TFAWS TECHNICAL COURSE

GSFC Coatings Committee

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NASA Goddard Space Flight Center

Thermal & Fluids Analysis Workshop
TFAWS 2023
August 21-25, 2023
NASA Goddard Space Flight Center
Greenbelt, MD

COURSE SUMMARY

- **Title:** GSFC Coatings Committee
- **Instructor:** Nithin S. Abraham
  NASA Goddard Space Flight Center
- **Description:** This technical course will provide an overview about the coatings committee at NASA Goddard Space Flight Center (GSFC) that is responsible for reviewing the coatings properties used in the thermal design of NASA missions.

  Topics include understanding the process used to determine the Beginning of Life (BOL) and End of Life (EOL) solar absorptance and hemispherical emittance values of critical thermal surfaces and the key factors that influence the degradation of thermal coatings, thin films, tapes, and blanket materials.

AGENDA

- **Gold Rule Requirement**
- **Coatings Committee Background**
- **Natural Environment Coatings Degradation Factors**
  - Atomic Oxygen, UV Radiation, Charged Particles, and Orbit Altitude, Conditions & Duration
- **Induced Environment Coatings Degradation Factors**
  - Contamination and Application
- **Coatings Property Data**
  - Ground & Flight Test Data, Instrument Measurement Uncertainty, Emittance Conversion, and Other Factors
- **Coatings Committee Process & Examples**

GSFC GOLD
RULE REQUIREMENT

GOLD RULE REQUIREMENT

Goddard Open Learning Design (GOLD) Rules

- GOLD rules are **engineering principles** and **practices** that have evolved in the GSFC community for the design, development, verification, and operation of flight systems
- It specifies the **requirements** in the form of a rule statement, supporting rationale, and guidance on activities and verifications at each project lifecycle phase
- The rules are intended to apply to all space flight projects, regardless of implementation, approach, or mission classification (exceptions may apply)
- It provides visibility to senior management when a project deviates from standard GSFC “**best practices**”

GOLD RULE REQUIREMENT

Goddard Open Learning Design (GOLD) Rules

- **GSFC-STD-1000** is a NASA Goddard technical standard that describes the GOLD rules
- Revision H of the document is publicly available online on the NASA Technical Standards System (NTSS)

https://standards.nasa.gov/standard/GSFC/GSFC-STD-1000

GODDARD TECHNICAL STANDARD	GSFC-STD-1000H
Goddard Space Flight Center Greenbelt, MD 20771	**Approved:** 03-15-2023 **Revalidation Date:** 03-15-2028 Superseding GSFC-STD-1000G

Goddard Space Flight Center

Rules for the Design, Development, Verification, and Operation of Flight Systems

THIS STANDARD HAS BEEN REVIEWED FOR EXPORT CONTROL RESTRICTIONS;
APPROVED FOR PUBLIC RELEASE
DISTRIBUTION IS UNLIMITED

GOLD RULE REQUIREMENT

- The GSFC Coatings Committee was established through **GOLD Rule Requirement # 4.06** for the validation of thermal coatings properties

4.06	**GSFC-STD-1000 REV H, GOLD RULE REQUIREMENT # 4.06** VALIDATION OF THERMAL COATINGS PROPERTIES
RULE	• All thermal coatings properties that **drive thermally significant performance** shall be determined, measured and validated to be accurate for materials and mission flight parameters over the lifecycle of the mission • All thermal analysis shall employ these properties • GSFC Coatings Committee shall review and approve the thermal coatings properties
RATIONALE	• Thermal coatings properties directly affect **mission success** through spacecraft or instrument thermal design • Early assessment of thermal coatings properties ensures mission objectives will be met

SOURCE: HTTPS://STANDARDS.NASA.GOV/STANDARD/GSFC/GSFC-STD-1000

GOLD RULE REQUIREMENT

4.06

GSFC-STD-1000 REV H, GOLD RULE REQUIREMENT # 4.06
VALIDATION OF THERMAL COATINGS PROPERTIES

NASA Life Cycle **PHASE**	<A	A	B	C	D	E	F
	CONCEPT STUDIES	CONCEPT AND TECHNOLOGY DEVELOPMENT	PRELIMINARY DESIGN AND TECHNOLOGY COMPLETION	FINAL DESIGN AND FABRICATION	SYSTEM ASSEMBLY, INTEGRATION & TEST, LAUNCH & CHECKOUT	OPERATIONS AND SUSTAINMENT	CLOSE OUT
ACTIVITIES	• Assess proposed thermal coatings for the mission design parameters	• Assess proposed thermal coatings for the mission design parameters	• Determine appropriate BOL and EOL coatings properties to be used in the thermal analysis • Determine mission specific thermal coating requirements	• Update thermal coatings properties as coatings selection matures	• Update thermal coatings properties as coatings selection matures • Measure coatings properties when appropriate as determined by the Thermal Engineer / Coatings Engineer • Develop notional plan for assessing in flight	• Assess thermal coating performance through flight data as appropriate	• N/A
VERIFICATION	• Specify needed environmental tests on thermal coatings	• Specify needed environmental tests on thermal coatings	• Verify through peer review / GSFC Coatings Committee, test results, analysis, and at PDR	• Verify through peer review / GSFC Coatings Committee, test results, analysis, and at CDR	• Verify at PER as determined by the Thermal Engineer / Coatings Engineer	• Confirm performance with available flight data as appropriate	• N/A

SOURCE: HTTPS://STANDARDS.NASA.GOV/STANDARD/GSFC/GSFC-STD-1000

Preliminary Design Review (PDR)   Critical Design Review (CDR)   Pre-Environmental Review (PER)

GSFC COATINGS COMMITTEE BACKGROUND

COATINGS COMMITTEE

- The **GSFC Coatings Committee** is chaired by the Contamination and Coatings Engineering Branch (Code 546) at NASA Goddard
- The committee was established in the **early 1980s**
  - To review coatings properties used in the thermal design

BOL and EOL (or Hot and Cold Case) thermal/optical property values for **SOLAR ABSORPTANCE** (α_S) and **HEMISPHERICAL EMITTANCE** (ε_H), and if requested, for transmittance, reflectance, and specularity

  - To recommend coatings & testing that meet project environmental performance requirements

COATINGS COMMITTEE

There are currently 8 members on the committee with representation from branch management

CHAIR

Mark Hasegawa
Thermal Coatings Group Lead
NASA GSFC/546

MEMBER

Nithin Abraham
Thermal Coatings Engineer
NASA GSFC/546

MEMBER

Kristin McKittrick
Thermal Coatings Engineer
KBR/546

MEMBER

Griffin Jayne
Thermal Coatings Engineer
NASA GSFC/546

MEMBER

Jim Heaney
Coatings Consultant
KBR/546

MEMBER

Jack Triolo
Coatings Consultant
RETIRED/546

MEMBER

Ray LeVesque
Coatings Consultant
KBR/546

MEMBER

Ted Michalek
Thermal Consultant
LENTECH/545

BRANCH REP

Code 546, Contamination & Coatings Engineering Branch Management Representative

Randy Hedgeland &
Tina Montt de Garcia
NASA GSFC/546

BRANCH REP

Code 545, Thermal Engineering Branch Management Representative

Veronica Otero, Juan
Rodriquez, & Deepak Patel
NASA GSFC/545

BOL & EOL COATINGS PROPERTIES

- Each mission's BOL & EOL coatings properties are **unique**
  - e.g., Values that were approved by the GSFC Coatings Committee for use in the thermal design on one project **may not apply** on another project
- Predicting the coatings properties for a specific mission can be **challenging** because it can vary significantly depending on several factors and assumptions that are associated with coatings degradation and measurements that are unique to that mission's environment
  - Degradation due to natural environments (i.e., space)
  - Degradation due to induced environments
  - Availability of ground and flight measurement test data
  - Other miscellaneous factors

NATURAL ENVIRONMENT COATINGS DEGRADATION FACTORS

ATOMIC OXYGEN, UV RADIATION, CHARGED PARTICLES, AND ORBIT ALTITUDE, CONDITIONS & DURATION

SPACE ENVIRONMENT

- Thermal coatings are expected to degrade in the harsh conditions of space (e.g., natural environment) due to exposure to **atomic oxygen** (AO), **ultraviolet** (UV) radiation, and energetic **charged particles** (CP)

- The synergistic interactions with space radiation and environmental effects are extremely complex
- The resulting damage directly impacts EOL coatings properties
- Darkened surfaces result in an increase to solar absorptance

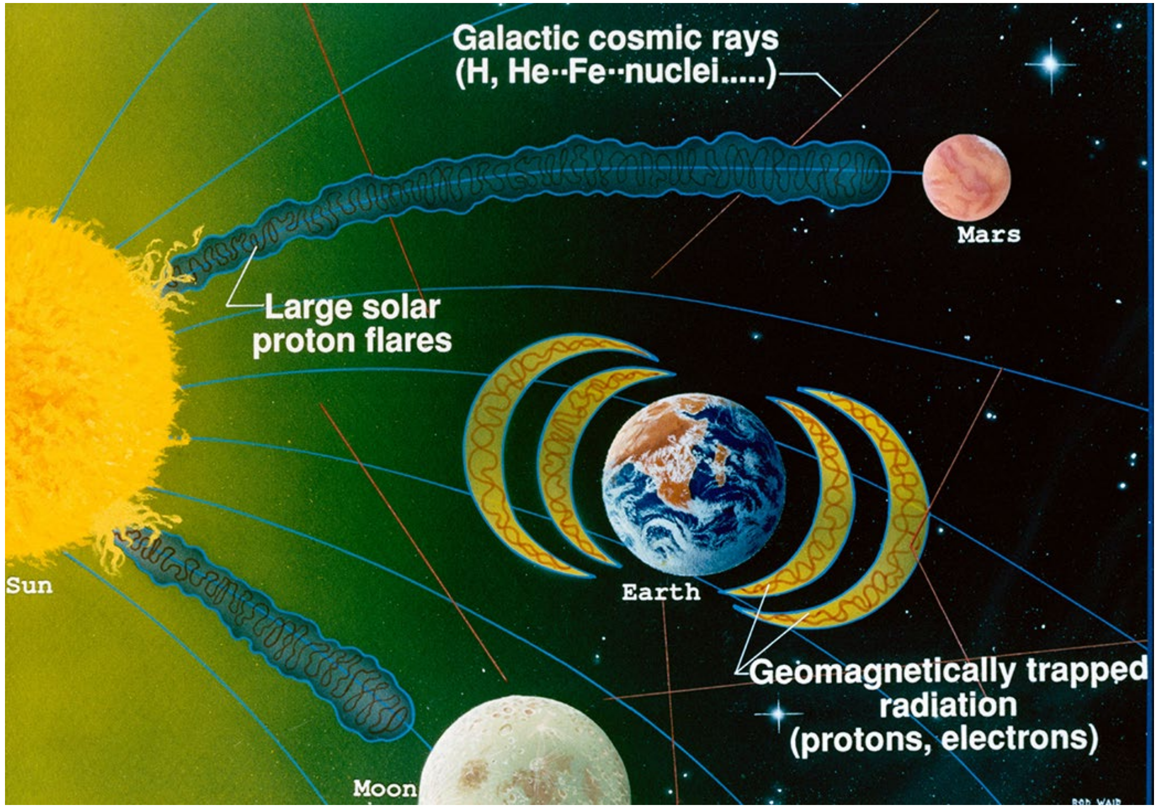
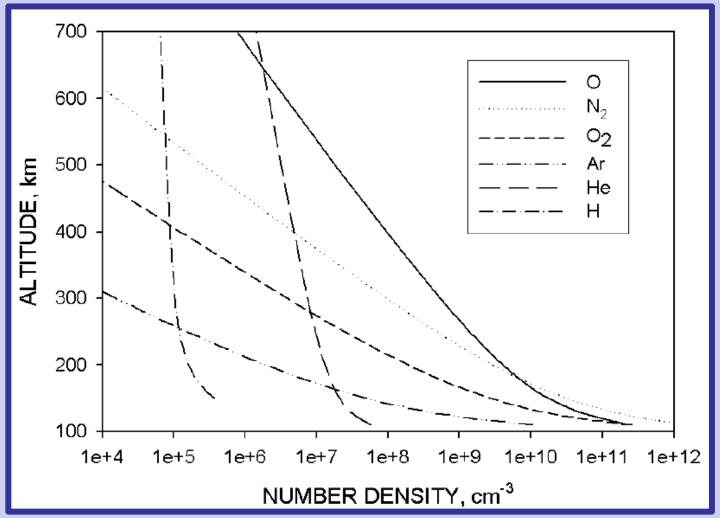


IMAGE CREDIT: NASA

ATOMIC OXYGEN

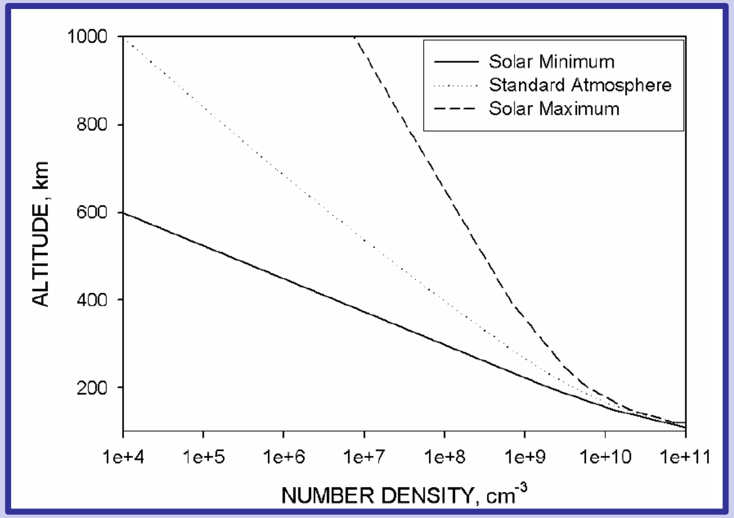
- AO is **very reactive** (e.g., oxidation)
- It is the most abundant species that is present in Low Earth Orbit (LEO)
- The expected AO fluence and erosion rates are based on altitude, target launch date (e.g., solar minimum & solar maximum), mission duration, and surface orientation relative to the ram direction

ATMOSPHERIC CONSTITUENT FLUENCE VS. ALTITUDE



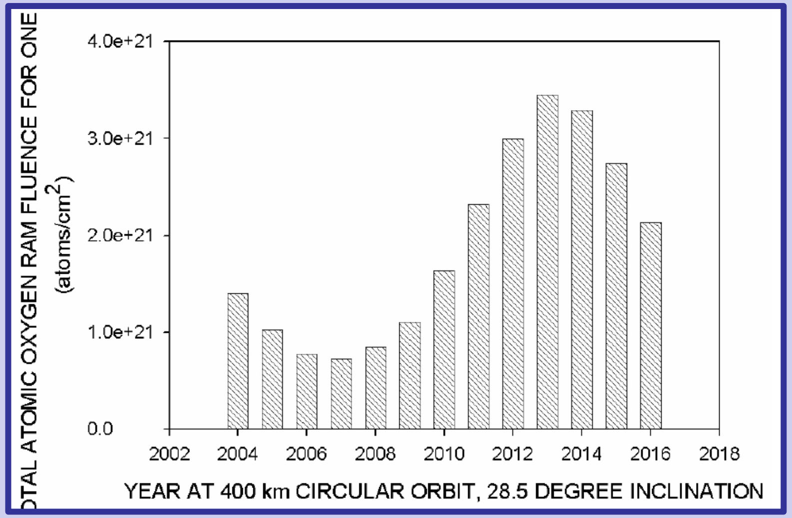
BANKS, BRUCE A., ET AL., "LOW EARTH ORBITAL ATOMIC OXYGEN INTERACTIONS WITH SPACECRAFT MATERIALS", NASA/TM—2004-213400

AO FLUENCE VS. ALTITUDE FOR SOLAR MIN & MAX AND NOMINAL CONDITIONS



BANKS, BRUCE A., ET AL., "LOW EARTH ORBITAL ATOMIC OXYGEN INTERACTIONS WITH MATERIALS", NASA/TM—2004-21322318

AO FLUENCE PER YEAR DURING A SOLAR CYCLE



BANKS, BRUCE A., ET AL., "LOW EARTH ORBITAL ATOMIC OXYGEN INTERACTIONS WITH MATERIALS", NASA/TM—2004-21322318

ATOMIC OXYGEN

- Thermal coatings that are made of **organic** binders (e.g., silicones, polymers) and unprotected pigments are expected to degrade due to AO exposure
- **Inorganic** thermal coatings (e.g., oxides, metals) are expected to be more stable and unaffected by AO (i.e., fully oxidized, protected pigments)
- Thermal surfaces, such as Teflon and Kapton materials, are impacted by AO

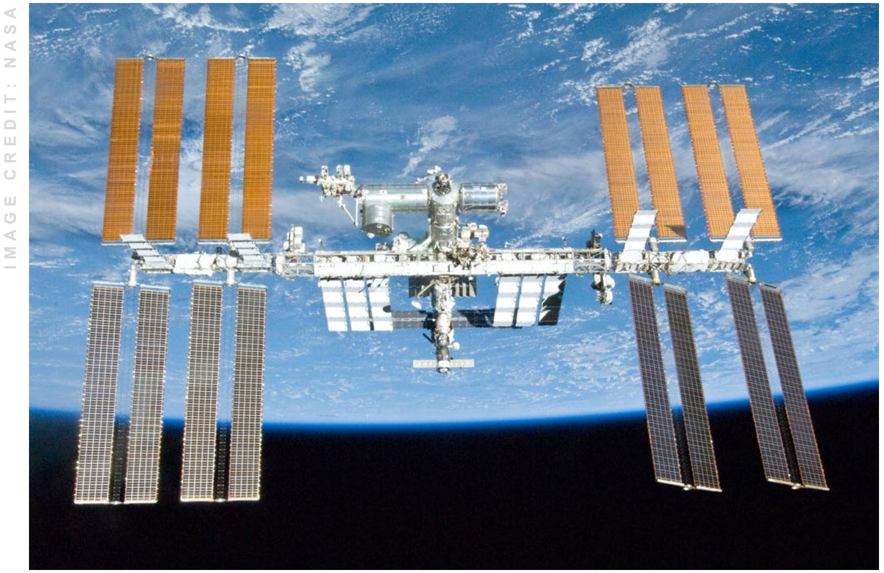


IMAGE CREDIT: NASA

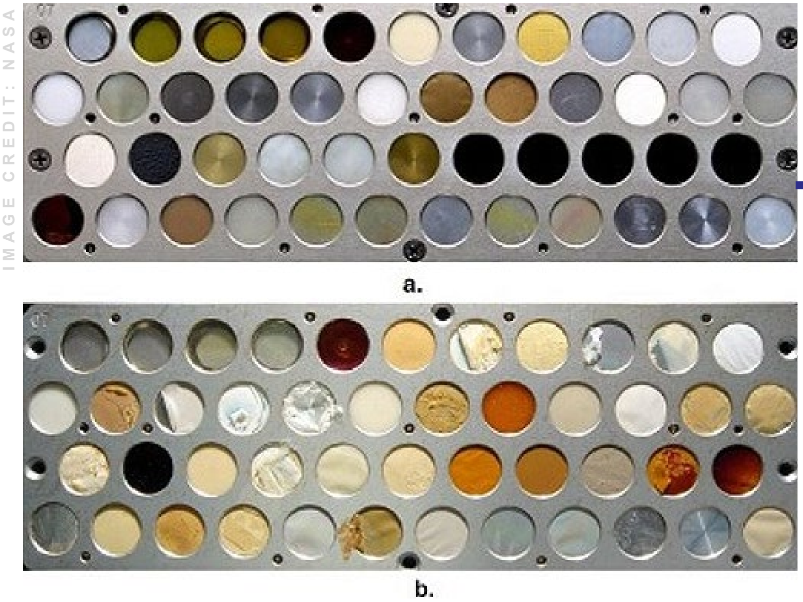


IMAGE CREDIT: NASA

Materials International Space Station Experiment-2 (MISSE-2)

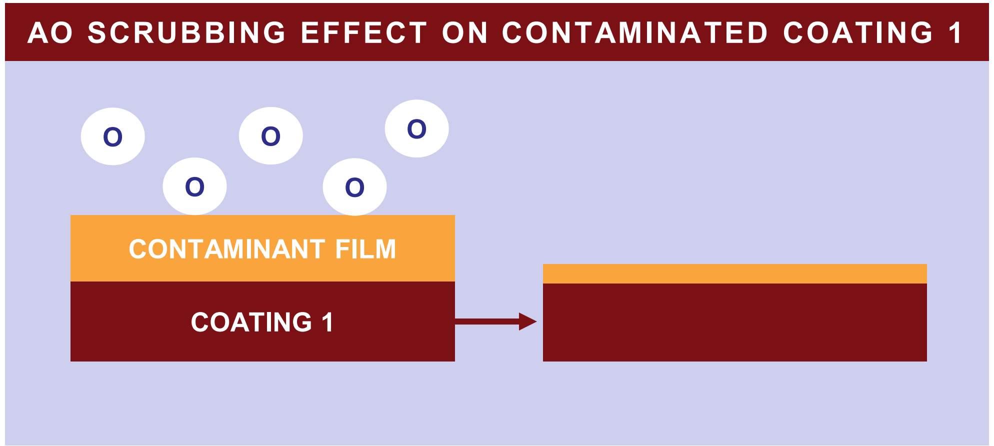
Polymer Erosion and Contamination Experiment (PEACE)

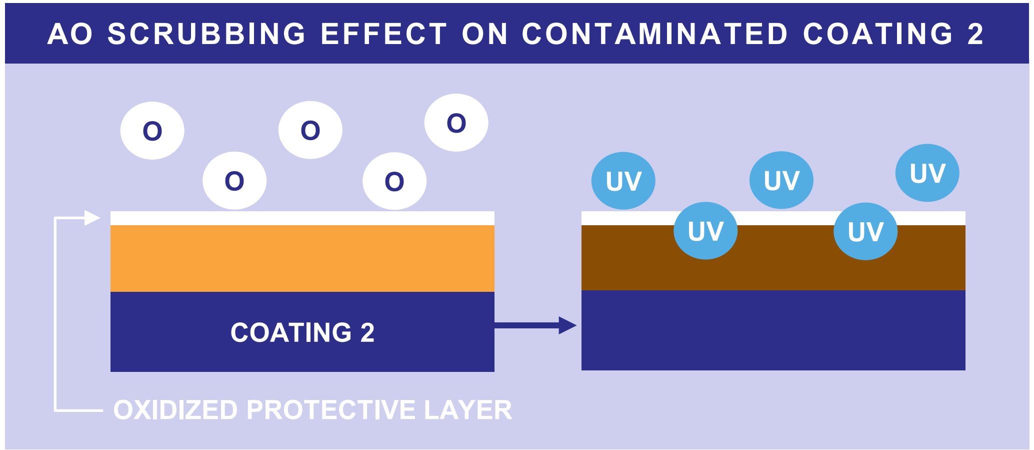
a.) before flight

b.) after four years of space exposure on the exterior of the International Space Station.

ATOMIC OXYGEN

- AO **"scrubbing"** effect or material erosion in the ram (forward) facing direction may reduce the damage caused by organic contamination effects on some coating surfaces; however, it may also worsen the darkening effects when combined with UV radiation on other coatings
  - e.g., Silicone-based systems may **oxidize** and form an **outer protective layer** that inhibits the removal of the contaminant, which will then continue to degrade in UV

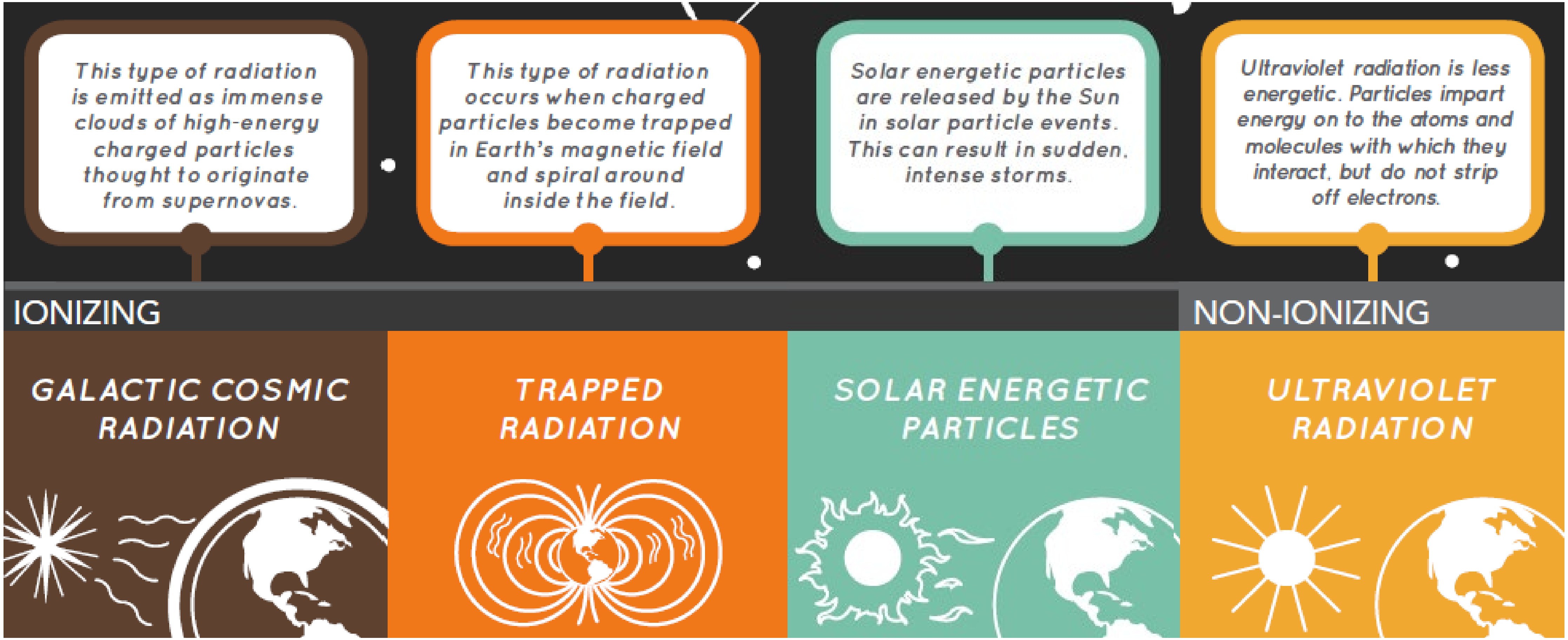




SPACE RADIATION

SOURCE: HTTPS://WWW.NASA.GOV/SITES/DEFAULT/FILES/NP-2014-03-001-JSC-ORION_RADIATION_HANDOUT.PDF

IMAGE CREDIT: NASA



This type of radiation is emitted as immense clouds of high-energy charged particles thought to originate from supernovas.

This type of radiation occurs when charged particles become trapped in Earth's magnetic field and spiral around inside the field.

Solar energetic particles are released by the Sun in solar particle events. This can result in sudden, intense storms.

Ultraviolet radiation is less energetic. Particles impart energy on to the atoms and molecules with which they interact, but do not strip off electrons.

IONIZING

NON-IONIZING

GALACTIC COSMIC RADIATION

TRAPPED RADIATION

SOLAR ENERGETIC PARTICLES

ULTRAVIOLET RADIATION

Combined interactions with all forms of space radiation at varying fluence and energy doses influence the degradation that occurs on thermal control surfaces

ULTRAVIOLET RADIATION

- Thermal coatings are susceptible to damage (i.e., darkening) due to UV, **non-ionizing (low energy)** radiation from the sun
- UV damage is expected at most orbits in varying fluence amounts (e.g., more UV is present in LEO due to the Earth's Albedo effects)
- **Surface orientation** and spacecraft design also determine the amount of UV degradation that occurs
  - *Is the coated surface ram or wake facing?*
  - *Is the coated surface always sun facing?*
  - *If not, for how long through mission life?*
  - *What are the* ***Equivalent Solar Hours*** *(ESH)?*

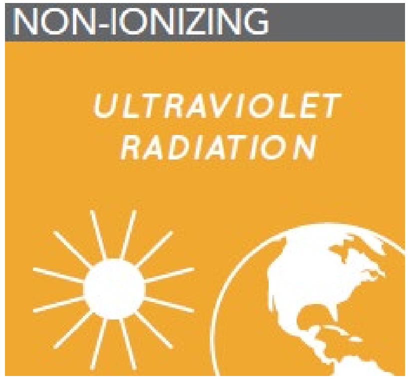


IMAGE CREDIT: NASA

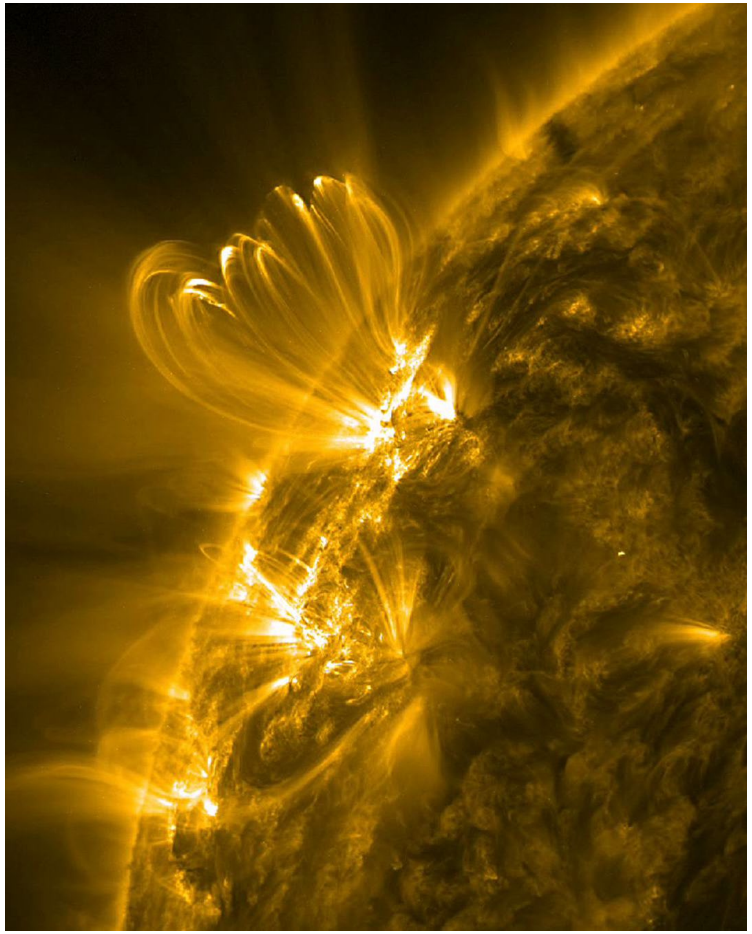


IMAGE CREDIT: NASA

CHARGED PARTICLES

- Thermal coatings are susceptible to damage (i.e., darkening) due to CP, **ionizing (high energy) radiation** (e.g., protons & electrons)

SOURCE: HTTPS://WWW.NASA.GOV/SITES/DEFAULT/FILES/NP-2014-03-001-JSC-ORION_RADIATION_HANDOUT.PDF

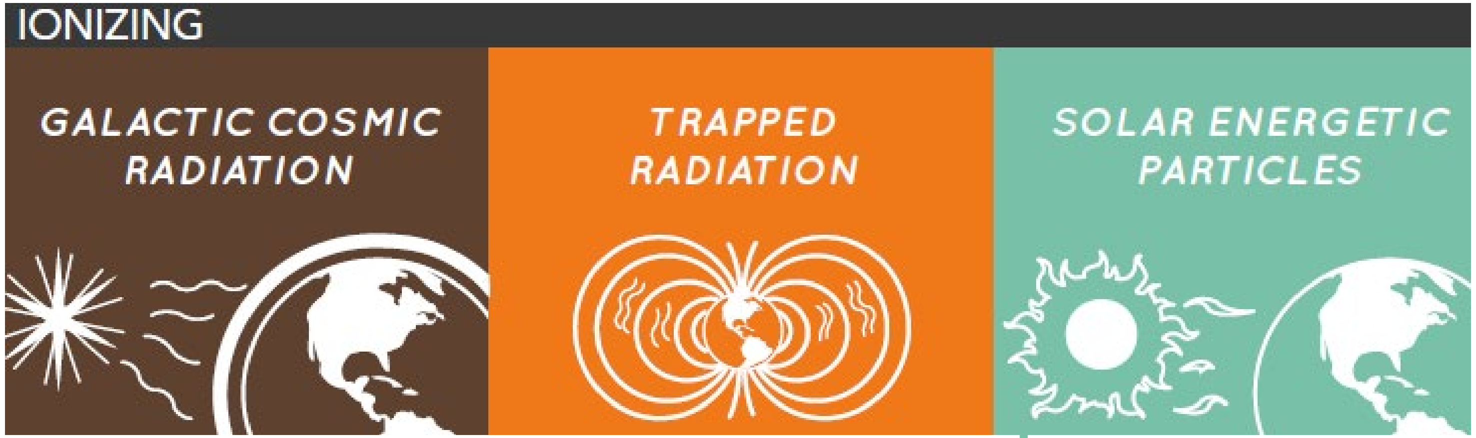


IMAGE CREDIT: NASA

- From solar flares (solar wind plasma)

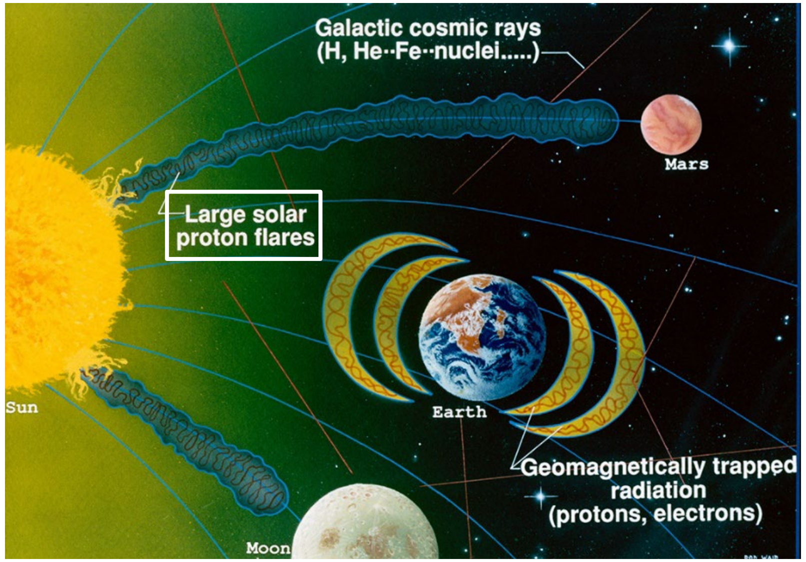
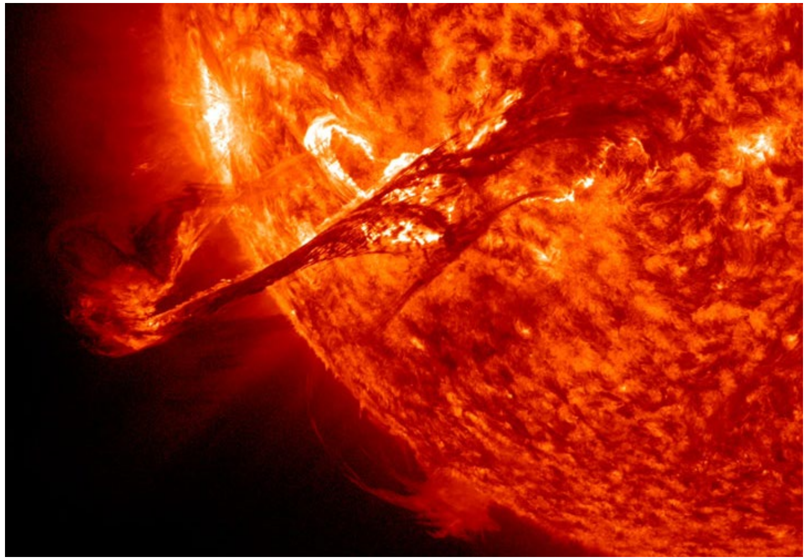


IMAGE CREDIT: NASA



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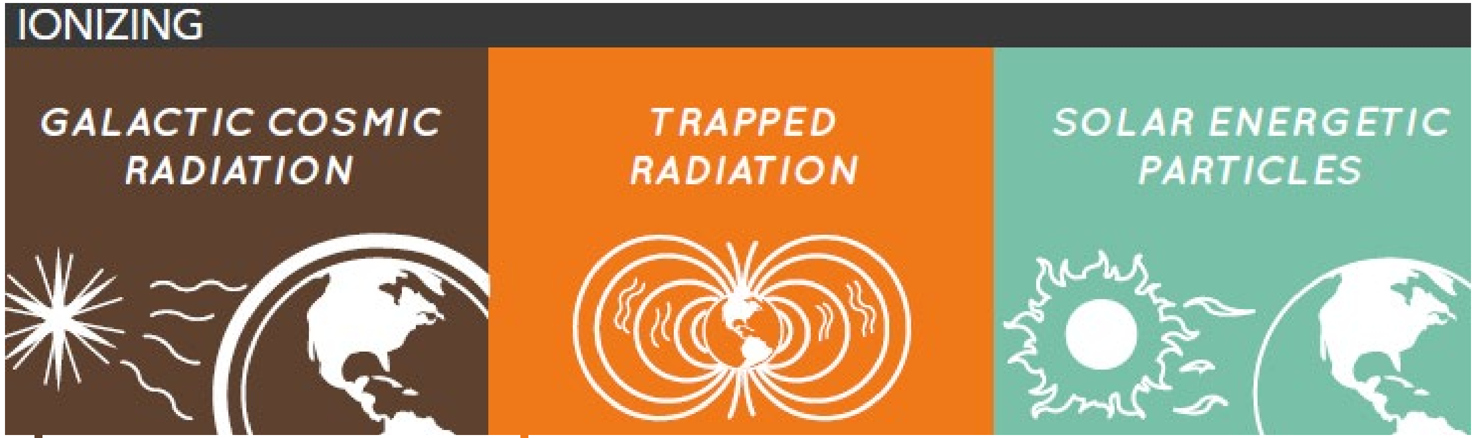


IMAGE CREDIT: NASA

- From outside our solar system

- From Earth’s magnetic field
- Van Allen Belts
- More expected at polar horns

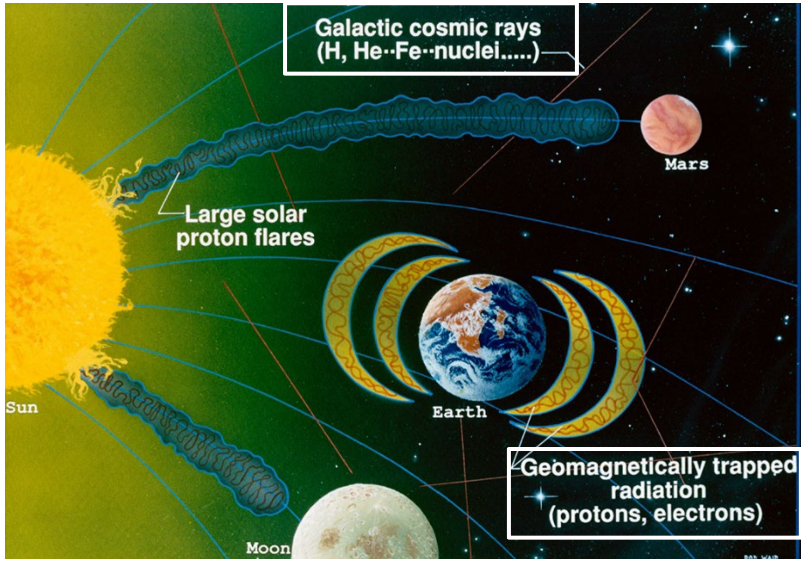


IMAGE CREDIT: NASA

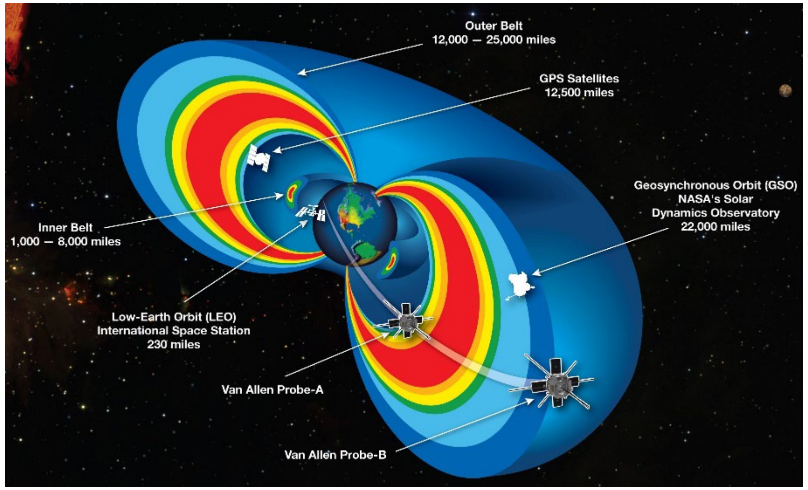


IMAGE CREDIT: NASA

ORBIT: ALTITUDE & CONDITIONS

ORBIT	ALTITUDE	AO	UV	CP	FLUENCE NOTES
Low Earth Orbit (LEO)	< 2000 km	X	X	X	• AO low to high • UV moderate to high • CP low
Medium Earth Orbit (MEO)	> 2000 km to 35,780 km		X	X	• UV (varies, orientation) • CP very high
Geosynchronous Orbit (GEO)	35,780 km		X	X	• UV (varies, orientation) • CP high
Lagrange Points (L1, L2)	1.5 million km		X	X	• UV (varies, orientation) • CP low to moderate
Lunar	384,400 km		X	X	• UV (varies, orientation) • CP low to moderate

ORBIT SPECIFICS

- **Polar**
- **Sun-Synchronous**
- **Elliptical**
- **Near-rectilinear Halo**

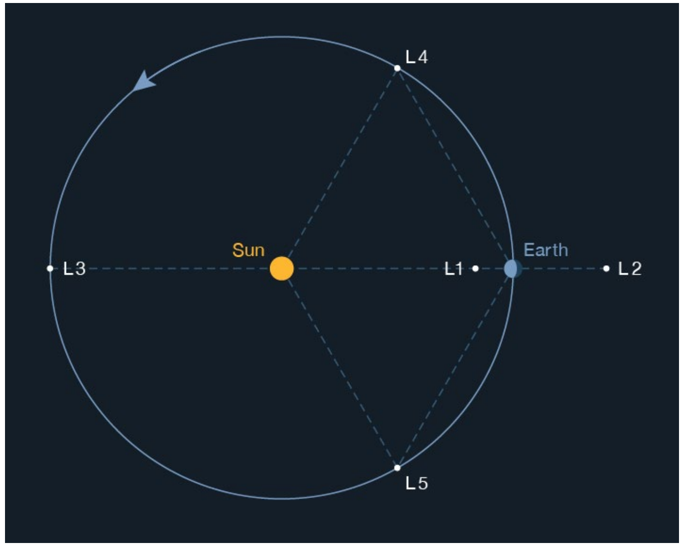


IMAGE CREDIT: NASA

ORBIT: DURATION

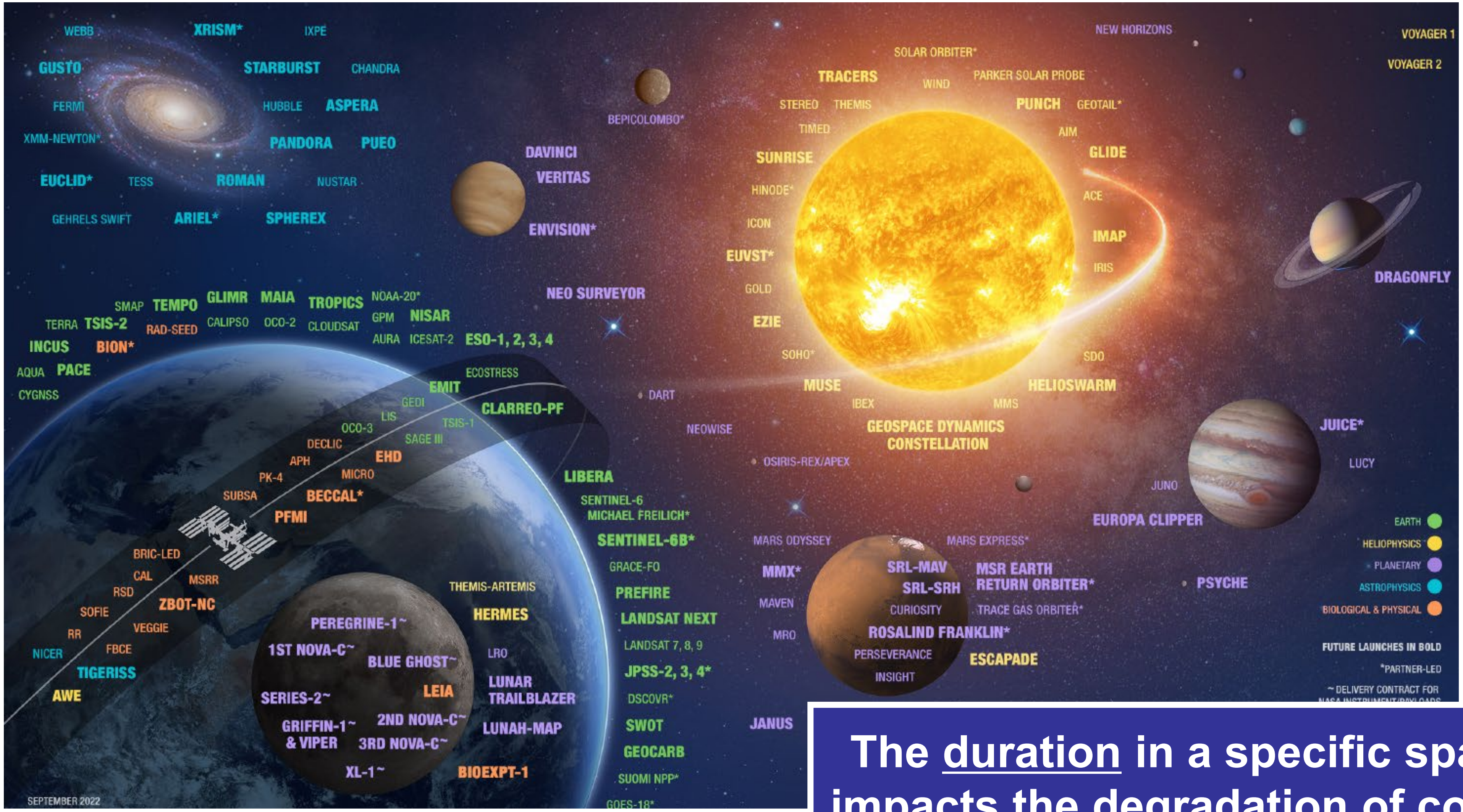


IMAGE CREDIT: NASA

It is important to consider how long the coating will be exposed during the:

CRUISE PHASE

(i.e., journey to the destination)

SCIENCE OPERATIONS PHASE

(i.e., at the mission orbit or environment)

↑

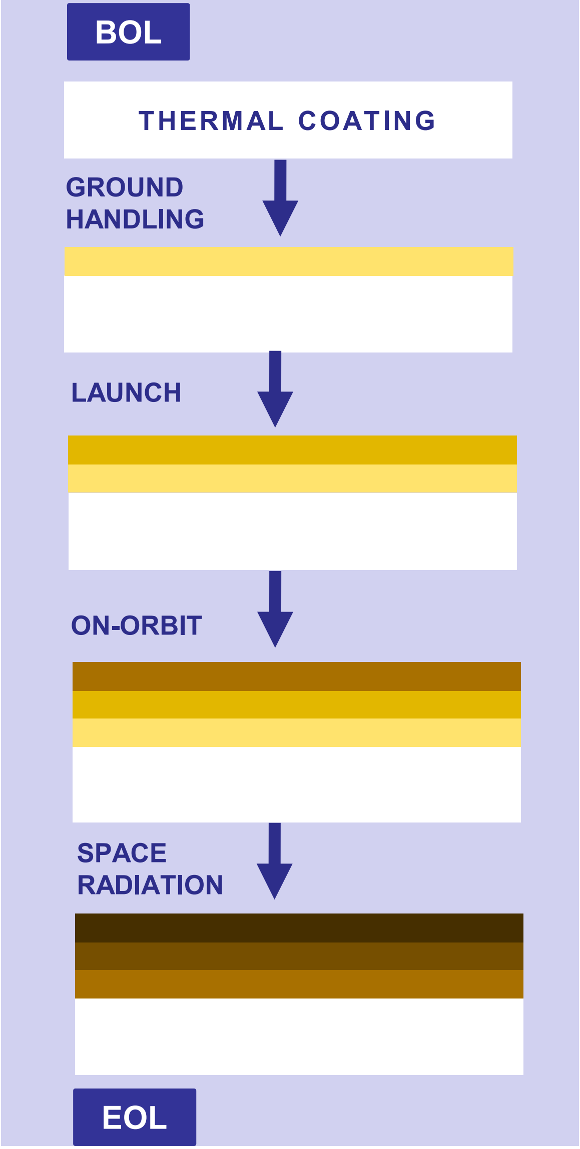
The duration in a specific space environment impacts the degradation of coatings properties

INDUCED ENVIRONMENT COATINGS DEGRADATION FACTORS

CONTAMINATION & APPLICATION

CONTAMINATION

- **Molecular contamination** that directly deposits on thermal coatings may change **solar absorptance** (e.g., thin film interference on mirrors, on low solar absorptance coatings and specular surfaces)
- This may occur from **ground handling** during Integration and Testing (I&T) activities (e.g., contamination/damage on high wear & tear surfaces, especially near cable bundles), from **launch** conditions, and during **on-orbit** operations (e.g., outgassed materials)
- Furthermore, the deposited thin film contaminant layers are susceptible to **darkening** due to <u>photochemical polymerization</u> and <u>synergistic interactions</u> with solar UV radiation in the space environment



CONTAMINATION

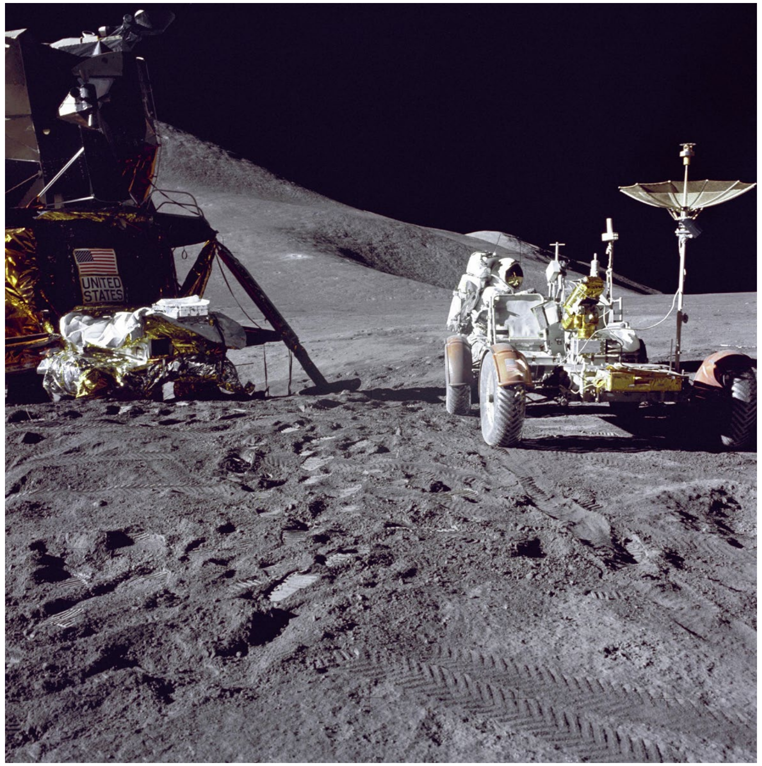


IMAGE CREDIT: NASA

- Transport analysis modeling and contamination control budgets drive the BOL and EOL molecular contamination requirements on a mission
- Molecular contaminants on **low emittance** thermal surfaces (e.g., polished metals) are also impacted
- **Particle contamination** (e.g., debris, dust) that occurs from the induced environments of ground handling or launch activities typically has less of an impact on coatings properties when the Percent Area Coverage (PAC) is < 1 to 2 %
- However, particle contamination that occurs from the natural space environment during on-orbit conditions may have a significant impact to solar absorptance and emittance properties (e.g., **lunar dust transport** to thermal coating surfaces on lunar landers or on berthing events on Gateway)

CONTAMINATION

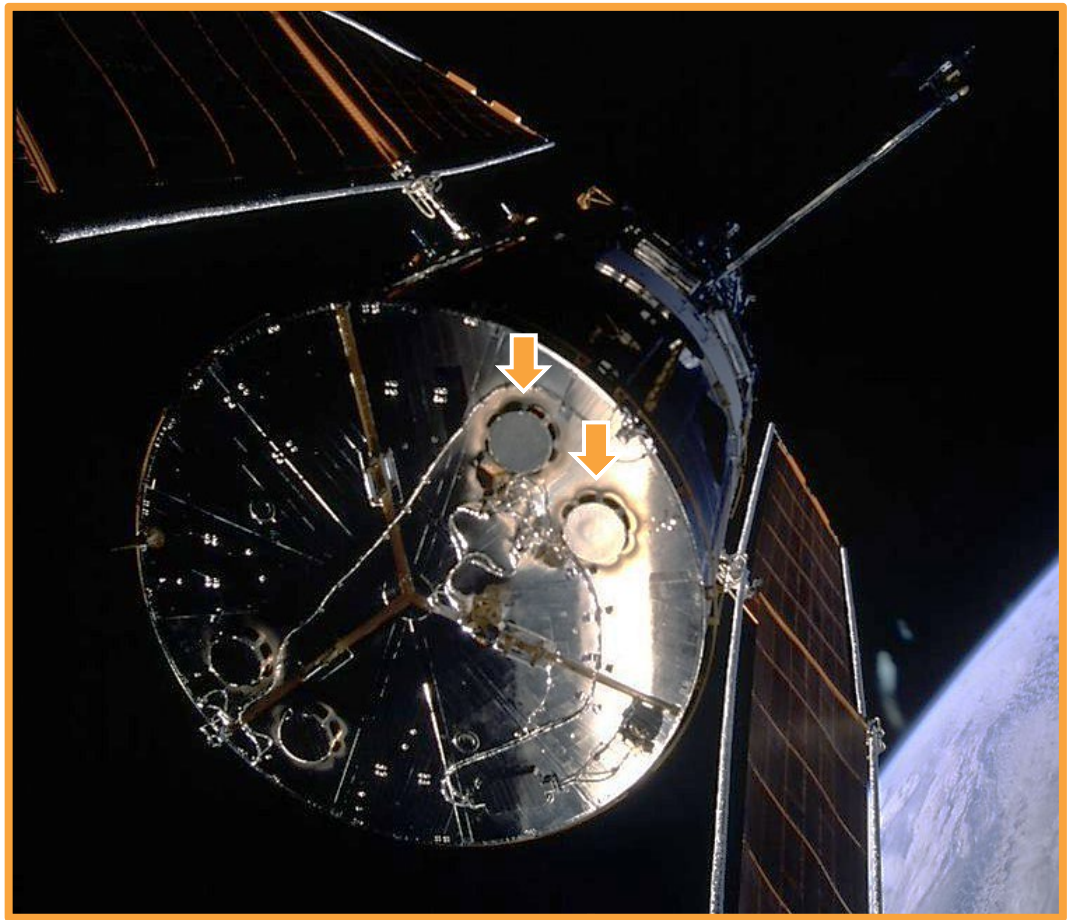


IMAGE CREDIT: NASA

Silver Teflon tape near aft vents on the Hubble Space Telescope (HST)

Various thermal control surfaces on the Pressurized Mating Adaptor (PMA) connected to the Russian Zarya vehicle on the International Space Station (ISS)

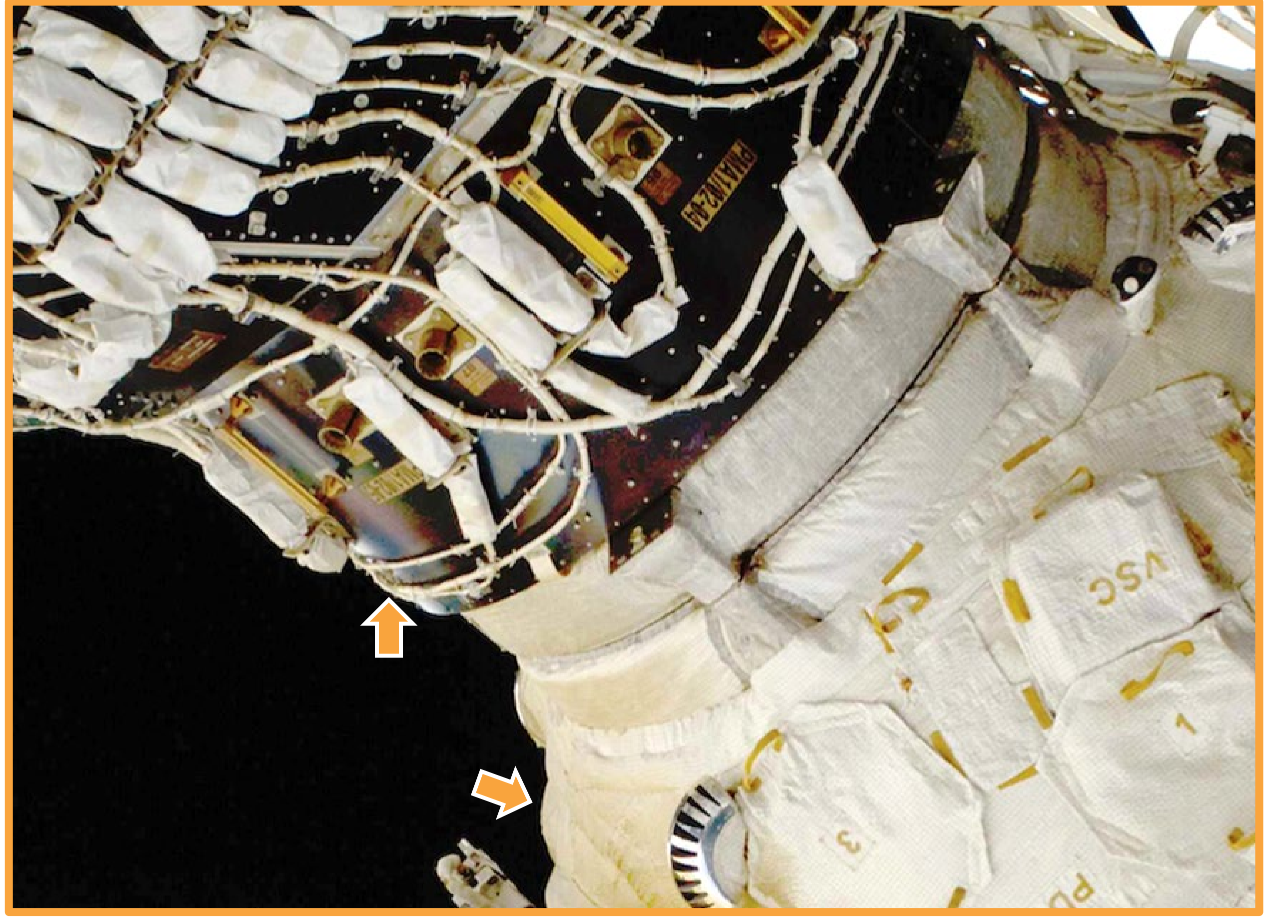


IMAGE CREDIT: NASA

CONTAMINATION

- The GSFC Coatings Committee requests input from the project's **Contamination Control Engineers** (CCE) on the BOL and EOL molecular contamination requirements for the mission, specifically the expected cleanliness **Non-Volatile Residue (NVR)** levels on all critical thermal control surfaces

- A conservative approach is used to **estimate** solar absorptance degradation based on the EOL accumulation of contamination film thickness assuming the density of the unknown mixture of contaminants is ~ 1 g/cm^3

Former IEST-STD-CC1246* NVR Level	Maximum Allowable NVR Limit Mass (μg/cm^2)	Estimated Contamination Thickness (Å)	Estimated Solar Absorptance Degradation ($\Delta\alpha_S$)
A/10	0.1	10	0.001
A/2	0.5	50	0.005
A	1	100	0.01
B	2	200	0.02
C	3	300	0.03
D	4	400	0.04
E	5	500	0.05
F	7	700	0.07
G	10	1000	0.10
H	15	1500	0.15
J	25	2500	0.25

* **IEST-STD-CC1246** is a standard for product cleanliness levels: applications, requirements, and determination for contamination critical products

INSTITUTE OF ENVIRONMENTAL SCIENCES AND TECHNOLOGY (IEST)

APPLICATION

- Application parameters may influence the BOL and EOL coatings properties due to manufacturer/applicator experience, complexity of the hardware, and/or process variability and controls
- Thermal control surfaces that are the most impacted by this include but are not limited to:
  - **Chemical Conversion Coatings** (i.e., Chem Film, Chromate Coating)
  - **Anodic Coatings**
  - **Silver Teflon Tapes** (Ag/FEP)

CHEMICAL CONVERSION COATINGS

- e.g., Iridite, Alodine
- Gel-like coatings that are relatively soft and may degrade in vacuum
- Formed by a chemical reaction with the aluminum or aluminum alloy surface
- Military Specification(s): MIL-DTL-81706 and/or MIL-DTL-5541

ANODIC COATINGS

- e.g., Anodize
- Hard, ceramic coatings that are relatively durable and stable in vacuum
- Formed by an electrolytic reaction with the aluminum or aluminum alloy surface
- Military Specification(s): MIL-A-8625

APPLICATION: CHEM FILMS & ANODIC COATINGS

- Thermal/optical properties of chemical conversion coatings (i.e., chem films) and anodic coatings are **highly variable** and **widespread** due to application process variability and controls
- BOL and EOL values are enveloped within a **broad range** based on the widespread measurement data available; however, this may impact thermal design performance
- This range can be **further refined** with specifics about the application, and measurements on representative samples and if possible, directly on the flight hardware itself (however, this is not always an option)
- Chem films and anodic coatings on internal surfaces are not expected to degrade; however, those on external surfaces may degrade in the space environment (limited data exists)

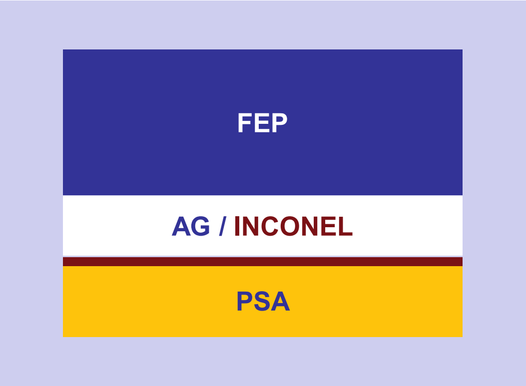
APPLICATION: CHEM FILMS & ANODIC COATINGS

FACTORS THAT INFLUENCE VARIABILITY OF CHEM FILM & ANODIC COATINGS PROPERTIES

- **Manufacturer** (e.g., vendor / applicator experience)
- **Application Technique** (e.g., brush, spray, bath immersion, pen)
- **Aluminum Substrate** (e.g., temper, alloy, form)
- **Coating Thickness** (e.g., difficult to control)
- **Surface Finish** (e.g., polished, machined)
- **Surface Prep** (e.g., sanded, grit blasted, etched)
- **Surface Cleanliness** (e.g., residue)
- **Specification** (e.g., procedures may be free for interpretation by applicator)
- **Classification** (e.g., type, class, dyes)
- **Bath Chemistry** (e.g., uniformity, current density, voltage)
- **Process Control & Workmanship** (e.g., repeatability, consistency)
- **Hardware Geometry** (e.g., complexity, pockets, flat)

APPLICATION: AG/FEP TAPES

- Silver Teflon (Ag/FEP) tapes are commonly used for its low solar absorptance and high emittance properties
- Silver is coated on one side of the Teflon as a second surface mirror; Inconel (or a protective overcoat layer) is typically applied to prevent the silver from oxidizing



- Improper application of Ag/FEP tapes may result in severe degradation of the thermal/optical properties due to **silver cracking**
- Note: This application-induced damage is not always evident right after application

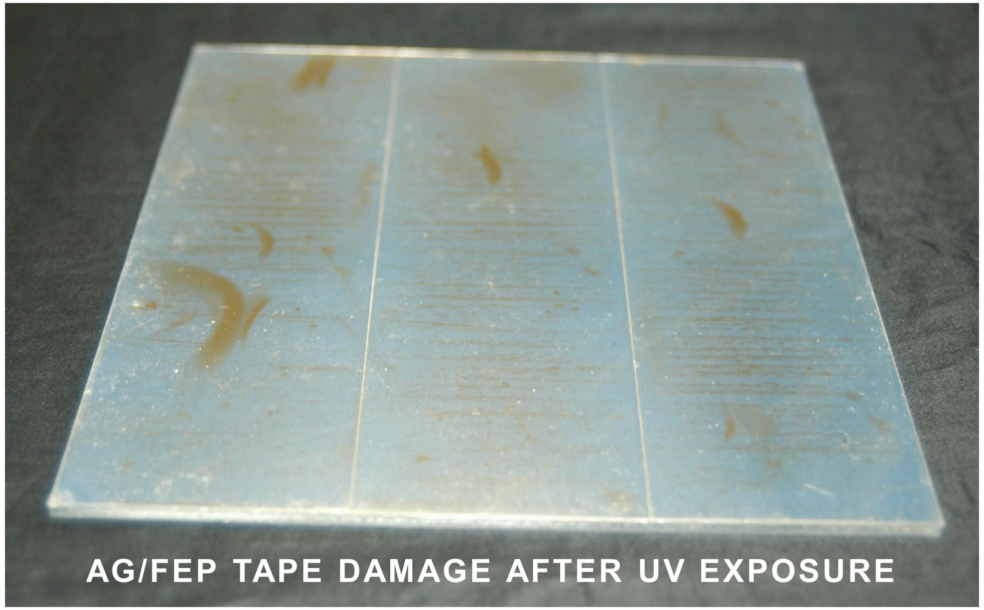

AG/FEP TAPE DAMAGE AFTER UV EXPOSURE

IMAGE CREDIT: NASA

APPLICATION: AG/FEP TAPES

Adhesion Intrusion

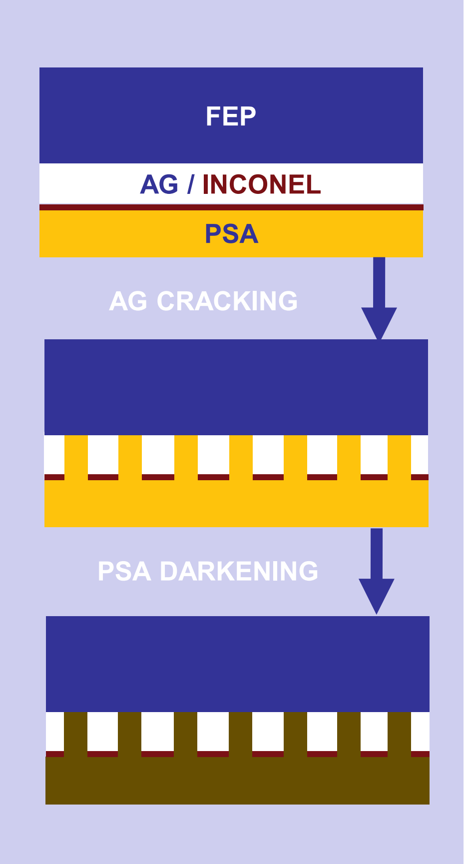
- The cracks at the Ag/Inconel interface layer create a path for the Pressure Sensitive Adhesive (PSA) to leach through and later become susceptible to AO and space radiation effects on-orbit

i.e., Results in darkening and solar absorptance increases!

Silver Oxidation

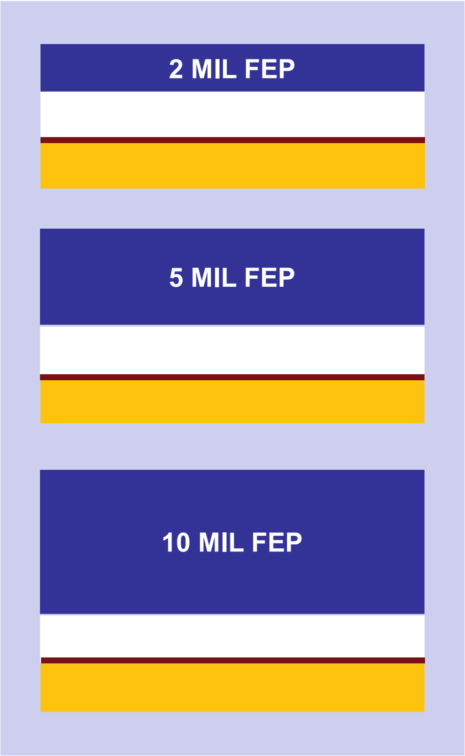
- The cracks can also allow for oxidation of the silver to occur with its compromised protective overcoat (e.g., tarnishing)

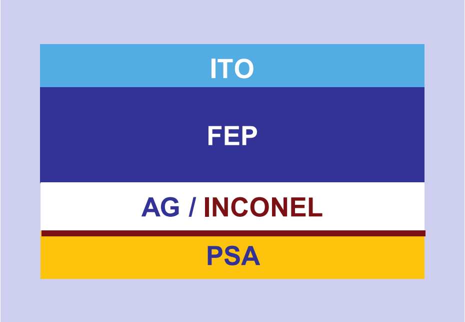
i.e., Results in darkening and solar absorptance increases!



APPLICATION: AG/FEP TAPES

- It is recommended for Ag/FEP tapes on **critical thermal surfaces** to be applied by experienced personnel to limit damage that may occur during the application process
- The risk may be reduced with special application techniques (e.g., limit bends, folds, etc..) and with the thickness of tape used for specific hardware geometries (e.g., 2, 5, vs 10 mils)
- Ag/FEP tapes with an **Indium Tin Oxide** (ITO) topcoat to meet electrical conductivity requirements may offer some added protection against AO (assuming it is intact, as well, after application and ground handling during I&T)
- The addition of ITO and perforation patterns with conductive PSA may have a slight impact on solar absorptance, as well





COATINGS PROPERTY DATA

GROUND & FLIGHT TEST DATA, INSTRUMENT MEASUREMENT UNCERTAINTY, EMITTANCE CONVERSION, & OTHER FACTORS

MEASUREMENT TEST DATA

- The GSFC Coatings Committee reviews all currently available measurement data and considers the known interactions with the environment in its most **conservative case** to establish the BOL and EOL coatings property values
- Additional measurements, environmental testing, and other research and development efforts may be requested, especially for newer coatings, or on coatings with limited test data
- A **larger statistical sampling** is used, when available (e.g., establishing an average, standard deviation, minimum and maximum ranges vs. a single measurement on one sample)
- Variability and uncertainties associated with measurements are considered
- An **additive methodology** is implemented to sum the degradation components for the total expected thermal/optical property change

MEASUREMENT TEST DATA

- Data from **on-orbit observations** on missions and flight experiments

THIS WILL BE USED AS THE PRINCIPAL DATA WHEN AVAILABLE. HOWEVER, IT IS OFTEN LIMITED, ESPECIALLY FOR NEWER COATINGS.

- Ground simulated environmental test data using an accelerated source (e.g., solar wind; proton and electron exposure at similar fluences or that match dose depth profiles, UV and vacuum UV, AO, thermal cycling)
- Calorimetric test data (e.g., temperature, thickness)
- As received sample measurements (e.g., on test coupons, on representative surfaces, and directly on flight hardware; in air and vacuum, if available)
- Historic Coatings Committee approved values on past missions
- Manufacturer supplied product values from technical data sheets

ITERATIVE PROCESS → Any new measurement test data will be considered

INSTRUMENT MEASUREMENT UNCERTAINTY

MEASUREMENT INSTRUMENTS
NORMAL EMITTANCE
• **Gier Dunkle DB-100** Infrared Reflectometer (5-40 microns)
• **Surface Optics SOC-100 HDR** Hemispherical Directional Reflectometer (2-100 microns)
SOLAR ABSORPTANCE
• **Agilent Cary 5000** UV-Vis-NIR Spectrophotometer (250-2500 nm)
• **AZ Technology LPSR 300** Laboratory Portable Spectro-reflectometer (250-2800 nm)
• **Perkin Elmer Lambda 950** UV-Vis-NIR Spectrophotometer (250-2500 nm)

- There is **uncertainty** associated with <u>all measurements</u>
  - e.g., instrument accuracy/precision, user error, margin/interval and confidence level from ‘true’ value
- The GSFC Coatings Committee incorporates an **instrument measurement uncertainty** factor of ± 0.02 to the measured solar absorptance and emittance values
  - e.g., a measured value of 0.15 with the uncertainty factored in results in a range between 0.13 to 0.17

EMITTANCE CONVERSION

- Thermal design models require the **hemispherical** emittance (ε_H)
- **Normal** emittance (ε_N) is more commonly measured on thermal coating surfaces due to the relatively “quick & easy” nature of the measurement itself (e.g., using the DB-100)
- The emittance as a function of angle must be integrated over the entire hemisphere to obtain the total hemispherical emittance
- The ratio between hemispherical and normal emittance can be simplified to the following relationship:

$$\frac{\varepsilon_H}{\varepsilon_n} = \frac{\frac{1}{\pi}\int_0^{2\pi} \varepsilon(\beta,\theta,)\cos\beta \, d\omega}{\varepsilon(\beta,0,)}$$

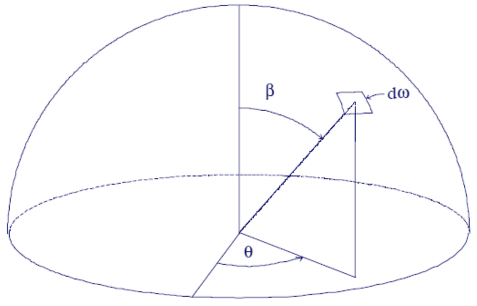


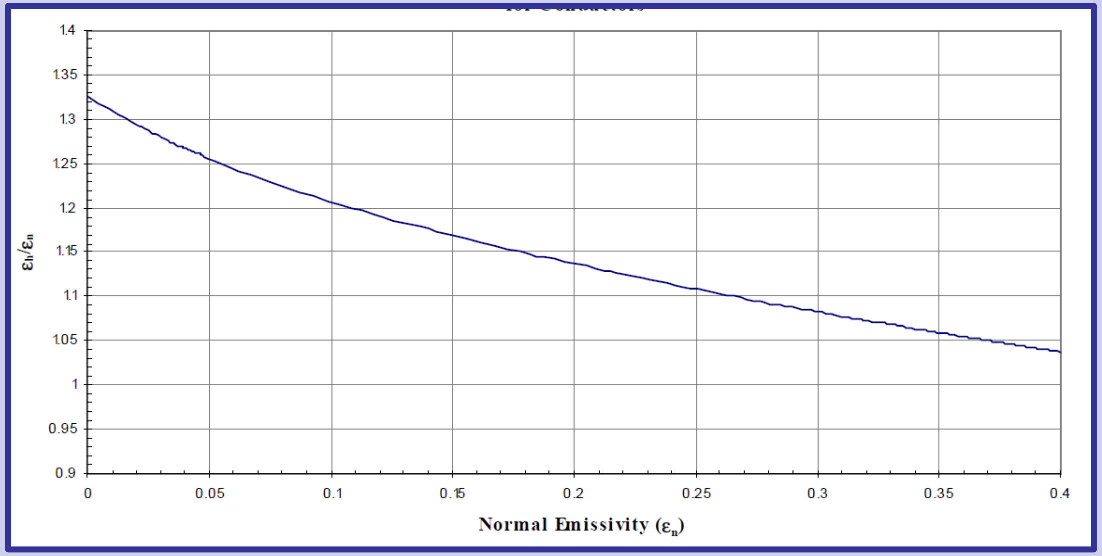
Figure 1.1-4. Hemispherical emittance coordinate system

KAUDER, LONNY, “SPACECRAFT THERMAL CONTROL COATING REFERENCES” NASA/TP-2005-212792

EMITTANCE CONVERSION

- The GSFC Coatings Committee uses a **Conversion Factor** (CF) to estimate the hemispherical emittance when the measurement data that are available are normal emittance values

RATIO OF HEMISPHERICAL TO NORMAL EMITTANCE FOR CONDUCTORS



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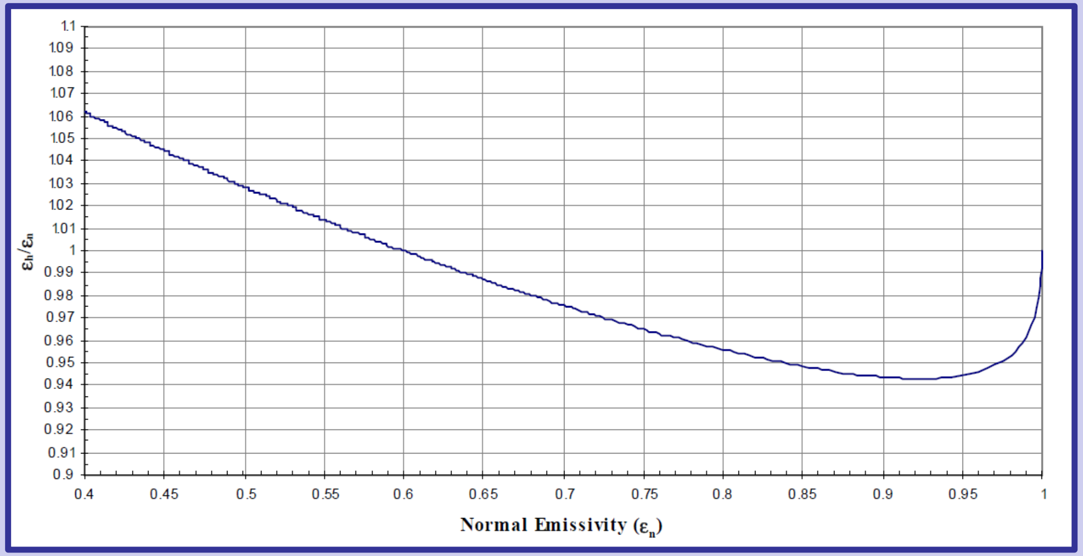
RATIO OF HEMISPHERICAL TO NORMAL EMITTANCE FOR INSULATORS



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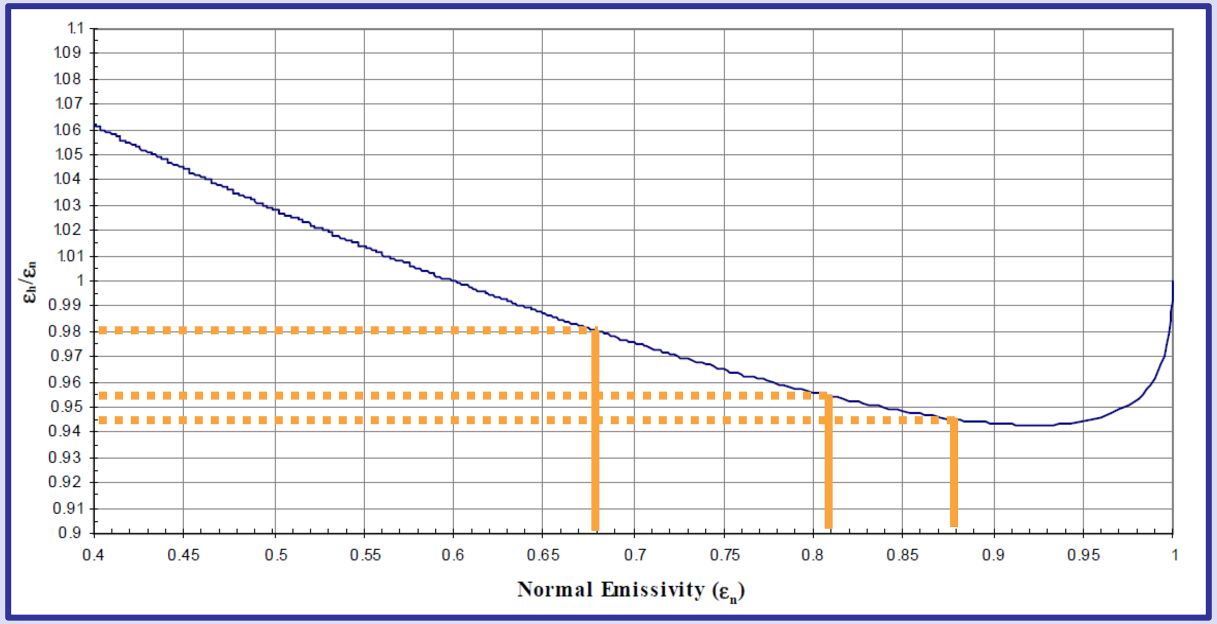
EMITTANCE CONVERSION

- Here is an example of how to convert a measured normal emittance to an estimated hemispherical emittance that will be used for BOL and EOL coatings property evaluation by the GSFC Coatings Committee (e.g., Ag/FEP)

AG/FEP TAPE THICKNESS	MEASURED NORMAL EMITTANCE	CONVERSION FACTOR	ESTIMATED HEMISPHERICAL EMITTANCE
2 mil	0.68	~ 0.98	~ 0.67
5 mil	0.81	~ 0.95	~ 0.77
10 mil	0.88	~ 0.95	~ 0.84

RATIO OF HEMISPHERICAL TO NORMAL EMITTANCE FOR INSULATORS



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TEMPERATURE & EMISSIVITY

- **Temperature** directly impacts the emittance properties of thermal coatings, specifically by decreasing at colder operating temperatures (e.g., for **cryogenic** applications) and **thickness** plays an important role in its performance, as well

- The emittance at a given temperature can be measured by a **calorimetric technique** in vacuum or approximated using the following equations based on the reflectance properties:

ρ, *Reflectance*
θ, *Angle of Incidence*
φ, *Circumferential Angle*
λ, *Wavelength*
h, *Planck's Constant*
c, *Speed of Light Constant*
k, *Stefan-Boltzman Constant*
T, *Temperature (K)*

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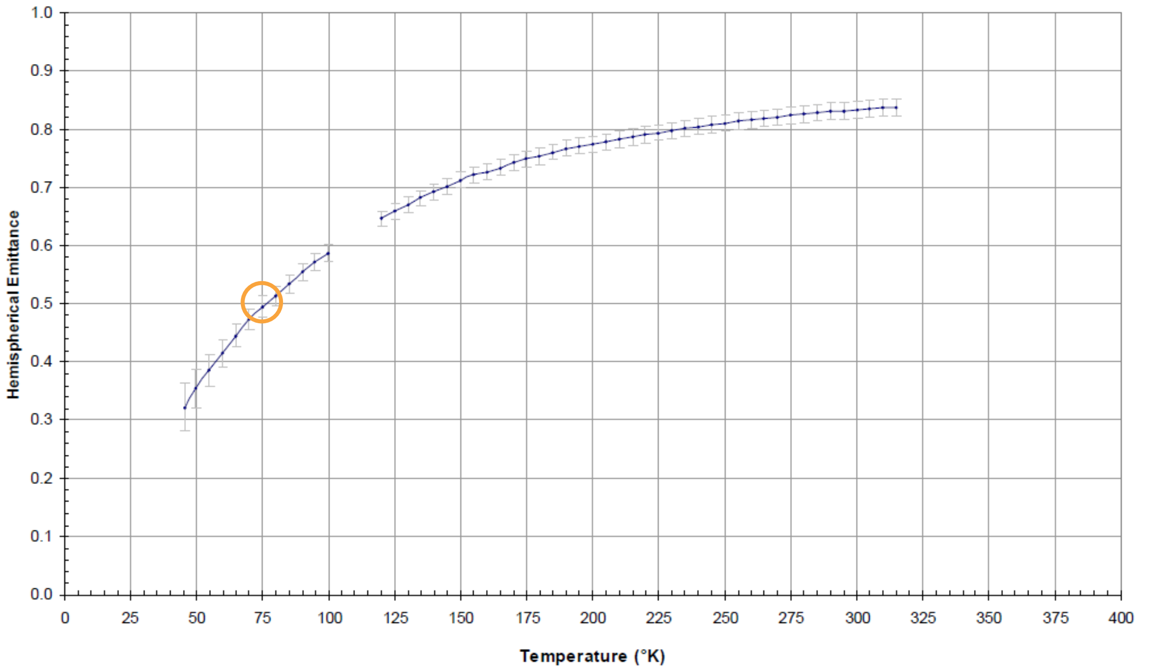
$$\varepsilon_t(\theta,\phi,\lambda) = 1 - \frac{\int_0^{\pi/2}\int_0^{\pi/2}\int_0^{\infty}\rho(\theta,\phi,\lambda)\frac{8\pi hc}{\lambda^5\left(e^{hc/\lambda Tk}-1\right)}\,d\lambda\, d\phi\, d\theta}{\int_0^{\infty}\frac{8\pi hc}{\lambda^5\left(e^{hc/\lambda Tk}-1\right)}}$$

$$\varepsilon_h = 2\int_0^{\pi/2}\varepsilon_t(\theta,\phi,\lambda)\sin(\theta)\cos(\theta)\,d\theta$$

TEMPERATURE & EMISSIVITY

Z306 (1.1 mils)

BLACK POLYURETHANE-BASED THERMAL COATING



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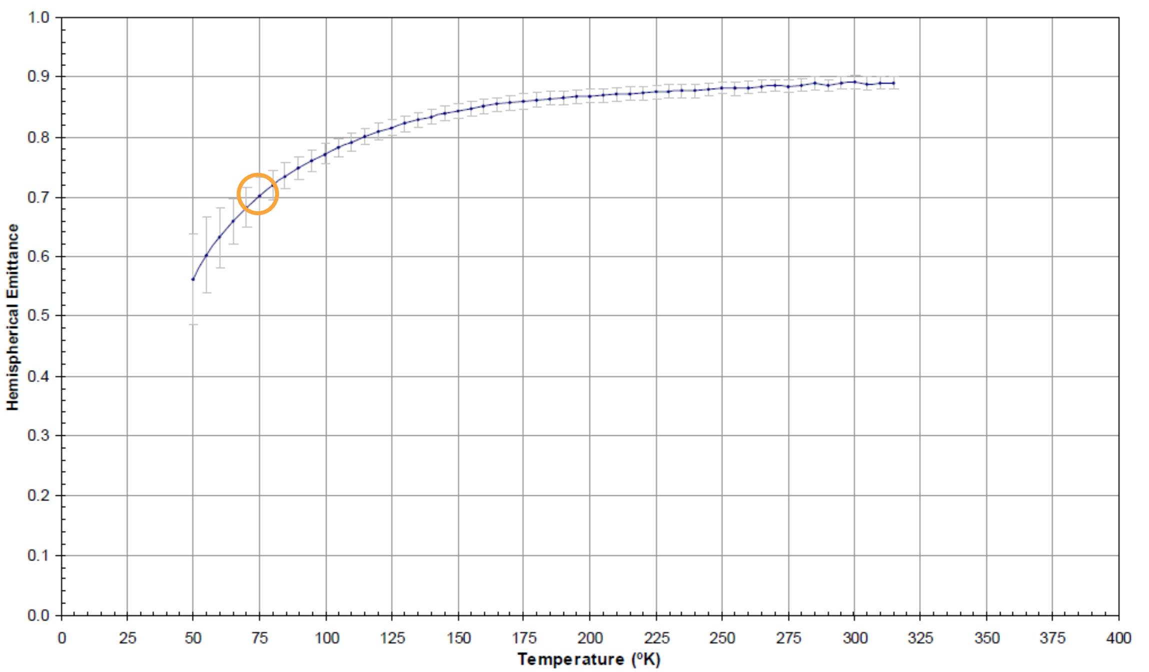
Z306 (1.5 mils)

BLACK POLYURETHANE-BASED THERMAL COATING



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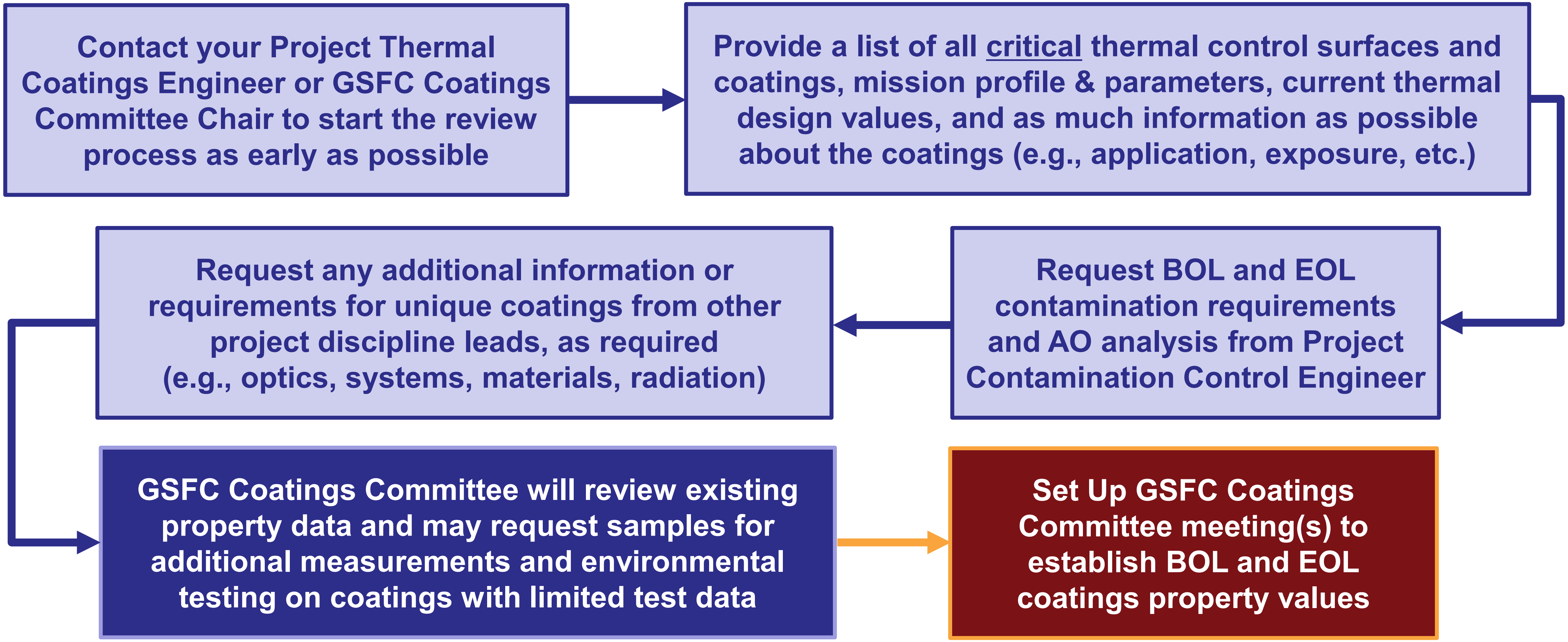
OTHER FACTORS

- Lastly, there are a few other factors that may impact coatings properties that the GSFC Coatings Committee takes into account during the review process
  - Hardware complexity (e.g., coating thickness)
  - Impact of coating dehydration in vacuum conditions
  - Additive layers and features (e.g., ITO, perforations)
  - Surface location (e.g., internal vs external)

GSFC COATINGS COMMITTEE PROCESS & EXAMPLES

PROCESS PREP

NASA Life Cycle **PHASE**	<A	A	B	C	D	E	F
	CONCEPT STUDIES	CONCEPT AND TECHNOLOGY DEVELOPMENT	PRELIMINARY DESIGN AND TECHNOLOGY COMPLETION	FINAL DESIGN AND FABRICATION	SYSTEM ASSEMBLY, INTEGRATION & TEST, LAUNCH & CHECKOUT	OPERATIONS AND SUSTAINMENT	CLOSE OUT



Contact your Project Thermal Coatings Engineer or GSFC Coatings Committee Chair to start the review process as early as possible

Provide a list of all <u>critical</u> thermal control surfaces and coatings, mission profile & parameters, current thermal design values, and as much information as possible about the coatings (e.g., application, exposure, etc.)

Request BOL and EOL contamination requirements and AO analysis from Project Contamination Control Engineer

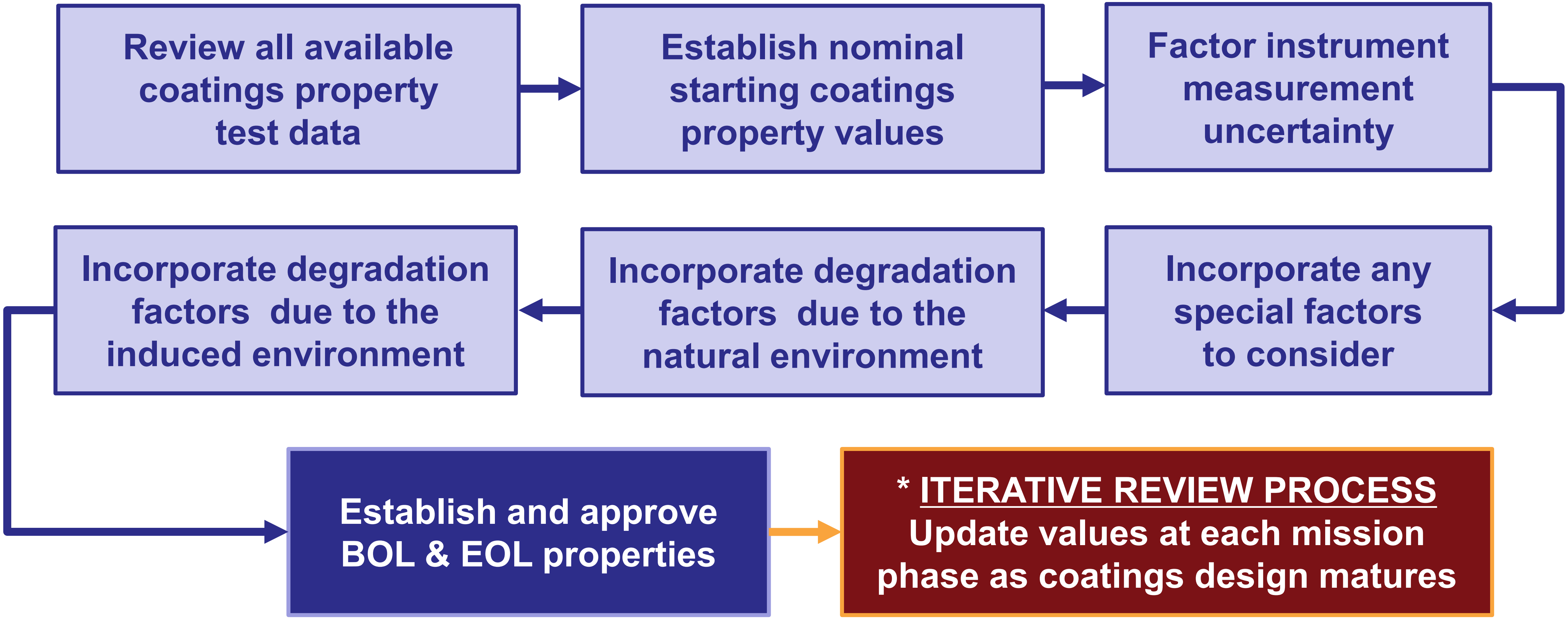
Request any additional information or requirements for unique coatings from other project discipline leads, as required (e.g., optics, systems, materials, radiation)

GSFC Coatings Committee will review existing property data and may request samples for additional measurements and environmental testing on coatings with limited test data

Set Up GSFC Coatings Committee meeting(s) to establish BOL and EOL coatings property values

PROCESS OVERVIEW

NASA Life Cycle **PHASE**	<A	A	B	C	D	E	F
	CONCEPT STUDIES	CONCEPT AND TECHNOLOGY DEVELOPMENT	PRELIMINARY DESIGN AND TECHNOLOGY COMPLETION	FINAL DESIGN AND FABRICATION	SYSTEM ASSEMBLY, INTEGRATION & TEST, LAUNCH & CHECKOUT	OPERATIONS AND SUSTAINMENT	CLOSE OUT



Review all available coatings property test data

Establish nominal starting coatings property values

Factor instrument measurement uncertainty

Incorporate any special factors to consider

Incorporate degradation factors due to the natural environment

Incorporate degradation factors due to the induced environment

Establish and approve BOL & EOL properties

*** <u>ITERATIVE REVIEW PROCESS</u>**
Update values at each mission phase as coatings design matures

EXAMPLE: SILVER TEFLON (APPLICATION)

		Ag/FEP Tape (5 mil, ITO, Perforated) in LEO applied by Company X				Ag/FEP Tape (5 mil) in LEO applied by Company Y			
		SOLAR ABSORPTANCE		HEMISPHERICAL EMITTANCE		SOLAR ABSORPTANCE		HEMISPHERICAL EMITTANCE	
		COLD CASE	HOT CASE	COLD CASE	HOT CASE	COLD CASE	HOT CASE	COLD CASE	HOT CASE
SURFACE LOCATION: EXTERNAL		αS BOL	αS EOL	εH BOL	εH EOL	αS BOL	αS EOL	εH BOL	εH EOL
NOMINAL MEASURED VALUE		0.08	0.08	0.80 x 0.95 CF	0.80 x 0.95 CF	0.08	0.08	0.80 x 0.95 CF	0.80 x 0.95 CF
STARTING THERMAL DESIGN VALUE		0.08	0.08	0.76	0.76	0.08	0.08	0.76	0.76
MEASUREMENT UNCERTAINTY		----	+ 0.02	+ 0.02	- 0.02	----	+ 0.02	+ 0.02	- 0.02
OTHER FACTORS	ITO	----	+ 0.01	----	----	----	+ 0.01	----	----
	PERFORATIONS	----	+ 0.01	----	----	----	+ 0.01	----	----
DEGRADATION DUE TO NATURAL ENVIRONMENT	ATOMIC OXYGEN	----	+ 0.02	----	----	----	+ 0.02	----	----
	ULTRAVIOLET	----	+ 0.01	----	----	----	+ 0.01	----	----
	CHARGED PARTICLES	----	+ 0.01	----	----	----	+ 0.01	----	----
DEGRADATION DUE TO INDUCED ENVIRONMENT	CONTAMINATION	----	+ 0.03	----	----	----	+ 0.03	----	----
	APPLICATION	----	+ 0.01	----	----	----	+ 0.20	----	----
	UNCERTAINTY	----	----	----	----	----	----	----	----
FINAL THERMAL DESIGN VALUE		**0.08**	**0.20**	**0.78**	**0.74**	**0.08**	**0.39**	**0.78**	**0.74**

!!! NOTE !!! **The BOL & EOL thermal/optical properties shown here are NOT APPROVED by the GSFC Coatings Committee for any specific NASA mission. The exercise is solely meant to be used as an example for this technical course only. Please DO NOT use the values shown here in your thermal design. Please consult with the Project Coatings Engineer.**

EXAMPLE: WHITE RADIATOR COATING (TYPE)

		White Silicate-Based Thermal Coating in LEO at 400 km in ram direction				White Silicone-Based Thermal Coating in LEO at 400 km in ram direction			
		SOLAR ABSORPTANCE		HEMISPHERICAL EMITTANCE		SOLAR ABSORPTANCE		HEMISPHERICAL EMITTANCE	
		COLD CASE	HOT CASE	COLD CASE	HOT CASE	COLD CASE	HOT CASE	COLD CASE	HOT CASE
SURFACE LOCATION: EXTERNAL		α_S BOL	α_S EOL	ε_H BOL	ε_H EOL	α_S BOL	α_S EOL	ε_H BOL	ε_H EOL
NOMINAL MEASURED VALUE		0.16	0.16	0.92 x 0.95 CF	0.92 x 0.95 CF	0.20	0.20	0.90 x 0.95 CF	0.90 x 0.95 CF
STARTING THERMAL DESIGN VALUE		0.16	0.16	0.87	0.87	0.20	0.20	0.86	0.86
MEASUREMENT UNCERTAINTY		- 0.02	+ 0.02	+ 0.02	- 0.02	- 0.02	+ 0.02	+ 0.02	- 0.02
OTHER FACTORS	THICKNESS VARIATIONS	----	+ 0.01	----	----	----	----	----	----
	----	----	----	----	----	----	----	----	----
DEGRADATION DUE TO NATURAL ENVIRONMENT	ATOMIC OXYGEN	----	----	----	----	----	+ 0.11	----	----
	ULTRAVIOLET	----	+ 0.04	----	----	----	+ 0.04	----	----
	CHARGED PARTICLES	----	----	----	----	----	----	----	----
DEGRADATION DUE TO INDUCED ENVIRONMENT	CONTAMINATION	----	+ 0.03	----	----	----	+ 0.03	----	----
	APPLICATION	----	----	----	----	----	----	----	----
	UNCERTAINTY	----	----	----	----	----	----	----	----
FINAL THERMAL DESIGN VALUE		**0.14**	**0.26**	**0.89**	**0.85**	**0.18**	**0.40**	**0.88**	**0.84**

!!! NOTE !!! The BOL & EOL thermal/optical properties shown here are NOT APPROVED by the GSFC Coatings Committee for any specific NASA mission. The exercise is solely meant to be used as an example for this technical course only. Please DO NOT use the values shown here in your thermal design. Please consult with the Project Coatings Engineer.

EXAMPLE: WHITE RADIATOR COATING (ORBIT)

		White Silicate-Based Thermal Coating in LEO				White Silicate-Based Thermal Coating in L2			
		SOLAR ABSORPTANCE		HEMISPHERICAL EMITTANCE		SOLAR ABSORPTANCE		HEMISPHERICAL EMITTANCE	
		COLD CASE	HOT CASE	COLD CASE	HOT CASE	COLD CASE	HOT CASE	COLD CASE	HOT CASE
SURFACE LOCATION: EXTERNAL		αS BOL	αS EOL	εH BOL	εH EOL	αS BOL	αS EOL	εH BOL	εH EOL
NOMINAL MEASURED VALUE		0.16	0.16	0.92 x 0.95 CF	0.92 x 0.95 CF	0.16	0.16	0.92 x 0.95 CF	0.92 x 0.95 CF
STARTING THERMAL DESIGN VALUE		0.16	0.16	0.87	0.87	0.16	0.16	0.87	0.87
MEASUREMENT UNCERTAINTY		- 0.02	+ 0.02	+ 0.02	- 0.02	- 0.02	+ 0.02	+ 0.02	- 0.02
OTHER FACTORS	THICKNESS VARIATIONS	----	+ 0.01	----	----	----	+ 0.01	----	----
	----	----	----	----	----	----	----	----	----
DEGRADATION DUE TO NATURAL ENVIRONMENT	ATOMIC OXYGEN	----	----	----	----	----	----	----	----
	ULTRAVIOLET	----	+ 0.05	----	----	----	+ 0.03	----	----
	CHARGED PARTICLES	----	----	----	----	----	+ 0.05	----	----
DEGRADATION DUE TO INDUCED ENVIRONMENT	CONTAMINATION	----	+ 0.03	----	----	----	+ 0.03	----	----
	APPLICATION	----	----	----	----	----	----	----	----
	UNCERTAINTY	----	----	----	----	----	----	----	----
FINAL THERMAL DESIGN VALUE		**0.14**	**0.27**	**0.89**	**0.85**	**0.14**	**0.30**	**0.89**	**0.85**

!!! NOTE !!! **The BOL & EOL thermal/optical properties shown here are NOT APPROVED by the GSFC Coatings Committee for any specific NASA mission. The exercise is solely meant to be used as an example for this technical course only. Please DO NOT use the values shown here in your thermal design. Please consult with the Project Coatings Engineer.**

EXAMPLE: WHITE RADIATOR COATING (TEMPERATURE)

		White Silicate-Based Thermal Coating in LEO at 250 K				White Silicate-Based Thermal Coating in LEO at 150 K			
		SOLAR ABSORPTANCE		HEMISPHERICAL EMITTANCE		SOLAR ABSORPTANCE		HEMISPHERICAL EMITTANCE	
		COLD CASE	HOT CASE	COLD CASE	HOT CASE	COLD CASE	HOT CASE	COLD CASE	HOT CASE
SURFACE LOCATION: EXTERNAL		αS BOL	αS EOL	εH BOL	εH EOL	αS BOL	αS EOL	εH BOL	εH EOL
NOMINAL MEASURED VALUE		0.16	0.16	0.92 x 0.95 CF	0.92 x 0.95 CF	0.16	0.16	0.89 x 0.95 CF	0.89 x 0.95 CF
STARTING THERMAL DESIGN VALUE		0.16	0.16	0.87	0.87	0.16	0.16	0.84	0.84
MEASUREMENT UNCERTAINTY		- 0.02	+ 0.02	+ 0.02	- 0.02	- 0.02	+ 0.02	+ 0.02	- 0.02
OTHER FACTORS	THICKNESS VARIATIONS	----	+ 0.01	----	----	----	+ 0.01	----	----
	----	----	----	----	----	----	----	----	----
DEGRADATION DUE TO NATURAL ENVIRONMENT	ATOMIC OXYGEN	----	----	----	----	----	----	----	----
	ULTRAVIOLET	----	+ 0.04	----	----	----	+ 0.04	----	----
	CHARGED PARTICLES	----	----	----	----	----	----	----	----
DEGRADATION DUE TO INDUCED ENVIRONMENT	CONTAMINATION	----	+ 0.03	----	----	----	+ 0.03	----	----
	APPLICATION	----	----	----	----	----	----	----	----
	UNCERTAINTY	----	----	----	----	----	----	----	----
FINAL THERMAL DESIGN VALUE		**0.14**	**0.26**	**0.89**	**0.85**	**0.14**	**0.26**	**0.86**	**0.82**

!!! NOTE !!! The BOL & EOL thermal/optical properties shown here are NOT APPROVED by the GSFC Coatings Committee for any specific NASA mission. The exercise is solely meant to be used as an example for this technical course only. Please DO NOT use the values shown here in your thermal design. Please consult with the Project Coatings Engineer.

Q&A

Any Questions?

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CONTACT INFORMATION


IMAGE CREDIT: NASA / PAT IZZO

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