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14. Abstract/Notes

The main subject of this work is to make experimental measurements of the effective emittance of Multilayer Thermal Insulations (M.L.I.) constructed with materials produced in Brazil. The emissivities obtained are compared with theoretical and literature points. The heat are carefully calculated and a study of the results uncertainties is made. The obtained results are encouraging and it is possible to produce and furnish the necessary thermal blankets for Brazilian satellites. New materials were find and other M.L.I. configurations will be tested.

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MULTILAYER THERMAL INSULATION TESTS

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ABSTRACT

The main subject of this work is to make experimental measurements of the effective emittance of Multilayer Thermal Insulations (M.L.I.)constructed with materials produced in Brazil. The emissivities obtained are compared with theoretical and literature points. The heat are carefully calculated and a study of the results uncertainties is made. The obtained results are encouraging and it is possible to produce and furnish the necessary thermal blankets for Brazilian satellites. New materials were find and other MLI configurations will be tested.

1. INTRODUCTION

With the implantation of the Brazilian space program, Brazil has projected satellites, developing, as much as possible, its own technology. The objective of this work is to make experimental measurement of the effective emittance (ε_{eff}) of Multilayer Thermal Insulations (M.L.I.) constructed with materials made in Brazil, with the aim of supplying the thermal blankets necessary to the satellites thermal control.

A M.L.I. is a thermal superinsulation projected to insulate maimly radiation heat transfer. It consists of several layers of closely spaced radiation reflecting shields. To avoid direct contact between the shields, and so, conduction heat transfer, low conductivity spacers are used between the layers.

Many factors affect an actual assembly of M.L.I. so that it is very difficult to make a mathematical model that predict, with precision, its performance.

Most of the avaiable experimental data concerning heat transfer through multilayer insulations are based on a Fourier-law type "effective conductivity", K_{eff} given by:

$$\frac{Q}{A} = K_{eff} \frac{T_H - T_C}{t} , \qquad (1)$$

where:

A = normal area to the temperature gradient [m²],

Q = heat flow through the insulation [W],

T_C = cold boundary temperature [K],

T_H = warm boundary temperature [K],

K_{eff} = effective thermal conductivity $[W.m^{-1}.K^{-1}]$,

t = blanket thickness [m].

In this work, due to the uncertainty in the thickness t, the performance of the M.L.I. blankets is given in terms of an effective emittance, ε_{eff}, given by:

$$\frac{Q}{A} = \gamma\,\varepsilon_{eff}\,(T_H^4 - T_C^4)\,, \tag{2}$$

where:

γ = Stefan - Boltzmann constant $[W.m^{-2}.K^{-4}]$.

The effective emittance (ε_{eff}) is a simple and interesting way to understand the behavior of a thermal blanket: it work as if, in times of M.L.I. installation, the surface to be insulated was revested with a material with an emittance equivalent to ε_{eff}.

A theoretical lower limit to the effective emittance can be given considering that heat is transfered through the insulator only by radiation between adjacent layers, then:

$$\varepsilon_{eff} = \frac{1}{\frac{1}{\varepsilon_p} + \frac{A_p}{A}\,\frac{(1-\varepsilon)}{\varepsilon} + \frac{(2-\varepsilon)}{\varepsilon}\,(n-1) + \frac{1}{\varepsilon_n}}\,, \tag{3}$$

where:

ε = emissivity of double aluminized polyester film faces,

ε_p = main heater surface emissivity,

A_p = main heater area,

A = blanket area,

n = number of layers.

2. EXPERIMENTAL FACILITIES

2.1 - Experimental Apparatus

Two main series of tests were developed (A and B). The apparatus used in the series A was modified to improve the reliability of the test and only the best configuration (series B) is described here. It consists of a flat square heater plate with 30 x 30 cm made in two separate sections identified as the main heater and the guard heater, as shown in Fig. 1. The main and guard heater are made by thermofoil leaters. sandwiched between two 1,5 mm thick cooper plates. Both faces of the heater are black painted (the emissivity is about 0,85). There is a gap of 5 mm between the heaters to avoid the heat to be transfered by conduction. To decouple them radiatively, the faces that see each other in the gap are recovered by aluminum tapes(emissivity of 0,05).

The distance between the main and guard heater is Kept in 5 mm by means of five holders made of two thin (1 mm), 20 x 25 mm low conductivity material, the celeron, pressed against the heaters by a screw installed in their center (this screw is not in physical contact with the heaters), as it is shown in Fig. 2.

The main heater temperature is monitored by two thermocouples, placed in the centre of each face and the guard heater temperature is monitored by three thermocouples, two located in one face and the third in the other face. To maintain the main and guard heater in the same temperature, the heaters imput power are controlled by a microcomputer and a Data Acquisition System, with an AC/DC and DC/AC conversor. All the data obtained are stored in diskets to be further used.

In this work, the physical propriety to be measured is the transversal emittance, considering that no heat is transfered laterally. After installing the thermal blanket in the experimental apparatus (see next section), it is verified a nonhomogeneity in three blanket edges, and a difference of temperature between the centre and these boundaries, resulting a lateral heat transfer.

The guard heater is used to maintain an adiabatic boundary condition on the perimeter of the main heater, avoiding this effect. The actual test section coincides with the main heater areas (the two faces).

2.2 - Blankets Mounting

The thermal blankets constructed in Brazil are made with these two principal components:

a) 12 µm thick double aluminized film (Therphane, furmished by Rhodia S.A), with a 300 Å thick metallic coating in each face.

b) 155 µm thick Nylon net spacer.

All the aluminized film is perforated to unable the blankets gases evacuation. The holes have 10,5 mm of diameter, and 20 mm of distance between themselves.

It was tested two types of thermal blankets: with one and two spacers.

For each test, the heater was wrapped by the blankets, as shown in Fig. 3. The fixation of the shields was made by means of Kapton tapes. This assembly avoids the heat to be transfered to the environment by radiation through the blankets edges.

The tests were conducted in a vacuum of the order of 10^{-6} torr, obtained in a thermal vacuum chamber with LN_2 cooled walls.

3. RESULTS

The experimental data obtained are listed in Table 1. The letters A and B refer to the first and second series of testes. The first mine table rows refer to thermal blankets with one spacer between layers, and the last six, to the blankets with two spacers. This table relates the number of polyester films and spacers with: the main and guard heater temperatures, the powers: dissipated and lost by the main heater, and the effective emissivities: measured and theoretical. The effective emissivity is calculated according to Eq. (2) and the theoretical effective emissivity according to Eq. (3).

The results were plotted in three graphics: the first one (Fig. 4) relates experimental and theoretical effective emittance with number of polyester films for blankets with one spacer between layers, the second one (Fig. 5) for two spacers between layers and the third ofr the two types of blankets, for comparison (Fig. 6).

To know the test repeatability, the effective emittance of the blankets assemblies: three layers with and two spacers were measured in two different times (the repeatibility was under 5%).

Actually, the M.L.I. used for space applications are constructed with different materials than that used in this work; it is easy to find blankets made with 6 μm thick polyester films and polyester or dacron nets. This way, it is difficult to compare the experimental data obtained with literature points. In spite of this fact, some literature data for blankets with a configuration similar to these tested here, were taken for comparison, as it is shown in Table 2. It must be noted that the blankets compared are not the same, and so the same effective emittance values are not expected. The objective of this comparison is to verify if Brazilian M.L.I. have a performance good enough to be used for satellite applications. To facilitate the visualization, these data are plotted in Fig. 7.

3.1 - Heat leaks

As seen in section 2, all the measurements were done in a vacuum chamber with LN_2 cooled walls. The heaters temperature were about $55^{o}C$, and as the thermocouple and power wires were in physical contact with the heater and the chamber walls, conduction and radiation heat leaks by them were expected. In table 1, it is shown that there was a difference of temperature between the main and guard heater, causing heat exchanges by conduction through the celeron holders and by radiation through the gap.

To estimate the heat leaks by the wires, they were considered an infinite conducting and radiating fins, with known basis temperature. To avoid too many heat to be transferred by the wires, it was done a thermal grounding: the wires were put in physical contact with the guard heater for at least 90 cm in order to achieve its temperature, so that all the heat leaks to the ambient was from the guard heater, not affecting the main heater, that corresponds to the actual measurements area.

The gap radiation heat leaks were calculated considering gray surfaces enclosure with emissivity of 0,02, since the gap heater surfaces were recovered with an aluminum tape, and the blankets layers are aluminized.

3.2 - Results uncertaining calculation

As seen before the thermal effective emittance calculation is made through Eq.(2), rewritten here:

$$\epsilon_{eff} = \frac{Q}{A\ \gamma\ (T_H^{\ 4} - T_C^{\ 4})} .$$

Supposing that the experimental measurements have a normal distribution around their average, the effective emissivity uncertainty is given by:

$$(\Delta\ \epsilon_{eff})^2 = (\frac{\partial\epsilon}{\partial Q})^2\ \Delta Q^2 + (\frac{\partial\epsilon}{\partial A})^2\ \Delta A^2 + (\frac{\partial\epsilon}{\partial T_H})^2\ \Delta T_H^{\ 2} + (\frac{\partial\epsilon}{\partial T_C})^2\ \Delta T_C^{\ 2} \quad , \qquad (4)$$

considering that all the variables are independent and that $\Delta Q = 2\ \sigma_{or}$, $\Delta A = 2\sigma_A$, $\Delta T_H = 2\sigma_{TH}$, $\Delta T_C = 2\sigma_{TC}$, where σ is the standard deviation.

The power dissipated in main heater is obtained by the equation:

$$Q = \frac{V^2}{R} , \qquad (5)$$

where:

V = voltage in main heater [V],

R = heater resistance [R]

and the heater resistance is obtained by the equation:

$$R = \frac{V}{I} \qquad (6)$$

where:

I = current in main heater [A].

It must be noted that the variables Q and R must be considered independent because the measurements of the voltages to calculate them were made independently with different multimeters.

The uncertainty obtained by Eq. (4) for all the measurements, are given in Table 3.

4. DISCUSSION

Analizing the experimental results, it is possible to conclude that the blankets tested are good radiating insulatiors. This fact is clear in Figs. 4 and 5, because the experimental and theoretical points have similar behavior and the mathematical model, considerers that no heat is transferred by conduction.

It is shown in Fig. 6 that the blankets with one spacer between layers are more efficient than that with two spacers. The explanation is that the presence of two spacers together separates too much the layers, increasing the lateral heat leaks, and causes a higher degasification, increasing the blanket internal convection heat transfer.

In Fig. 7, the experimental data obtained in this work is compared with literature ones. This comparisons indicates that the effective emittance values of the blankets constructed and tested are of the same order for three points; for the other two they are greater than the experimental results. It shows that Brazilian M.L.I. are appropriated for satellites applications.

It must noted that the M.L.I. emittance values are very small, so that it is difficult to obtain a big precision in these measurements.

For thermal control purposes in satellites applications, variations in the effective emittance of a thermal blanket are not very important, if these values are small (about 0,05). Analizing Table 3, the uncertainty levels obtained are not big (under 12% of the emittance values). These variations do not affect meaningfully the satellites temperature, what makes the results trustful. It means that the experimental apparatus project is very good for effective emittance measurements.

5. CONCLUSIONS

In this work, the results obtained are very satisfactory, so that all the thermal blankets constructed and tested have the same performance of the M.L.I. used in satellites in the world. It means that it is possible to produce and furnish the superinsulators necessary to Brazilian satellites.

The blankets were constructed with the available material, not with the ideal ones. For instance, the polyester films used were 12 μm thick and the ideal one has 6 μm (the blankets with 12 μm thick polyester films are very heavy). Recently, the Brazilian industry started to produce 5 μm thick polyester films, that was experimentally metallized for tests. A better spacer was locallized in the market: thinner and made with polyester threads.

The next step in M.L.I. study is to construct thermal blankets with this new material, to make superinsulators more suitable for space applications.

6. NOMENCLATURE

A	normal area to the temperature gradient, m^2
I	current in main heater, A
K	thermal conductivity, W/m.K
n	number of layers
Q	heat flow through the insulation, W
R	heater resitance, Ω
t	blanket thickners, m
T	temperature, K
V	voltage in main heater, V
Δ	measurement uncertainty
ε	emissivity, emittance
γ	Stefan - Boltzmann Constant, $W/m^2.K^4$
σ	standard deviation
C	cold boundary
eff	effective
H	hot boundary
n	n^{th}
p	main heater

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1 - Donato, L. and Haris, A., Experimental Investigation Into the Insulating Properties of Metallized and Non Metallized Multilayer Thermal Blankets, RML-009-80-60, July 1980.

2 - Lizon-Tati, J., MLI Effective Emittance Experimental Results, Mantelli, M.B.H., Instituto de Pesquisas Espaciais, August 1986, Personal Communication.

Table 1 - EXPERIMENTAL RESULTS.

TEST NO.	FILMS NO.	SPAC. NO.	TEMPER. (C DEGREES) AVERAGE GUARD H.	TEMPER. (C DEGREES) AVERAGE MAIN H.	POWER DISS. (W) MAIN H.	THERMAL LEAKS (WATTS)	EFFECT. EMITT.	THEORET. EFFECT. EMITT.
1B	1	1	56.78488	57.63242	1.826098	0.013410	0.039407	0.016949
2B	3	1	56.77640	57.71796	0.797901	0.014146	0.017021	0.007299
5B	3	1	56.79477	56.66465	0.797901	0.005766	0.017425	0.007299
1A	5	1	57.12	57.31	1.3085	0.66547	0.00922	0.00559
3B	7	1	56.82894	56.86863	0.382425	0.007094	0.008235	0.003412
3A	10	1	50.28	50.38	0.9066	0.60434	0.00461	0.0028
4B	12	1	56.93450	56.83991	0.441180	0.006051	0.009551	0.002049
4A	15	1	55.53	55.55	0.9955	0.63056	0.00526	0.00187
5A	20	1	53.66	53.71	0.9679	0.62207	0.00508	0.00104
6B	3	2	56.69415	56.33648	0.606426	0.003985	0.013305	0.007299
9B	3	2	56.70130	56.71356	1.062295	0.006873	0.023202	0.007299
6A	5	2	53.35	53.38	1.2372	0.62071	0.00929	0.00559
7B	7	2	56.79095	56.70328	0.606426	0.006097	0.013199	0.003412
7A	10	2	53.93	53.93	1.125	0.62458	0.00744	0.0028
8B	12	2	56.80293	56.80114	0.504131	0.006769	0.010922	0.002049

Table 2 - COMPARISON BETWEEN EXPERIMENTAL AND LITERATURE DATA.

FILMS NO.	SPAC.NO.	EXPERIM. EFFECT. EMITT.	LITERAT.EFF.EMITT. [1]	LITERAT.EFF.EMITT. [2]	THEORET EFFECT EMITT.
1	1	0.039407	0.049		0.016949
2	1		0.029		0.010204
3	1	0.017021	0.02		0.007299
3	1	0.017425			0.007299
4	1		0.02		0.005681
5	1	0.00922	0.022		0.00559
7	1	0.008235			0.003412
10	1	0.00461		0.004067	0.0028
12	1	0.009551			0.002049
15	1	0.00526			0.00187
20	1	0.00508			0.00104
3	2	0.013305			0.007299
3	2	0.023202			0.007299
5	2	0.00929			0.00559
7	2	0.013199			0.003412
10	2	0.00744			0.0028
12	2	0.010922			0.002049

Table 3 - RESULTS UNCERTAINTY

FILMS NO.	SPAC.NO.	EFFECT. EMITT.	THEORET. EFFECT. EMITT.	EFFECT. EMITT. UNCERT.
1	1	0.039407	0.016949	4.48E-03
3	1	0.017021	0.007299	1.93E-03
3	1	0.017425	0.007299	1.98E-03
5	1	0.00922	0.00559	1.05E-03
7	1	0.008235	0.003412	9.36E-04
10	1	0.00461	0.0028	5.30E-04
12	1	0.009551	0.002049	1.09E-03
15	1	0.00526	0.00187	[illegible]
20	1	0.00508	0.00104	5.84E-04
3	2	0.013305	0.007299	1.51E-03
3	2	0.023202	0.007299	2.64E-03
5	2	0.00929	0.00559	1.06E-03
7	2	0.013199	0.003412	1.50E-03
10	2	0.00744	0.0028	8.56E-04
12	2	0.010922	0.002049	1.24E-03

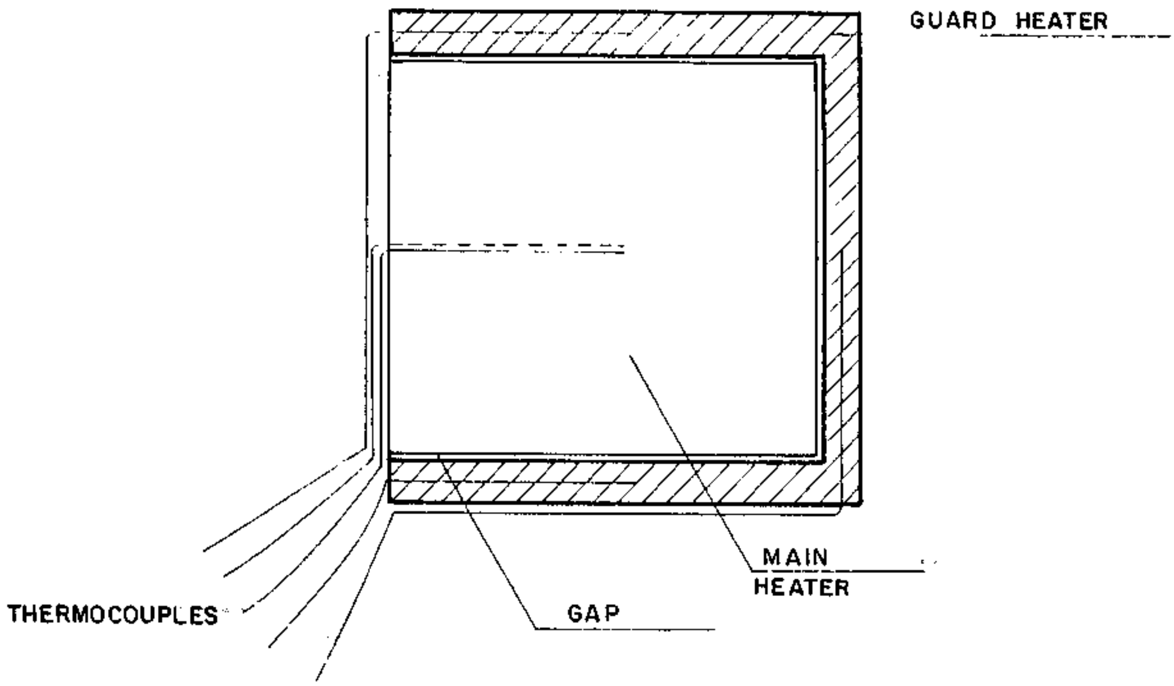

Fig. 1 - Experimental Apparatus.

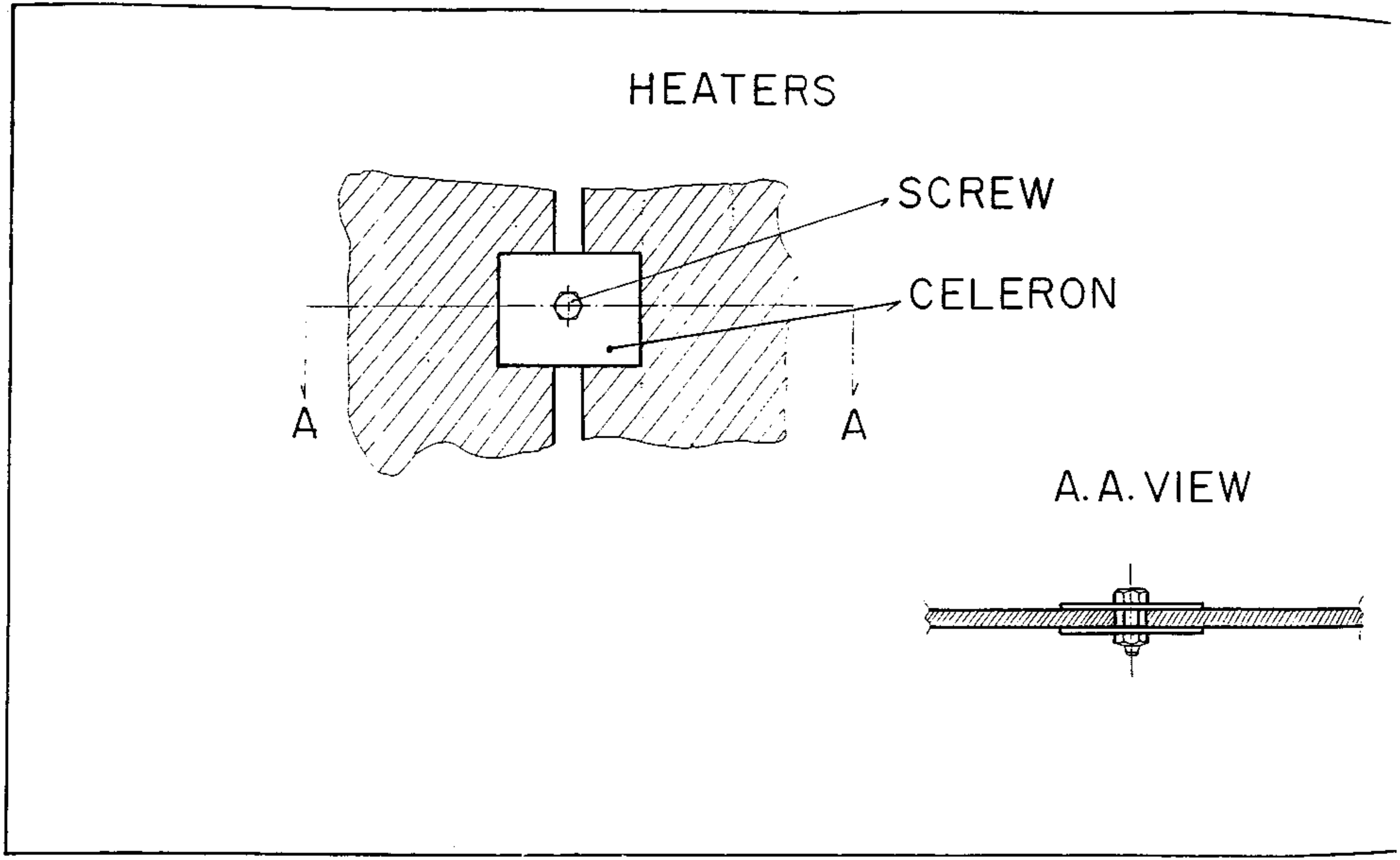

Fig. 2 - Celeron Holders

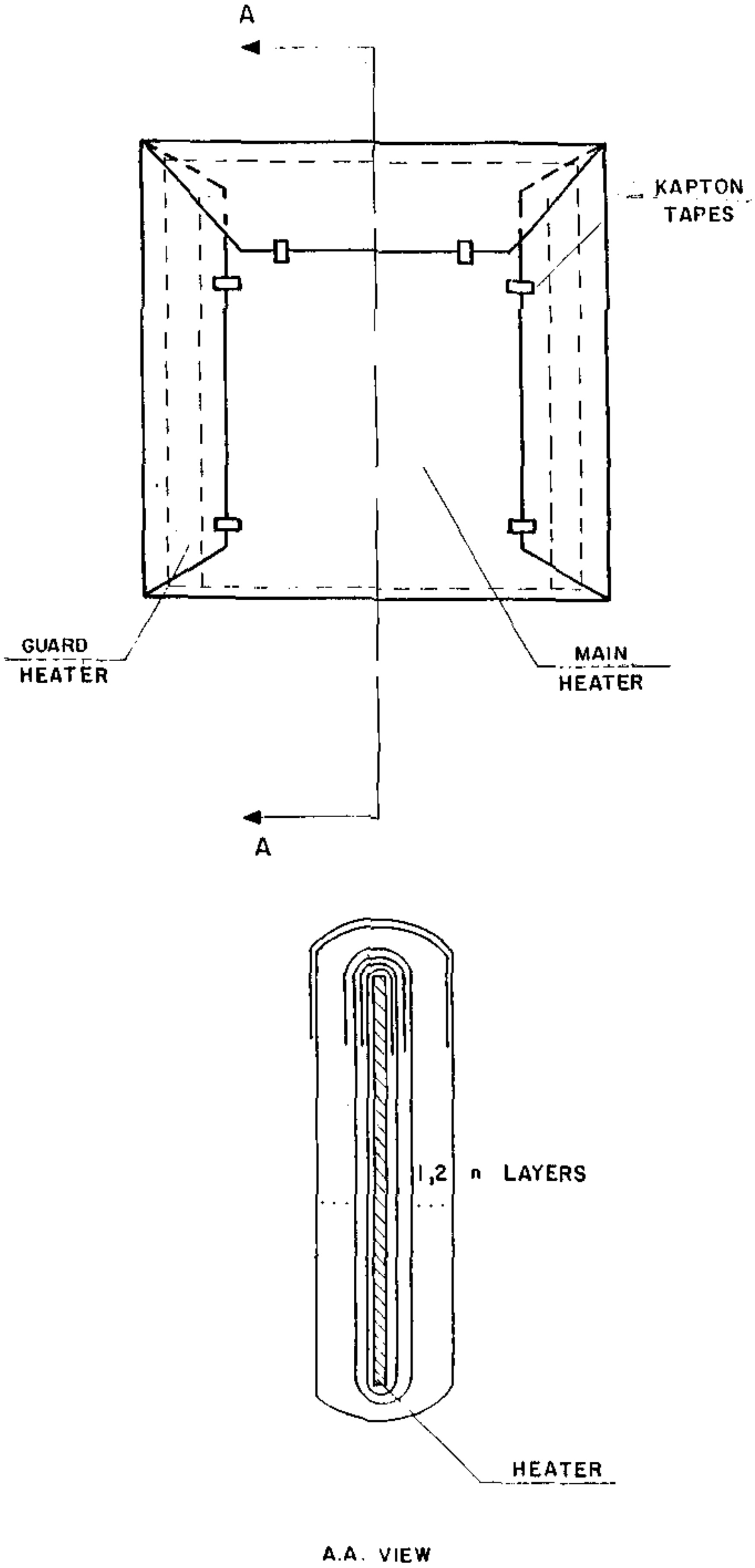

Fig. 3 - Mounting of the MLI blankets.

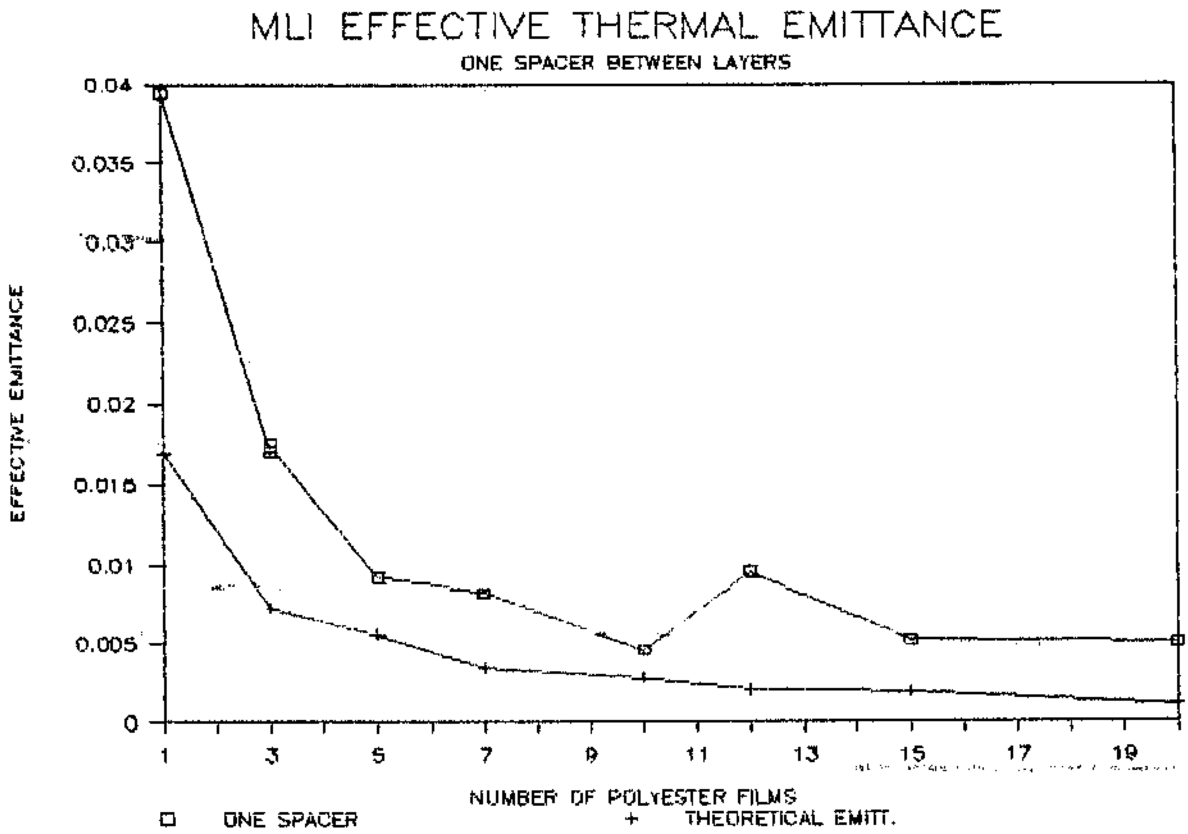

Fig. 4 - Effective Thermal Emittance as a Function of the Number of Layers for Blankets with One Spacer Between Layers.

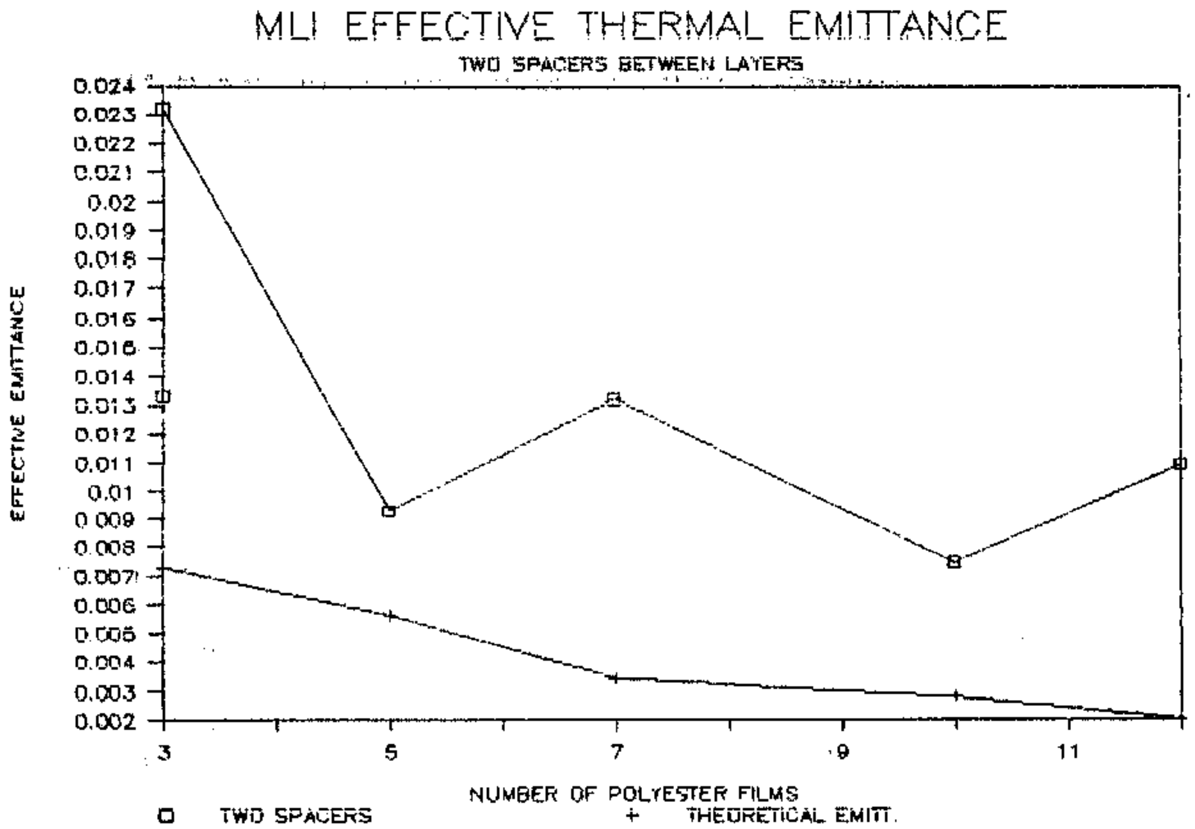

Fig. 5 - Effective Thermal Emittance as a Function of the Number of Layers for Blankets with Two Spacers Between Layers.

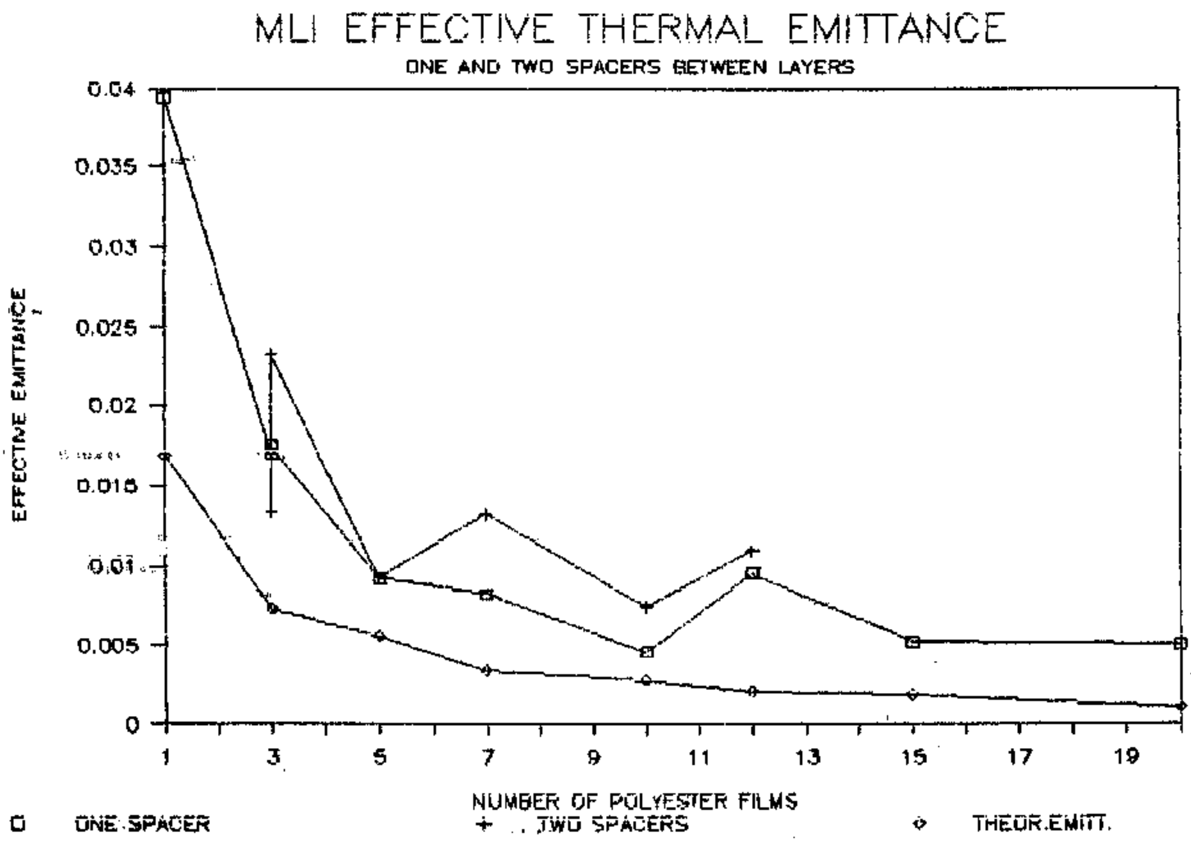

Fig. 6 - Effective Thermal Emittance as a Function of the Number of Layers for the Two types of Blankets

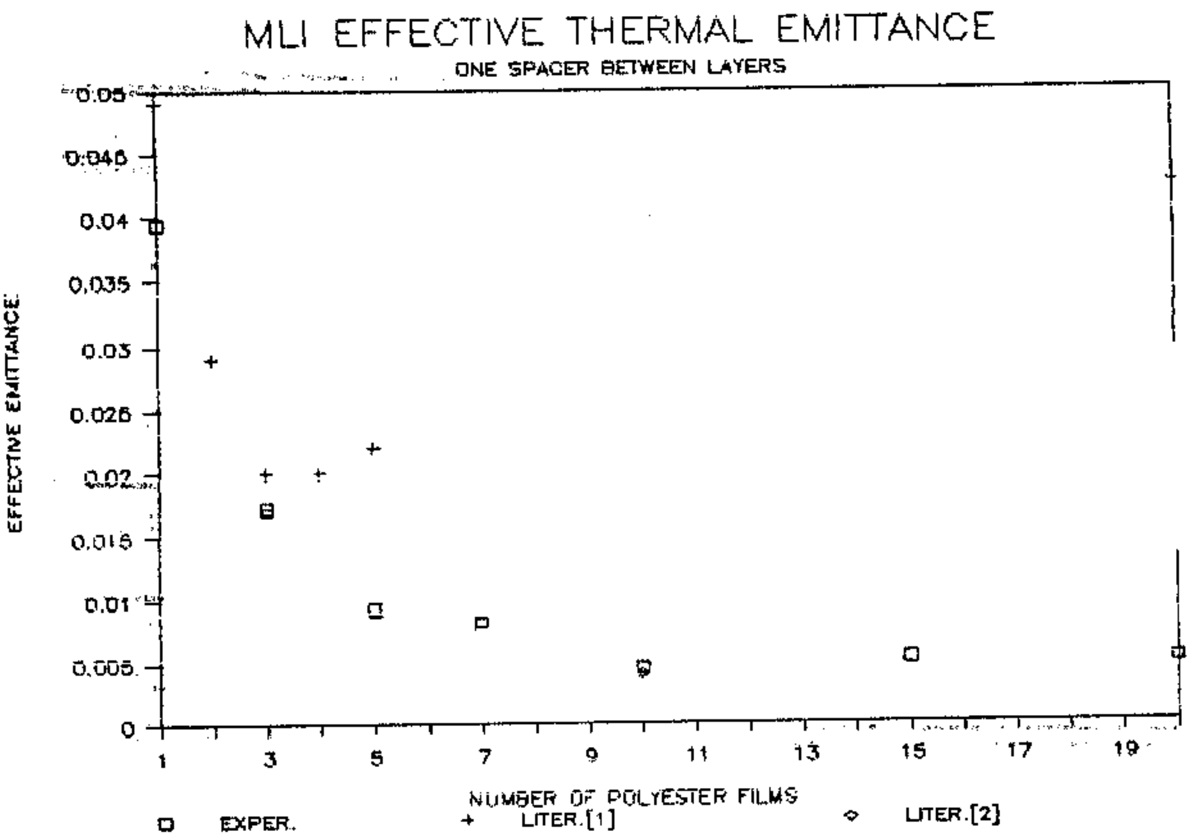

Fig. 7 - Comparision Between Experimental and Literature Effective Emittance Points.