National Aeronautics and Space Administration (NASA) Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM)

Final Report on NASA Portable Laser Coating Removal Systems Field Demonstrations and Testing

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Acronyms and Abbreviations

AWT	Altitude Wind Tunnel
CAA	Clean Air Act
CL	Clean-Lasersysteme
CrVI	hexavalent chromium
CWA	Clean Water Act
DoD	US Department of Defense
EDS	Energy Dispersive Spectroscopy
ESTCP	Environmental Security Technology Certification Program
GRC	John H. Glenn Research Center
GSE	Ground Support Equipment
ioz	inorganic zinc
JG-PP	Joint Group on Pollution Prevention
kHz	kiloHertz
KSC	John F. Kennedy Space Center
mm	millimeters
MST	Mobile Support Tower
NASA	National Aeronautics and Space Administration
NDE	non-destructive evaluation
nm	nanometers
OSHA	Occupational Safety and Health Administration
PPE	personal protective equipment
RCRA	Resource Conservation and Recovery Act
SEM	Scanning Electron Microscopy
SRB	Solid Rocket Booster
SSP	Space Shuttle Program
TEERM	NASA Technology Evaluation for Environmental Risk Mitigation Principal Center
TPS	Thermal Protection System
US	United States
USA	United Space Alliance
VOC	Volatile Organic Compound
W	Watt
WPAFB	Wright-Patterson Air Force Base

Executive Summary

Processes currently used throughout the National Aeronautics and Space Administration (NASA) to remove corrosion and coatings from structures, ground service equipment, small parts and flight components result in waste streams consisting of toxic chemicals, spent media blast materials, and waste water. When chemicals are used in these processes they are typically high in volatile organic compounds (VOC) and are considered hazardous air pollutants (HAP). When blast media is used, the volume of hazardous waste generated is increased significantly.

Many of the coatings historically used within NASA contain toxic metals such as hexavalent chromium, and lead. These materials are highly regulated and restrictions on worker exposure continue to increase. Most recently the Occupational Safety and Health Administration (OSHA) reduced the permissible exposure limit (PEL) for hexavalent chromium (CrVI) from 52 to 5 micrograms per cubic meter of air as an 8-hour time-weighted average. Hexavalent chromium is found in numerous pretreatment and primer coatings used within the Space Shuttle Program.

In response to the need to continue to protect assets within the agency and the growing concern over these new regulations, NASA is researching different ways to continue the required maintenance of both facility and flight equipment in a safe, efficient, and environmentally preferable manner.

The use of laser energy to prepare surfaces for a variety of processes, such as corrosion and coating removal, weld preparation, and non destructive evaluation (NDE) is a relatively new application of the technology that has been proven to be environmentally preferable and in many cases less labor intensive than currently used removal methods. The novel process eliminates VOCs and blast media and captures the removed coatings with an integrated vacuum system. This means that the only waste generated are the coatings that are removed, resulting in an overall cleaner process.

The development of a Portable Laser Coating Removal System (PLCRS) started as the goal of a Joint Group on Pollution Prevention (JG-PP) project, led by the Air Force, where several types of lasers in several configurations were thoroughly evaluated. Following this project, NASA decided to evaluate the best performers on processes and coatings specific to the agency. Laser systems used during this project were all of a similar design, between 40 and 500 Watts, most of which had integrated vacuum systems in order to collect materials removed from substrate surfaces during operation.

Due to the fact that the technology lends itself to a wide variety of processes, several site demonstrations were organized in order to allow for greater evaluation of the laser systems across NASA. The project consisted initially of an introductory demonstration and a more in-depth evaluation at Wright-Patterson Air Force Base. Additionally, field demonstrations occurred at Glenn Research Center and Kennedy Space Center (KSC). The objectives were to allow interested parties to observe the process on their items and ease any concerns that might provide a hurdle to implementation.

During these demonstrations several NASA specific applications were evaluated, including the removal of coatings within Orbiter tile cavities, removal of Teflon from Space Shuttle Main

Engine gaskets, removal of heavy grease from Solid Rocket Booster components, and the removal of coatings on weld lines for Shuttle and general ground service equipment for NDE. This entailed collecting measurements such as strip rates and temperature readings and performing NDE inspections after stripping.

In addition, several general industry applications such as corrosion removal, structural coating removal, weld line preparation and surface cleaning were evaluated. This included removal of coatings and corrosion from surfaces containing lead-based coatings and applications similar to launch structure maintenance and Crawler maintenance.

During the project lifecycle, an attempt was made to answer process specific concerns and questions as they arose. Some of these initially unexpected questions concerned the effects lasers might have on substrates used on flight equipment including strength, surface remelting, substrate temperature and corrosion resistance effects. Additionally a concern was what personal protective equipment (PPE) would be required for operating such a system including eye, breathing, and hearing protection. These questions although not initially planned, were fully explored as a part of this project.

Generally the results from testing were very positive. Corrosion was effectively removed from steel, but less successfully from aluminum alloys. While it easily removes corrosion from steel substrates even at low powers, white or light colored corrosion products typical of aluminum were not able to be removed. Coatings were able to be removed, with varying results, generally dark, matte and thin coatings were easier to remove. Coatings up to 16 mills thick were removable even with the lowest power laser, however such thick coatings took long periods of time to remove. For such applications higher power lasers should be used. Steel and aluminum panels were able to be cleaned for welding, with no known deleterious effects and weld lines were able to have coatings removed in critical areas for NDE while saving time as compared to other methods.

Shuttle components were able to be stripped efficiently and coatings were able to be completely removed, but the selectivity of the hand-held laser was not sensitive enough to allow for removal of only the primer layer, as the process demanded. Removing only the primer layer on Shuttle tile cavities allows for the preservation of underlying pretreatment which aids in corrosion resistance. It should be noted that a stationary two dimensional scanning laser was able to successfully remove primers while preserving pretreatments, showing promise for this type of application.

The technology in general had difficulty removing very thick coatings, such as those typically found on exterior structures. It should only be considered for this type of application for small-areas that may be difficult to work on with conventional methods. Additionally, higher power units such as the 300W, 500W or 750W lasers would be recommended. Similarly, the laser was able to remove contamination from parts, but the heavy greases found on the solid rocket boosters was very difficult to remove and frequent cleaning of the laser was required, however a modification of the vacuum system might alleviate this issue.

It was determined that substrates were not negatively affected by laser energy and corrosion rates of materials exposed to lasers was not increased as a result of exposure.

Air sampling showed that with the vacuum operating air exposure was not a risk to workers and no breathing protection would be required. Noise sampling showed that while the laser system did not exceed any limits, hearing protection is recommended would be likely be required at KSC if implemented.

It is the recommendation of the NASA Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM) that KSC consider implementing this technology for cleaning, surface preparation for adhesive bonding, NDE, weld line preparation, small area depainting, and corrosion removal where chemical or media blasting is not optimum or completion of work is time-critical. Upon implementation other potential applications not tested during this project should be thoroughly explored and areas for further implementation identified. As NASA moves forward, other opportunities exist to continue the development of joint testing of this technology on larger-scale processes, including with the Air Force as they continue to test laser technologies and implement them in aircraft depainting processes.

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Preface and Acknowledgements

This report was prepared by ITB, Inc. through the National Aeronautics and Space Administration (NASA) Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM) under Contract Number NNH06CC40C Delivery Order No. 012. The structure, format, and depth of technical content of the report were determined by TEERM, Government contractors, and other Government technical representatives in response to the specific needs of this project.

The information contained in this report was leveraged from the Joint Group on Pollution Prevention (JG-PP) document entitled *Portable Handheld Laser Small Area Supplemental Coatings Removal System*, prepared by the HQ Air Force Materiel Command Depot Modernization and Logistics Environmental Office, dated 17 Aug 2005 and funded by the Environmental Security Technology Certification Program (ESTCP).

TEERM acknowledges the efforts of Martin Boyd and Larry Nielson for helping to gather interest during the beginning stages of this effort and for their continued support throughout. We also appreciate the cooperation of Boeing personnel, namely Doug Boerigter, Marcy Solomon and Paul DeVries for assisting with selection of test articles and providing information found in this report. We also appreciate the cooperation of United Space Alliance personnel, namely Larry Nielson, Jon Seibert, Julia Hess, and Sandy Rozzo for assisting with selection of test articles and providing information found in this report. A special thanks to Doug Boerigter for his assistance with the coordination of testing and teleconferences as well as the assembly of test reports for metallurgical analysis. Thanks to the numerous participants and project stakeholders, without their technical expertise, patience and insight, the completion of this report would not have been possible.

TEERM also recognizes the efforts of the facility owners, process foreman and technicians for answering questions relating to specific processes. Their efforts assisted in the completion of this report. We wish to acknowledge the invaluable contributions provided by all the organizations involved in the creation of this document.

1.0. Introduction

The National Aeronautics and Space Administration (NASA) built off of a successful project conducted by the Joint Group on Pollution Prevention (JG-PP) and Environmental Security Technology Certification Program (ESTCP) that evaluated Portable Laser Coating Removal System (PLCRS) technology. The laser technology is of interest to not only NASA, but also other military agencies that have painting/depainting other surface preparation related applications.

Various metallic surfaces on aerospace components exist in corrosive environments at NASA facilities. These components may include flight hardware, ground support equipment, or structures. Maintenance is a regular activity that must be performed regardless of the corrosivity of the environment in order to ensure that components meet or exceed design life. The standard practice for protecting metallic substrates in atmospheric environments is the application of an applied coating system. Applied coating systems work via a variety of methods (barrier, galvanic and/or inhibitor) and adhere to the substrate through a combination of chemical and physical bonds.

Surface preparation including coating and corrosion removal is a vital precursor to applying coating systems. A suitable substrate condition promotes the adhesion properties of the coating system and allows the coating system to perform to its designed capabilities. The level of cleanliness or anchor profile desired is typically a function of the type of coating to be applied or is outlined in a specific standard. Cleanliness and surface profile requirements for aluminum, steel, and stainless steel dictate the use of abrasive media, chemical strippers, or other methods of coating removal while not causing irreversible damage to the substrate or surrounding substrates of the equipment.

Many of the surface preparation methods used across NASA generate fugitive particulate emissions, waste, and can have significant process cycle times. The high quantities of airborne dust and waste generated from these operations pose significant processing and environmental concerns. Minimizing or eliminating the waste generated from the coating removal process will further minimize this risk. Chemical strippers often require multiple applications separated by lengthy wait times. Reducing cycle time can represent a significant cost savings.

1.1. Cost Comparison, and Life-Cycle Cost Analysis

Cost comparison data and Life Cycle Analysis can be found in the JG-PP/ESTCP Final Report titled *Joint Test Report for Validation of Coating Removal Systems* and dated 25 May 2005. Even though a comparison between specific NASA depot processes that might utilize such an alternative depainting technology has not been fully characterized, cost savings are assumed to be realizable.

1.2. Objectives of NASA Demonstrations

The objective of demonstrating this technology is to evaluate the performance on NASA-specific substrates, coatings, and components to determine both the effectiveness of using hand-held lasers as decoating tools for paint and coating systems at NASA and to better understand the procedures required to implement such a process within NASA. In addition to conventional demonstration and validation testing, the development of several documents was required in order to operate a Class IV laser within a NASA shop. Although this initially was not considered as part of the scope of the testing, the methodology and documentation required to perform the testing was lengthy and brought with it a large volume of information that will be required to understand prior to any implementation. Examples of a checklist and radiation use approval form are included as appendices for reference. *Checklist for Clean-Lasersysteme Demonstration & Operation at NASA KSC* is attached as Appendix C and *Radiation Protection Program Use Authorization*, Form K-LA-50147 is attached as Appendix E. These documents were adopted from similar Air Force PLCRS Projects Standard Operating Procedures. Please see the References section for other related documentation.

1.3. Regulatory & Other Drivers

Coating removal and other surface preparation activities are impacted by a number of regulations including the Clean Water Act (CWA), Clean Air Act (CAA), and Resource Conservation and Recovery Act (RCRA). Washing surfaces following such operations can generate quantities of wastewater contaminated with media and residues. Discharging wastewater with traces of hazardous waste can result in a direct violation of the CWA. The most common regulation associated with coating removal operations is the CAA, including the efforts to minimize the use of hazardous air pollutants. The RCRA directly regulates disposal of wastes generated by coating removal operations. The RCRA regulates how and where depainting waste can be disposed and transported as well as any future liabilities resulting from environmental damage.

Chemical and mechanical coating removal operations also require consideration for worker protection and training under Occupational Safety and Health Administration (OSHA) guidelines. OSHA sets worker exposure limits for substances commonly used in coatings, and associated removal processes. These include hexavalent chromium, cadmium, lead, and methylene chloride among others.

NASA is involved in a number of coating removal operations and is concerned with the identification of alternative methodologies. If proven viable, laser coating removal systems could provide facilities with an environmentally friendly alternative to some of these types of operations. The use of laser paint stripping systems is applicable to coating removal on aerospace components, aerospace support equipment, and ground support equipment and systems.

2.0. Technology Description

This project involved the use of similar equipment with the same technology as the JG-PP/ESTCP funded PLCRS project. In general, the project utilized several differently sized Q-switched pulsed portable hand held neodymium-doped yttrium aluminum garnet (Nd:YAG)

lasers (40Watt (W), 120W & 500W), most of which had integrated vacuum containment systems. Q-switching allows a laser to produce a pulsed output beam and allows the production of light pulses with extremely high peak powers, much higher than would be produced by the same laser if it were operating in a constant output mode. A laser that is operating at 100W continuous can produce pulses in the gigawatt range with Q-switching. Several of the lasers used a rastering mechanism integrated into the end piece where the beam exits the hand-held unit, herein referred to as the 'end effector', allowing more versatility than a single beam laser alone offers. In the case of the 120W laser, this allows the fiber optically delivered beam to produce a 0.4 mm wide linear beam shape that can be adjusted from 1.3 to 50 mm in length at a varied speed (40 to 100) Hertz (Hz). A more detailed description of the technologies demonstrated as a part of the JG-PP projects and reviewed during this project can be found in the JG-PP/ESTCP Final Report.

3.0. Field Demonstrations

3.1. Previous Testing

The JG-PP/ESTCP project originally focused on the development of a specification for a laser system to accomplish small-area depainting. Several companies worked with the Air Force to develop, design and test systems that would meet this specification. JG-PP/ESTCP testing was very robust and consisted of tests listed in Table 3-1A.

Table 3-1A: JG-PP/ESTCP Testing of PLCRS Technology

Test Title	Performance Criterion / Metric
Performance – Qualitative	Coating Removal w/o Damage
Performance – Qualitative	Ease of Use, Handling and Reliability
Coating Strip Rate	Less than or equal to baselines or 0.06 ft^2 per minute at 6 mils, nominal thickness
Warping/Denting	No warping / denting visually observed
Metal / Composite Erosion	No metal / composite erosion observable at 10X magnification
Hardness	No significant change in hardness
Tensile Adhesion	Compare Tensile Strength of samples values obtained with control samples of base materials (non-stripped and non-coated samples)
Wet Tape Adhesion	Wet Tape Adhesion performance greater than or equal to 4a as specified in ASTM D3359
Confirmation of Cladding Penetration	No black indication
Surface Profile / Roughness	2024-T3 Aluminum Clad: Not to exceed 125 micro inches. 2024-T3 Bare: Not to exceed 125 micro inches
Substrate Temperature During Coating Removal Process	7075-T6 Aluminum: 300°F maximum spike condition. Carbon Epoxy Laminate: 200°F maximum spike condition
Four Point Flexure	No significant change at 90% confidence
Rotary Wing Metallic Substrate Assessment	No significant change at 90% confidence

Test Title	Performance Criterion / Metric
Damage Assessment to Honeycomb Structural Materials	Testing detail and results shall be documented for review and determination of pass/fail values
Tensile Strength Testing of Substrates	The average tensile ultimate strength, tensile yield strength, and elongation for each of the aluminum substrates after depainting cycles with laser
Conductivity	Evaluated after 4 depaint cycles
Air Sampling	Identification of air-based health risks; Tested on DoD Coatings

3.2. NASA Interest in Follow-on Field Demonstrations

The JG-PP/ESTCP PLCRS project focused more on Air Force and DoD (Department of Defense) substrates and coatings. These efforts represented a data gap in NASA-specific substrates and coatings. The previous project also resulted in questions regarding the full effects of the laser on the substrate such as micro-structural anomalies observed on some surfaces, herein referred to as a 'remelt layer' and whether or not an Anodized layer could be left intact. The remelt layer refers to an observed grain structure of the surface of the substrate, with a depth of less than 7 microns when a 120W laser is used. This phenomenon is analyzed in the United Space Alliance (USA) report *Advanced Coating Removal Techniques* dated 18 Jan 2006.

Boeing conducted some testing in support of the Orbiter for Space Shuttle Program (SSP) and recommended further demonstrations at NASA facilities, particularly Kennedy Space Center (KSC). The initial tests included laser stripping of 12" x 13" x 0.040" 2024 aluminum panels and 11.5" x 11.5" x 0.025" graphite epoxy panels that were coated with several primers. Because the effects of energy departed on a substrate were of concern, temperature indicating labels were attached to the back of each panel and readings taken immediately after stripping with both the 120W Clean Laser and 40W Quantel Nd:YAG lasers. Tables 3-2A & B below show the strip rates and temperatures for the various aluminum and graphite epoxy panels that were tested.

Table 3-2A: Aluminum Panel Decoating Data

Decoating Rate of Aluminum Test Panels					
* All panels were Bare 2024 aluminum, pretreated with Alodine 1200, and wiped with isopropyl alcohol prior to application of primer					
Panel Number	**Primers**	**Coating Removal Rates**		**Temperature**	**Laser Used**
		Rate (sq ft / min)	**Rate (min / sq ft)**		
1	Super Koropon (515-K012 / 910-K017)	0.0754	13.2615	< 100 °F	CL 120W
2		0.0624	16.0308	< 100 °F	QL 40W
5	PRC DeSoto (EWAE118 batch 675298)	0.0750	13.3385	≈ 100 °F	CL 120W
6		0.0743	13.4615	< 100 °F	QL 40W
9	PRC DeSoto (EWDY048 batch 694925)	0.0939	10.6462	≈ 100 °F	CL 120W
10		0.0607	16.4615	< 100 °F	QL 40W

Table 3-2B: Graphite Epoxy Panel Decoating Data

Decoating Rate of Graphite Epoxy Test Panels
All panels were abraded (240 grit) and wiped with methyl ethyl ketone prior to application of primer

Panel Number	Primers	Coating Removal Rates		Temperature	Laser Used
		Rate (sq ft / min)	Rate (min / sq ft)		
3	Super Koropon (515-K012 / 910-K017)	0.1125	8.8922	< 100 °F	CL 120W
4		0.1087	9.2008	≈ 100 °F	QL 40W
8	PRC DeSoto (EWAE118 batch 675298)	0.0950	10.5255	≈ 125 °F	CL 120W
7		0.0864	11.5781	≈ 150 °F	QL 40W
11	PRC DeSoto (EWDY048 batch 694925)	0.0637	15.6975	≈ 125 °F	CL 120W
12		0.0480	20.8333	≈ 150 °F	QL 40W

The lasers were able to remove coatings from the aluminum and graphite epoxy panels. Temperatures observed did not exceed those allowable but some warping was observed in both substrates. Warping observations showed that there was some adverse impact on graphite epoxy panels, but the extent was unknown. Both the 40W and 120W lasers were effective in removing Super Koropon and both PRC DeSoto primers. It was observed that in general, laser paint stripping is slower than conventional methods, however, there does appear to be a niche for portable lasers in smaller scale applications. The 120W rastering laser was determined to be more effective on larger, relatively flat surfaces while the 40W single-point laser appeared to be more effective on complex geometries or hard to reach areas. It appears that the lasers tested would be effective in removing Super Koropon from tile cavities and other parts with complex geometries or hard to reach surfaces on the Orbiter. More detailed results of the Boeing testing can be found in Lab Report No. M&PE-3-1567, *Portable Laser Coating Removal Task* dated 06 Dec 2004.

3.3. Wright-Patterson Air Force Base Demonstration (August 9-11, 2004)

Initial testing with the SSP-specific and other NASA Ground Support Equipment (GSE) performed was successful, and gained enough interest within Boeing, USA, and NASA to organize more detailed demonstrations of the technology. NASA Technology Evaluation for Environmental Risk Mitigation Principal Center (TEERM) began to identify NASA stakeholders wanting to test the technology further. In August 2004, several engineers from Glenn Research Center (GRC) and KSC attended a short demonstration of the technology at Wright-Patterson Air Force Base (WPAFB). This demonstration was performed at the Laser Hardened Materials Evaluation Laboratory at WPAFB near Dayton, Ohio. This facility is managed by the Air Force Research Laboratory, Hardened Materials Branch and is operated by Anteon Corporation. Besides the relatively close proximity of WPAFB to GRC, another reason that WPAFB was chosen for the initial demonstration site is the extensive amount of safety documentation and planning that must be generated for a demonstration involving lasers.

3.3.1. Objective

The objective of this demonstration at WPAFB was for GRC, Johnson Space Center, and KSC engineers to witness laser stripping technologies. It was also an opportunity for interested parties within NASA to begin considering how it could best be utilized within maintenance and manufacturing operations at their perspective facilities.

3.3.2. Field Test and Evaluation Plan

No formal test plan was developed for this demonstration. Engineers were asked to bring samples of representative substrates and coatings. GRC sent three aluminum test panels from aircraft with coatings that they strip at their facility. While this was their primary reason for interest in laser stripping, they also expressed interest in other stripping applications within their facility. KSC sent five test panels. Four of the panels were aluminum and one was a composite honeycomb/aluminum material. Each test panel was coated with Koropon paint. Some test panels included Anodize layers as well. Additionally some panels consisted of Koropon and room-temperature vulcanizing silicone adhesive (RTV) used as a component of the Orbiter Thermal Protection System (TPS). One test panel was a mock-up of the Orbiter tile cavity, as it would appear when one tile is missing prior to replacement. The interests of the team were to demonstrate the ability of the laser to selectively remove materials such as Koropon and RTV from aluminum or honeycomb without causing disbonding or disturbing the Anodized layer, and to determine effects of laser energy on the TPS materials such as filler bar and tiles.

3.3.3. Conclusions/Recommendations

Most results were incorporated into lab activity reports by Boeing and USA, as referenced in section 3.2 of this report. The stakeholders committed to determine what future follow-on testing was needed to fulfill any demonstration/validation requirements necessary for implementation of a laser stripping unit at their facility.

It should be noted that aluminum surfaces that are used as part of the TPS on Orbiter have unique requirements that include maintaining an Anodized layer for corrosion protection and adhesion properties. An added constraint is that chem-film cannot be applied to these surfaces if the Anodized layer is not intact. Current process for preserving the Anodized layer is bead blast media. At the time of this demonstration, the bead blast process was under review because of contamination issues in adjoining tile spaces. Boeing and USA stripped representative coatings to analyze the effects on the Anodized layer and initially concluded that the Anodized layer could not be left on the surfaces by any of the hand held lasers. Further testing was recommended to evaluate if laser processing with a stationary 2-D scanning head could leave Anodize intact on such surfaces.

3.4. Glenn Research Center Demonstration (October 24-28, 2005)

The first official coordinated demonstration of the PLCRS technology for this project took place in October 2005. The purpose of the visit to GRC was to test the hand held 120 Watt (W) Clean-Lasersysteme (CL) Nd:YAG laser in order to demonstrate the feasibility of the technology for use on GSE and small-area structural depainting within NASA. Participants from KSC, GRC, and Stennis Space Center were involved with this effort.

Prior to work beginning at the facility, Laser and Health Safety inspections were carried out for the test cell at GRC. Immediately following the inspection and approval, safety training from GRC and WPAFB representatives on the use of lasers for this activity was given. Only

those with previous training and operational permission with this laser system were allowed to use the laser at GRC.

3.4.1. Objective

The objectives included stripping test panels, fielded scrap GSE articles, structural samples, and field testing of the technology on an outdoor structure at GRC.

3.4.2. Field Test and Evaluation Plans

A number of tests were planned to be performed as documented in *Field Evaluations Test Plan for Validation of Portable Laser Coating Removal Systems for use on Ground Service Equipment*, dated October 13, 2005. Due to the availability of certified personnel, data from all planned tests was not able to be collected. Testing on field articles and test panels and demonstration of the laser was performed throughout the week. Testing of the laser on the outdoor structure known as the Altitude Wind Tunnel (AWT) began on the afternoon of October 27^{th} and all testing was completed by that evening.

Samples were photographed; spaces were measured, and stripped to bare metal. Strip rates were taken and extrapolated to both square feet per minute and minutes per square feet. Photographs were also taken after stripping was complete and a certified technician from ASRC Aerospace made SSPC Vis 1 assessments where applicable. All samples were stripped with the 120W Nd:YAG laser at the following setting unless otherwise noted: Pulse: 20kHz, Scan Width: 50 millimeters (mm), Scan Speed: 75Hz. The frequency of the Nd:YAG laser is always 1064 nanometers (nm).

3.4.3. Results

Some of the testing was done in conjunction with the TEERM Depainting Technology for Structural Steel project and therefore some of the results are included in the *Depainting Technology for Structural Steel Final Report*, dated 15 Mar 2006.

Findings included that lighter colored coatings proved more difficult to strip due to lower heat absorption. Additionally, limited non-destructive evaluation (NDE) testing results from laser stripped weld lines were excellent. Field tests showed that the PLCRS excelled in corrosion removal. Corrosion on steel substrates was removed quickly and completely, even cleaning out pitted areas leaving the substrate in excellent condition for immediate recoating. Lighter colored corrosion typical of aluminum substrates was more difficult and in most cases not completely removed.

Table 3-4A contains the strip rates calculated from samples tested with the laser. Operators and observers present during the testing did not notice any results inconsistent with previous results during the JG-PP/ESTCP project.

Table 3-4A: Strip Rates of Test Specimen, GRC

No.	Description	Coating Thickness	Rate (sq ft /min)	Rate (min / sq ft)
1A	Cold-rolled Steel "Be Safe" sign	1-1.5 mil	**0.103**	**9.71**
1B	Steel Support Rail for Air Handling Unit	11.5 mil	**0.013**	**76.92**
1C	8 in Steel strut	1.5 mil	**0.057**	**17.54**
1D	Valve Spring-Loaded Actuator	3 mil	**0.063**	**15.87**
1E	Angle Iron	2-5 mil	**0.027**	**37.04**
2A	High-Temp Silicone Coating and Garlock on Sheet Steel	15-16 mil	**0.017**	**58.82**
2B	Locktite #2 (Permatex #2) and Garlock on Steel	12-15 mil	**0.018**	**55.56**
5A	Aged Coating on Launch Structural Steel	11 mil	**0.018**	**55.56**
5B	Launch Structure with clean/new coating	12 mil	**0.013**	**76.92**
5C	Structural Steel from Launch Complex (heavily corroded)	15 mil	**0.010**	**100**
5D	GSE for Shuttle Components	4 mil	**0.024**	**41.67**
99A	Bearing House for M1 Tank with grease and carbon buildup	N/A	**N/A**	**N/A**
99B	Outdoor AWT Structure	11 mil	**0.017**	**58.82**

3.4.4. Laboratory Analysis

Table 3-4B below shows the analysis of chemical sampling to better understand the composition of the exterior paint that exists on the AWT. The composition of the paint includes a significant amount of lead.

Table 3-4B: Chemical Sampling of Exterior Paint

Environmental Management Office Chemical Sampling and Analysis Team ANALYTICAL REPORT	
Date:	April 18, 2005
Requester:	Eugene DiSanto
Work Order #:	EMD 0007
Analyst:	Wai Ching Wan (3-5599)
Metal concentrations in the paint sample AWT-ExtPaint-Metals-002 (Red/Silver) are as follows:	
EXTERIOR Paint	
Metal	Parts per million (ppm)
Magnesium	816
Manganese	128
Zinc	179
Aluminum	89932
Chromium	25332
Copper	51
Iron	17296
Lead	219388 (21.9 % by Weight.)
Nickel	26
Calcium	1709
Silicon	153

Mercury	0.10
Cadmium	1

Details on initial metallurgical analysis from activities performed on structural steel can be found in *NASA KSC-MSL-2005-0561 Laser Depainting Metallurgical Report* which is included as Appendix C of the *Depainting Technology for Structural Steel Final Report.* Essentially there were no measurable differences between laser treated and non-treated areas with respect to microstructure, hardness, or surface roughness. Only some superficial mechanical deformation of the surface was noted.

3.4.5. Conclusions/Recommendations

This was a very successful effort and brought NASA closer to implementation of the technology. Visitors that observed the work at GRC were impressed with the promise this technology holds for near-zero waste generating depainting activities. There was increased interest in comparing results from a 500W laser to that of the smaller 120W laser. Of interest to observers of the technology, was the ability of the laser to remove corrosion from steel and the ability of the 120W to remove coatings on the Shuttle GSE relatively quickly, especially on weld lines for NDE analysis. Another area of particular interest was the possibility of reducing the environmental impacts of decommissioning structures that were painted with lead-based coatings such as the AWT at GRC.

At the time of the demonstration, the AWT was to be scheduled for demolition. The disturbance of coatings on the exterior present potentially problematic issues during this planned demolition, considering the high content of several toxic metals within its coatings.

One potential solution posed during the demonstration would be to remove only the coatings where cutting needs to take place to demolish the structure. Demonstration of the capability of a laser to remove these coatings without exposing the worker to such toxic metals was the primary goal. Testing was performed, and it was shown that compared to other methods of physical removal of coatings, PLCRS reduced or eliminated worker exposure to hazardous dusts via vacuum containment, but that removing coatings would take a considerably greater amount of time unless a more powerful laser was utilized due primarily to the thickness of the coating on such structures. More research into how best to use the technology for such an undertaking would be necessary before qualifying it for such work.

In total, there were 12 fielded GSE samples, 1 structure, and 8 test coupons brought for the depainting project. Several of the test panels were not used during field testing at GRC, but were saved for stripping at WPAFB with a 500W Nd:YAG laser. The coatings on samples varied in thickness from 1 to 16 mils. The ability of the laser to remove coatings from the Shuttle GSE component also highlighted the ability of the technology to remove coatings from weld lines on components that typically would require NDE during their lifecycle. Further analysis of the ability of lasers to remove coatings for GSE and to selectively strip weld lines for NDE were explored during the KSC Demonstration in 2006.

3.5. Wright-Patterson Air Force Base Demonstration (November 1-4, 2005)

A second, more detailed demonstration at WPAFB followed quickly upon the completion of testing at GRC.

3.5.1. Objective

The objectives of this demonstration were to field test the hand held 120W & 500W CL Nd:YAG lasers and the Quantel 40W Nd:YAG laser to validate the technology for use on Orbiter flight equipment and to further test the lasers for use on some of the GSE and structural steels tested at GRC.

3.5.2. Field Test and Evaluation Plans

For the demonstration a formal agenda was drafted that specified when each grouping of submitted specimen would be evaluated throughout the week and in some instances the degree of coating removal was also specified. Test samples included coupons with varying coatings, including Anodized and non-Anodized pretreatments, primers, topcoats, and some with RTV. In addition to the coupons, another tile cavity mock-up was manufactured allowing for each tile to be removed so that the same variety of coatings could be tested in a real-world setting. The tile array was manufactured to be attached to support beams in an inverted fashion to further simulate real-world working conditions on the Orbiter. With this tile array mock-up, the ability of the laser to remove coatings and any negative affects that it might have on surrounding TPS were explored. A test plan was developed for the tile array mock-up, outlining all tests to be performed during the demonstration. Testing included removal of various coatings found within Orbiter tile cavities. The effectiveness of the laser at removing these coatings along with the temperature observed during stripping as well as other observations. Additional testing was performed to characterize how materials other than the coatings to be removed react to laser exposure. This testing included RTV, filler bar, felt, and tile surfaces (tops and edges). Exposure times varied in order to determine effects of incidental and worst-case scenario exposure. Related to this testing, a theoretical procedure was developed to effectively mask the tile cavity with materials that are already approved for use in the Orbiter Processing Facility.

Two previously flown flight articles; an Elevon Cove Seal Cover or "flipper door" and a Window Retainer from the crew cabin were brought to test the lasers on other substrates and components that occasionally require refurbishment prior to flight. Since temperature is of considerable significance to Orbiter, temperature readings were taken using several methods during the testing to determine if the substrate ever exceeded the limit of 350 °F since there is a requirement that the aluminum substrate of the Orbiter belly never exceeds this level.

Table 3-5A: Test Panel Configurations for Testing, WPAFB

Panel Configurations	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6	Specimen 7
	1A/B, *34/B (extra)*	14A/B, *17A (extra)*	6A/B, *12A (extra)*	4A/B	18A/B	13A/B	
New Koropon	Bare Aluminum	chem-Film	Anodized	Bare Aluminum	chem-Film	Anodized	
(thickness variations)	Koropon	Koropon	Koropon	2 coats Koropon	2 coats Koropon	2 coats Koropon	

Old Koropon *(artificially aged – 5yr, 10yr, 20yr)*		15A/B, *17B (extra)* chem-Film Koropon Artificial Aging	7A/B, *12B (extra)* Anodized Koropon Artificial Aging				
Other *TPS coatings and configurations*	2A/B Bare Aluminum Koropon RTV560	16A/B chem-Film Koropon RTV560	8A/B Anodized Koropon RTV560	5A/B Bare Aluminum RTV560			
Face Sheet coatings and configurations	21A/B Bare Aluminum Face Sheet Koropon RTV560	24A/B, 26 *(extra)* Bare Aluminum Face Sheet chem-Film Koropon	*25 (extra)* *Bare Aluminum* *Face Sheet* *Anodized* *Koropon*	22A/B Bare Aluminum Face Sheet RTV560		23A/B Aluminum Face Sheet Anodized 2 coats Koropon	
Non *TPS coatings*	9A/B, *10A (extra)* Anodized Koropon Tie Coat (old) Thermal control coating		11A/B, *10B (extra)* Anodized Koropon Gloss Polyurethane	KSC Inconel Pyromark (In house: KSC coated part)	KSC Aluminum (2024) Corrosion Panel 1	KSC Aluminum (2024) Corrosion Panel 2	KSC Aluminum (2024) Corrosion Panel 3
Additional Coatings	SRB Aluminum Primer Hentzen topcoat	SRB Aluminum Primer Deft topcoat	SRB Aluminum Primer Hypalon topcoat	SRB Steel Primer Rustoleum topcoat	NSLD Aluminum Koropon Silverized coating	NSLD Aluminum Koropon* Gloss Polyurethane	NSLD Laminate Composite Koropon Conductive Coating

Coating Legend:

Koropon	MB0125-055	Thermal Control Coating	MB0125-080
Koropon*	MIL-P-23777 Type II class C	Tie Coat (old)	MB0125-094
Chem Film	MIL-C-5541	Gloss Polyurethane	MB0125-095
Anodize	MIL-A-8625	Silverized Coating	MB0125-098
RTV 560	MB0130-119 Type II	Conductive Coating	MB0125-070
Pyromark	MB0125-063		

Table 3-5B: Panel Configuration, WPAFB

Panel ID Numbers	(part and panel sized varied)
Window Retainer	Anodized Aluminum / Koropon / Gloss Polyurethane (black)
Elevon Door	Inconel Honeycomb / Pyromark
GSE-1	Cradle Assembly / Epoxy Polyamide Primer / Yellow Polyurethane Topcoat
GSE-2	Support Stand (carbon steel box beam) / Inorganic Zinc Silicate Primer / White Topcoat (~ 11 mil)
NSLD-1A	Bare Aluminum (2024-O) / Koropon / Aluminized Coating
NSLD-1B	Inconel (X750) / Koropon / Aluminized Coating
NSLD-2	Bare Aluminum (2024-O) / Epoxy Primer (1) / Gloss Polyurethane
NSLD-3 L1/L2	Laminate (Aramid/Epoxy prepreg – Kevlar –MB0130-127) / Koropon / Conductive Coating

NSLD-3 L3/L4	Laminate (Aramid/Epoxy prepreg – Kevlar –MB0130-127) / Conductive Coating
USA-1	Aluminum (6061-T6) / chem-film / Epoxy Primer (Mil-P-53022B) / Hentzen Topcoat
USA-2	Aluminum (6061-T6) / chem-film / Epoxy Primer (Mil-PRF-85582D) / Deft Topcoat
USA-3	Aluminum (6061-T6) / chem-film / Epoxy Primer (Mil-PRF-85582D) / Hentzen Topcoat / Hypalon Topcoat
USA-4	Steel (4130) / Epoxy Primer (zinc rich) / Polyamide Epoxy Topcoat
C-1	Aluminum (2024) / Corrosion
C-2	Aluminum (2024) / Corrosion
C-3	Bare Aluminum (2024) / Corrosion
Structure	Rusted I-Beam
A3	Anodized Aluminum / Koropon (Adapt Laser Panel)
TPS Array	TPS Test Panel consisting of 10 tiles with various surface prep and bonding configurations
TPS Tile	An individual tile with the strain isolation pad attached to the inner mold line layer

After completion of testing at WPAFB, several of the panels stripped were exposed to B-117 salt fog testing for 14 days (336 Hours) at Boeing's Huntington Beach laboratory to determine if removing the coating had any effect on the corrosion of these coupons when compared to other coating removal methods. The interest was to see if the laser left enough Anodize behind to provide any level of corrosion protection.

Concurrent to the second WPAFB demonstration, several aluminum panels were shipped to Adapt Laser in order to test the capabilities of a gantry-mounted 2D scanning laser. The goal was to determine whether this laser stripping technique had a detrimental effect on the corrosion protection layer (i.e. Anodize or chem-film). These panels were also analyzed for any detrimental effects to the substrate through hardness, corrosion potential, and through observation using Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS).

3.5.3. Results

Temperature results were included in the Boeing Lab Report No. MP&E-3-1766 *Evaluation of Hand-Held Lasers To Remove Surface Finishes*, dated 07 Aug 2006. Temperature measurements ranged from 110 °F to 170 °F, which are well below the maximum allowable of 350 °F. In tests performed to simulate a worst case scenario (i.e. where an operator might hold a laser on one location for extended periods of time at non-optimized laser settings) temperatures ranged from 116 °F to 222 °F, still below the maximum allowable.

Table 3-5C contains the strip rates calculated from Koropon coated samples tested with the laser. Operators and observers present during the testing did not notice any results inconsistent with previous results during the JG-PP/ESTCP project.

Table 3-5C: Strip Rates of Artificially Aged Panels, WPAFB

Panel	Artificial Aging	Coatings	Rate (sq ft / min)	Rate (min / sq ft)	Operator
14A	0 years	Koropon (0.79 mils) / Chem-film	**0.098**	**10.20**	#1
15A	5 years	Koropon (0.78 mils) / Chem-film	**0.135**	**7.41**	#2
15B	10 years	Koropon (0.86 mils) / Chem-film	**0.135**	**7.41**	#2

17B	20 years	Koropon (0.76 mils) / Chem-film	**0.150**	**6.67**	#2
6B	0 years	Koropon (1.09 mils) / Anodize	**0.056**	**17.86**	#1
7A	5 years	Koropon (1.06 mils) / Anodize	**0.086**	**11.63**	#2
7B	10 years	Koropon (1.10 mils) / Anodize	**0.106**	**9.43**	#2
12B	20 years	Koropon (1.15 mils) / Anodize	**0.122**	**8.20**	#2
Note: Operator #1 was Harold (Pete) Hall, Operator #2 was Derek Upchurch from Anteon Corporation (this information is recorded because decoating techniques and strip rates tend to differ from one person to another)					

Some of the selected test panels were tested in greater detail during this demonstration. Table 3-5D contains a listing of the parameters used during laser testing of test Panel 23B. Hardness testing was not achieved as the base material was approximately 0.011 inches thick and was thinner than allowed using the Rockwell B scale (requires a minimum thickness of approximately 0.028 inch), or the 15T superficial scale (requires a minimum material thickness of approximately 0.013 inch). Hardness readings can also be affected by surface treatments such as Anodize and Alodine. Conclusions drawn from detailed analysis of Panel 23B are found in Section 3.5.5. of this report.

Table 3-5D: Laser Parameters for Testing

Area	Laser	Scan Width (SCW)	Scan (SCSP)	Pulse Frequency (PF)	Current (Amps)	Time (min:sec)	IR Temp (Surface)
23B-1	40 watt	N/A	120 Hz			1:29	130 °F
23B-2	120 watt	50 mm	75 Hz	22 kHz		4:43	120 °F
23B-3	500 watt	70 mm	70 Hz	24 kHz	41	1	170 °F
24B-1	40 watt		120 Hz			1:24	110 °F
24B-2	120 watt	50 mm	73 Hz	22 kHz		1:43	120 °F
24B-3	500 watt	70 mm	70 Hz	24 kHz	41	:25	140 °F

Corrosion potential testing was performed on a section of unaffected base material (i.e. a control sample) and sections taken from each of the laser stripped areas. Table 3-5E shows the results of the Conductivity Testing of Panel 23Bwhich are consistent with the T3 condition.

Table 3-5E: Conductivity Results

Sample	23B Control	23B-1	23B-2	23B-3	24B Control	24B-1	24B-2	24B-3
Corrosion Potential	-609	-611	-618	-617	-613	-619	-617	-619

3.5.4. Laboratory Analysis

Previous conclusions made during the GRC demonstration regarding the Anodized layer were revisited. Several test panels were shipped to the Adapt Laser facility in Kansas City, Missouri in mid-January 2006. First sensitivity of the hand held lasers was adjusted and then a mounted 2-D scanning head was also utilized. The 2-D scanning head allowed for the Anodized layer to be selectively left on the substrate. Such a scanning head could be attached to a tripod and inverted and used on Orbiter tile cavities.

These panels were later analyzed by Boeing and included in Lab Report No. MP&E-3-1766 *Evaluation of Hand-Held Lasers To Remove Surface Finishes*, dated 07 Aug 2006. Tests were performed to determine if using a stationary 2-D scanning head would allow enough sensitivity and control to remove only primer, leaving the Anodized layer intact, and to determine if the remelt layer phenomenon could be eliminated with greater sensitivity. Boeing results are in Table 18 of the aforementioned report. Table 3-5F shows the maximum temperature readings observed during laser decoating.

Table 3-5F: Temperature Results

	Single Coat Maximum Temperature	Double Coat Maximum Temperature
40 W Laser	110 °F	130 °F
120 W Laser	117 °F	120 °F
500 W Laser	140 °F	170 °F

3.5.5. Conclusions/Recommendations

<u>TPS Materials</u>

A concern of the stakeholders was a remelt layer of aluminum that was observed during metallurgical tests by USA after the initial demonstration at WPAFB in 2004 which is documented in *Advanced Coating Removal Techniques* dated 18 Jan 2006. Panels that represent Orbiter substrates and coatings were stripped at various laser settings so that further analysis could be performed on this phenomenon.

The lasers were successful at removing Koropon from the aluminum test panels whether it was bare, had chem-film, or Anodized. The lasers had difficulty with RTV, particularly for thicknesses of 9-12 mils, and lower intensities. If the RTV was skived from the surface prior to laser use, or aged, the lasers were more successful at these thicknesses.

Boeing Lab Report No. MP&E-3-1766 *Evaluation of Hand-Held Lasers To Remove Surface Finishes*, dated 07 Aug 2006 also drew some conclusions about laser-induced damage to TPS materials. Plasma flame was observed as the laser charred the filler bar. When the laser was directed at the tile, there was damage, although it was deemed to be repairable. Attempts to remove the felt strain isolation pad from the backside of a tile resulted in an open flame and a charred and scored inner mold line layer.

When testing TPS related coatings, all three lasers showed the ability to remove coatings that would typically be found on Orbiter including Koropon, aged Koropon, and thin layers of RTV. A small plasma flame was observed when ablating skived RTV560. Continuity testing and later metallurgical tests confirmed the removal of the Anodized layer during these tests. Some experimentation was done using several tapes authorized for use on TPS materials for protection against laser damage. A Kapton/aluminum taping system was developed and tested as protection for surrounding TPS materials when the lasers were being used. This protection system was effectively used to protect the filler bar and tiles in several decoating procedures. Both the 40W and the 120W lasers can easily char and damage the filler bar (a thin layer of RTV560 over Nomex felt), when the filler bar is left unprotected. A plasma flame was observed

as the laser burned through the filler bar. Both the 40W and the 120W lasers can cause damage to the tiles when the beam is applied directly to them. All of the damage seen during this evaluation was considered repairable.

SEM Results from TPS Surface Testing

After using the three lasers on all coupons and test articles brought to WPAFB, some samples were shipped to Boeing for metallurgical analysis and scanning electron microscope analysis to determine how the substrates were affected during stripping activities using the laser systems. A key interest was evaluating the ability of the technology to selectively strip coatings such as leaving behind the Anodize layer, and if so, how much could be left behind (*Advanced Coating Removal Techniques* dated 18 Jan 2006). This was important to structural engineers and thermal protection engineers that work on the Orbiter tile cavities because according to specifications, Anodize must be present and chem-film replacement of Anodize is not permitted for this area of the Orbiter. This means that paint can be removed, but Anodize cannot. It was undetermined at the time of this demonstration if current methods for preparing tile cavities removed Anodized, or how much remains on the surface prior to repainting.

Preliminary analysis of coupons and components stripped with lasers showed that at least some Anodize was removed during all stripping activities. This was not entirely conclusive, as the full effect on Anodization was not captured.

Tables 16 and 17 of Boeing Lap Report No. MP&E-3-1766 include the results of comparative analyses between conventional hand sanding and laser stripping of both Anodized and primer layers. Hand-sanding can be used to remove Koropon while leaving the Anodized layer intact. Excessive sanding will break through the Anodized layer. The hand held lasers do not have the sensitivity and selectivity to remove Koropon while leaving the Anodized layer intact. It was discovered that the Adapt Laser automated CL 120W Gantry Mounted Q-switched laser (2D Scanning) can remove Koropon while leaving the Anodized layer intact.

Despite the initial testing that revealed hurdles to implementation for the Orbiter tile cavity application, other applications of interest exist. NASA personnel who were present during the technology demonstrations were optimistic that if a small room were constructed within the Orbiter Processing Facility, a laser could be used there for small part depainting and this approach would hold the highest potential for near-term flight hardware implementation. There was more optimism for implementation of the technology for use on GSE.

Inconel Substrates

The transition area on the upper surface between the torque box and the movable elevon consists of a series of hinged panels that provide a closeout of the wing-to-elevon cavity. These panels are a combination of Inconel honeycomb sandwich and titanium honeycomb sandwich construction. The testing performed at WPAFB involved an inconel elevon cove seal cover and a window retainer from the crew cabin, both coated in a thermally protective coating (Pyromark). Coatings were able to be removed from Inconel substrates, however, discoloration of the

substrate did take place in some areas. Continuation of this phenomenon was explored during the demonstration at KSC.

Corrosion Resistance

According to MIL-A-8625F, type II sulfuric acid Anodized coatings should be able to withstand 14 days of salt spray testing per ASTM B117. Both the Automated Laser and the hand-sanding decoating methods left an effective Anodized layer after the Koropon primer was removed. The hand-held laser decoating method also left surfaces that showed more resistance to corrosion than was expected since testing showed most of the Anodized layer to be removed. Possible explanations include traces of chromium from the original Koropon application still reside on the panel, traces of chromium are leaching out of the adjacent painted surfaces in the salt fog process providing some unseen protection, or Anodize or chem-film still resides on the pre-treated aluminum panels.

Non-TPS Materials

When testing non-TPS specific coatings, all three lasers showed the ability to remove coatings, but some were more difficult to others, in general this can be attributed to the thickness of coatings and the color. White coatings, like the Thermal Control Coating and Gloss Polyurethane were the most difficult to remove. The 500W and 120W in all cases were more uniform in their ability to remove coatings while leaving a nicer surface finish upon completion.

In general, lasers appeared to have no obvious negative effect on substrate when compared to controls, however a remelt layer was observed which may reduce fatigue properties of the substrates and it was recommended that further fatigue testing be performed.

Other conclusions include that the laser decoating process affects the surface of 2024-T3 aluminum, increasing its resistance to corrosion for the short term (long term effects unknown), higher power settings correspond to more corrosion resistance, and may be some sort of surface heat treatment effect happening (possibly the remelt layer that has been observed for higher power settings).

SEM Analysis

The following discussion and recommendations come primarily from the Boeing Metallurgical Report, Case Number 401679, dated 30 Nov 2005 which also contains more detail regarding the analysis of corrosion potential.

Testing of the laser stripped areas was performed in an effort to identify possible detrimental effects of laser processing on the panel corrosion protection system (anodize or chem-film) and aluminum base material. To this end, SEM and microstructural evaluation were effective analytical tools in that they confirmed that all process settings resulted in removal of most, if not all of the corrosion control coatings from the base plate and that some settings produced a thin remelt layer on the panel surface. Attempts to identify the effect of this surface layer using hardness and conductivity tests were ineffective as the panel material was too thin to

test reliably. Similarly, corrosion potential testing resulted in corrosion of the sample surface and it seems likely that the remelt layer would be destroyed long before stable corrosion potential readings could be obtained.

SEM and microstructural analysis provided usable information regarding the effects of laser stripping on the panel and should continue to be used as preliminary investigation tools for evaluating the laser stripping process. Hardness and conductivity are typically used concurrently to determine conformance to thermal treatment, however, material thickness requirements will limit test effectiveness in panels under approximately 0.030 inch thick. It is possible that the remelt layer may reduce material response to fatigue, thus it may be advisable to investigate such a possibility.

The pictures below are taken from the Boeing Metallurgical Report, Case Number 401679 and show magnified views of Panel 23B. EDS results indicate that the Anodized layer was removed. Only little white chunks as shown in the middle frame remain of the Anodized layer. In the frame on the right side shows the splattering effect observed, or remelt layer.

Sample 23B Area 2

Case 401679

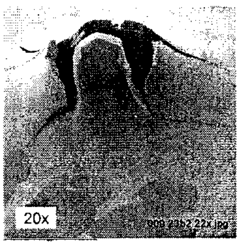

Figure 14

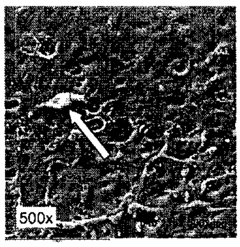

Figure 15

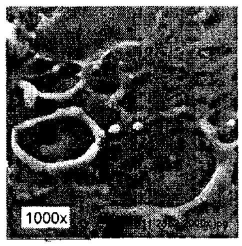

Figure 16

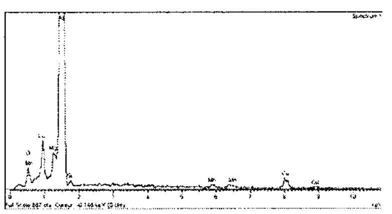

Figure 17

Sample 23B-2 was stripped using a 120 watt laser operating at 75 Hz with a pulse rate of 22 kHz. EDS spectra i similar to that of the base material indicating the loss of the Anodize coating. Surface exhibits spatter-like ridges that suggest surface melting. The small particle in center figure is a Anodize remnant.

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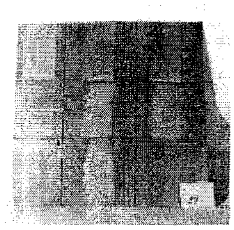
Magnified views of Panel 27 and 6A below show a comparison of laser decoating with hand-sanding. In most cases, the Anodized layer was removed by the hand-held laser; and remained intact with hand-sanding.

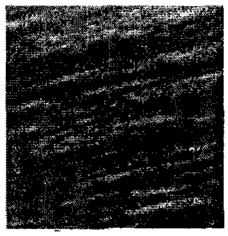
Panel 27 Anodized aluminum
SEM pictures - 500X

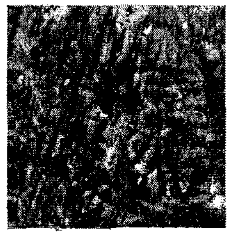

Panel 27


Anodized Control – section 9

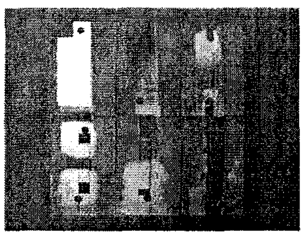

120 watt 35 kHz – section 1

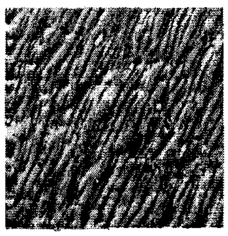

120 watt 35 kHz 14 passes
section 4

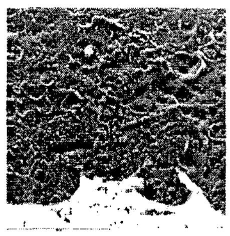

sanded 400 grit Z pattern
section 5

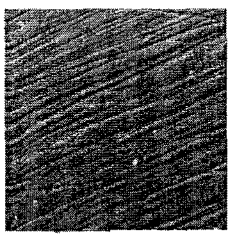

sanded 400 grit circle pattern
section 7

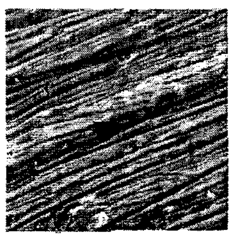
Panel 6A – Anodized aluminum / Koropon (1.12 mils)
SEM pictures - 500X

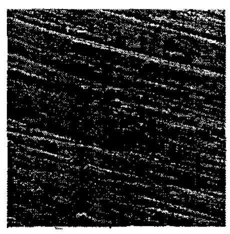

Panel 6A


Anodized Control (backside)
no conductance


120 watt 35 kHz – section 1
conductance


Removed remaining Koropon – sect 4A
sanded 400 grit to breakthrough
mostly no conductance


Removed remaining Koropon – sect 4B
sanded 220 grit to breakthrough
mostly no conductance

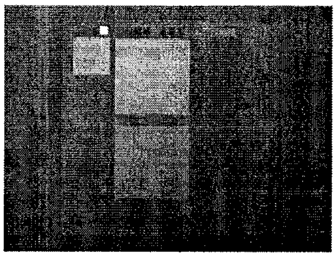

Removed remaining Koropon – sect 6E
sanded excessively 400 grit
conductance

The panel that Adapt Laser decoated using a 2-D scanning head is shown in the magnified views below. This method was able to leave the Anodized layer intact.

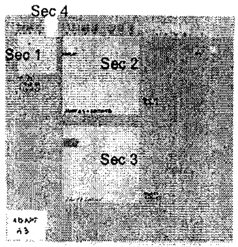
Panel Adapt A3 – Anodized aluminum / Koropon (0.85 mils)

Decoated with CL120 Q-switched laser and a gantry mounted 2D scanner

SEM pictures - 500X

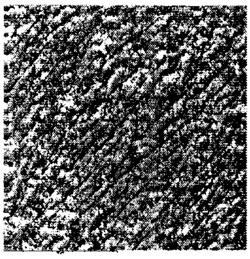


Adapt panel A3

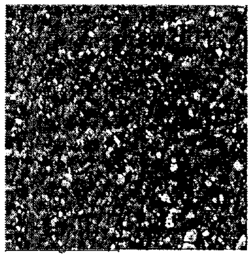


Adapt panel A3 after sectioning

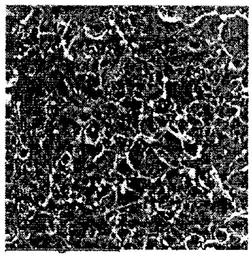
Anodized control



Section 2 after Koropon removal
30 kHz 3000 mm/s
no conductance



Section 3 after Koropon removal
30 kHz 3000 mm/s
no conductance



Section 4 after Koropon removal
settings unknown
conductance

In order to ascertain whether the hand-held PLCRS removes a protective Anodized layer, an aluminum panel was treated with a sulfuric Anodization, coated with a single layer of epoxy primer, and exposed to all three lasers. Afterwards, the panel was examined using EDS to determine if the Anodized layer remained. Evidence indicates that the lasers were unsuccessful in preserving the Anodized layer when removing the epoxy primer.

Corrosion Removal

To test corrosion removal capabilities, several samples with various corrosion types were subjected to laser treatment. While the laser was able to completely remove rust-colored corrosion, it had more trouble with white corrosive products typical of aluminum substrates. The rust color was able to fully absorb the laser energy while the white corrosion reflected much of the energy rather than absorbing it.

Protection from Incidental Damage to Tile Cavities

Media blasting becomes undesirable when the part to be subjected to coating removal lies next to a sensitive piece of flight hardware such as thermal protection tiles. Although the lasers did have some damaging effects on a tile surface and filler bar materials when directly exposed, it was also demonstrated that the RTV filler bar and the tile system could be adequately protected using a system of Kapton and aluminum tapes.

3.6. Kennedy Space Center Demonstration (October 16 – November 3, 2006)

PLCRS equipment was at the KSC Launch Equipment Services shop for a six (6) week period in order to demonstrate the technology on a variety of aluminum and steel substrates and configurations (weld lines, I-beams, Anodized, zinc coatings, polyurethane topcoats, etc.). Overall there were about 80 items that were decoated during the demonstration.

The laser used for the demonstration was the CL 120 Q™ - Mobile Laser Cleaning Unit from Adapt Laser Systems, LLC. This unit is an older model used primarily for demonstrations; more powerful units are available that would increase strip rates. For example, the CL 500 Q™ - High Power Mobile Laser Cleaning Unit increases productivity an estimated 550% over the CL 120 Q™. Nearly ninety attendees, representing more than a dozen NASA and contractor entities, were present at various times during the demonstration at KSC to observe the PLCRS in operation.

3.6.1. Objective

The objective was to demonstrate candidate portable laser surface preparation/depainting technologies for GSE applications under the specifications for the standard processes. The performance of the proposed surface preparation/depainting alternatives would be compared to existing surface preparation/depainting processes.

In addition to laboratory-prepared test panels that were coated in a variety of coatings used on flight and support equipment, several SSP-specific fielded materials were tested. Orbiter materials tested included a window retainer, cove seal cover, Space Shuttle Main Engine gasket and a mock-up shuttle tile array. In-service SSP GSE was also tested during this demonstration. Several scale plates used in weighing the Orbiter prior to launch were tested to determine if the laser could effectively be used to strip coatings, especially on weld lines where NDE inspection was required.

3.6.2. Field Test and Evaluation Plans

Tests that were planned to be performed were documented in *Field Evaluations Test Plan For Validation of Portable Laser Coating Removal Systems for use on Ground Service Equipment*, dated 11 Oct 2006. Due to the availability of certified personnel not all of the tests planned were accomplished and some data was not collected.

Previous air monitoring during the JG-PP/ESTCP project showed that all samples for hazardous materials were below actionable limits, but their testing did not include NASA specific coating systems. While Air Force corrosion inhibiting pretreatments and primers are very similar to their NASA counterparts, some NASA specific coating systems have material compositions with relatively higher amounts of chemicals that present exposure hazards. Primary coating systems of concern are chromium-based pretreatments and primers for corrosion protection and lead-based paints that are found on older structures at KSC.

3.6.3. Results

As with the other demonstrations no inconsistent results were observed. The lasers were easy to operate. Table 3-6A shows strip rates from samples tested during the KSC demonstration.

Table 3-6A: Strip Rates of Test Specimen, KSC

No.	Code	Description	Rate (sq ft / min)	Rate (min / sq ft)
Item 5	A-4	12" x 12" 2024-T3 Chem-film + Koropon	**0.058**	**17.24**
Item 6	D-17	12" x 12" 5052-H32 Anodized	**0.151**	**6.62**
Item 7	G-1	6" x 12" Steel Angle	**0.089**	**11.24**
Item 8	A-6	12" x 12" 2024-T3 Chem-film + 2-Coat Koropon	**0.031**	**32.26**
Item 9	D-25	12" x 12" 6061-T6 Anodized	**0.147**	**6.80**
Item 10	A-12	12" x 12" 2024-T3 Chem-film Koropon	**0.081**	**12.35**
Item 11	A-16	12" x 12" 2024-T3 Tie Coat + Thermal Control Coat	**0.012**	**83.33**
Item 12	B-30	13" x 13.5" 2024-T81 Red Sulfuric Anodize	**0.044**	**22.73**
Item 13	B-32	13" 13.5" 2024-T81 Red Sulfuric Anodize, Koropon, Grey Topcoat	**0.019**	**52.63**
Item 14	B-1	12" x 12" 6061-T6 Alodine+ Hentzen Primer + Hentzen Topcoat	**0.010**	**100**
Item 16	C-2	12" x 12" A36 Steel Weld Lines - IOZ primer + Epoxy Midcoat + White Urethane Topcoat	**0.005**	**200**
Item 17	C-2A	12" x 12" A36 Steel Weld Lines - IOZ primer + Epoxy Midcoat + White Urethane Topcoat	**0.006**	**166.67**
Item 18	C-3	12" x 12" A36 Steel Weld Lines - IOZ primer + Grey IOZ Topcoat	**0.010**	**100**
Item 19	C-4	12" x 12" A36 Steel Weld Lines - IOZ primer + Grey IOZ Topcoat	**0.014**	**71.43**
Item 20	C-5	12" x 12" 5052-H32 - Epoxy primer + White Urethane Topcoat	**0.012**	**83.33**
Item 21	C-12	12" x 12" 6061-T6 - Epoxy primer + White Urethane Topcoat	**0.020**	**50**
Item 23	C-6	12" x 12" 5052-H32 - Epoxy primer + White Urethane Topcoat	**0.017**	**58.82**
Item 24	C-7	12" x 12" 5052-H32 - Epoxy primer + White Urethane Topcoat	**0.015**	**66.67**
Item 25	C-8	12" x 12" 5052-H32 - Epoxy primer + White Urethane Topcoat	**0.009**	**111.11**
Item 26	C-9	12" x 12" 6061-T6 - Epoxy primer + White Urethane Topcoat	**0.013**	**76.92**
Item 27	C-10	12" x 12" 6061-T6 - Epoxy primer + White Urethane Topcoat	**0.014**	**71.43**
Item 28	C-11	12" x 12" 6061-T6 - Epoxy primer + White Urethane Topcoat	**0.013**	**76.92**
Item 29	D-1	12" x 12" A36 - IOZ Primer + Epoxy Primer Midcoat + White Urethane Topcoat	**0.024**	**41.67**
Item 30	D-5	12" x 12" A36 - IOZ Primer + Grey Inorganic Topcoat	**0.028**	**35.71**
Item 31	D-9	12" x 12" 5052-H32 - Epoxy primer + White Urethane Topcoat	**0.016**	**62.5**
Item 34	D-10A	12" x 12" - 5052-H32 Epoxy Primer + White Urethane Topcoat w/ Black - Unknown Origin	**0.015**	**66.67**
Item 35 a	D-13	12" x 12" - 6061-T6 Epoxy Primer + White Urethane Topcoat - 1/8 of panel with black ink added stripped	**0.008**	**125**
Item 35 b	D-13	12" x 12" - 6061-T6 Epoxy Primer + White Urethane Topcoat - 1/8 w/o black ink added stripped	**0.011**	**90.91**
Item 36	D-18	12" x 12" - 5052-H32 - Anodized	**0.187**	**5.35**
Item 37	D-26	12" x 12" - 6061-T6 - Anodized	**0.203**	**4.93**
Item 70	C-1A	12" x 12" A36 Steel - w/Weld - IOZ Primer + Epoxy Primer Midcoat + White Urethane Topcoat	**0.008**	**125**
Item 71	G-23	12" x 12" Textured A36 Steel with IOZ Primer	**0.012**	**83.33**
Item 72	G-24	I-Beam - IOZ Primer	**0.010**	**100**

Note: Group F panels were exposed to laser for subsequent corrosion rate testing, not for strip rate efficiency.

Surface cleaning and surface roughness was not accomplished as part of the KSC demonstration because the lab reports by Boeing and USA from previous demonstrations were felt to be sufficient. These reports showed that the PLCRS appeared to clean the corroded areas

to meet the SSPC-SP-10/NACE-No. 2 Near-White Blast Cleaning specification, but laboratory and other field tests have show this to be only true in some situations.

A series of steel and aluminum test panels were exposed to the PLCRS in order to determine if the surface effects observed in SEM analysis caused any significant changes in corrosion resistance of the bare substrates. The resulting Atmospheric Beach Exposure and Salt Fog testing data is captured by Tables 3-6B & C. Detailed analysis of this testing is documented in the ASRC report entitled *Laser Depainted Corrosion Study of Aluminum and Steel Substrates*, dated 20 July 2007.

Table 3-6B: Average Weight Loss for Metal Panels

Sample	Average Weight Loss, grams	Standard Deviation
Beach - Al control	**0.076**	**0.008**
Beach - Uncoated Al lasered	**0.086**	**0.019**
Beach - Coated Al lasered	**0.090**	**0.017**
Salt Fog - Al (control)	**0.698**	**0.034**
Salt Fog - Uncoated Al lasered	**0.655**	**0.021**
Salt Fog - Coated Al lasered	**0.699**	**0.009**
Beach - Steel control	**11.872**	**0.277**
Beach - Uncoated steel lasered	**14.545**	**2.000**
Beach - Coated steel lasered	**13.036**	**0.964**
Salt Fog - Steel control	**44.918**	**2.808**
Salt Fog - Uncoated steel lasered	**48.828**	**1.755**
Salt Fog - Coated steel lasered	**42.364**	**1.590**

Table 3-6C: Calculated t-values for Weight Loss Compared to Control

Sample	Calculated t value when compared to control
Beach - Al control	**0.00**
Beach - Uncoated Al lasered	**0.82**
Beach - Coated Al lasered	**1.30**
Salt Fog - Light blast Al (control)	**0.00**
Salt Fog - Uncoated Al lasered	**1.84**
Salt Fog - Coated Al lasered	**0.02**
Beach - Steel control	**0.00**
Beach - Uncoated steel lasered	**2.29**
Beach - Coated steel lasered	**2.01**
Salt Fog - Steel control	**0.00**
Salt Fog - Uncoated steel lasered	**2.04**
Salt Fog - Coated steel lasered	**1.37**

According to the ASRC report, laser exposed coated and uncoated steel panels were placed at the beach and in salt fog chamber and were compared to control panels that were not exposed to laser energy. Using the student t-test to determine statistical significance, it was observed that the uncoated laser exposed steel panel placed at the beach lost slightly more weight when compared to the beach control at the 90% confidence limit, this is observed in the t-values of 2.29 for laser exposed and 2.13 for the control. The steel panels that were previously coated

prior to laser removal of those coatings showed no significant difference in weight loss compared to the beach control. There is no significant difference in the amount of mass lost on the steel panels when comparing the control salt fog panels to the coated and uncoated laser exposed panels placed in the salt fog chamber.

Similar comparisons were conducted for aluminum panels placed at the beach and in the salt fog chamber. Statistically, there is no significant difference in the amount of aluminum lost on the coated and uncoated aluminum when compared to controls.

Table 3-6D shows the average results for the corrosion rates in mils per year of the aluminum and steel panels.

Table 3-6D: Average Corrosion Rates of Metal Panels

Sample	Average corrosion rate, mils per year
Beach - Al control	**0.070**
Beach - Uncoated Al lasered	**0.079**
Beach - Coated Al lasered	**0.084**
Salt Fog - Al (control)	**2.798**
Salt Fog - Uncoated Al lasered	**2.627**
Salt Fog - Coated Al lasered	**2.800**
Beach - Steel control	**3.895**
Beach - Uncoated steel lasered	**4.772**
Beach - Coated steel lasered	**4.277**
Salt Fog - Steel control	**63.666**
Salt Fog - Uncoated steel lasered	**69.208**
Salt Fog - Coated steel lasered	**60.046**

Even though there is a significant difference between the beach and the accelerated samples, there were no significant measurable differences in pitting between the respective sets. Further analysis of the corrosion testing results can be found in ASRC report, *Laser Depainted Corrosion Study of Aluminum and Steel Substrates* dated 31 Jan 2007.

The ability of PLCRS to prepare weld lines for NDE testing was of interest to the stakeholders. Several test panels with coated weld lines were prepared for this test. Table 3-6E below shows the results from the weld line stripping for NDE that was performed.

Table 3-6E: NDE Preparation of Weld Lines

Sample plate	Time to strip weld	NDE Method	Results
C-1, A36 IOZ, EP, PU	20 min roller/free	Magnetic Particle	Surface good, NDE excellent results with no further prep
C-2, A36 IOZ, EP, PU	18 min freehand	Magnetic Particle	Weld bead coated with sharpie – surface good, NDE excellent results with no further prep
C-2a, A36 IOZ, EP, PU	15 min freehand	Magnetic Particle	Sharpie continuous 5 coats, surface good, NDE excellent results, no further prep required
C-3, A36 IOZ, IOZ	8:33 min freehand	Magnetic Particle	Surface good, ioz removed NDE excellent results
C-4, A36 IOZ, IOZ	7:27 min roller	Magnetic Particle	Surface good, roller strips faster, ioz removed, excellent NDE results

Sample plate	Time to strip weld	NDE Method	Results
C-5, Al 5052 EP, PU	7:16 min roller	Dye Penetrant	Surface excellent, very clean surface, NDE excellent results
C-6, Al 5052 EP, PU	5:40 min freehand	Dye Penetrant	Surface excellent, very clean surface, NDE excellent results
C-7, Al 5052 EP, PU	6:50 min roller	Dye Penetrant	Sharpie, surface excellent, very clean surface, NDE excellent results
C-8, Al 5052 EP, PU	9:50 min freehand	Dye Penetrant	Sharpie, surface excellent, very clean surface, NDE excellent results
C-9, Al 6061 EP, PU	6:49 min roller	Dye Penetrant	Surface excellent, very clean surface, NDE excellent results
C-10, Al 6061 EP, PU	6:20 min freehand	Dye Penetrant	Surface excellent, very clean surface, NDE excellent results
C-11, Al 6061 EP, PU	6:28 min roller	Dye Penetrant	Sharpie, surface excellent, very clean surface, NDE excellent results
C-12, Al 6061 EP, PU	4:20 min freehand	Dye Penetrant	Double coated with sharpie, surface excellent, very clean surface, NDE excellent results

Air sampling was of concern to NASA stakeholders due to the toxic metals found in coatings used within the Agency. Tables 3-6F, G, & H show the results of air sampling required by KSC. None of the contaminants were detected in significant quantities and the integrated vacuum removal system was effective in removing the requisite source contaminants.

Table 3-6F: Air Sampling

INDUSTRIAL HYGIENE EVALUATION – CHEMICAL SAMPLING DURING SPECIAL LASER PAINT REMOVAL TEST
K6-1397 / PAINT SHOP

JBOSC ENVIRONMENTAL HEALTH AND SERVICES
CHEMICAL AIR SAMPLING REPORT
ADMINISTRATIVE DATA

Facility Number	Facility Name	Task Tracking Number
K6-1397	NASA Paint Shop	T200610-5494

EXPOSURE GROUP DATA

COMPANY	NAME OF EXPOSURE GROUP (*JOB CLASSIFICATION OF AFFECTED EMPLOYEES*)	OPERATIONS	NUMBER OF PERSONNEL IN EXPOSURE GROUP
ITB	Senior Engineer	Paint Removal	1

HAZARD DATA

HAZARD MATERIAL	CHEMICAL ABSTRACTS SERVICES (CAS) NO.	SAMPLED COMMODITY NOMENCLATURE	SAMPLING METHOD AND INSTRUMENTATION	EXPOSURE CRITERIA (MG/M^3) ACGIH TLV	OSHA TWA	STEL ACGIH	STEL OSHA	OSHA CEILING
Paint and Coatings Removed from Metal Cuts	7440-47-3	Hexavalent Chromium	OSHA ID-215, 37mm filter cassette	0.01	0.005	N/A	N/A	N/A
	7440-39-3	Barium	NIOSH 7300, .8 micron filter cassette	0.5	0.5	N/A	N/A	N/A
	7440-43-9	Cadmium	NIOSH 7300, .8 micron filter cassette	0.002	0.005	N/A	N/A	N/A
	7440-47-3	Total Chromium	NIOSH 7300, .8 micron filter cassette	0.5	0.5	N/A	N/A	N/A
	7439-89-6	Iron Oxide	NIOSH 7300, .8 micron filter cassette	5	10	N/A	N/A	N/A
	7439-92-1	Lead	NIOSH 7300, .8 micron filter cassette	0.05	0.05	N/A	N/A	N/A
	7440-66-6	Zinc Oxide	NIOSH 7300, .8 micron filter cassette	2	5	10	N/A	N/A
	7647-01-0	Hydrochloric Acid	Drager PAC III	N/A	N/A	2PPM	N/A	5PPM
	10102-44-0	Nitrogen Dioxide	Drager PAC III	3PPM	N/A	5PPM	N/A	5PPM

Table 3-6G: Air Sampling

JBOSC ENVIRONMENTAL HEALTH AND SERVICES

CHEMICAL AIR SAMPLING REPORT

LASER PAINT REMOVAL, BLDG K6-1397 – OCT 19/20, 2006

AIR SAMPLING DATA					
DATE	TIME	DURATION	COMMODITY	EXPOSURE RESULTS	
				TWA	8-HR TWA
10/19/06	09:06 – 11:55	169 MINS	Hexavalent Chromium	0.000092	0.00003
10/19/06	09:06 – 11:55	169 MINS	Barium	<0.0029	<0.001
10/19/06	09:06 – 11:55	169 MINS	Cadmium	<0.0014	<0.0004
10/19/06	09:06 – 11:55	169 MINS	Total Chromium	<0.0029	<0.001
10/19/06	09:06 – 11:55	169 MINS	Iron	0.0038	0.001
10/19/06	09:06 – 11:55	169 MINS	Lead	<0.0029	<0.001
10/19/06	09:06 – 11:55	169 MINS	Zinc	<0.0029	<0.001
10/19/06	09:06 – 11:55	169 MINS	Hydrochloric Acid	<LOD	<LOD
10/19/06	09:06 – 11:55	169 MINS	Nitrogen Dioxide	<LOD	<LOD
10/20/06	08:24 – 11:45	201 MINS	Hexavalent Chromium	<0.000055	<0.00002
10/20/06	08:24 – 11:45	201 MINS	Barium	<0.0025	<0.001
10/20/06	08:24 – 11:45	201 MINS	Cadmium	<0.0012	<0.0005
10/20/06	08:24 – 11:45	201 MINS	Chromium	<0.0025	<0.001
10/20/06	08:24 – 11:45	201 MINS	Iron	<0.0025	<0.001
10/20/06	08:24 – 11:45	201 MINS	Lead	<0.0025	<0.001
10/20/06	08:24 – 11:45	201 MINS	Zinc	<0.0025	<0.001
10/20/06	08:24 – 11:45	201 MINS	Hydrochloric Acid	<LOD	<LOD
10/20/06	08:24 – 11:45	201 MINS	Nitrogen Dioxide	<LOD	<LOD
CONCLUSIONS					
• *As indicated by the results of air sampling conducted, no significant levels of the contaminants were detected.*					
• *Use of the extraction system has been demonstrated to effectively remove contaminants at the source.*					

Table 3-6H: Air Sampling

JBOSC ENVIRONMENTAL HEALTH AND SERVICES

CHEMICAL AIR SAMPLING REPORT

LASER PAINT REMOVAL, BLDG K6-1397 – 11/14 - 11/15, 2006

AIR SAMPLING DATA					
DATE	TIME	DURATION	COMMODITY	EXPOSURE RESULTS	
				TWA	8-HR TWA
11/14/06	13:00 – 15:10	130MINS	Hexavalent Chromium	0.000022	0.000006
11/14/06	13:00 – 15:10	130MINS	Barium	<0.0013	<0.00035
11/14/06	13:00 – 15:10	130MINS	Cadmium	<0.00067	<0.0002
11/14/06	13:00 – 15:10	130MINS	Total Chromium	<0.0013	<0.00035
11/14/06	13:00 – 15:10	130MINS	Iron	<0.0013	<0.00035
11/14/06	13:00 – 15:10	130MINS	Lead	<0.0013	<0.00035
11/14/06	13:00 – 15:10	130MINS	Zinc	0.0021	0.0006
11/15/06	09:00 -11:37	157MINS	Hexavalent Chromium	<0.000019	<0.00002
11/15/06	09:00 -11:37	157MINS	Barium	<0.0013	<0.0004
11/15/06	09:00 -11:37	157MINS	Cadmium	<0.00063	<0.0002
11/15/06	09:00 -11:37	157MINS	Chromium	<0.0013	<0.0004
11/15/06	09:00 -11:37	157MINS	Iron	0.0029	0.0009

11/15/06	09:00 -11:37	157MINS	Lead	<0.0013	<0.0004
11/15/06	09:00 -11:37	157MINS	Zinc	0.0021	0.0007

CONCLUSIONS
• *As indicated by the results of air sampling conducted, no significant levels of the contaminants were detected.*
• *Use of the extraction system has been demonstrated to effectively remove contaminants at the source.*

Noise sampling was conducted to help determine amounts of personal protective equipment (PPE) that would be required if implementation were to occur. The noise data is shown in Table 3-6I.

Table 3-6I: Noise Sampling

Dosimetry Data							
Monitoring Date		**10/19/06**		**10/19/2006**		**10/20/06**	
Logging start time (24 hr)**Total** (min.)		**Start:** 0834	**Total** 3 hrs 22 min	**Start:** 0840	**Total:** 3 hrs 18 min	**Start:** 0828	**Total:** 3 hrs 18 min
Exchange Rate (dB) & **Criterion** (dBA)		**ER:** 5	**Criterion:** 85	**ER:** 5	**Criterion:** 85	**ER:** 5	**Criterion:** 85
Time > 110 dBA (minutes)		< 1		< 1		< 1	
Time ≥ 85 dBA (minutes)		34		< 1		16	
L(ACGIH)**TWA** (dB ER; 8-hr TWA)		79.2		75.0		76.9	
Noise Exposure	**L avg** (dBA)	80.5		76.9		78.7	
	Dose (%)	**22.6**		**13.4**		**17.3**	
	8-hr TWA (dBA)	**74.3**		**70.5**		**72.3**	

Dosimetry Data							
Monitoring Date		**11/14/06**		**11/15/06**			
Logging start time (24 hr)**Total** (min.)		**Start:** 1259	**Total** 1 hrs 19 min	**Start:** 0914	**Total:** 1 hrs 58 min	**Start:**	**Total**
Exchange Rate (dB) & **Criterion** (dBA)		**ER:** 5	**Criterion:** 85	**ER:** 5	**Criterion:** 85	**ER:**	**Criterion:**
Time > 110 dBA (minutes)		0		< 1			
Time ≥ 85 dBA (minutes)		43		7			
L(ACGIH)**TWA** (dB ER; 8-hr TWA)		78.9		75.5			
Noise Exposure	**L avg** (dBA)	83.9		75.4			
	Dose (%)	21.2		8.7			
	8-hr TWA (dBA)	73.8		**67.4**			

Some follow-on testing with an inconel gasket from the Space Shuttle Main Engine Shop was performed in order to determine if the technology could remove Teflon coatings. Two identical gaskets were brought to the test site at KSC, one was used during the demonstration where the hand-held laser was used to remove the coatings. While the coating was removed there was significant heating and some discoloration of the inconel substrate. The identical ring

was sent to the Adapt Laser facility in Germany in order to test the ability of the same laser to remove the coatings without damage using the 2D scanning laser. The 2D scanning laser was able to remove the Teflon coatings without significant observable damage to the gasket.

3.6.4. Conclusions/Recommendations

MST Samples

Personnel from Space Launch Complex 17 provided two pieces of sample Mobile Support Tower (MST) materials for field evaluation, one piece of diamond plate steel, and one section of steel I-beam. Both samples had been recently coated with the Zinc Clad 5 Primer and are representative of the Cape Canaveral Air Force Station Space Launch Complex structures. It was noted that the 120W laser did have difficulty actually stripping the zinc based paint, taking approximately 25 minutes to adequately remove the paint from 1/4 sq. ft. of the diamond plate steel panel (the 500W model would take less than 5 minutes to do the same area). Focusing the beam on the contoured dimensions of the diamond shapes took additional time. Some coatings, especially lighter colored coatings proved tougher to strip due to lower heat absorption.

Corrosion/Refurbishment

There is potential for this technology for use on the MST, since refurbishment work is actually removing corrosion instead of existing protective coating. Field tests showed that the PLCRS excelled in corrosion removal. Corrosion was removed quickly and completely, even cleaning out pitted areas leaving the substrate in excellent condition for immediate recoating. In areas where the protective coating has already been compromised, little if any of the original zinc coating is left to remove. Coated areas that have not been compromised are not stripped; only deteriorated areas are refurbished as required. Therefore, further evaluation under actual conditions may be warranted for testing on the MST. With a scheduled refurbishment section prepared for the PLCRS, corroded areas may be effectively cleaned up and rapidly recoated once complete. The PLCRS would practically eliminate cleanup since removed material is collected with the aid of a HEPA vacuum system.

The PLCRS appeared to clean the corroded areas to meet the SSPC-SP-10/NACE-No. 2 Near-White Blast Cleaning specification, but laboratory and other field tests have show this to be only true in some situations. One aspect to note is that the PLCRS does not alter or establish a surface profile, but only removes the coating or corrosion. If a specific profile is required after stripping, this would need to be produced with hand tools capable of establishing the desired profile, unless there was a previously acceptable anchor profile on the substrate, in which case, it would be preserved. It appears that corroded substrates, if still structurally sound, may provide a less desirable profile than when originally coated. The PLCRS has a potential for use on the MST or similar structure since traditional blast methods cannot be used. There does not appear to be an adequate purpose for its consideration on the Fixed Umbilical Tower since traditional blast methods can be used.

Similar interest was shown for use on the Mobile Launch Platform and Crawler for SSP. The prime interest is removing corrosion and nearby affected coatings from steel for re-painting.

There was a concerted effort by interested stakeholders to demonstrate the laser on the Crawler, but there was not adequate time to plan the demonstration, primarily due to proper preparation of the site to avoid safety concerns and the launch schedule which would not allow for the site to be cleared of non-essential personnel for the demonstration.

NDE Weld Line Prep

One of the more successful efforts during this demonstration involved using the laser to decoat weld lines (both aluminum and steel) or other areas in need of surface inspection. It was found during the demonstration that the lasers are able to successfully prepare an area for NDE. When using the lasers, no secondary or preparation steps were required (i.e. no chemical stripping or cleaning steps) before performing the appropriate NDE tests. Typically, after chemically stripping weld lines the surface must be cleaned and prepped prior to the NDE. Using the lasers to do the decoating and prep work resulted in a much cleaner and shorter process when working with both the weld lines and other NDE testing.

Another test for weld lines was the preparation of joint and interface areas of two panels prior to welding. These areas of bare substrates must be cleaned properly to achieve an acceptable weld. This technology is currently used widely within several auto-manufacturing facilities for this expressed purpose. Welds were to be tested for strength, but the stakeholder that was involved retired prior to accomplishing these tests. It is assumed that this testing would have been successful, but was not completed.

SRB Grease Test

The Solid Rocket Booster (SRB) Grease tests had some significant problems. While the laser could remove the paint and grease on the SRB sample, it caused a moderate amount of grease to splatter onto the glass that protects the laser source from dirt and debris. Because of this, the glass had to be cleaned every 5-10 minutes to maintain laser efficiency and protect the glass from overheating. Unless engineered differently, the hand-held laser would not be very productive for this type of application.

Safety, Air, and Noise

Safety, Air, and Noise sampling went well. All tests were below the level of action for noise, however because noise levels indoors were very close to action levels, ear protection is still recommended for the laser operator and if the process were implemented at KSC hearing protection would be required until further testing could be performed. Chromium and cadmium based coatings were stripped over 3 days of air sampling and all test results were well below the action limits.

4.0. Discussions, Conclusions, & Recommendations

While it is unlikely that this technology could be implemented for use on the Orbiter due to Anodize related specifications, the technology should not be precluded from use or further testing for other space flight hardware and/or future vehicles because of these conflicts. Should

KSC procure a laser system for GSE and non-flight equipment depainting processes, testing this technology for use within flight hardware processes should be fully explored.

Lasers as demonstrated during this project stripped slower than conventional technologies, but according to the JG-PP/ESTCP Final Report the amount of PPE required was reduced, and time to setup equipment, don PPE, doff PPE, and post-stripping cleanup was also reduced. It is recommended that lasers be used for small area applications or applications where there is not a short timeline scheduled for the activity.

When considering the use of lasers as decoating tools, concerns began to be voiced within the SSP community regarding issues such as laser temperatures, potential for damage, coating removal, effectiveness, damage to substrate and surrounding TPS materials, corrosion resistance, and the Anodized layer. Data from this project addresses many of these issues and should be helpful in assessing the value of hand held lasers for various decoating needs that will inevitably arise within SSP and other NASA programs.

Lasers do not present a threat to the established aluminum structure limits which are set at 350°F. It should also be noted that the temperature profiles for coating removal are expected to differ from one paint system to another.

Another goal of this project was to evaluate the possibility of using hand-held lasers within the tile cavities of the Orbiter. In summary, both the 40W and 120W lasers were effective in removing skived RTV and Koropon within these areas. The lasers have the potential to damage TPS materials as documented in Section 3.4., however, it should also be noted that a workable procedure was developed to protect TPS soft goods when employing the lasers as decoating tools. When taking proper steps to protect surrounding tiles and filler bar, all decoating tests for this program were successful. It should be noted that the two hand-held lasers were inefficient in removing thick layers of RTV and they do not have the sensitivity and selectivity to remove Koropon while leaving the Anodized layer intact.

Leaving the Anodized layer intact to preserve an element of corrosion protection in the tile cavities is a concern for many in the SSP. Several tests were conducted comparing the hand-held lasers effect on the Anodized layer with the effects of using standard 220 and 400-grit sandpaper. It seemed that the hand-held lasers removed the Anodized layer in patches while hand-sanding was able to remove the Anodized surface one layer at a time allowing for easier preservation of the Anodized layer. As a follow up to this testing, Adapt Laser decoated an Anodized/Koropon panel using their CL120 gantry-mounted Q-Switched laser. After some experimentation with various laser settings, the automated laser demonstrated the ability to remove Koropon while leaving the Anodized layer intact.

In general, darker and thinner coatings tend to be easier to remove than the lighter and thick coatings when applying the lasers to various coating systems. Color, chemical composition, and thickness of the target layer all impact the effectiveness in the removal process. Overall, the 40W, 120W, and 500W lasers were able to remove each coating; however, the degree of success varied. Results were consistent with other methods of coating removal. In other applications it was shown that the lasers were successful in removing corrosion from most

substrates, but limited in their ability to remove all corrosion and pitting from aluminum substrates.

The Nd:YAG laser systems have proven to be quite versatile and practically maintenance-free. The 40W Nd:YAG system was very easy to use but was found to be tedious to use when stripping larger surface areas. This was due to the end effector design that produces a small, unrastered beam diameter on the part substrate. Likewise, the 120W Nd:YAG system was also very easy to use, but its end effector is designed to perform stripping on larger flat surfaces. Stripping of these flat or slightly contoured surfaces was performed very efficiently using this system, but the end effector design was found to be cumbersome when stripping components with complicated geometries. Newly developed laser systems have the ability to incorporate both types of laser by having multiple end effectors and a simple switching mechanism. Additionally, newer versions of the same 120W laser documented here have increased power ratings at 250W and 300W and lower maintenance costs due to switching from a lamp to a diode pumped laser. These newly marketed lasers would perform better and with higher reliability than the lasers reviewed here, and would be recommended for any potential implementation.

References

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14 Kennedy NASA Procedural Requirements. KSC Ionizing Radiation Protection Program (KNPR 1860.1). 15 Oct 2004.

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Appendix A: Test Articles and Matrices

Group A: **Boeing Huntington Beach** – Doug Boerigter
Group B: **USA** – Jon Seibert
Group C: **Weld-Line Panels** – LES Shop
Group D: **GSE Panels** – Boeing & USA
Group E: **NSLD Panels** – Julia Hess
Group F: **Lab Test Panels** – Jerry Curran (KSC)
Group G: **Field Articles** – Martin Boyd, Ernie Banks, Carol Waddell, Julia Hess, Jon Siebert, Jennifer Van Den Driessche, Jennifer Parson & Jim Mullican

No.	Description	Substrate	Pretreatment	Primer	Topcoat
1A, 1B, 3A	12" x 12" (0.050" thick)	2024-T3	Bare Aluminum	Koropon (MB0125-055)	None
A-4 (AKA 14-B)	12" x 12" (0.050" thick)	2024-T3	Chem-film (MIL-C-5541)	Koropon (MB0125-055)	None
4B	12" x 12" (0.050" thick)	2024-T3	Bare Aluminum	2-Coats Koropon (MB0125-055)	None
A-6 (AKA 18B)	12" x 12" (0.050" thick)	2024-T3	Chem-film (MIL-C-5541)	2-Coats Koropon (MB0125-055)	None
2A	12" x 12" (0.050" thick)	2024-T3	Bare Aluminum	Koropon (MB0125-055)	RTV 560 (MB0130-119 Type II)
8B	12" x 12" (0.050" thick)	2024-T3	Anodized (MIL-A-8625)	Koropon (MB0125-055)	RTV 560 (MB0130-119 Type II)
5A, 5B	12" x 12" (0.050" thick)	2024-T3	Bare Aluminum	None	RTV 560 (MB0130-119 Type II)
21B	12" x 12" (0.012" - 0.016" thick)	2024-T3	Bare Aluminum / Face Sheet	Koropon (MB0125-055)	RTV 560 (MB0130-119 Type II)
A-12 (AKA 24A, 26A)	12" x 12" (0.012" - 0.016" thick)	2024-T3	Chem-film (MIL-C-5541)	Koropon (MB0125-055)	
22A, 22B	12" x 12" (0.012" - 0.016" thick)	2024-T3	Bare Aluminum / Face Sheet	None	RTV 560 (MB0130-119 Type II)
A-16 (AKA 9A, 9B)	12" x 12" (0.050" thick)	2024-T3	Anodized (MIL-A-8625)	Tie Coat (old) (MB0125-094)	Thermal Control Coating (MB0125-080)
11A	12" x 12" (0.050" thick)	2024-T3	Anodized (MIL-A-8625)	Koropon (MB0125-055)	Gloss Polyurethane (MB0125-095)
B-1	12" x 12"	6061-T6	Alodine 1200	Hentzen Primer	Hentzen Topcoat
B-30	13" x 13 1/2" (0.016" thick)	2024-T81	Red Sulfuric Anodize	No Primer	No Topcoat
B-32	13" x 13 1/2" (0.016" thick)	2024-T81	Red Sulfuric Anodize	Koropon	MB0125-039 Gray
C-1, 2	12" x 12" with Weld	A 36 Steel	None	IOZ Primer / Epoxy Primer (Midcoat)	White Urethane Topcoat
C-3, 4	12" x 12" with Weld	A 36 Steel	None	IOZ Primer	Grey IOZ Topcoat
C-5 through 8	12" x 12" with Weld	5052-H32	None	Epoxy Primer	White Urethane Topcoat
C-9 through 12	12" x 12" with Weld	6061-T6	None	Epoxy Primer	White Urethane Topcoat

No.	Description	Substrate	Pretreatment	Primer	Topcoat
D-1	12" x 12" (USA)	A36 Steel	None	IOZ Primer / Epoxy Primer (Midcoat)	White Urethane Topcoat
D-5	12" x 12" (USA)	A36 Steel	None	IOZ Primer	Grey Inorganic Topcoat
D-9, 10	12" x 12" (USA)	5052-H32	None	IOZ Primer	White Urethane Topcoat
D-13	12" x 12" (USA)	6061-T6	None	Epoxy Primer	White Urethane Topcoat
D-17, 18	12" x 12"	5052-H32	Anodized	None	None
D-25, 26	12" x 12"	6061-T6	Anodized	None	None
F-1, 2	3" x 6"	Steel 1018	CT - Pretreatment	CT - Primer	CT - Topcoat
F-3, 4	3" x 6"	Steel 1018	No Pretreatment	No Primer	No Topcoat
F- 5, 6	3" x 6"	Steel 1018	No Pretreatment	No Primer	No Topcoat
F-7, 8	3" x 6"	2024-T3	CT - Pretreatment	CT - Primer	CT - Topcoat
F-9, 10	3" x 6"	2024-T3	No Pretreatment	No Primer	No Topcoat
F-11, 12	3" x 6"	2024-T3	No Pretreatment	No Primer	No Topcoat
G-1	6" x 12" Steel angles From Banks	Steel	Unknown	Unknown	Unknown
G-23	CCAFS / Patrick AFB Test Articles From Mullican – Diamond Plate	Steel	None	Zinc Clad Primer	None
G-24	CCAFS / Patrick AFB Test Articles From Mullican – I-Beam	Steel	None	Zinc Clad Primer	None

Appendix B: Attendees of Field Demonstrations

Attendees to First WPAFB Demo

Last Name	First Name	Title	Organization
Banks	Marvin (Ernie)	M&P Engineer	Boeing
Beck	Phil	Mech. Eng. Technician	NASA
Boyd	Martin	NASA STR	NASA
Brown	Christina	TEERM Program Mgr	NASA
Chakravarthy	Sreevatsa	Subsystem Area Mgr	USA
Hall	Harold (Pete)	Paint Stripping Coord.	Anteon
Hayes	Steve	Mech. Eng. Technician	NASA
Headley	David	Project Engineer	Boeing
Hull	Robert	Program Manager	Anteon
Lee	Charlie	M&P Engineer	USA
Mongelli	Gerard	Manager, AF Programs	CTC
Nielsen	Larry	TPS Manager	USA
Rothgeb	Matthew	Engineer	TEERM (ITB)
Rozzo	Sandy	TPS Engineer	USA
Sekura	Linda	Environmental Research	SAIC
Wagner	Ken	Structural Engineer	USA
Wagner	Pete	Project Leader	USA

Attendees to GRC Demo

Last Name	First Name	Title	Organization
Banks	Marvin (Ernie)	M&P Engineer	Boeing
Bertone	Ernie	Building Mgmt Spec.	NASA GRC
Blasio	Chris	Health Physicist	NASA GRC
Buettner	Sandy	Electronics Engineer	NASA GRC
Cherry	Clint	Carpenter	JDDI
Coates	Bryan	Facilities Development	NASA GRC
Curran	Jerry	Engineer	ASRC
Dyke	Mike	Safety Engineer	NASA GRC
Forth	Dave	Program Manager	SAIC
Gibson	Theresa	Electrical Engineer	NASA GRC
Giriunas	Julius	Gas & Fluid Systems	NASA GRC
Greenwalt	Christine	Industrial Hygienist	NASA GRC
Hall	Harold (Pete)	Paint Stripping Coord.	WPAFB
Hempstead	Tyrone	Carpenter	CHI
Howser	Bill	Facilities Division	SAIC
Jeziorowsky	Luz	Industrial Hygienist	NASA GRC
Kearney	Dick	Tech Services Grp Mgr	MTI
Liou	Larry	Res Test Support Mgr	NASA GRC
Marabito	Scott	Electrical Foreman	CHI
McClanahan	Ron	Safety Engineer	NASA GRC
Merriweather	Jim	Model Maker	NASA GRC
Papcke	Dan	P2/Sustainability Lead	NASA GRC
Parrott	Edith	Electrical Engineer	NASA GRC
Rothgeb	Matthew	Engineer	TEERM (ITB)
Schade	Greg	Electrical Engineer	NASA GRC
Seibert	Jon	Engineer	USA
Sekura	Linda	Environmental Specialist	NASA (CSU)
Smith	Tim	Aerospace Engineer	NASA GRC

Straw	Randy	Engineer	WPAFB
Waddell	Carol	Engineer	NASA KSC
White	Dan	Admin Mgmt Spec	NASA GRC
Windau	Angela	Industrial Hygienist	SAIC

Attendees to Second WPAFB Demo

Last Name	First Name	Title	Organization
Banks	Marvin (Ernie)	M&P Engineer	Boeing
Boerigter	Doug	Engineer / Scientist	Boeing HTS
Boyd	Martin	NASA STR	NASA
Chakravarthy	Sreevatsa	Subsystem Area Mgr	USA
Heidelmann	Georg		Adapt Laser
Hess	Julia	M&P Engineer	Boeing NSLD
Nielsen	Larry	TPS Manager	USA
Parsons	Jennifer	Structures Engineer	USA
Rothgeb	Matthew	Engineer	TEERM (ITB)
Rozzo	Sandy	TPS Engineer	USA
Seibert	Jon	Engineer	USA

Attendees to KSC Demo

Last Name	First Name	Title	Organization
Aman	Bob		Wiltech
Ballington	Joe	Manager	USA
Banks	Marvin (Ernie)	M&P Engineer	Boeing
Batson	Kurt	Boeing M&P	Boeing
Beckage	Frank	Boeing Environmental	Boeing
Benison	Wendy	USA Safety and Health	USA
Bergstrom	Gary	Industrial Hygienist	CHS
Bland	Jamel	Engineer	USA
Boehmer	Linda	USA Safety and Health	USA
Boerigter	Doug	Engineer / Scientist	Boeing HTS
Boyd	Martin	NASA STR	NASA
Brown	Christina	TEERM Program Mgr	NASA
Brown	Dale	M&P Engineer	Boeing
Brown	David	Engineer	ATK
Brown	Julias	Property Spec	Boeing / APL
Byrd	Curtis	Environmental Manager	SGS/CHS
Clark	Johnny	Mechanical Engineer	Lockheed Martin
Corsa	Anna	Engineer	NASA
Curran	Jerry	Engineer	ASRC
Daly	Shawn	Avionics LSP	NASA
Devlin	Joe	Industrial Hygienist	CHS
Doucet	Russell	Engineer	ASRC-17
Exell	Wally	MATE	USA
Fineberg	Larry	Engineer	NASA
Franco	Rogelio	Engineer	NASA
Freeman	Bob	Nuclear Launch Approval	NASA
Gayle	Michael	Video Tech	Indyne
Geber	Kurt	Agency Health Physicist	Dyn-4 NASA Occ. Health
Goforth	Greg	Tech	USA

Last Name	First Name	Title	Organization
Gracom	Glenn	Process Engineer	USA
Greene	Brian	Senior Engineer	TEERM (ITB)
Hall	Harold (Pete)	Paint Stripping Coord.	WPAFB
Harrell	Laura	NDE Inspector	USA
Harris	Bill	Engineer	ASRC
Harris	Robin	M&P Engineer	Boeing
Hayes	Christine A	Environmental Engineer	SGS/CHS
Heidelmann	Georg		Adapt
Herrington	John	Engineer	TEERM (ITB)
Hess	Julia	M&P Engineer	Boeing NSLD
Hoepfner	Howard	LEAD	WYLE/FSA-1
Hoover	Darrell	BOSN	USA
Hull	Dan	Aero Tech	NASA
Jiménez	Luis	Engineer	Wiltech
Jonjevic	Nathan		Adapt
Kessel	Kurt	Senior Engineer	TEERM (ITB)
Layne	Andrew	NASA OHE	NASA
Lewis	Pattie	Engineer	TEERM (ITB)
Llibre	John	Industrial Hygienist	USA
Lockhart	Leon	Body & Fender Mechanic	CMTI
Loftin	Sam	Property Spec	Boeing / APL
McCauley	Larry	System Administrator	USA
McClure	Michael	OHE Engineer	USA
McLaughlin	David	Tech	NASA
Millwood	Rick	Property Spec	Boeing / CMT
Mitchell	John	Engineer	Lockheed Martin
Muktarian	Ed	Engineer	ASRC-17
Myers	Jim	Engineer	NASA
Nielsen	Larry	TPS Manager	USA
Nguyen	Hien T.	Environmental Specialist	NASA
O'Connor	Cristina	Engineer	NASA
Parsons	Jennifer	Structures Engineer	USA
Poimboeuf	Ken	Project Manager	ASRC
Remusat	Todd	Industrial Hygienist	CHS
Richer	David	Engineer	UPC/Wyle
Ring	Rich	Engineer	USA
Roberts	Glenn	USA OHE	USA
Robinson	Anthony	Video Tech	Indyne
Rothgeb	Matthew	Engineer	TEERM (ITB)
Seibert	Jon	Engineer	USA
Sikora	Ed	SSME-USA	USA
Solomon	Marcella	M&P Engineer	Boeing
Stevenson	Charles	NASA OHE	NASA
Straw	Randy	Engineer	WPAFB
Summers	Robert	NASA OHE	NASA
Swartz	Rich	Engineer	Lockheed Martin
Thompson	Gary	Video Tech	Indyne

Last Name	First Name	Title	Organization
Thompson	Randy	M&P Engineer	Analex
Waddell	Carol	Engineer	NASA
Walsh	Earl	Body and Fender Mechanic	CMTI
Waters	George T	QA	USA
Wendorff	Bill	M&P Engineer	Boeing
White	Brian	Process Engineer	USA
Wickwire	Pete	Industrial Hygienist	Boeing Delta
Williamson	Steve	Project Manager	Wiltech
Witkowski	Rich	Engineer	NASA
Woods	Jim	NDE Inspector	USA
Yarborough	Becky	Property Spec	Boeing / APL
Zink	Nevin (Ray)		USA

Appendix C: Operations Checklist Example

Checklist for Clean-Lasersysteme Demonstration & Operation at NASA KSC

*As stated in the Standard Operating Procedures, laser operators should complete this checklist prior to use at each new location of operation and daily before first operations of the day at a minimum.

Note: Qualified Laser operator onsite is to complete this checklist prior to operation of the Clean-Lasersysteme Portable Laser Coating Removal System. Deviations from the list must be approved by the Radiation Protection Officer through the Health Physics Office at KSC.

Before Operations can begin, assure the following pre-requisites are met for the appropriate environment of operation:

A ROOM WILL HAVE:

1. ☐ Adequate ventilation or cooling to control thermal buildup,
2. ☐ Vacuum designed to handle the vaporized paint or paint chips,
3. ☐ Hearing protection, if requested, for personnel inside the room,
4. ☐ Laser interrupt, if door opens,
5. ☐ Laser warning signs,
6. ☐ Laser operation warning lights,

A CONTROLLED SPACE WILL HAVE:

1. ☐ Only laser protective curtains designed for the particular laser operations shall be used,
2. ☐ Adequate ventilation to control thermal buildup,
3. ☐ Vacuum designed to handle the vaporized paint or paint chips,
4. ☐ Hearing protection,
5. ☐ Controlled entry point with laser interrupt, if unauthorized personnel enter controlled space,
6. ☐ Laser warning signs,
7. ☐ Laser operation warning light.

VERIFY BEFORE PROCEEDING WITH STARTUP:

1. ☐ Verify operation of interlock system **(inside use)**
2. ☐ Verify room exhaust ventilation is operating **(inside use)**
3. ☐ Verify particle capture system is operational with appropriate filters in place
4. ☐ Verify flashing sign(s) and warning lights are operational
5. ☐ Verify warning signs in place
6. ☐ Verify laser curtains erected and barricades established per safety plan **(outside use)**
7. ☐ Ensure person(s) monitoring safety barricade have been briefed regarding responsibilities
8. ☐ Verify operator and observers are wearing appropriate laser eye protection
9. ☐ Verify appropriate fire suppression system is available

STARTUP PROCEDURE

1. ☐ Verify that all cables and lines are in place and secure.
2. ☐ Turn on laser warning lights.
3. ☐ Verify laser warning signs are posted.
4. ☐ Secure test area.
5. ☐ Verify that beam stops are in place.
6. ☐ Verify that the power is switched OFF.
7. ☐ Follow **Table 1** to start the laser.

TABLE 1: STARTUP PROCEDURES

№	x	Action	Laser System Reaction	Note
a.	☐	Turn the main switch (mains supply) to the "On" position	Shutter display flashes shortly (lamp test). Cooling display lights up. Numerical display "8888" appears	Wait approximately 5 seconds
b.	☐	Wait approximately 5 seconds	Cooling water temperature in °C is displayed. When the temperature is below the preheating temperature, the water pump and the heating switch turns on automatically. The cooling control lamp #3 lights up; automatic preheating is activated	If the preheating temperature is already reached, go to point 4
c.	☐	Wait for set temperature to be reached	Automatic disconnection of the preheating and the water pump. Cooling control lamp #3 extinguishes. Start interlock of the laser is automatically released	Starting the laser is now possible
d.	☐	Pull emergency shutdown switch	None	Do not block the switch
e.	☐	Insert key switch (laser) and turn to position "On"	Green laser function display "Ready" lights up	Laser beam source is ready for start
f.	☐	Start the laser system by turning and holding of the key switch in the "Start" position for approximately 1 second	When the key is actuated the yellow control lamp (start) on the operating panel lights up. When the key is released, it returns to the "On" position. Make sure water pump is working. The laser beam source must ignite between 5 –20 seconds. This is displayed by a flash of the function display "Laser"	The laser radiation for the cleaning process is generated in the resonator Note: Strict supervision must be adhered when key is inserted in the laser system
g.	☐	Wait approximately 5 seconds	Listen for the water pump working. The function displays "Ready" and "Laser" light up	Laser beam cleaning system is ready for operation

OPERATION:

1. Place sample in target area
2. Follow Start-up procedure
3. To open the shutter on the laser head and fire the laser, press the trigger button (pistol grip) simultaneously with the green button on the end effector on the dial pad, using both hands. The laser is now firing.
4. You can now release the green button on dial pad.
5. Adjust operating parameters (pulse frequency, scan frequency, scan width) if needed.
6. Move the end piece over the target area by slowly rolling the end piece back and forth over the target area.
7. Release the trigger button to stop the laser.

SHUTDOWN PROCEDURES:

1. Follow **Table 2** for shut-down procedures
2. Never disconnect the laser system directly using the main switch or by pulling the mains plug! Always actuate the key switch first to shut down the laser.

№	x	Action	Laser System Reaction	Note
a.	☐	Turn key switch (laser) to the "Off" position for approximately 1 second and release it Remove key	Display "Laser" extinguishes	Wait until the cooling system has cooled down to set temperature (normally 23°C)
b.	☐	Wait 5 seconds	Cooling water pump stops. Compressor cooling system switches off audibly	Laser beam source is switched off. The laser system can now be separated from the mains supply.
c.	☐	Turn main switch (mains supply) to the "Off" position	Cooling display extinguishes. Cooling adjuster beeps shortly	Laser system is now switched off.
d.	☐	Protect laser against unauthorized connection		

EMERGENCY SHUTDOWN PROCEDURE:

1. Push the red emergency OFF button located on the laser system unit.

Appendix D: Example Depainting Inspection Form

DEPAINTING SYSTEM EVALUATION AND INSPECTION REPORT			
DATE	PROJECT REF. NO.		PAGE OF
PROJECT NAME		LOCATION	
INSPECTION ORGANIZATION		INSPECTOR	
PRODUCT MANUFACTURER / NAME			
1. EASE OF USE—Technician Evaluation			
NOISE LEVEL			
2. COATING STRIP RATE			
AVERAGE COATING THICKNESS	mils		
TOTAL STRIPPING TIME min	CALCULATED STRIP RATE ft^2/min		
STRIPPING SURFACE AREA ft^2			
AVERAGE POWER CONSUMED			
COMMENTS			
3. SSPC SURFACE CLEANING LEVEL			
4. LEVEL OF WASTE GENERATED			
5. PARTICULATE GENERATION			
6. COATING REMOVAL DAMAGE APPRAISAL			
WARPING / DENTING—Technician Evaluation			
METAL / COMPOSITE EROSION—Technician Evaluation			
COMMENTS			
7. SURFACE PROFILE / ROUGHNESS			
READING #1	READING #6		
READING #2	READING #7		
READING #3	READING #8		
READING #4	READING #9		
READING #5	READING #10		
COMMENTS			
INSPECTOR'S SIGNATURE	DATE		

Appendix E: Radiation Use Authorization Form

RADIATION PROTECTION PROGRAM USE AUTHORIZATION

Use Authorization: K-LA-50147 **Modification: 000** **Date: 9/12/2006**

User Organization: **United Space Alliance (USA)**
Mail Code: USK-142
Kennedy Space Center, FL 32899

Area Radiation Officer: **John Llibre** Phone: **(321) 861-2385** Fax: **(321) 867-8169**

I. PROTECTION GUIDES:

The Protection Guides (PGs) applicable to the evaluation of this UA are determined in accordance with ANSI Z136.1 (2000) and specified for each authorized source in Section VI.A. of this UA.

II. DESCRIPTION OF USE:

The PLCRS (Portable Laser Coating Removal System) is a Class IV, Nd:YAG, hand held laser. It will be use to demonstrate coating/stripping removal.

III. AUTHORIZED SOURCES AND APPROVED USE/STORAGE LOCATIONS:

Use Authorization K-LA-50147 provides for the radiation source and locations described below:

A. Authorized Sources:

Manufacturer	No. of Sources	Model Number	Serial Number	Wavelength (nanometers)	ANSI Class	Use Description
Clean Lasersysteme	1	CL120Q	391H0304	1064	IV	Coating Removal Stripping

B. Authorized Locations:

Building/Area I.D	Location Type	Source Authorization
K6-1397/ Paint Barn	Use/Storage	All

IV. AUTHORIZED PERSONNEL:

The following named personnel are approved for activities under Use Authorization K-LA-50147.

Name	Function/Duties
John Llibre	Area Radiation Officer (ARO for USA)
*Matthew Rothgeb	Area Radiation Officer (All others)
*Rich Ring	Use Supervisor/Custodian (US/C)
*Georg Heidelmann	Operator/Maintenance
*Nathan Jonjevic	Operator/Maintenance

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IV. AUTHORIZED PERSONNEL: (cont.)

*Alan Baleyko	Operator
*Donald Walsh	Operator
*Jeff Demming	Operator
*Carson L. Yates	Operator
*Jon Hamlin	Operator
*Everett R. Smith	Operator
*Randall Straw	Operator
*Harold Hall Jr.	Operator
*Brian Greene	Observer
*Kurt Kessel	Observer
*John Herrington	Observer
*Pattie Lewis	Observer
*Jon Seibert	Observer
*Marcella Solomon	Observer
*Jerome Curran	Observer
*Marvin E. Banks Jr.	Operator
*Doug Boerigter	Observer
*Jennifer Urbauer-Parsons	Observer
*Julia Hess	Observer
*Larry Nielsen	Observer
*Christina Brown	Observer
*Joe Devlin	Observer
*Hien Nguyen	Observer

*Training and Experience Summary (T&E) form attached.

All operator personnel are required to have continuing laser training on an annual basis.
This training will be provided by the Health Physics Office (HPO) and coordinated through your ARO.

All other personnel listed above have a T&E on file in the HPO.

All users will be under the supervision of the ARO / US/C and be familiar with the provisions and controls outlined below.

V. PROCEDURES:

Use of the laser identified by the provisions of this UA will be in accordance with user-submitted procedures identified below and the radiation protection controls and provisions identified in Section VII. of this UA.

1) Manufacturer's Instruction
2) USA OP 000448

VI. HAZARD EVALUATION:

Hazard evaluations have been made based on the Protection Guide (PG) and operating parameters identified for the authorized source specified in Section A. below:

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VI. HAZARD EVALUATION: (cont.)
A. Evaluation Parameters:

1. **Clean Lasersysteme**

Manufacture	:	Clean Lasersysteme / N0934
Laser Type	:	Nd:YAG (Q-switched)
Wavelength	:	1064 nm
Peak Power	:	160 kW
Jules/Pulse	:	9.8 mJ
Pulse Duration	:	130 nsec
PRF	:	10 kHz
Beam Divergence	:	4 mrad
Beam Waist Diameter	:	200 um
Beam Waist Range	:	10 cm
MPE (Ocular)	:	2.81 e^{-7} J/cm^2

B. Worst-Case Hazard Assessment:

Worst-case hazard assessment defines the controlled area and any personal protective equipment requirements for operation of the authorized laser under 'uncontrolled' conditions.

Nominal Ocular Hazard Distance (NOHD)

The NOHD is defined for unprotected intrabeam viewing (IBV) conditions.

Optical Density (OD) Requirements
The OD is defined at specific wavelengths for unprotected IBV exposure conditions within the NOHD control areas.

Source Description	NOHD	O.D.
Clean Lasersysteme / Nd:YAG	521.6 meters (1711 feet)	5 or greater

VII. CONTROL PROVISIONS:

Continued authorized use of the source identified by this UA is contingent upon operations in accordance with the representation of the RUR submittal and the controls and provision described herein.

A. Operational Controls:

1. Laser Radiation Controlled Areas (LRCA)
A Laser Radiation Controlled Area (LRCA) as required and defined by this document (see section VI. B. NOHD) will be posted in accordance with the provisions of this UA and access limited to approved user /operator personnel.

2. Postings and Labeling Requirements
a. The LRCA will be posted with approved "Laser Warning Signs" whenever the lasers are in operation as defined by ANSI Z136.1.

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VII. CONTROL PROVISIONS: (cont.)
A. Operational Controls: (cont.)

b. All lasers will be appropriately labeled in accordance with their ANSI classification. Labels shall be affixed to a conspicuous location on the laser housing.

3. Notification Requirements
a. Telephone numbers for the Health Physics Office (HPO) notifications are:

During Normal Working Hours:	HPO: 853-5688 (Mon-Fri 0700-1630)
NASA/KSC Radiation Protection Officer	RPO: 867-6958
After Normal Working Hours:	KSC/CCAFS: 853-5211

b. The ARO must notify the HPO upon initial power/testing of the laser device to facilitate the required Health Physics Survey/Inspection.

c. Operation of the laser device in other than the represented configuration will not occur without prior notification to and approval from the KSC Radiation Protection Officer, through the HPO.

d. The ARO must notify the HPO upon transfer of the laser source on or off of KSC/CCAFS areas.

e. All real or suspected exposures to laser radiation must be immediately reported to the HPO.

4. Medical Surveillance Requirements
All approved operators of the laser will have on file, a LOP eye exam as defined by KNPR 1860.2 "Noninonzing Radiation Protection Program" and ANSI Z136.1. (2000).

5. Personal Protective Equipment (PPE) Requirement
All operators will wear laser safety glasses/goggles with an Optical Density (OD) of 5.0 or greater as described in section VI.B. at all times during operation of this Class IV Laser system.

6. Inventory/Accountability Requirements
a. Inventory and accountability control of all lasers shall be maintained by the ARO.

b. The ARO will function as the point of contact for scheduling of periodic survey/audits by the HPO and will coordinate operational schedules to accommodate such surveys/audits on a non-interference basis to the extent possible.

7. General Operating Provisions
a. Only qualified and authorized personnel identified by Section IV of this UA will operate the laser system.

b. Personnel whose job duties require operation of the device listed in Section III. A shall be adequately trained, provided with appropriate PPE where required, and be familiar with the administrative and procedural controls established by operating procedures and this UA.

c. Maintenance of the laser source must be performed by qualified and approved personnel only.

d. It is the responsibility of the user organization ARO to supply the hazard evaluation information listed in Section VI.A & B. of this UA to the organization performing maintenance on the laser device.

e. Intrabeam viewing (IBV) is not authorized unless prior approval from the KSC Radiation Protection Officer (RPO) is obtained.

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VII. CONTROL PROVISIONS: (cont.)
A. Operational Controls: (cont.)

f. The entrance doors to the laser etching room (paint barn) shall be equipped with interlocks that shut down the laser if the door is opened during laser operations. The door interlocks will be tested daily, prior to operation.

g. A flashing warning light at the entrance door of the paint barn shall be activated during all laser operations.

h. All entrance ways to the paint barn will be posted with approved Class IV laser warning signs.

i. An adequate exhaust system will be activated prior to laser operations.

j. The laser system will be equipped with an emergency stop button that will shut down the laser in the event of an emergency.

k. The laser switch key must be removed when the laser system will be left unattended. The key will be returned to the US/C at the end of the day.

B. Administrative Provisions:

1. Authorized Use Period
Radiation Use Authorization K-LA-50147 is valid for a one (1) year period ending 9/30/2007 for the use, operation, procedures, and personnel defined by this UA document.

2. Changes to Authorized Use
a. Changes in sources, procedures, personnel, or use/storage location as described by this UA must be identified through submittal of KSC Form 16-353NS "Modification of Radiation Use Authorization" describing such changes to the KSC RPO.

b. Request for changes in authorized use must be submitted not less than thirty (30) days prior to implementation of intended change, as described by KNPR 1860.2.

3. Operations not in accordance with the conditions of this Use Authorization may result in revocation of Use Authorization and possible impoundment of radiation source.

4. Further correspondence regarding sources, personnel or procedures governed by this UA must reference Use Authorization Number K-LA-50147.

CHS/Health Physics Dept.

Date:

NASA/KSC Radiation Protection Officer

Date:

EMS

Primary Distribution List

Last Name	First Name	Organization	Role / Title
Amidei	David	NASA HQ (EMD)	Program Manager
Boerigter	Doug	Boeing	Engineer/Scientist
Boyd	Martin	NASA	NASA STR
Greene	Brian	TEERM (ITB Inc.)	ITB Manager
Griffin	Chuck	NASA (KT-A2)	TEERM Program Manager
Hess	Julia	Boeing NLSD	M&P Engineer
Nielsen	Larry	USA	TPS Manager
Rothgeb	Matthew	TEERM (ITB Inc.)	Project Manager/Author
Seibert	Jon	USA	Engineer
Sekura	Linda	NASA (CSU)	Environmental Specialist
Solomon	Marcella	Boeing	M&P Engineer
Waddell	Carol	NASA	Engineer