Thermal performance of the multilayer insulation systems for cryogenic applications

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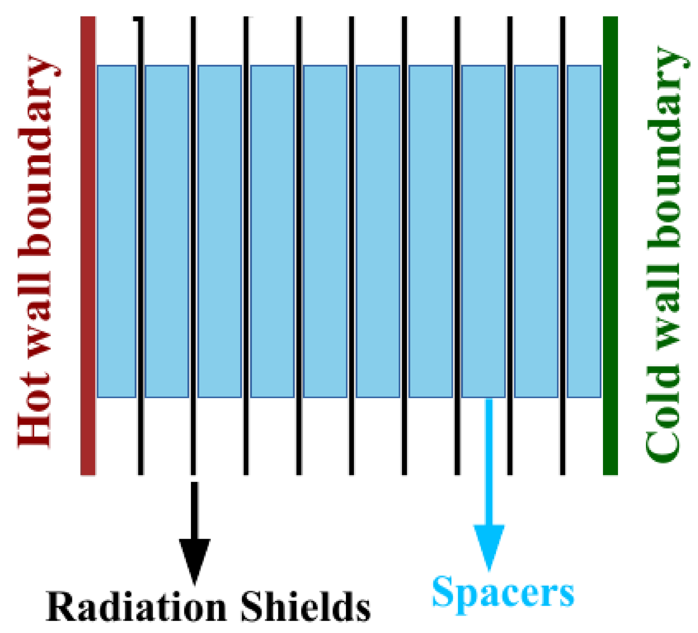
1. Introduction

▲ Cryostat: A double walled container
▲ filled with cryogenic liquid
▲ provide thermal insulation
▲ Multilayer Insulation (MLI) technique: composed of radiation shields and low conductivity spacers
◙ MLI reduces radiation heat load by multiple reflection of incident radiation



● Radiation shield: Polished with highly reflecting metals for reflection
● To ignore solid conduction: Spacers are placed in between the radiation shields

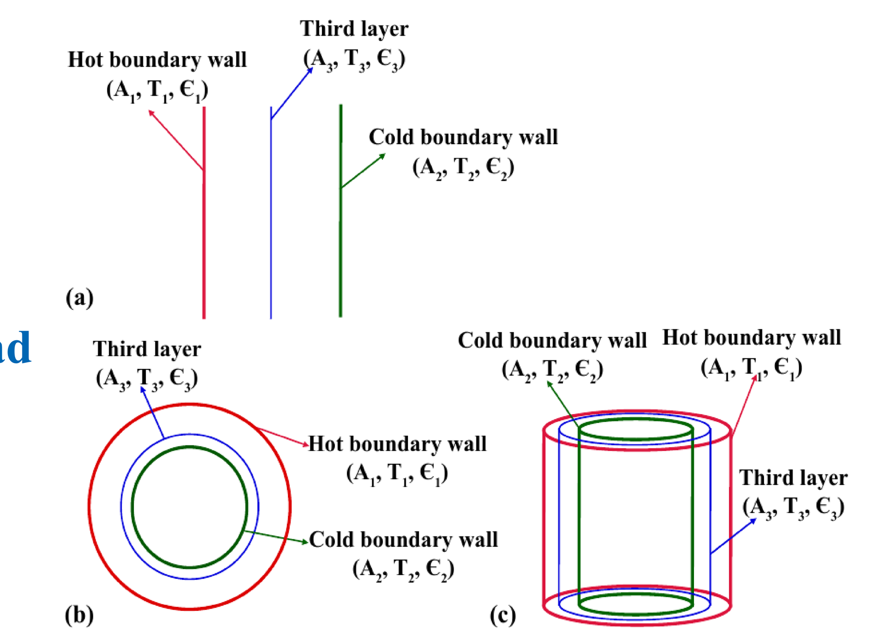
S.No.	Materials	Constants		
		CR	CS	CG
1	Unperforated DAM with Silk-Net	5.39×10^{-10}	8.95×10^{-8}	1.46×10^{-4}
2	Perforated DAM with Glass-Tissue	7.07×10^{-10}	7.30×10^{-8}	1.46×10^{-4}
3	Perforated DAM with Dacron	4.94×10^{-10}	—	1.46×10^{-4}

● Why we study ?

Cryostat is used to offer the mechanical housing, shielding and cooling to the device under observation and the reliable functioning of a device requires minimum heat load.

2. Exchange of Heat and Formulation

● Solid conduction
● Residual gas conduction
● Thermal radiation
■ Thermal radiation is major part
■ MLI Technique reduces radiation heat load



Heat load without inserting any layer

$$q_{1-2} = \frac{\sigma A_2 (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_2} + \frac{1-\varepsilon_1}{\varepsilon_1}\left(\frac{A_2}{A_1}\right)}$$

Heat load with inserting a single layer

$$q_{1-2} = \frac{\sigma A_2 (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_2} + \left(\frac{1}{\varepsilon_1} - 1\right)\frac{A_2}{A_1} + 2\left(\frac{1}{\varepsilon_3} - 1\right)\frac{A_2}{A_3} + \frac{A_2}{A_3}}$$

Modified Lockheed Equation for Silk net and Glass tissue

$$q_{total} = \frac{C_R\,\varepsilon\,(T_h^{4.67} - T_c^{4.67})}{N} + \frac{C_S\,\bar{N}^{2.63}(T_h - T_c)(T_h + T_c)}{2\,(N+1)} + \frac{C_G\,P\,(T_h^{0.52} - T_c^{0.52})}{N}$$

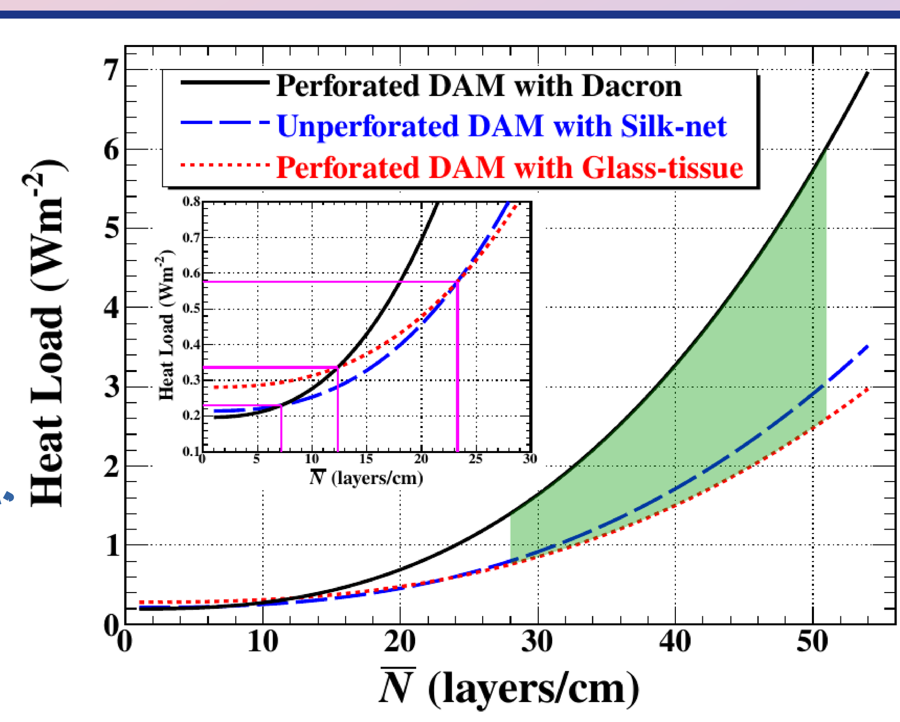
Modified Lockheed Equation for Dacron

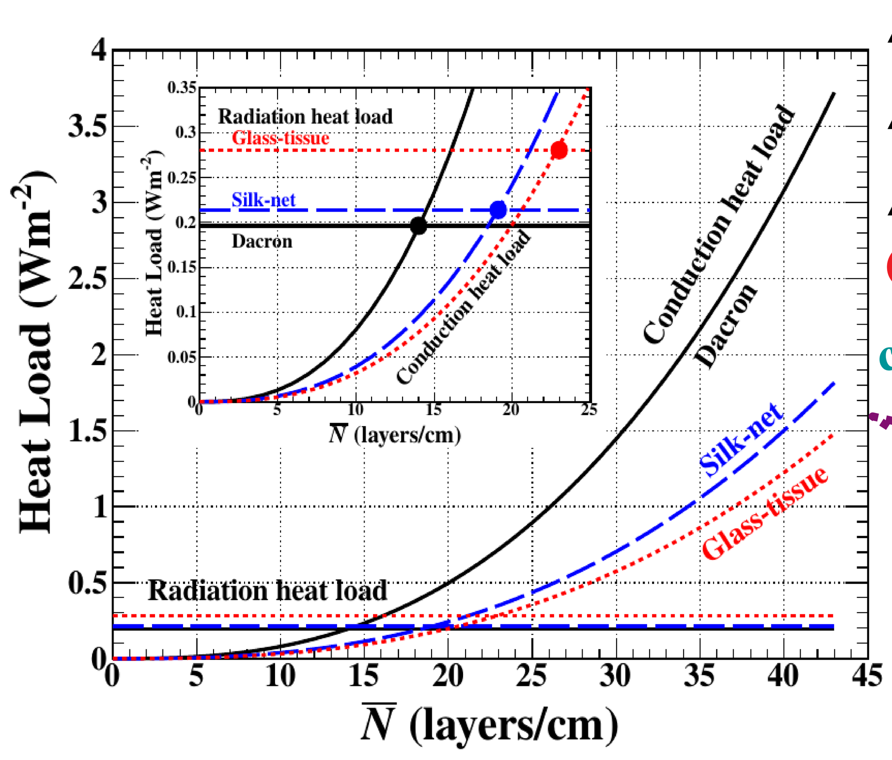
$$q_{total} = \left(\frac{2.4\times10^{-4}(0.017 + 7\times10^{-6}\,(800 - T) + 0.0228\,ln(T))\,\bar{N}^{2.63}(T_h - T_c)}{N}\right) + \left(\frac{C_R\,\varepsilon\,(T_h^{4.67} - T_c^{4.67})}{N}\right) + \left(\frac{C_G\,P\,(T_h^{0.52} - T_c^{0.52})}{N}\right)$$

3. Analysis and Results

◙ Increment of heat load due to conduction
◙ With layer density
◙ At constant N=40
▲ Therefore Layer density has a limit.

with 82% increment in layer density, heat load increments are:
● 282% for Silk-Net
● 242% for Glass-Tissue
● 330% for Dacron



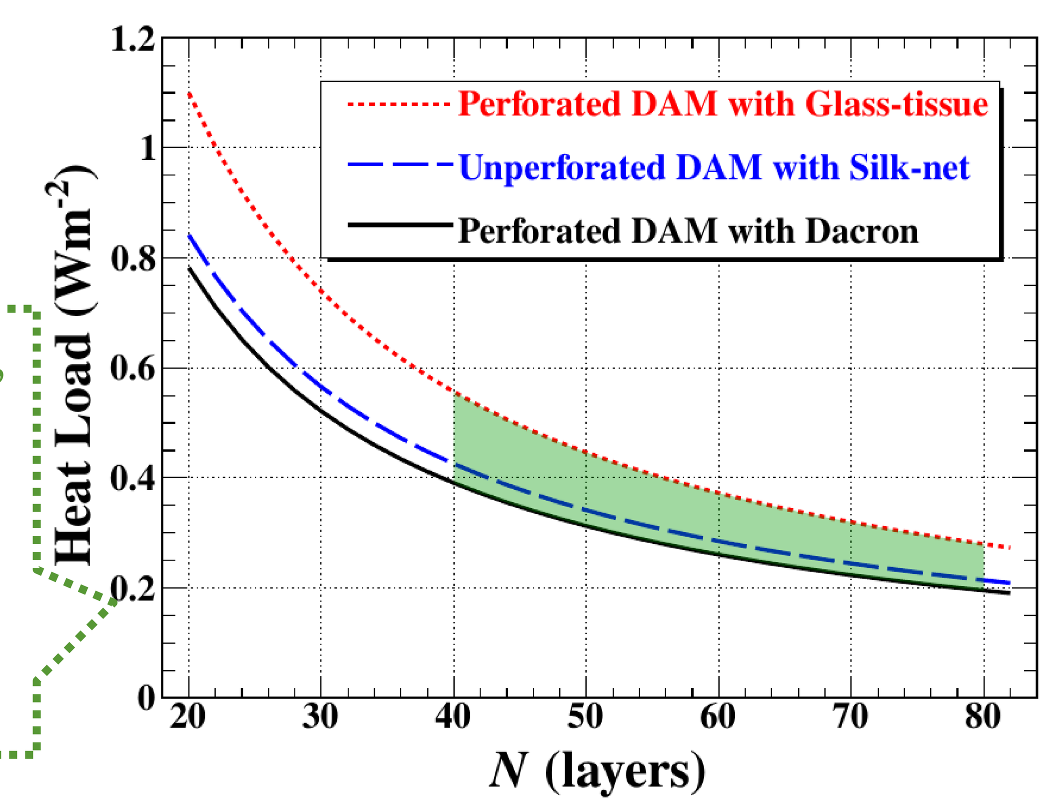


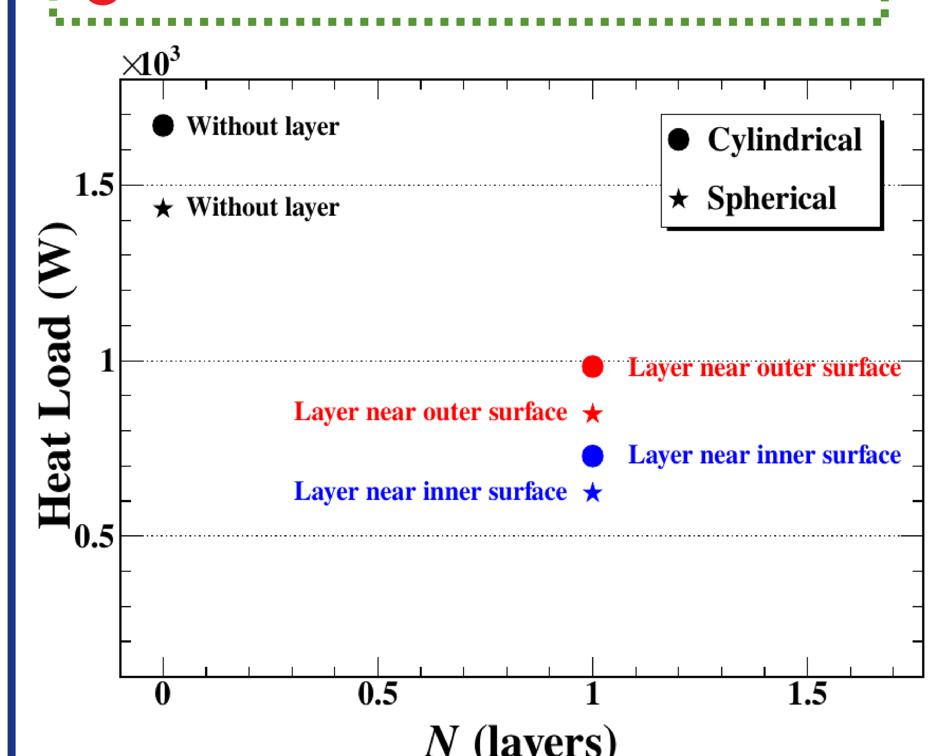
▲ Radiation decreases with layer density
▲ Conduction increases with layer density
▲ Requires optimized layer density
▲ At constant N=40
● Equilibrium between radiation and conduction represents layer densuty.

Layer densities (layers/cm) are:
● 19.0 for Silk-Net
● 22.7 for Glass-Tissue
● 14.0 for Dacron

● With Number of layers
● At calculated layer density
● Decrement in heat load

with 100% increment in layer density, heat load increments are:
● 50% for Silk-Net
● 50% for Glass-Tissue
● 50% for Dacron





▲ Different shapes have different heat loads.
Comparative heat loads for spherical and cylindrical cryostats

	Geometry	
	Spherical	Cylindrical
N	Heat Load (W)	
0 (Without any layer)	1.43×10^3	1.67×10^3
1 (Near inner surface)	6.23×10^2	7.28×10^2
1 (Near outer surface)	8.48×10^2	9.83×10^2

4. Summary

Glass-Tissue is found the best choice for Spacer with :
● Lowest increment in heat load
● Highest layer density and thinest MLI blanket

Spherical geometry is the most effective configuration but cylindrical cryostats are used because of of most economical configuration and easy to build as well.

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