NASA Conference Publication 3297

Aerospace Environmental Technology Conference—Executive Summary

A.F. Whitaker, Editor
Marshall Space Flight Center • MSFC, Alabama

Summary of a conference held in
Huntsville, Alabama
August 10–11, 1994

National Aeronautics and Space Administration
Marshall Space Flight Center • MSFC, Alabama 35812

March 1995

AEROSPACE ENVIRONMENTAL TECHNOLOGY CONFERENCE CO-SPONSORS

- Marshall Space Flight Center
  MSFC, AL 35812

- NASA Operational Environment Team
  MSFC, AL 35812

- Office of Space Flight, NASA Headquarters
  Washington, DC 20546-0001

- SAMPE Space Manufacturing Thrust Committee
  P.O. Box 2459
  Covina, CA 91722

- American Institute of Aeronautics and Astronautics
  370 L'Enfant Promenade SW
  Washington, DC 20024-2518

- National Center for Manufacturing Sciences
  3025 Boardwalk
  Ann Arbor, MI 48108

FOREWORD

The mandated elimination of CFCs, Halons, TCA and other ozone depleting chemicals and specific hazardous materials has required changes and new developments in aerospace materials and processes. The aerospace industry has been involved for several years in providing product substitutions, redesigning entire production processes and developing new materials that minimize or eliminate damage to the environment. These activities can be, for the most part, defined as environmental impact avoidance technology through the introduction of environmentally friendly replacement materials and processes and are consistent with achieving the Administration's "Technology for a Sustainable Future" initiative goals. This Conference has offered an opportunity for aerospace scientists and engineers to assess this evolving technology.

The current emphasis within environmental technology is on: replacement cleaning solvents and their application verifications, compliant coating applications including corrosion protection systems and removal techniques, chemical propulsion effects on the environment, and the initiation of modifications to relevant processing and manufacturing specifications and standards. Already, many applications of materials and processes have been affected by this new environmental technology. This volume synopsizes those results and implications. It is not a substitute for detailed conference papers to be published in 1995 or those that may be found in professional journals.

We would like to acknowledge those individuals who served on the Conference Steering Committee:

Paul Schuerer, Chairman
Ann Whitaker, Technical Program Chairman
DeWitt Burns
Ralph Carruth
Marceia Clark-Ingram
Richard Congo
Beth Cook
Eddie Davis
Ben Goldberg
Arthur Henderson
Tamara McIntyre
Ron Mize
Steve Newman
Freda Summers

Finally, we would like to thank the many people who helped make this Conference such a success: Marshall Space Flight Center Director, Porter Bridwell; Marshall Space Flight Center Acting Deputy Director, Charlie Blankenship; MSFC's Materials

and Processes Laboratory and Propulsion Laboratory personnel; NASA Headquarters Deputy Associate Administrator for the Space Shuttle, Bryan O'Connor; EPA Director of the Emission Standards Division, Bruce Jordan; White House Fellow, Office of Science and Technology Policy, Dr. Thomas Houlihan; the other Conference sponsoring organizations including the NASA Headquarters Office of Space Flight, the NASA Operational Environment Team, the AIAA, the SAMPE Space Manufacturing Thrust Committee, the National Center for Manufacturing Sciences, the University of Alabama's Office of Conferences and Marketing, and all the government, industry and academic investigators.

Robert J. Schwinghamer, Conference Chairman

TABLE OF CONTENTS

Page

FOREWORD iii

SESSIONS

OVERVIEW: KEYNOTE, PLENARY OPENING SESSION 1

CHEMICAL PROPULSION AND THE ENVIRONMENT 3

CORROSION PROTECTION REPLACEMENTS 7

NON-CFC CLEANING SOLVENTS, PROCESSES AND PARAMETERS 1 9

COMPLIANCE STRATEGIES 12

ENVIRONMENTALLY SAFE FUELS, FIRE SUPPRESSANTS, REFRIGERANTS, AND INSULATIONS 15

NON-CFC CLEANING SOLVENTS, PROCESSES AND PARAMETERS 2 19

EMERGING TECHNOLOGIES FOR THE PROPULSION INDUSTRY 22

ENVIRONMENTALLY COMPLIANT COATING APPLICATIONS AND REMOVAL TECHNIQUES 25

CLEANING VERIFICATION—INSTRUMENTATION AND TECHNIQUES 1 29

ENVIRONMENT TECHNOLOGY INFORMATION SYSTEMS—SPECIFICATIONS, STANDARDS, AND DATA BASES 32

ALTERNATIVE CLEANING TECHNOLOGY SYSTEMS 35

CLEANING VERIFICATION—INSTRUMENTATION AND TECHNIQUES 2 38

OVERVIEW: KEYNOTE, PLENARY OPENING SESSION

The Earth's environment affects all of us and its well being must be ensured. Legislation aimed at protecting our environment has resulted in limitations on the use of many traditional aerospace chemicals and processes. As a result, concentrated efforts to make our materials friendly to the environment are well underway in the aerospace industry, and this conference has provided a much needed opportunity for many technical experts to share their new-found knowledge with colleagues.

In his Keynote address, Bryan O'Connor, Deputy Associate Administrator (Space Shuttle), Office of Space Flight, NASA Headquarters, acknowledged the many who over the last several years have developed and tested innovative materials to assure that necessary environmental process changes result in increased safety and reliability in space transportation systems. He indicated that the industry and NASA challenge is to find new, compliant designs and materials for existing aerospace needs. "Until we have demonstrated that the alternatives work and then hand them over to the operators, we have not achieved our goals... The motivators, the problem solvers represented at this Aerospace Environmental Technology Conference... must lead industry into an environmentally compliant method of doing business. We must change our environment for the betterment of the Earth, and we must use the same teamwork that took us to the Moon 25 years ago."

Keynote Speaker

Bryan O'Connor, Deputy Associate Administrator (Space Shuttle), Office of Space Flight, NASA Headquarters, Washington, DC 20546-0001, (202-358-1200)

Chair, Plenary Session

Dr. Ann F. Whitaker, Chief of the Project and Environmental Engineering Division, NASA/Marshall Space Flight Center, EH41, MSFC, AL 35812, (205-544-2510)

Speakers

P1.1 Bruce Jordan, Director, Emissions Standards Division, U.S. Environmental Protection Agency, MS 13, Research Triangle Park, NC 27711, (919-541-5572)

P1.2 Robert J. Schwinghamer, Deputy Director for Space Transportation Systems, Science and Engineering, NASA/Marshall Space Flight Center, EA01, MSFC, AL 35812, (205-544-1001)

Luncheon Dr. Thomas Houlihan, Executive Office of the President, Office of Science and Technology Policy, Washington, DC 20500, (202-456-6085)

In the plenary session, Bruce Jordan, of the EPA discussed the environmental compliance timelines and the need for the aerospace industry and EPA to work together for shared solutions. EPA established the first Ozone Standard in 1970. In 1990, the Clean Air Act Amendments were strengthened, making compliance tougher. They are broad based and will influence almost any aerospace processing activity. Congress has given EPA a timetable to work which requires two major regulations to be promulgated per month. All future legislation follows the same trend of becoming tougher and tougher. One hundred seventy four NESHAP regulations must be written by the year 2000, and of these, at least twenty percent will affect NASA contractors. Compliance times are short with only eighteen months to implement reporting methods and less than three years for full implementation. EPA is asking for input to the hundreds of regulations which must be written within the next few years because EPA cannot write wisely without help in understanding the processes involved. "...therefore, use the opportunity to participate in the forming of these regulations," he said.

Robert Schwinghamer, Deputy Director of Science and Engineering for Space Transportation Systems at NASA's Marshall Space Flight Center, summed up the environmental technology efforts underway by NASA and the contractor community as... "working diligently with the EPA and with each other to develop environmentally friendly manufacturing processes and materials." He described the activities of the NASA Operational Environment Team (NOET) which he leads. The team was founded in 1992 to provide the Agency a central environmental technology resource drawing on all NASA Centers' capabilities with the objective of supporting program managers who must ultimately deliver environmentally compliant hardware. Combined efforts of NASA and its contractors have resulted in candidate replacements for a long list of materials and processes for use in manufacturing space flight hardware. Schwinghamer stated that, "NASA and its contractors again are rising to the challenges by shifting from waste management strategies to pollution prevention and efficient resource use. This is an effort that follows the philosophy to provide a 'Technology for a Sustainable Future'.

During his luncheon address, Dr. Thomas Houlihan of the Office of Science and Technology Policy described the Environmental Technology Policy Development leading to the Administration's "Technology for a Sustainable Future" initiative. He noted that environmental policy dates back to 1970 from.. Congress recognizing the impact of man's activity.. on the natural environment.... Environment is one of nine primary committees of the National Science and Technology Council. He stated that the new directions of environmental technology shift to pollution avoidance technologies while maintaining support for control and remediation. Executive orders levied on Federal Agencies that influence environmental technologies include requirements for increased energy efficiency, utilization of paper products with recycled fiber content, reduction of toxic emissions by 50% by 1999, and the procurement preference for environmentally compliant products.

SESSION A1

CHEMICAL PROPULSION AND THE ENVIRONMENT

This session provided an overview of the detrimental and beneficial consequences of the chemical propulsion industry as it relates to the environment. The consequences included those of technical and programmatic nature, both real and perceived, both local and global. All four of the papers may be examined within the context of the overarching major focus of the conference "Technology for a Sustainable Future". The session's relevance within this context is to the monitoring and assessment category which was reflected through the session in both of its implicit aspects: development of reliable and validated methodologies for measurement of environmentally related current conditions and determination of appropriate monitoring and analysis methodologies for assessing and predicting effects of future corrective measures. Papers A1.1, A1.2 and A1.4 constitute a collective summary of the effects of the chemical propulsion industry on environmental issues from manufacture, through test and flight and the resultant utility of the flight. Paper A1.3 reflects a special case of assessing currently employed analytical methodology for validity to chemical propulsion issues. Due to the natural grouping of papers, A1.3 proceeds the others.

Paper A1.3 used computational fluid dynamics (CFD) technology to evaluate the constituent products from the exhaust plume of an RD-170 engine. Typically, this analysis is made using frozen chemistry at the exit plane or throat of a motor or engine system, consistent with similar evaluations of industrial smoke stack exhaust species

Chairs

Dr. Ben Goldberg, RSRM Chief Engineer, NASA/ Marshall Space Flight Center, EE51, MSFC, AL 35812, (205-544-2683)

Dr. Clark Hawk, Director of Propulsion Research Center, University of Alabama in Huntsville, RI Bldg E26, Huntsville, AL 35899, (205-890-7200)

Speakers

A1.1 *Atmospheric Environmental Implications of Propulsion Systems*, Allan J. McDonald, Vice President and Senior Staff, Thiokol Corporation, Space Operations, P. O. Box 707, MS A10B, Brigham City, UT 84302-0717, (801-863-3855) and cloud dispersion modelling. The objective of this work was to develop a more appropriate technology for rocket motor exhaust plumes, which took into account an equilibrium chemistry for the plume throughout the near field, external-to-nozzle, reactive zones. The environmentally interesting constituents of the plume (carbon monoxide and thermal nitric oxides) were noted to change significantly using this three-dimensional, viscous flow, pressure-based CFD assessment. The test stand flow physics, including multiple-nozzle clustered engine plume interactions, air aspiration, plume mixing with entrained air, after-burning, counter-afterburning, water-quenching and plume impingement and turning were evaluated for effects and calculation sensitivity to these effects. The resultant effects indicated a very minor increase in nitric oxide formations (from 0 to .4 lb/sec). These predicted criteria pollutant total emission rates agreed reasonably well with those of existing hydrocarbon engine hot-firing test data. The resultant technology has clear applications in assessment of rocket launches and in the development of air breathing engines.

The remaining presentations examined the environmental impacts, both positive and negative, of chemical propulsion for manufacture, launch and associated usage. The manufacturing information may be summarized as follows:

The chemical propulsion industry makes up approximately .06% of the U. S. GNP but may account for approximately 3% of the nation's R&T dollars. A substantive portion of these dollars are currently targeted at addressing the special problems the industry has with development of new, environmentally compliant, materials and processes. The solid industry was identified as having two, significant challenges: pending elimination of 1,1,1 trichloroethane (TCA) and the disposal of waste propellants from current and past manufacture. The liquid propulsion

A1.2 *Manufacturing Waste Disposal Practices of the Chemical Propulsion Industry*, Dr. Ben Goldberg, RSRM Chief Engineer, EE51, NASA/MSFC, 35812, (205-544-2683)

A1.3 *CFD Assessment of the Pollutant Environment from RD-170 Propulsion System Testing*, Dr. Ten See Wang, NASA/Marshall Space Flight Center, ED32, MSFC, AL 35812, (205-544-0503)

A1.4 *Environmental Benefits of Chemical Propulsion*, Joyce A. Hayes, NASA/ Marshall Space Flight Center, ED52, MSFC, AL 35812, (205-544-1206) industry's most significant problems are associated with the elimination of CFC's, and specifically CFC 113. The chemical propulsion industry was estimated to use approximately 4 million pounds of the 691 million pounds of TCA produced in the U. S. in 1992. The liquid industry similarly represented usage of less than 1% of the CFCs produced, and 1-2% of the CFC 113. The chemical propulsion industry was identified as using approximately 12% of the U. S. manufactured liquid hydrogen, less than 1% of the liquid oxygen and a tiny portion of the hydrocarbon fuels. The metal components utilize a negligible .005% of the U. S. steel consumption and .03% of the aluminum. The solid industry's waste disposal issue, approximately 6,500 tons per year, represents 1% of the DoD generated Hazardous Waste levels and less than .02% of the U. S. production (which is dominated by production from the Chemical Manufacturing Industry).

The chemical propulsion industry's Atlas, Delta, Titan and Shuttle were shown to be making substantive improvements in their programs; the industry clearly is conducting a significant effort to pursue environmental replacement technologies for ODCs. The industry's environmental issues are comparatively small (typically less than 1% of the U. S. totals) but the industry has recognized those issues and is proactively addressing them in a manner that provides for technology transfer for the rest of the national industrial base.

Three independent studies examining the impact of rocket launches on the earth's environment were assessed during the first paper's presentation. The studies discussed the issues of acid rain in the troposphere, ozone depletion in the stratosphere, toxicity of chemical rocket exhaust products and the potential impact on global warming from CO_2 emissions. Local, regional, and global impact assessments were examined and compared with both natural sources and anthropogenic sources of known atmospheric pollutants with the following conclusions:

Neither solid nor liquid rocket launches have a significant impact on the earth's global environment, and there was not a significant difference in effect noted between the two. Regional and local atmospheric impacts are more significant than global impacts, but are of limited duration; the measurements quickly return to normal background conditions within a few hours after launch. Vastly increased space launch activities equivalent to 50 U. S. Space Shuttles or 50 Russian Energia launches per year would not significantly impact the above conclusions. These assessments were based upon homogeneous gas phase chemistry analysis; heterogeneous chemistry from exhaust particulates, such as aluminum oxide, ice contrails, soot etc... and the influence of plume temperature and afterburning of fuel-rich exhaust products, need to be further addressed. It was the consensus of these studies that computer modeling of interactive plume chemistry with the atmosphere needs to be improved and computer models need to be verified with experimental data. Rocket exhaust plume chemistry might be modified with propellant reformulation and changes in operating conditions, but, based upon the current state of knowledge, it does not appear that significant environmental improvements from propellant formulation changes can be made, or are warranted. Flight safety, reliability, and cost improvements are paramount for any new rocket system, and these important aspects cannot be compromised.

The final paper dealt with the benefits of chemical propulsion, which are tightly linked to the measurement and understanding of global climate change and Earth Observation. Anthropogenic and natural influences affecting the Earth system are recognized internationally as having potentially adverse, global consequences over the long term, threatening the current standards for quality of life. Measurement of fossil fuel resources, fish, wild life, metals and minerals, once performed with dousing rods and exploration parties may now be accomplished via satellite on a global scale. To accomplish this, chemical propulsion must be used, as only chemical propulsion allows satellite insertion. Satellites were identified as critical for appropriate environmental monitoring; in situ measurements are often constrained by local effects. Site variability is difficult to account for in large scale measurement efforts extending over multiple geographical regions. Low altitude data collection is also useful for characterizing complex Earth processes. It provides intermediate information on the atmospheric processes, as well as performing the calibration and validation functions for space-based remote-sensors. Both in situ and low altitude observations provide discreet data points, and therefore do not furnish a concise, dynamic picture of the global climate and interactions. The presentation pointed out that only rockets can raise payloads into the thermosphere and the highest of high altitude balloons can raise payloads into the mesosphere.

In summary, chemical propulsion, like all environmentally conscious industries, does provide limited, controlled pollutant sources through its manufacture and usage. However, chemical propulsion is the sole source which enables mankind to launch spacecraft and monitor the Earth. The information provided by remote sensing directly affects national and international policies designed to protect the environment and enhance the overall quality of life on Earth. The resultant of chemical propulsion is the capability to reduce overall pollutant emissions to the substantive benefit of mankind.

SESSION A2

CORROSION PROTECTION REPLACEMENTS

Corrosion control, as a discipline, is undergoing a radical change in its basic technologies due to environmental evaluations. It is necessary to achieve a balance between the losses and harm done by degradation of hardware and the harm due to the application and removal of protective materials. In design activities this means paying attention to avoidance and control of hazardous materials and processes by keeping abreast of replacement technology research and development. This session concentrated on distributing replacement technology developments for plating and chromium based systems.

Distribution of information was highlighted by the first presenter, Dr. Paul Chalmer, as he discussed *Pollution Prevention and Control Technology for Plating Operations*. The plating industry in particular has identified many basic materials and processes which will require replacement technologies but do not have a drop in replacement available. An ongoing project was established between the National Center for Manufacturing Sciences and the National Association of Metal Finishers to compile the available prevention and control technology and place it in a form that will aid the compliance planning for existing plating operations. Continuing efforts will document trends in chemical substitution, new regulatory impacts and waste recovery or disposal options.

Thin Film Sulfuric Acid Anodizing as a Replacement for Chromic Acid Anodizing dealt with replacement materials for reducing the hazardous components of a process and its waste stream. One of the significant side issues discussed by

Chairs

Randy Raley, United Space Boosters, Inc., 188 Sparkman Drive, Huntsville, AL 35807 (205-721-5787)

Mitchell Mendrek, NASA/Marshall Space Flight Center, Metallurgical Engineering Branch, EH24, MSFC, AL 35812,(205-544-2619)

Speakers

A2.1 *Assessment of Pollution Prevention and Control Technology for Plating Operations.* Dr. Paul D. Chalmer, Program Manager, National Center for Manufacturing Sciences, 3025 Boardwalk Drive, Ann Arbor, MI 48108 (313-995-4911)

Kelly Kallenborn was the problem associated with contracts which still call out specifications based on older technology. In addition to identification and development of replacements there are undocumented performance requirements and qualification issues to be resolved before successful introduction of replacements.

Mary Nelson and Earl Groshart emphasized another risk in development of replacement technologies in their presentation of *Cadmium Plating Replacements*. At the beginning of the project zinc-nickel and tin-zinc alloys were identified as viable substitute materials. Subsequently, new regulatory requirements for nickel have reduced the appeal of the zinc-nickel option. The need to maintain multiple options during development should be considered necessary, especially where components of the new technology are still under study for their own environmental impacts. Development of the control technology for plating alloys with consistent composition has been proven, and studies of process effects on the base metals are being conducted to complete the qualification requirements for substitution.

The final presentation made by Frank Zimmerman, *Replacement of Corrosion Protection Chromate Primers and Paints Used in Cryogenic Applications on the Space Shuttle with Wire Arc Sprayed Aluminum Coatings*, addressed change based on a new corrosion control philosophy. Corrosion protection was initially provided by a coating inhibitor system based on hexavalent chromium. The study showed that an active cathodic protection system based on a directly applied anodic metal, in this case aluminum, provided equal or superior corrosion control while meeting all performance requirements associated with the end use. In addition, the waste streams associated with application and removal of the metal coating are recyclable.

A2.2 *Thin Film Sulfuric Acid Anodizing As a Replacement for Chromic Acid Anodizing*, K. J. Kallenborn, Rocketdyne Division, Rockwell International Corporation, 6633 Canoga Avenue, Canoga Park, CA 91303, (818-586-7132)

A2.3 *Cadmium Plating Replacements*, Mary J. Nelson and E. C. Groshart, Boeing Defense and Space Group, P. O. Box 3999, Seattle, WA 98124-2499, (206-773-2273)

A2.4 *Replacement of Corrosion Protective Chromate Primers and Paints Used in Cryogenic Applications on the Space Shuttle with Arc Sprayed Aluminum Coatings*, Frank R. Zimmerman, NASA/Marshall Space Flight Center, EH25, MSFC, AL 35812, (205-544-4958)

SESSION A3

NON-CFC CLEANING SOLVENTS, PROCESSES AND PARAMETERS 1

The search for alternatives to replace two of the ozone depleting substances, CFC-113 and 1,1,1-trichloroethane (TCA), for cleaning applications is the subject of extensive test programs by a number of organizations. Numerous technologies are available to evaluate as potential replacements; however, each application has specific requirements which must be met and no one technology will be suitable for all applications. The testing required to qualify alternative technologies is extensive, particularly for high performance applications such as the precision cleaning of oxidizer hardware and surface preparation prior to bonding. The methodology used and test results obtained from current qualification programs can provide guidance for other users seeking alternatives.

Gale Allen and Kenneth Fishell of NASA/ Kennedy Space Center and Wiltech, respectively, described the final phase of implementing aqueous methods to replace CFC-113 for the precision cleaning and verification of small-scale hardware used in oxidizer systems for Space Shuttle hardware. Aqueous cleaning technology is utilized throughout the entire cleaning process, beginning with the gross clean phase using a parts washer and proceeding through the precision cleaning operation using aqueous detergent solutions and surfactants. Cleanliness verification is also performed using aqueous techniques to ensure the stringent particulate and nonvolatile residue requirements are met for oxidizer hardware. Nonvolatile residue verification, traditionally performed by the gravimetric analysis of a CFC-113

Chairs

Dr. Richard Congo, NASA/Marshall Space Flight Center, Chief of Materials Compatibility and Environmental Engineering Branch, EH42, MSFC, AL 35812, (205-544-2629).

Marilyn Fritzemeier, Rocketdyne Division, Rockwell International Corporation, 6633 Canoga Avenue, P. O. Box 7922, MC AC67, Canoga Park, CA 91309-7922, (818-586-7296)

Speakers

A3.1 *Aqueous Cleaning and Verification Processes for Precision Cleaning of Small Parts*, Gale J. Allen, Chief of Materials and Chemical Branch, NASA/ Kennedy Space Center, Materials Science Laboratory, DM-MSL-1, KSC, FL 32899, (407-867-3910) flush sample, is performed by the novel technique of Total Organic Carbon analysis of the final water rinse. For this application, the use of aqueous cleaning media used in conjunction with ultrasonic agitation has been shown to successfully clean hardware to the level currently achieved using CFC-113.

Effective cleaning depends on the selection of suitable agitation methods and equipment as well as identification of the most appropriate cleaning fluid. Use of ultrasonic agitation to enhance the cleaning effectiveness of aqueous solutions is prevalent among the industry. However, a multitude of ultrasonic equipment is available with varying frequencies, power levels and transducer types, making it difficult to select equipment for new cleaning facilities. An ultrasonic tank study as described by Joan Becker of Rocketdyne provided the basis for equipment selection as part of the design of a six tank aqueous ultrasonic precision cleaning facility. Cleaning performance testing was conducted using laboratory-scale and industrial-size (35 to 320 gallon) ultrasonic tanks with varying combinations of frequencies and power levels. Use of 25 kHz tanks for the two initial immersion cleaning operations and a 40 kHz tank for the final immersion cleaning was determined to provide the most effective cleaning. This study illustrates the type of testing required to select the ultrasonic equipment most suitable for use in a precision cleaning operation to remove particulate and organic film contaminants.

Due to the myriad of cleaning technologies currently available as substitutes for CFC-113 and TCA, selection of the most appropriate cleaner/technology for a particular application can be difficult and labor intensive. Roy Marrs indicated that the Thiokol Corporation has applied the methodology of Quality Function Deployment (QFD) analysis to downselect and evaluate alternate cleaners. Key

A3.2 *Ultrasonic Frequency Selection for Aqueous Fine Cleaning*, Joann F. Becker, Rocketdyne Division, Rockwell International Corporation, 6633 Canoga Avenue, P. O. Box 7922, MC AC67 Canoga Park, CA 91309-7922, (818-586-6577)

A3.3 *QFD Analysis of RSRM Aqueous Cleaners*, Roy D. Marrs, Thiokol Corporation, P. O. Box 707, MS L50, Brigham City, UT 84302, (801-863-3131)

A3.4 *Design of Experiments Test to Define Critical Spray Cleaning Parameters for Brulin 81SGD and Jettacin Cleaners*, Jill M. Keen, Thiokol Corp., Building 4712/Room B300, MSFC, AL 35812, (205-544-2748)

A3.5 *An Ozone Friendly HFC Alternative to CFC-113 and Methyl Chloroform*, Abid N. Merchant, Senior Research Associate, E. I. DuPont de Nemours and Co., Chestnut Run Plaza, 711F, Wilmington, DE 19880, (302-999-4269) requirements, identified and weighted through customer surveys and brainstorming sessions, were used to develop the testing and scoring used in the subsequent screening tests. Initial candidate screening included environmental and toxicity evaluations, as well as conducting laboratory performance tests. Weighted scoring of each cleaner was then used to provide a methodical downselect from fifteen candidate cleaners to five then with more extensive testing to two candidates. The step to downselect to the final candidate will proceed with more rigorous testing including cleaning effectiveness, corrosion potential, bond strengths and cleaner robustness as determined via a design of experiments methodology. This program clearly illustrates the advantages of using the QFD approach to provide a methodical, traceable technique with minimized testing to select the optimal cleaning technology for a specific application.

Jill Keen described test results from the program to identify alternatives to replace 1,1,1 trichloroethane for the cleaning of solid rocket motor metal substrates prior to bonding and demonstrated that the use of spray-in- air aqueous cleaning was superior to vapor degreasing. High cleaning efficiencies were demonstrated for the two downselected candidates by bond strength evaluations.

Potential cleaning alternatives to CFC-113 and TCA are not limited to the aqueous cleaners. In some applications, the advantages of organic solvents are required, particularly if the organic materials possess some of the attractive features of CFC-113. Among the potential candidates are the hydrofluorocarbons (HFCs). Abid Merchant presented an update of DuPont's progress in developing HFC 43-10. Toxicity testing of the HFC is near completion and commercial availability is expected in 1995. This particular HFC has physical properties similar to those of CFC-113 and is being offered as a potential alternative to CFC-113 and TCA for specific applications. It possesses the advantages of having zero ozone depleting potential and is nonflammable. The HFC can be azeotroped with other solvents to improve its cleaning ability.

The cleaning fluids and technologies described show that the use of the ozone depleting substances, CFC-113 and TCA, can be eliminated through the substitution of more environmentally benign substances. Under the "Technology for a Sustainable Future" initiative, these types of technology projects can be classified as "Avoidance Technologies". Although, in many cases, extensive qualification testing is required to implement the alternatives, reduction in the use of target regulated chemicals through elimination can provide long-term benefits.

SESSION B1

COMPLIANCE STRATEGIES

The "Compliance Strategies" session papers were focused on "avoidance" as the preferable environmental technology or "green technology" to produce the advances needed for sustainable development. Avoidance technology covered both the replacement of the use of hazardous chemicals with environmentally benign substitutes as well as the use of alternative processes which significantly minimized or eliminated the production of environmentally hazardous substances. Unique strategies and concepts for "control" technologies which render hazardous substances harmless, thus preventing release of these substances into the environment were also presented.

In the presentation by Clare Vinton, National Center for Manufacturing Sciences, "Green Design" of a new process or product is the recommended method to help in establishing a "Closed Industrial Ecology" and achieving sustainable development, thus meeting the goals of avoidance and control. Life cycle design in which pollution prevention, waste minimization, waste treatment and remediation of industrial wastes is considered up front as an important planning tool in today's environment. Emphasis is also placed on converting by-products, previously considered waste to raw materials suitable for other manufacturing processes. These recommendations focussed on both avoidance and control.

Innovative control technologies for effective and affordable volatile organic compounds (VOC) treatment of paint booth exhaust were described by Lewis C. Watt in *Air Pollution Control*

Chairs

Bob Hammond, Director of the Environmental Management Division, NASA Headquarters, Code J, Washington, DC 20546-0001, (202-358-1095)

Dr. Rebecca McCaleb, Director of the Environmental Engineering and Management Office, NASA/ Marshall Space Flight Center, AE01, MSFC, AL 35812, (205-544-4367)

Speakers

B1.1 *Environmentally Conscious Manufacturing*, Clare Vinton, Director of Environmentally Conscious Manufacturing, National Center for Manufacturing Sciences, 3025 Boardwalk, Ann Arbor, MI 48108-3266, (313-995-0300)

System Research - An Iterative Approach to Developing Affordable Systems, Laboratory scale, pilot scale, and production air control systems being researched include air recirculation, UV oxidation of VOCs, ozonated water treatment of VOCs, and carbon bed regeneration. Comparative analyses of these technologies individually and in combination were presented.

Presentations by Dr. James Shunk, *Evaluating the Cost Effectiveness of Environmental Projects: Case Studies in Aerospace and Defense*, and by Wesley Hammond, *Major Weapon System Environmental Life-cycle Cost Estimating for Conservation, Cleanup, Compliance and Pollution Prevention* (C^3P_2) both concentrate on methods and considerations to scope and cost environmental compliance considerations in new projects by analyzing current projects. Dr. Shunk's data was based on a case history of comparing conventional decoating methods such as chemical stripping with high pressure waterjet decoating, an avoidance technology. Process comparisons are described for both tangible and intangible benefits. This model demonstrated tangible benefits in terms of significant cost reductions and intangible benefits such as improvements in environmental safety since the residual hazardous waste produced with the waterjet process is limited to the coatings removed.

Hazardous waste volumes are higher for conventional methods by the introduction of hazardous chemicals or blasting agents that contribute to the final waste stream. Hammond, et al, provided the methodology developed for the U. S. Air Force to produce environmental life-cycle cost estimates for major weapon system acquisition programs. The Titan IV Space Launch Vehicle Program was selected for the pilot program. Life-cycle environmental issues focused on conservation, compliance, cleanup, and pollution prevention. The program life-cycle was reviewed from acquisition,

B1.2 *Air Pollution Control Systems Research - An Iterative Approach to Developing Affordable Systems*, Lewis C. Watt, Manager of Environmental Program, Applied Research Laboratory, The Pennsylvania State University, P. O. Box 30, State College, PA 16804, (814-865-6531)

B1.3 *The Search for CFC Alternatives is Over?*, Tim Crawford, Electronics Manufacturing Productivity Facility, 714 N. Senate Avenue, Indianapolis, IN 46202-3112, (317-226-5634)

B1.4 *Major Weapons System Life Cycle Cost Estimating for Conservation, Cleanup, Compliance and Pollution Prevention* (C^3P^2), Wesley Hammond, Program Manager, AFCESA/DC, Tyndall AFB, FL, (904-283-6261) through operation and support and ultimately to disposal and demilitarization. The final product can be used to assess environmental costs of such activities as building and operating automobiles, commercial airlines, etc.

Tim Crawford presented *The Search for CFC Alternatives is Over?*. Examples of approved CFC alternatives were provided which would assist users in avoiding the use of restricted and environmentally unfriendly chemicals. The search for CFC alternatives has been lengthy and process considerations extensive. The paper presents considerations specific to the printed circuit board assembly processes.

Scott Gallagher discussed the paper entitled *Prepsolv™: The Optimum Alternative to 1,1,1-Trichloroethane and Methyl Ethyl Ketone for Hand-Wipe Cleaning of Aerospace Materials*. Glidco has worked closely with such companies as Hercules Aerospace to customize terpenes to meet unique aerospace requirements such as zero-residue wipe cleaning. Through these cooperative efforts, Glidco has developed the product Prepsolv™, a terpene-based cleaning agent that has high solvency and ultra-low non-volatile residue properties. The new product is environmentally acceptable and considered a replacement for ozone-depleting and toxic solvents in hand-wipe cleaning.

The Oak Ridge Refrigerant Management Program was described by Thomas Kevil who provided information on how the Department of Energy's Oak Ridge Y-12 Plant developed an aggressive plan for the phase-out of chlorofluorocarbons (CFCs) in their air conditioning and process refrigeration systems as an avoidance technology or procedure. The paper summarizes lessons learned and discusses basic criteria for a successful conversion and retrofit plan based on their experience.

B1.5 *Evaluating the Cost Effectiveness of Environmental Projects: Case Studies in Aerospace and Defense*, Dr. James Shunk, Director of Business Development, United Technologies, Waterjet Systems Inc., P. O. Box 070019, Huntsville, AL 35807-7019, (205-721-2770)

B1.6 *The Oak Ridge Refrigerant Management Program*, Tom H. Kevil, Capital Construction Engineer, Martin Marietta Energy Systems, Oak Ridge Y-12 Plant, Oak Ridge, TN 37831-8096

B1.7 *Alternatives to 1,1,1-Trichloroethane and Ethyl Ketone for Hand-Wipe Cleaning of Aerospace Materials*, R. Scott Gallagher, Business Manager, Glidco Organics Corporation, P. O. Box 389, Jacksonville, FL 32201-0389, (904-768-5800)

SESSION B2

ENVIRONMENTALLY SAFE FUELS, FIRE SUPPRESSANTS, REFRIGERANTS, AND INSULATIONS

Seven presentations were included in Session B2, *Environmentally Safe Fuels, Fire Suppressants, Refrigerants and Insulations*. The first two speakers discussed the evaluation processes involved in finding an environmentally compliant foam blowing agent to replace the currently used CFC-11 in aerospace insulation foams. The third speaker looked at alternatives to the currently used ozone depleting refrigerants in test equipment. The next two speakers addressed the issue of maintaining safe fuel systems while eliminating the use of Ozone Depleting Chemicals (ODCs). The final speakers discussed the new fire suppression systems available through the market place.

The first presentation, *A Water Blown Urethane Insulation for Use in Cryogenic Environments*, was given by Elana Blevins of Martin Marietta Manned Space Systems. Blevins discussed the formulation of the Thermal Protection Systems (TPSs) used on the Space Shuttle's External Tank. These TPS insulations include polyurethane and polyisocyanurate modified polyurethane. The insulations, currently foamed with a CFC-11 blowing agent, serve to maintain cryogenic propellant quality, maintain the external tank structural temperature limits, and minimize the formulation of ice and frost that could potentially damage the ceramic insulation of the space shuttle orbiter. Due to environmental concerns, the polyurethane insulation industry and the External Tank Project are tasked with replacing CFC-11. The flight qualification of foam insulations employing HCFC-141b as a foaming agent is currently in progress

Chairs

Arthur Henderson, NASA/Marshall Space Flight Center, EH42, MSFC, AL 35812, (205-544-2577)

Patricia Liberio, WO/POSF Bldg 490, 1790 Loop Road N, Wright-Patterson AFB, OH 45433-7103, (513-255-6918)

Speakers

B2.1 *A Water Blown Urethane Insulation for Use in Cryogenic Environments*, Elana Blevins, Martin Marietta Manned Space Systems, TPS Materials Research Laboratory, MSFC, AL 35812, (205-544-0441)

B2.2 *Evaluation of HFC 245ca and HFC 236ea as Foam Blowing Agents*, Jon B. Sharpe, Martin Marietta Manned Space Systems, TPS Materials Research Laboratory, MSFC, AL 35812, (205-544-0441) with implementation into the production line projected for 1995. However, HCFC-141b is only an interim solution because it, too, will be phased out in 2003. A zero ozone depleting potential blowing agent is being developed as a component of the third generation insulation foam. She elaborated on the development criteria, statistical experimental approach, and resulting foam properties resulting from the evaluation of the HCFC-141b blowing agent for the TPS.

Jon Sharpe of the Martin Marietta Manned Space Systems discussed *Evaluation of HFC-245ca and HFC-236ea as Foam Blowing Agents*, which examines more closely the potential replacements for the HCFC-141b blowing agents. Physical blowing agents identified to date have included hydrocarbons, fluorocarbons, hydrofluoroethers, and more predominantly, hydrofluorocarbons (HFCs). Mr. Sharpe described results from a research program of two such candidate HFCs performed as a cooperative effort between Martin Marietta Manned Space Systems, the U. S. Environmental Protection Agency, and Oak Ridge National Laboratories. The purpose of this effort was to perform a cursory evaluation of the developmental HFCs, 245ca and 236ea, as blowing agents in urethane based insulations. These two materials were selected from screening tests of thirty-seven c_2, c_3, and c_4 isomers based on physical properties, atmospheric lifetime, flammability, estimated toxicity, difficulty of synthesis, suitability for dual use as a refrigerant, and other factors. Solubility of the two materials in typical foam components was tested, pour foaming trials were performed, and preliminary data was gathered regarding foam insulation performance.

Richard L. Hall of Battelle discussed *Alternatives to Ozone Depleting Refrigerants in Test Equipment*. Hall described the initial results of a retrofit project focused on the test

B2.3 *Alternatives to Ozone Depleting Refrigerants in Test Equipment*, Richard L. Hall, Senior Research Engineer, Battelle, 505 King Avenue, Columbus, OH 43201-2693, (614-424-5499)

B2.4 *Environmentally Safe Aviation Fuels*, Patricia D. Liberio, WO/POSF Bldg 490, 1790 Loop Road N, Wright-Patterson AFB, OH 45433-7103, (513-255-6918)

B2.5 *Development of a Non-Toxic, Environmentally Safe Fuel System Icing Inhibitor*, Ellen M. Steward, WL/POSF Bldg 490, 1790 Loop Road N, Wright Patterson AFB, OH 45433-7103, (513-255-4027)

B2.6 *Next Generation Fire Suppressants*, Jerry A. Brown, Director of Land Systems, Spectrex, Inc., 1487 Chain Bridge Road, Suite 304, McLean, VA 22101, (703-734-9626) equipment used at AGMC. The objective is to convert selected types of test equipment to properly operate on HFC alternative refrigerants, having no ozone depleting potential, without compromising system reliability or durability. He discussed the primary technical issues and summarized the test results for 12 different types of test equipment: seven environmental chambers, two coolant recirculators, one ultra-low temperature freezer, one temperature control unit, and one vapor degreaser.

Environmentally Safe Aviation Fuels was presented by Ms. Patricia D. Liberio from Wright-Patterson AFB. Liberio noted that many years ago there was a directive for military specifications to use commercially standard test methods in order to provide standard testing in private industry and government. As a result the test methods used in military specifications are governed by the American Society of Testing and Materials (ASTM). The Air Force has been very proactive in the removal or replacement of the ODCs and hazardous materials in the test methods. Throughout the presentation, Liberio described the Air Force's initiatives to remove ODCs and hazardous materials from the fuel and fuel related military specifications for which the Air Force Wright Laboratory is custodian, with the assistance of ASTM.

Another discussion relating to fuel systems was provided by Ellen M. Steward of Wright-Patterson AFB, on *Development of a Non-Toxic, Environmentally Safe Fuel System Icing Inhibitor.* Steward discussed a fuel system icing inhibitor (FSII) that is used in military jet fuel to prevent the freezing of dissolved and free water associated with the fuel. The formation of ice crystals in an aircraft fuel system will prevent the circulation of fuel through the system by plugging filters and other key components and can lead to engine flameout. Ethylene glycol monomethyl ether (EGME) and diethylene glycol

B2.7 *FM-200™, The New Solution for Fire Protection*, Al Thornton, Business Development Manager, Great Lakes Chemical Corporation, P. O. Box 2200, West Lafayette, IN 47906-0200, (317-497-6206) monomethyl ether (DiEGME) are the only currently approved FSIIs. However, removal of the resulting water bottoms costs the government in excess of $3 million a year. The Fuels Branch of Wright Laboratory is the focal point for the development of a non-toxic, environmentally safe FSII. The Fuels Branch is working closely with Armstrong Laboratory of Tyndall AFB and the Materials Directorate of Wright Laboratory in the development of non-toxic wing and runway deicers. The new icing inhibitor will eliminate hazardous waste in the form of fuel tank water bottoms and will eliminate the necessity to construct capture and control facilities for aircraft and runway deicing runoff.

Jerry A. Brown from Spectrex, Inc. addressed the session with the *Next Generation of Fire Suppressants*. Spectrex is developing three technologies that will impact users of fire suppressants in the near future. Spectrex has developed a method of creating finely dispersed aerosols by pyrotechnical means called SFE and using them as an efficient extinguishing medium. Brown described a family of aerosol products and their various applications.

The final presentation was by Mr. Al Thornton of Great Lakes Chemical Corporation who discussed *FM-200™, The New Solution for Fire Protection*. Performance and safety of a fire suppressant alternative are of critical importance to aerospace applications. FM-200™ is an effective active chemical fire fighting agent, extinguishing most fires at a concentration of 5.8% by volume. The toxicity profile of FM-200™ exceeds that of Halon 1301, and FM-200™ has proven efficient for a variety of system designs. This chemical has performed well in its testing, is identified by EPA as an acceptable alternative for Halon 1301 total flooding systems, and seems to be a suitable replacement for existing aerospace applications. However, government approval is necessary to introduce any halon alternative into aerospace applications. Additional testing is in progress to gain approval for several key aerospace applications.

SESSION B3

NON-CFC CLEANING SOLVENTS, PROCESSES AND PARAMETERS 2

Seven papers were presented during this session covering topics ranging from replacement of ozone depleting solvents to process redesign. With respect to activities in the "Technology for a Sustainable Future," all presentations addressed avoidance activities. Two papers detailed replacement of solvents for hand wiping operations, two papers discussed development of new solvent blends that have been patented, one presentation covered the successful use of water only on a reusable, static-fire, test bed motor, one discussed evaluation of an aqueous spray-in-air process, and one involved gravimetric analysis for nonvolatile residue determinations.

Lisa Thompson of Martin Marietta Energy Systems Materials Engineering Department, Y-12 Plat Oak Ridge, presented a paper entitled *Cleaning Without Chlorinated Solvents* which discussed replacement of ozone depleting solvents with organic blends which have been patented by the group. Evaluations dealt with compatibility, cleaning ability, and effects on bonding, welding, painting, and plating. Solvents have been identified for removal of rust preventative oils, lapping oils, machining coolants, lubricants, greases, and mold releases.

The second paper entitled *Replacement of Ozone Depleting and Toxic Chemicals in Gravimetric Analysis of Nonvolatile Residue* was given by Dr. Graham Arnold. Dr. Arnold discussed the development of a "drop in" replacement solvent for two Non-Volatile Residue (NVR) tests described in the two standards, ASTME 1235-88 and TR-89-63. Evaluations of organic solvents involved comparisons of

Chairs

Gale Allen, Chief of the Materials and Chemical Branch, NASA/Kennedy Space Center, MC DM-MSL-1, KSC, FL 32899, (407-867-3910)

Kenneth Ezell, Senior Manufacturing Engineer, Martin Marietta Corporation, Bldg 4712, MSFC, AL 35812, (205-544-2746)

Speakers

B3.1 *Cleaning Without Chlorinated Solvents*, Lisa M. Thompson, Martin Marietta Energy Systems, Inc., Oak Ridge Y-12 Plant, Materials Engineering Department, Development Division, Bldg 9202, P. O. Box 2009, Oak Ridge, TN 37831, (615-576-4227) physical and chemical properties of existing organic solvents using Beilstein references and Hansen characterization parameters. Safety, health, and environmental issues were included relative to these solvents.

Evaluation of Control Parameters for Aqueous Spray-in-Air (SIA) Cleaning, presented by Simon Davis of Microcraft Inc., discussed use of an aqueous spray system to clean the solid rocket motor hardware where cleanliness is necessary to eliminate bonding failures. Factors investigated included spray pressure, cleaner/solution concentration, solution application temperature, and soak time. HD-2 Conoco grease is the major contamination of this system and data presented indicated that the aqueous spray system could successfully clean to the required level.

Michael Kovach of United Solid Boosters Inc. discussed an extensive evaluation performed to find replacement solvents for hand wiping operations titled *Environmentally Compatible Handwipe Cleaning Solvents*. Nineteen solvents were evaluated on 40 different material surfaces using 24 different types of potential contamination involving over 7,000 individual determinations. In addition to cleaning performance; bonding, compatibility, and corrosion were also evaluated. Results indicate that there is no one "drop in" replacement and that each process must be evaluated individually. The paper provides excellent guidelines for individual evaluations.

Another evaluation on hand wipe solvents was given by Eric Eichinger of Rockwell Space Systems *Non-CFC Low VOC Wipe Solvents* describing the use of low vapor pressure replacement solvents. Twenty-seven candidates, aqueous, non-aqueous, or semi-aqueous solvents were evaluated for use on a variety of surfaces and for a variety of applications. Six physical and three performance tests were performed on each solvent. Selection of superior products was made on the basis

B3.2 *Replacement of Ozone Depleting and Toxic Chemicals In Gravimetric Analysis of Nonvolatile Residue*, Dr. Graham Arnold, Manager of Spacecraft Phenomena, Surface Science Department, Mechanics and Materials Technology Center, The Aerospace Corporation, P. O. Box 92957, Los Angeles, CA 90009-2957, (310-336-1935)

B3.3 *Evaluation of Control Parameters for Aqueous Spray-in-Air (SIA) Cleaning*, Simon J. Davis, Micro Craft Inc., 620 Discovery Drive, Huntsville, AL 35806, (205-971-9374)

B3.4 *Environmentally Compatible Hand Wipe Cleaning Solvents*, Michael Kovach, United Space Boosters Inc., Materials and Processes Department, P. O. Box 1900, Huntsville, AL 35807, (205-721-2412) of environmental effect, health effects, laboratory test data, and shop evaluations. This paper is also a good guide for individual replacement applications.

Ellen Swan discussed developments of HFCs and HFC blends by Allied Signal, Inc., New York in a paper titled *Hydrofluorocarbon Solvents as Alternatives to CFC-113 and Methyl Chloroform in Precision Cleaning*. The paper offered viable alternatives in selected processes when aqueous or semi-aqueous products could not be used. These HFC compounds can be used in vapor degreasing equipment in a manner similar to CFC-113 and methyl chloroform and in many instances could be used as a "drop-in" replacement. The products discussed have similar physical properties to CFC-113 but no ozone depleting characteristics.

The final presenter was Dr. Dale Hutchens of Thiokol Corporation, who discussed *Implementation of Environmentally Compliant Cleaning and Insulation Bonding for MNASA*. In this presentation alternate materials and processes developed and tested on the Modified NASA (MNASA) static test motor at Marshall Space Flight Center was covered. This presentation addressed the use of high pressure aqueous refurbishment, the use of two alternate aqueous cleaning agents for precision cleaning and the use of alternate primers and adhesives on critical bonding surfaces. The results of testing indicated that the alternative materials and processes met or exceeded MNASA program requirements. This work provides a midscale demonstration of a potential non Ozone Depleting Chemical bonding system for qualification and eventual implementation on the Redesigned Solid Rocket Motor (RSRM).

In general, it was noted that CFC materials are used in many critical applications in aerospace industry and the replacement of these solvents requires extensive testing and qualification. It should be emphasized that there is no one substitute for replacement of ozone depleting solvents. It is up to the user to evaluate the available alternatives and decide which is best for a specific application.

B3.5 *Non-CFC and Low VOC Wipe Solvents*, Eric Eichinger, Rockwell Space Systems Division, MS AD41, 12214 Lakewood Boulevard, Downey, CA 90241, (310-922-2850)

B3.6 *Hydrofluorocarbon (HFC) Solvents as Alternatives to CFC-113 and Methyl Chloroform in Precision Cleaning*, Ellen Swan, Allied Signal Inc., Buffalo Research Laboratory, 20 Peabody Street, Buffalo, NY 14210, (716-827-6231)

B3.7 *Implementation of Environmentally Compliant Cleaning and Insulation Bonding for MNASA*, Dr. Dale E. Hutchens, Supervisor, Thiokol Corporation, Huntsville, AL 35807, (205-544-2747)

SESSION C1

EMERGING TECHNOLOGIES FOR THE PROPULSION INDUSTRY

Seven presentations were included in the session entitled, "Emerging Technologies for the Propulsion Industry." The first five papers discussed various environmental issues pertaining to solid rocket propellants. The final two papers addressed technology transfer and prioritization techniques that have aided technology development throughout the propulsion industry.

Kathryn Miks of Thiokol Corporation presented the first paper on *AP Reclamation and Reuse in RSRM Propellant.* Mik's discussion was based on the premise that recovery and beneficial reuse of hazardous waste materials are favored over destruction in today's environment. Thiokol and the Joint Ordnance Commanders Group (JOCG) have initiated an effort to reclaim ammonium perchlorate (AP) from waste composite propellants and evaluate its reuse in rocket propellant. AP has been obtained from two standard propellant binder systems (PBAN and HTPB). Ms. Miks discussed results from analytical work performed at Thiokol which show that the AP meets specification purity requirements. Processing, cure, ballistic, mechanical and safety properties will also be evaluated on the vendor recrystallized AP. Based on initial AP and propellant properties, the reclaimed AP is expected to meet propellant requirements.

The second paper entitled, *Enhanced Alkaline Hydrolysis and Biodegradability Studies of Nitrocellulose-Bearing Missile Propellant* was given by C. Christodoulatos of the Environmental Engineering Center at the Stevens Institute of Technology. Christodoulatos discussed the

Chairs

Dr. Ronn Carpenter, Director of Technology, Thiokol Corporation, 6767 Old Madison Pike, Suite 490, Huntsville, AL 35806, (205-722-4922)

Clare Vinton, Director of Environmentally Conscious Manufacturing, National Center for Manufacturing Sciences, 3025 Boardwalk, Ann Arbor, MI 48108-3266, (313-995-0300)

Speakers

C1.1 *AP Reclamation and Reuse in RSRM Propellant,* Kathryn F. Miks, Thiokol Corp., MS 243, P. O. Box 707, Brigham City, UT 84302-0707 (801-863-9550)

Engineering Center's research into the safe destruction and disposal of a double base solid rocket propellant named AHH which contains nitrocellulose, nitroglycerine, two lead salts, triacetin, and 2-nitrosodiphenylamine (2-NDPA). A process train is being developed to convert the organic components of the propellant to biodegradable products and to remove the lead from the process stream. The effects of reaction time, temperature, sodium hydroxide concentration and other relevant parameters on the digestion efficiency and biodegradability have been studied. Christodoulatos' present work indicates that the AHH propellant can be disposed of safely with a combination of physiochemical and biological processes.

The third speaker, James Jacox of the Hercules Aerospace Company, spoke on *Environmentally Compatible Solid Rocket Propellants*. The environmentally more compatible propellants or "clean propellants" feature HCl levels at least an order of magnitude lower than conventional propellants. Two formulations of clean propellants, a sodium nitrate scavenged HTPB and an HCl-free hydroxy terminated polyether (HTPE) propellant, were selected by Hercules for scale-up to one and five gallon mixes for ballistic, mechanical, and rheological properties characterizations. Using the best available technology in the areas of performance analyses, metal fuel combustion efficiency, and environmentally acceptable processing, the clean propellants were tailored to provide two "robust" options for environmentally acceptable space boosters.

Dr. Robert Bennett of Thiokol Corporation spoke on *Low Acid Producing Solid Propellants*. The acidic deposition onto the land near launch or test sites has been documented as a negative effect of rocket exhaust on the environment. Bennett discussed the various solid propellant options which

C1.2 *Enhanced Alkaline Hydrolysis and Biodegradability Studies of Nitrocellulose-Bearing Missile Propellant*, C.Christodoulatis, Environmental Engineering Center, Stevens Institute of Technology, Hoboken, NJ 07030, (201-216-8305)

C1.3 *Environmentally Compatible Solid Rocket Propellants*, James L. Jacox, Hercules Aerospace Company, Bacchus Works, P.O. Box 98, Magna, UT 84044-0098, (801-250-5911)

C1.4 *Low Acid Producing Solid Propellants*, Dr. Robert R. Bennett, Thiokol Corp., MS 243, P.O. Box 707, Brigham City, UT 84302, (801-863-8267)

C1.5 *Improved Hybrid Rocket Fuel*, David L. Dean, McDonnell Douglas Aerospace-Huntsville, 689 Discovery Drive, Huntsville, AL 35806, (205-722-4897) have been proposed as being more environmentally benign than current systems by reducing HCl emissions. These options include acid neutralized or scavenged propellants, non-chlorine propellants, and non-particulate propellants. An assessment is needed in order to judge whether the potential improvements justify the expenditures of developing the new propellant systems.

C1.6 *Technology Transfer Into the Solid Propulsion Industry*, Ralph Campbell, Sverdrup Technologies, 620 Discovery Drive, Huntsville, AL 35806, (205-971-0100)

David L. Dean of McDonnell Douglas discussed *Improved Hybrid Rocket Fuel*. Hybrid rocket propulsion allows hazardous and polluting rocket propellants containing ammonium perchlorate to be replaced with a much safer, relatively inert, environmentally benign fuel. McDonnell Douglas Aerospace-Huntsville has formulated and tested a new hybrid rocket fuel which contains only carbon, hydrogen, oxygen, and nitrogen. This clean burning fuel contains no oxidizing species, making it safe to handle, process, and store. It can be started, stopped, restarted, and throttled, and it exhibits a higher regression rate than existing hybrid fuels. These characteristics enable a much wider variety of design options as well as a significantly lowered environmental impact for a rocket propulsion system compared to commercialized solid propulsion technologies.

C1.7 *Uses of a Prioritization Methodology for Chemical Replacement*, Wendy Cruit, Marshall Space Flight Center, Structures and Dynamics Laboratory, ED73, MSFC, AL 35812, (205-544-1130)

Ralph Campbell continued the session with a presentation entitled, *Technology Transfer into the Solid Propulsion Industry*. Campbell reviewed the waste minimization efforts in industries outside of aerospace for possible applications in the solid rocket motor (SRM) manufacture and the processes involved in the production of SRMs for NASA. The SRM process review data was then used to decide which processes might have similar applications in commercial technologies. Commercial industries were surveyed for waste control successes which could be transferred to SRM production. The candidate processes were then evaluated with respect to applicability, effectiveness, cost, and maturity.

Wendy Cruit from Marshall Space Flight Center was the final presenter and discussed the *Uses of a Prioritization Methodology for Chemical Replacement*. The handbook "Prioritization Methodology for Chemical Replacement" (NASA TP 3421) was published as a guideline for categorizing/evaluating and prioritizing the chemicals and processes which, under pending or existing legislation, must be requested from potential users.. Cruit also presented several case histories focused on the utilization of the handbook methodology, and the associated benefits and problems.

SESSION C2

ENVIRONMENTALLY COMPLIANT COATING APPLICATIONS AND REMOVAL TECHNIQUES

The aerospace community faces an ever-increasing challenge to find environmentally friendly coatings and coating removal techniques. Environmental regulatory requirements are being expanded to encompass areas of technology never before regulated to restrictive standards. In response to these regulations and the high cost of controlling emissions, aerospace organizations have begun to emphasize replacement of materials and processes where possible in manufacturing and rework operations.

This emphasis on replacement of hazardous materials instead of monitoring and controlling their release is considered an "avoidance activity," supporting the first category in the "Technology for a Sustainable Future" initiative. In many cases, replacement or elimination of materials or processes has resulted in better technical performance, cost savings in materials and hazardous waste treatment, and reduction of permitting requirements and overall emissions.

The first speaker in this session, Virginia Morris, discussed the changing regulatory requirements and their implications for the aerospace industry in her presentation, *Environmentally Regulated Aerospace Coatings*. A detailed outline of regulations and policies included requirements from the proposed "National Emission Standard for Hazardous Air Pollutants for Aerospace Manufacturing and Rework" and the Control Techniques Guideline for Aerospace Manufacturing and Rework currently being prepared by EPA. In

Chairs

Marceia Clark-Ingram, NASA/ Marshall Space Flight Center, EH42, MSFC, AL 35812, (205-544-6229)

Gail Murphree, United Space Boosters Inc., P. O. Box 1900, Huntsville, AL 35807, (205-721-2717)

Speakers

C2.1 *Environmentally Regulated Aerospace Coatings*, Virginia Morris, Manager of Environmental Technology Development, Northrop B-2 Division, 8900 E. Washington Blvd, Pico Rivera, CA 90660, (310-942-5913) addition, mandates for elimination of ozone depleting chemicals, executive orders related to pollution prevention and federal recycling, and the requirements of the Occupational Safety and Health Administration (OSHA), were discussed with their potential impacts to aerospace operations. Morris described strategies for complying with the requirements of environmental and safety regulations while controlling costs and remaining competitive in the industry. The heart of this strategy involves incorporation of regulatory requirements into every aspect of the manufacturing and rework process. Key elements of this strategy include (1) development of an approach integrating performance requirements with environmental requirements, (2) development of a long range plan, and (3) incorporating automation in the tracking of the manufacturing process.

The next speaker, Jack Scarpa, described a novel coating process which eliminates the need to use solvents in coating application. In his presentation, *Convergent Spray Process for Environmentally Friendly Coatings*, Mr. Scarpa related that many current coating application processes involve very poor transfer efficiencies and are largely limited by the viscosity of the material being sprayed. Inefficient transfer and limited pot life of coatings can result in significant waste of material and disposal costs. Inability to spray high viscosity coatings can preclude the use of many environmentally friendly, high solids materials. Addition of sufficient solvent to spray many coatings using conventional application methods would raise the volatile organic content (VOC) of the coatings significantly.

The novel "Convergent Spray" process requires no premixing of coating resin and catalyst, nor is any diluent required for viscosity control since viscosity is not a consideration. The coating components are fed to the spray nozzle separately and mixed at the spray

C2.2 *Convergent Spray Process for Environmentally Friendly Coating*, Jack Scarpa, United Space Boosters Inc., P.O. Box 1900, Huntsville, AL 35807, (205-721-2792

C2.3 *SSME Main Combustion Chamber (MCC) "Hot Oil" Dewaxing*, Anthony U. Akpati, Rocketdyne Division, Rockwell International Corporation, 6633 Canoga Avenue, P.O. Box 7922, MC AC67, Canoga Park, CA 91309-7922, (818-586-4993)

C2.4 *Bicarbonate of Soda Paint Stripping Process Validation and Materials Characterization*, Michael N. Haas, SA-ALC/LAPSC, 375 Airlift Drive, Kelly AFB, TX 78241-6334, (210-925-8541)

C2.5 *Waterjet Processes for Coating Removal*, Fletcher Burgess, United Space Boosters Inc., M&P Department, P.O. Box 1900, Huntsville, AL 35807, (205-544-2648) head. A detailed description of the process with a schematic diagram is included in the paper. Scarpa gave as an example of the many uses of such a system the replacement of a high-VOC insulation used on the Space Shuttle Solid Rocket Booster with a solventless system sprayed with the convergent spray technology.

Anthony Akpati followed with a presentation entitled *SSME Main Combustion Chamber (MCC) 'Hot Oil' Dewaxing*. The Space Shuttle Main Engine (SSME) uses a casting compound, Rigidax, in processing the main combustion chamber and associated hardware. In the past, this waxy material has been removed from these complex components after processing using perchloroethylene both in vapor degreasing and in flush cleaning operations. Because perchloroethylene is listed as a Hazardous Air Pollutant in the Clean Air Act Amendments of 1990, in addition to its status as a suspected carcinogen, its elimination from processing operations was highly desirable.

Seven alternate dewaxing fluids were evaluated in the replacement effort; nine different substrates were included in the testing to determine material compatibility. After lab testing, a mineral oil was selected as the choice fluid and testing was scaled up to actual hardware use. The final, eight stage process involves simultaneous immersion and flushing of the components. Nonvolatile residue (NVR) analysis has confirmed that the process results in cleanliness comparable to the conventional perchloroethylene process, both in the laboratory and in actual production usage.

The remainder of the session dealt with mechanical methods of coating removal. These methods generally replace the use of ozone depleting compounds and hazardous materials in the conventional removal of paints and coatings. Often, they are also effective in cleaning and surface preparation. Information on

C2.6 *Waterjet Systems for Cleaning, Decoating, and Depainting Industrial, Commercial, Military and Aerospace Hardware*, Gerald Haynes, United Technologies Waterjet Systems Inc., P. O. Box 070019, Huntsville, AL 35807-7019, (205-721-5570)

C2.7 *Ultra-High Pressure Water Jetting for Coating Removal and Surface Preparation*, Spencer T. Johnson, Jet Edge Inc., 825 Rhode Island Avenue, Minneapolis, MN 55426, (612-545-1477)

U. S. Air Force work was presented by Michael Haas in his paper entitled *Bicarbonate of Soda Paint Stripping Process Validation and Materials Characterization.* This environmentally friendly technology has been implemented in operations for removing carbon from engine nozzles and gas turbine engine parts, depainting cowlings, and other processes. Haas discussed the rigorous process characterization and validation testing conducted. Of special importance to aerospace manufacturing was the study of the effects of the blasting process on thin-skinned aluminum substrates.

Fletcher Burgess, in discussing *Waterjet Processes for Coating Removal,* described the use of waterjet blasting for coating removal on the Space Shuttle Solid Rocket Booster. The boosters are recovered after each flight and refurbished for use on future Shuttle flights. On recovery, robotic waterjet blasting is used to remove the thermal protective coating on the exterior. The technology has been refined through extensive testing and the use of robotic automation to the degree that coatings may be removed layer by layer if desired. Ongoing investigations into the use of abrasive media in the water stream, development of more efficient specialized nozzles, and effectiveness of waterjet blasting in precision cleaning were also described.

Further applications of waterjet blast technology were detailed by Gerald Haynes in his presentation, *Waterjet Systems for Cleaning, Decoating and Depainting Industrial, Commercial, Military and Aerospace Hardware.* A film and slides were shown depicting the use of waterjet systems for cleaning and removing material from a wide variety of structures and components. Automated waterjet systems have been proven and installed for a wide range of applications including stripping thermal protection systems, stripping paint and primer from aerospace and aircraft components, and stripping engine parts during refurbishment.

Ultra-High Pressure Water Jetting for Coating Removal and Surface Preparation was the concluding presentation for this session. Spencer Johnson related that handheld waterjet systems can be an effective replacement for such processes as chemical stripping, sand blasting, and power tool scarification. Details on use of waterjet technology for propellant removal and the decommissioning of military hardware were also discussed. Johnson emphasized that this technology can potentially reduce the waste stream associated with such operations and provide a safe means of processing hazardous and toxic materials.

SESSION C3

CLEANING VERIFICATION-INSTRUMENTATION AND TECHNIQUES 1

There are numerous operations involving optical surfaces and surfaces to be bonded that require surface cleanliness to a pre-defined level. Verification of cleanliness levels has been accomplished in the past by using solvents to sample surface area and measure the non-volatile residue (NVR). Black light visual examinations are also used but the level of sensitivity is not good. The increasing limitations on solvent use and the need to perform surface cleanliness verification in a fast, efficient manner during manufacturing have led to development efforts for new techniques to obtain this data. Elimination of solvents currently used for NVR analysis is consistent with the goals of the "Technology for a Sustainable Future" initiative. The work described in this session is related to the Avoidance Technology Category since hazardous materials (solvents) used for cleanliness verification are being replaced with new inspection technologies. In this session techniques presently being used in manufacturing were described and work on new techniques which may yield more useful data, more easily and quickly was discussed.

An overview of the Surface Contamination Analysis Technology (SCAT) team and the efforts that are ongoing under its auspices were presented by DeWitt Burns. The SCAT team was formed in the Physical Sciences Branch of the Materials and Processes Laboratory at NASA's Marshall Space Flight Center. It is comprised of NASA, shuttle prime contractors, university and other support contractor personnel. The SCAT team goal is to develop a multi-purpose inspection

Chairs

M. R. Carruth, Chief of the Engineering Physics Division, NASA/Marshall Space Flight Center, EH11, MSFC, AL 35812, (205-544-7647)

Daniel F. Perey, NASA/Langley Research Center, MS 231, Hampton, VA 23665-5225, (804-864-4796)

Presenters

C3.1 *Surface Contamination Analysis Team Overview*, H. DeWitt Burns, NASA/Marshall Space Flight Center, EH12, MSFC, AL 35812, (205-544-2529)

C3.2 *Standardization of Surface Contamination Analysis Systems*, Richard E. Boothe, AC Engineering, 1085 Jordan Road, P. O. Box 17069, Huntsville, AL 35810, (205-851-9020) system for surface cleanliness evaluation of critical shuttle system surfaces. The initial major area of interest was application to the redesigned solid rocket motor (RSRM) portion of the space shuttle program. Techniques being evaluated include optically stimulated electron emission (OSEE), near infrared (NIR) fiber optic spectroscopy, Fourier transform infrared (FTIR) spectroscopy, ultraviolet fluorescence (UVF) spectroscopy, and ellipsometry. Work accomplished by the team was presented in two sessions.

The first presentation was followed by a discussion of some of the basic laboratory research which involves the definition of clean for surfaces and operations, how contamination standards are made, and how various studies are carried out which are a function of known contamination levels. Richard Boothe described techniques for preparing and preserving contamination standards. To ensure that consistent qualitative and quantitative information is obtained from these analyses, standards are required to develop techniques for identifying and quantifying contamination, to establish sensitivity to potential contaminants, and to develop calibration curves. Methods were presented for evaluating the effects of potential contaminants on critical bonding properties. This work was accomplished as part of the SCAT team effort at MSFC. Robert Mattes described the application of OSEE in Thiokol manufacturing processes for monitoring contamination prior to bonding operations. The technique provides process control information to help assure bond surface quality and repeatability prior to bonding. The paper included a description of OSEE theory of operation, technique sensitivity, and instrumentation implementation at Thiokol since 1987. Data form hardware processing was also presented.

C3.3 *Cleanliness Inspection Tool for RSRM Bond Surfaces*, Robert A. Mattes, Thiokol Corporation, 6767 Old Madison Pike N.W., Suite 490, Huntsville, AL 35806, (205-544-1784)

C3.4 *Design and Performance Considerations for the Third Generation OSEE Probe and Associated Electronics*, Daniel F. Perey, NASA/Langley Research Center, MS 231, Hampton, VA 23665-5225, (804-864-4796)

C3.5 *Study of Surfaces Using Near Infrared Optical Fiber Spectroscopy*, Dr. Gary L. Workman, Center for Automation and Robotics, The University of Alabama in Huntsville, Huntsville, AL 35899, (205-895-6578)

C3.6 *Contamination Detection NDE for Cleaning Process Inspection*, William Marinelli, Physical Sciences Inc., 20 New England Business Center, Andover, MA 01810, (508-689-0003)

The fourth presentation by Daniel Perey from NASA's Langley Research Center (LaRC was on the redesign effort undertaken on the OSEE equipment. The third generation OSEE system resulted from a combined MSFC SCAT Team, Thiokol, and LaRC teaming effort. MSFC and Thiokol made input in the design as a result of lessons learned and needed improvements for the current OSEE equipment used in the RSRM program. A detailed description of OSEE system electronic and mechanical improvements was presented.

C3.7 *Ultraviolet Fluorescence Imaging for In-Process Surface Contamination Detection*, Ted V. Kublin, NASA/ Marshall Space Flight Center, PT21, MSFC, AL 35812, (205-544-8631)

The session was concluded with papers on NIR and UVF spectroscopy which hold promise for near term application in surface contamination detection, identification and quantification. Dr. Gary Workman from The University of Alabama in Huntsville presented the work accomplished with fiber optic NIR spectroscopy. Unique capabilities of the system were discussed. NIR spectroscopy coupled with improved data analysis software including principal component analysis, principal component regression, and partial least squares regression allowed for quantification of various contaminants on different RSRM substrates of interest. This development work initiated as part of the MSFC SCAT team effort could be applicable for a wide range of process monitoring applications.Two UV fluorescence systems developed were described in the first session. The first was a system which uses an excimer laser source and was developed by Physical Sciences Incorporated (PSI) under a small business innovative research (SBIR) contract with NASA. A system design overview was followed by data showing capability of detecting contamination at less than 10 milligrams per square foot on common RSRM bonding substrates including rubber insulation, steel, and aluminum. The second UV fluorescence system designed by Science Applications International Corporation (SAIC) uses a UV flash lamp source. The UV fluorescence technique shows promise for near term application in surface contamination detection, identification, and quantification.

SESSION D1

ENVIRONMENT TECHNOLOGY INFORMATION SYSTEMS - SPECIFICATIONS, STANDARDS AND DATABASES

This session, titled "Environmental Technology Information Systems - Specifications, Standards, and Databases," consisted of five presentations. The first two speakers discussed available databases to aid in environmental compliance efforts. The third presenter discussed the effect that ozone depleting chemical (ODC) phaseouts have on NASA specifications. The fourth speaker provided a test plan for qualifying chlorofluorocarbon (CFC) -free solvents in liquid oxygen (LOX) and gaseous oxygen (GOX) environments. The final presenter overviewed a document which provides technical assistance in CFC replacement activities.

The first presentation, titled *Environmental Databases and Other Computerized Information Tools*, was presented by Marceia Clark-Ingram. Clark-Ingram noted that increasing environmental legislation has brought about the development of many new environmental databases and software application packages to aid in the quest for environmental compliance. These databases and software packages are useful tools and are applicable to a wide range of environmental areas from atmospheric modeling to materials replacement technology. The great abundance of such products and services can be very overwhelming when trying to identify the tools which best meet specific needs. She discussed several types of environmental databases and software packages available, product capabilities, and hardware requirements.

Chairs

Dr. J. Wayne McCain, Senior Research Scientist, The University of Alabama in Huntsville, Huntsville, AL 35899, (205-895-6243)

M. Beth Cook, NASA/Marshall Space Flight Center, EH42, MSFC, AL 35812, (205-544-2545)

Speakers

D1.1 *Databases as Environmental Information Tools*, Marceia Clark-Ingram, NASA/ Marshall Space Flight Center, EH42, MSFC, AL 35812, (205-544-6229)

D1.2 *NASA Environmental Information System (NEIS)*, M. Beth Cook, NASA/ Marshall Space Flight Center, EH42, MSFC, AL 35812, (205-544-2545)

M. Beth Cook presented the second topic titled *The NASA Environmental Information System (NEIS)*. The NEIS is a tool design to support the functions of the NASA Operational Environment Team (NOET). The NEIS is designed to provide a central technology resource which draws on all NASA centers' and prime contractors' capabilities. The NEIS tracks environmental regulations, usages of materials, and technology developments. It has proven useful for channeling information throughout the aerospace community, NASA, other federal agencies, educational institutions, and contractors. Cook discussed the many dynamic databases within the NEIS and its usefulness in environmental compliance efforts.

The third presentation, *The Effect of Environmental Initiatives on NASA Specifications and Standards Activities*, was made by Dennis E. Griffin. Griffin provided the results of a NOET survey made throughout all NASA centers to identify any specifications and standards that require the use of ODCs (class I). Along with the results of this survey, Mr. Griffin discussed a pathfinder approach utilized at Marshall Space Flight Center (MSFC) to eliminate the use of ODCs in targeted specifications and standards. The pathfinder revision was to replace CFC-113 in a significant MSFC specification for cleaning and cleanliness verification methods for oxygen, fuel and pneumatic service. Lessons learned from this pathfinder document revision were also provided.

John W. Strickland continued the session with *An Overview of NASA Testing Requirements for Alternate Cleaning Solvents Used in Liquid and Gaseous Oxygen Environments*. The elimination of CFC-containing cleaning solvents has prompted the development of a number of alternate cleaning solvents that must now be evaluated not only for clean-ability, but compatibility as well. NASA Handbook 8060.1 (NHB 8060.1) establishes the requirements for

D1.3 *The Effect of Environmental Initiatives on NASA Specifications and Standards Activities*, Dennis E. Griffin, Chief of Project Engineering Branch, NASA/ Marshall Space Flight Center, EH43, MSFC, AL 35812, (205-544-2493)

D1.4 *An Overview of NASA Testing Requirements for Alternate Cleaning Solvents Used in Liquid and Gaseous Oxygen Environments*, John W. Strickland, BAMSI Inc., MEDB, P. O. Box 9154, Huntsville, AL 35812, (205-544-7375)

D1.5 *Development of a Critical Area Response Package for Chlorofluorocarbon (CFC) Replacement*, Dr. J. Wayne McCain, The University of Alabama in Huntsville, Huntsville, AL 35899, (205-895-6243) evaluation, testing, and selection of materials for use in oxygen enriched environments. Materials intended for use in space vehicles, specified test facilities, and ground support equipment must meet the requirements of this document. In addition to the requirements of NHB 8060.1 for oxygen service, alternate cleaning solvents must also be evaluated in other areas (such as corrosivity, non-metals compatibility, non-volatile residue contamination, etc.). Strickland provided preliminary results of early screening tests performed at MSFC's Material Combustion Research Facility.

The final presenter was Dr. J. Wayne McCain, who discussed the *Development of a Critical Area Response Package for Chlorofluorocarbon (CFC) Replacement.* Ozone, a chemical variation of the oxygen molecule, acts as a filtering shield to reduce ultraviolet radiation and the associated harmful effects such as cancers, eye diseases, timber losses, crop losses, and the threat to marine life. MSFC's Technology Utilization Office frequently receives requests for technical assistance in adapting existing processes and products to non-CFC based chemicals. In an effort to be more responsive to these requests, The University of Alabama in Huntsville compiled a "Critical Area Response" (CAR) package regarding this subject for MSFC. Included in the package is background information concerning the basics of how ozone molecules are depleted, legislation affecting CFC replacement schedules, and specific alternatives for solvents, refrigerants, and cleaning methods. McCain summarized the contents of the CAR package and discussed the development of other such packages in the context of MSFC's technology transfer program.

SESSION D2

ALTERNATIVE CLEANING TECHNOLOGY SYSTEMS

The Clean Air Act mandates elimination of or improved control over a variety of chemicals, including ozone depleting compounds (ODCs), hazardous air pollutants (HAPs) and volatile organic compounds. Many common industrial and aerospace cleaning processes employ these chemicals. This session, "Alternative Cleaning Technology Systems", examined four general categories of environmentally benign cleaning processes: Water and aqueous solution cleaning, dry ice blasting, closed loop, "near zero emissions", using either solvent spray or immersion, and plasma cleaning. All of these technologies, whose goal is to avoid pollution altogether are avoidance technologies under the "Technology for a Sustainable Future" initiative. While all these technologies are commercially available, presentations in this session described refinements to either equipment or materials which improve cleaning efficiency or process robustness.

Water and Aqueous Solution Cleaning was discussed by Dillard, Meltser, and Fuchs. Dillard described screening ultra high pressure (36,000 psi) waterjet cleaning of metals to replace 1,1,1 trichloroethane vapor degreasing. This work demonstrated cleaning of metal parts contaminated with paint, epoxy adhesive residues and viscous hydrocarbon grease. Blacklight and water break-free inspections confirmed cleanliness.

Meltser, substituting for Maltby, presented a review of aqueous solutions design issues that control regulatory compliance, simplicity of maintenance,

Chairs

Dr. Dale E. Hutchens, Supervisor, Thiokol Corporation, Bldg 4712, Marshall Space Flight Center, MSFC, AL 35812, (205-544-2747)

Simon J. Davis, Microcraft Inc., 620 Discovery Drive, Huntsville, AL 35806, (205-971-9374)

Speakers

D2.1 *Aqueous Cleaning Design Presentation*, Mark Meltser, Forward Technology Industries Inc., 13500 County Road 6, Minneapolis, MN 55441 (612-559-1785) improved cleanliness and effectiveness of drying. The presentation recommended careful definition of potential soils (e.g., flux, grease/oil, buffing compounds or particulates) which strongly influence cleaning solution chemical requirements and filtration. Meltser also stressed that cleanliness criteria be carefully researched to establish realistic specifications, as over-specifying cleanliness raises design, construction and maintenance costs.

Fuchs' presentation, *The How and Why of Ultrasonic Cleaning*, complemented Meltser with depth and detail into ultrasonic theory. The presentation reviewed generation of ultrasonic energy, the ultrasound on a liquid, maximizing the effect of ultrasonic augmentation, overviews of equipment and process design. The presentation dispelled several myths, and employed visual aids advantageously.

Barnett, presenting for Pazabanick, described a commercial dry ice pellet system which delivers 0.125 inch pellets at supersonic speeds for cleaning. The thermal and kinetic energy of impact explode contaminants from surfaces. Since the dry ice sublimes on contact to gaseous CO_2, the surfaces are dry, and contaminants require no further treatment prior to disposal. Foster described a dry ice pellet system which accelerates the pellets using a continuous centrifuge. These pellets are employed for both surface cleaning and etching.

Addressing *Closed-loop Near Zero Emissions Solvent Cleaning*, Rodgers described an ultratight, closed-loop cleaning system which accommodates environmentally or physiologically hazardous solvents, such as perchloroethylene or trichloroethylene. Differing from low emission vapor degreaser (LEVD) technology, the subject system cleans with a liquid solvent spray in a closed chamber. Then vacuum

D2.2 *Evaluation of Pressurized Water Cleaning Systems for Hardware Refurbishment*, Terry W. Dillard, Thiokol Corporation, Bldg 4712, Marshall Space Flight Center, MSFC, AL 35812, (205-544-4328)

D2.3 *The How and Why of Ultrasonic Cleaning*, F. John Fuchs, Blackstone Ultrasonics, P. O. Box 220, 9 North Main Street, Jamestown, NY 14702-0220, (716-665-2340)

D2.4 *A Centrifuge CO_2 Pellet Cleaning System*, C. A. Foster, Oak Ridge National Laboratory, P. O. Box 2009, Oak Ridge, TN 37831-8071, (615-574-1128)

D2.5 *CO_2 (Dry Ice) Cleaning System*, Don Barnett, TOMCO$_2$ Equipment Company, 3340 Rosebud Road, Loganville, GA 30249, (404-979-8000) is applied to the sealed chamber to evaporate solvent, which is then recondensed for reuse. The equipment should be directly applicable to HFC solvents when they become commercially available.

Thompson presented Tsai's paper *A Microwave Plasma Cleaning Apparatus*, which described cleaning using reactive plasmas of oxygen mixed with argon which were generated by a microwave electron cyclotron resonance plasma source. The effect of such parameters as gas pressure, magnetic field, substrate biasing and microwave biasing were found to influence cleaning efficiency.

D2.6 *Near Zero Emission Cleaning System*, Joel E. Rodgers, Vice President, Baron-Blakeslee Inc., 1500 W. 16th Street, Long Beach, CA 90813, (310-491-1228)

D2.7 *A Microwave Plasma Cleaning Apparatus*, Lisa Thompson, Oak Ridge National Laboratory, Fusion Energy Division, Oak Ridge, TN 37831-8071, (615-626-7926)

SESSION D3

CLEANING VERIFICATION-INSTRUMENTATION AND TECHNIQUES 2

Cleaning of critical surfaces and subsequent verification of their cleanliness require environmentally safe cleaning agents and monitoring techniques to ensure cleanliness. Replacement cleaning systems for the traditional chlorofluorocarbon and chlorocarbons used on critical surfaces and the methodology for the real-time analysis of chemical contaminants on critical surfaces, were the topics covered. Topics related to liquid fuel and solid rocket motors propulsion systems were both covered in this group of papers with each system providing a different set of problems within the manufacturing environment.

The standards development work has applicability in testing any new proposed cleanliness inspection technique. Techniques discussed in this session include optically stimulated electron emission, infrared spectroscopy, ultraviolet fluorescence, and ellipsometry. These techniques will be characterized for possible Shuttle programs applications to replace currently used chlorinated solvent nonvolatile residue analysis performed on critical surfaces. The application of these techniques is consistent with avoidance technologies or activities as defined in the "Technology for a Sustainable Future" initiative.

Historically, non-volatile residue (NVR) analysis using CFCs has provided a good indicator of surface contamination in near real time. Attempts to find other solvents which can provide similar indications on critical surfaces have been a major undertaking by every aerospace manufacturer. Marilyn

Chairs

Dr. Gary L. Workman, Center for Automation and Robotics, The University of Alabama in Huntsville, Huntsville, AL 35899, (205-895-6578)

H. Dewitt Burns, NASA/Marshall Space Flight Center, Physical Sciences Branch, EH12, MSFC, AL 35812, (205-544-2529)

Speakers

D3.1 *Investigation of Cleanliness Verification Techniques for Rocket Engine Hardware*, Marilyn Fritzemeier, Rocketdyne Division, Rockwell International Corporation, 6633 Canoga Avenue, P. O. Box 7922, MC AC67, Canoga Park, CA 91309-7922, (818-586-7296)

Fritzemeier showed the results of work with a series of alternative cleaning reagents. Several of the aqueous cleaners tried showed good results for most contaminating organics; however, no single cleaning agent was able to perform well for all contaminants. In comparison with CFC-113 and 1,1,1-trichloroethane, several practical cleaning agents appear to represent good replacements for detecting many of the contaminants.

Gregory Melton, at KSC, has successfully applied an air/water impingement process to small parts to remove surface contamination. The effectiveness of the air/water impingement process is being directly compared with CFC-113 as a potential replacement in cleanliness verification for small parts in liquid engine support systems.

Qualitative cleanliness inspection techniques such as white and blacklight inspection have proved adequate for Solid Rocket Booster bond systems as reported by Rodney Myers. Potential contaminants in the manufacturing environment were identified, then tested with bond systems of interest to determine critical contamination levels for each bond. The currently used inspection techniques detected contaminants below the critical levels.

The impact of contaminants on critical bonding surfaces has been studied principally for their usage in the manufacturing environment associated with the redesigned solid rocket motor (RSRM). Both the solid rocket motor cases and nozzles have critical bonding surfaces which can be easily contaminated. In addition to NVR approaches, other real time techniques of interest have been under development and were presented.

The primary work of Dr. G. L. Powell of Martin Marietta Energy Systems at the Oak Ridge Center for Manufacturing Technology has been to design and build FTIR instruments which provide

D3.2 *Cleaning Verification by Air/Water Impingement*, Gregory S. Melton, NASA/Kennedy Space Center, MC DM-MSL-21, KSC, FL 32899, (407-867-7048)

D.3.3 *Verification of Surface Preparation for Adhesive Bonding*, Rodney S. Myers, United Space Boosters Inc., P.O. Box 1900, Huntsville, AL 35807, (205-721-2907)

D3.4 *Surface Inspection Using FTIR Spectroscopy*, Dr. G. L. Powell, Oak Ridge Y-12 Plant, Martin Marietta Energy Systems Inc., Oak Ridge, TN 37831-8096, (615-574-1717)

D3.5 *Cleanliness Evaluation of Rough Surfaces with Diffuse IR Reflectance*, Dr. L. H. Pearson, Thiokol Corporation, P.O. Box 707, MS 244, Brigham City, UT 84302, (801-863-6398) quantitative analysis of chemical substances on surfaces. He has worked closely with manufacturers to optimize the capabilities of the instruments. Three types of instruments have been developed through this approach: diffuse reflectance, internal reflection and external reflectance FTIR spectrometers. This group of instruments also includes portable systems for in-plant surface inspections and the capability to adapt to robotic scanning.

Dr. L. Pearson at Thiokol has worked in the mid-IR region using both acousto-modulation and filter instruments to provide a portable approach to contaminant identification on diffuse surfaces. The most recent work on the quantification of hydrocarbon contaminants such as HD2 grease has been accomplished through the development of the Surfmap IR instrument.

Jeffrey Hale from the University of Nebraska presented data on spectrometric ellipsometry to show the sensitivity of the technique to organic residual surface films. The instrumentation is marketed through the J. A. Woollam Co. and provides a useful modelling fit of the data to identify film optical constants and/or film thicknesses.

A more elemental approach to the identification and quantification of surface contamination was presented by Dr. M. Leslie of Thiokol. He presented data using surface analysis instruments such as Auger, SIMS and ESCA to identify residuals from replacement processes of vapor degreasing with 1,1,1-trichloroethane. The surface sensitive analytical techniques provide a useful role in comparing the cleanliness of the surfaces after cleaning with various agents. Of particular interest in his report is the lack of correlation between organic contaminants and bonding. None of these techniques is applicable to real time inspection, but they do identify useful cleanliness characteristics of bonding surfaces.

D3.6 *Spectroscopic Ellipsometry As a Sensitive Monitor of Materials Contamination,* Jeffrey S. Hale, Center for Micro-electronic and Optical Materials Research, University of Nebraska, Lincoln, NE 68508, (402-477-7501)

D3.7 *The Role of Surface Chemical Analysis in a Study to Select Replacement Processes for TCA Vapor Degreasing,* Dr. M. W. Lesley, Thiokol Corporation, Science and Engineering, Analytical Laboratories Department, P.O. Box 707, Brigham City, UT 84302-0717, (801-863-5854)

☆ U.S. GOVERNMENT PRINTING OFFICE—1995—633-109/20026

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1995	Conference Publication

4. TITLE AND SUBTITLE
Aerospace Environmental Technology Conference—Executive Summary

5. FUNDING NUMBERS

6. AUTHOR(S)
A.F. Whitaker, Editor

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

8. PERFORMING ORGANIZATION REPORT NUMBER
M-774

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CP-3297

11. SUPPLEMENTARY NOTES
Summary of a conference held at Huntsville, AL, August 10–11, 1994

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified – Unlimited
Subject Category 23

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The mandated elimination of CFC's, Halons, TCA, and other ozone depleting chemicals and specific hazardous materials has required changes and new developments in aerospace materials and processes. The aerospace industry has been involved for several years in providing product substitutions, redesigning entire production processes, and developing new materials that minimize or eliminate damage to the environment. These activities emphasize replacement cleaning solvents and their application verifications, compliant coatings including corrosion protection systems, and removal techniques, chemical propulsion effects on the environment, and the initiation of modifications to relevant processing and manufacturing specifications and standards.

The papers from this conference are being published in a separate volume as NASA CP-3298.

14. SUBJECT TERMS
environment, replacement technology, propulsion, solvents, non-CFC's, cleaning technology, corrosion protections, cleaning verification, blowing agents, degreasers, fuels, insulations

15. NUMBER OF PAGES
46

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited