BepiColombo
Technology Status Review

TDA: ETTI

– Extreme Temperature Thermal Insulation

TDA: ETTCM

– Extreme Temperature Thermal Control Components

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Noordwijk, 22-23 February 2005

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Table of Contents

- TDA: ETTI – Extreme Temperature Thermal Insulation
- ETTI continued by HT-MLI – High Temperature MuliLayer Insulation
- TDA: ETTCM – Extreme Temperature Thermal Control Components

>>Reporting Status: Feb.2005

Table of Contents:

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- **High Temperature Multi-Layer Insulation (MLI)** to protect the spacecraft from high temperatures on the surfaces exposed to solar and planetary radiation and cold temperatures on surfaces facing deep space.
- **Sun-shield** integrated to the outer part of the MLI to protect the MLI from the highly degrading UV and particle irradiation and to limit the surface temperature to +350°C.
- **Solar Reflector Coating (SRC)** to be applied, for instance, over the High Gain Antenna reflector for temperature reduction to about 300°C by means of a low solar absorption coefficient and a high infra-red emission coefficient.
- **Optical Solar Reflector (OSR)** system to be attached to external surfaces of the spacecraft with a solar absorptivity to IR emissivity ratio of about 0.2 for temperatures up to 250°C.
- **Infra Red Rejection Device (IRRD)** to reduce the infra-red heat load on the MPO optical instruments.

ETTI – Extreme Temperature Thermal Insulation

Baseline concept of High Temperature MLI

- **One common concept for solar facing and Mercury facing surfaces**
- **Reflective screens**:
  - **5 aluminum layers** on hot side
  - **15 Upilex-S layers**, aluminized on both sides
  - Number of foils can be adjusted to thermal requirements
  - 1 Kapton film 25µm aluminized on one side on inner side
- **Spacers**: **Tissue-Glass** (6 g/m²) ➔ difficult to handle
- **Sun shield**: **ABS fabric** with aluminum backing
- **Connection of layers**: sewing and buttons

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ETTI (cont'd)

- **Venting**: over edge and by perforation (0.5%)
- **Mounting**: Velcro, preferably steel Velcro
- **Grounding**: Bonding straps for metallic and Upilex foils and via sewing thread for ceramic radiation shield
- **Blanket to Blanket I/F**: Overlapping of MLI parts

HT-MLI - High Temperature MultiLayer Insulation

- Selection and characterisation of **sunshield** of improved radiation stability
- Development of improved **spacer** wrt. easier handling and better technical properties
- Improvement of **blanket** (e.g. replacement of part of Upilex layers by Kapton saves mass and cost)
- Extended **verification**

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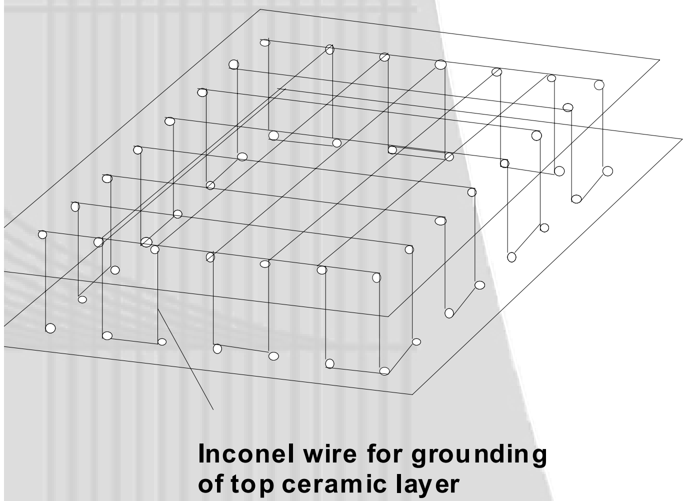
- Sun Shield made by Alumina-Boro-Silicate (ABS) **Nextel AF-10 fabric**.
- **Backing by an aluminum foil** for reflection of the solar radiation transmitted through the ABS fabric (about 2%) and as electrical grounding.
- ABS fabric provides **excellent temperature stability**, a white surface of low solar absorptance and high infrared emittance (α=0.2, ε=0.8)
- For **electrical grounding** fabric and aluminum foil are sewn together by **stainless steel thread** in a 20mm square pattern.
- Surface resistance of ABS fabric alone has been measured to R=$10^{14}\Omega$/sq. The thread pattern limits a charge build-up on the fabric surface.
- Charging test will be performed later to verify the charging requirements of the spacecraft.



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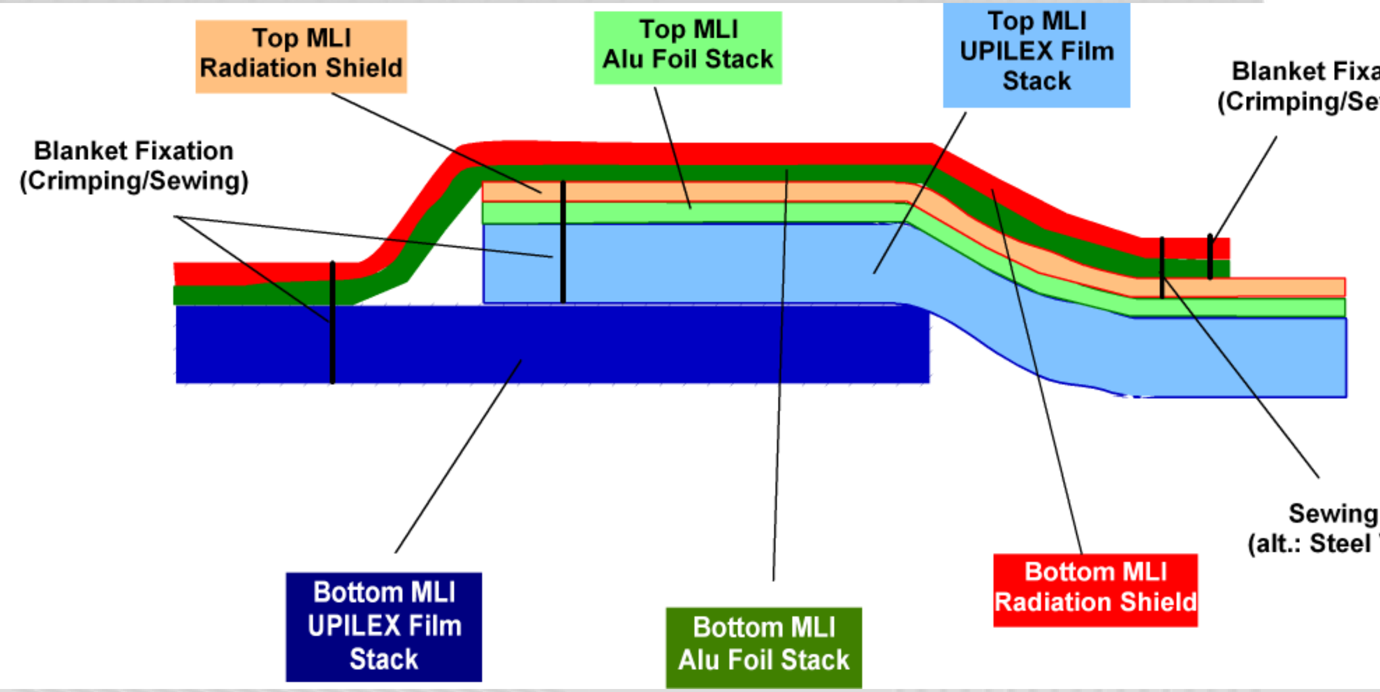
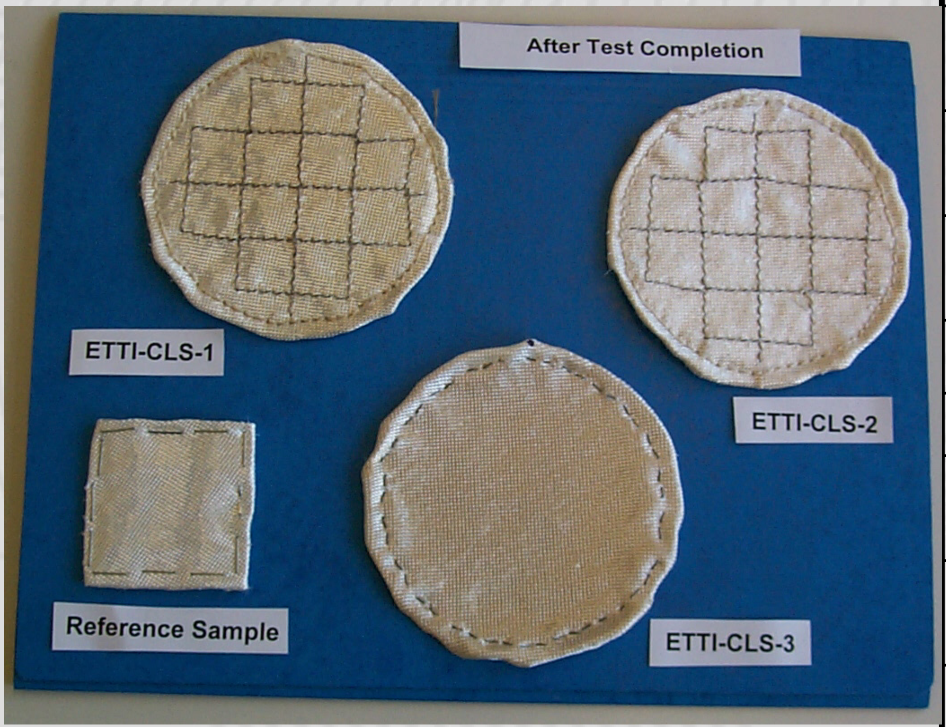
MLI – Blanket to Blanket Interface

- Minimization of heat leak would require overlapping and interleaving layer by layer ➔ very complex
- Compromise by interleaving parts of the blankets



UV and Particle Radiation Testing on Sun Shield Samples



Sample No.	CLS-1	CLS-2	CLS-3
UV + Solar Fluence (ESH)	100	-	154
VUV Fluence (ESH)	500	-	770
Protons (Ws/cm^{-2})	0.3	0.9	0.9
Electrons (Ws/cm^{-2})	1.07	3.23	3.23
Solar Absorbtivity [-]			
Before test	0.15	0.15	---
Minutes after test	0.22	0.23	0.28
24 hours after test	0.22	0.22	0.26
18 days after test	0.22	0.22	0.26

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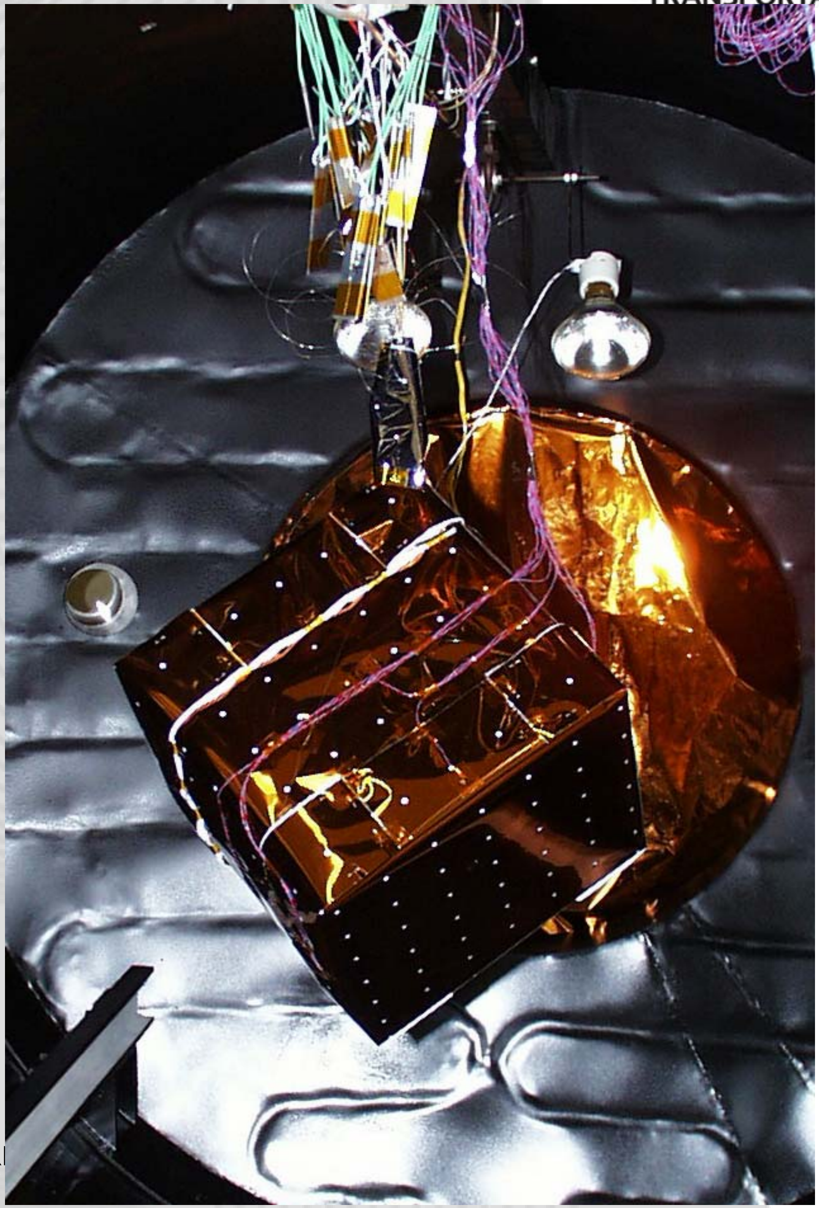
3D-Thermal Conductance Test

- Thermal conductance tests of both ideal and complex-shaped MLI blankets have been performed.
- 3D-blanket assembly was tested in the vacuum chamber at Astrium, Bremen.
- Configuration: cube of 300x300x300mm covered by three MLI blankets in a box-like manner.
- MLI in mounted inside-out. Heater is located within the box.



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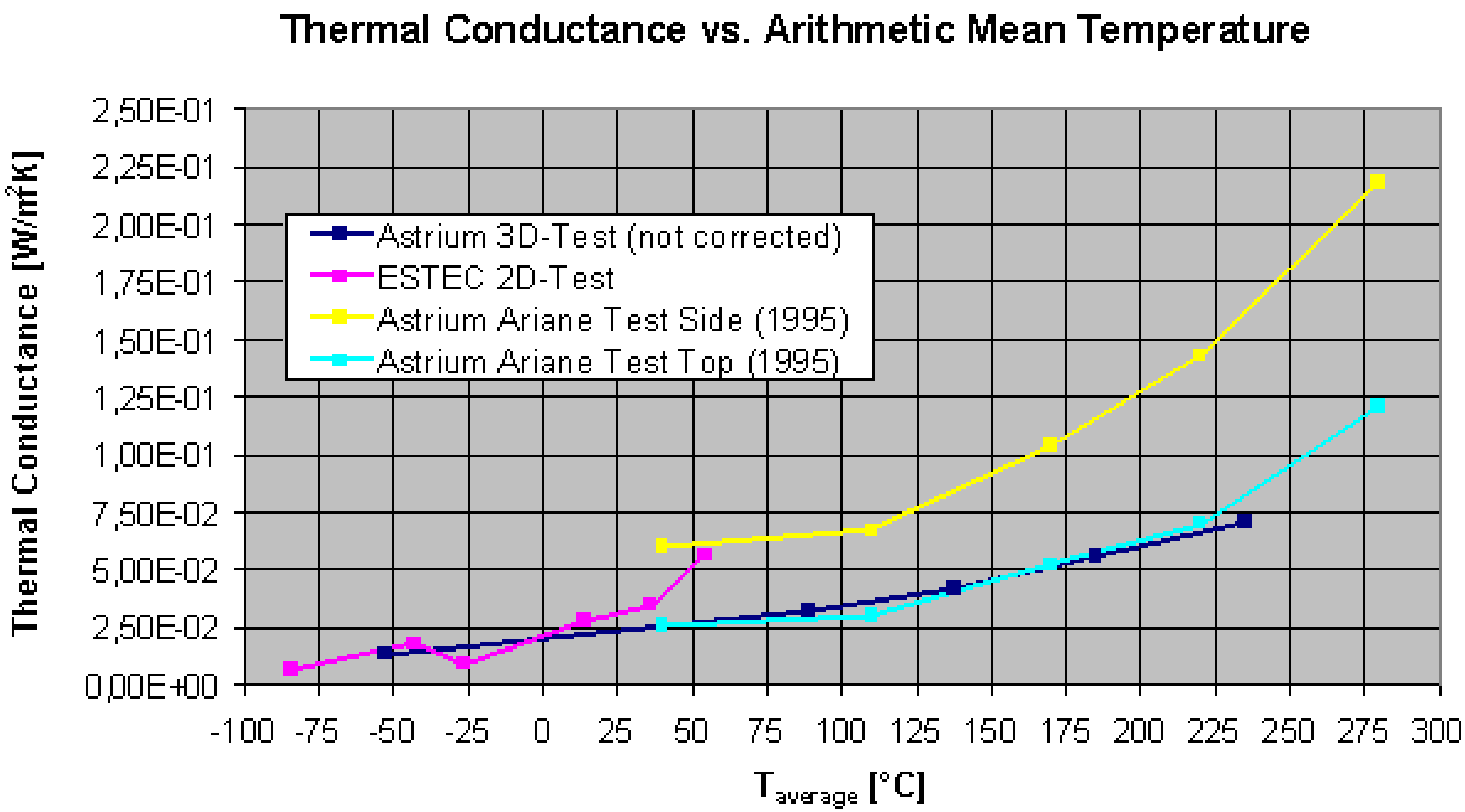
- Thermal conductance corresponds well to the results of standard MLI manufactured for Ariane 5 with the same number of reflective layers.



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1. Brief recall of original Objectives of TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
ETTI:		
Investigate, define and verify high-temperature insulating systems high-temperature MLI: Sunshield and blanket	Y	
HT-MLI:		
Demonstration of feasibility of critical technologies by August 2005	Y	
Good understanding of all the available technologies, robust and consolidated development plan.	Y	
Improvement of existing HT-MLI ... applicable to the BepiColombo mission. Characterisation and verification of this product. Fully developed MLI system ... subsequently be qualified. Qualification is not part of this activity.	Y	Significant part of tests covered by Option 1 and Option 2
The total duration shall be 18 months. The design work to be completed by August	Y	

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2. Technology Requirements

Planned Accomplishment	Level of Accomplishment	
	Compliance	**Comments**
The MLI blankets shall be designed to protect a flat plate with insulated rear face and active side exposed to the following two different steady thermal environments:	**Y**	
Solar fluxes: Qsun = 14,500 W/m2, IR planetary fluxes: Qp = 2,500 W/m2	**Y**	**14500 W/m^2 applies to max.Temp., mean value applies to endurance. Margin will not be applied to load.**
Solar fluxes: Qsun = 1,500 W/m2, IR planetary fluxes: Qp = 10,000 W/m2	**Y**	
Minimum operational temperature of the blanket: 90 K	**Y**	
Reference internal side temperature: 293 K	**Y**	
A margin of at least 50 K with respect to the maximum operational temperature of the materials constituting the blanket shall be used in the design	**Y**	

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Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
The blankets shall be designed to withstand 2-year exposure to the space environment encountered in the interplanetary transfer from the Earth to Mercury and successive 2-year exposure to the space environment in Mercury orbit with degradation </= 15 % of mechanical and thermal properties	TBV	To be verified. Degradation requirement should be more precisely defined. Delta development by HT-MLI concerning irradiation stable sunshield. MLI thermally and optically verified; mechanically not verified.
Specific mass of the assembled blankets: ≤ 1 kg/m2.	Y	Requires to keep the present thermally efficient and lightweight design.

3. Scope of TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Definition of high-temperature MLI: identification of possible improvements on conventional MLI, screening of most appropriate materials, definition and trade-off of blanket layouts	Y	
Establishment of verification test plan	X	Verification plan not established in ETTI and will only partially be achieved by BC-HT-MLI
Manufacturing of samples	Y	
Perform test campaign	Y	Testing will be continued in HT-MLI but present contract covers only part of the required verification tests.

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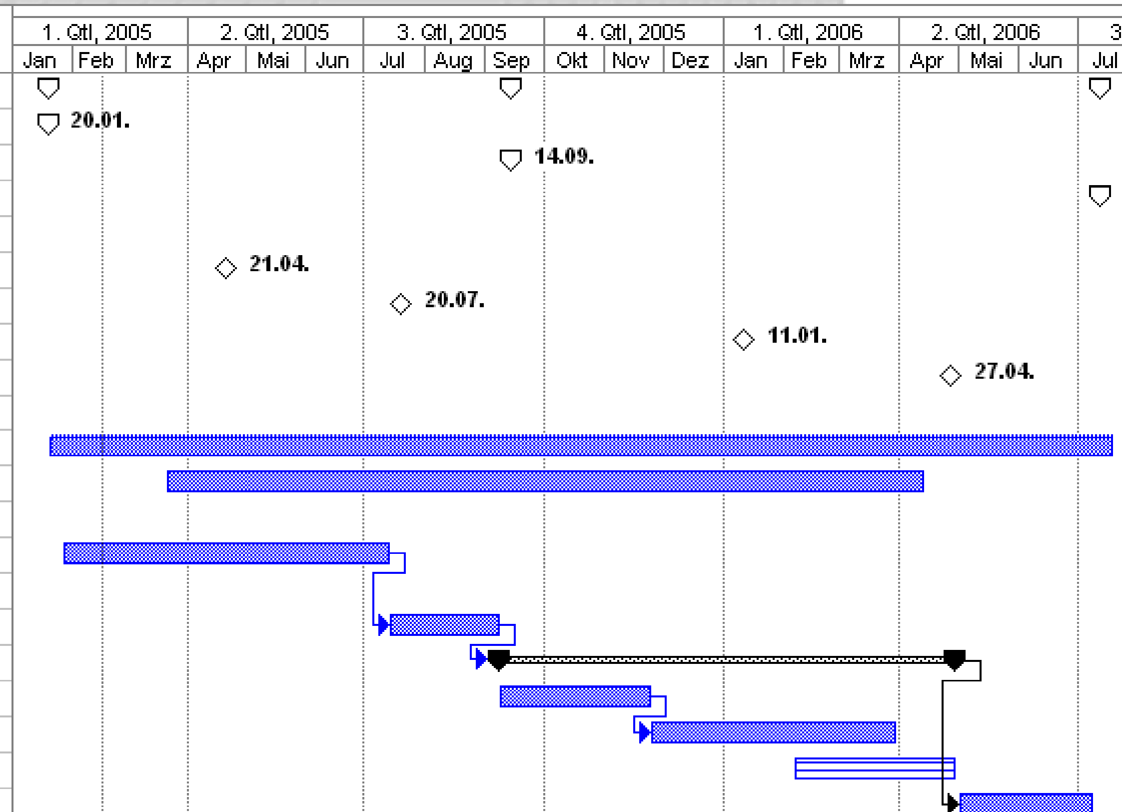
4. Schedule of TDA – HT-MLI

Nr.	Vorgangsname
1	**Milestones**
2	KOM
3	IR
4	FR
5	**Progress Meetings**
6	PM1
7	PM2
8	PM3
9	PM4
10	
11	WP-1000 - Management
12	WP-2000 - Product Assurance
13	WP-3000 - DELETED
14	WP-4000 - Improvement of MLI Design
15	WP-5000 - DELETED
16	WP-6000 - Verification Test Plan
17	**WP-7000 - Verification Testing**
18	WP-7100 - Sample Manufacturing & Instrumentation
19	WP-7200 - Characterisation Testing
20	(WP-7300 - Validation Testing - Option 3)
21	WP-8000 - Synthesis & Recommendation



5. Deliverables of TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Samples of material validated in laboratory environment	Y	All samples manufactured will be delivered if requested

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6. Critical Technology Requirements not met and performances not achieved by the TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Current Status of Technology: TRL 3	Y	
Expected Status of TRL at end of activity: TRL 4	Y	HT-MLI will improve to TRL 4
Achieved TRL:		
Blanket: TRL 3 (see EADS ST Report FTS-RIBRE-TN-0017: Degree of Accomplishment of Thermal Control Components developed for BepiColombo)	Y	Overall TRL=4 In addition to HT-MLI tests are required to achieve TRL=5: Outgassing at high temp., electrical properties, 3D-MLI box test, ESD, measurement of critical properties, thermal cycling, thermal shock, sun trapping, UV and charged particles endurance.
Sunshield: TRL 2 (see EADS ST Report FTS-RIBRE-TN-0017: Degree of Accomplishment of Thermal Control Components developed for BepiColombo)	Y	

7. Critical technology items not covered by scope of TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Blanket: Thermal endurance (TV-test), thermal cycling and thermal shock on component and subsystem level not yet performed Sunshield: Selected material not stable to radiations Within the given objectives and budget, qualification will not be complete. Technological readiness is between TRL=2 and TRL=5	X X X	planned for HT-MLI except thermal shock Important verification tests presently optional, UV and particle endurance test not yet planned. New sunshield to be developed in HT-MLI HT-MLI will achieve TRL-4

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8. Planning to Flight Model status

- **HT-MLI** – Kick-Off on 20.Jan.2005; Budget 300k€
- **Delta Development** to achieve TRL 5: Defined by Options 1 and 2 to HT-MLI proposal + UV and particle endurance test
- **Development and Design** incl. preparations for production
- **Schedule:**

	Duration	Termination
– HT-MLI	18 mon	Jun. 2006
– Delta Qualification:	15 mon	Aug. 2007
– Integration Dev. & Design:	6 mon	Mar. 2008

ETTCM – Extreme Temperature Thermal Control Components

- **Solar Reflector Coating (SRC)** – two inorganic coatings under investigation: YB-71P and AZ-2000-IEW - maximum operational temperature MOT: 300°C – in first tests stable to thermal and radiation loads - at present: thermal endurance problem.
- **Optical Solar Reflector (OSR)** - system of 125μm glass mirror glued to structure by silicone adhesive. Two adhesives considered: RTV566 + Chobond and RTV-S-692. MOT: 250°C – in first tests stable to thermal and radiation loads - at present: thermal endurance problem.
- **Infra Red Rejection Device (IRRD)** three solutions developed. MOT=80°C.

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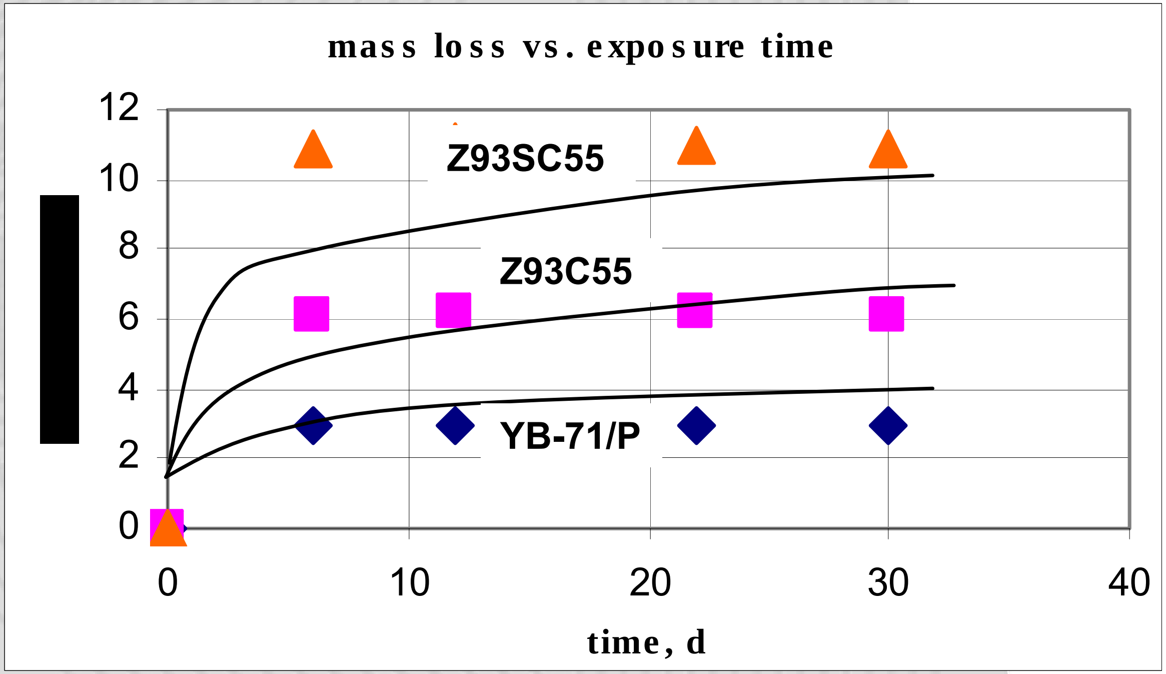
SRC - Solar Reflector Coating Development

SRC - Mass Loss



Mass loss after 30d exposure to 350°C in vacuum: YB-71/P arrives at 3% while Z93C55 is at 6% and Z93SC55 at 11%.

The mass loss of all three coatings approaches a limit value. The outgassing process is almost finished already after five days. Pre-outgassing of coated flight components promises to significantly reduce the mass loss.

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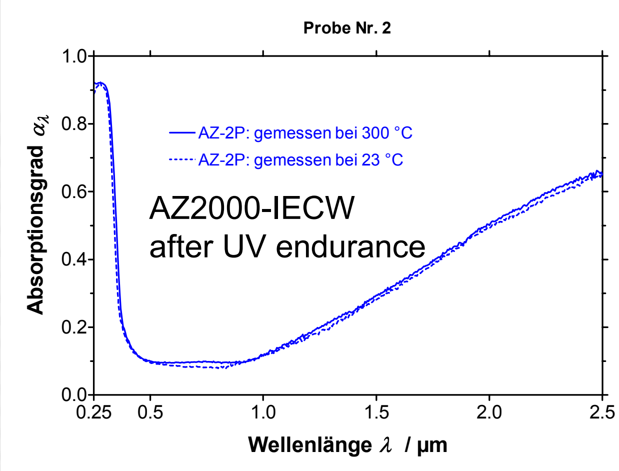
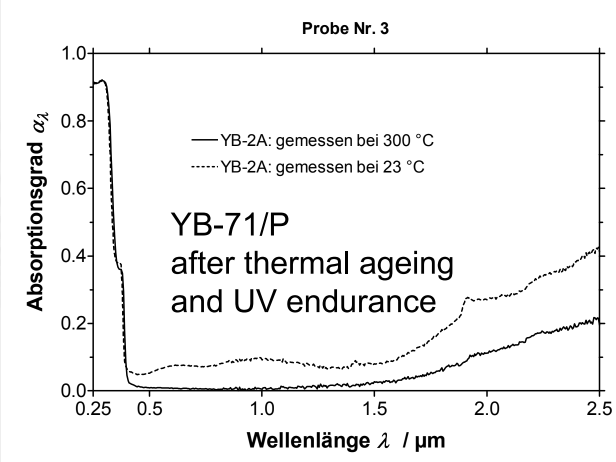
SRC – UV Endurance Test

- After completion of the 2nd thermal ageing campaign, the coatings YB-71/P, Z93C55 and AZ2000-IECW coatings were subjected to accelerated ageing by UV irradiation:
- Wavelength: 200 - 400nm
- UV-flux: 14 solar constants
- Acceleration factor: 2.1
- Temperature: ~120°C
- Pressure: ambient
- time: 30 days

Spectral absorptivity of two samples measured after endurance testing at 23°C and 300°C





OSR - Optical Solar Reflector Development

OSR Concept - Principal Solutions

- Development of an optical solar reflector system of low solar absorptance, high IR emittance and high radiation resistance, temperature range of -150°/ +250°C, life time of 3.5 years cruise plus two years operation.
- Advantages: Simple design, OSR technology qualified through several projects –SSM's glued to the spacecraft substrate.
- ITO and UV coated SSM's – high solar reflectance, small α_s/ε ratio, high max operating temperature, good electrical bonding
- Silicone Adhesive – thin layer, upper operating temp. approx. 300°C, el. conductivity required, low outgassing
- Stability to be verified by development: – Degradation of glass transparency due to UV and particle irradiation, increased surface absorptivity due to surface contamination.

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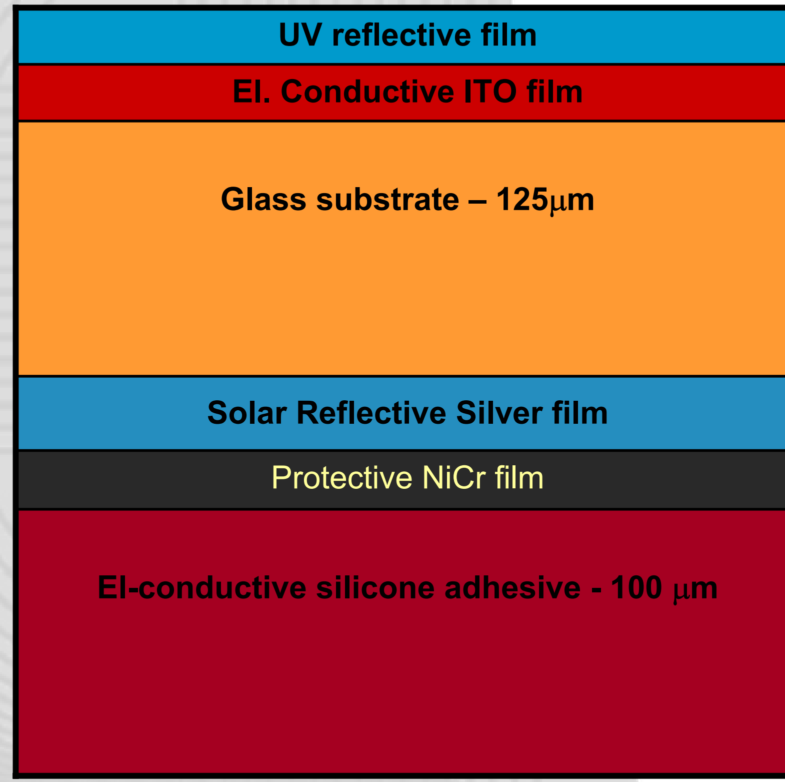
OSR Concept

- Initially several alternative technologies have been investigated to manufacture OSR like plasma spray, Plasmocer, PVD, CVD, sputter
- Selection prefers a **classical mirror based on a Glass-SSM**.
- SSM is **assumed to be rather stable to radiation - verification by radiation tests**.



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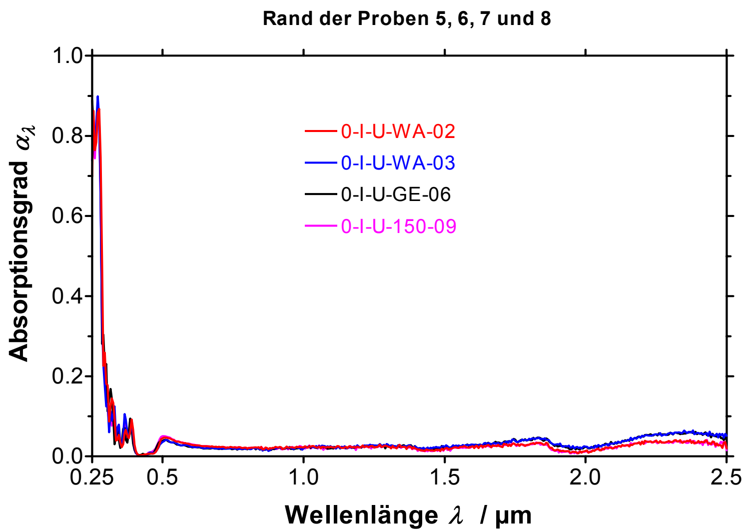
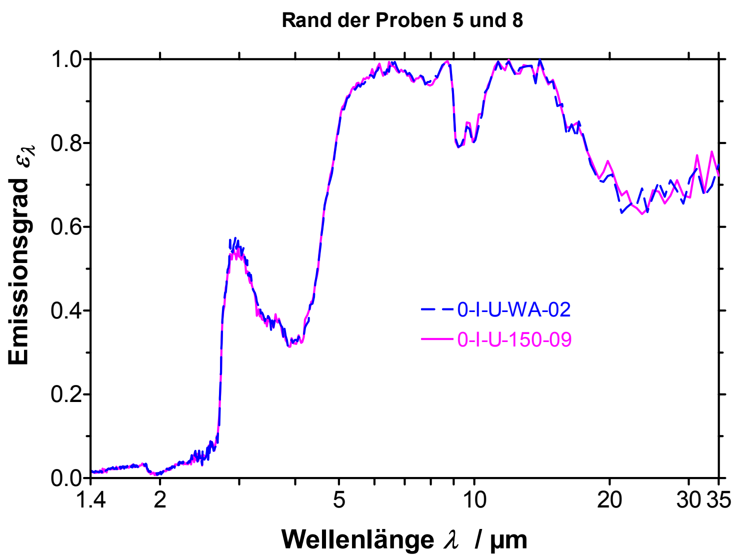
OSR – Post Test Optical Properties

OSR absorptivity and emissivity measured spectrally in center of sample at 23°C and 250°C in air by ZAE, Würzburg, D





Absorptance SSM: 0.03

Emittance 23°C: 0.86

Emittance 250°C: 0.83

No measurable change in absorptance after 32 days exposure to 250°C corresponding to 2.6 years on Mercury orbit.

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IRRD - Infra Red Rejection Device Development

- The **IRRD** is defined as a broadband filter. The characteristics required make it hard to apply interference filter technology. Three different concepts have been proposed:
- An VIS transmitting - IR attenuating filter (Type 1)
- A selectively reflecting mirror to reflect VIS and either transmit or absorb IR (Type 2)
- An VIS transmitting - IR reflecting filter, which is the preferable solution (Type 3)

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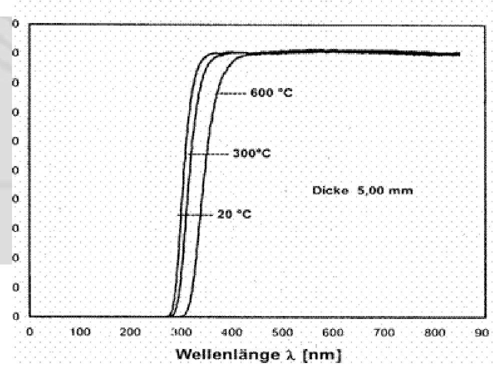
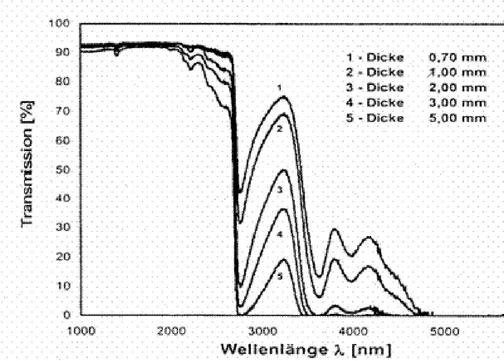
IRRD - Concept - Principal Solutions

Visible transmitting IR attenuating filter - passes the spectrum of the signal and absorbs the infrared light. Because of the high amount of infrared radiation, to be absorbed, the filter will become hot and needs to be cooled.

- Advantage: - Simple design, - IR filter by choice of glass e.g. BK7, Borofloat, Herasil, Suprasil, if necessary, an additional interference film will improve the step-up or step-down
- Disadvantage: - Heat load to be removed by TCS, adds complexity to SC due to heat pipes or thermal straps; - size limitation due to thermal distortion; - thermal contact along circumference leads to high thermal gradients





Transmissivity of Borofloat 33 (Schott)

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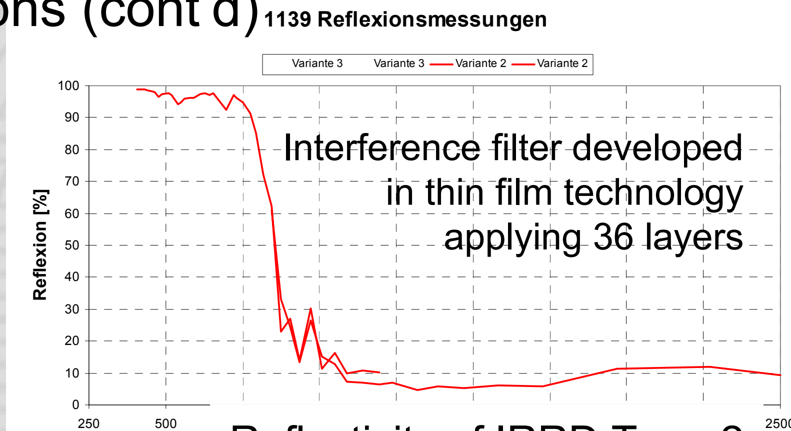
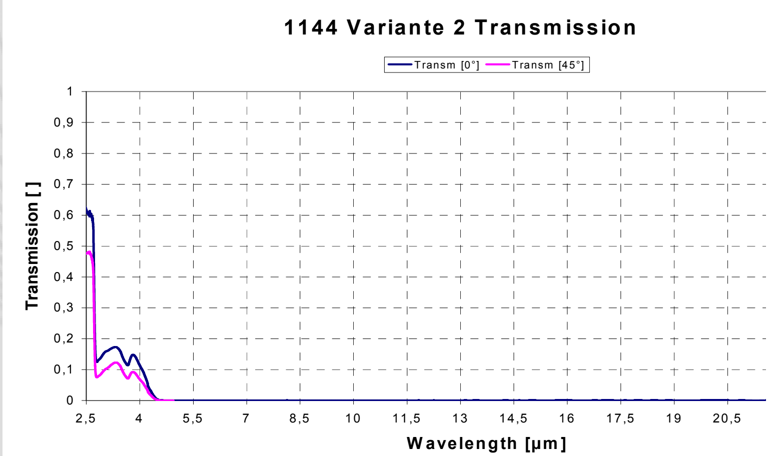
IRRD - Concept - Principal Solutions (cont'd)

Visible reflecting IR absorbing mirror - directs the signal to the sensor by reflection. IR radiation is absorbed by the glass and by an absorber attached to the rear side. The heat is removed full surface from the rear .

- Realised by interference filter technology
- Advantage: - Simple design, - IR filter by choice of glass e.g. BK7, Borofloat, Herasil, Suprasil
- Disadvantage: - Heat load to be removed by TCS
- Improvement by IR transmitting glass possible. Broadband IR transmitting substrate required.



Reflectivity of IRRD Type-2



IR-Transmissivity of IRRD Type 2 under 0° and 45°

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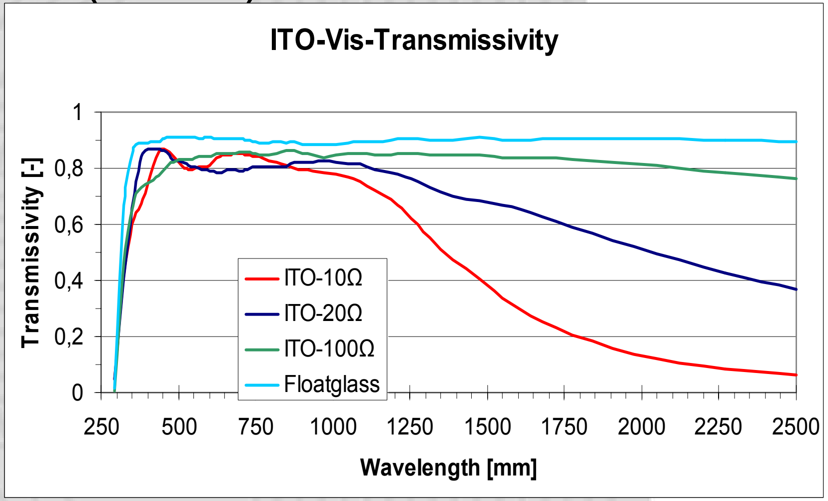
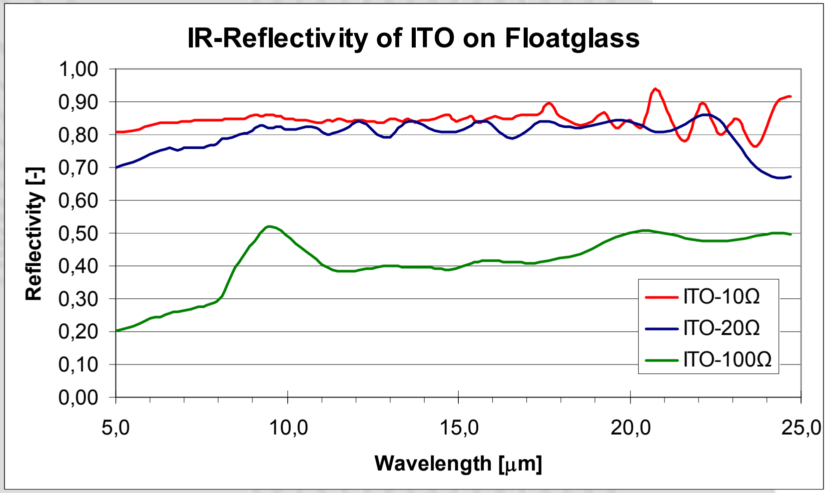
IRRD - Concept - Principal Solutions (cont'd)

- **Visual transmitting IR reflecting filter** - In this case, the IR will be reflected - preferred solution
- Advantage: heat load on TCS and added complexity are avoided
- Disadvantage: broadband mirror is difficult to achieve
- Realised by ITO thin film of 10Ω/sq to 100Ω/sq coating. Concern: environmental stability of ITO – presently being investigated.





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1. Brief recall of original Objectives of TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Development of thermal control materials (Solar Reflector Coating, Optical Solar Reflectors and Dichroic Filter) able to withstand the high-temperature, high-flux environment in the vicinity of Mercury	Y	

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2. Technology Requirements

Planned Accomplishment	Level of Accomplishment	
	Compl iance	Comments
<u>Solar Reflector Coating:</u>		
Average solar absorptance at Beginning-Of-Life (BOL): $\alpha s \leq 0.2$ throughout the temperature range –150°C/300°C	Y/N	Depends on selection of coating
Hemispherical total emittance (BOL): $\varepsilon H \geq 0.8$ throughout the temperature range: –150°C/300°C	Y	
Maximum degradation due to UV and particle radiation environment at End-Of-Life (EOL): $\Delta\alpha s \leq 0.1$ throughout the temperature range: –150°C/300°C.	Y/N	Depends on selection of coating, conflict with αBOL requirement
Maximum operational temperature: 300°C in vacuum	Y	
Surface electrical resistance: $\rho \leq 10{,}000$ ohms per square	N	Although lower resistance specified by manufacturer for AZ - to be verified by ESD test
<u>Optical Solar Reflector</u>:		
Average solar absorptance at Beginning-Of-Life (BOL): $\alpha s \leq 0.1$ throughout the temperature range –150°C /250°C	Y	

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Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Hemispherical total emittance (BOL): $\varepsilon H \geq 0.8$ throughout the temperature range –150°C/250°C	Y	
Maximum degradation due to UV and particle radiation environment at End-Of-Life (EOL): $\Delta\alpha s \leq 0.05$ throughout the temperature range: –150°C/250°C	Y	
Maximum Diffuse Solar Reflectance α<1% of the Total Solar Reflectance	Y	
Maximum operational temperature: 250°C in vacuum	Y	
Surface electrical resistance: $\rho \leq$ 10,000 ohms per square	X	Resistance of ITO layer is ca. 1000Ohms but not measurable due to UV protective coating on top of electrically conductive coating. Verification by ESD test required
<u>Dichroic Filter (IRRD)</u>:		
Filter type: shortwave-pass	Y	
Cut-off wavelength: 2.5 μm	Y	
Maximum operational temperature: 60°C	Y	

3. Scope of TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Review of current state-of-the-art in high-temperature thermal control materials (Solar Reflector Coating, Optical Solar Reflectors and Dichroic Coating). Identification of necessary improvements to the current state-of-the-art and/or new developments	Y	
Identification of Mercury mission requirements. Characterisation of Mercury environment and of its effects on performances and degradation of thermal control materials.	Y	
Preliminary design, analyses and trade-offs of thermal control materials.	Y	
Development of possible new concepts for manufacturing and fixation methods.	Y	
Definition and manufacturing of test samples of thermal control materials.	Y	

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Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Trade-off and set-up of proper test procedures and facilities to evaluate thermal control materials performances and degradation	Y	
Testing of performances and degradation of thermal control materials	Y	Additional tests required for full component level verification: ESD, thermal shock, validation in vacuum of UV endurance tests performed in air and validation by test in vacuum.

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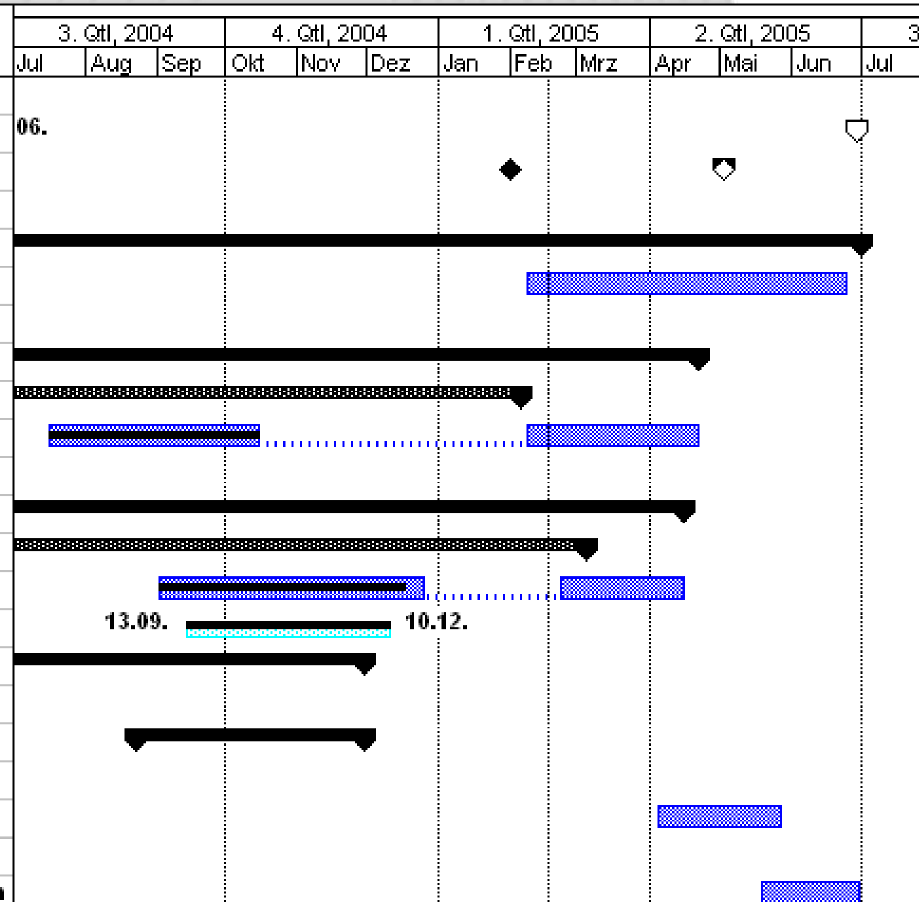
4. Schedule of TDA

Nr.	Vorgangsname
1	**Milestones**
2	**ATP, IR, FR**
6	**Progress Meetings**
12	
13	**WP-1000 - Management**
16	**WP-2000 - Product Assurance**
17	
18	**WP-3000 - Solar Reflector Coating**
19	**3100 - SRC Development**
23	3200 - SRC Charakterisation
24	
25	**WP-4000 - Optical Solar Reflector**
26	**4100 - OSR Development**
30	4200 - OSR Characterisation
31	SSM Investigation
32	**WP-5000 - InfraRed Rejection Device**
33	**5100 - IRRD Development**
37	**5200 - IRRD Characterisation**
58	
59	**WP-6000 - Validation Testing**
60	
61	**WP-7000 - Synthesis & Recommendation**



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5. Deliverables of TDA

Planned Accomplishment	Level of Accomplishment	
	Compl iance	Comments
Samples of high-temperature thermal control materials validated in laboratory environment	Y	To be delivered on request

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6. Critical Technology Requirements not met and performances not achieved by the TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Expected Status of TRL at end of activity: TRL 4	Y	Current Status TRL: 3
Achieved TRL:		
Solar Reflector Coating: TRL 4 (see EADS ST Report FTS-RIBRE-TN-0017: Degree of Accomplishment of Thermal Control Components developed for BepiColombo)	N	Present problem of stability wrt. thermal endurance: TRL=3, to be resolved by end of activity.
Optical Solar Reflector: TRL 4 (see EADS ST Report FTS-RIBRE-TN-0017: Degree of Accomplishment of Thermal Control Components developed for BepiColombo)	N	Present problem of stability wrt. thermal endurance: TRL=3-4, to be resolved by end of activity.
Dichroic Filter (IRRD):(see EADS ST Report FTS-RIBRE-TN-0017: Degree of Accomplishment of Thermal Control Components developed for BepiColombo)	N	TRL-4 will be achieved but specific development of optical component for the instrument concerned will be required.

BepiColombo TSR
ETTI + HT-MLI + ETTCM

7. Critical technology items not covered by scope of TDA

Planned Accomplishment	Level of Accomplishment	
	Compliance	Comments
Solar Reflector Coating: By March 2005 pre-qualification will be about half way achieved	Y	
Optical Solar Reflector: By March 2005 delta qualification (250°C, 10-fold UV irradiation) will be about half way finished	Y	Validation of previous UV endurance test in air required by UV-test in vacuum
Dichroic Filter (IRRD): Instrument requirements needed for further development of IRRD. The IRRD need to be qualified with the instrument	Y	
Within the given objectives and budget, qualification will not be complete at any of the developed TCC. Technological readiness will range between TRL=3 and TRL=5 Required Activities: SRC: Pre-qualification OSR: Delta qualification IRRD: Development to be continued to instrument requirements	X	In general TRL-4 will be achieved SRC, OSR and IRRD: - additional tests for pre-qualification required (ESD, Thermal shock) - additional tests for component level qualification required - qualification on subsystem/system level required

8. Planning to Flight Model status

- **ETTCM** planned to be finished by June 2005
  - Present thermal endurance problem – Corrective activities in March
- **Delta Development** to achieve TRL 5:
  - SRC and OSR: additional tests for pre-qualification
  - IRRD: instrument dedicated development, design and qualification
- **Development and Design:**
  - SRC and OSR: qualification on subsystem level
  - IRRD: qualification together with instrument