of supply voltage (110 V or 240 V), insulation, dimensions and weight. They are thought to be used in industrial pipelines and hazardous areas.

No data in flexibility and dielectric strength are available. Temperature limits and thickness appear in Table 4-9.

Table 4-9: Specifications of ISOPAD electrical heaters. From ISOPAD (1990)

Type	Reference Name	V [V]	W/l [W/m]	R/l [Ω/m]	T_{min} [K]	T_{max} [K]	Thickness x10^3 [m]	Width x10^3[m]	l_{max} x10^3 [m]
ISOTAPE	FTW/SS	240	16	3600	203	493	2,0	6,0	348,0
			33	1745					
			44	1309					
			48	1200					
			55	1047					
	ITW/SS	240	16	3600	203	483	3,0	8,0	108,5
			33	1745		443			
			44	1309		413			
			55	1047		383			
ISOTRACE	FSL-1/13	110	13	931					75
	FSL-1/26		26	465					64
	FSL-2/13	240	13	4431	228	338	5,0	13,0	150
	FSL-2/26		26	2215					128
	ISL-1/10	110	10	1210	233	338	3,5	7,35	100
	ISL-1/20		20	605				7,35	85
	ISL-1/30		30	403				9,5	64
	ISL-2/10	240	10	5760	233	338	3,5	7,35	150
	ISL-2/20		20	2880				7,35	165
	ISL-2/30		30	1920				9,5	130

Type	**Reference Name**	***V* [V]**	***W/l* [W/m]**	***R/l* [Ω/m]**	**T_{min} [K]**	**T_{max} [K]**	**Thickness x10³ [m]**	**Width x10³[m]**	**l_{max} x10³ [m]**
UNITRACE	IVR-10	240	10	5760	223	423	6,5	11,0	150
	IVR-20		20	2880		403			100
	IVR-30		30	1920		373			70
	FZR-10	240	10	5760	223	453	5,0	15,0	150
	FZR-15		15	3840		432			104
	FZR-30		30	1920		377			72
	FZR-45		45	1280		341			68
	FZR-10	240	10	5760	223	423	5,0	15,0	150
	FZR-15		15	3840		413			104
	FZR-30		30	1920		393			72
	FZR-45		45	1280		353			68
	FZR-60		60	960		313			60

Materials employed for the different trace heaters are:

- ISOTAPE:

  Heating element: Nickel chrome or copper nickel alloys.

  Outer covering: Robust 18/8 stainless steel braid type 316.

- ISOTRACE:

  Heating element: Self-limiting conductive core material.

  Bus wire: Nickel plated copper wire.

  Overbraid: SS - Stainless steel sheath

  TC - Tinned copper sheath

  NC - Nickel plated copper sheath

  Oversheath (optional): Fluoropolymer.

- UNITRACE:

  Heating element: Nickel chrome.

  Conductors: Copper.

  Conductor/element connection: Metallic bond.

  Overbraid (optional):SS, TC, NC.

4.5.2.5 Shape, dimensions and electrical resistance

The particular geometry of a trace heater is defined by their width and maximum usable length. Dimensions and the resistance per unit length appear in Table 4-9.

Figure 4-9 represents sections of the different heaters.

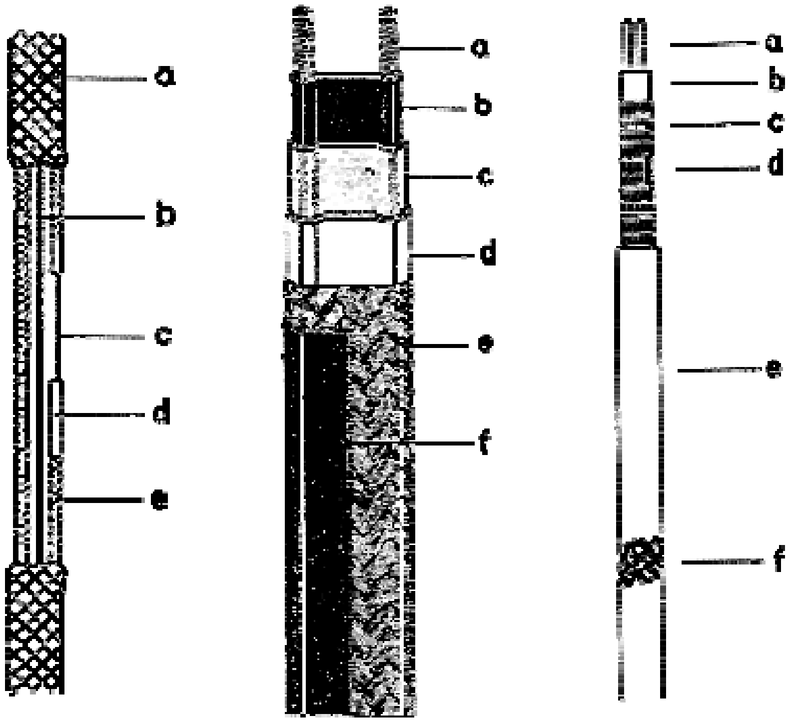


Figure 4-9: Standard ISOPAD products. (a) ISOTAPE, (b) ISOTRACE and (c) UNITRACE. From ISOPAD (1990) [2].

Explanation

	ISOPAD	ISOTRACE	UNITRACE
a	Glass braid	Bus wires	Conductors
b	PTFE insulation	Self limiting heating element	Inner sheath
c	Element	Primary insulation	Heating element
d	Element spacer	Secondary insulation	Circuit connection
e	Stainless steel braid	Outer braid	Outer sheath
f		Optional over sheath	Overbraid

4.5.2.6 Attachment

- ISOTAPE: Fixing tape FT/2 (glass fiber) or FT/3 (aluminium foil).
- ISOTRACE: FT/1 Fixing tape.
- UNITRACE: FT/2 or FT/3 self-adhesive tape.

4.5.2.7 Watt densities

See Table 4-9.

4.5.2.8 Leads and/or wires

See Figure 4-9 for some examples of standard leads.

5
Electrical cooling

5.1 General

5.1.1 Description

Thermoelectric coolers (TECs) are solid state devices that work as small heat pumps, obeying the laws of thermodynamics as do conventional mechanical heat pumps (refrigerators), absorption refrigerators, and other devices involving the transfer of heat.

5.1.2 Advantages of use

Some of the advantages of using thermoelectric cooling in space applications are:

- Flexible and easy to control thermal regulation system: localized cooling; temperature control above or below ambient; heating or cooling, depending on current direction; and precision temperature control to less than 0,05 K.
- Resistant, reliable and easy operation system: maintenance free; solid state reliability; high resistance to shock and vibration; operation in high-g levels; no moving parts; operation in zero gravity; and in any orientation.
- Easy integration with another spacecraft's subsystems: DC powered; no gases or refrigerant required; small, lightweight package; no acoustical noise (vibrations); and no electrical noise.

5.1.3 Physical phenomena

A thermoelectric cooler consists of a type N and a type P semiconductor of bismuth telluride as shown in Fig. 5-1 (Scott (1974) [10]). A junction between these dissimilar semiconductors is formed at the surface to be cooled and a DC voltage is applied across the other junction at the hot surface where heat is transferred to the surroundings. The extra electrons in the N type material and the holes left in the P type material are the carriers that transfer the heat from the cold to the hot junction. The heat is pumped by virtue of the Peltier effect (see clause 5.2).

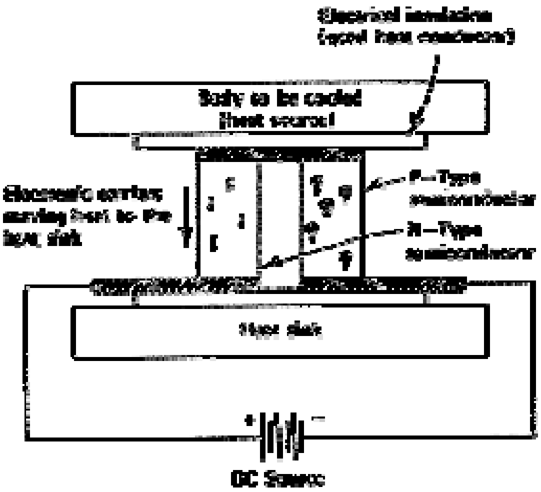


Figure 5-1: Schematic of a thermoelectric cooling element. From Scott (1974) [10].

Thermoelectric elements are usually connected thermally in parallel and electrically in series to obtain the required power handling capacity. A drawing of a typical module assembly is shown in Figure 5-2.

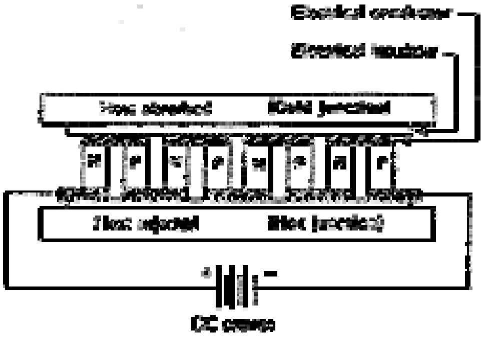


Figure 5-2: Schematic of a typical thermoelectric module assembly. Elements electrically in series and thermally in parallel. From Scott (1974) [10].

5.1.4 Multi-stage thermoelectric devices

A multi-stage cascade is essentially two or more single thermoelectric modules, stacked in series. Each successive higher temperature stage pumps not only the cold side heat but also the heat dissipated by the lower temperature modules. Therefore each stage needs more thermoelectric couples than the colder ones and this is the reason of the pyramid type appearance of the cascade module.

The applied heat load generally determines the maximum temperature difference that can be achieved by the thermoelectric cooler. However, even with zero heat load, regardless of the amount of power applied, every module has a theoretical maximum temperature difference. It depends on the number of stages and the properties of the thermoelectric material, as can be seen in Figure 5-3.

Using several thermoelectric coolers thermally in parallel it is possible to achieve large cooling capacities.

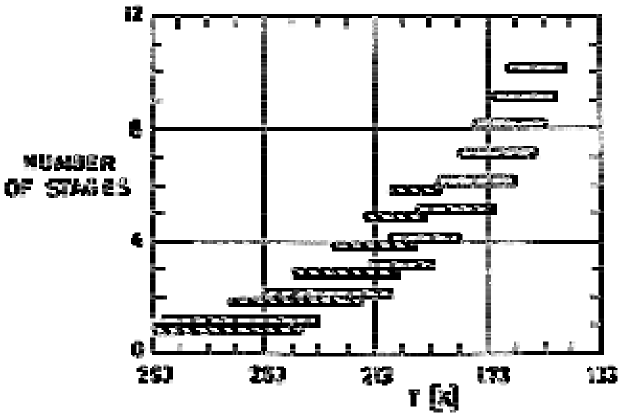


Figure 5-3: Maximum temperature difference versus number of stages in a module. From MARLOW (1988) [3].

5.1.5 Heat dissipation

It is necessary to transfer the heat dissipated at the hot side of the TEC to the environment using a heat sink. The amount of heat dissipated at the hot side consists of the heat pumped from the cold side plus the input power to the thermoelectric cooler.

The temperature distribution through a TEC is shown in Figure 5-4. The heat generated by the electronic component are first conducted through an alumina ceramic insulator and then through a metal contact which makes the electrical connection between the N and P type semiconductor materials. In order to conduct this heat, from the component to the cold junction, the component must be hotter than the junction. The cold junction itself is the coldest point in the thermoelectric cooling system. Once the heat is pumped to the hot junction, it is conducted through another metal contact, through another ceramic insulator, and then be transferred to the surroundings by radiation.

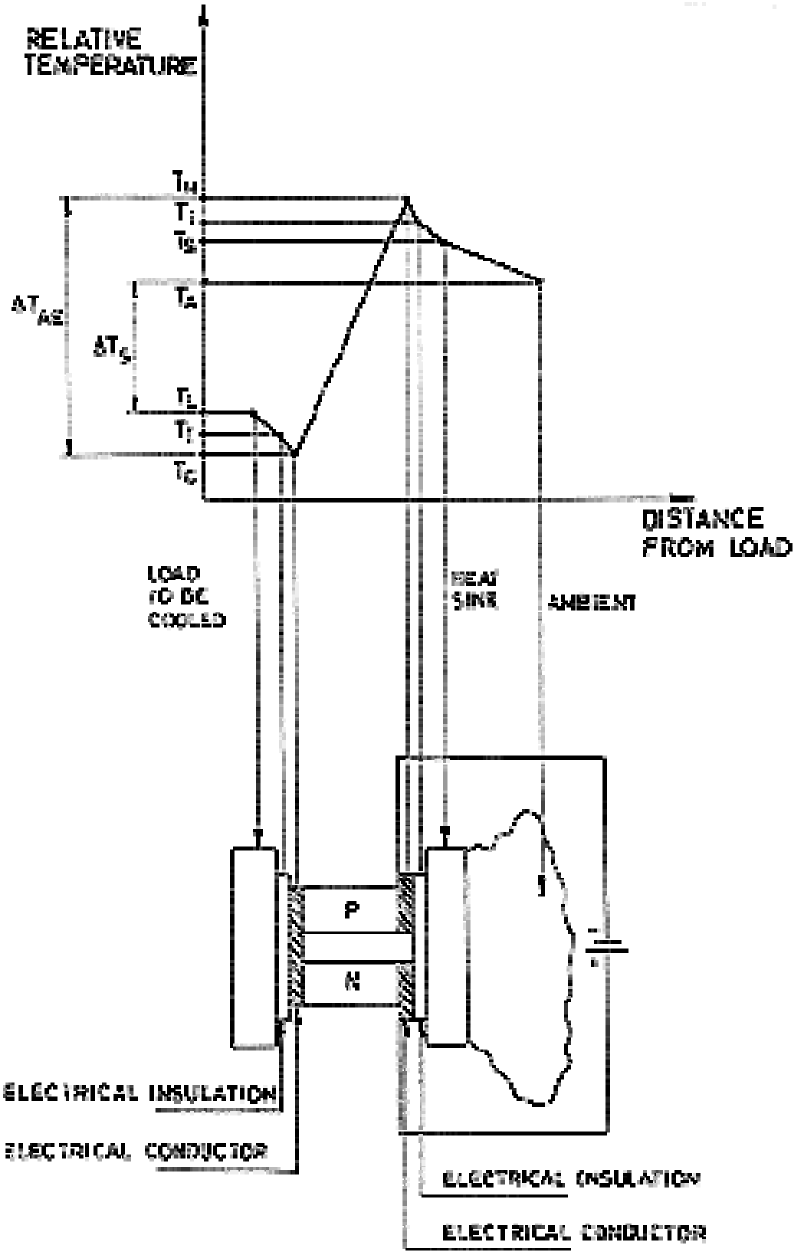


Figure 5-4: Temperature distribution through a thermoelectric cooling unit. From Scott (1974) [10].

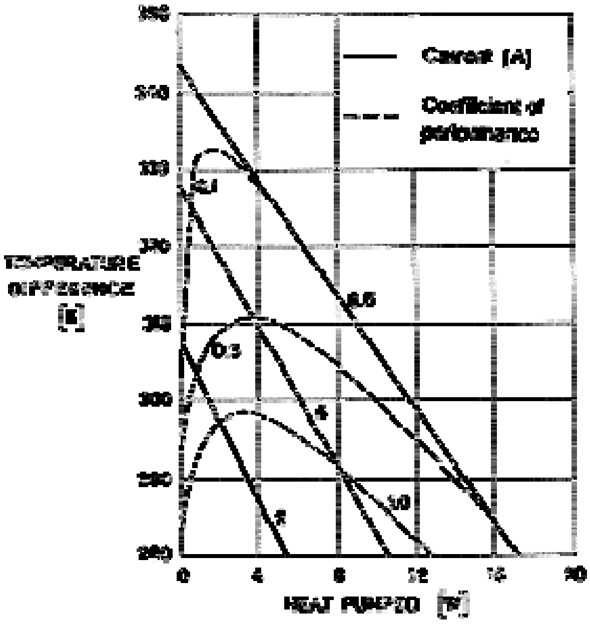
5.1.6 Performance characteristics

Thermoelectric devices are typically rated by their characteristics at I_{max} with a hot side temperature fixed at 300 K. Four performance parameters are used:

I_{max}:	Current which yields the greatest net cooling.
ΔT_{max}:	Temperature difference across the cooler at I_{max} with no applied heat load.

Q_{max}:	The amount of applied heat load necessary to suppress the temperature difference across the device to zero at I_{max}.
V_{max}:	Thermoelectric cooler voltage at I_{max} without heat load.

The thermoelectric cooler efficiency and the heat pumped increase as the temperature difference across it decreases, see Figure 5-5, where the coefficient of performance is defined as the ratio of the heat pumped from the cold to the hot junction to the power that is supplied to operate the module.



Note: non-si units are used in this figure

Figure 5-5: Temperature difference across a typical thermoelectric cooling unit versus heat pumped. From Scott (1974) [10].

5.2 Theory

The thermoelectric phenomenon is the result of five distinct effects (Seebeck, Peltier, Thomson, Joule and Fourier) that act concurrently.

The Seebeck, Peltier and Thomson effects are reversible thermodynamic phenomena, whereas the Joule and Fourier effects are irreversible. See Chapter & Johnson (1973) [1].

5.2.1 Seebeck effect

Thermoelectric power generation is the result of the Seebeck effect. When the two junctions formed by the dissimilar materials are maintained at different temperatures a voltage is created resulting in the flow of current. The open circuit potential difference is expressed as:

$\Delta V_S = a \Delta T$

where a is the Seebeck coefficient.

5.2.2 Peltier effect

Thermoelectric heat pumping makes use of the phenomenon known as the Peltier effect. Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to the carrier current passing through the circuit:

$\Delta Q_P = aTI$

where T is the absolute temperature at the junction and I is the electrical current.

5.2.3 Thomson effect

The Thomson effect results in a heating or cooling in a homogeneous conductor when an electrical current flows in the direction of the temperature gradient. The Thomson effect per unit of conductor length can be expressed as

$q_T = \tau I dT/dx$

where τ is the Thomson coefficient.

5.2.4 Joule effect

The Joule effect represents the heat generated within a conductor when an electrical current flows along it:

$Q_J = I^2R$.

5.2.5 Fourier effect

The conductive heat transfer, as result of the Fourier effect, is given by:

$Q_F = -kAdT/dx$

where k is the thermal conductivity of the material.

5.3 Space applications

Active thermal control systems for long duration missions of spacecrafts such as satellites, planetary probes and space stations require an inherently reliable design that can be provided by thermoelectric heaters, and Peltier effect coolers. One attractive design feature of the thermoelectric modules is their capability to provide variable heat pumping between a surface and a spacecraft radiator/absorber (see Figure 5-6).

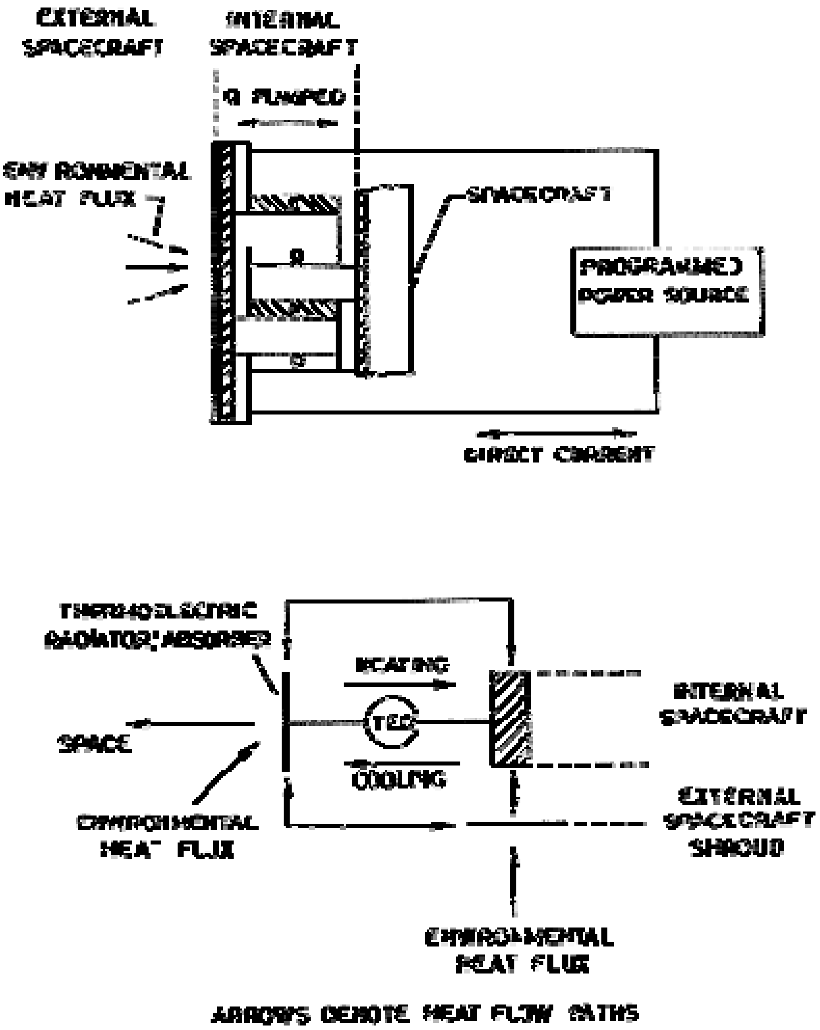


Figure 5-6: Spacecraft thermal control using thermoelectric devices (TEDs). From Chapter & Johnsen (1973) [1].

5.3.1 Electro-optics applications

Electro-optics applications in space include:

- Space Telescope Cameras.
- Laser Gyros for Navigation.
- Thermal Viewers.
- High Resolution CCD Cameras.
- Black Body References.

5.3.2 Fluid refrigeration

Thermoelectric coolers are used in cooling small volumes of air or liquid in space environment:

- Small Forced-Air Cooling Systems.
- NASA Life Science Environmental Chambers.

- Inertial Guidance Systems.
- Electronic Enclosures.

5.3.3 Cooling of electronic equipment

Various electronic components can be refrigerated:

- High Speed Integrated Circuits.
- Parametric Amplifiers.
- Avalanche Photo Diodes.
- Vidicon Tubes.

5.4 Existing systems

Data on commercially-available thermoelectric devices are presented in this clause. Data are arranged as follows:

1. Manufacturer
2. Commercial Name
3. General Description
4. Standard Models and Specifications
5. Attachment
6. Leads and/or Wires

5.4.2 Marlow Industries, Inc.

5.4.2.1 Manufacturer

Marlow Industries, Inc.
10451 Vista Park Road.
Dallas, Texas 75238-1645
U.S.A.
TEL: 214 340-4900
FAX: 214 341-5212

Marlow Industries UK
P.O. Box 41, Tadworth
Surrey KT20 6JL
England
TEL: 0737 833079
FAX: 0737 833140

5.4.2.2 Commercial name

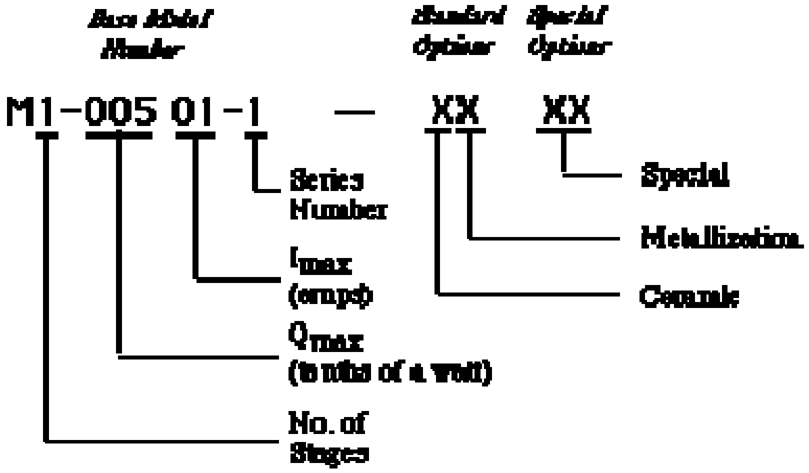
Thermoelectric Coolers (TECs).

5.4.2.3 General description

In addition to the Standard Product line, custom design services to meet special requirements are available.

Special TECs can be optimized with high performance thermoelectric materials for specific operating temperatures, increased reliability for space applications, and added strength for High-G environments. A special telecom grade screening process is also available which includes burn-in and rigorous cleaning to minimize contamination in a hermetic package for extended life.

Standard Thermoelectric Coolers may have special options:



Standard Options

Ceramic Material:

A: Aluminium oxide ceramic

B: Beryllium oxide ceramic (Not available on all models.)

Metallization: This digit indicates whether or not full face metallization is desired for solder mounting. Metallization is not available on all modules, and it no required for mounting with epoxy or the clamping method.

0 = No metallization

1 = Base only metallized

2 = Both sides metallized

Special Options

00 = Standard, no options.

01 = Pretinned hot side ceramic with 390 K solder.

02 = Pretinned hot and cold side ceramics with 390 K solder.

03 = Pretinned hot side ceramic with 369 K solder.

04 = Pretinned hot and cold side ceramics with 369 K solder.

05 = Thermistor (P/N 2228-07) mounted on edge of cold ceramic.

06 = Thermistor (P/N 2228-07) calibrated and mounted on edge of cold ceramic.

07 = Lapped to ±0,025 x 10^{-3} m (Not available on all models.)

08 = Telecom grade, pre-screening for extended life.

5.4.2.4 Standard models and specifications

In Table 5-1 the performance characteristics and dimensions for the Standard Thermoelectric Coolers are presented.

Table 5-1: Performance characteristics and dimensions of MARLOW Standard Thermoelectric Coolers. From MARLOW (1988) [3].

I_{max} [A]	ΔT_{max} [K]	Q_{max} [W]	V_{max} [V]	Dimensions [a] x 10^3 [m]				
				A	B	C	D	E
0,6	110	0,43	7,0	13,2	17,2	4,1	8,0	8,8
0,7	90-122	0,31-0,47	1,9-5,8	6,6-11,0	6,6-17,2	2,2-4,0	3,3-4,0	4,3-11,2
0,9	67	0,8-4,0	1,3-6,5	4,1-6,0	7,1-29,6	4,1-6,0	6,1-27,9	2,2-3,2
1,0	67-114	0,3-4,8	0,4-8,5	4,0-13,2	4,0-17,2	2,0-13,2	4,0-13,2	2,4-8,8
1,2	67-117	1,0-2,4	1,3-5,4	6,6-11,0	6,9-9,9	2,5-8,8	2,5-6,6	2,2-7,9
1,3	109-110	0,33-0,62	1,9-3,4	6,6-8,8	6,6-8,8	2,5-4,1	2,5-4,4	5,4-5,9
1,4	89-91	0,39-1,9	0,8-4,4	3,9-24,4	3,9-6,6	3,2-24,6	3,2-4,8	3,8-4,2
1,5	67	1,3-2,0	1,3-2,0	4,1-6,0	7,1-7,2	4,1-6,0	6,0-6,1	2,2
1,8	65-122	0,28-9,2	0,8-8,0	4,0-21,7	4,0-28,3	4,0-13,2	4,0-22,2	2,1-21,4
1,9	84	3,1	3,9	4,8	22,0	5,3	13,2	4,4
3,6	133	0,58	6,3	21,7	28,3	5,2	5,2	20,5
4,0	120	2,7	6,8	21,7	28,2	6,4	10,8	14,3
4,2	67	38,0	14,4	29,7	33,5	29,7	29,7	3,2
4,5	105-109	5,6	7,3	21,7	28,3	8,1-8,6	13,0-31,8	10,9-14,5
5,0	91	14,0	8,4	29,6	29,6	19,6	19,6	7,4
5,3	67	2,6-48,0	0,8-14,4	9,7-38,1	9,7-41,9	9,7-38,1	9,7-38,1	3,6
5,5	96	1,1	0,8	9,7	9,7	5,2	5,2	7,5
5,6	99	9,6	8,2	29,6	29,6	13,0	13,0	7,4
9,0	67	20,0	3,5	29,5	29,5	29,5	29,5	5,4
11,6	67	25,0	3,5	29,6	29,6	29,6	29,6	4,9
14,0	67	31,0	3,4	29,7	29,7	29,7	29,7	4,5

[a] A: Base Ceramic Width; B: Base Ceramic Length; C: Top Ceramic Width; D: Top Ceramic Length; E: Cooler Thickness.

5.4.2.5 Attachment

Mounting methods include:

- CLAMPING: It has been described in clause 4.5.1.6 for thermoelectric heaters.
- SOLDERING: Using 390 K solder or 369 K solder. Full face metallizationis needed for solder mounting.
- EPOXY: Hardening epoxy is used for permanent thermal interfaces.
- COMPRESSION: Non-hardening thermal grease is used for compression thermal interfaces.

5.4.2.6 Leads and/or wires

Four different headers are available:

- TO-3: 8 pins, gold plated.
- TO-37: 6 pins, gold plated.
- Round Plate: 41 x 10^{-3} m dia., 6 x 10^{-3} m thick, with 4, 6 or 8 insulated terminals, nickel plated.
- Flat Plate: 54 x 10^{-3} m x 35 x 10^{-3} m x 3 x 10^{-3} m with 2 mounting holes, nickel plated.

5.4.3 Melcor

5.4.3.1 Manufacturer

Materials Electronic Product Corp.

994 Spruce St.

Trenton, NJ 08648

U.S.A.

TEL: 609 393-4178

FAX: 609 393-9461

5.4.3.2 Commercial name

FRIGICHIP Thermoelectric Heat Pumps.

5.4.3.3 General description

Thermocouples are constructed of N & P elements of high grade bismuth telluride in form of oriented polycrystalline ingots. Ingot ends are soldered to copper bus bars interfaced with ceramic plates, affording good mechanical integrity, high dielectric strength and thermal conductivity. Solid state construction.

Temperature range: 123 K to 353 K.

Three types of standard options are available:

- Type L: Both hot and cold faces lapped flat.
- Type TT: Both faces metallized and tinned.

— Type TL: Hybrid, hot face tinned, cold face lapped.

Special heat pump assemblies designed to particular specifications can be supplied, with features such as integral heat exchangers or multi-stage cascaded thermoelectric modules with ceramic construction with solder interfacing between stages.

5.4.3.4 Standard models and specifications

There are two standard series of thermoelectric heat pumps:

- FC series: Miniature modules for use where space and electrical power are limited. Their performance characteristics and dimensions are presented in Table 5-2.
- CP series: Larger modules with cooling capacities to 125 W at 60 A, and temperature differentials up to 70 K. Their performance characteristics and dimensions are given in Table 5-3.

Table 5-2: MELCOR Thermoelectric Heat Pump Module Specifications. FC Series. From MELCOR (1987) [4]

I_{max} [A]	ΔT_{max} [K]	Q_{max} [W]	V_{max} [V]	N [a]	Dimensions [b] x 10³ [m]			
					A	B	C	D
0,8	67	0,22-3,56	0,48-7,98	4-66	1,8-9,9	3,4-9,1	3,4-11,5	2,4
1,2	67	0,32-5,34	0,48-7,98	4-66	2,2-12,3	4,2-11,3	4,2-14,4	2,7
1,5	67	0,40-6,67	0,48-7,98	4-66	2,2-12,3	4,2-11,3	4,2-14,4	2,4
2,0	67	0,54-4,31	0,48-3,87	4-32	2,4-9,3	4,7-9,3	4,7-11,6	2,4

[a] Number of thermocouples in the module.

[b] See Figure 5-7 for dimensions definition.

Table 5-3: MELCOR Thermoelectric Heat Pump Module Specifications. CP Series. From MELCOR (1987) [4]

I_{max} [A]	ΔT_{max} [K]	Q_{max} [W]	V_{max} [V]	N [a]	Dimensions [b] x 10^3 [m]			
					A	B	C	D
3,0	67	1,4-25,7	0,85-15,4	7-127	8-30	8-30		3,6
3,9	67	1,8-33,4	0,85-15,4	7-127	8-30	8-30		3,2
3,9	70	33,4	15,4	127	40	40		4,7
6,0	67	1,2-51,4	0,36-15,4	3-127	5-40	10-40		3,8
8,5	65	1,6-68,8	0,36-15,4	3-127	5-40	10-40		3,3
9,0	70	43,1	8,60	71	44	44		5,6
14,0	67	2,8-67,0	0,36-8,60	3-71	8-44	15-44		4,6
24,0	67	51,8	3,87	32	40	40		5,0
39,0	70	81,5	3,75	31	55	55		5,8
60,0	67	125	3,75	31	55	55		4,9

[a] Number of thermocouples in the module.

[b] See Figure 5-7 for dimensions definition.

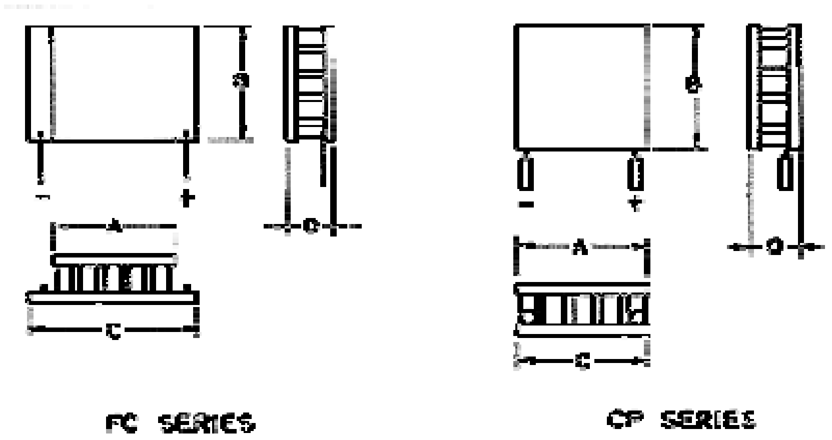


Figure 5-7: MELCOR Thermoelectric Heat Pump Module configurations. From MELCOR (1987) [4]

5.4.3.5 Attachment

No data available.

5.4.3.6 Leads and/or wires

Wire standards appear in Table 5-4.

Table 5-4: MELCOR Wire Standards. From MELCOR (1987) [4]

Module Type	Wire Gauge (AWG)	Length x 10^3 [m]	Insulation
FC 0,45-ALL	32 (SOLID)	50	None
FC 0,6-ALL	30 (SOLID)	50	None
FC 0,7-ALL	30 (SOLID)	50	None
CP 1,0-ALL	24 (STRANDED)	114	PVC
CP 1,4-ALL	22 (STRANDED)	114	PVC
CP 2-ALL	18 (STRANDED)	114	PVC
CP 2,8-ALL	16 (STRANDED)	114	PVC
CP 5-XX-10	14 (STRANDED)	114	PVC
CP 5-XX-06	12 (STRANDED)	114	PVC

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