Notes on MLI blankets. This report focuses on the cookie blanket and its extensions. The goal is to find where we can win the most by using new fabrication techniques.

"The effect of discontinuities introduced by application of MLI on spacecraft has been to increase the heat loss even more (by an order of magnitude or greater) over calorimeter testing." [10]

For reference we use the following numbers:

The area of the top of the cookie is 2600 cm^2. The nominal blanket is 18 layers, with 16 VDA2.

The effective emissivity of the blanket is e^* = 0.008 (theory). This can be achieved in a well controlled calorimeter ([3], Figure 7).

For a cookie at 293K, the total available power is Q=107 W. With the best blanket, we cut the flux to Q*e^* = 0.9 W.

All the cited literature concerns heat transfer between 77 and 300K, nearly identical to our situation.

The wavelength of radiation is between 10 to 30 microns or 0.001 cm to 0.003 cm. The spacing between layers is 0.03 cm or 10 to 20 wavelengths so we model the ray's path as geometric. The emissivity of aluminum is about 0.013. At 45 deg incidence, a ray can travel 75 bounces, or about 3 cm, before it is diminished by e^(-1). In other words, radiation travels laterally through the blanket quite well. The netting, to some degree, mitigates this effect.

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Number of blankets.

Shu et al. [6] find that the best number of layers of MLI is 30 (VDA1). For covering cold copper, they find a heat flux of...

Painted copper	Al taped Cu	5 MLI layers	10 MLI	20 MLI	30 MLI
1	0.19	0.06	0.037	0.027	0.022

For more than 30 layers, they find that the thermal conductivity of the blanket dominates the insulating properties. Thus, there is little gain beyond 30 layers.

Note that their optimal blanketing over our surface would result in a leak of 3 Watts, and this is before penetrations are accounted for.

Do we have the optimal number of layers for a 2-sided blanket?

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Cracks and Slits in MLI --the other "black crack" problem.

Shu et al. [7], [8]. [9] have carefully investigated this both experimentally and theoretically. They find:

a) a 1-d slit in the MLI is not detectable.
b) A slit of width 2 mm with unfinished edges radiates 60 W/m^2.
c) A slit of width greater than 4 mm with unfinished edges radiates 150 W/m^2.
d) Not until the slit is very large does one see power from the substrate. In fact, the emissivity of the material on the bottom of the slit has little to do with the slit's effective emissivity. This was done with an MLI blanket over a cold plate.
e) The mechanism is that the edges of a blanket (unfinished) are black. They couple well to anything that is warm.
f) The area around the crack/slit heats up further reducing the blankets effectiveness.

The bottom line is that cutouts in the blankets are bad, even if they are taped along the edge.

Patches interspersed throughout the layers, 6 sufficed for a 30 layer blanket, bringing the blanket back to its theoretical value. Warm patches are most effective. Patches with VDA on both side are best.

Finishing the edges will help and our geometry will help.

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Edge effects

This is covered in part in Donabedian & Gilmore [9] and in Stimpson and Jaworski [S&J, 10]. S&J are most concerned with what happens when blankets are stitched and how one covers a stitched area. Stu reports that this was once the practice at JPL.

The bottom line is that they say patches over edges must extend over 2" beyond the edge. This agrees well with our rough estimate of the transverse radiation length. They also recommend that penetrations and joints between blankets be made by overlapping each 5 layer sub-set of the blanket and then taping the outside. This is similar to what we arrived at for the guide close out.

S&J give a plot that appears in D&G based on years of blanketing experience. I believe this is the source of Stu's estimates. For an 18 layer blanket of area 0.25 m^2 with a high "discontinuity density" the effective e^* can be 0.1 ! Yikes.

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Blanket loft

Bapat et al [1],[2] Show that blanket loft is very important. For an eighteen layer blanket (VDA1) with glass fabric spacing, they find for heat transfer between 300 and 80 K:

Density (layers/cm)	Heat flow (W)	[Normalized]
63	0.6	[3.8]
50	0.35	[2.3]
30	0.15	[1.2]
20	0.13	[1.0]

They, like others, show the temperature distribution transverse to the blankets is roughly linear.

This means that the MLI behind the GA struts is not doing its job. The compression loss is compounded by the fact that the outermost layer radiates very well.

It also means that creases, folds, etc in the MLI radiate significantly. Recall that a fold affects roughly +/- 5 cm of blanket.

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Temperature distribution

Jacob et al. [3], [4], and Bapat et al. [1], [2], show that the temperature distribution through the blankets is roughly linear. This unintuitive behavior is the result of a combination of conductive and radiative coupling between layers. It also depends on the blanket loft.

This means that the effective radiating temperature of the fifth layer above the cookie is 248K. A 1/16" wide gap around the cookie will radiate 0.6 W (someone please check!) This is a lot!

Jacob et al. also show that the time constant of blanket can be 45 hours.

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Recommendations:

1) Patches around waveguide every 4 blankets, as discusses. The patches should be 10 cm in diameter where possible. I realize this simply may not be possible for many cases.

2) No Kapton on outer layer. It should be Al. The reason is that this layer gets folded into lower layers to make edge connections etc. It also couples well to whatever thermal environment it is in.

3) The cookie blanket should be made on a template. The seams for every few layers should run in a different direction. I think 18 layer may not be enough but the difference between VDA2 and VDA well does not seem well discussed in the literature.

4) All seams overlap 2.25 inches and all are interleave. scrim between interleave layers.

5) Minimal edge taping. When taping is required (for exposed edges), it should be done with VDA tape. No Kapton.

6) No compressed blankets.

7) As discussed, one blanket should come from midway up the GAC and go to the top of the cookie. There should not be a direct link between the top of the FPA and the top of the GAC. We should also consider making this blanket on a template as it is critical and will be difficult.

8) Depending on how difficult it is to make a blanket.... The penetrations might be made by firmly tying MLI to the obstruction and interleaving these attached layers with the larger blankets.

9) Patches should go on the bottom of the w/g as well, similar to what was done last time.

10) Teepees should go on the top of the top blanket where possible. Teepees on the bottom will help too. In general, the less contact with the w/g the better though.

11) We need to carefully measure the space behind the diagonal struts. The blanket should not be compressed here. Perhaps fewer layers are required in this area.

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Shu is at Fermilab. We might consider calling him in for a consultation. Steve do you know him?

References:

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[3] S. Jacob, S. Kasthurirengan & R. Karunanithi "Investigations into the Thermal Performance of Multilayer Insulation (300-77 K) Part 1:Calorimetric studies."

[4] S. Jacob, S. Kasthurirengan & R. Karunanithi "Investigations into the Thermal Performance of Multilayer Insulation (300-77 K) Part 2: Thermal Analysis."

[5] Q. Shu, R Fast, & H Hart, "Theory and Technique for Reducing

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[10]L. Stimpson & W. Jaworski, "Effects of Overlaps, Stiches, and Patches on Multilayer Insulation," AIAA, 1972, 72-265.