Environmentally-driven Materials Obsolescence: Material Replacements and Lessons Learned from NASA's Space Shuttle Program

October 24, 2013
ESRIN, Frascati, Italy
2013 International Workshop on Environment and Alternative Energy

Anne Meinhold
ITB, Inc./NASA Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM)

Outline

- Space Shuttle Overview
- Montreal Protocol and Later Regulatory Challenges
- Space Shuttle Approach to Mitigation
- Space Shuttle Environmentally-driven Materials Obsolescence Risks
- Major Mitigation Actions
- Space Launch System and Future Risks
- Lessons Learned

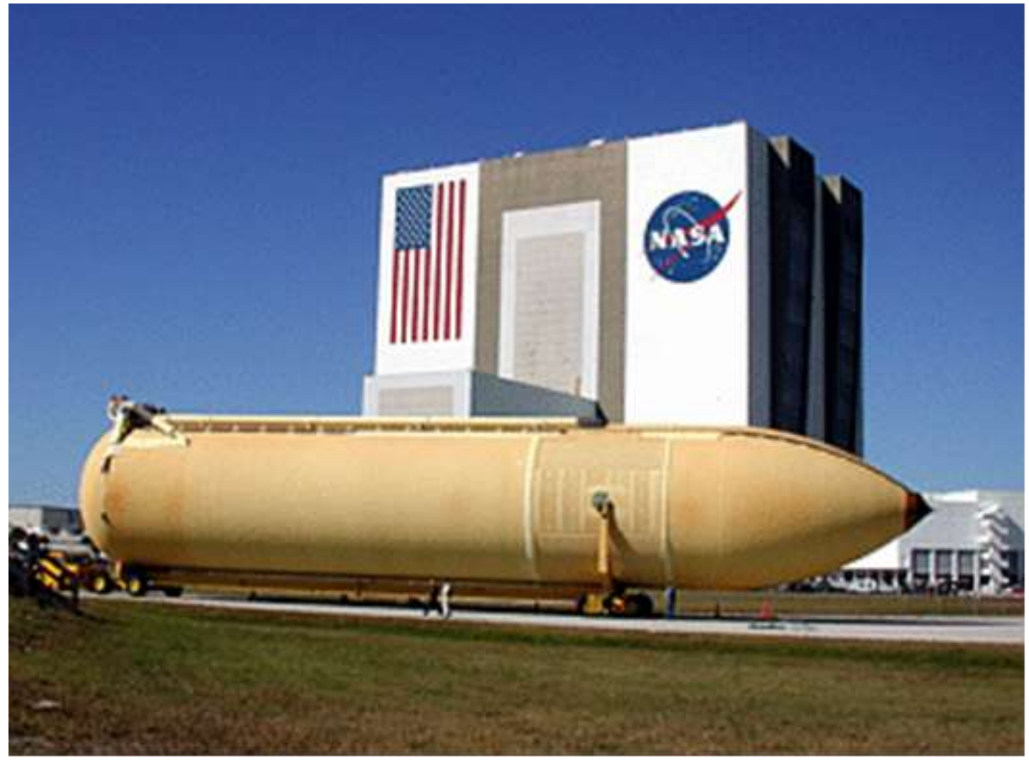
NASA Space Shuttle Program (SSP)
Operations 1981-2011

NASA Space Shuttle Elements

- Orbiter – Re-useable Spacecraft
- Space Shuttle Main Engines (SSME, LOX/LOH fueled)
- External Tank (ET) – Cryogenic LOX/LOH tanks for SSMEs
- Solid Rocket Boosters/Motors (SRB, RSRM) – ammonium perchlorate solid propellant
- Ground Support Equipment (GSE)

Montreal Protocol 1987

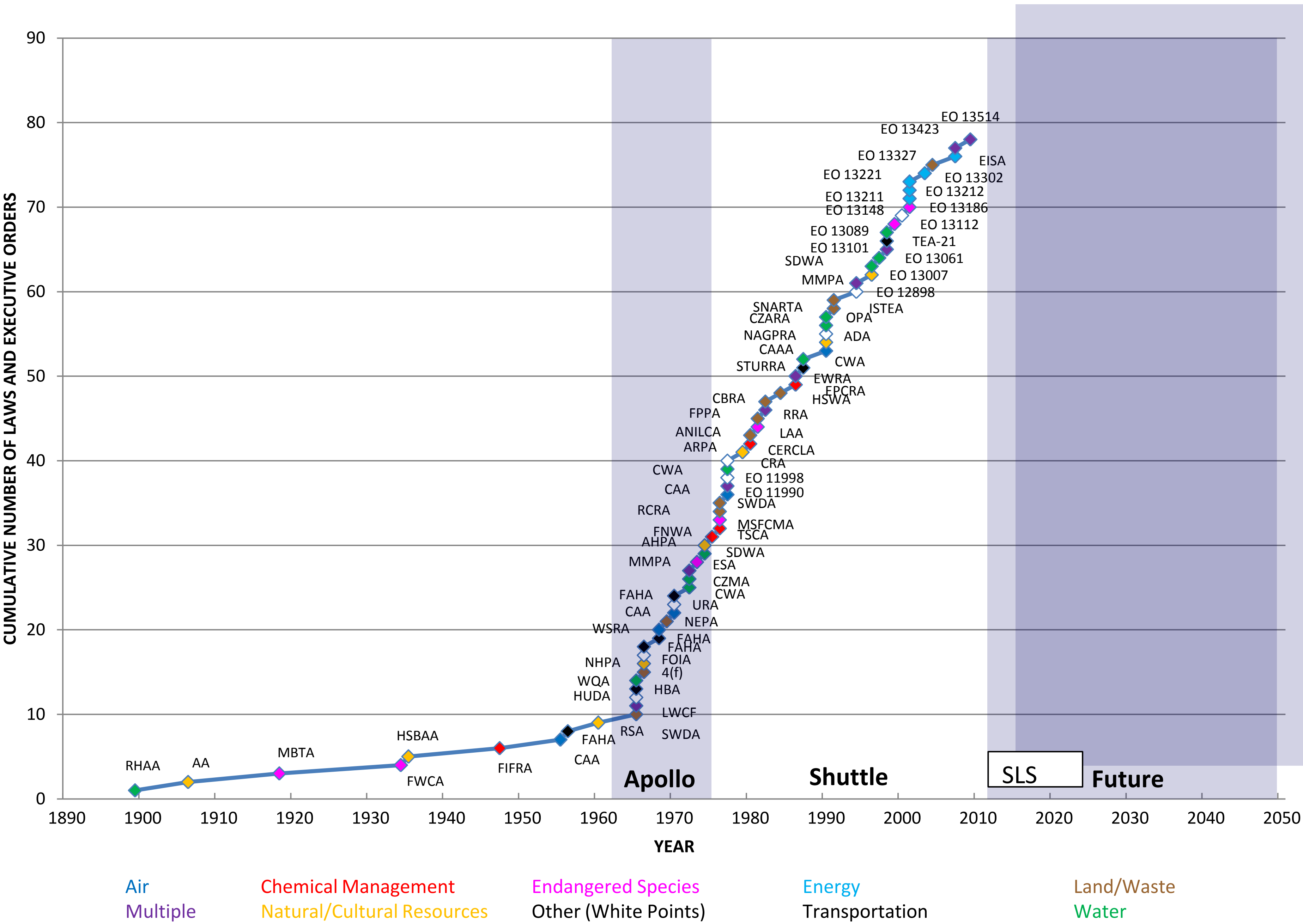
- First big environmental driver of materials obsolescence.
- Class I Ozone Depleting Substances (ODS) phased out included chlorofluorocarbons (CFCs) and 1,1,1 trichloroethane (TCA).
- CFCs were used in many Shuttle operations including CFC-113 for precision cleaning and CFC-11 as a blowing agent in polyurethane foam.
- TCA was used in critical bonding applications during Orbiter processing, RSRM manufacturing operations, and SRB bonding operations and coatings.



Later Challenges

- Direct regulation or restriction increased in the U.S.
- U.S. National Environmental Standards for Hazardous Air Pollutants (NESHAPS)
- Criteria Pollutant Regulations: Volatile Organic Carbon (VOCs)
- Occupational Safety and Health Administration restrictive standards for chromium, cadmium and lead
- New European regulations that could affect availability of critical materials
- New European regulations that could impact additives to materials, reformulations, increased uncertainty

Evolution of Environmental Requirements
(from NASA Regulatory Risk Analysis and Communication (RRAC) Principal Center)



Space Shuttle Program Approach to Environmentally-driven Materials Obsolescence

- In response to the Montreal Protocol, Materials and Processes (M&P) representatives began to meet informally
- NASA and the SSP established teams of subject matter experts.
- In 2000, the SSP chartered the Shuttle Environmental Assurance (SEA) Initiative.
- SEA worked closely with the Regulatory Risk Analysis and Communication Principal Center (RRAC) to identify emerging and changing regulations that could affect SSP operations.
- SEA used a continuous risk management approach to identify, analyze, mitigate, and track environmentally driven materials obsolescence issues.
- Mitigation approaches included:
  - regulatory mitigations
  - qualification of reformulated materials
  - replacement of materials
  - changes in the process to be able to delete materials
  - stockpiling
- Some risks, especially near the end of the SSP, were tracked or accepted.
- Coordinated proactive effort involving NASA HQ, Regulatory team, Materials and Process Engineers, Program Elements and Prime Contractors.

Regulatory Drivers and Shuttle Materials Impacts

Requirement/Regulation	Material Affected	SSP Impacts
Protection of Stratospheric Ozone Montreal Protocol; CAA, Title VI	Class I ODS: CFCs, Freon® Class I ODS: Halon Class I ODS: TCA	Precision cleaning; blowing agent Fire protection: Orbiter and GSE Cleaning operations RSRM and Orbiter
Protection of Stratospheric Ozone Montreal Protocol; CAA, Title VI	Class II ODS: HCFC 141b	Thermal Protection System (TPS): ET, RSRM, RSRB, Orbiter
NESHAPs CAA, Title III	HAPs	Surface cleaning coating, and associated operations
Criteria Pollutant Regulations CAA, Title I	VOCs	Surface cleaning coating, and associated operations
National Ambient Air Quality Standards: NAAQS for Ozone	ozone	Potential increased restrictions on VOC emissions
Florida Groundwater Regulations	Perchlorate	Discharges from RSRM post-flight processes
TSCA	Perfluorinated chemicals	PFOS, PFAS, PFOA in many applications; materials restricted
RCRA	Perchloroethylene	SRB post-flight removal of hypalon triggered hazardous waste requirements
Permissible Exposure Limits: OSHA	Cr(VI)	Operations to prevent corrosion aluminum substrates, ET, Orbiter: potential for increased PPE and monitoring
Permissible Exposure Limits OSHA	Lead	Used in SRB AL topcoat, increased PPE and monitoring
European Regulations REACH	BFRs, Heavy Metals, other toxic materials	Impacts to industry resulting in materials obsolescence
European Regulations RoHS	BFRs, Heavy metals, other toxic materials	Impacts to industry resulting in materials obsolescence
European Regulations WEEE	Leaded solders and leaded electrical components	Orbiter, SRB, SSME, EMU

Shuttle Environmentally-Driven Obsolescence Risks By Element

External Tank

- HCFC-141b
- Cadmium
- Hexavalent Chromium
- High VOC coatings
- Cleaning and verification solvents
- Methyl ethyl ketone
- BFRs
- PFOA

Reuseable Solid Rocket Motors

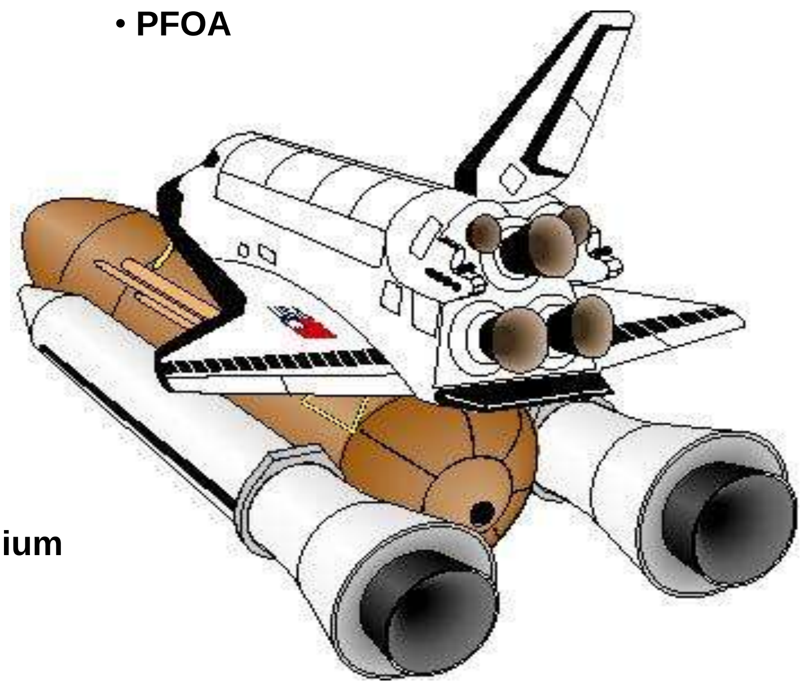
- HCFC 141b
- Trichloroethane
- Cadmium
- Hexavalent Chromium
- High VOC Coatings
- Hypalon
- Lead-free electronics
- BFRs
- PFOA

Ground Support

- Cadmium
- Hexavalent Chromium
- PFOA

Orbiter

- HCFC-141b
- Trichloroethane
- Cadmium
- Hexavalent Chromium
- Methyl Ethyl Ketone
- High VOC coatings
- Lead-free electronics
- Hazardous Air Pollutant Inks
- Cleaning and verification solvents
- Methyl ethyl ketone
- PFAS
- BFRs
- PFOA



Space Shuttle Main Engines

- Hexavalent Chromium
- Cadmium
- Lead-free electronics
- Cleaning/verification solvents
- PFOA

Solid Rocket Boosters

- HCFC-141b blowing agent
- Hexavalent Chromium
- Lube-Lok
- High VOC Coatings
- Hypalon paint
- Lead-free electronics
- BFRs
- PFOA

Flight Crew Equipment/Space Suit

- Hexavalent Chromium
- Lead-free electronics
- BFRs
- PFOA

Status Shuttle Environmentally-Driven Materials Obsolescence Risks 2001-2010

	2001	2006	2010
1,1,1 Trichloroethane (Orbiter use)			
1,1,1 Trichloroethane (RSRM use)			ACCEPTED
Cadmium Replacement in Plating Applications			ACCEPTED
Hexavalent Chromium Replacement in Primers			ACCEPTED
Hexavalent Chromium Replacement in Conversion Coat			
Chemical Paint Stripper Alternatives			ACCEPTED
Alternate Dry-Film Lubricant			CLOSED
High Volatile Organic Compound Coatings			ACCEPTED
Hypalon Paint (perchoroethylene)			CLOSED
Lead-Free Electronics			
Hexavalent Chromium in Alkaline Cleaners			CLOSED
Hazardous Air Pollutant Inks			ACCEPTED
Methyl Ethyl Ketone		CLOSED	CLOSED
Precision Cleaning and Verification Solvents			CLOSED
Perfluoroalkyl Sulfonates			CLOSED
Brominated Flame Retardants			
HCFC 141b Blowing Agent			
PFOA perfluorooctanoic acid			

Major Mitigation Approaches

CFC 11 (Class I ODS)

- Replaced with HCFC 141b (Class II ODS) as the blowing agent in Thermal Protection System foam on the External Tank

CFC 113 (Class I ODS)

- For most cleaning applications, aqueous cleaners were qualified and implemented
- For ET, CFC-113 was replaced with HCFC-225 in clean room cleaning operations for all LOX and most liquid hydrogen compatible hardware.
- Some applications still required a final CFC-113 flush for cleanliness verification

Trichloroethane (TCA, Class I ODS)

- Replacement depended on application
- Aqueous processes, d-limonene, Vertrel MCA, Isopropyl alcohol, AK225G, and others
- TCA still required for rubber activation on RSRM: Essential Use Exemption /Stockpile

HCFC 141b (Class II ODS)

- More than 200 blowing agents were researched. No viable material was found that met the ET requirements.
- Exemption allowance for production and use on specific SSP applications

Major Mitigation Approaches

Hexavalent chromium

- Cr(VI) was commonly used in primers and coatings for Al surfaces because of its effectiveness in preventing corrosion.
- SSME: Chromated coatings were replaced with TT-P-2756, a non-chromated, VOC-compliant, self-priming topcoat.
- SRB: conversion coating replacement qualified was Alodine® 5700 (Henkel). The primer and topcoat replacements qualified were Hentzen Coatings, Inc. 05510WEP-X/05511CEH-X primer and 4636WUX-3/4600CHA-SG topcoat.
- Orbiter: Largest effort was focused on the corrosion resistant primer Super Koropon®. Akzo Nobel 10PW22-2 non-chromated, low-VOC, replacement primer was implemented on a limited basis.

Cadmium

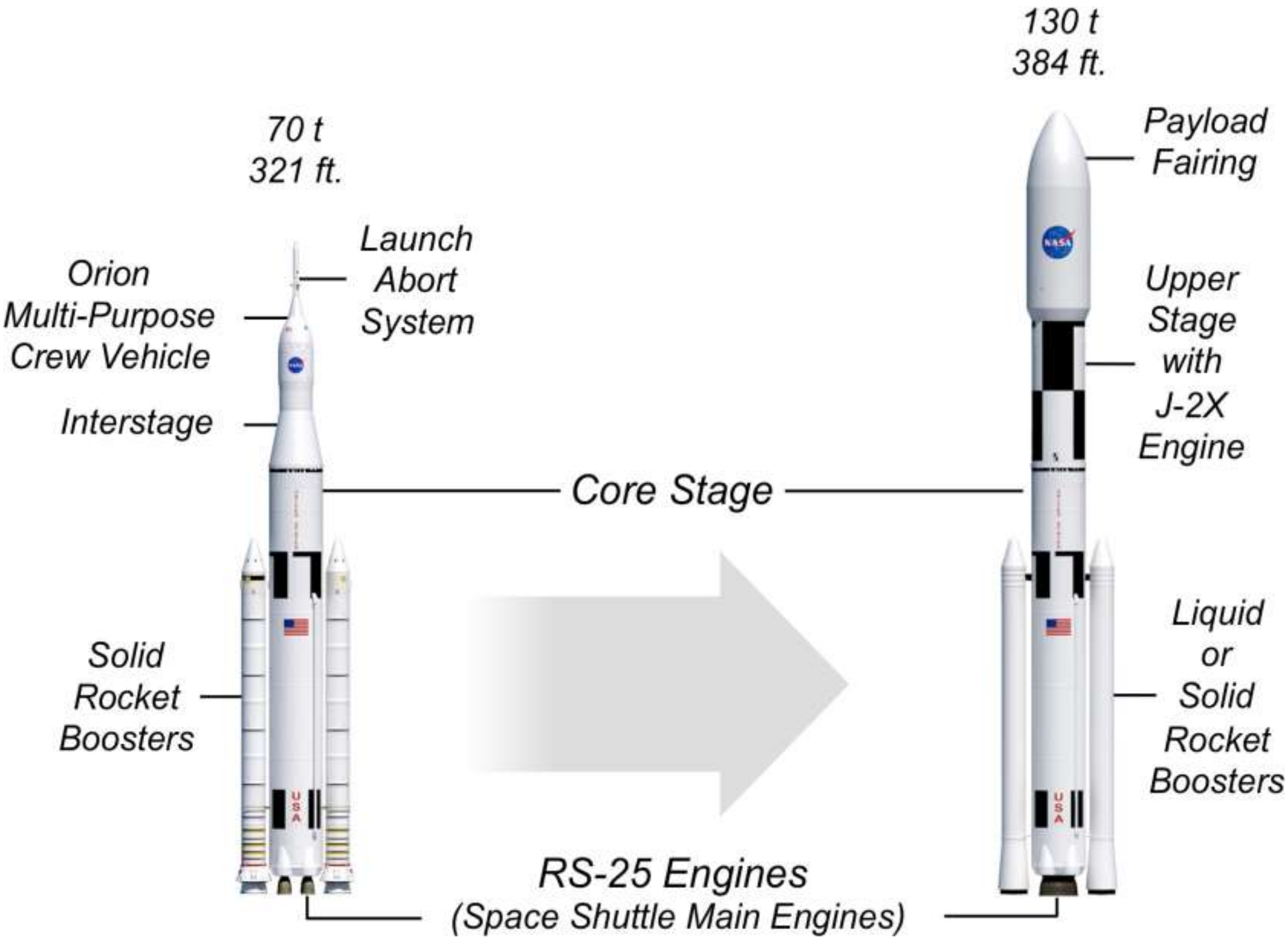
- The SSP Elements replaced many of the Cd-plated bolts used on the shuttle with bolts coated with various alternative metallic coatings.
- The SSP ET used thousands of Cd-plated parts on several different substrates in hundreds of different applications, the majority of which were high-strength fasteners.. ET conducted down-select testing of tin-zinc and zinc-nickel and recommended the zinc-nickel system as a Cd replacement alternative.

Major Mitigation Approaches

Lead Free Electronics

- Purchasing contracts stipulated that vendors had to notify the SSP of any material changes, but distributors often did not know about changes made in original equipment manufacturers' processes.
- SSP Elements inspected their existing parts, checked new parts, and monitored part suppliers to ensure adequate lead was included to protect critical circuitry.
- Where necessary, the SSP Elements stockpiled critical lead-containing parts to ensure an adequate supply of reliable materials.
- Orbiter performed x-ray fluorescence spectrometry testing on a subset of the orbiter inventory and concluded that the older orbiter parts were less of a concern than more recently purchased industry parts, so careful monitoring of new parts was implemented.

NASA Space Launch System (SLS) Under Development

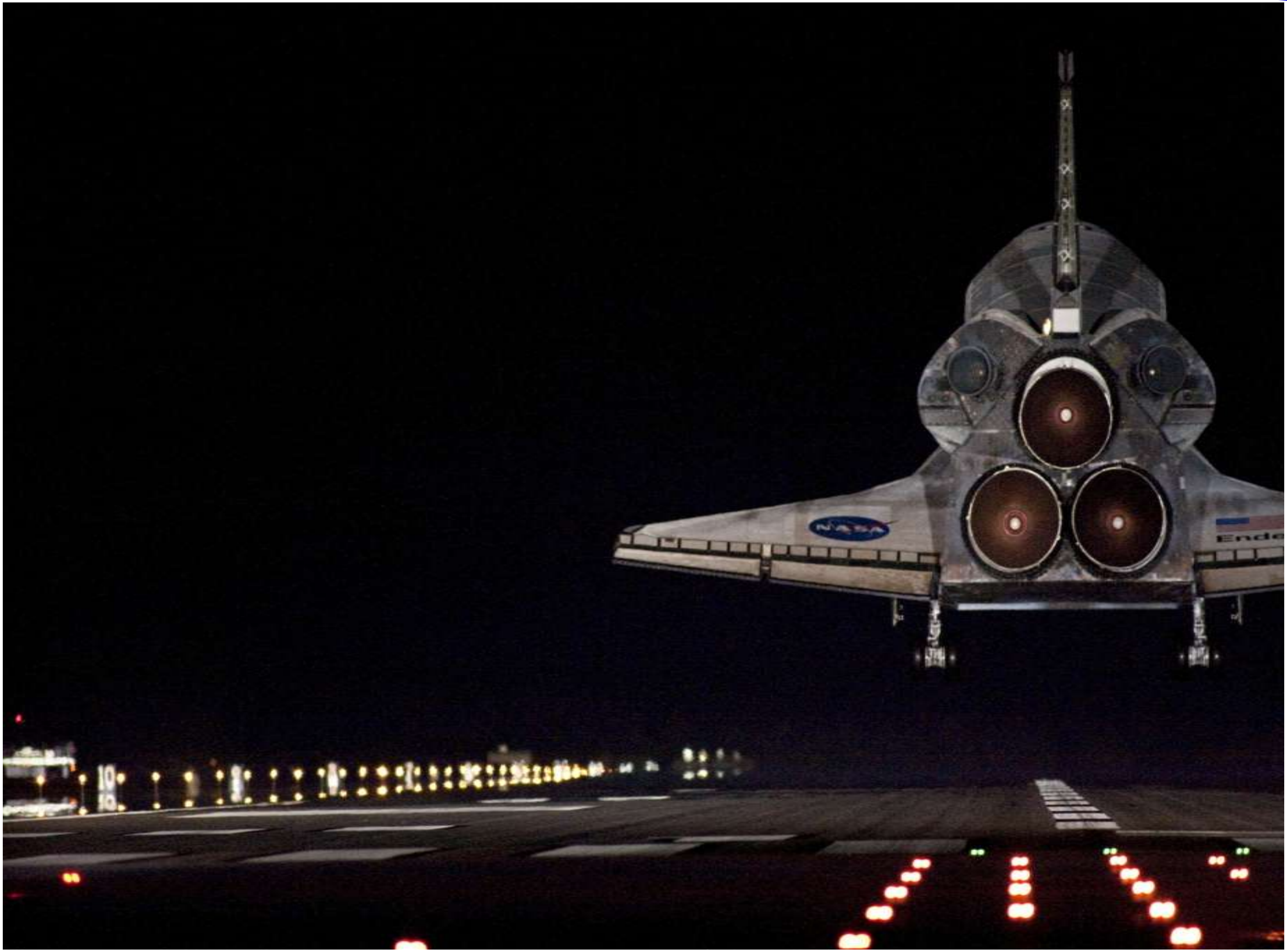


Future Materials Obsolescence Challenges

- SLS and other NASA Programs will continue to face environmentally-driven materials obsolescence risks
- SLS will face materials obsolescence risks similar to those faced by the Shuttle
- REACH will have bigger effect:
  - chemicals on REACH Substances of Very High Concern (SVHC) list
  - difficult to identify potential applications and resulting risk
  - materials commonly used on space vehicles on REACH authorization list
- Uncertainty on continued availability of materials and changes made by vendors
- ODSs, hexavalent chromium, cadmium, lead free solder, brominated flame retardants, perfluorooctanoic acid

Lessons Learned

- Expect continuous change in environmental risk drivers
- Materials obsolescence can be driven by regulation, vendor changes, technology and market forces
- Regulatory screening, evaluation and risk assessment is critical
- Coordinated, team approach is best practice
- All stages of a project life cycle should involve environmental assurance discipline
- Material obsolescence can be a major cost to programs and projects
- Material stockpiles have limited sustainability and may be costly, but sometimes are the only option
- Important to know where materials are/will be used and criticality
- Formulation changes can occur in numerous ways
  --primary ingredient change
  --processing chemical change
  --process change
  --supplier change


NASA
Endo