SUBJECT: A stray-light baffle design for thermal strap entry ports

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KEYWORDS: thermal strap, stray-light, baffles

COMMENTS: **This document presents possible designs for a stray-light control baffle to be fitted to the thermal straps needed for the SPIRE detectors, at the points where the straps pass through covers or bulkheads.**

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1. INTRODUCTION

The SPIRE detectors will be cooled by means of thermal straps connected between them and a suitable point in the liquid Helium cryostat. The straps must pass through suitable holes in the instrument structure on their way to the detectors. As a consequence, the possibility of thermal radiation from 15 K surfaces penetrating into the heart of the instrument via these holes must be guarded against. This note presents a design for a stray-light baffle to be fitted between a cold thermal strap and a bulkhead so as to cover the hole or slot through which the thermal strap passes. The design equations are presented so that the parameters for an optimally minimum-mass baffle and the space volume required for it can all be determined.

2. THE PROBLEM

Figures 1 and 2 show the sort of situation that is envisaged. Figure 1 shows, in plan view, a thermally conducting strap (or straps, each assumed to have a circular cross-section) passing through a circular or slotted hole made in one of the covers of the SPIRE instrument. The strap is assumed to make an angle of 90 degrees to the cover near the hole. Figure 2 shows a sectional view.

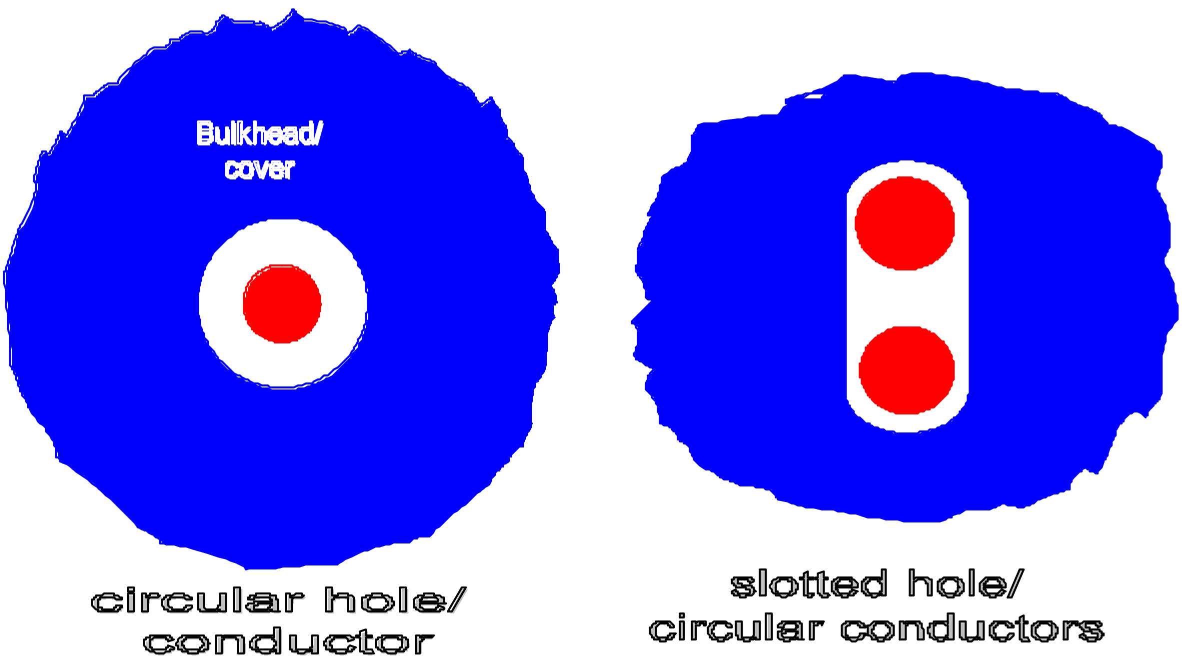

Figure 1 Plan view of a possible thermal strap/ instrument cover interface.

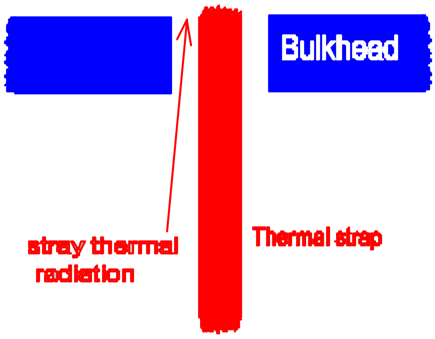

Figure 2 Sectional view of a possible thermal strap/ instrument cover interface

The problem is to cover the gap that must necessarily be left between the thermal-strap and the bulkhead through which it passes, without significantly increasing the thermal loss from the strap to its local surroundings.

3. POSSIBLE SOLUTIONS

Figure 3 shows, in cross-sectional view, how the gap between a thermal strap and a bulkhead might be bridged using a two-piece stray-light baffle. One piece (the base) fits to the bulkhead, the other piece (the cover) fits to the strap. When properly fitted and located, the two pieces are designed not to make contact with each other, a nominal clearance D being maintained at all points.

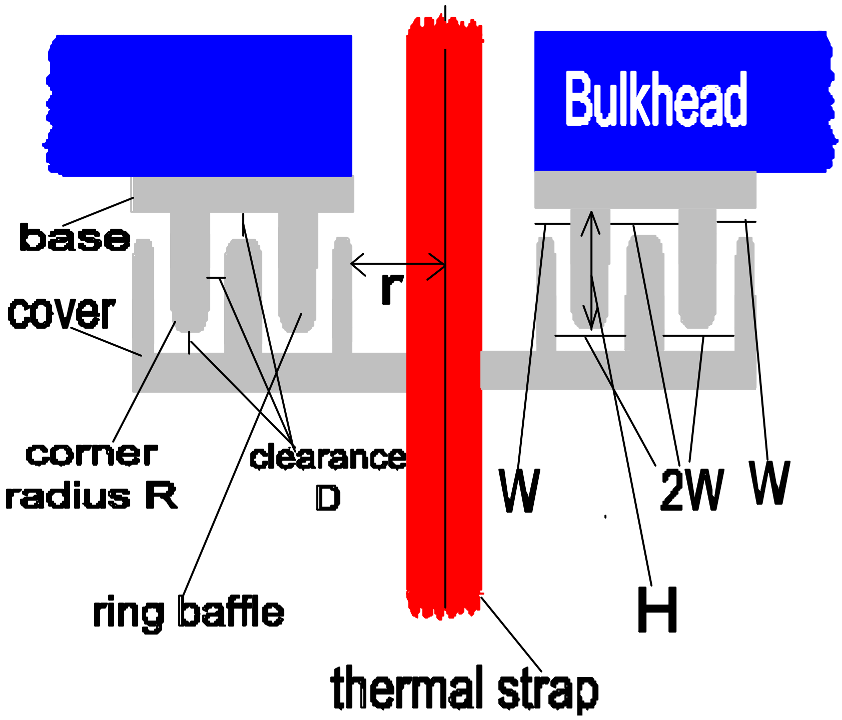

Figure 3 Sectional view through a proposed baffle design

The performance of the proposed baffle depends on the detailed geometry of the ring baffles that are indicated to be parts of both the base and cover sections of the baffle. The main design parameters will be the clearance D, the spacing 2*W and the height H of the ring baffles. Also important will be the radius R of the internal edges of the ring baffles.

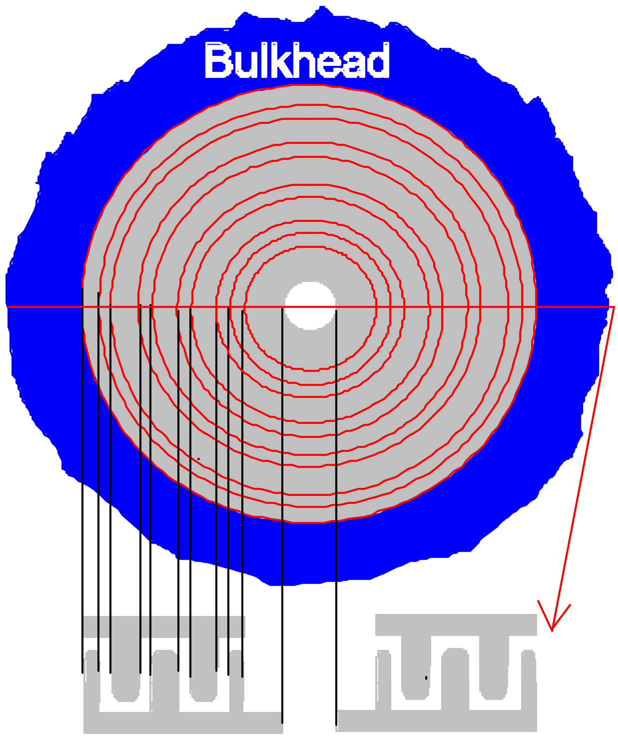

Figure 4 Circular baffle sectional view

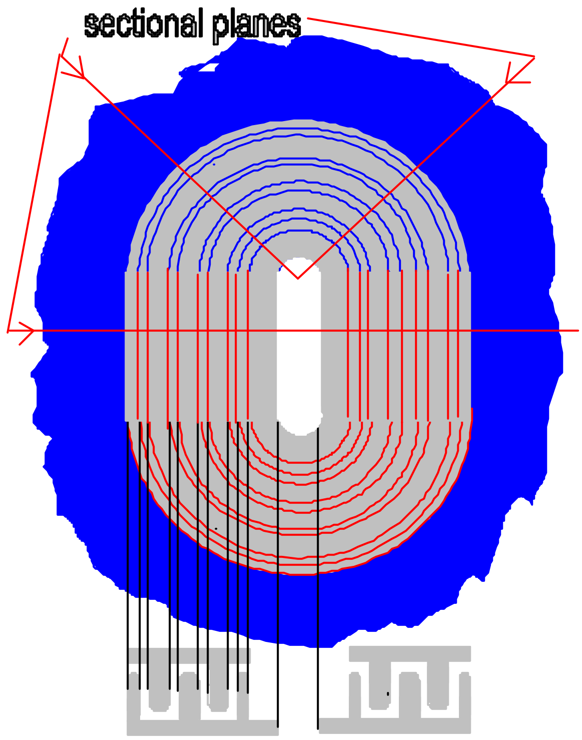

Figure 5 Slotted baffle sectional view

Figures 4 and 5 show how the sectional view shown in figure 3 might relate to baffles fitted over both circular and slotted holes in a bulkhead. The so-called 'ring baffles' shown only in section in figure 3 are understood to be continuous around the hole being covered.

4. BAFFLE OPERATION

Figure 6 shows the intended mode of operation of the baffle. Sections through four versions of the baffle are shown, each version differing in the number of baffle rings that it includes. The baffle operates by forcing external radiation to undergo multiple reflections from internal baffle surfaces before it can enter the cavity between the thermal strap and the bulkhead that the latter is passing through. The more rings, the more reflections are forced, provided that certain design rules are followed. These rules will be set out in the next section. The efficiency with which the baffle attenuates and absorbs incident external radiation depends on the finishes chosen for the internal baffle surfaces combined with the number of reflections that are forced on the radiation.

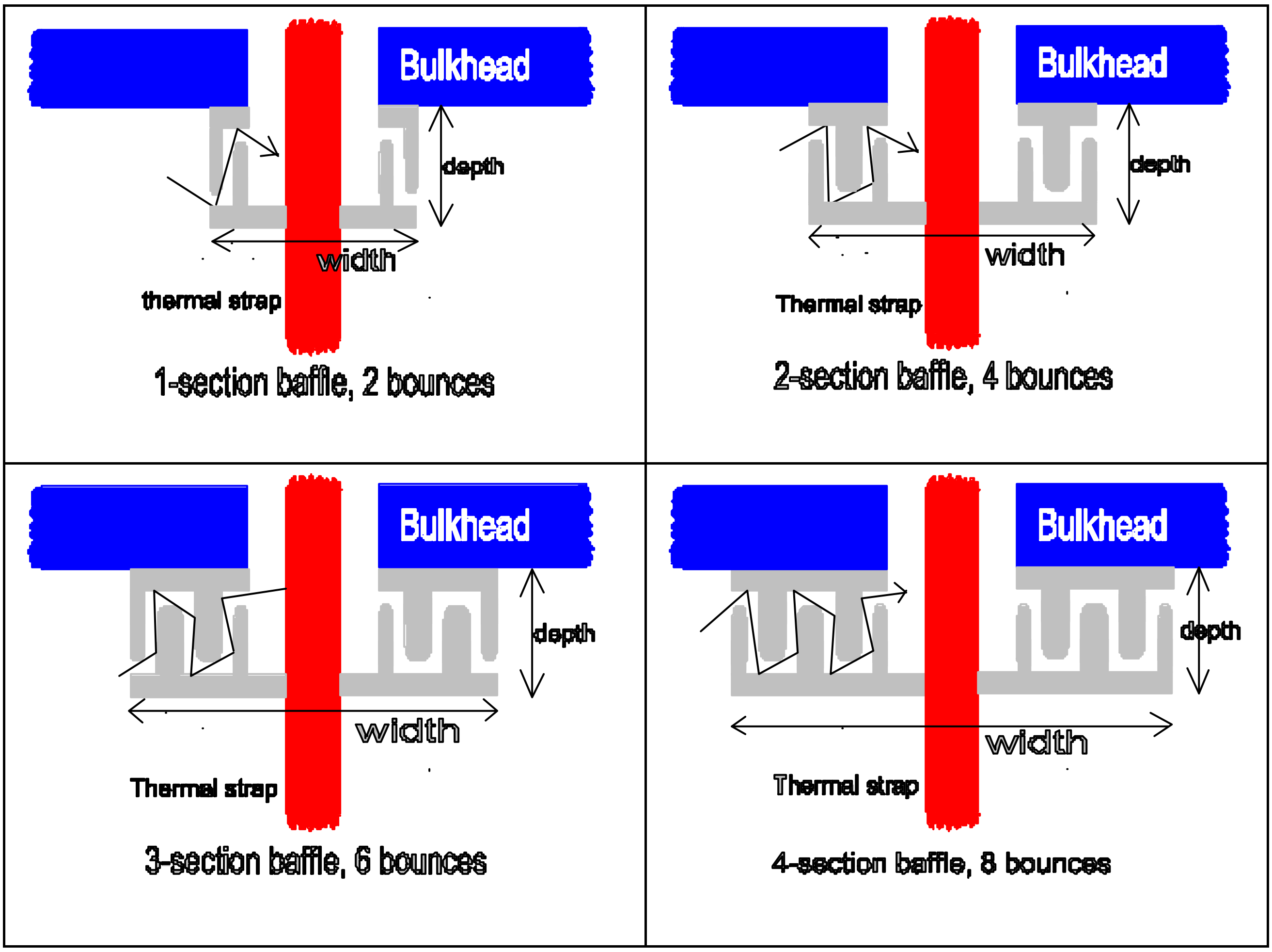

Figure 6 Baffle behaviour as the number of ring sections is increased from 1 to 4

For a given baffle depth, ring spacing and ring thickness, it is clear that the overall width of the baffle increases as the number of baffle rings is increased, just as the efficiency with which the baffle intercepts external radiation also increases. Thus a more efficient baffle will take up more space and require more material (and hence contribute more mass). The next section will show how it is possible to optimise the baffle to use a minimum of material for a given number of baffle rings by adjusting the baffle depth (or height).

5. BAFFLE DESIGN EQUATIONS

The basic property sought for the baffle design is illustrated in figure 7. The thickness of the baffle rings, **T**, is combined with their height **H** and the clearance **D** to ensure the existence of 'shadow' regions between baffle rings such as those indicated and labelled **'1','2'** and **'3'** in the figure. Region **1** cannot send radiation direct to region **2** and region **2** cannot send radiation direct to region **3**. Radiation leaving surfaces in **or before** (to the left of) region **1** must scatter at least twice from internal surfaces before it can reach region **2 or beyond**. In this way each additional baffle section forces two more reflections.

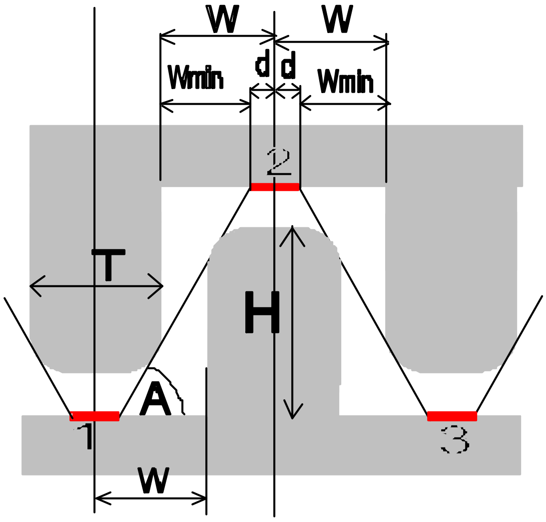

Figure 7 Illustration of main baffle design property

The existence and size of the aforementioned ‘shadow’ regions depends on the value chosen for the parameter ‘**d**’ in figure 7. The minimum width **Wmin** can be determined using the main parameters **D, H** and **R**, the radius of top edges of the baffle rings, via the determination of the angle labelled ‘**A**’. Increasing the width parameter by the amount ‘**d**’ ensures a margin of safety to ensure proper operation of the baffle by forcing a certain finite size for the regions ‘**1**’ and ‘**2**’, etc. The design equations are derived by considering the geometry of figure 8.

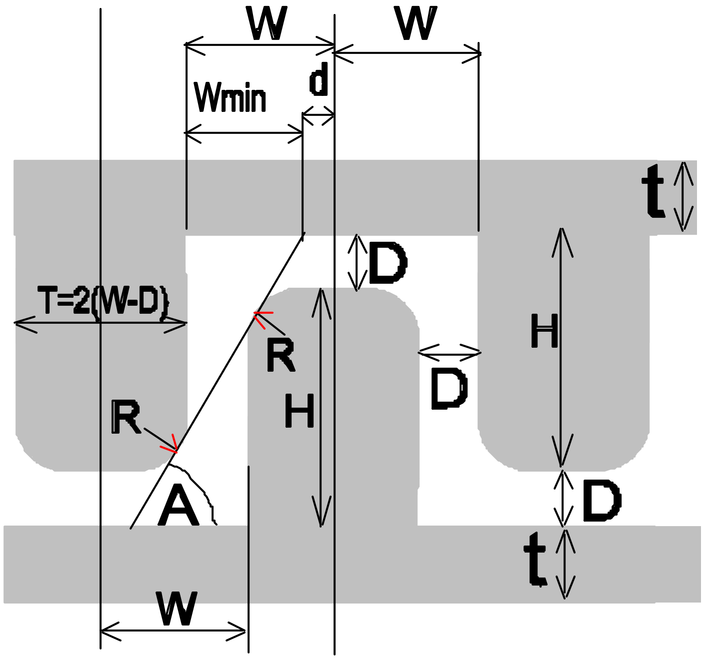

Figure 8 Main baffle design parameters

Table 1 lists the values selected for the dimensions shown in figure 8. Some values, such as the clearance **D**, base and cover thickness **t** and ‘shadow’ half-width ‘**d**’ are flagged as ‘fixed’. Others, such as the baffle ring height **H** and the edge radius **R** are allowed to vary over a range in order to determine an optimum design, if one exists. All dimensions are in millimetres.

Table 1 Baffle design parameters

Parameter	Value/ range (step)	Fixed/variable
D	2.0	fixed
d	0.5	fixed
t	2.0	fixed
R	0.0 → 1.0 (0.2)	variable
H	D+2→20.0 (0.5)	variable

The basic design equation involves the determination of the angle labelled '**A**' as a function of the parameters **H, D** and **R**. This equation is as follows:

$$Tan(A/2) = \frac{\sqrt{(D+2*R)^2 + (H-D)*(H-D-4*R)} - (D+2*R)}{(H-D-4*R)}$$ **if H>or<D+4*R** **Eq.(1)**

$$Tan(A/2) = \frac{H}{2*(D+2*R)}$$ **if H=D+4*R**

Having solved for **A**, we can then find the quantities **Wmin** and **W** in figures 7 and 8 using

$$W\min = \frac{D + R*(1-\cos(A))}{Tan(A)} + R*(1-\sin(A)) + D$$ **Eq.(2)**

$W = W\min + d$ If Wmin+d> R+D **Eq.(3)**
$W = R + D$ If Wmin+d< R+D

The second part of eq.(3) ensures that a baffle vane width, **Wbaf= 2*(W-D),** cannot be made less than **2*R.** The quantity **2*(W-D)** is plotted in figure 9 as a function of **H**, for several values of **R**.

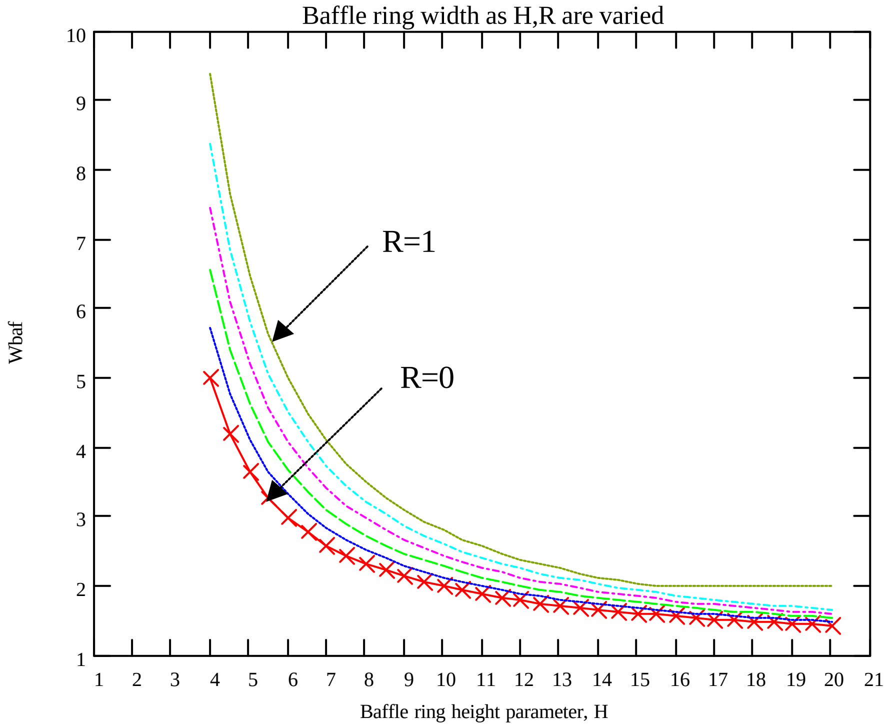

Figure 9 Behaviour of baffle ring width Wbaf as H and R are varied

Figure 9 shows how **Wbaf** rapidly falls as **H** is increased from its starting value of 4, and also how its sensitivity to the value of **R** also changes as **H** increases. The change in slope of the **R**=1 curve near **H**=15.5 is caused by the application of the second part of eq.(3), which ensures a minimum value for **Wbaf** for **H** values greater than this.

6. OPTIMISATION

The designs illustrated in figure 6 use innermost and outermost baffle vanes that have half the width of the main intervening baffle vanes (N.B. the 1-section baffle has no intervening baffle vanes). The intervening baffle vanes have the full width **Wbaf**. It can be shown that for an n-section baffle (with section as defined in figure 6), the overall width of the baffle cover, WTOT(n), will be given by

$$WTOT(n) = 2*(r + n*(Wbaf + D)) \qquad \textbf{Eq.(4)}$$

The overall depth or height of the baffle, HTOT(H), will be given by

$$HTOT(H) = 2*t + H + D \qquad \textbf{Eq.(5)}$$

The behaviour of **WTOT** will essentially follow the behaviour of **Wbaf**, which is shown in figure 9. The actual values will depend on the value chosen for **r** and **n.** Plots of WTOT and HTOT are given in figure 10, for which r=10 has been assumed.

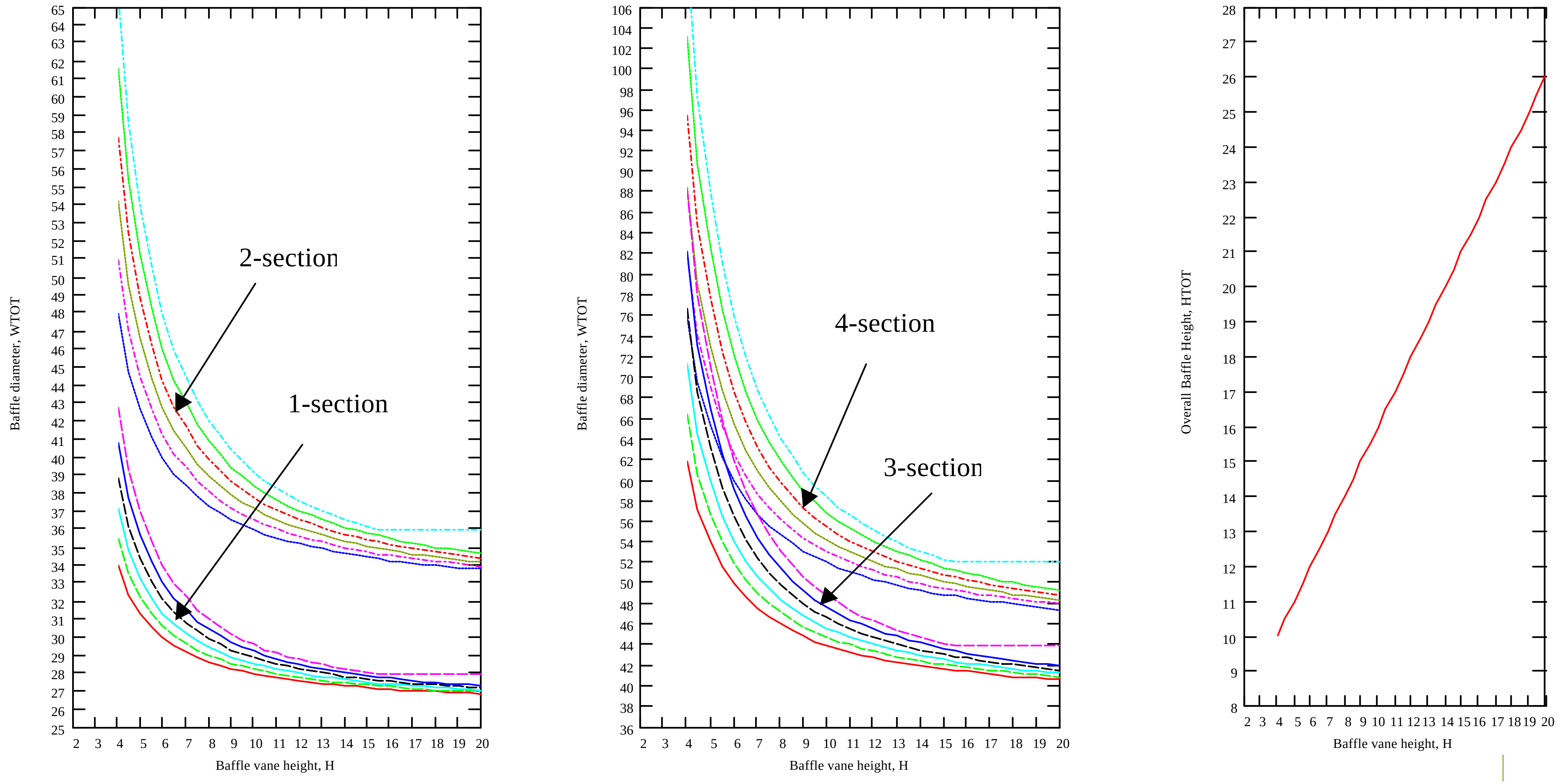

Figure 10 Variation of Overall Baffle Diameter WTOT and Height HTOT with vane height H, for multisection baffles

In order to find an optimised baffle, the volume of material required to make a baffle for a circular hole (see figure 4) will be computed. The dependence on the number **n** of baffle sections will be illustrated. When computing the volume of material, we need to compute the volumes of three components:

- the base, between edge of hole and rim,
- the cover, between thermal strap and rim,
- the baffle vanes extending from both base and cover.

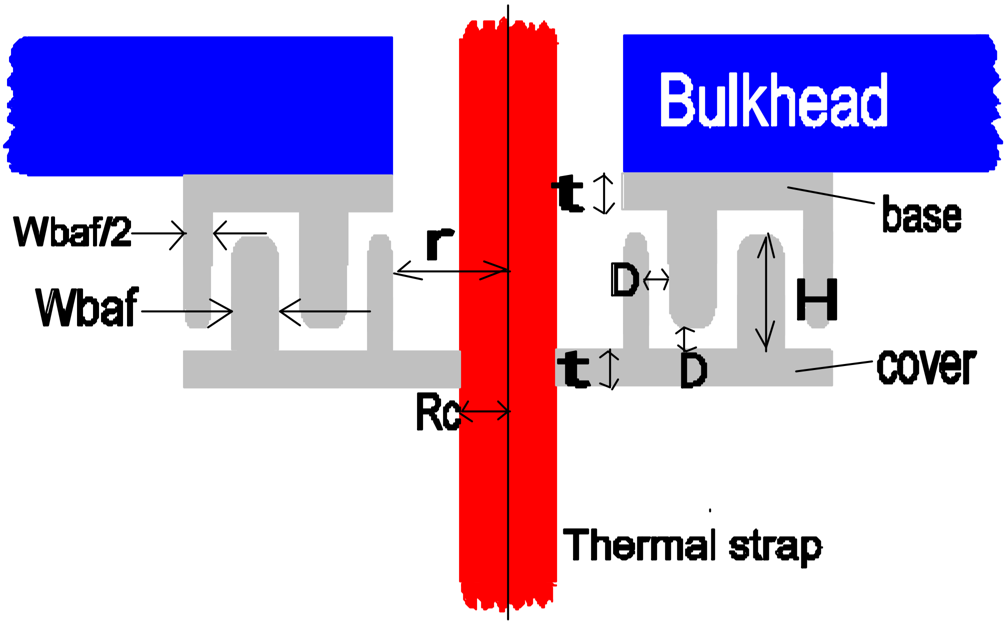

Figure 11 Dimensions required to compute the volume of baffle material

Figure 11 shows the dimensions of interest. It can be shown from this that the volume of baffle material required for an n-section baffle, **VOL(n)** is given by

$$VOL(n) = Vbase(n) + V\,cover(n) + Vbaffa(n) + Vbaffb(n) \qquad \textbf{Eq.(6)}$$

$$Vbase(n) = p * \left[(n*Wbaf + n*D + r)^2 - r^2\right]*t \qquad \textbf{Eq.(7)}$$

$$V\,cover(n) = p * \left[(n*Wbaf + n*D + r)^2 - Rc^2\right]*t \qquad \textbf{Eq.(8)}$$

$$Vbaffa(n) = p * H * \left\{\sum_{1}^{n} \left\{(Wbaf/2 + r + (n-1)*(Wbaf + D))^2 - (r + (n-1)*(Wbaf + D))^2\right\}\right\} \qquad \textbf{Eq.(9)}$$

$$Vbaffb(n) = p * H * \left\{\sum_{1}^{n} \left\{(r + n*(Wbaf + D))^2 - (r + n*(Wbaf + D) - (Wbaf/2))^2\right\}\right\} \qquad \textbf{Eq.(10)}$$

VOL(n), in cubic-centimetres, is plotted in figure 12. These curves were generated using r=10 and Rc=5 for the radii of the hole and the thermal strap respectively. Note that the vane volume formulae, eq.(9) and (10) both ignore the small volume removed by adding an edge radius, so that VOL(n) will be overestimated by these small amounts.

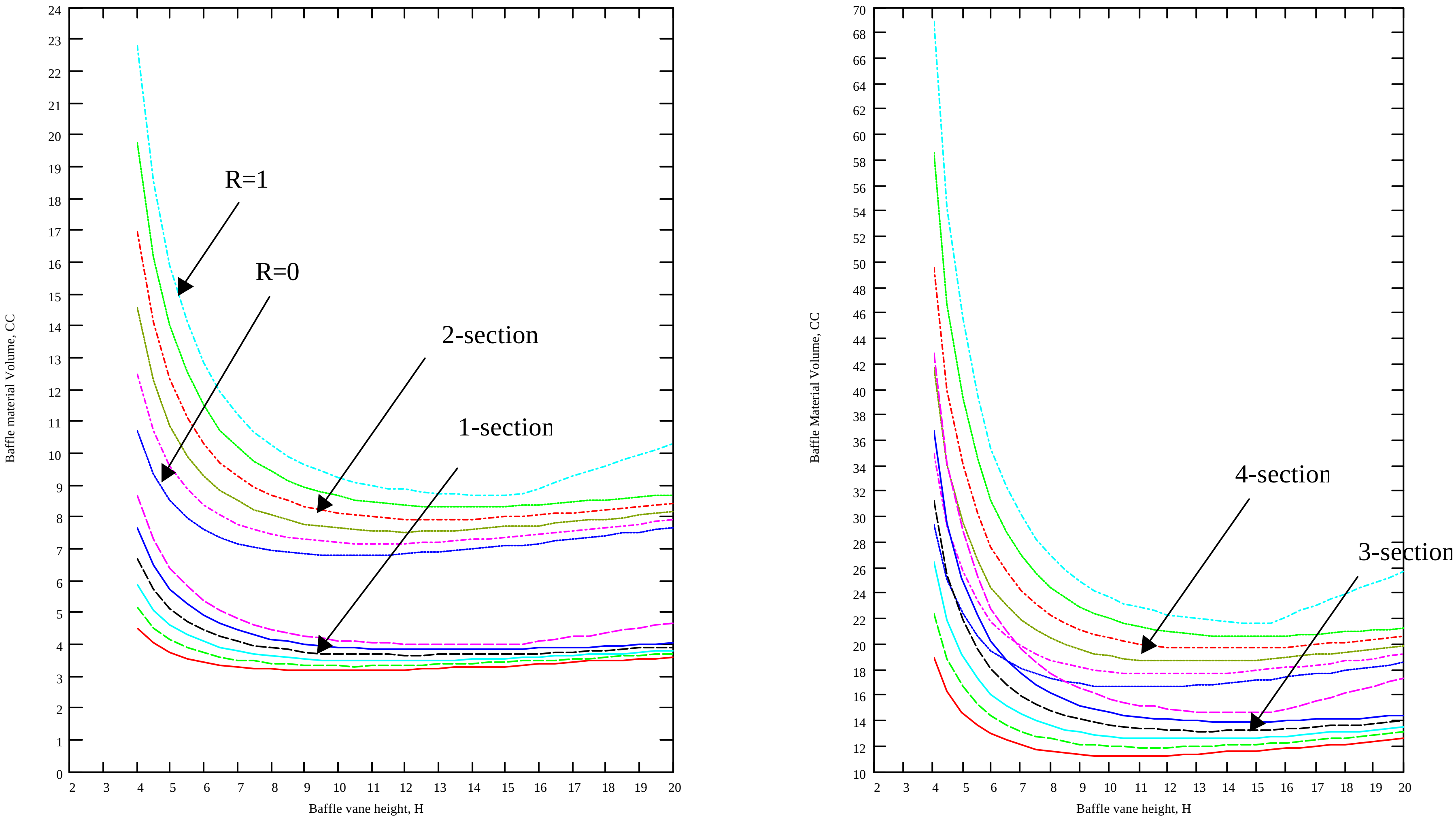

Figure 12 Baffle material volume, VTOT, for multisection baffles, as a function of baffle vane height, H and edge radius R

The plots in figure 12 show that there exist designs that minimise VTOT and that the minima occur over a range of values for H, the baffle vane height. For a given number of baffle sections, it would appear that there is more variation in the value of H at which the minimum volume occurs due to variation of edge radius R than there is due to changing the number of sections in the baffle whilst keeping R constant. Optimal designs typically occupy the range 9<H<15 and reference to figure 10 shows that for H in this range, the overall diameters to be expected have fallen to reasonable values which require large increases in H in order to reduce them by further significant amounts. Figure 9 shows that baffle ring widths between 1 and 2 millimetres are to be expected for this range of H.

7. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the generic design that is presented here for a thermal-strap lead-through baffle is theoretically capable of yielding a high attenuation within an optimised volume. It is recommended that

- The 4-section baffle design be considered as the baseline as this forces 8 bounces on the external stray radiation passing through it,
- Investigations are carried out to determine the space available for fitting such a baffle in the relevant areas of the instrument,
- Investigations are carried out to verify that absorber-coated baffle vanes with very small edge radius can be manufactured, enabling the size and mass of the baffle to be kept to a minimum,
- Highly absorbing coatings be used on the inside surfaces of the baffle,
- Estimates are made of the mechanical misalignment tolerances likely to exist between the thermal strap and the hole in the structure that it must pass through, so that the baffle design can be modified to maintain its performance in the presence of these misalignments.