Item Unique Identification (IUID)
Environmental Survivability Testing Report

Independent Assessment of Vendor-Supplied Materials

Naval Surface Warfare Center, Corona Division
Item Unique Identification (IUID) Center

August 2011

v 1.0

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

Table of Contents

Introduction

Prompted by findings from the Government Accountability Office (GAO) revealing a lack of accountability of its assets, the Department of Defense (DoD) developed a plan to address these findings. Item Unique Identification (IUID) is the centerpiece of that plan and involves, generally speaking, a definition of items which fall under the policy, a requirement to mark these items with an individually unique, two dimensional (2D) Error Correction Code[1] (ECC) 200 data matrix symbol depicted in Figure 1, a requirement for these marks to be as permanent as the normal life expectancy of the item and be capable of withstanding the environmental tests and cleaning procedures specified for the item to which it is affixed.

Figure 1. ECC200 data matrix symbol

These requirements are established for qualifying items by the Defense Federal Acquisition Regulation Supplement (DFARS)[2] and various DoD instructions (DoDI) and directives[3] (DoDD).

Although challenges exist in other facets of implementing IUID, this report addresses, in a limited way, some of the challenges with meeting the permanency requirements of IUID policy. Failure of the permanency requirement falls into two broad categories:

- Attachment failure – where the mark either falls off of the item or is forcefully removed.
- Degradation failure – where the mark is worn to the point where it is unreadable.

Although recounting the broad categories of failure seems to indicate a simple problem, it becomes incredibly complex under even modest examination. The diversity of environments in which the DoD operates (e.g., sea, space, air, desert, tropics, arctic) and the prolific variety of equipment the DoD employs to achieve its mission lead to a large number of permutations. In fact, so large is the variety of items and environments some combinations produce mutually exclusive solutions. For example, some IUID marks may need to be flexible for parachutes and others may need to be rigid to survive supersonic air streams. As such, it is impossible to define a singular marking material or methodology which is best, or even suitable, for all applications. In light of this perspective, the DoD has not specified marking materials nor methods, but rather has left these decisions to the item managers on an item-by-item basis. Dividing the problem among the item managers who know the environments to which their equipment will be subjected solves the first half of the problem.

The second half of the problem is addressed by each of the item managers individually identifying the materials and methods most suited to their items within their environments. In response to this need, the vendor community has developed hundreds of materials, tens of thousands of adhesives, multiple marking methods and protective coatings which can be mixed and matched to produce many permutations. The large number of permutations means most needs can be met, often in multiple ways. This allows for price competition and the security of multiple suppliers. Unfortunately, the item manager is often overwhelmed by the available choices and has few tools to help navigate to an answer. To fulfill the need for adequate,

[1] ECC is also known as Error Checking and Correction by some
[2] DFARS 211.274, DFARS 252.211-7003, DFARS 252.211-7007
[3] DoDI 5000.02, DoDI 5000.64, DoDI 8320.04, DoDD 8320.03

comparable information regarding the performance and applicability of marking methods and materials, the Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) (OUSD (AT&L)) Unique Identification (UID) Policy Office requested an independent assessment of commercially available marking methods and materials. This testing was performed as an element of that request.

This report is intended as an aid in the selection of appropriate marking materials for IUID implementation. The quantity of available materials and the wide range of environments in which the DoD operates make an exhaustive study of all possible permutations unfeasible. Direct part marked items were not included in this study and combined environmental effects such as abrasion resistance after exposure to various chemicals were also not included. This report contains analysis of environmental test data collected from materials submitted by eight companies. For the purposes of this document, the term label refers to flexible adhesive backed materials, data plates, and materials submitted by companies for testing. The testing does not include all commercially available materials or all relevant tests.

Organization

This report is divided into a body and several appendices. The body contains limited detail and is intended to help the reader understand the basics of the IUID environmental survivability tests performed. The body should also provide sufficient information to determine which, if any, of the labels tested performed well enough in simulated environments to be used for the readers' intended IUID application.

The appendices provide more in-depth analysis of specific topics. Some of the appendices provide details of the test methods used. Other subjects such as statistics, data analysis methods, and verifier variability are also discussed in the appendices.

Testing Approach

Standardized tests are one method used to differentiate label quality for use in intended environments. Instances of IUID labels passing standardized tests (e.g., MIL-PRF-61002, MIL-DTL-15024, FED-STD-191, MIL-STD-13231) and then failing in the field have been reported. One example of this is labels passing the abrasion test described in American Society for Testing and Materials (ASTM) D4060 for a set number of cycles and then failing in abrasion intensive military environments such as Iraq and Afghanistan.

These types of failures suggest the need to adapt tests to be more applicable to data matrices. Many of the standard tests for labels and data plates were developed for linear bar codes and/or human readable information and are not optimized for IUID compliant two dimensional data matrices. Another deficiency of many standard tests is adherence to specific pass/fail thresholds which may be applicable for particular environments, but may not be generally applicable.

Several standard tests were adapted to include assessments of data matrix legibility in an effort to establish IUID relevance. These adapted tests are detailed in Appendix 8 through Appendix 12, and the standard tests they were adapted from are given in the reference material section of the respective appendix. Data matrix legibility is assessed by a process known as verification[4]. Adapting tests to capture data on the quality of a data matrix as a function of test severity eliminates specific "pass/fail" thresholds and allows users of the data to determine how severe their environment is and select relevant testing thresholds. Where possible, tests were conducted until the data matrix failed verification and became unreadable. Some tests had minimal effect on many of the submitted labels. Tests with minimal effect were discontinued prior to data matrices failing verification to allow resources to be focused on more discriminating tests.

[4] Verification is an optical measurement technique that digitally measures data matrix quality using multiple parameters as defined in established standards ISO/IEC 15415, AS9132, and AIM-DPM-1-2006.

Overview of Materials Submitted and Tests Conducted

Industry participation in this study was solicited via a sources sought notification during 8 Jun 2010 to 9 Jul 2010. The notification identified the types of tests to be conducted and limited each vendor's submission to a maximum of six labels types with 250 labels of each label type. The six label types could be specified for high or low surface energy[5] substrates in simulated desert, marine, or submarine environments. In order to minimize variability, companies were given tight tolerances on label submissions, data matrix dimensions, and were requested to encode the data matrices identically. See Appendix 3 for the sources sought notification and supplemental specifications.

Companies were provided a list of possible tests to encourage submission of labels thought to perform optimally in the simulated environments. The risk of this strategy is companies may submit labels optimized for tests in a laboratory and not the real environment. However, laboratory testing is intended to simulate a specific degrading influence of an environment and allow side by side comparison of multiple labels to an identical quantity of the "degrading influence." For instance, salt fog testing performed in this study couples humidity, elevated temperature, and corrosion. By exposing all submitted labels to this environment simultaneously, resistance to this type of degradation can be compared and ranked. Users of this report can then determine if salt fog testing is relevant for their applications and utilize the data accordingly. Appendix 3 shows the list of possible tests provided to interested companies. Submitted label types are listed in Table 1.

All tested labels were verified prior to any testing to baseline the mark quality and subsequently verified after each increment of testing until the testing ceased. Verification was performed using a Microscan UID DPM[6] Compliance verifier to the AIM-DPM-1-2006 standard.

The tests performed from the list of possible tests identified in Appendix 3 are shown below. Tests were selected based on three main factors:

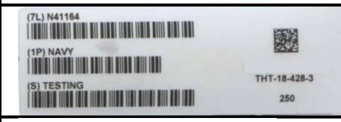
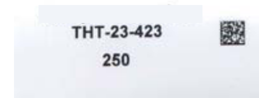
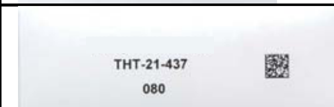
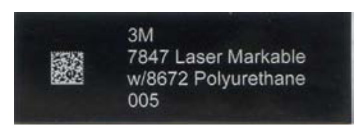
1. Department of the Navy interest in the test
2. Time and funding constraints
3. Availability of equipment and materials

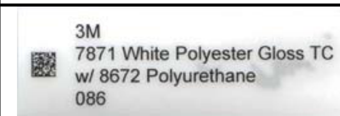
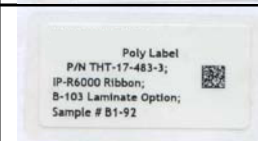
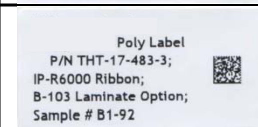
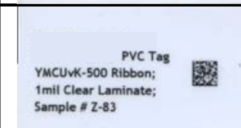
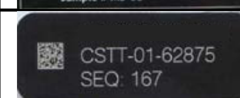
Some tests were damaging enough to cause most labels to experience adhesive or verification failure, allowing clear differentiation between labels. Other tests had less of an effect on the majority of labels and rankings within those tests indicate labels were still verifiable in many cases but showed statistically significant degradation. These "tests to failure" and "tests with limited effect" are shown below in Table 2. Appendix 4 discusses the statistical method chosen for analysis of test results. Details of each test method and in-depth data analysis of the results are given in respective appendices.

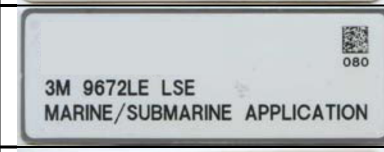
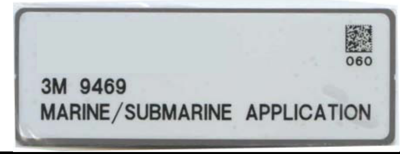
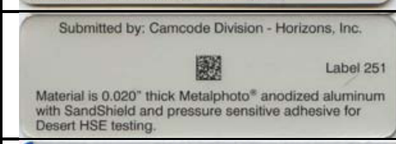
[5] Surface energy is a measure of the attractive forces a surface exerts. Plastics tend to have low surface energy (water beads and is not attracted to the surface). Uncoated metals and glass have high surface energy (water coats and is attracted to the surface). Surface energy also indicates the magnitude of attraction between adhesives and a surface. Special formulations of adhesives are required for high strength bonding to low surface energy materials.

[6] Direct Part Marking

Table 1. Submitted label types

Material ID	Product	Label Material	Adhesive	Submitter	Description	Label
BR1	B-422	Polyester	Permanent Acrylic		Label	
BR2	B-423	Polyester	Permanent Acrylic		Label	
BR3	B-437	Polyvinyl louride	Permanent Acrylic		Label	
BR4	B-457	Polyimide	Permanent Acrylic		Label	
JE1	7246	Polyester	3M Adhesive 350		Label	
JE2	7247	Polyester	3M Adhesive 350		Label	
JE3	7847	Acrylate	3M Adhesive 350		Label	
JE4	7871	Polyester	3M Adhesive 350		Label	
JE5	7847	Acrylate	3M Adhesive 350		Label	
	8672	Polyurethane	3M Adhesive 350		Laminate	

<table>
<tr><th>Material ID</th><th>Product</th><th>Label Material</th><th>Adhesive</th><th>Submitter</th><th>Description</th><th>Label</th></tr>
<tr><td rowspan="2">JE6</td><td>7871</td><td>Polyester</td><td>3M Adhesive 350</td><td rowspan="2"></td><td>Label</td><td rowspan="2">
</td></tr>
<tr><td>8672</td><td>Polyurethane</td><td>3M Adhesive 350</td><td>Laminate</td></tr>
<tr><td rowspan="2">ID1</td><td>B-483</td><td>Polyester</td><td>Permanent Rubber Based</td><td rowspan="2"></td><td>Label</td><td rowspan="2">
</td></tr>
<tr><td>B-103</td><td>Polyester</td><td>Permanent Acrylic</td><td>Laminate</td></tr>
<tr><td rowspan="2">ID2</td><td>B-483</td><td>Polyester</td><td>Permanent Rubber Based</td><td rowspan="2"></td><td>Label</td><td rowspan="2">
</td></tr>
<tr><td>B-7639</td><td>Polyester</td><td>Pressure Sensitive Acrylic</td><td>Laminate</td></tr>
<tr><td>ID3</td><td>B-483</td><td>Polyester</td><td>Permanent Rubber Based</td><td></td><td>Label</td><td>
</td></tr>
<tr><td>ID4</td><td>PVC Card</td><td>Polyvinyl Chloride</td><td>tesa 4965</td><td></td><td>Label</td><td>
</td></tr>
<tr><td>ID5</td><td>7847 Inverse</td><td>Acrylate</td><td>3M Adhesive 350</td><td></td><td>Label</td><td>
</td></tr>
<tr><td>CO1</td><td>1100-H14 (Plate)</td><td>Anodized Aluminum</td><td>tesa 62875</td><td></td><td>Label</td><td>
</td></tr>
<tr><td>CO2</td><td>tesa Secure 6973 PV6</td><td>Polyacrylic</td><td>High Performance Acrylic</td><td></td><td>Label</td><td>
</td></tr>
<tr><td rowspan="2">HO1</td><td>AlumaMark Black Plus</td><td>Photo-sensitive Aluminum</td><td>3M 9485</td><td rowspan="2">Horizons Imaging Systems Group</td><td>Label</td><td rowspan="2">
</td></tr>
<tr><td>Field Coat #08804</td><td>Topcoat Water-based Liquid</td><td></td><td>Cover</td></tr>
</table>

Material ID	Product	Label Material	Adhesive	Submitter	Description	Label
ME1	XPA074 Metalphoto Anodized Aluminum Image Intensi ied	Photo-sensitive Aluminum	3M 9672 LE		Label	
ME2	SL600 Plate	Ceramic on Stainless Steel	3M 9672 LE		Label	
ME3	XPA074 Metalphoto Anodized Aluminum Image Intensi ied	Photo-sensitive Aluminum	3M 9469		Label	
ME4	SL600 Plate	Ceramic on Stainless Steel	3M 9469		Label	
CA1	Metalphoto Anodized Aluminum	Photo-sensitive Aluminum	3M 9485 PSA	Camcode	Label	
CA2	Metalphoto Anodized Aluminum with Durable Metal Overcoat	Photo-sensitive Aluminum	3M 9485 PSA	Camcode	Label	
CA3	Metalphoto Anodized Aluminum with Sand Shield	Photo-sensitive Aluminum	3M 9485 PSA	Camcode	Label	
FL1	mFOM Holder U07530RB-A1	Retro-Re lective Base Polyvinylidene Fluoride Cover	Permanent Acrylic		Base Cover	

Note: Numerical designations of label types and the order of label types in the "Material ID" column have no correlation to performance in tests described in this report.

Table 2. Testing categories

Tests to Failure	Tests with Limited Effect
Chipping	High/low temperature exposure
Abrasion	Salt fog
Chemical immersion – Methyl Isobutyl Keytone (MIBK)	Chemical immersion - acetic acid
Adhesion	Chemical immersion - synthetic hydraulic fluid

Data Discussion

Eight tests[7] were performed using multiple surfaces[8] with 26 label types[9] tested in triplicate or quadruplicate. Each test had multiple test increments and verification was conducted after each test increment. Verification measures ten parameters of interest at ten lighting angles. The ten parameters of interest are defined in ISO/IEC 15415 and AIM-DPM-1-2006: overall grade, unused error correction (UEC), fixed pattern damage, cell modulation, axial non-uniformity, grid non-uniformity, cell contrast, reference decode, minimum reflectance, and cell size.

Analysis of the data showed cell modulation and fixed pattern damage affected the overall grades the most. UEC however is the most useful parameter for analysis of damaging influence on the data matrix which would render it unreadable. A data matrix has information encoded along with error correction code. When the data matrix is damaged, often the information can still be decoded by using some fraction of the error correction code. A UEC score of one means none of the error correction code was required to decode the mark. UEC scores decrease to zero as the level of damage increases. Given enough damage, the data matrix cannot be decoded and would have a UEC score of zero. This makes the UEC score a good indicator for the level of data matrix damage. See Appendix 4 for more detail.

Variability in verification of barcodes has been an ongoing problem for the industry for many years. The problem remains despite extensive efforts at the national and international level to establish hardware, software, and testing procedures to remove the variability. Variability in these results was also noticed when different verifiers from the same manufacturer were tested, as well as in results given by the same verifier. This study did not fully explore the extent of the variability but did observe the variability increased for data matrix verification results as the matrices degraded. A limited discussion of this is undertaken in Appendix 5.

The "tests to failure" provided more direct data analysis. Groups of labels would cease to decode at various test increments and were removed from further testing. Any labels that survived to the final test increment were compared using statistical analysis techniques described in Appendix 4 and statistically significant groupings were identified.

- Chemical immersion – Methyl Isobutyl Ketone (MIBK) testing eventually caused all labels to detach from the glass slides they were mounted to. Labels were removed from the MIBK test when they ceased to decode or started peeling from the slide, whichever came first.
- Adhesion testing determined adhesive strength by peeling flexible labels at a 90° angle at a specific speed and measuring the force to peel or shear rigid plates and measuring the force to detach. The adhesion test was coupled with high/low temperature exposure which appeared to have minimal effect on data matrix survivability but altered the adhesion strength in some cases.
- A chipping test was developed for this report. It involved dropping a set quantity of gravel through a tube from a predetermined height onto the data matrix below.

---

[7] See Table 2.
[8] High Surface Energy (HSE) used 4"x4" glass plates, Low Surface Energy (LSE) used 4"x4" polypropylene plates, chemical tests used microscope slides, chipping tests used 4"x4" galvanized steel plates.
[9] See Table 1.

- Abrasion testing used a testing machine called a Taber abraser. Data matrices were mounted on High Surface Energy (HSE) or Low Surface Energy (LSE) plates. The plates were rotated under coarse rubber wheels that would rub, skid, and roll over the surface abrading it.

Non-parametric statistical analysis techniques were applied to "tests with limited effect" to identify labels with statistically significant degradation which may have eventually failed had testing continued. High/low temperature exposure subjected labels to temperature extremes that may be experienced in harsh service conditions[10]. Labels are exposed alternately to high and low temperature extremes for predetermined time periods. This test was coupled with the adhesion test.

- Salt fog testing exposed labels to a corrosive environment of salinity, elevated temperature, and humidity. Labels were exposed to the corrosive environment for predetermined lengths of time.
- Chemical immersion testing exposed labels to separate chemical solutions of 5% acetic acid and synthetic hydraulic fluid for predetermined lengths of time.

See Appendix 8 through Appendix 12 for more detailed information about each test.

Table 3 lists all tested labels in the left most column and tests conducted along the top row. At the intersection of a label and a test, a score in the form of "x of y" is found. This means the results of the particular test divided into y groups which were statistically similar within a group and statistically different from other groups. Any label with the score "x of y" was in the x^{th} best group. Labels scoring "1 of y" are the best performers of a test, while labels scoring "y of y" are the worst performers. For example, label ID2 scored "3 of 7" in the Taber HSE test. The score "3 of 7" indicates the results of Taber HSE grouped into 7 statistically significant groupings and ID2 was in the 3rd highest grouping, where "1 of 7" would be the group of best performers and "7 of 7" would be the group of worst performers in the Taber HSE test.

Table 4 through Table 11 provide the same information as Table 3, but divided by test. These tables give detail about the meaning of the groupings on the left and list all labels in each grouping in the body of the table. These two table formats give decision makers multiple paths for choosing a label. Table 3 could be used for selecting labels using weighting functions or sorting results in a spreadsheet. Table 4 through Table 11 may be used in a top-down or bottom-up search. This could be done by finding top performers from several tests representative of expected environments or by eliminating poor performers. For example, if a user wanted maximum chipping resistance with no other considerations, Table 4 indicates label ID4 is the best choice. However, if the user wants as high as possible chipping resistance with maximum abrasion resistance for both HSE and LSE items, the best choice using Table 4, Table 10, and Table 11 becomes CA3.

Another example illustrates a deficiency of data within the report to support a definitive selection of a suitable label for some environments. This results in many labels appearing suitable where additional data may allow more accurate selections to be made. Consider plastic items requiring data matrices which will be stored on the deck of a ship in direct sunlight. These items will likely be exposed to ultraviolet (UV) radiation, high temperatures, humidity, and salty air. UV exposure tests were not performed in this testing, so this degrading effect cannot be learned from the results of this report. LSE salt fog and thermal cycling tests should be considered. Analysis of Table 3 reveals 20 suitable labels out of the possible 26 labels listed in Table 1. Three labels were not tested in salt fog LSE or temperature LSE tests because they were not designed for LSE surfaces and three other labels were not in the highest performing group in the salt fog LSE test. There can be no additional differentiation between labels due to the temperature LSE test since all of the labels performed similarly for that test. These results could likely be narrowed further if additional data, such as UV radiation exposure degradation, were available.

[10] MIL-HDBK-310

Table 3. Aggregate test results

Material ID	Chipping	Acetic Acid	Hydraulic Fluid	MIBK	Temperature HSE	Temperature LSE	Salt Fog HSE	Salt Fog LSE	Taber HSE	Taber LSE
BR1	5 of 6	1 of 3	1 of 2	4 of 4	1 of 1	1 of 1	1 of 3	1 of 3	6 of 7	6 of 7
BR2	6 of 6	1 of 3	1 of 2	4 of 4	1 of 1	1 of 1	1 of 3	3 of 3	7 of 7	7 of 7
BR3	5 of 6	1 of 3	1 of 2	3 of 4	1 of 1	1 of 1	1 of 3	1 of 3	6 of 7	6 of 7
BR4	5 of 6	1 of 3	1 of 2	4 of 4	1 of 1	1 of 1	1 of 3	1 of 3	7 of 7	7 of 7
JE1	6 of 6	1 of 3	1 of 2	4 of 4	1 of 1	1 of 1	1 of 3	1 of 3	7 of 7	7 of 7
JE2	5 of 6	1 of 3	1 of 2	4 of 4	1 of 1	1 of 1	1 of 3	1 of 3	7 of 7	7 of 7
JE3	5 of 6	1 of 3	1 of 2	3 of 4	1 of 1	1 of 1	1 of 3	1 of 3	6 of 7	6 of 7
JE4	5 of 6	1 of 3	1 of 2	4 of 4	1 of 1	1 of 1	1 of 3	1 of 3	7 of 7	7 of 7
JE5	3 of 6	1 of 3	1 of 2	2 of 4	1 of 1	1 of 1	1 of 3	1 of 3	1 of 7	1 of 7
JE6	3 of 6	1 of 3	1 of 2	3 of 4	1 of 1	1 of 1	1 of 3	1 of 3	1 of 7	1 of 7
ID1	4 of 6	1 of 3	1 of 2	1 of 4	1 of 1	1 of 1	1 of 3	1 of 3	3 of 7	3 of 7
ID2	5 of 6	1 of 3	1 of 2	1 of 4	1 of 1	1 of 1	1 of 3	1 of 3	3 of 7	2 of 7
ID3	6 of 6	1 of 3	1 of 2	4 of 4	1 of 1	1 of 1	1 of 3	1 of 3	7 of 7	7 of 7
ID4	1 of 6	1 of 3	1 of 2	2 of 4	---	1 of 1	---	1 of 3	---	5 of 7
ID5	5 of 6	1 of 3	1 of 2	4 of 4	1 of 1	---	1 of 3	---	6 of 7	---
CO1	3 of 6	1 of 3	1 of 2	1 of 4	---	1 of 1	---	3 of 3	---	4 of 7
CO2	4 of 6	1 of 3	1 of 2	1 of 4	1 of 1	1 of 1	1 of 3	1 of 3	6 of 7	6 of 7
HO1	5 of 6	3 of 3	1 of 2	1 of 4	1 of 1	1 of 1	2 of 3	2 of 3	2 of 7	2 of 7
ME1	3 of 6	1 of 3	1 of 2	1 of 4	---	1 of 1	---	1 of 3	---	3 of 7
ME2	5 of 6	1 of 3	1 of 2	1 of 4	---	1 of 1	---	1 of 3	---	1 of 7
ME3	3 of 6	1 of 3	1 of 2	1 of 4	1 of 1	---	1 of 3	---	3 of 7	---
ME4	5 of 6	1 of 3	1 of 2	1 of 4	1 of 1	---	1 of 3	---	1 of 7	---
CA1	3 of 6	1 of 3	1 of 2	1 of 4	1 of 1	1 of 1	1of 3	1 of 3	1 of 7	1 of 7
CA2	4 of 6	1 of 3	1 of 2	1 of 4	1 of 1	1 of 1	1 of 3	1 of 3	1 of 7	1 of 7
CA3	2 of 6	1 of 3	1 of 2	1 of 4	1 of 1	1 of 1	1 of 3	1 of 3	1 of 7	1 of 7
FL1	5 of 6	2 of 3	2 of 2	2 of 4	1 of 1	1 of 1	1 of 3	1 of 3	7 of 7	5 of 7

Labels are shown in the left hand column and the tests performed are shown across the top row. Temperature cycling had effects on adhesion strength as seen in Appendix 11, but little effect on UEC. Statistical groupings were not relevant at the last test increment because labels were peeled off the substrate at various points in the test and only 1 label of each label type remained at the final test increment.

Table 4. Chipping test results

	Testing Reached	Group No.	Material ID																									
Pass	Less UEC used	Group 1														ID4												
	More UEC used	Group 2																									CA3	
Fail	Failed at 3000mL, 50'	Group 3									JE5	JE6						CO1			ME1		ME3		CA1			
	Failed at 2000mL, 50'	Group 4											ID1						CO2							CA2		
	Failed at 1000mL, 50'	Group 5	BR1		BR3	BR4		JE2	JE3	JE4				ID2			ID5			HO1		ME2		ME4				FL1
	Failed at 500mL, 50'	Group 6		BR2			JE1								ID3													

Table 5. Acetic acid chemical immersion test results

	Testing Reached	Group No.	Material ID																									
Pass	Minimal Degradation	Group 1	BR1	BR2	BR3	BR4	JE1	JE2	JE3	JE4	JE5	JE6	ID1	ID2	ID3	ID4	ID5	CO1	CO2		ME1	ME2	ME3	ME4	CA1	CA2	CA3	
	Increasing Degradation	Group 2																										FL1
	Further Degradation	Group 3																		HO1								

Table 6. Synthetic hydraulic fluid chemical immersion test results

	Testing Reached	Group No.	Material ID																									
Pass	Minimal Degradation	Group 1	BR1	BR2	BR3	BR4	JE1	JE2	JE3	JE4	JE5	JE6	ID1	ID2	ID3	ID4	ID5	CO1	CO2	HO1	ME1	ME2	ME3	ME4	CA1	CA2	CA3	
	Increasing Degradation	Group 2																										FL1

Table 7. MIBK chemical immersion test results

	Testing Reached	Group No.	Material ID																									
Fail	Fail at 1 week	Group 1											ID1	ID2				CO1	CO2	HO1	ME1	ME2	ME3	ME4	CA1	CA2	CA3	
	Fail at 24 hours	Group 2									JE5					ID4												FL1
	Fail at 1 hour	Group 3			BR3				JE3			JE6																
	Fail at 10 minutes	Group 4	BR1	BR2		BR4	JE1	JE2		JE4					ID3		ID5											

Table 8. HSE salt fog test results

	Testing Reached	Group No.	Material ID																									
Pass	Minimal Degradation	Group 1	BR1	BR2	BR3	BR4	JE1	JE2	JE3	JE4	JE5	JE6	ID1	ID2	ID3		ID5		CO2				ME3	ME4	CA1	CA2	CA3	FL1
	Increasing Degradation	Group 2																		HO1								
Fail	Failed Test	Group 3																										

Table 9. LSE salt fog test results

	Testing Reached	Group No.	Material ID																									
Pass	Minimal Degradation	Group 1	BR1		BR3	BR4	JE1	JE2	JE3	JE4	JE5	JE6	ID1	ID2	ID3	ID4			CO2		ME1	ME2			CA1	CA2	CA3	FL1
	Increasing Degradation	Group 2																		HO1								
Fail	Failed Test	Group 3		BR2														CO1										

Table 10. HSE abrasion test results

	Testing Reached	Group No.	Material ID																									
Pass	Less UEC used	Group 1									JE5	JE6												ME4	CA1	CA2	CA3	
	More UEC used	Group 2																		HO1								
Fail	Failed at 2500 rev	Group 3											ID1	ID2									ME3					
	Failed at 1000 rev	Group 4																										
	Failed at 500 rev	Group 5																										
	Failed at 250 rev	Group 6	BR1		BR3				JE3								ID5		CO2									
	Failed before 100 rev	Group 7		BR2		BR4	JE1	JE2		JE4					ID3													FL1

Table 11. LSE abrasion test results

	Testing Reached	Group No.	Material ID																									
Pass	Less UEC used	Group 1									JE5	JE6										ME2			CA1	CA2	CA3	
	More UEC used	Group 2												ID2						HO1								
Fail	Failed at 2500 rev	Group 3											ID1								ME1							
	Failed at 1000 rev	Group 4																CO1										
	Failed at 500 rev	Group 5														ID4												FL1
	Failed at 250 rev	Group 6	BR1		BR3				JE3										CO2									
	Failed before 100 rev	Group 7		BR2		BR4	JE1	JE2		JE4					ID3													FL1

Note: Result tables for temperature exposure and adhesion tests for HSE and LSE are not needed because insufficient data existed to determine statistically significant groupings and thus there is only one group for each test. Adhesion test results are displayed graphically in Appendix 11.

Conclusions

Many conclusions follow directly from the primacy of this effort, being the first round of environmental material testing performed by the Naval Surface Warfare Center, Corona Division, IUID Center. The need to limit the scope of testing was immediately clear for many reasons, among them the tens of thousands of available adhesives. It is debatable where the appropriate line was to be drawn to define the scope, but three main factors were used:

1. Department of the Navy interest
2. Time and funding constraints
3. Availability of equipment and materials

These decisions are perhaps less important given future work is possible to redress any oversight. Listing all the delayed/omitted tests is not particularly profitable; however, it is worth mentioning two large and important classes of omitted testing:

1. Direct part marks
2. Combined effects of different tests together (e.g., measuring peel strength at high temperature)

A predictable outcome for any first round of tests is limited participation from the vendor community. Efforts to engage the entire vendor community and publicize the opportunity to submit materials were not fully successful. Many companies discovered the opportunity after testing had commenced and their products could not be accommodated. More complete participation is expected with further testing.

Perhaps the most valuable contribution the report makes to the community is a body of tests and testing methodology designed to measure data matrix degradation. The necessary survey of established standard test procedures, identifying the utility and deficiencies of each, and the subsequent modifications to mitigate the weaknesses and adapting them to data matrices has been accomplished and documented. This establishes a body of knowledge that will enable future work to progress more meaningfully, on a shorter schedule, and at a reduced cost.

Although many environmental considerations, marking materials, and methodologies of interest remain untested, no future work is scheduled to address these shortcomings. Interested parties are encouraged to vocalize their concerns and areas of interest in future testing. Requests for ultraviolet (UV) resistance testing are anticipated since fading due to UV exposure is a common failure mode of labels. Future efforts could address this and potentially other emergent needs utilizing the fundamental methodologies established within this report.

An expected but important observation of these tests is a single solution optimized for every environment does not exist, at least not among the environments and labels tested. What is somewhat surprising is the small variety of materials and adhesives chosen by vendors to meet the needs of six realistic, generalized environments. They provided but ten different types of materials and a handful of adhesives most of which were pressure sensitive acrylic adhesives (some vendors did not provide specific formulations but gave generic names; at most 17 of the 30 adhesives were identical and at least 9 of the 30 were identical). Given the limited participation of the vendor community, one would not want to make more of the observation than is warranted. Still, it provides basis for the possibility that a handful of the millions of possible products may in large, serve the need of the DoD with respect to IUID.

Decision makers may find the data collected in this study to be useful by determining the most relevant factors in their expected environments for data matrix degradation and selecting marking materials with resistance to those types of degradation. Weighing cost, schedule, and performance is important for optimal IUID implementation. This report only addresses the performance aspect of marking materials.

Appendix 1 Acronyms

Acronym	**Definition**
ABS	Acrylonitrile butadiene styrene
AIM	Association for Automatic Identification and Mobility
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
CCD	Charge-Coupled Device
CTC	Calibration Test Card
DFARS	Defense Federal Acquisition Regulation Supplement
DON	Department of the Navy
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DPM	Direct Part Marking
DSS	Deep Submergence Systems
ECC	Error Correction Code also known as Error Checking and Correction
EOT	End of Transmission
FAR	Federal Acquisition Regulation
GAO	Government Accountability Office
HSE	High Surface Energy
IPA	Isopropyl alcohol
IUID	Item Unique Identification
LSE	Low Surface Energy
MIBK	Methyl isobutyl ketone
MSDS	Material Safety Data Sheet
NSN	National Stock Number
OUSD (AT&L)	Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics
PSA	Pressure Sensitive Adhesive
PVC	Polyvinyl chloride
RFI	Request for Information
RFP	Request for Proposal
SAS	Statistical Analysis Software
UEC	Unused Error Correction
UID	Unique Identification
UII	Unique Item Identifier
UV	Ultraviolet

Appendix 2 References

DFARS 252.211-7003	Item Identification and Valuation
DoD Dir. 8320.03	Unique Identification (UID) Standards for a Net-Centric Department of Defense, March 23, 2007
DoD Guide	Department of Defense Guide to Uniquely Identifying Items
DoD Guidelines	Department of Defense Guidelines for Engineering, Manufacturing and Maintenance Item Unique Identification (IUID) Standards for Tangible Personal Property
DoD Instr. 4151.19	Serialized Item Management (SIM) for Materiel Maintenance
DoD Instr. 5000.02	Operation of the Defense Acquisition System
DoD Instr. 5000.64	Accountability and Management of DoD-Owned Equipment and Other Accountable Property
DoD Instr. 8320.04	Item Unique Identification (IUID) Standards for Tangible Personal Property
(FAR) 15.201	Federal Acquisition Regulation, Contracting by Negotiation, Exchanges With Industry Before Receipt of Proposals
AIM-DPM-1-2006	AIM Direct Part Mark Quality Guideline released in December 2006
AS9132	Data Matrix Coding and Quality Requirements for Parts Marking
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus
ASTM D2794	Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation
ASTM D3170	Standard Test Method for Chipping Resistance of Coatings
ASTM D3330	Standard Test Method for Peel Adhesion of Pressure-Sensitive Tape
ASTM D4060	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
FED-STD-191	Federal Standard: Textile Test Methods
ISO/IEC 15415	Information technology — Automatic identification and data capture techniques — Bar code print quality test specification — Two-dimensional symbols
MIL-DTL-15024	Detail Specification: Plates, Tags, and Bands for Identification of Equipment, General Specification
MIL-HDBK-310	Military Handbook: Global Climatic Data for Developing Military Products
MIL-PRF-61002	Performance Specification: Pressure-Sensitive Adhesive Labels for Bar Coding
MIL-STD-130	Standard Practice: Identification Marking of U.S. Military Property
MIL-STD-13231	Standard Practice: Marking of Electronic Items
MIL-STD-810	Test Method Standard for Environmental Engineering Considerations and Laboratory Tests
SS800-AG-MAN-010/P-9290	System Certification Procedures and Criteria Manual for Deep Submergence Systems

Appendix 3 Request for Information

Sources Sought Notification

Solicitation Number: N0024410SS001
Notice Type: Sources Sought
Synopsis: Added Jun 08, 2010 12:56 pm
ITEM UNIQUE IDENTIFICATION MARKING PRODUCTS

REQUEST FOR INFORMATION (RFI) as defined in the Federal Acquisition Regulation (FAR) 15.201. The Fleet and Industrial Supply Center, San Diego, Regional Contracts Dept., Seal Beach Division, is conducting a market survey to obtain information on available Item Unique Identification (IUID) marking products. All interested sources may participate.

The IUID Center at the Naval Surface Warfare Center Corona Division has been tasked by the Department of the Navy IUID lead in the office of the Deputy Assistant Secretary of the Navy (Acquisition & Logistics Management) to conduct independent assessments of the available IUID marking products and to provide technical performance data to the community.

Two environments have been selected for initial testing. The first environment is of primary interest to the Department of Navy and encompasses marine environments with a subset of the marine environment including submarines. The second environment will simulate to test IUID data matrix survivability in a desert environment.

Samples are to be provided at no charge. Samples will not be returned to the vendor after testing. Test results will be shared with the IUID community for consideration in their decision making processes. IUID implementation strategies and product selection may be influenced by the results of these environmental survivability studies resulting in the possibility of future contract awards.

Please provide a maximum of six materials:
1. Marking method optimized for low surface energy (LSE) substrates in a marine environment.
2. Marking method optimized for high surface energy (HSE) substrates in a marine environment.
3. Marking method optimized for LSE substrates in a submarine.
4. Marking method optimized for HSE substrates in a submarine.
5. Marking method optimized for LSE substrates in a desert environment.
6. Marking method optimized for HSE substrates in a desert environment.

Lists of the material properties that will be tested and an outline of the test plan are available. Sample quantity, data matrix details, and label or data plate size details are also available.

In order to be considered for the testing, all samples must be received by IUID Center no later than 09 July 2010. All samples shall be sent to:

If by shipper (e.g., UPS, FEDEX, etc.):
NAVAL SURFACE WARFARE CENTER CORONA DIVISION ATTN: IUID CENTER (PE00A), BLDG. 518
1999 FOURTH STREET NORCO, CA 92860-1915

If by United States Postal Service (USPS):
NAVAL SURFACE WARFARE CENTER CORONA DIVISION ATTN: IUID CENTER (PE00A), BLDG. 518
P. O. BOX 5000 CORONA, CA 92878-5000

As indicated above, this RFI is for testing and evaluation purposes only and is not to be construed as a Request for Proposal (RFP) or an Invitation/Request for Sealed Bids. The Government will not award a contract on the basis of this notice, nor pay respondents for any information that they submit in response to this RFI. Any information or samples submitted by respondents to this synopsis is strictly voluntary.

Original Links:
https://www.fbo.gov/index?s=opportunity&mode=form&id=8a5a240f1de05e17fa71086828409d87&tab=core&tabmode=list&=
https://www.neco.navy.mil/synopsis/detail.aspx?id=265742

Supplemental Specifications

IUID Survivability Testing Label Requirements

Thank you for considering submitting materials for survivability testing. This document gives specifications of label size and IUID matrix requirements (content and cell size). We request at most six types of "label" to address low surface energy and high surface energy substrates in desert, marine, and submarine environments.

In this round of testing we are focusing on labels, data plates, and protective coatings/covers. Direct part marking methods may be tested in later studies. We will conduct IUID matrix verification prior to testing using AIM-DPM-1-2006 or the latest version of this standard. Marks must pass acceptance criteria detailed in MIL-STD-130N 5.2.7.2b or they will not be tested. Testing will continue until the mark receives an overall grade of F or a particular test is determined to not affect mark readability.

Due to the large number of tests please send at least 250 samples of each label type.
Samples must be 2-4" long and 0.5-1" wide.

Specification for the Data Matrix barcode for testing purposes:

Module size: 0.008" < module size < 0.010"
Matrix size: 22 x 22
Quiet Zone At least 2 modules wide on perimeter of data matrix
Content: [)>r/s06g/s7LN41164g/s1PNAVYg/sSTESTINGr/sEOT
r/s Record Separator {ASCII Chr (30)}
g/s Group Separator {ASCII Chr (29)}
EOT End of Transmission {ASCII Chr (4)}
Encoding: ASCII

The data matrix should look like the example below (module size specified above)

Please include human readable information that identifies your company, the label, and preferably sequential numbering 001-250 to identify each individual label.

IUID Survivability Testing Plan

Thank you for considering submitting materials for survivability testing. This document is intended to aid your company's technical experts in selecting IUID marking solutions that will perform optimally in various environments. We realize that laboratory tests may not accurately simulate every environment. However, there is benefit from a stable test plan for comparing results over time. If you feel that any of the tests have limited value or can be made significantly better with minor changes please let us know and we will seriously consider your input.

We intend to couple existing testing standards with IUID matrix verification at various time intervals. The standards we plan to use for our tests are detailed below.

Material properties required for marine environments:

- Low out-gassing (required for submarines)
- Chipping and mar resistant
- Abrasion resistant (Taber)
- Chemical resistant
- Ocean water/salt fog exposure
- Flowing/flooding water
- Temperature resistance (-40°F to +140°F)
- Pressure wash

Material properties required for desert environments:

- Abrasion resistant (sand storm)
- Abrasion resistant (Taber abraser)
- Chipping and mar resistant
- Chemical resistant
- UV tolerant
- Temperature resistance (100°F to 160°F)
- Low humidity coupled with heat
- Pressure wash

We plan to use the following methods to test material properties.

Out-gassing	SS800-AG-MAN-010/P-9290 <u>System Certification Procedures and Criteria Manual for Deep Submergence Systems</u> Appendix F General Guidelines for Control of Atmospheric Contaminants in Manned DSS. Test to list provided by submarine community.
Chipping resistance	Hybridize test method from ASTM D3170 and ASTM D2794 to test for a fixed volume or number of gravel chunks (silica or granite also possible) of various sizes falling from increasing heights on a sample placed at 45 degrees to angle of impact. After each gravel bombardment the IUID mark will be tested for mark quality against AIM-DPM-1-2006 (verification). Number of impacts or height or size of gravel will be increased until IUID mark fails verification.
Chemical resistance	Sample will be immersed in chemicals commonly encountered in the environment for one minute, one hour, 24 hours, multiple days. IUID mark will be verified after each time period and increasing exposure periods (up to 1 month) will be utilized until mark fails verification.
Abrasion resistance 1	ASTM D4060 using CS-17 wheel under one Kg load. Mark verified at regular intervals and tested until mark fails verification.

Abrasion resistance 2	MIL-STD-810 Method 510.5 Procedure II at sand densities and velocities relevant to Iraq and Afghanistan.
UV tolerance	MIL-STD-810 Method 505.5 Procedure II.
Heat tolerance	Effect of exposure to thermal cycling in environmental test chamber on IUID mark quality (verification) and adhesion strength as measured by ASTM D3330 Method F. IUID mark verification should be conducted after first hot cold cycle and then at regular intervals there after. Peel tests will require multiple samples to be inserted simultaneously and removed at regular intervals to track adhesive strength vs time.
Peel test	After thermal cycling, determine changes in adhesion strength using peel test as described in ASTM D3330 method F.
Flowing water	Bombard label with jet of 5% saline at relevant velocity to simulate wave impact or flooding dive chamber. Stop after set time or when label peels.
Pressure wash	Bombard label with water or washing solution at to simulate pressure washing. Stop after set time or when label peels.
Temp resistance Marine	Material exposed to -40°F to +140°F in 5% saline humid atmosphere. Icing, and UV tolerance may be coupled with this test. Testing stops if mark fails verification or peels away from substrate.
Temp resistance Desert	Material exposed to 100°F to 160°F in low humidity atmosphere for relevant times to simulate hot dry desert exposure. Testing stops if mark fails verification or peels away from substrate.
Salt fog	Perform test according to MIL-STD-810 method 509.5 or ASTM B117. 24 hours in chamber 24 hour drying period with IUID mark verification after drying. Continue until mark fails.

If mark readability is determined to be minimally affected by a given test, the test will be terminated and this will be noted in the report.

Appendix 4 Statistics and Data Analysis

Variability comes from many sources. The manufacturing method used to make a material or adhesive may introduce inconsistencies. The marking method (printing, laser etching, engraving etc.) may not be identical on each sample. Human error introduced in testing or variations in the test method can contribute to the variability. Additionally, location within a testing apparatus or sequencing on test equipment can cause variations.

Sources of variability should be identified and mitigated where possible. The specifications in Appendix 3 were one effort to minimize variability by requesting companies use similarly sized data matrices and labels. This was so labels printed with larger data matrices would not have an advantage over ones printed with smaller data matrices. In order to reduce error introduced experimentally, test procedures outlined in later appendices were closely followed and labels were kept in a temperature and humidity controlled environment when not being tested. Additionally, labels were tested simultaneously so day to day variations of testing equipment would affect all labels in a given test together. Another effort to mitigate variability was testing multiple labels of each label type for each test and using ten different lighting angles on the verifier with the AIM-DPM-1-2006 standard. This not only provided for more statistically relevant data, but also represented the variation of lighting a data matrix might encounter in operational use. A known source of variability detected which could not be mitigated was within the verification process. This is discussed further in Appendix 5.

Although it may seem reasonable to use the overall grade of the data matrix as the primary statistic of interest, it does not work well in practice. Overall grade is given as a letter grade (A through F) which does not lend itself to many useful quantitative statistical techniques. Additionally, data matrices may receive a grade of F for one parameter making the overall grade an F and yet, the data matrix can still be read. For this report, data matrices were tested past the point of receiving an overall grade of F to a state of degradation where the encoded information could no longer be read by the verifier. Use of the terms "fail" or "failed" or "failure" in this document refer to the state of degradation where the data matrix could not be decoded by the verifier. UEC was found to give the best correlation with data matrix degradation. A UEC score of zero indicated the information in the data matrix was no longer readable. Accordingly, UEC was chosen as the verifier parameter of interest we would use to compare labels.

"Tests to failure" allowed clear differentiation between the labels. For example, a group of labels survived less than 100 revolutions in the abrasion test before becoming unreadable (see Appendix 9). These labels formed a statistically significant group. After determining which labels fail at each test increment, anything surviving to the final test increment can be further analyzed with a comparative statistical technique to determine if any statistically significant groups exist.

"Tests with limited effect" had most of the labels survive to the final test increment. These labels were analyzed with a comparative statistical technique and statistically significant groups were determined.

In order to measure degradation of the data matrix from the initial state to the final state, we subtracted the UEC values in the final increment from the UEC values taken before any testing had occurred. Labels with scores of zero had not degraded to within the sensitivity of the verifier or were caused by verifier variability. Labels with negative scores had lower final UEC values than initial values and had likely degraded. Due to verifier variability (see Appendix 5), some labels had positive scores. The statistical techniques used to analyze the data are discussed below.

Statistical Method

Variability is inherent to any process and the manufacturing of labels is no exception. This implies that when gathering data during label testing, small differences between sample means is to be expected. The objective of the statistical tests in this report is to determine whether these differences are statistically significant. In other words, is the difference more than what might occur by chance?

Analysis of Variance (ANOVA) is a statistical technique used to compare the means of two or more groups of observations to see if they are similarly distributed (have the same variability). Many textbooks present ANOVA in terms of a linear model which makes the following assumptions about the probability distribution of the data being analyzed.

- The individual data are independent (the value of one data point does not depend on the value of another).
- The data is normally distributed (follows the Normal distribution – the bell curve).
- The individual populations all have the same variance.

For the test results in this report, the assumption the data is normally distributed is violated. This was verified using the Shapiro-Wilks Normality Test and thus a distribution-free or non-parametric ANOVA approach was utilized in performing the statistical tests. The Kruskal-Wallace Test indicated the data came from different populations and the Dunn Test was then used to locate and isolate the differing populations.

In ANOVA, hypotheses are formulated and tested, i.e. assertions that are capable of being proven false using a test of the observed data. The null hypothesis, written as H_0, is the default position. In the case of ANOVA, H_0 is all of the means of the data being tested are equally distributed (have the same variance). Proving this hypothesis false lends credence to what is called the alternative hypothesis (H_A), namely the means are not equally distributed. It is important to understand the null hypothesis cannot be proven – the data can only reject or fail to reject a null hypothesis at some significance level. The significance level is usually denoted by the Greek symbol α (alpha). Popular levels of significance are 10% (0.1), 5% (0.05), and 1% (0.01). Statistical tests of significance provide a single value called the p-value. If the p-value is lower than the α-level, the null hypothesis is rejected.

The software used to analyze the test results was JMP Pro 9.0.0 developed by SAS Institute Inc, and all statistical tests were performed at the $\alpha = 0.05$ level. The non-parametric Dunn method was used in the analyses. This method allows one to compare *n* experimental groups simultaneously while preserving the familywise error rate. This procedure ranks all of the observations in the combined samples into a single joint ranking[11]. Next the rank sum and average rank for each sample is computed and the *i*th and *j*th population are compared by looking at the difference between their average ranks. The null hypothesis is rejected if

Equation 1. $$\left|\boldsymbol{R_i} - \boldsymbol{R_j}\right| > \frac{z_\alpha}{k(k-1)} \sqrt{\frac{N(N+1)}{12}\left(\frac{1}{n_i} + \frac{1}{n_j}\right)}$$

[11] In non-parametric statistics, rather than using the actual data in performing tests, one uses the ranks of the data points and then compares these. A single joint ranking is created by ranking all of the observations, from two or more samples, together from smallest to largest.

Where R_i is the mean of the joint ranks for the *i*th group, R_j is the mean of the joint ranks for the *j*th group, and n_i and n_j are the sample sizes in the two groups, respectively, N is the total sample size, k is the total number of groups, and z_α is the critical value and corresponds to a given significance level (α).

Appendix 5 Verifier Variability

Verifier variability was found to increase as data matrix quality decreased. An experiment conducted to determine the degree of variability was to verify the same data matrix multiple times on the same verifier without moving the data matrix or changing the lighting in the room. A label that received overall grades between A and B was selected and sequentially verified 65 times without moving the label. The same label was then verified 55 times having an operator remove and replace the label each time. This process was repeated with the same label but on a different verifier of the same model. One hour was dedicated to collecting data for each method. All results are shown in Figure 2.

Verifiers normally operate such that they will never assign grades higher than deserved, but may assign grades lower than deserved. During verification an image of the data matrix is focused onto a photosensitive chip (a Charged Couple Device (CCD)) within the verifier. Optimum operation requires the image to be perfectly focused onto the CCD, for the edges of the data matrix to perfectly align with the photosensitive checkerboard pattern on the CCD, and lastly, for any lighting external to the verifier to be the same as when the verifier was "normalized" for the external light. In all these cases, any deviation from the ideal condition mimics damage or flaws in the data matrix under test.

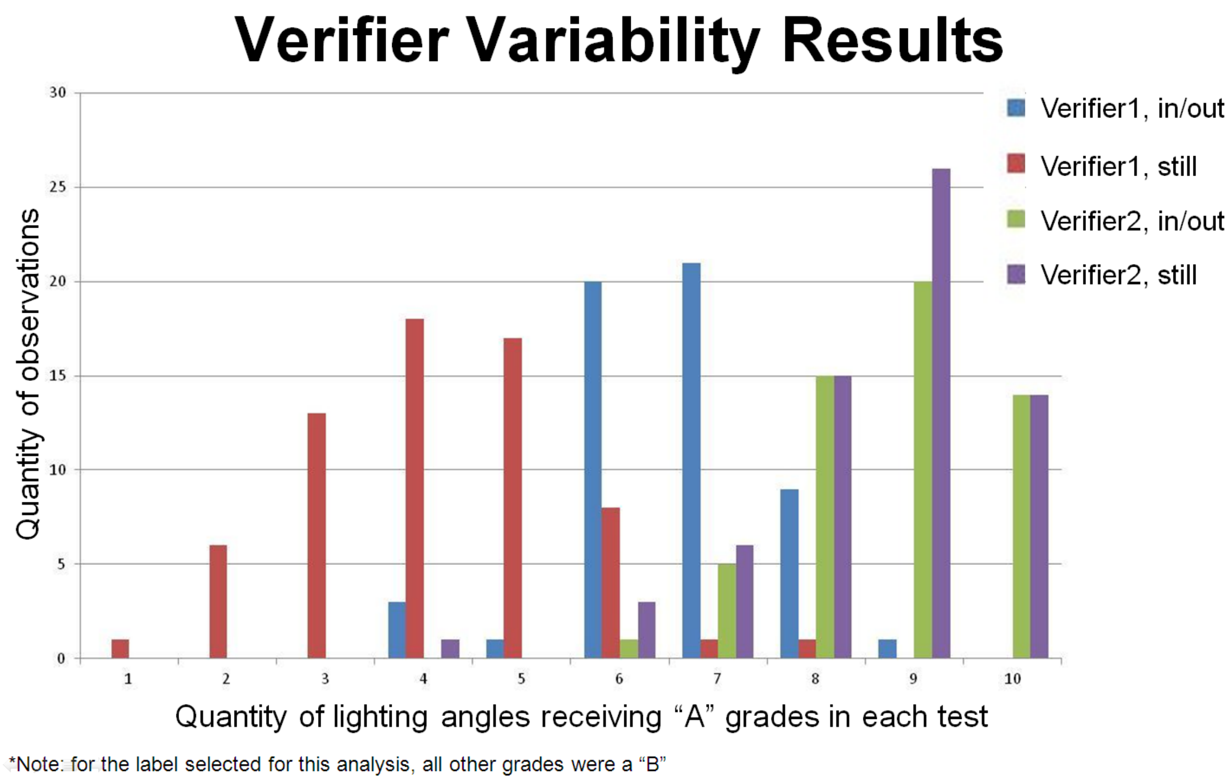


Figure 2. Verifier variability showing number of occurrences of grade ‘A’ for each verification at ten lighting angles.

The far right bar on Figure 2 indicates 14 of the 65 times the label was verified on verifier2 without disturbing the label, all ten lighting angles had overall grades of “A”. In some experimental designs, the variability or noise introduced by the test equipment can be quantified and separated from the testing results. A method to do this for the verifier was not available. Testing results, including verifier variability, were analyzed using a statistical non-parametric method that accounted for the variability. The statistical analysis allowed meaningful differences in data to be distinguished from inherent variability in the test equipment to a high level of confidence. Additional details of the statistical analysis can be found in Appendix 4.

Appendix 6 Verifier Operation

Normalization is a setup procedure for the Microscan UID DPM Compliance verifier. It adjusts the processing of the image to account for variations in external lighting. If a verifier is moved or if the lighting of the environment changes throughout the testing period, perform this step.

Verifier Setup

1.0 Normalization
- 1.1 Connect the verifier to a computer with HawkEye Normalization and UIDChecker software installed.
- 1.2 Open HawkEye Normalization software.
- 1.3 Enter the verifier's IP[12] address in the "Select Camera To Normalize" pop-up dialog box.
- 1.4 Click on the "UID Verifier-Multifunction Light" radio button.
- 1.5 Remove the Calibration Test Card (CTC) from its protective envelope and place it under the verifier so the solid black square image displays on the computer screen.
- 1.6 When the dialog box "Please center one of the black squares on the calibration standard in center of the camera of field of view, then press the normalize button" displays, click "OK".
- 1.7 Adjust the CTC so the black square image is close to the center of the camera field of view.
- 1.8 Click on the "Normalize" button.
- 1.9 When the normalization process is completed, the HawkEye Normalization message window will display, click "OK".
- 1.10 Close HawkEye Normalization software.
- 1.11 Remove the CTC from the verifier.

2.0 Verifier Reflectance Calibration
- 2.1 Open the UIDChecker software.
- 2.2 Click on the "Reader" menu, click "Reflectance Calibrate" from the dropdown menu.
- 2.3 When the UID-COMPLIANCE-CHECKER message box displays, click "OK".
- 2.4 Place the CTC under the verifier so the data matrix is centered and displays on the computer screen.
- 2.5 Enter the Contrast & Rmax values given on the CTC.
- 2.6 Click on the "Calibrate" button.
- 2.7 When the calibration is completed, all of the lighting angles displayed on the left panel should be highlighted green.
- 2.8 Click the "Close" button.
- 2.9 Remove the CTC and return the card to its protective envelope.

Verification of Data Matrices

1.0 Click on the "Live Video (90)" button and use the AIM-DPM-1-2006 ten lighting angles.

2.0 Center the data matrix under the verifier so the matrix aligns with the square alignment marks on the computer screen.

3.0 Push one of the black buttons labeled "IO TRIGGER" on the verifier.

4.0 Remove the data matrix from the verifier.

5.0 Repeat the sequence for other data matrices.

---

[12] Internet Protocol (IP).

Appendix 7 Cleaning and Label Application

Cleaning

The cleaning and application procedures are based on a 3M process.
http://www.wrisupply.com/images/docs/add_file_1/5.1SubstrateSelectionandPreparationForGraphiocFilmApplication.pdf

Because new glass and polypropylene plates were used for most tests, cleaning was simplified. Microscope slides were used for chemical tests and metal electrical junction box covers were used for chipping tests both of which were also initially fairly clean.

A 50% water 50% isopropyl alcohol mixture was used to clean the surfaces. Plates were wiped with the mixture and the plates were immediately wiped completely dry with clean absorbent paper towels. This process dissolves oils and atmospheric residues in the water alcohol mixture and then absorbs them in the towel. Allowing the plates to air-dry re-deposits any contaminates dissolved in the water alcohol mixture.

Label Application

Prior to application of a pressure sensitive adhesive backed label, the surface to be adhered to must be at least 50°F. The labels should be above manufacturer's specified application temperature for the label (because the adhesive may become too firm to adhere readily below this temperature). The surface must be clean and dry prior to label application. Remove the liner with a metal spatula and position the label on the surface being careful not to touch the adhesive with your fingers or to allow the adhesive to become contaminated with dust, dirt, etc. Using firm even pressure, roll the entire surface of the label and as a final step burnish the edges. Greater pressure provides higher bond strength and allows the adhesive to "flow" into the tiny cracks and crevices between the adhesive and the surface. The adhesive bond will grow stronger with time; achieving final bond strength in the manufacturer's specified dwell time.

Appendix 8 Chipping Test

Test Procedure

1.0 Description:
The chipping test simulates debris impact a label could experience while in the field. A fixed volume of 1/8" and 3/4" pea gravel was dropped through a 4" diameter pipe from increasing heights onto a label placed 45° to the impact angle. The data matrix was verified after each testing increment and continued until the testing cycle was complete. The chipping test was developed as a hybridized test method of ASTM D3170 and ASTM D2794. Figure 3 shows the chipping tower setup.

Figure 3. Views of the chipping tower, clockwise from top left: full tower, gravel collimator, side view diagram of gravel target, gravel target.

1.1 Equipment, Fixtures, and Materials
- 1.1.1 Pea gravel (size variation between 1/8" and 3/4")
- 1.1.2 4" x 10' Acrylonitrile Butadiene Styrene (ABS) piping
- 1.1.3 4" ABS T-connector
- 1.1.4 4" to 2" ABS reducer coupling (gravel collimator)
- 1.1.5 45° base data plate holder/ gravel collector
- 1.1.6 Rubber tie down straps

1.1.7 4"x4" galvanized steel plates[13]

1.2 Procedural Steps

1.2.1 Label preparation

1.2.1.1 Clean the testing surface appropriately (see Appendix 7).

1.2.1.2 Adhere labels for testing to plate (see Appendix 7).

1.2.1.3 Verify the data matrix and record the results (see Appendix 6).

1.2.2 Tower preparation

1.2.2.1 Connect the pipes with T-connectors[14] and attach pipes to the testing location[15]. Ensure the pipes are vertically aligned.

1.2.2.2 Attach plate in the label holder below pipe drop zone.

1.2.2.3 Place the collimator at the top of the pipe at the recommended drop height and pour the gravel through for a better impact spread and to decrease gravel and pipe wall collisions.

1.2.3 Testing instructions

Option 1 – Used to collect data found in this report.

i. 10' drop with 500mL pea gravel
ii. 20' drop with 500mL pea gravel
iii. 50' drop with 500mL pea gravel
iv. 50' drop with 1000mL pea gravel
v. 50' drop with 2000mL pea gravel
vi. 50' drop with 3000mL pea gravel

Option 2 – Alternate method proposed from lessons learned to reduce the number of required tests performed.

Initial test: Drop 500mL of pea gravel from a height of 50'. If the data matrix fails verification follow testing path A with a new label, if it passes proceed to testing path B with the same label.

Path A: Drop 500mL pea gravel for each test beginning at 10' and incrementally increasing drop height by 10' until concluding testing at 50'. Do not replace the label between test increments.

Path B: Drop the gravel from a height of 50' for each test beginning with 1000mL and incrementally increasing the volume of pea gravel by 1000mL until concluding testing with 3000mL. Do not replace the label between test increments.

1.2.3.1 Wipe dust and debris from label.

1.2.3.2 Verify the data matrix and record the results after each increment.

1.2.3.3 Proceed through gravel drops until the data matrix fails verification or the end of the test is reached.

1.3 Reference Material

1.3.1 ASTM D 3170

1.3.2 ASTM D 2794

1.3.3 AIM-DPM-1-2006

Given the chipping test was developed for this testing and not adapted from existing standards, additional detail is provided. The expected impact velocity of gravel falling from various heights

[13] Electrical junction box covers

[14] T-connectors limit pressure differentials in pipe. Do not glue pipes together for ease of disassembly and performing tests at various heights.

[15] Rubber straps work well because the pipes can be slid up and down to gain access to 10' and 20' test heights.

was of interest. Since drag forces are minimal at low velocities for dense objects, the freefall velocity achieved in a vacuum is expected to be a reasonable estimate of actual gravel velocities. The equation for the velocity of the gravel is given in Equation 2, where v is the impact velocity, x is the drop height, and a is the acceleration due to gravity. Uniformity tests from gravel drops at 10', 20', and 50' are shown in Figure 4.

Equation 2. $$v = \sqrt{2xa}$$

Gravel velocities achievable from a given height are listed in Table 12.

Table 12. Gravel velocity vs. height

Tower Height (ft)	Gravel Velocity (mph)[16]
10.0	17.3
20.0	24.4
50.0	38.6

Gravel velocity versus drop height calculated using Equation 2.

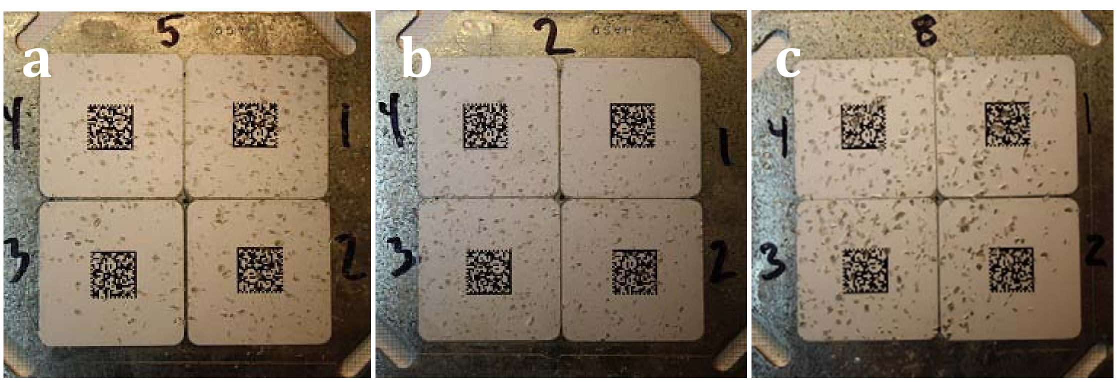


Figure 4. Uniformity tests of gravel impact distribution, a – 10'; b – 20'; c – 50'

If a label survived the entirety of the testing, it was subjected to a total of 7500mL of gravel dropped over varying heights. 7500mL is approximately two gallons of gravel with most of it impacting the plate at about 40mph. This may be far beyond the required chipping resistance for many applications.

Test Results

Results of the chipping test are shown in Table 13. Since chipping was a new test developed for this report, the test was executed twice to ensure consistent results. In most cases all labels of a label type failed at the same test increment in the sequential tests. In cases where one or more labels of a label type failed at different test increments, the last surviving label determined the score of the label type. In one case, one label received a minimal amount of gravel impacts and this label was removed from the test when the other three labels tested on the plate failed.

[16] Gravel velocity in miles per hour (mph).

Table 13. Chipping test results

Pass		Fail			
Less UEC used	More UEC used	Failed at 3000mL, 50'	Failed at 2000mL, 50'	Failed at 1000mL, 50'	Failed at 500mL, 50'
ID4	CA3	CA1	CA2	BR1	BR2
		CO1	CO2	BR3	ID3
		JE5	ID1	BR4	JE1
		JE6		FL1	
		ME1		HO1	
		ME3		ID2	
				ID5	
				JE2	
				JE3	
				JE4	
				ME2	
				ME4	

Appendix 9 Abrasion Test

Test Procedure

1.0 Description:

The Taber abraser, shown in Figure 5, is an instrument designed to simulate accelerated wear testing. It uses abrasive wheels that are dragged and rolled across a specimen producing abrasion damage. This test was performed in accordance with ASTM D4060.

Figure 5. The Taber abraser. Revolution counter (top right), vacuum suction control, and timer seen on right hand side of instrument. Two metallic weights, two green abrasive wheels, vacuum suction arm and metal rotating plate seen on left hand side of instrument. Test plates are bolted to the rotating plate and the green abrasive wheels are off center so they drag/skid/rotate as the test plate rotates beneath them.

- 1.1 Equipment, Fixtures, and Materials
  - 1.1.1 Taber abraser
  - 1.1.2 Abrasive wheels, CS-17
  - 1.1.3 Weights, 1Kg, one on each arm
  - 1.1.4 Resurfacing disks, S-11
  - 1.1.5 Vacuum
- 1.2 Procedural Steps
  - 1.2.1 Label preparation
    - 1.2.1.1 Clean the testing surface appropriately (see Appendix 7).
    - 1.2.1.2 Ensure the data matrix will be within the path line of the Taber wheels.
    - 1.2.1.3 Adhere labels for testing to plate (see Appendix 7).
    - 1.2.1.4 Verify the data matrix and record the results (see Appendix 6).
  - 1.2.2 Operation of the Taber abraser
    - 1.2.2.1 Attach weights to the Taber abraser.
    - 1.2.2.2 Attach coarse rubber wheels.
    - 1.2.2.3 Attach plate to the Taber abraser.
    - 1.2.2.4 Re-surface the coarse rubber wheels with 150 grit disks for 50 revolutions after each 500 revolutions of testing.
  - 1.2.3 Testing instructions

    Initial test: 100 revolutions (rev). Perform steps 1.2.3.1 and 1.2.3.2. If the data matrix fails verification, follow path A with a new label, if it passes proceed to path B with the same label.

    Path A: Begin with 10 rev, increase to 15 rev, 25 rev, and conclude with 50 rev.

Path B: Continue to 150 rev, increase to 250 rev, 500, rev, and conclude with 1000 rev.

1.2.3.1 Wipe dust and debris from label.

1.2.3.2 Verify the data matrix and record the results after each increment.

1.2.3.3 Proceed through increments until the data matrix fails verification or the end of the test is reached.

1.3 Reference Material

1.3.1 ASTM D 4060

1.3.2 AIM-DPM-1-2006

1.3.3 MIL-DTL-15024

1.3.4 MIL-STD-13231

If a label survived the entirety of the testing, it was subjected to a total of 100 revs through Path A or 2500 revs through Path B.

Abrasion testing using a Taber abraser is required by many standards. Two examples of this are MIL-DTL-15024 and MIL-STD-13231 which require labels tested using CS-17 wheels and a one kg load to survive 500 and 200 revs respectively. As mentioned in the body, instances of labels passing standardized abrasion tests and then failing in the field have been reported. Decision makers are encouraged to determine the level of abrasion expected in their environments and select labels accordingly.

A standard test plate is shown in Figure 6a, the dashed lines show the path of the abrasive wheels. The test plate is a 4" x 4" square with a hole in the center to bolt the test plate to the rotating metal plate of the Taber abraser. Four labels of each label type were tested. Usually four labels fit on a plate, but occasionally only two would fit so two plates of two labels would be used. Glass plates were used for HSE abrasion tests and polypropylene plates were used for LSE abrasion tests.

Figure 6b and c show one of the unexpected results of the abrasion test. The abrasive wheels of the Taber abraser created a wide enough circular path to allow some variation in label placement while still having the data matrix entirely abraded. On labels with laminate covers this caused variability in results. FL1 is a label holder with a laminate top layer. In HSE abrasion testing, the label holders were placed as shown in Figure 6c. As the laminate edge peeled during abrasion testing, the adhesive was smeared and obscured the data matrix in less than 100 cycles. The LSE abrasion testing labels for FL1 were placed as shown in Figure 6b. A longer path to the data matrix prevented the smearing adhesive from obscuring the data matrix and labels could be verified past 250 revolutions. These variations in test procedure and setup explain the variability for label FL1. Labels may encounter a situation in the field where label adhesive similarly smears across the data matrix and therefore the lower of the two test results may be a better indicator of this label's performance. For the purposes of testing, uniform test procedures were used as much as possible.

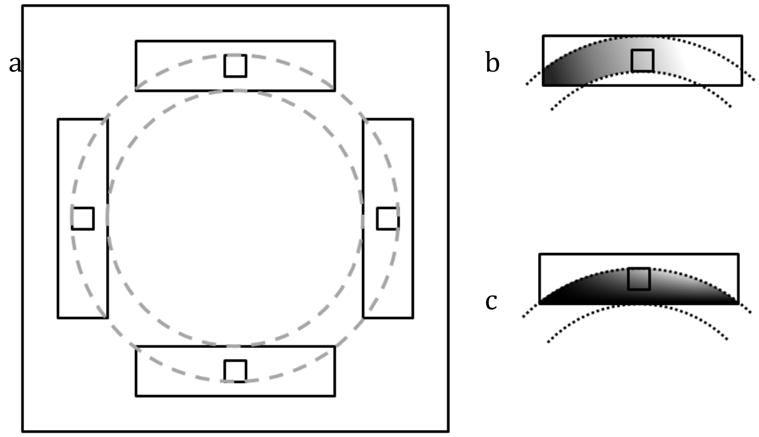


Figure 6. A Taber abraser plate with possible label placements inside the abrasion path shown in b and c

Test Results

Abrasion test results for HSE and LSE substrates are given in Table 14 and Table 15. Note that HSE and LSE results for the same label type are similar in most cases. Starred (*) label types are exceptions. Exceptions include ID2 in HSE and LSE which appear different. In the abrasion LSE test, ID2 barely made it past 2500 cycles (low UEC score). Additionally, FL1 results look different for HSE and LSE but this is described by the label placement analysis from Figure 6. One of the glass plates with CA3 labels broke in the abrasion HSE test. This required the results of the unbroken plate to be doubled to for use in the statistical analysis.

Table 14. HSE abrasion test results

Pass		Fail				
Less UEC used	More UEC used	Failed at 2500 cycles	Failed at 1000 cycles	Failed at 500 cycles	Failed at 250 cycles	Failed before 100 cycles
CA1	HO1	ID1			BR1	BR2
CA2		ID2*			BR3	BR4
CA3		ME3			CO2	FL1*
JE5					ID5	ID3
JE6					JE3	JE1
ME4						JE2
						JE4

Table 15. LSE abrasion test results

Pass		Fail				
Less UEC used	More UEC used	Failed at 2500 cycles	Failed at 1000 cycles	Failed at 500 cycles	Failed at 250 cycles	Failed before 100 cycles
CA1	HO1	ID1	CO1	FL1*	BR1	BR2
CA2	ID2*	ME1		ID4	BR3	BR4
CA3					CO2	JE1
JE5					JE3	JE2
JE6						JE4
ME2						ID3

Appendix 10   Chemical Immersion Test

Test Procedure

1.0 Description:

The chemical test, shown in Figure 7, immerses labels in different chemicals that may be encountered in service. Acetic acid, methyl isobutyl ketone (MIBK), synthetic hydraulic fluid, ethylene glycol, acetone, and isopropyl alcohol (IPA) were the chemicals tested. The labels were immersed for different increments of ten minutes, one hour, 24 hours, and one week.

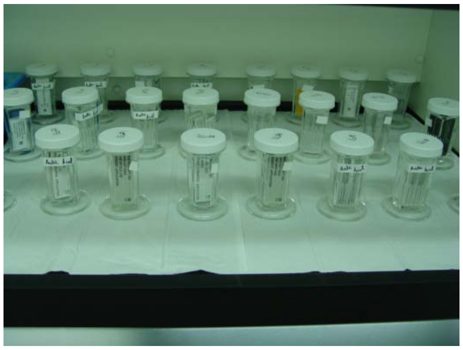


Figure 7. Chemical test containers in the fume hood

1.1 Equipment, Fixtures, Materials, and Reagents
- 1.1.1 Sealable glass container
- 1.1.2 Kimwipes
- 1.1.3 Microscope slides
- 1.1.4 Reagents used
  - 1.1.4.1 Acetic acid
  - 1.1.4.2 Methyl Isobutyl Ketone (MIBK)
  - 1.1.4.3 Synthetic hydraulic fluid
  - 1.1.4.4 Acetone
  - 1.1.4.5 Isopropyl alcohol
  - 1.1.4.6 Ethylene glycol

1.2 Procedural Steps
- 1.2.1 Safety note: Chemicals used in this procedure may be toxic, flammable, or corrosive. Avoid physical contact with the chemicals or inhalation of chemical vapors. Follow laboratory safety procedures and MSDS (Material Safety Data Sheet) documentation.
- 1.2.2 Label preparation
  - 1.2.2.1 Clean the testing surface appropriately (see Appendix 7).
  - 1.2.2.2 Adhere labels for testing to plate (see Appendix 7).
  - 1.2.2.3 Verify the data matrix and record the results (see Appendix 6).
- 1.2.3 Testing instructions
  - 1.2.3.1 Insert three slides with labels into a sealable container, ensuring no contact between the slides.
  - 1.2.3.2 Mark the container with chemical name, rinse solvent, and label type.

1.2.3.3 Fill the container with the test chemical to ensure the data matrix is fully immersed in the test solution.
1.2.3.4 Seal container for a specified time (one minutes, one hour, 24 hours, and one week).
1.2.3.5 After the specified exposure time, remove slides and allow excess chemical to drip into container. Wipe label with a Kimwipe to remove any excess chemical and to simulate a cleaning process.
1.2.3.6 Visually inspect labels and document results (e.g., smear, no change, peeling).
1.2.3.7 Rinse slides with appropriate solvent (e.g., water, IPA) to remove the test chemical and dry.
1.2.3.8 Verify the data matrix and record the results.
1.2.3.9 Re-submerge the slides into the same test solution and repeat steps 1.2.3.3 – 1.2.3.8 after the next test increment. If necessary, add additional test solution to ensure the data matrices are fully submerged.
1.2.3.10 Note: after the final test increment, the label will have been immersed in the chemical of choice for a total of eight days, one hour and ten minutes.

1.3 References

1.3.1 MIL-STD-810 Method 504.

Other potential chemicals not tested here may include include: kerosene, diesel, gasoline, hydraulic fluid (petroleum based), damping fluid (silicone based), mineral oil, motor oil, motor oil (synthetic), detergent (NSN 7930-00-899-9534), isopropyl alcohol, denatured alcohol, acetone, trans-1-2dichloroethylene, ethylene glycol, CRYOTECH E-36, EcoTru-1453, polyalphaolefin, nitric acid, paint remover/thinner, lacquer remover/thinner, rifle bore cleaner, naphtha, MIL-L-63460E compliant material, insect repellant (DEET[17]), automatic transmission fluid, decontaminating agent STB, decontaminating agent DS-200, and Penair M-5704A or MIL-PRF-85704C compliant cleaner.

Test Results

Although six chemicals were tested, testing procedures were properly followed for three of them. While data from all six tests may be good enough to analyze, confidence in the data quality is only high enough to publish results from the three chemical tests below.

Methyl Isobutyl Ketone (MIBK)

This is a strong organic solvent and no label survived to the final test increment. Results of this test may be indicative of acetone or isopropyl alcohol exposure performance. However, much longer survival times would be expected in these weaker organic solvents.

Failure in the MIBK test happened two ways. First was failing verification due to ink smearing and the data matrix becoming unreadable. The second failure mode was adhesive failure. When the label began to peel or detach from the glass slide to which it was affixed, the label was removed from the test even if it could still be verified. Results for MIBK testing are shown in Table 16.

[17] An insect repellent

Table 16. MIBK Test Results

Fail			
Fail at 1 week	Fail at 24 hr	Fail at 1 hr	Fail at 10 min
CA1	FL1	BR3	BR1
CA2	ID4	JE3	BR2
CA3	JE5	JE6	BR4
CO1			ID3
CO2			ID5
HO1			JE1
ID1			JE2
ID2			JE4
ME1			
ME2			
ME3			
ME4			

Acetic Acid

Acetic acid was used at 5% concentration similar to household vinegar. Results for acetic acid testing are shown in Table 17.

Table 17. Acetic acid test results for 1 week - initial UEC scores

Pass		
Minimal Degradation	Increasing Degradation	Further Degradation
BR1	FL1	HO1
BR2		
BR3		
BR4		
CA1		
CA2		
CA3		
CO1		
CO2		
ID1		
ID2		
ID3		
ID4		
ID5		
JE1		
JE2		
JE3		
JE4		
JE5		
JE6		
ME1		
ME2		
ME3		
ME4		

Synthetic Hydraulic Fluid

Hydraulic fluid is found commonly in depot overhaul and maintenance facilities because of its ubiquitous use within various vehicles. As a result, a film of hydraulic fluid is found on many surfaces. Anyone working in such a facility is likely to have a film of hydraulic fluid on their hands when handling equipment and may smudge a data matrix if they are not careful to avoid it. Results for hydraulic fluid testing are shown in Table 18.

Table 18. Synthetic hydraulic fluid test results for 1 week - initial UEC scores

Pass	
Minimal Degradation	Increasing Degradation
BR1	FL1
BR2	
BR3	
BR4	
CA1	
CA2	
CA3	
CO1	
CO2	
HO1	
ID1	
ID2	
ID3	
ID4	
ID5	
JE1	
JE2	
JE3	
JE4	
JE5	
JE6	
ME1	
ME2	
ME3	
ME4	

Appendix 11 High/Low Temperature Exposure and Adhesion Test

Test Procedure

1.0 Description:

The temperature test exposes labels to high and low temperatures reasonably encountered while in service. The data matrix is verified after each testing increment. After a predetermined amount of thermal exposure, labels were tested to determine if any changes in adhesion strength could be observed. Thermal test chambers are shown in Figure 8.

Figure 8. Environmental test chambers (left) and labels after a cold increment (right).

The adhesion test measures the force required to pull an adhered label from another surface at a constant rate. After a predefined temperature test increment, the labels were peeled from a surface at a 90° angle with an Instron model 4201 to determine the adhesion strength. This is described in ASTM D3330 method F. Rigid labels such as aluminum were pulled in shear because they were not able to bend at a 90° angle. Both peel and shear test setups are pictured in Figure 9.

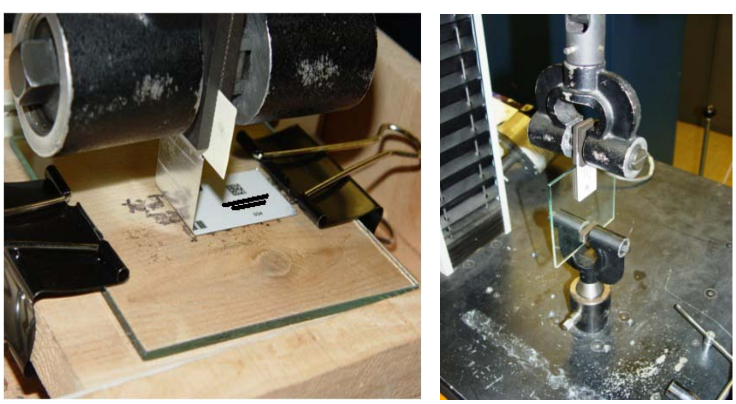


Figure 9. Instron peeling a flexible label at 90° (left) and shearing a rigid label off a plate (right).

1.1 Equipment, Fixtures, and Materials

1.1.1 Hot temperature chamber

1.1.2 Cold temperature chamber

1.1.3 Instron with accessories
    1.1.3.1 Instron and load cells must be within calibration specifications.
1.1.4 Thermocouple

1.2 Procedural Steps
1.2.1 Label preparation
    1.2.1.1 Clean the testing surface appropriately (see Appendix 7).
    1.2.1.2 Adhere labels for testing to plate (see Appendix 7).
    1.2.1.3 Leave approximately 1" of the label unattached to the testing surface (hanging off of the edge) to attach the Instron for the peel (flexible label) or shear (rigid label) tests.
    1.2.1.4 Verify the data matrix and record the results (see Appendix 6).
1.2.2 Temperature chamber settings
    1.2.2.1 The temperature for the hot chamber: 160°F ± 5°F.
    1.2.2.2 The temperature of the cold chamber: -40°F± 5°F.
    1.2.2.3 Use a thermocouple to ensure the chambers are operating within temperature requirements.
1.2.3 Testing instructions
    1.2.3.1 Six labels of each label type were tested as shown in Table 19 and Table 20.
    1.2.3.2 Measure and record the width and length of the labels' edges attached to the HSE or LSE substrate.
    1.2.3.3 Place labels in chambers ensuring no contact between test plates.
    1.2.3.4 Verify the data matrix (v) and record the results after each temperature increment.
    1.2.3.5 Perform an adhesion test (a) after each adhesion increment as shown in Table 19 and Table 20.
        1.2.3.5.1 Peel tests are conducted at a cross head extension rate of 2"/min.
        1.2.3.5.2 Shear tests are conducted at a cross head extension rate of 0.5"/min.

1.3 Reference Material
1.3.1 ASTM D 3330
1.3.2 AIM-DPM-1-2006
1.3.3 MIL-HDBK-310

Table 19. LSE temperature exposure and adhesion test increments.

Room Temp	24hr Hot	24 hr Cold	72 hr Hot	1 week Cold	1 week Hot	72 hr Cold	72 hr Hot
v a0							
v a0							
v a0							
v	v	v	v	v a1			
v	v	v	v	v	v	v a2	
v	v	v	v	v	v	v	v a3

(v) = verify, (a) = adhesion test (peel or shear)

Table 20. HSE temperature exposure and adhesion test increments.

Room Temp	24hr Hot	24 hr Cold	72 hr Hot	72 hr Cold	1 week Hot	1 week Cold	72 hr Hot
v a0							
v a0							
v a0							
v	v	v	v	v a1			
v	v	v	v	v	v	v a2	
v	v	v	v	v	v	v	V a3

(v) = verify, (a) = adhesion test (peel or shear)

Test Results

No statistically significant groupings could be determined from temperature exposure effects on verification UEC score. This is because labels were peeled and only one label of each label type was verified at the final test increment. Thus, meaningful statistics could not be obtained. Please see peel strength and shear strength data plots in Figure 10, Figure 11, Figure 12, and Figure 13.

Peel Tests

90° peel tests were performed on flexible labels and laminates. The peel test was conducted at 2"/min peel rate. A pilot study to determine the appropriate peel rate found apparent peel strengths vary greatly with peel rate. Results are normalized by the width of the label and given in N/mm[18]. All peel tests were performed at room temperature.

Three labels were peeled initially (a0) and one label after each additional adhesion increment (a1, a2, a3). Error estimates were determined by the Instron operator by estimating deviations from average peel stress on the force-displacement graphs. The results for LSE and HSE peel tests are shown in Figure 10 and Figure 11 respectively. The a0 data in the figures are an average of three data points. a0, a1, a2, and a3 are the adhesion increments shown in Table 19 and Table 20. In Figure 10, a large decrease in the peel strength of JE2 after thermal exposures on the LSE substrate is not understood. JE1, JE3, and JE4 use the same adhesive as JE2 and some decrease in their peel strengths is observed, but not as pronounced. In Figure 11 (HSE) there is a missing data point for JE2 due to incorrect load cell calibration. Where possible, the adhesion strength of laminates or label holder covers was tested. This was done by applying the laminate over the label in the regular manner, but not adhering one edge of the laminate so it could be gripped by the Instron to determine adhesion strength. The laminate adhesion strength was first tested and then the label it was adhered to was tested after peeling the laminate off. The adhesion strength of the laminates of JE5 and JE6 were not tested because they were pre-applied and a loose edge was not available to grip with the Instron.

[18] Units of N/mm are Newton per millimeter.

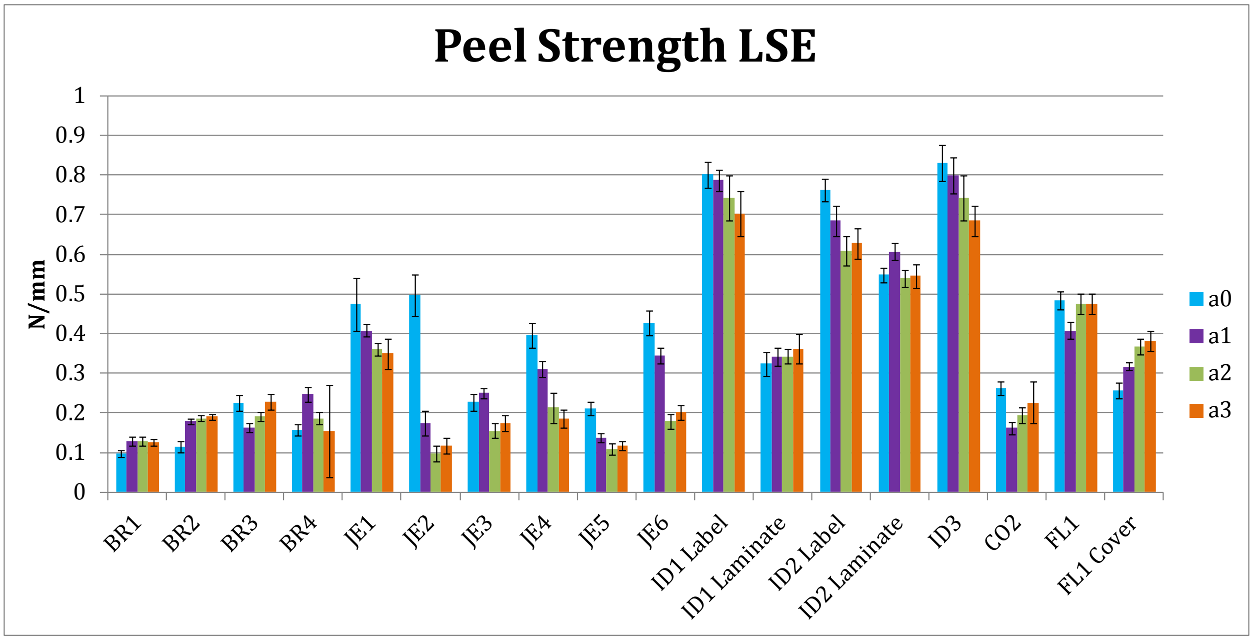


Figure 10. LSE peel test results

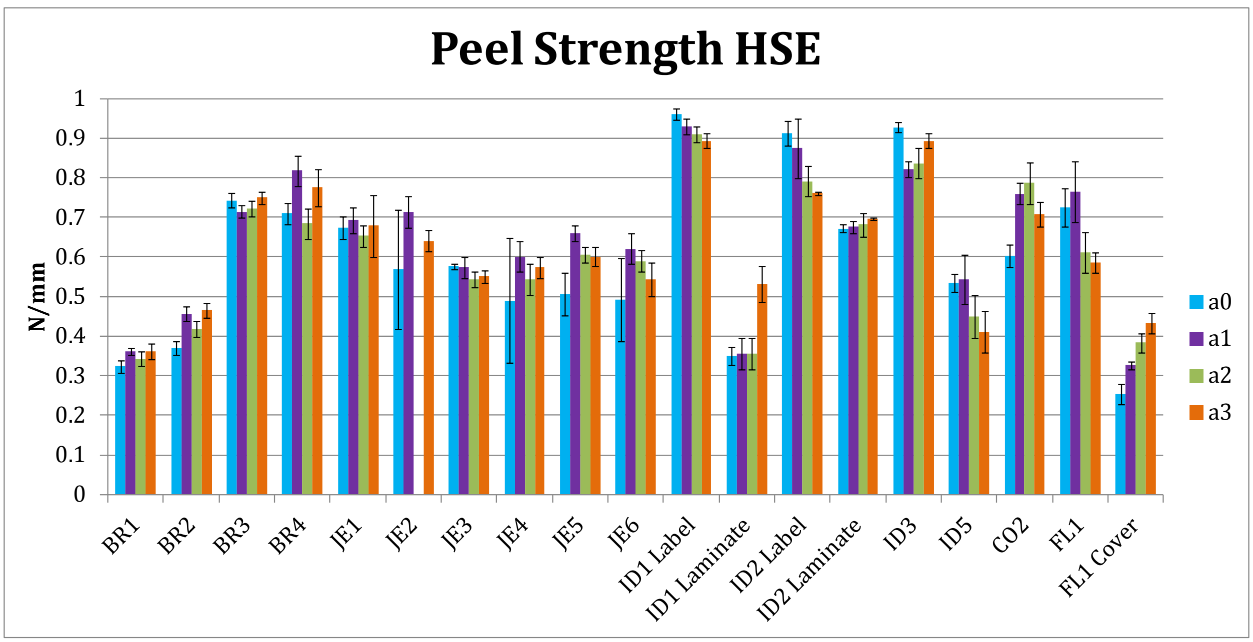


Figure 11. HSE peel test results

Shear Tests

Shear tests were performed on plates that did not bend easily to 90°. Shear tests were performed at a rate of 0.5"/min so as not to break the substrate or overload the Instron load cell. The results of shear tests are given in units[19] of N/cm^2. The force required to shear a data plate/label off the substrate is normalized by the surface area sticking to the substrate. These results cannot be

[19] Units of N/cm^2 are Newton per square centimeter.

compared to the 90° peel test results and are only meaningfully compared to other shear test results. All shear tests were performed at room temperature.

Three labels were sheared initially (a0) and one label after each additional adhesion increment (a1, a2, a3). Error is determined for a0 by taking the standard deviation of the three initial shear strengths. Error estimates of a1, a2, and a3 are indeterminable because of insufficient sample size and force-displacement graphs only gave a maximum value at the point where the label sheared off the substrate. The results for LSE and HSE shear tests are shown in Figure 12 and Figure 13 respectively. The a0 data in the figures are an average of three data points in most cases. a0, a1, a2, and a3 are the adhesion increments shown in Table 19 and Table 20. In Figure 12 (LSE), CA3 has only one a0 data point and therefore no error bars, ID4 has only two a0 data points and ME1 is missing all a0 and a1 data because the label material failed before the adhesive failed. As seen in Figure 13 (HSE), not all data was collected for a2 and a3 because ME4 repeatedly slipped out of label grips. In an effort to gather ME4 data, grips were over tightened and broken. Replacements could not be ordered in time to finish collecting data. Additionally in Figure 13, CA2 and HO1 have only two a0 data points, CA3 is missing the a1 data point due to the glass plate breaking, and ME3 has no data because the label material failed before the adhesive failed.

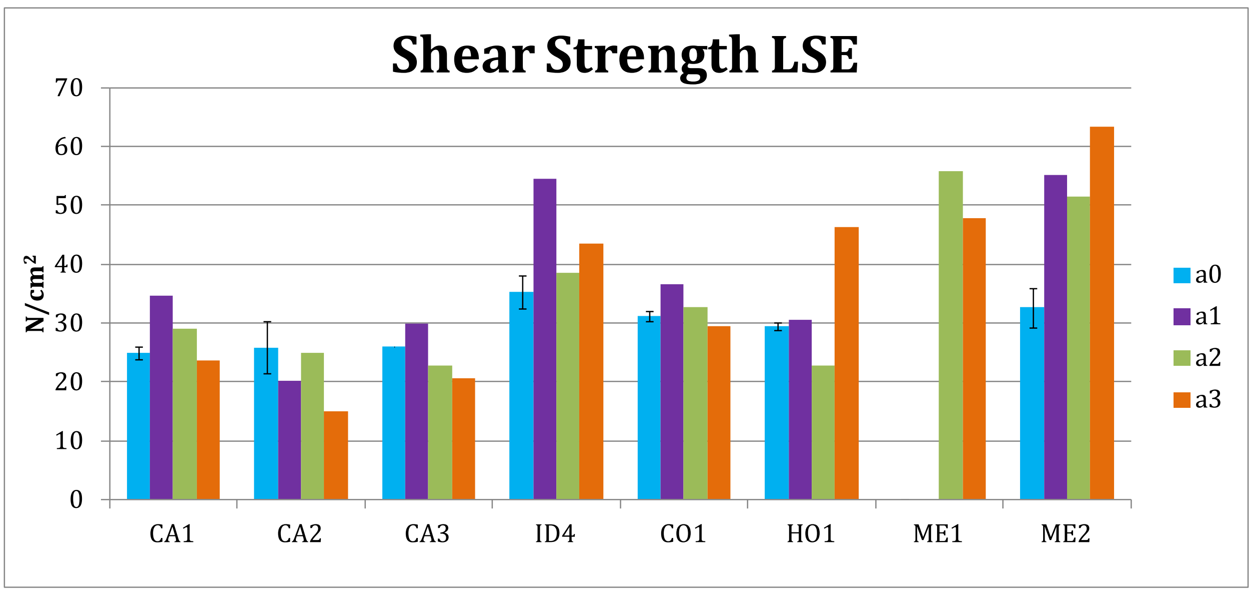


Figure 12. LSE shear test results

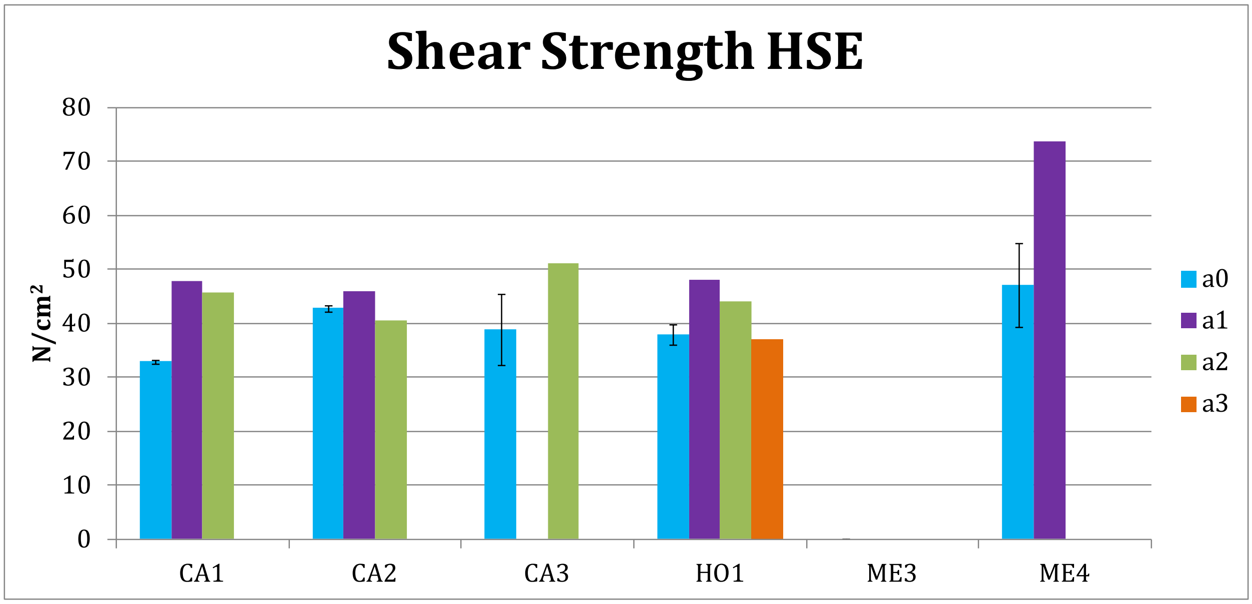


Figure 13. HSE shear test results

Appendix 12 Salt Fog Test

Test Procedure

1.0 Description:

The salt fog test is an accelerated corrosion test exposing labels to a corrosive environment of elevated temperature, humidity, and salinity (equivalent to sea water). The salt fog chamber was operated according to specifications of MIL-STD-810 method 509.5 and ASTM B117. Test increments were a hybrid of exposure times from both test methods. Data matrices were verified after each test increment and continued until the testing was complete. The salt fog chamber is shown in Figure 14.

Figure 14. Two views of the salt fog chamber

- 1.1 Equipment, Fixtures, Materials, and Reagents
  - 1.1.1 Salt fog machine and accessories
  - 1.1.2 Deionized water
  - 1.1.3 Pure salt[20]
  - 1.1.4 Compressed air
- 1.2 Procedural Steps
  - 1.2.1 Label preparation
    - 1.2.1.1 Clean the testing surface appropriately (see Appendix 7)
    - 1.2.1.2 Adhere labels for testing to plate (see Appendix 7)
    - 1.2.1.3 Verify the data matrix and record the results (see Appendix 6).
  - 1.2.2 Operation of salt fog machine
    - 1.2.2.1 Bubble tower pressure, bubble tower temperature, chamber temperature, salinity, and pH of collected condensate must be in accordance to MIL-STD-810G method 509.5 and ASTM B117.
  - 1.2.3 Testing instructions
    - 1.2.3.1 Once all specified parameters are within MIL-STD-810G method 509.5 and ASTM B117 specifications, place labels inside of the salt fog chamber, held at a 45° angle to avoid any condensate collection and allow the condensate to drip off of the label without dripping onto other labels.
    - 1.2.3.2 Testing per MIL-STD-810G method 509.5:
      - 1.2.3.2.1 24 hours in.
      - 1.2.3.2.2 24 hours out.
      - 1.2.3.2.3 Rinse with water to remove salt crystals.
      - 1.2.3.2.4 Verify the data matrix and record the results.

[20] Morton Salt Culinox® 999® was used for this testing.

1.2.3.2.5 Repeat steps 1-4 until data matrix fails verification or is deemed unaffected by test.

1.2.3.3 Testing per ASTM B117: Same parameters as in 1.2.2.1 with a user defined exposure time.

1.2.3.4 Testing for this report consisted of five cycles of 1.2.3.2 followed by one week of exposure time using 1.2.3.3 and lastly drying the plate for 24 hours.

1.3 Reference Material

1.3.1 MIL-STD-810G method 509.5

1.3.2 ASTM B117

Test Results

Salt fog test results are shown in Table 21 and Table 22. Salt fog testing was different from other "minimal effect tests" in that two labels failed in LSE testing.

Table 21. LSE salt fog test results for final - initial UEC scores

Pass		**Fail**
Minimal Degradation	Increasing Degradation	Failed Test
BR1	HO1	BR2
BR3		CO1
BR4		
ID3		
JE1		
JE2		
JE3		
JE4		
JE5		
JE6		
ID1		
ID2		
ID4		
CO2		
ME1		
ME2		
CA1		
CA2		
CA3		
FL1		

Table 22. HSE salt fog test results for final - initial UEC scores

Pass	
Minimal Degradation	Increasing Degradation
BR1	HO1
BR2	
BR3	
BR4	
CA1	
CA2	
CA3	
CO2	
FL1	
ID1	
ID2	
ID3	
ID5	
JE1	
JE2	
JE3	
JE4	
JE5	
JE6	
ME3	
ME4	