Preservation of Thermal Control Specular Gold Baffle Surface on the James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM) Electronics Compartment (IEC)

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ABSTRACT

Extremely tight thermal control property degradation allowances on the vapor-deposited, gold-coated IEC baffle surface, made necessary by the cryogenic JWST Observatory operations, dictate tight contamination requirements on adjacent surfaces. Theoretical degradation in emittance with contaminant thickness was calculated. Maximum allowable source outgassing rates were calculated using worst case view factors from source to baffle surface. Tight requirements pushed the team to change the design of the adjacent surfaces to minimize the outgassing sources.

Keywords: Emittance degradation, contamination, outgassing, NVR contamination, particulate contamination, emittance degradation with contamination, vapor deposited gold emittance degradation, outgassing in vacuum

1. INTRODUCTION

This paper documents the methods and processes used to determine contamination requirements for the gold-plated, thermal control baffles and radiator panels on the JWST IEC. These requirements are driven by 1) the operational requirements of the thermal control baffles, which are integrated adjacent to the radiators, and 2) the need to minimize self contamination within in the IEC, (i.e. from its radiators to its baffles to prevent degradation of the baffle thermal properties).

2. BACKGROUND

The IEC is a composite shell that houses the electronics boxes for the four scientific instruments on JWST. The IEC is part of the Integrated Scientific Instrument Module (ISIM). It uses radiators to passively maintain operational temperatures of the instrument electronic boxes. Additionally, in order to direct the infra-red (IR) flux from these radiators away from the JWST sunshield and optics train, the IEC design incorporates gold-plated baffles in front of the radiators. When considering the performance of the baffles in order to derive contamination requirements, both the optical scatter properties and the thermal performance of the baffles need to be considered.

The IEC thermal design allocates a 0.010 change in hemispherical emittance, ε, on the gold-plated baffles at end-of-life (EOL) due to contamination. The gold baffles are assumed to have an initial hemispherical ε of 0.026 $\pm$ 0.026 (error), and a 0.010 increase due to contamination. These combine to a maximum EOL hemispherical ε limit of 0.062 at EOL. The following outgassing and particulate requirements are derived from the allowable 0.010 increase in ε due to contamination.

The degradation in ε from contamination (ε_{cont}) will be due to a combination of particulate and molecular contamination resident on the surface of the gold. Splitting the delta-ε equally between each type of contamination, there will be an allowable 0.005 change due to particulate contamination, and a 0.005 change due to surface molecular contamination at EOL.

A core requirement for baffle performance is derived from scatter. A 1.5 percent area coverage (PAC) yields a calculated scatter of 2.5 %, which has been deemed acceptable. This value is well above the PAC required to keep the change in ε_{cont} less than 0.010 (see section 3) to maintain thermal performance. Thus the thermal requirements are the driver for deriving the contamination requirements to maintain the performance of the gold baffles.

3. CHANGE IN EMITTANCE DUE TO PARTICULATE CONTAMINATION

The change of 0.005 in ε_{cont} due to particulate can be determined using the weighted average of the contributions from the base material and the particulate contamination.

Using the $\boldsymbol{\varepsilon} = 0.026$ value for the gold surface and assuming an $\boldsymbol{\varepsilon} = 0.9$ value for the particles, a parametric correlation can be plotted (Figure 1). This indicates an EOL particulate requirement of 0.57 PAC.

The EOL particulate level will be due to the particulate on the baffles at the time of launch from ground processing, plus the particulate deposited on the baffles during launch, commonly referred to as particulate redistribution during launch. After launch, it is well understood that any particles generated in and around the spacecraft on orbit will not move around to deposit on other surfaces. Since there are no moving parts on the baffles to generate particles, the particulate budget after launch is not considered.

The only piece of information missing in the particulate budgeting calculations is the expected particle contribution to the baffle surface from redistribution during launch; this number will be provided by the JWST program. To be conservative, part of the 0.57 PAC EOL will be allocated for launch redistribution.

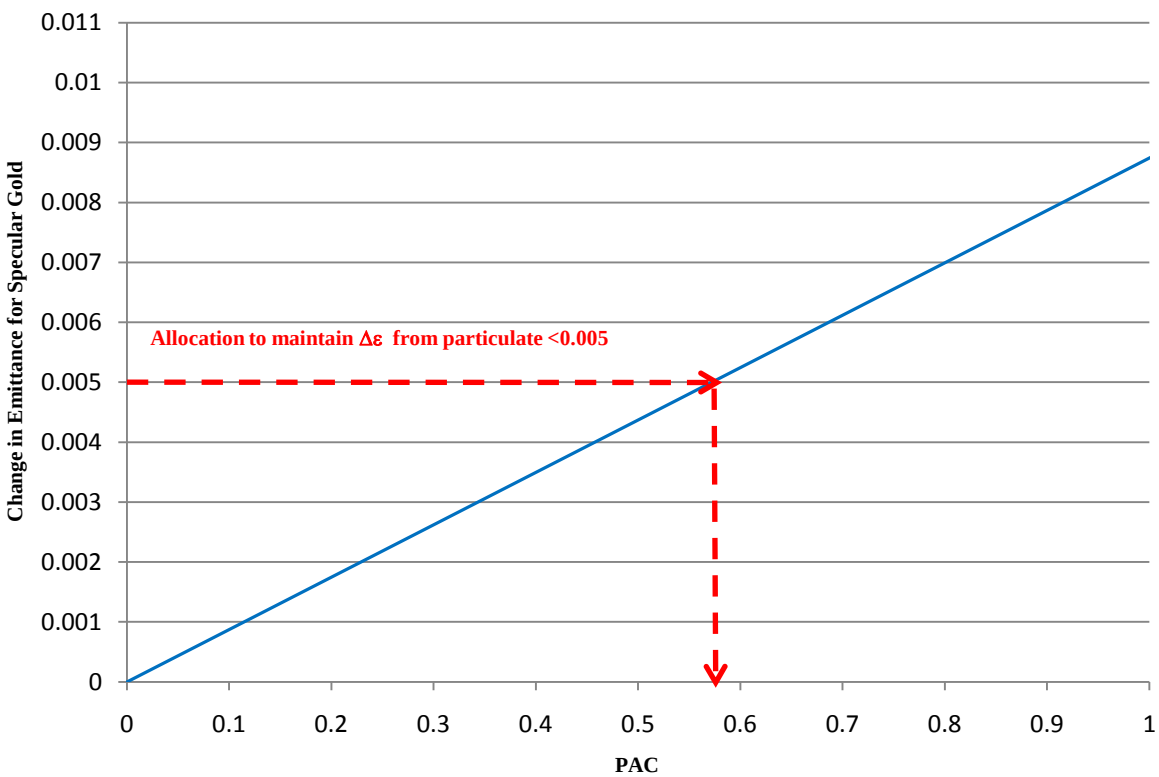

Figure 1: Change in Gold Emittance with PAC from particles of emissivity = 0.9.

4. MOLECULAR CONTAMINATION

Many factors were considered when predicting the molecular deposition that would correspond to an increase in $\boldsymbol{\varepsilon}_{cont}$ of 0.005. The two theories used to predict the molecular film thickness on a surface that will produce a change in $\boldsymbol{\varepsilon}_{cont}$ of 0.005 are Beer's Law (where the absorption of the contamination film is considered) and Thin Film Interference (TFI) (where the absorption of the contamination film and the subsequent reflection off the underlying surface is combined). Beer's law predicts a molecular film of 150Å while Thin Film Interference predicts a thickness of 650Å (see Figure 2)[1]. The JWST ISIM contamination control (CC) team chose to use the average of the Beer's Law and TFI prediction methods, which leads to a requirement that the total deposition at EOL shall be no more than 400Å on the gold baffle surface in order to maintain a $\Delta\varepsilon_{cont} \leq 0.005$ due to non-volatile residue (NVR) or molecular deposition.

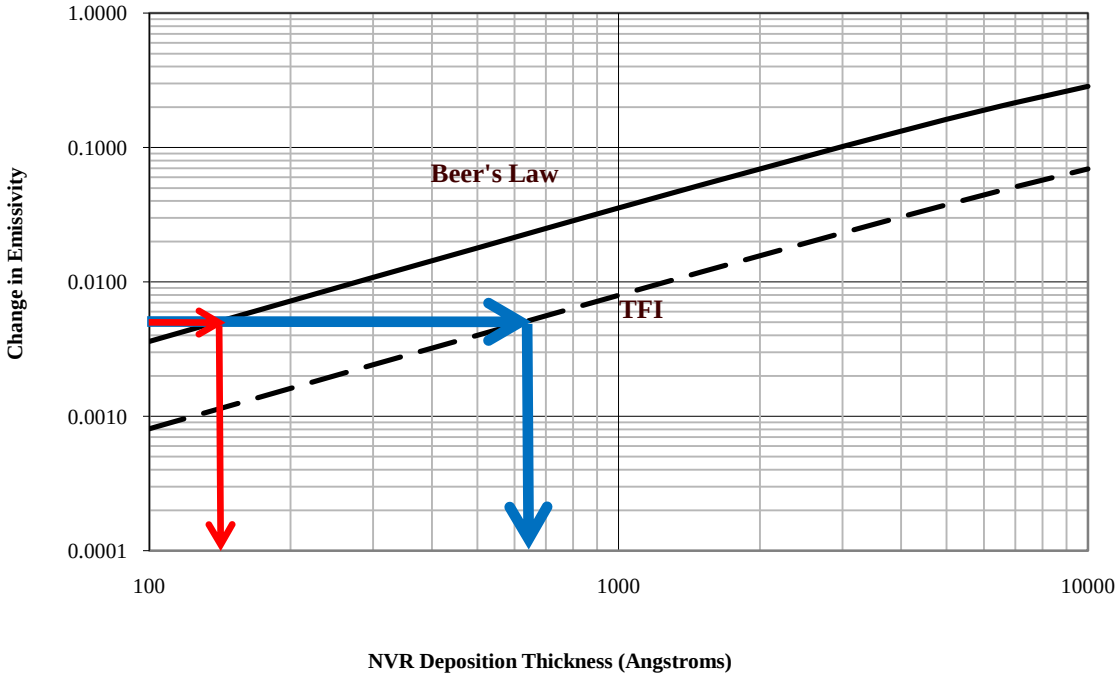

Figure 2: Beer's Law and Thin Film Interference predictions for $\Delta\,\varepsilon$ with NVR thickness, based on calculations performed by J. Hueser (BATC) for the SIRTF mission.[1]

Contamination sources on the IEC are relatively isolated from the rest of the spacecraft and so the spacecraft requirements levied on the IEC are not very stringent. Conversely, there are not significant contamination sources on the spacecraft with a view to the baffles. Additionally, the IEC is designed such that effluent from the interior of the IEC compartment will be vented in a direction that prevents impingement onto the baffle surface. Thus, the largest molecular contaminant contributor to the IEC baffle surface is the IEC radiators sitting directly underneath them. Thermal predictions have demonstrated that the radiators operate at a temperature as much as 140 °C above the baffle temperatures; this means that the majority of the outgassing from the radiators will condense on the baffle surfaces, for the duration of the mission on orbit.

The requirement levied on the IEC by ISIM, is to deliver the IEC to ISIM with a maximum of 100Å on all IEC surfaces. This requirement was not derived from the allowable deposition on the IEC baffles, but is part of a budget generated to protect the scientific instruments and other sensitive surfaces on JWST. Accounting for this 100 Å and to preserve the

400 Å EOL, 300Å of deposition is allowed for the post delivery to ISIM Integration and Test (I&T) activities and for the 5 year mission.

Splitting this evenly between before and after launch, the outgassing requirement for the radiators must be low enough that no more than 150Å is deposited on the baffles over 5 years on-orbit. The resulting outgassing rate (OGR) allowance for the flight radiators equated to 5.0 x 10^{-14} g/cm^2-s or 2.88 x 10^{-10} g/s as measured by a measuring device at -90°C, (where -90°C represents the minimum expected temperature of the baffles on-orbit and the outgassing rate is normalized by the paint surface area in square centimeters). In addition, a particle and NVR budget for IEC level testing was generated to ensure that ground operations will not exceed allocations for PAC and NVR during this phase of the processing. This budget is a subset of the overall JWST budget for the IEC which will ensure that the PAC and NVR at EOL will not be exceeded. The current IEC Baffle I&T Contamination Budget is shown in the table below.

Table 1: IEC Baffle Contamination Budget

Phase	Start Date	End Date	Duration	Particle-Horizontal (PAC)	Particle-Vertical (PAC)	Particle-Inverted (PAC)	NVR (Å)
Initial Clean			1	0.02	0.02	0.02	20
Coatings	28-Aug-09	11-Dec-09	105	1.27	0.15	0.03	21
Baffle Assembly	16-Nov-09	30-Nov-09	14	1.27	0.15	0.04	21
Baffle only Tvac Test	1-Dec-09	29-Dec-09	28	1.28	0.15	0.04	39
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Prep 4-Cycle Tvac	26-May-10	9-Jun-10	14	2.41	0.27	0.06	42
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ISIM Delivery	10-Sep-10	10-Sep-10	1	0.02	0.02	0.02	100
T-0 Launch				0.5	0.5	0.5	250
EOL				0.57	0.57	0.57	400

In addition, for the Flight Directional Baffle Thermal Vacuum (TV) Test that occurred at the Goddard Space Flight Center (GSFC) in early 2010, using the flight baffles and GSE radiator panels, the CC team had budgeted an allowable deposition of 15Å over 1 day of thermal vacuum exposure, for each baffle. The allocation of an allowable deposition of 15Å over 1 day was part of the allowable pre-ISIM delivery NVR deposition budget of 100Å. This philosophy allowed for a much higher OGR for these GSE radiators than the flight radiators, by a factor of ~183, assuming the delta $\boldsymbol{\varepsilon}_{cont}$ = 0.010 is not changed. Part of the justification for allowing such a high deposition rate (15Å/day) during the Flight Directional Baffle TV Test is the qualitative understanding that the majority of the material deposited during this test, at cryogenic temperatures will evaporate upon return to ambient temperature and pressure. Further, the contamination team was concerned about the ability of the existing flight radiator coatings design (also used on these GSE radiators) to meet these low outgassing rates. The Flight Directional Baffle TV Test and the preceding GSE radiator vacuum bakeout, with the same coatings design as the flight radiators, provided data to help determine if the current coatings design would be able to meet the flight OGR requirements.

5. GSE RADIATOR VALIDATION APPROACH

A GSE radiator bakeout was performed in order to verify that the radiators would not deposit more than 15Å to the baffles during the Flight Directional Baffle TV Test, which was assumed to be a 1-day test for each set of baffles. In addition, the CC team used the outgassing data to determine the bakeout length of time for a similarly coated flight radiator panel to reach the allowable flight OGR. The certification phase of this bakeout was conducted with the shrouds set to -100ºC and the radiators at +40ºC. The quartz crystal microbalance (QCM) as placed approximately 10 cm from the painted surface of the radiator and set to -90ºC. This set-up allowed the QCM to have the majority of the radiator surface in its field of view, without much view of the chamber walls. The outgassing requirement for this validation phase is $\leq$ of 9.17e-12 g/cm^2/s, the square centimeters represents the paint surface area. Using a QCM Research 15MHz QCM, situated approximately 10 cm above the radiator painted surface, the corresponding collection rate required on the QCM was $\leq$ 7.6 Hz/hr. Additionally, margin was applied to the allowable frequency rate in order to account for a test that takes longer than 24 hours per baffle. The resulting QCM frequency rate was 2.5 Hz/hr. See figure 3 below to see the test set-up at the chamber 238 facility at GSFC.

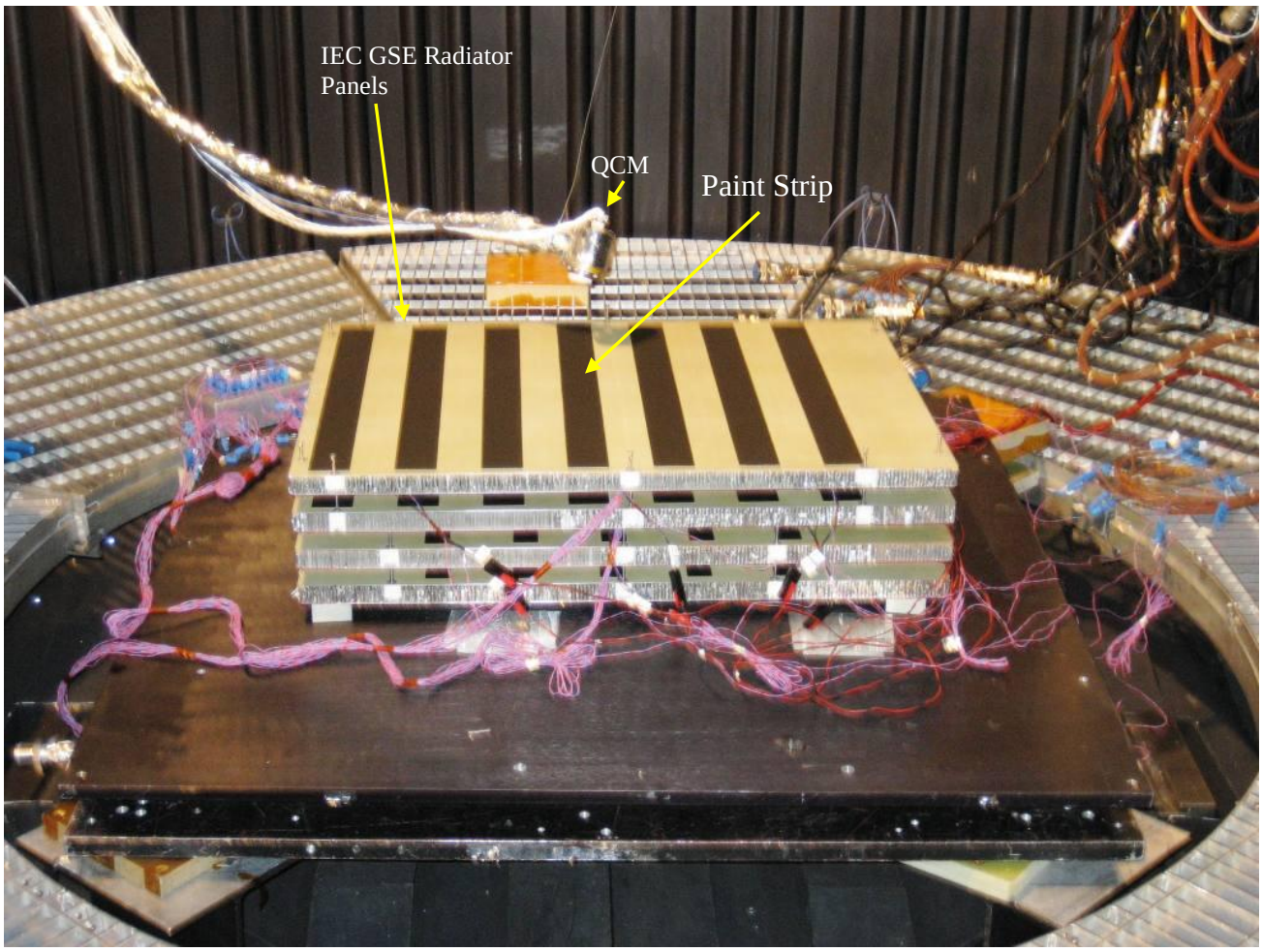

Figure 3: GSE Radiator Panel Bakeout Configuration in Chamber 238 at GSFC.

Following the test, an outgassing rate (g/cm^2-s) versus time data fit was perfromed using a power law regression. Statistical analysis of the fit to the data demonstrated that the lower 95% confidence interval equated to a bakeout

duration of 54 months necessary to meet the flight OGR using a similar coatings design. The power law fit and lower 95% confidence interval equated to bakeout durations of 3.75 months and 18 days, respectively. See figure 4 below.

Given the cost and schedule implications for an extended bakeout; these results led the CC team to recommend switching the radiator coating to water-based silicate paint with equivalent thermal properties. Prior to the recommendation to switch the flight coatings design other options such as an elevated bakeout temperature were explored. Due to the irradiated coatings on areas not covered by painted stripes, it was determined that a thermal environment exceeding the ones established for the GSE Radiator Panel Bakeout, was not feasible.

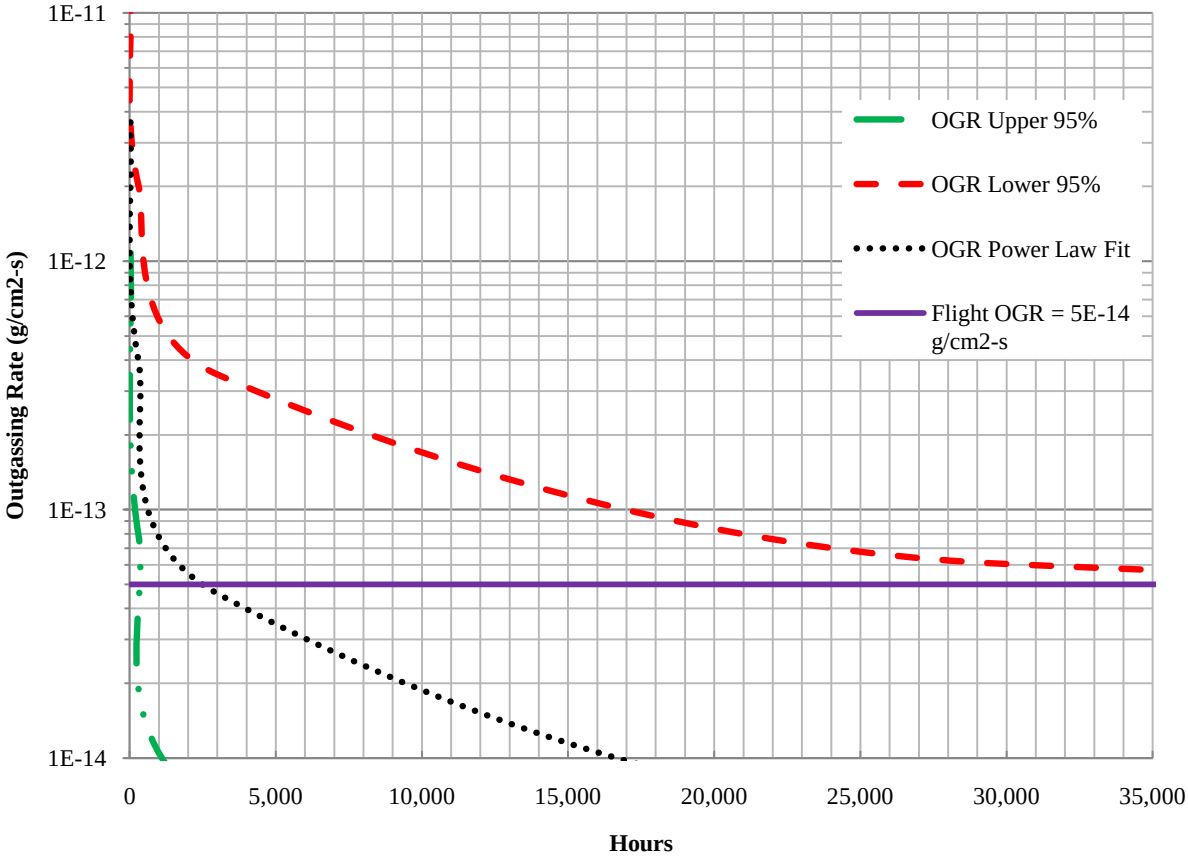

Figure 4: GSE Radiator OGR Regression and Extrapolation for Flight OGR.

6. CONCLUSION

Re-assessing several variables assumed in this initial run-through of IEC "self" contamination requirements might result in more reasonable outgassing requirements.

- A better understanding of the mission operational temperatures of the baffles might allow higher QCM collection temperatures for the outgassing evaluations.
- A larger allotment of $\boldsymbol{\varepsilon}_{cont}$ for contamination would allow for higher deposition rates (i.e. higher radiator outgassing rates).
- Non-organic coatings (e.g. silicate paints and vapor deposited coatings) would inherently decrease the outgassing products from the radiators.

Another driving assumption is that these calculations assume that there is no contribution of outgassing products from the interior of the IEC, i.e. the IEC vents direct the outgassing products away from the baffles, away from any surfaces that could reflect outgassing products back to the baffles, and that the radiator composite structure is vented into the IEC, not out toward the baffles. Any unintentional venting from around the shell towards the baffles must be avoided; all open seams must be closed out with Kapton tape or another approved method. In order to maintain these tight deposition requirements, it is imperative that the flight design of the IEC vents, and the radiator vent paths adhere to these assumptions.

The IEC GSE radiator test demonstrated that the flight radiator OGR requirement is difficult to achieve with the current flight radiator coatings design. Therefore, the contamination team recommended changing the flight coatings design to a non-organic combination of coatings in addition to loosening the allowable delta $\boldsymbol{\varepsilon}_{cont}$. Currently the particle budget will be easier to maintain than the NVR budget due to the adverse impacts to the emissivity of the gold coated baffles.

REFERENCES

[1] IEC CDR package

[2] Hueser, J. , "Emissivity Degradation of the OS and SC Shield due to Surface Contaminant Buildup During I&T and On-orbit Cooldown ," System Engineering Report S20447-SYS-018, Ball Aerospace Technologies, Jan. 21, 1999.

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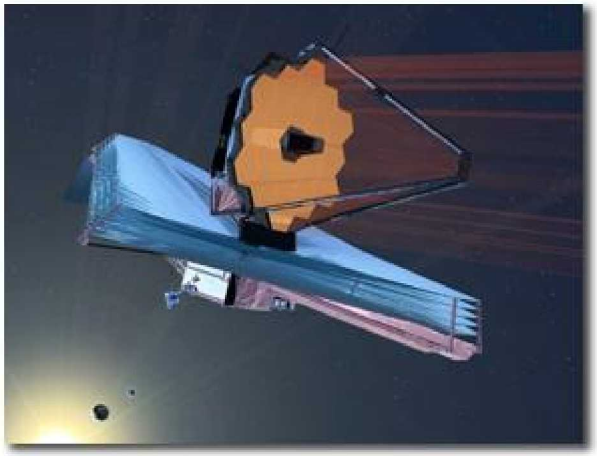
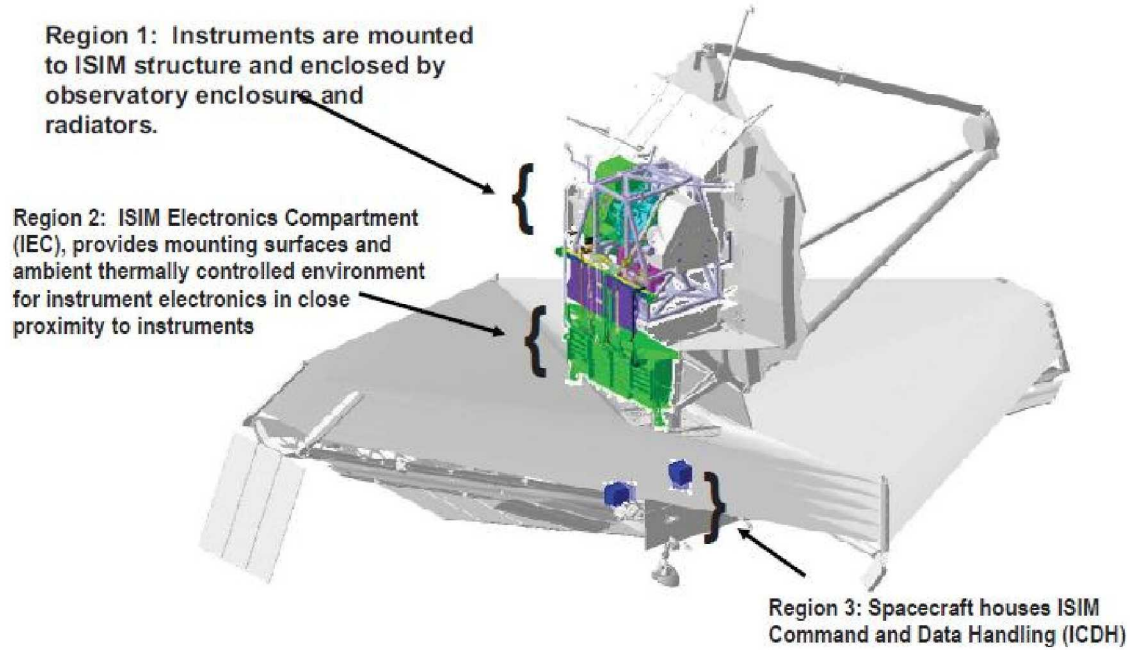
OPTICAL SYSTEM CONTAMINATION: EFFECTS, MEASUREMENTS, AND CONTROL 2010
SAN DIEGO CONVENTION CENTER

JWST Overview

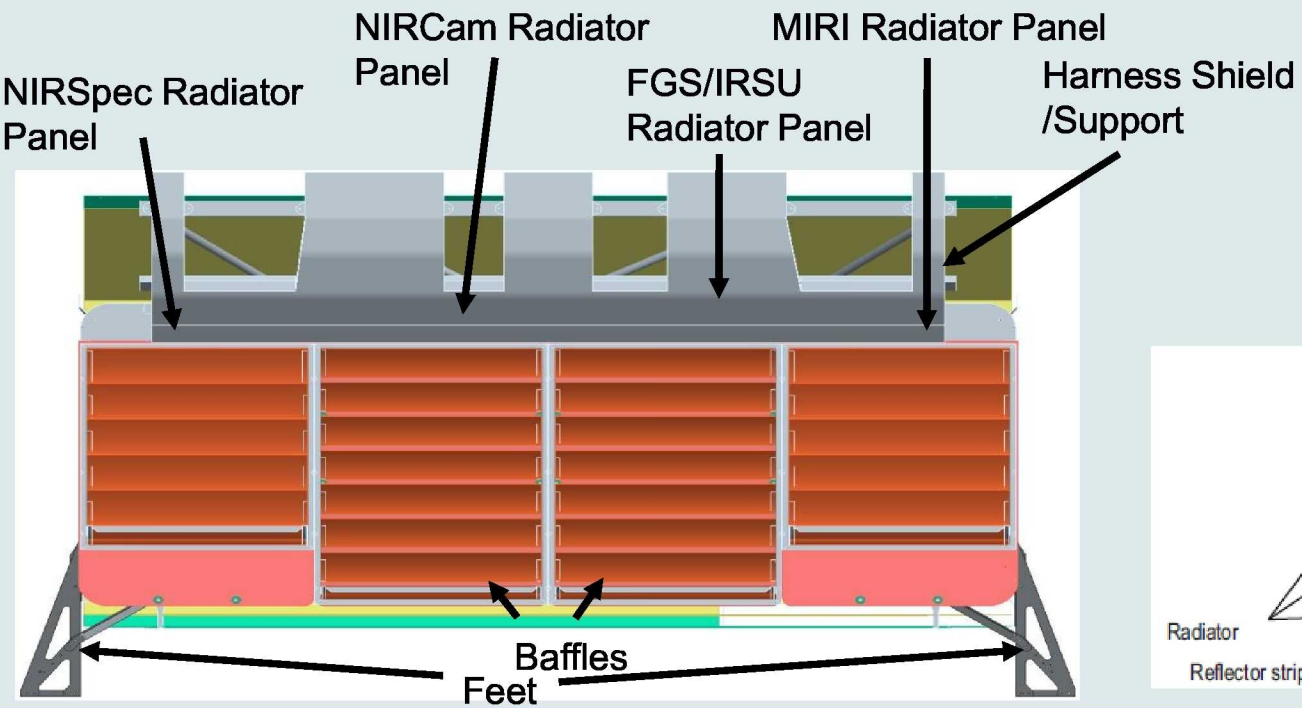


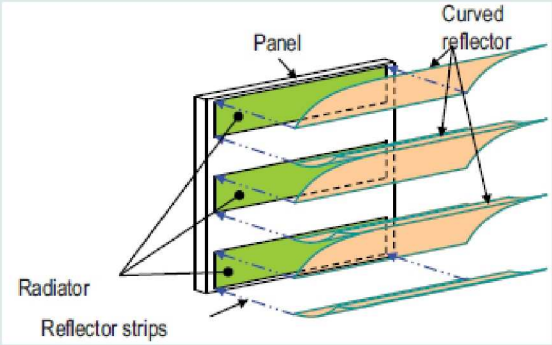


IEC Overview

- Mass = 125 Kg
- Power = 200-230W
- SI electronic boxes, T = 273-313K
- Fiberglass shell w/Nomex core

- Baffles: 36 total vanes, 21 inner and 15 outer
- 6 different vane shapes
- Painted radiator strips lie between the vanes



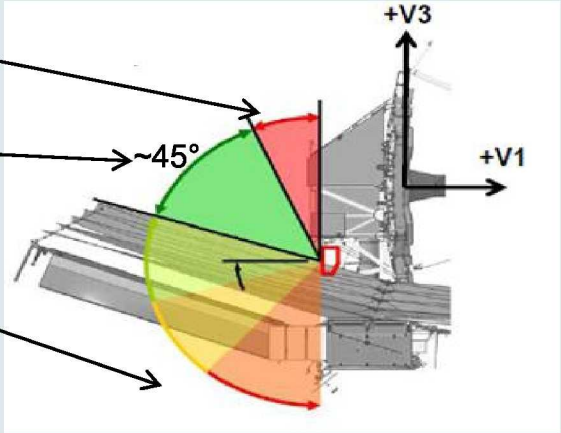


Generated Incident Heat Load Rqm't

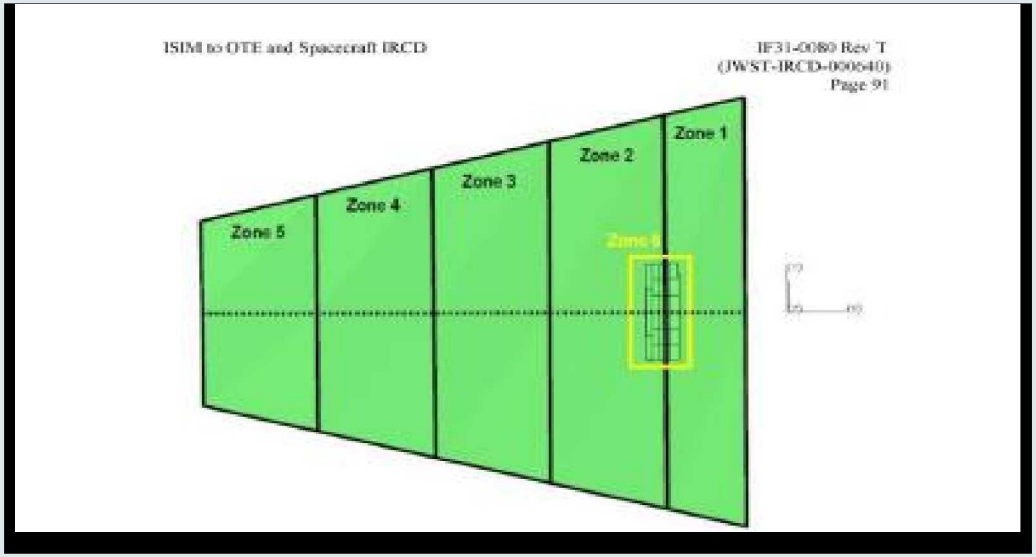
Exclusion zone No emission towards BSF

Desired emission to space

Undesired zone with steep angles directing heat back towards ISIM /OTE



Sunshield Zones	Incident Heat Load
Zone 1	0.2
Zone 2	13.5
Zone 3	31.5
Zone 4	14.5
Zone 5	4.5
Zone 6	7.0



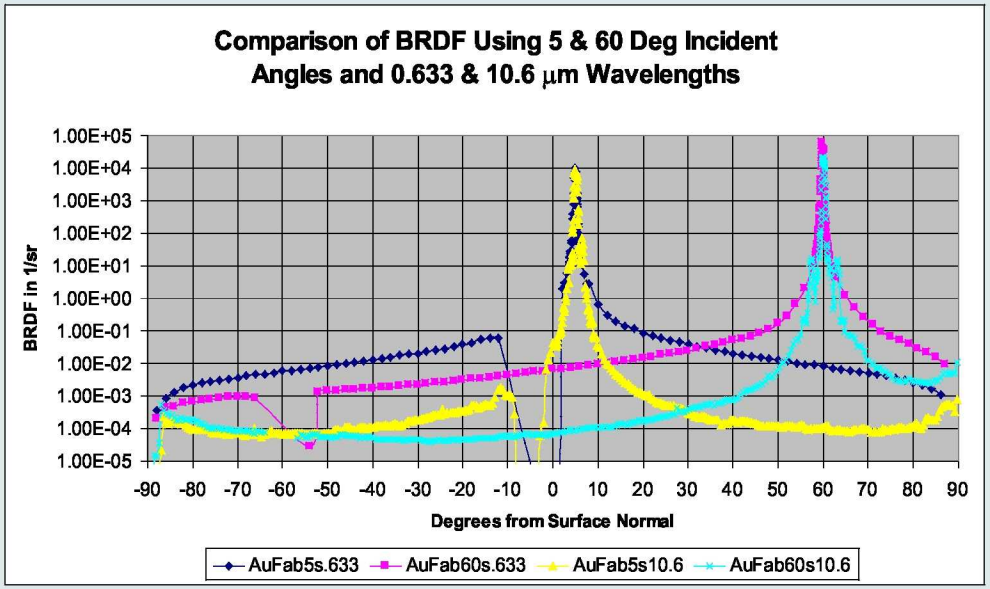
Baffle Performance - Optical

- Zemax model using Monte Carlo Ray Tracing Method
  - Mirror shape
  - Positional Errors
  - Surface Roughness
  - Particle Contamination

Input:

$BRDF_{Tot} = BRDF_{meas} + BRDF_{Dust}$

  - PAC of 1.5 meets heat rejection rqm't



Particle Contamination not Limiting Case for Optical Performance.

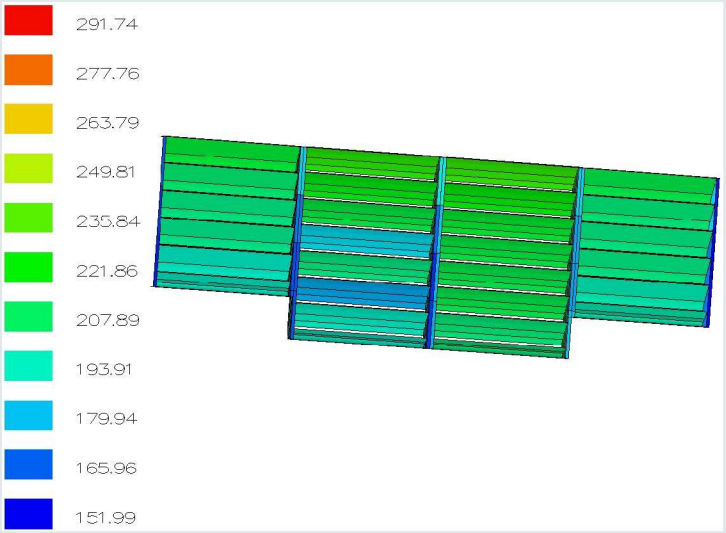
Baffle Performance - Thermal

- Mirrors coated with vapor-deposited gold
  - 3% emissivity BOL
  - 98% specularity
  - Non-VDG surfaces will be covered with MLI to reduce uncontrolled emissions (including outgassing)

$$\varepsilon_{hemi} = 0.026_{AU} + 0.026_{MUF} + 0.01_{contam} = 0.062$$

$$\Delta\varepsilon = 0.005_{PAC} + 0.005_{NVR} = 0.01_{contam}$$

Hot Case Predict



Hot Case: Concern for molecular deposition

Cold Case: Regions of the underside of the housing and nodes away from any boxes at 90K (concern for molecular + H_2O)

Baffle Surface Contamination Reqm't (1/2)

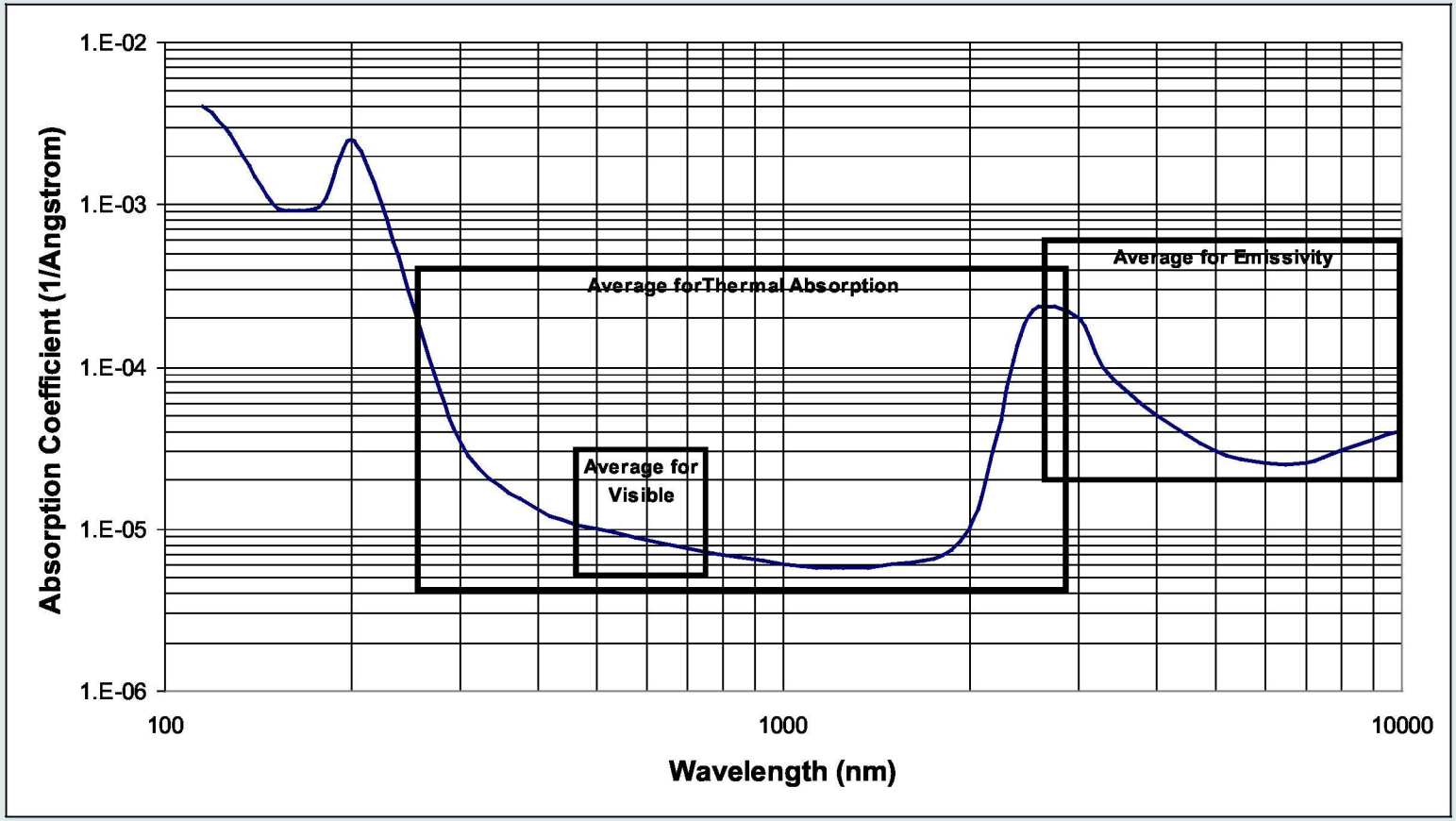
- Particle Requirement - $\Delta\varepsilon \leq 0.005$

  Allowable EOL particulate % area coverage (PAC) can be determined from the weighted average of emittance contributions from the gold and the particulate, assuming the particulate has an emittance of 0.9:

$$\Delta\varepsilon = 0.005 = ([1- PAC/100] * 0.026 + PAC/100 * 0.9) - 0.026$$

$$PAC \text{ at EOL } \leq 0.57$$

Envelope of Absorption Coefficients



Based on:

- Hueser, J., contamination control plans for ACS (BATC IN0077-109) and COS (BATC IN0090-111)
- Muscari, J. A., *Nonmetallic Materials Contamination Studies Final Technical Report*, MCR-80-637, (1980)

Estimating Contamination Effects

Beer-Lambert Law

$$I = I_0 e^{-\alpha(2t)}$$

$$\alpha = 4\pi k/\lambda$$

Typically considered a bounding case

Thin-Film Interference (TFI)

$$I = I_r +$$

Baffle Surface Contamination Reqm't (2/2)

- Molecular Requirement - $\Delta\varepsilon \leq 0.005$
  - Beer's Law predicts a 150 Å layer of NVR
  - Thin Film Interference (TFI) predicts a 650 Å layer of NVR

Use the average of the two predictions:

EOL NVR ≤ 400 Å

Baffle Contamination Budget

EOL Surface Cleanliness Rqm't of PAC of 0.5 and 400A

- Tracked via a budget for ground operations (I&T)
- Included are allocations for on-orbit accumulations.
- OGR ensures on-orbit molecular allocation is not exceeded (150Å).
- Very little particle accumulation on-orbit – launch particle redistribution taken into account.
- Concern for molecular accumulations on-orbit that will exceed allocation

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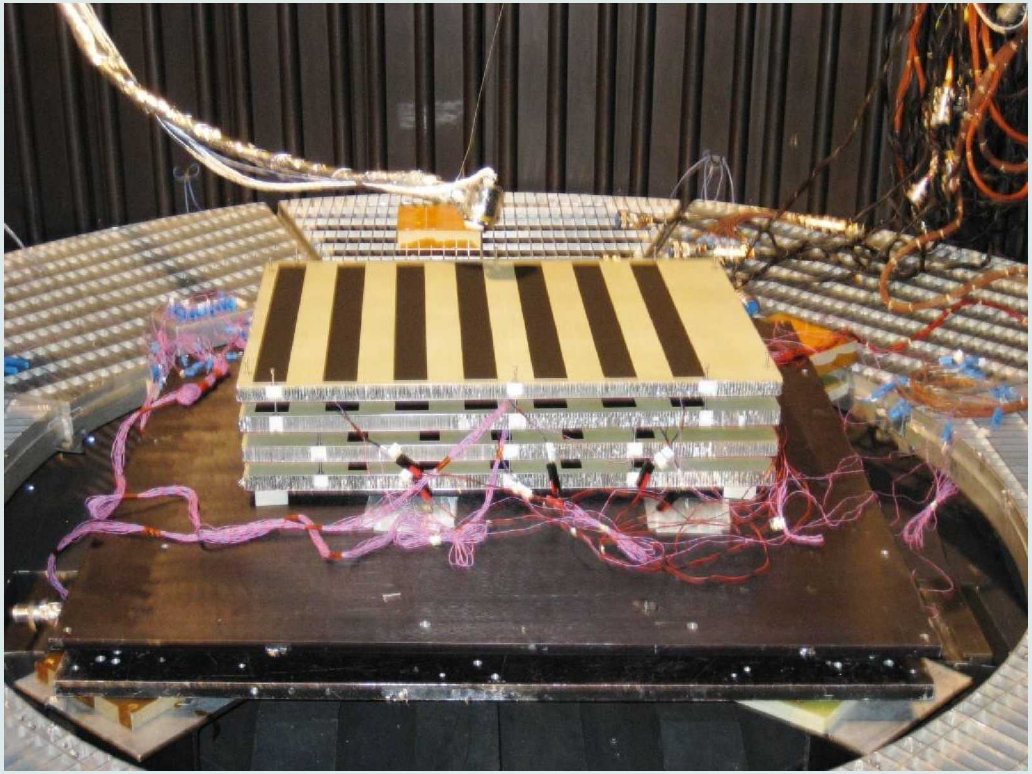
EOL				0.57	0.57	0.57	400

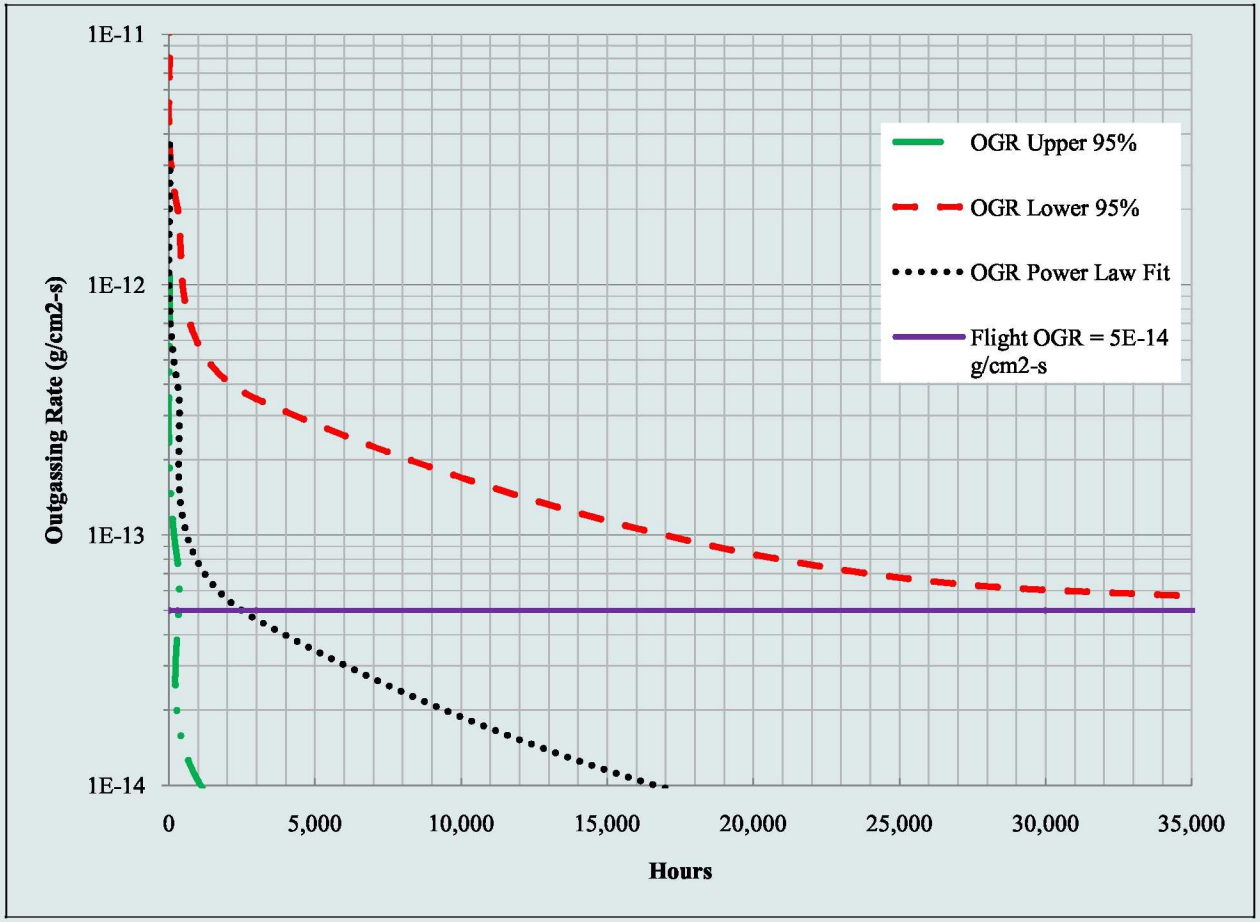
GSE Radiator Panel Outgassing Test

- Internal IEC compartment completely shielded from views to baffles
- Baffles only view high emissivity paint strips
- Current flight-like paint strips are coated with a molecular based paint
- Direct deposition rate calculated with TQCMs in a cold wall bakeout at GSFC



Flight Radiator Panel OGR

- Power Law Regression used to Fit TQCM data
- Nominal ± 95% confidence interval
- Cost/Schedule concerns for bakeout duration
- Recommendation to switch to a water-based silicate paint



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