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ENVIRONMENTALLY REGULATED AEROSPACE COATINGS

Virginia L. Morris
Northrop Grumman Corporation
Environmental Technology Development
B-2 Division
8900 E. Washington Blvd.
Pico Rivera, CA 90660
Phone: 310-942-5913, FAX: 310-948-8146

ABSTRACT

Aerospace coatings represent a complex technology which must meet stringent performance requirements in the protection of aerospace vehicles. Topcoats and primers are used, primarily, to protect the structural elements of the air vehicle from exposure to and subsequent degradation by environmental elements. There are also many coatings which perform special functions, i.e., chafing resistance, rain erosion resistance, radiation and electric effects, fuel tank coatings, maskants, wire and fastener coatings.

The scheduled promulgation of federal environmental regulations for aerospace manufacture and rework materials and processes will regulate the emissions of photochemically reactive precursors to smog and air toxics. Aerospace organizations will be required to identify, qualify and implement less polluting materials. The elimination of ozone depleting chemicals [ODCs] and implementation of pollution prevention requirements are added constraints which must be addressed concurrently. The broad categories of operations affected are the manufacture, operation, maintenance, and repair of military, commercial, general aviation, and space vehicles.

The federal aerospace regulations were developed around the precept that technology had to be available to support the reduction of organic and air toxic emissions, i.e., the regulations cannot be technology forcing. In many cases, the regulations which are currently in effect in the South Coast Air Quality Management District [SCAQMD], located in Southern California, were used as the baseline for the federal regulations. This paper addresses strategies used by Southern California aerospace organizations to cope with these regulatory impacts on aerospace productions programs. ***All of these regulatory changes are scheduled for implementation in 1993 and 1994, with varying compliance dates established.***

INTRODUCTION

1.0 Regulatory Requirements and Policies

Clean Air Act Amendments. The 1990 Clean Air Act Amendments [CAAA] require the Environmental Protection Agency [EPA] to develop regulations designed to reduce the emissions of volatile organic compounds [VOCs] and hazardous air pollutants [HAPs] generated by the US aerospace industry. The EPA solicited data from major aerospace organizations, including both civilian and government sources, to determine the processes which were the most polluting, emitting both reactive organic gases [precursors to urban smog] and hazardous air pollutants, which cause harm to the general public health.

Section 183[b][3] of the CAAA dictates the development of a control techniques guideline [CTG] which provides guidance to state and local agencies for the development of regulations to reduce VOCs. Only areas designated as in "non-attainment" with federal standards are mandated to follow the baseline emissions standards for VOC. Section 112 of the CAAA requires the promulgation of National Emission Standards for Hazardous Air Pollutants [NESHAP] to control the emissions of HAPs from major sources. A major source is defined as any source with the potential to emit 10 tons per year of a single HAP or 25 tons per year of the aggregate HAP emissions from a facility. Both regulations are scheduled for promulgation by the end of 1994, with compliance dates of 18 to 36 months following promulgation.

An aerospace facility, as defined by the EPA, is a facility that produces in any amount an aerospace vehicle or component, or a facility that reworks [or repairs] these vehicles or components. Aerospace operations at any major source that conduct both aerospace and non-aerospace work would be subject to the proposed standards, regardless of the relative proportion of aerospace and non-aerospace work at the facility. The EPA estimates there are 2,879 aerospace facilities that will be subject to the proposed standards. Of this number 1,395 manufacture or rework commercial products, and 1,474 manufacture or rework military products. The combined HAP emissions from these facilities [excluding subcontractors] are estimated to be over 208,000 tons per year.

The aerospace coatings regulated under the NESHAP are shown in **Figure 1**. Materials and processes regulated under the NESHAP are subject to maximum achievable control technology [MACT], as emissions from these materials are believed to be carcinogens, reproductive toxicants, or can create other serious health effects for exposed personnel. Additional materials and processes which are regulated under the NESHAP, but not discussed in this paper, are: cleaning operations; hand-wipe solvents; coating spray gun cleaning; flush cleaning; aircraft depaint operations; chemical milling maskants; and procedures for handling non-RCRA waste.

Figure 2 shows the aerospace coatings and materials proposed for regulation under the CTG. These materials are subject to reasonably available control technology [RACT], which has less stringent regulatory requirements and has a lower cost of compliance. The materials regulated under the CTG are 3% [6500 tons] of the total of the aerospace emissions.

SOURCE	REQUIREMENTS	DESCRIPTION
Primer & Topcoat	Standards	Uncontrolled Primers 1. Organic HAP content limit: 350 grams/liter [less water] as applied. 2. VOC Content limit: 350 grams/liter [less water and exempt solvents] as applied Uncontrolled topcoats 3. Organic HAP content limit: 420 grams/liter [less water] as applied. 4. VOC content limit: 420 grams/liter [less water and exempt solvents] as applied Uncontrolled Primers and Topcoats 5. Primers and topcoats can achieve compliance through: [1] being below limit in themselves or [2] average with compliant primers 6. Primers and topcoats cannot be averaged together. Controlled Primers and Topcoats 7. If control device is used, must be designed to capture and control all emissions from the application operations and must achieve an overall control efficiency of at least 81%. All Primers and Topcoats 8. Specific application techniques must be used. If alternative is sought, can only be used if emissions are less than or equal to HVLP or electrostatic spray application techniques as demonstrated under actual production conditions. 9. All application equipment must be operated according to manufacturer's specifications 10. Exemptions from 8 above provided for certain situations 11. Operating requirements for the application of primers that contain inorganic HAP, including control with either particulate filters or waterwash and shutdown if pressure falls outside manufacture's specified operating limits. 12. Exemptions from 11 provided for certain application operations.

Figure 1. NESHAP Standards Established for Primers and Topcoats

There are additional requirements for performance tests and test periods; test methods and procedures to determine the organic HAPs content of the primers and topcoats, the efficiency of the carbon adsorber, and alternative application methods; monitoring and recordkeeping requirements; and reporting requirements.

COATING	EPA PROPOSED VOC [grams/liter]	AIA PROPOSED VOC [grams/liter]
Ablative	600	720
Adhesion Promoter	890	890
Antichafe	660	660
Clear Coating	530	720
Commercial Exterior Primer	350	650
Adhesive Primer	770	770
Corrosion Inhibiting Compound	700	700
Electric or Radiation Effect Coatings	800	800
Fire Resistant Coating	800	800
Flexible Primer	*635*	*635*
Flight Test Coatings	840	840
Flight Test Coatings - missiles or single use craft	420	420
Fuel Tank	*720*	*720*
High Temperature	850	850
Impact Resistant	600	600
Ink - screen print	840	840
Ink - part marking	850	850
Insulation Covering	710	770
Lacquers	*830*	*830*
Metallized Epoxy	*650*	*740*
Mold Releases	30	770
Optical Anti-Reflection	700	750
Pretreatment	750	780
Protective Oils & Waxes	840	960
Rain Erosion Resistant	347	850
Rain Erosion Resistant Compatible Primer	850	850
Solid Film Lubricant	526	960
Space Vehicle Coatings	890	890
Specialized Function Coatings	890	890
Temporary Protective Coatings	250	350
Thermal Control	770	770
Wing Coating	*750*	*850*

Figure 2. Volatile organic content limits proposed for coatings regulated under the Control Techniques Guidelines [CTG] AIA is the Aerospace Industries Association

A public hearing is scheduled for the NESHAP on 15 August 1994, with promulgation within 30 days. The CTG is currently under development by a joint task force composed of representatives from the EPA, Aerospace Industries Association [AIA], Department of Defense, and NASA. The italicized materials in Figure 2 are candidates for transfer to the NESHAP document, because of their high VOC and somewhat higher volumes of usage.

Elimination of Ozone Depleting Chemicals. The requirement to cease the manufacture of Class I ozone depleting chemicals [ODCs], as stipulated by the 1990 CAAA, is imposed concurrently with the requirements to comply with the NESHAP and CTG. Executive Order 12843, signed by President Clinton in June 1993, mandates the elimination of the use of ODCs at federal facilities and requires the elimination of contract language that requires government contractors to use or deliver contract deliverables which contain Class I ODCs in new or modified contracts.

Ozone depleting chemicals have historically been classified as "exempt" compounds, i.e., their emissions did not contribute to the VOC emissions from materials. Consequently, many organizations diluted their materials with "exempt" solvents to reduce the emissions to the regulatory-mandated limit. ODCs have been used quite widely throughout the aerospace industry for many processes which require non-aqueous solvents that are non-flammable and have high evaporation rates.

The concurrent elimination of ODCs will complicate the process of complying with the CTG and NESHAP, as these materials will no longer be allowed for use in aerospace materials and processes.

Pollution Prevention. Under federal regulations, all organizations are required to develop pollution prevention programs. However, the signing of Executive Order 12856 Pollution Prevention and Right-to-Know in the Government [October 1993] placed additional requirements on federal facilities and organizations that perform on government-issued contracts. Most government agencies have established a goal of the reduction by 50 percent of releases and off-site transfers of SARA Title III chemicals for treatment and disposal by 1999. This reduction is planned not only for the federal facilities, but will also be included in the acquisition process for new and existing aerospace programs.

The primary focus of the 50 percent reduction in the use of toxic materials is on the following chemical constituents, which are the largest volume use streams of the SARA Title III chemicals or pose significant health hazards:

Benzene	Methyl ethyl ketone [MEK]
Cadmium	Methyl isobutyl ketone [MIBK]
Carbon Tetrachloride	Nickel
Chloroform	Tetrachloroethylene
Cyanide	Toluene
Dichloromethane	Trichloroethane
Lead	Trichloroethylene
Mercury	Xylene
Methylene dianiline [MDA]	Diisocyanate
Freons	Chromium

In addition to the reduction requirements, government agencies have imposed the requirement for aerospace contractors to produce metrics on the volumes used of each product which contains these constituents and reduction status. The additional requirement in the Executive Order to revise Technical Orders and Military Specifications that require these materials is an enormous task.

Federal Acquisition, Recycling, and Waste Prevention. Executive order 19873 Federal Acquisition, Recycling, and Waste Prevention, signed October 1993, mandates the review and revision of specifications, product descriptions, and standards to enhance procurement of recycled or environmentally preferable products by government agencies. The order sets a minimum content standard for printing and writing papers and sets agency goals for waste reduction and procurement of environmentally preferable products.

Additional requirements are environmental factors must be considered in acquisition planning for all procurements and in contract awards. Federal agencies must identify, evaluate, and revise standards or specifications that present barriers to minimizing the emission of harmful by-products. Each federal agency is required to establish goals for solid waste prevention and recycling to be achieved by 1995. The requirements in executive order 19873 will be flowed to the aerospace contractor via contractual language on new and modified contracts.

Occupational Health and Safety [OSHA]. OSHA has also imposed more stringent industrial hygiene controls on some key aerospace materials: hexavalent chromium, cadmium, methylene dianiline, and methylene chloride. The increased controls, which include personal protective equipment, increased ventilation, specialized "set aside" control areas for use of these materials, add cost to fixed price production contracts which were not originally anticipated or included in the government contract or the final price of the product .

The aerospace industry has a unique problem in complying with changes in regulatory requirements. It can take up to 10 years to design a completely new aircraft. The production of complex aircraft, both commercial and military, relies on "long lead" procurement of assemblies, subassemblies and parts. Even though "rate manufacturing" can be between 5 to 50 units per year, many of the parts used were procured years earlier. Compatibility of reengineered materials with the "long lead" units already procured is a very large area of risk for this industry.

2.0 Strategies for Survival and Cost Control

Elements of the Strategy. The aerospace industry changes materials and processes in a very cautious manner, as these materials and processes must support a complex aircraft assembly which performs in a high risk environment. The pilot cannot pull the aircraft to the side of the road if an in-flight failure occurs which interferes with the ability the fly the aircraft safely. All aircraft have stringent performance requirements, which are defined by the aircraft mission, i.e., commercial [where passenger safety is critical]; military fight aircraft [where speed and agility are critical]; stealth aircraft [where low observability is a critical performance factor]. A simple material or process change can, in some cases, require the design allowables performance measurements be conducted again to verify the modified aircraft still meets the mission and flight safety requirements.

A key element in developing a strategy for incorporation of regulatory requirements into the design, manufacture, operation, maintenance and repair of the aircraft is the development of an integrated strategy, which includes both the engineering performance requirements as well as the regulatory requirements. Many organizations delegate their regulatory compliance responsibility to an administrative organization that has little visibility or understanding of the aerospace product performance requirements or the inherent risks of changing the materials or processes without a complete engineering evaluation of the subsequent impacts. The administrative organization will also be frustrated because the design, manufacturing, and logistical support community will not employ source reduction, where possible, to reduce the regulatory risk.

The second element in developing a successful strategy is the development of a long range strategic plan that will accommodate the advance planning for "long lead" procurements of components or assemblies for the aircraft.

The third element of a successful strategy is automation. Most of the regulations, both environmental and occupational health and safety, require the knowledge of all hazardous and VOC-emitting constituents of each material and process used. It is atypical for the engineering design community to be knowledgeable of the chemical composition of the coatings, adhesives, sealants, and other materials used on the air vehicle. The design engineer is untrained in the basic chemistry of the materials and processes. The use of automation to marry the regulatory requirements to the regulated constituents in aerospace materials is essential in ensuring compliance and in cost control in the design effort. Automation also facilitates the preparation of the extensive reports required by the regulatory agencies.

Strategy Development. Most aircraft systems are unique in their design, i.e., each system will have a unique fatigue profile for the design and materials of construction. Therefore, the first step in the development of a long range strategic plan is recognition that, in general, there must be a plan for each aircraft system. A "common" plan for multiple aircraft systems is more probable for commercial aircraft. Military aircraft are at the other end of the spectrum and a unique plan is usually required for each system. Space vehicles fall more toward the military end of the spectrum.

Project or Integrated Product Team. The environmental, occupational health and safety, and engineering community must integrate their missions, usually by employing a teamed approach to material and process changes. Typically the team will be composed of the following organizations: Materials and Processes; Logistics; Test Flight; Contracts; Procurement; Design; System Safety; Research & Development; Environmental Management, Occupational Health & Safety, and the Program Office. The development of the long range strategic plan and all subsequent changes to the materials and processes are reviewed by this team for all potential impacts.

Automation. All regulated constituents in the air vehicle materials and processes can be scanned into or manually entered into a relational database. The data is extracted from the Material Safety Data Sheet and supplier data. All regulated constituents are identified by their chemical abstracts number [CAS#]. The multiple material safety data sheets that comprise a material system are grouped to identify all constituents in the "as applied" material system [i.e. a two-part coating which uses a thinner or reducer]. The material system is then linked to the command media, i.e., military or contractor specification, technical order.

Commercial software is available which links the regulated constituents to all state, federal and local regulatory requirements. The final linkage is from the regulatory database to the command media which specifies it. The command media is the document used by all aerospace programs to ensure that only "qualified" materials and processes are used on an air vehicle.

This type of automation allows users to quickly identify which materials are regulated by high risk or recently changed and new regulations. The automation also allows tracking of the volumes of the materials used. When cost control is desirable, the objective must be to spend the limited dollars on the materials which represent the highest risk, which includes volume and ranked regulatory risk.

Approach. The approach used by Northrop B-2 Division was to progressively eliminate the use of the *highest risk* chemical constituents which posed the *lowest technical risk and cost.* Each material is characterized by the automation described above, which matrixes all local, state, and federal regulations which impact the materials or processes. All known "pending" or probable regulations are included in this matrix. This provides an approximate five year forecast of new regulations. The SCAQMD has been most helpful in assisting in these forecasts. All materials and processes are then designed to the most stringent regulatory requirements and forecasts.

This five year forecast approach adds cost in the up-front design effort, but recovers the cost many times over by reducing the multiple qualifications of materials and processes as the regulations change.

Each regulated constituent used was ranked, as shown in Figure 3.

RANK	DEFINITION
1	Command and control regulatory requirements
2	Acutely Toxic: causes biological damage as result of single exposure to relatively small amounts
3	Reproductive toxicants
4	Carcinogens, Chronic Exposure [IARC 1>2>3]
5	Non-carcinogen, Chronic Exposure
6	Threshold regulations: control to an emissions level

Figure 3. Ranking of regulated constituents based upon regulatory and exposure risks.

An iterative decision process **[Figure 4]** was utilized to identify the highest-risk materials for replacement or implementation of control technology. The decision process incorporates both the engineering technical requirements with the regulatory requirements using a risk-based decision process.

This process has allowed a rational management of regulatory requirements with a reduced cost. Production schedule interruptions are minimized as the plan allows the forecast of material changes and places them on a schedule. Cost control is achieved by avoiding the use of the regulated constituents in the initial design and by preventing iterative qualifications of the same material caused by implementation of new regulations.

The long range strategic plan places the implementation of new regulatory requirements and the engineering closure plan to eliminate the material on the same time line. Each material is evaluated for total cost to use, i.e., hazardous waste, contingent liability, technical risk, health risk, regulatory risk, touch labor impacts, and capital asset replacement costs. Each project is assigned a process owner and metrics of progress on the project are reviewed regularly.

The benefit of this approach is the production program will soon move ahead of the regulations. The process will no longer be **compliance** driven.

Conclusions

Compliance with the rapidly changing environmental and health and safety regulations is about 10 percent science of material substitution and 90 percent managing the process to control cost, schedule and performance. It requires that non-traditional teams from the regulatory and the engineering departments within an organization be formed to develop common goals and approaches. Where applicable, minimization of high risk constituents, rather than elimination, is employed to reduce risk to the air vehicle

The cost of complying can be reduced significantly with automation, which also reduces the risk of non-compliance with a large and complex body of regulations. The goals of improving the environment and meeting the mission and performance requirements are not mutually exclusive - just a large management task which lends itself well to a systems engineering approach.

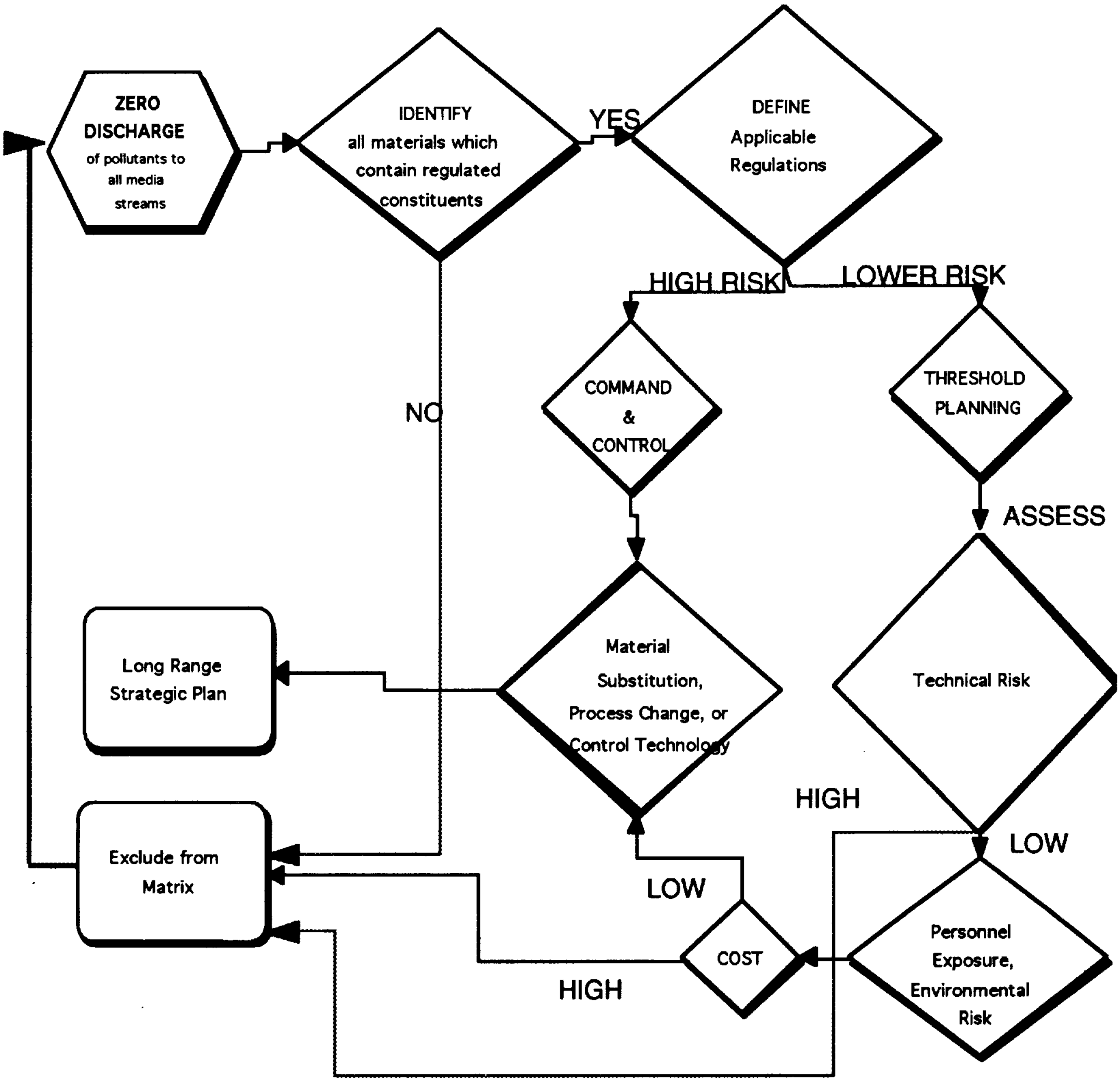

Figure 4. Risk-based decision process for process management and development of the long range strategic plan