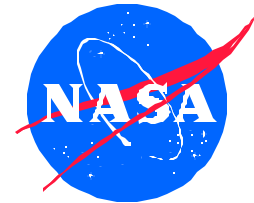


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# **Control of Materials Flammability Hazards**

Dennis E. Griffin  
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Materials, Processes, and Manufacturing Department

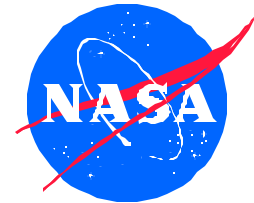
# Control of Materials Flammability Hazards



- Fire is one of many potentially catastrophic hazards associated with materials used in the operation of manned spacecraft
- Appropriate materials selection and control of flammable materials is an important element of NASA's approach to fire control
- Major lesson learned from the Apollo 204 fire in 1966 was ignition sources can be minimized but never completely eliminated
- Spacecraft fire control is based on minimizing potential ignition sources and "eliminating materials that can propagate fire"
  - This means controlling quantity and configuration of flammable materials to eliminate potential fire propagation paths and ensure any fire would be small, localized, isolated and would self-extinguish without harm to the crew
- Fire extinguishers are always provided on manned spacecraft but are not considered as part of the fire control process

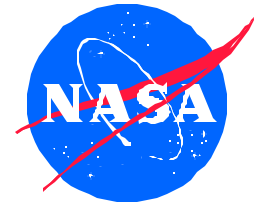
# Control of Materials Flammability Hazards (continued)

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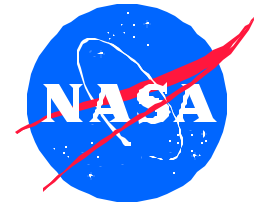
- Ground-based flammability testing is conservative but has not proven to be unusually restrictive for materials in manned spacecraft environments
  - Adequate sources of nonflammable materials for vehicle design
- Many solutions have been developed for controlling the configuration of flammable materials and materials in commercial “off-the-shelf” (COTS) hardware so that they can be used safely in manned spacecraft
- NSTS 22648, “*Flammability Configuration Analysis for Spacecraft Applications*,” describes these design solutions so customers can design safe and cost-effective flight hardware
- Current processes for controlling materials flammability hazards have successfully assured space flight materials and systems do not constitute an uncontrolled fire hazard
- Materials control processes include requirements, guidelines, testing, data bases, data requirement submittals, design analyses, deviation evaluation, hazard mitigation, verification, approval and certification

# Flammability Requirements



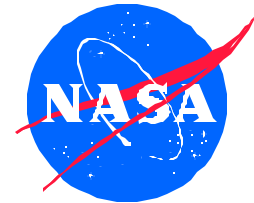
- All flight hardware used in NASA manned space programs must comply with the flammability requirements of NASA-STD-6001, *“Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion”*
- Establishes NASA program requirements for evaluation, testing and selection of materials to preclude unsafe conditions related to flammability in the following environments:
  - Habitable flight compartments (internal)
  - Locations outside habitable areas (external)
  - Ground Support Equipment (GSE) and specified test facilities
  - Vented and sealed containers
  - Liquid and gaseous oxygen (LOX/GOX)
  - Breathing gases
- NASA-STD-6001 describes required flammability tests and requires a system flammability evaluation for materials that fail these tests

# Flammability Requirements (continued)



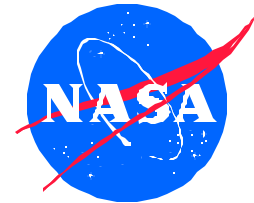
- NASA-STD-6001 contains several materials flammability and ignition tests:
  - Test 1 - Upward Flame Propagation (fundamental test for solid materials)
  - Test 2 - Heat and Visible Smoke Release Rates (cone calorimeter)
  - Test 3 - Flash Point of Liquids (ASTM D 93 Pensky-Martens closed tester)
  - Test 5 - Electrical Connector Potting & Conformal Coating Flammability (deleted)
  - Test 4 - Electrical Wire Insulation Flammability (15° inclined @ 125°C/ overload)
  - Test 8 - Flammability Test for Materials in Vented or Sealed Containers
  - Test 10 - Simulated Panel or Major Assembly Flammability (configuration Test 1)
  - Test 11 - Simulated Crew Bay Configuration Flammability Verification (deleted)
  - Test 13 - Mechanical Impact for Materials in Ambient/Pressurized LOX/GOX
  - Test 14 - Pressurized Gaseous Oxygen (GOX) Pneumatic Impact for Nonmetals
  - Test 17 - Upward Flammability of Materials in GOX (only for pressurized O<sub>2</sub> sys.)
  - Test 18 - Arc Tracking (for electrical wire insulation - not true flammability test)

# Flammability Requirements and System Evaluations



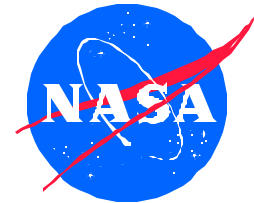
- Nonflammable – a material that self-extinguishes within 6” when ignited and does not propagate a flame by transfer of burning debris (for at least 3 standard sized samples)
- Standard chemical ignition source – energy  $750 \pm 50$  cal., temperature  $2000 \pm 160^\circ\text{F}$ , burning duration  $25 \pm 5$  sec., flame height  $2.5 \pm 0.25$ ”
- “Worst-case” anticipated use environment (most hazardous pressure, temperature, material thickness, and fluid exposure conditions) must be used in the testing and evaluation process
- Materials shown to meet the acceptance criteria of the required test(s) are acceptable for further consideration in design
- Systems containing materials that have not been tested or do not meet the criteria of the required test(s) must be verified acceptable in the use configuration by analysis or testing
- Fundamental requirements is for overall system to be safe from a flammability standpoint
- Test methods exist to provide data needed to support systems evaluation

# Flammability Requirements and System Evaluations (continued)



- An acceptable alternative to flammability testing is to assume material is flammable and demonstrate by analysis that the material configuration cannot propagate fire (e.g. for COTS hardware and electronic equipment)
- These requirements are implemented through various NASA program and Materials and Processes (M&P) requirements documents:
  - JSC SE-R-0006/MSFC-STD-506, *General M&P Standard (Shuttle)*
  - SSP 30233, *Space Station Requirements for M&P (ISS)*
  - NSTS 1700.7, *Safety Policy & Requirements for Payloads Using the Space Transportation System* and (same requirements in the) *ISS Addendum*
- NSTS 1700.7 tailors the NASA-STD-6001 requirements by exempting payload materials used in small quantities (less than 0.1 lb. or 10 square inches in manned crew environments and less than 1 lb. and/or 12 linear inches for external materials)
- Hardware containing materials that do not meet flammability requirements require Board approval with acceptance rationale and system evaluation documented in Materials Usage Agreements (MUAs) or Hazard Reports

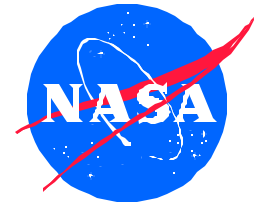
# System Evaluations and Environments



- Systems flammability evaluations or oxygen hazards analyses are required consistent with the hazards assessment guidelines and requirement of:
  - NSTS 22648, *Flammability Configuration Analysis for Spacecraft Applications*
  - NASA TM 104823, *Guide for Oxygen Hazards Analyses on Comp. and Systems*
  - NSS 1740.15, *Standard for Oxygen and Oxygen Systems, Guidelines for Design*
- Standard rationale codes (for Class III MUAs) are available for the most common acceptable configurations containing flammable materials
- Approval of hazard assessments documented in M&P Certification
- Materials flammability depends strongly on the oxygen concentration in the environment to which the materials will be exposed (the effect of pressure is much smaller and can be ignored at crew cabin pressures < 1 Atm)
- Past NASA programs used much higher oxygen concentrations than the current 30% maximum for ISS/Shuttle (100% for Apollo and 70% for Skylab)
- Configurations found to be acceptable under higher oxygen concentrations are considered acceptable for lower oxygen concentrations

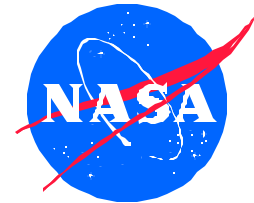


# System Evaluations



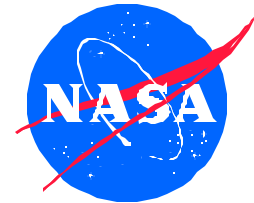
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- When a flammability assessment results in an unacceptable configuration reduction of flammability hazards is necessary to correct the problems
  - Primary methods used by NASA to reduce flammability hazards are:
    - Minimize or limit the use of flammable materials by replacement with nonflammable materials
    - Eliminate or restrict propagation paths
      - Covering flammable material with a nonflammable material
      - Separation of flammable materials
    - Isolate flammable materials from ignition sources or eliminate ignition sources
  - When results of flammability configuration analysis are inconclusive the hardware configuration may be tested for flammability to determine acceptability
  - Alternatively the hardware organization may choose to assume the configuration is flammable and implement appropriate measures to eliminate the flammability hazard

# System Evaluations (continued)



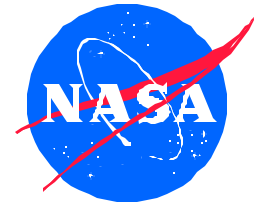
- To conduct a flammability configuration assessment - **Evaluate the overall hardware configuration:**
  - If the hardware is a closed box without vents or power, the materials inside will not contribute to the fire hazard unless the box is constructed from flammable materials – the box acts as a fire barrier
  - If the only electrical power within the box is from batteries, the maximum short-circuit power draw is nearly always too low to act as an ignition source
    - NASA testing during the Apollo era showed that solid materials cannot be ignited by electrical powers below 25 watts
- **Evaluate the way in which the hardware will be used:**
  - Hardware that is normally stowed in a fireproof container (stowage locker, many NASA provided stowage bags and ISS crew transfer bags) and exposed to the cabin environment for short periods during use may comply with stowage policy:
    - Max dimensions 10 in. and unstowed less than 1 day/week
    - Unstowed less than 1 hour/day
    - Contingency use only

# System Evaluations (continued)



- 
- Maximum dimension <6 in. and always stowed when not in actual use
  - Used only when covered by crew clothing
  - Exposed surface area < 1 sq. ft. and always worn by crew when unstowed
  - A full flammability analysis is required for hardware that is permanently mounted in a rack or a locker space
  - **Identify the major materials to be assessed**
    - Amounts greater than 0.1 pounds (or 6 linear inches maximum dimension and/or 10 square inches maximum area) in crew-habitable compartments
    - Amounts greater than 1.0 pounds (or 12 linear inches) in other compartments
    - Metallic panels and structures are nonflammable in Shuttle/ISS environment (even magnesium and titanium) and need not be considered
    - Metallic screens may be flammable and must be addressed
    - Inorganic materials (ceramics) are also nonflammable in Shuttle/ISS environments and need not be considered
    - Adhesives (sandwiched between two surfaces) and materials covered overcoated by nonflammable materials need not be considered

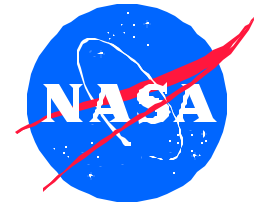
# System Evaluations and Flammability Data



- 
- Flammability characteristics of materials can be determined by consulting the NASA/MSFC Materials and Processes Technical Information System (MAPTIS) at [http://map1.msfc.nasa.gov/WWW\\_Root/html/page7.html](http://map1.msfc.nasa.gov/WWW_Root/html/page7.html)
  - An A-rating in MAPTIS for test conditions that are the same as the use conditions means the material is acceptable in unlimited quantities
  - Any other rating means the material quantity/exposure must be controlled  
The following key factors in materials
  - Note the following key factors when using MAPTIS flammability data:
    - Oxygen concentration - MAPTIS flammability data obtained at higher oxygen concentrations than the use concentration are always conservative (unpowered and painted metal boxes, or hardware stowed/transferred in a standard locker, Shuttle container or crew transfer bag for external use are acceptable)
    - Material thickness – generally, flammability decreases with increasing thickness, so the thickness associated with the MAPTIS rating should be the same as the use thickness of the material, or it is acceptable if a thinner version of the same material is rated A for flammability

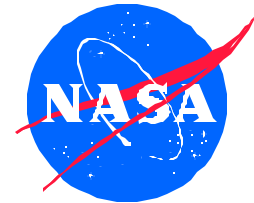
# System Evaluations and Flammability Data (continued)

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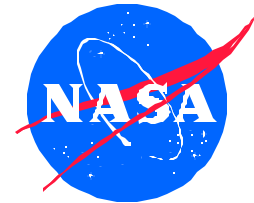
- Coatings on substrates – thin coatings bonded or sprayed on metallic substrates are generally not flammable because the substrate acts as a heat sink, coating flammability always decreases with increasing substrate thickness, so a coating is always acceptable if it is A-rated for flammability on a thinner substrate, if the coating is <2 mils thick and the metal substrate is  $\geq 20$  mils thick the coating is acceptable, nonmetallic substrates are not effective as heat sinks
- Determine fire propagation paths
  - Determine whether the externally exposed materials represent fire propagation paths exceeding 6” in crew compartments and 12” in other areas, propagation from one flammable material application to the next is not acceptable, and must be limited by fire breaks or positive action to control the hazard
- Evaluate the ability of container to contain fire
  - Sealed containers have no vents and are verified to a max. of  $1 \times 10^{-4}$  cm<sup>3</sup>/sec
    - Contains no oxygen or inert gas an internal fire will not be initiated
    - Contains air and nonflammable wall  $\geq 60$  mils thick fire will be contained
    - Internal void space limited to less than 30% of total volume acceptable

# System Evaluations (continued)



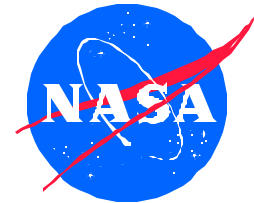
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- Vented containers have active vents and associated cooling airflow
    - Vent area <1% of total surface area and vents covered with a fine metal (stainless steel or nickel, not Al, Ti or Mg) screen will contain fire
    - Carefully evaluate/test and reduce hazard by:
      - Minimize number and size of vents (avoid chimney effect)
      - Cover vents with fine CRES or Ni screen
      - Minimize free volume by adding nonflammable packaging materials , e.g. polyimide foam
      - If forced air flow not required, cover all vents and evaluate as intermediate
      - Relation between flow rate and flammability complex
      - At low flow rates flammable materials burn more vigorously with increasing flow rate (decreasing effectiveness of the container)
      - At high flow rate airflow will prevent stable flames (blowing out fire)
      - Intermediate flow rates are worse case and are configuration and microgravity dependent

# System Evaluations (continued)



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- Intermediate containers have no active vents or cooling airflow
    - NASA-provided stowage lockers and bags are treated as containers that can act as barriers to external fires
    - Many commercial electronics items may be addressed by stowage policy or can be obtained with metallic or nonflammable polycarbonate case and with internal components packed closely such that void space is of no concern
    - Internal ignition of small commercial items powered by alkaline batteries is not considered credible
    - Potential for ignition from external sources can be eliminated with nonflammable case or by covering the case with a nonflammable material

# Processes to Control Materials Flammability Hazards

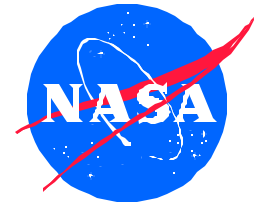


- **Elements of effective materials flammability control have successfully precluded uncontrolled fires on orbit:**
- Requirements - NASA-STD-6001 implemented by program requirements
- Guidelines - NSTS 22648, MSFC-PROC-1301, NSS 1740.15, etc.
- Testing – active program for new materials, applications & configurations
- Data bases - MAPTIS provides 85,000 test reports on >32,000 materials
  - Used to publish MSFC-HDBK-527/JSC 09604, *Materials Selection Lists for Space Hardware Systems*, all materials have unique NASA Material Code
- Data requirement submittals – Type 1 Approval, MCPs, MIULs and MUAs
  - Materials Control Plans – Describes how requirements will be implemented
  - Materials Identification Usage Lists – Identifies where specific materials are used, quantities, environments, application, thicknesses, cure, applicable test data, etc.
  - Materials Usage Agreements – used to approve materials that fail to meet requirements, describes application and hazard assessment with technical acceptance rationale for evaluation of deviation
  - Engineering Drawings



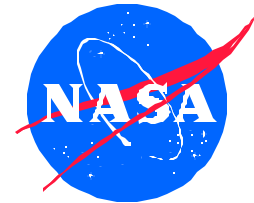
# Processes to Control Materials Flammability Hazards (continued)

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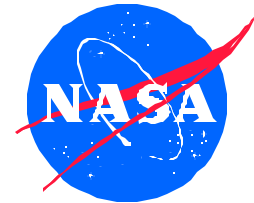
- Design review/approval – M&P approval signature required on all engineering documentation
- Design analysis – formal hazards analysis, inspections, walk-throughs
- Hazard mitigation – numerous techniques developed and documented
- Oversight/Insight – M&P approval signature and representation required for milestone design reviews (SRRs, PDRs, CDRs, DCRs), Safety Review Boards/Panels, Certification of Flight Readiness Reviews (CoFRs)
- Verification – data submittal, assessment and closure for generic flammability hazard, reconcile as-designed versus as-built configuration
- Materials and Processes (M&P) organization responsible for preparing and approving certification that materials meet flammability requirements for CoFR and Safety Panel
- Reciprocal Materials Agreements
  - JSC, MSFC, JPL, GRC, GSFC maintain Intercenter Materials Agreements
  - NASA, ESA, NASDA and RSA maintain Interagency Materials Agreements

# Flammability Reduction Methods



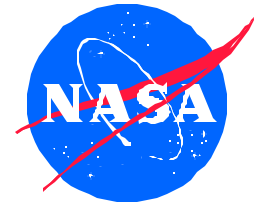
- Commercial items with flammable outer surfaces (ABS, PVC, polyethylene, and/or polyamides) may be wrapped in nonflammable tape
  - 3 mil aluminum tape (L-T-80) will protect most plastics, foams and cardboard
  - Nonflammable fiberglass tape with silicone adhesive will provide same protection if each rotation or wrap overlaps the previous one by 50%
- For long-term applications and aesthetics, flammable surfaces may be coated with nonflammable barrier such as Fluorel ® (expensive, complex, fair durability)
- Common case materials for commercial items are generally extremely flammable ABS or normally acceptable polycarbonate (up to 30%) or metal
- Electrically powered items with internal flammable materials can usually be treated or filled with a suitable material (nonflammable glass-filled-epoxy potting compound) to provide protection from internal ignition sources

# Wire and Cable



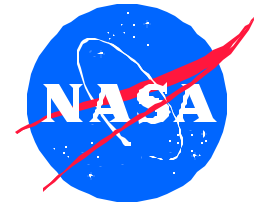
- Most aerospace-grade electrical wire insulation is nonflammable in Shuttle/ISS environments
- Limitations are usually driven by such factors as flexibility and cut-through resistance:
  - Teflon (MIL-W-22759, MIL-C-27500, or equivalent) – good general-purpose wire with high flexibility but poor cut-through resistance
  - Polyimide (MIL-W-81381) – no longer used except in flat circuits because of propensity to arc track
  - Teflon-Polyimide Hybrids (MIL-W-22759, MIL-C-27500, or equivalent) – good general-purpose wire with lower flexibility than Teflon but higher cut-through resistance
  - Tefzel (MIL-W-22759, MIL-C-27500, or equivalent) – suitable for external applications but flammable in enriched oxygen with performance similar to hybrid
  - ISS also uses a custom silicone-insulated construction in power circuits (SSQ 21652) that is nonflammable in ISS environments and exceptionally flexible

## Wire and Cable (continued)



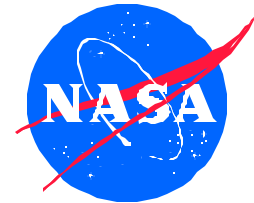
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- COTS hardware typically has electrical wiring with PVC, polyethylene, or chloroprene insulations which are flammable in all Shuttle/ISS environments
  - Their use is generally discouraged and may be used only when demonstrated to be acceptable in configuration by flammability analysis
  - Commercial wiring inside electronics boxes and low-power signal wiring outside such boxes can usually be accepted by this method
  - External power cables nearly always need to be replaced or protected from ignition
  - Flammable insulation is acceptable on wires in external payloads that are not powered (including during ground testing) until in vacuum

# Wire, Cable and Electrical Accessories



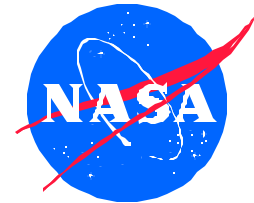
- Methods for protecting flammable cables include:
  - Covering with braided Teflon sleeve, such as Goretex<sup>®</sup> sleeving
  - Wrapping with nonflammable fiberglass-backed-silicone adhesive tape
  - Covering with sleeve of 7.2 oz/yd<sup>2</sup> natural Nomex HT-9040 fabric, beta cloth, polybenzimidazole (PBI), or other nonflammable fabrics
  - Covering by heat shrinking polyvinylidene fluoride or Teflon sleeve onto cable
- Wire and cable accessories such as cable markers, spacers, and cable ties should not contribute to fire propagation paths
- Polyvinylidene fluoride/fluoroelastomeric cable markers are generally used
- Other types of cable marker material may be acceptable if used in small discrete amounts or covered with a clear Teflon TFE or FEP sleeve
- Most types of spacers are usually acceptable because of heat sink effects
- Acceptable lacing cords are Teflon TFE, Teflon TFE/fiberglass, or Nomex

# Electrical Accessories Hoses and Tubes



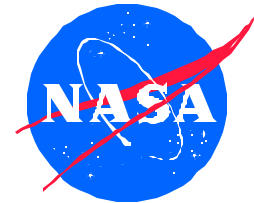
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- Acceptable cable ties can be made from ETFE or ECTFE fluoropolymers
  - If flammable cable tie wraps are used on nonflammable cables they should be spaced at least 2 inches apart to prevent fire propagation
  - In air and moderately-enriched oxygen environments (up to 40 percent oxygen) the shell of a metal shell electrical connector prevents fire propagation from the nonmetallic materials used inside the connector to other nonmetallic materials, regardless of the material inside the connector
  - Flammability configuration analysis is required for nonmetallic shell connectors
  - Acceptability of the nonmetallic materials used inside the connector depends on the flammability of the shell material and its ability to act as a fire barrier
  - External tubes or hoses (such as a vacuum cleaner hose) made from flammable materials may be replaced with a nonflammable material or covered with a fire barrier material

# Hoses and Tubes Hook and Loop Fasteners



- Clear TFE or FEP Teflon tubes and hoses are readily available to replace flammable materials
- If flammable tubes or hoses must be used, the exterior can be protected by a covering of 7.2 oz/yd<sup>2</sup> natural Nomex HT-9040, PBI, Beta cloth, or other nonflammable fabric
- In these cases potential for ignition of the tube walls from inside must be addressed
- Although some hook-and-loop fastener materials are less flammable than others, all common types are flammable in spacecraft habitable areas
- To prevent long flame propagation paths, the following usage limits are generally applied to hook and loop fasteners in habitable areas:
  - Maximum size: 4 square inches, individually or in pieces
  - Maximum length: 4 inches
  - Minimum separation distance: 2 inches in any direction from another piece
- NASA normally uses nylon fasteners in habitable areas for greater durability and Nomex in EVA operations for good low-temperature performance

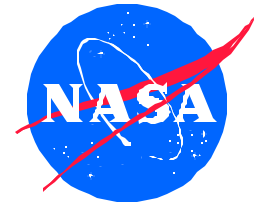
# Stowage Bags and Lockers



- Metal stowage lockers that do not contain ignition sources are acceptable
- Material selection criteria for nonmetallic stowage lockers must be based on fire containment capability and should be supported by test data
- Acceptable stowage bags may be constructed from the following fabrics:
  - Beta cloth - acceptable for stowage of potentially flammable materials but has low durability and a tendency to shed glass fibers
  - Natural Nomex HT-9040 fabric weighing at least 7.2 ounces/square yard
  - Lighter weights of natural Nomex HT-9040 are acceptable in double layers
  - Navy blue single-layer Nomex weighing 6.5 ounces/square yard treated with ammonia dihydrogen phosphate fire retardant
    - Used on the Shuttle but discouraged for ISS because the fabric cannot be wiped down without removing the fire retardant
  - PBI and other flame-retardant fabrics (see MAPTIS)
- These containers can have flammable items stowed inside them provided they do not contain ignition sources and are not susceptible to spontaneous ignition or chemical reaction

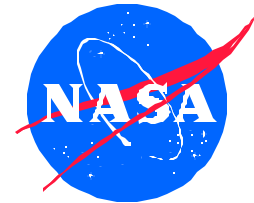


# Thermal Control Blankets



- Thermal control blankets are the most widely used potentially flammable external materials
- Blankets typically contain 12 to 40 layers of film (0.0005 to 0.002 inches in thickness) separated by some type of scrim cloth
- Blanket materials are usually constructed of metal-coated polyethylene terephthalate or polyimide film with an organic separator scrim
- The inner and outer layers are generally heavier than the internal layers for durability
- Outer layer has controlled optical properties and is usually polyimide, silver-Teflon, or Beta cloth
- Acceptable thermal control blankets are typically constructed as follows:
  - The outer layer is made of nonflammable material such as polyimide film (at least 1.5 mil thick), metal foil, silver-Teflon, or Beta cloth
  - Internal layers can be a combination of flammable films or scrims
  - Edges are hemmed or suitably finished so that the inner flammable layers are protected and Atomic Oxygen is a consideration for long- term LEO exposure

# Fiber Reinforced Laminates



- 
- Fiber-reinforced laminates are used as structural materials
  - Laminates may be flammable if used in thickness  $< 0.125$  inches
  - Flammability characteristics of thin laminates should be verified by test or the laminates should be protected
  - Flammable laminates may be used in external payloads provided that ignition sources (electrical wires, heaters, etc.) are not located within 6 inches of the laminates
  - Otherwise firebreaks should be placed on the exposed surfaces of these laminates at 12 inch intervals, e.g. Aluminum tape 3 mils thick X 3 inches wide (Federal Standard L-T-80)