Army Research Laboratory

Chemical Agent Resistant Coating Topcoat Usage: Drivers and Trends

by William Lum, Daniel Pope, and John Escarsega

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14. ABSTRACT
This report describes the factors that affect the chemical agent resistant coating (CARC) production batches used by the U.S. Army and Marine Corps. CARC is used on exterior surfaces of all joint services equipment as mandated by the U.S. Army Regulation 750-1 doctrine. The U.S. Army Research Laboratory evaluates and validates all CARC batches from the manufacturers of CARC products listed in the qualified product database. The batch approval data analysis points out many significant findings. These findings show a drop in the overall volatile organic compounds per gallon of paint over the past four fiscal years. A gradual decline in the number of batch approvals has resulted from the drawdown of the wars in Afghanistan and Iraq. Certain camouflage colors that are widely used in the current battlefield environment are on the rise, along with the increase in using polymeric flattening agents over siliceous materials. The failure rate of batches is low and generally declining over time.

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1. Background

The guiding principle of chemical agent resistant coating (CARC) is the U.S. Army Regulation 750-1 (*1*) document. This article mandates that CARC should be on all U.S. Army equipment; other joint services have followed suit with their ground assets. CARC qualification is one of many key responsibilities of the Organic Coatings Team of the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, MD. The team, which is the lead and managing activity for CARC system specifications, owns these military specifications ranging from topcoats and primers to CARC system application procedures. In meeting the specification requirements, full qualification testing is performed to ensure that these products have met all criteria. Products are then approved as qualified in the listing known as the qualified products database. The Defense Logistic Agency database website is an access to Defense and Federal specifications and standards. Qualified product information is provided by using the ASSIST Online database at https://assist.daps.dla.mil.

A coating product is characterized as CARC when it passes CARC testing of the two chemical and biological warfare agents—sulfur mustard HD (*2*) and Soman GD (*3*). HD is a mustard gas and blister agent, and GD is nerve agent. The product must also pass all physical and chemical tests described in the specifications (*2*, *3*). A camouflage coating must pass visual color and spectral reflectance analysis in the infrared (IR) region. CARC must also resist corrosion and degradation and removal by a decontamination solution, such as super topical bleach (STB), a standard decontaminant.

The two CARC topcoat requirements are defined in MIL-DTL-53039D (*2*) and MIL-DTL-64159B (*3*) detail specifications. MIL-DTL-53039D is the single-component, moisture-cure polyurethane coating document, and MIL-DTL-64159B is the two-component, water-reducible polyurethane specification. These specifications require paints that are free of organic hazardous air pollutants (HAPs) and inorganic HAPs other than cobalt and nonhexavalent chromium (*2*, *3*).

Qualified CARC manufacturers can make these products as production batches. The batch validation request form must be filled out by the manufacturer submitting samples for conformance inspection testing. In order to get ARL's approval for government use, this conformance inspection or batch acceptance testing is required under the verification section of CARC topcoat specifications. On the form, the product description request is prompted by various fields, including batch number and size in gallons, manufacturer's code, specification and type, color, qualified products list (QPL) number, and the signature of the authorized manufacturer's point of contact. The specification type details what types of flattening agents (i.e., silica or polymeric beads) were used. It also defines the maximum allowable level of the volatile organic compounds (VOCs).

The batch validation process is comprised of the following tests: color and near-IR spectral reflectance, gloss at 60° and 85°, and STB resistance. Batch samples must pass all of these elements. These analyses are done on every production lot, and the lot is approved by ARL before being used by Joint Services on tactical assets.

The dry film thickness (DFT) will affect the usage in gallons. In the specification, the DFT is 1.8–2.2 mil for CARC topcoats. For CARC primers, it is 0.8–1.2 mil. The batch size is reported in gallons of primers produced. Thus, the primer volume usage is expected to be less than one-half of the CARC topcoat volume. Another reason for this difference is that during recoating processes where assets are stripped to bare metal, re-topcoated, or touched up, small sections are painted and often done with no primer included. The next section outlines how this usage data was tabulated, and a step-by-step method is described.

2. Compilation Procedures

The batches are received and logged in the record logbook daily. Before the end of every month, batches are entered in the database. From the database, the monthly number of total batches and gallons, total failures and gallons, and the last 12 months' volumes are tabulated using formulas embedded in the Excel sheet's cells. Two failure rates are calculated—one based on the number of batches and the other based on volume. The volume graph is then constructed and shows gallons declining from almost 2.2 million in fiscal year (FY) 2008 to 1.4 million in FY 2011.

The batch validation request form lists the following fields: color, batch size (in gallons), specification, and type for every sample submitted by the manufacturer. A database was created for this information. This database is the basis in generating reports for total batches, total volume, failure rates, and 12-month volume numbers.

VOC limits are determined by the specification types. This information can be cross-referenced using the QPL and manufacturer's code numbers. ARL test reports include the VOC results as determined by the ASTM D3960 (*4*) test method.

The paint suppliers provide a number of items when submitting samples for batch testing. The paint supplier provides technical data sheets that list the product description and VOC. They also provide a statement of composition form that details the individual components used in a paint formulation. This form is a proprietary document that ARL cannot disclose. The statement of composition form also has the VOC listed and verified by signatures from the supplier and a notary public. The manufacturers also submit the material safety data sheet.

Various sources, such as QPL paperwork and logbooks, were utilized for this report. The information was gathered and compiled, and databases were arranged. From these numbers, various tables, line graphs, and pie charts were generated.

Color analysis, specular gloss, and STB resistance are the experimental tests performed on each batch. Color measurement is performed by using ASTM E308 and E1331 (*5*, *6*) test methods on the Agilent Technologies Cary 5000 spectrophotometer. Gloss is measured by using the ASTM D523 (*7*) test method with the BYK Gardner micro tri 4430 glossmeter. An STB slurry mix is made by mixing 40 parts STB and 60 parts deionized water by weight.

In submitting samples for batch testing, the paint manufacturers provide an STB panel and gloss and color cards (figure 1). For STB resistance measurements, panels of Tan 686A no. 33446 are shown with a 1-in-diameter wax ring using a china marker on the painted surface in sample preparation for the test (figure 2). Approximately 1 mL of STB agent is then placed on the panel surface. The agent is allowed to stand 30 min. In passing criteria, the paint film has no blistering, wrinkling, or film softening after washing with water and a maximum color change of 2.5 National Bureau of Standards units using tristimulus color coordinates after drying.

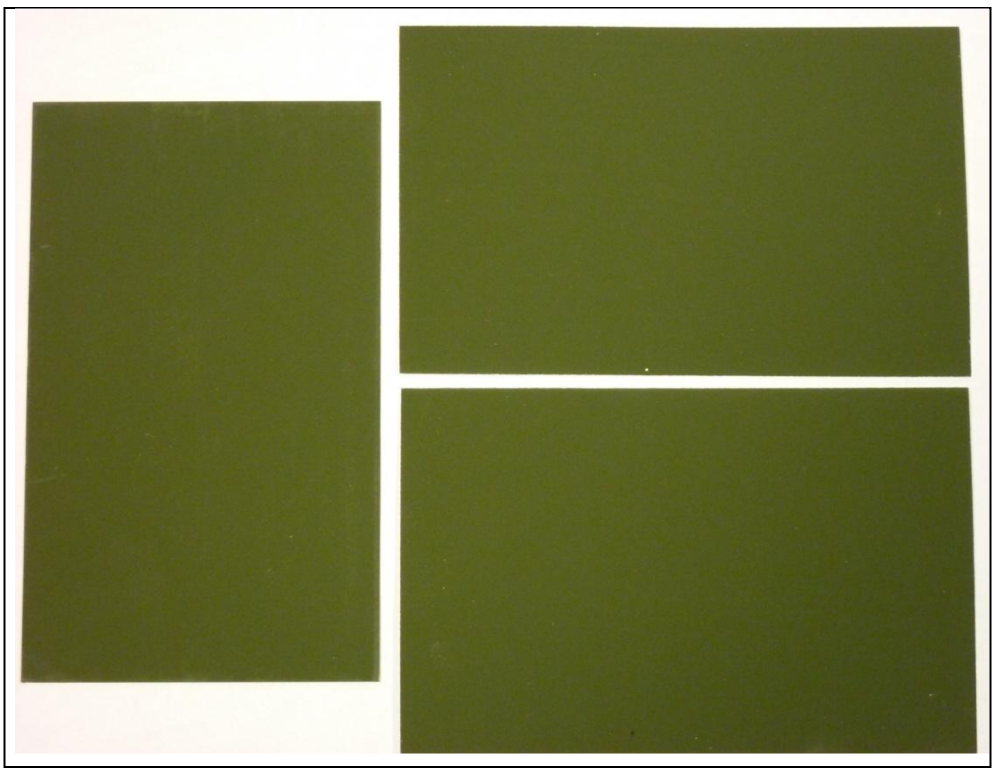

Figure 1. Batch submittal (green 383 no. 34094) of an STB panel (left), gloss card (top right), and color card (top right).

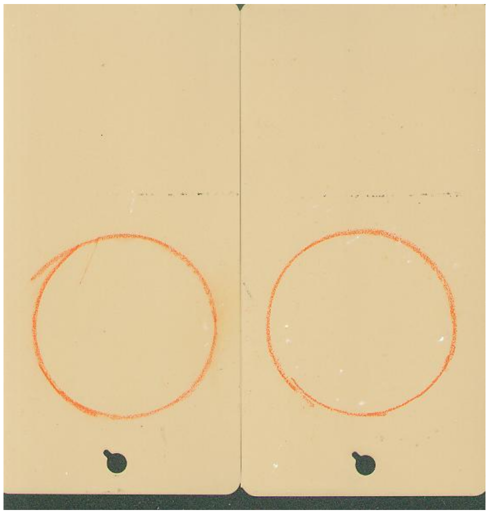

Figure 2. STB resistance test panels.

3. Compilation Results

The total yearly volume has steadily dropped from the drawdown of the wars in Afghanistan and Iraq (figure 3). At the height of these wars, more than 2.1 million gallons of CARC paints were produced by the suppliers, approved by ARL, and used by the Government. This showed the significant impact of CARC in joint military operations. Paint usages rose rapidly as the war progressed. As the war effort in Iraq declined and ended, the usage dropped to 1.3 million gallons in the first month of FY 2012. The precise numbers of the batch validation volume totals in gallons are presented in table 1.

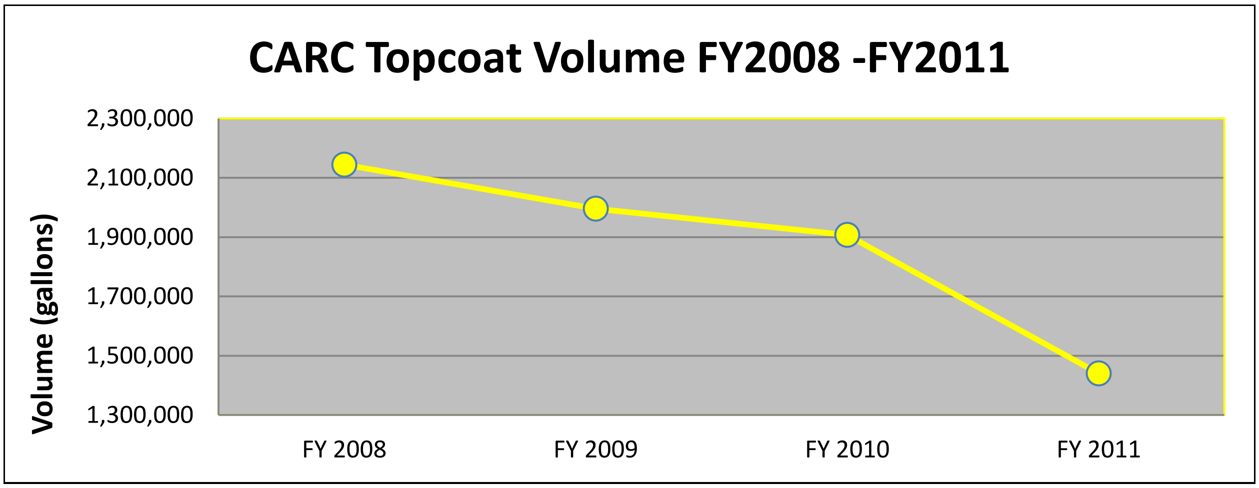

Figure 3. Batch validation volume in gallons from FY 2008 to FY 2011.

Table 1. Batch validation volume total in gallons by fiscal years.

2008	2009	2010	2011
2,144,242	1,995,931	1,907,530	1,440,465

By viewing a snapshot as a depth profile graph, we can see that solvent-borne MIL-DTL-53039 products are more commonly used than the water-based MIL-DTL-64159 products (see figure 4). The market share differences in the coatings industry for solvent-borne (MIL-DTL-53039) and water-reducible (MIL-DTL-64159) specification products have been fairly constant. MIL-DTL-53039 comprises ~82% of CARC usage while MIL-DTL-64159 comprises 18%. The solvent-borne product is preferred because of its dry time and cost.

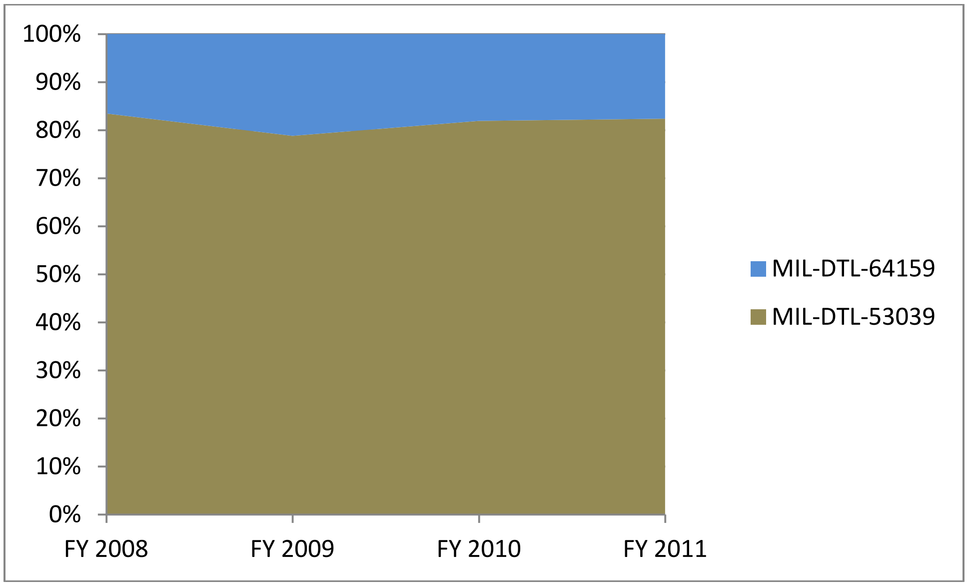

Figure 4. A visual showing the two CARC topcoats in percentages of batch approvals as a depth profile.

The Army has the three-color camouflage patterns on the equipment for a typical woodland environment (figure 5). These colors include green, black, and brown, where green is used predominantly, and brown is used the least. In addition, solid green is often with no brown or black in certain environments (figure 6). In the desert setting, the ground equipment is a solid tan color (figure 7). Because of this, the two highest volume colors are Tan 686A Federal Standard 595 no. 33446 and Green 383 Federal Standard 595 no. 34094, as seen in table 2 and figures 8–11. The solid green camouflage of figure 7 is used in jungle surroundings or as a summer verdant scheme.

Source: U.S. Air Force Senior Master Sgt. David H. Lipp.

Figure 5. Three-color camouflage pattern of a high-mobility, multipurpose, wheeled vehicle in North Dakota.

Source: Jason Kaye.

Figure 6. Solid green camouflage color of a Stryker in Washington.

Source: Gregory Gieske.

Figure 7. Solid tan camouflage color of an M109 Paladin in Iraq.

Table 2. Total CARC volume (gal), total VOC emissions (lb), and average VOC (lb/gal) by fiscal years.

Characteristic	**2007**	**2008**	**2009**	**2010**	**2011**
Total gallons of CARC topcoat	1,651,285	2,112,553	2,034,757	1,907,533	1,440,465
Total VOC emission (lb)	4,486,183	5,607,217	5,113,577	4,439,966	3,335,325
Average VOC per gallon of paint (lb/gal)	2.7168	2.6542	2.5131	2.3276	2.3155

By categorizing the different camouflage colors, we can see the highest percentage used is Tan 686A for FY 2010 and FY 2011 (see table 3). Given the current war zone environment, this is not surprising. Tan 686A no. 33446 will continue to be the dominant color in plant production and ARL approval. However, the usage of Green 383 surpassed Tan 686A in FY 2008 and FY 2009. This could be a result of state-side equipment getting refurbished at the time this information was collected. The total gallons of color usage across all years is 7,488,168 gallons. Green 383 accounts for 40.8% of that total amount.

Table 3. Volume in gallons and percentages of camouflage colors from FY 2008 to FY 2011.

Volume in Gallons	Green 383	Black	Brown	Tan 686A	Aircraft Green	Other
FY 2011 volume	575,404.25	150,470.50	12,206.75	655,849	16,931.75	29,603
Percent volume	39.946	10.446	0.847	45.530	1.175	2.055
FY 2010 volume	695,934.50	223,420.75	15,325	939,234	12,279.50	21,336.25
Percent volume	36.484	11.713	0.803	49.238	0.644	1.119
FY 2009 volume	857,057.75	269,496	18,256	809,919.50	15,845.50	25,356.25
Percent volume	42.940	13.502	0.915	40.579	0.794	1.270
FY 2008 volume	927,039.25	269,016.75	21,371.25	875,890.75	18,764.50	32,159.50
Percent volume	43.234	12.546	0.997	40.849	0.875	1.500
Total gallons per color (FY 2008–FY 2011)	3,055,436	912,404	67,159	3,280,893	63,821	108,455
Percent volume (FY 2008–FY 2011)	40.80	12.18	0.90	43.81	0.85	1.45

Usage of Black Federal Standard 595 no. 37030 has remained steady throughout the four fiscal years, anywhere from 10.446% (FY 2011) to 13.502% (FY 2009). Black is used in other places, such as urban and night equipment and all black items inside the aircraft. Brown 383 Federal 595 no. 30051, ranging from 0.803% (FY 2010) to 0.997% (FY 2008), has a similar trend to Green 383; both volumes are relatively flat. Brown and Green are different from Black, which has declined in volume.

Aircraft Green Federal 595 no. 34031 is from 0.644% (FY 2010) to 1.175% (FY 2011). This increase is an indication that helicopters were being worked on, possibly as a result of the withdrawal from Iraq, or it could be a result of stockpiling the color in anticipation of future refurbishment. For the other 2 years, aircraft green usage was in a period of normal depot operation.

Other colors, such as Sand no. 33303, Field Drab no. 33105, Olive Drab no. 34088, Aircraft Black no. 37038, Dark Sandstone no. 33510, Aircraft Gray no. 36300, Aircraft White no. 37875, and Interior Aircraft Black 37031, range from 1.119% (FY 2010) to 2.055% (FY 2011).

The pie chart in figure 8 is for FY 2008. The color distribution can be seen fairly quickly. Green 383 is the most used color, followed closely by Tan 686A. Black Federal Standard 595 no. 37030 is third in production lot acceptance.

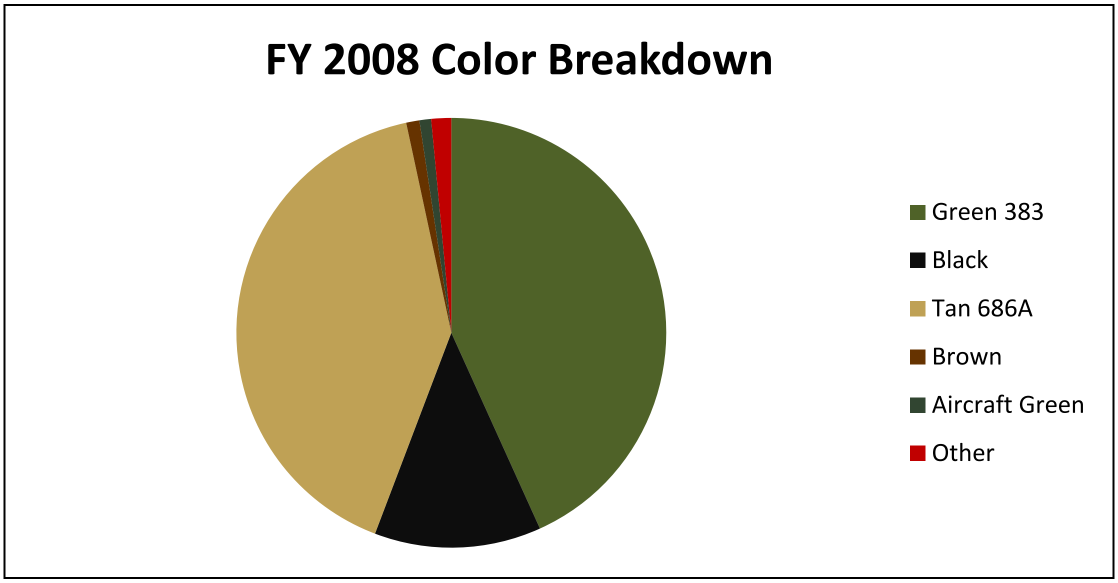

Figure 8. Color approvals and usage in FY 2008.

The chart shows Green 383 no. 34094 as the dominant color for the fiscal year 2009, as in FY 2008 (see figure 9). By looking at the following color pie charts, we see that Tan 686A no. 33446 became the most produced and approved color by FY 2010.

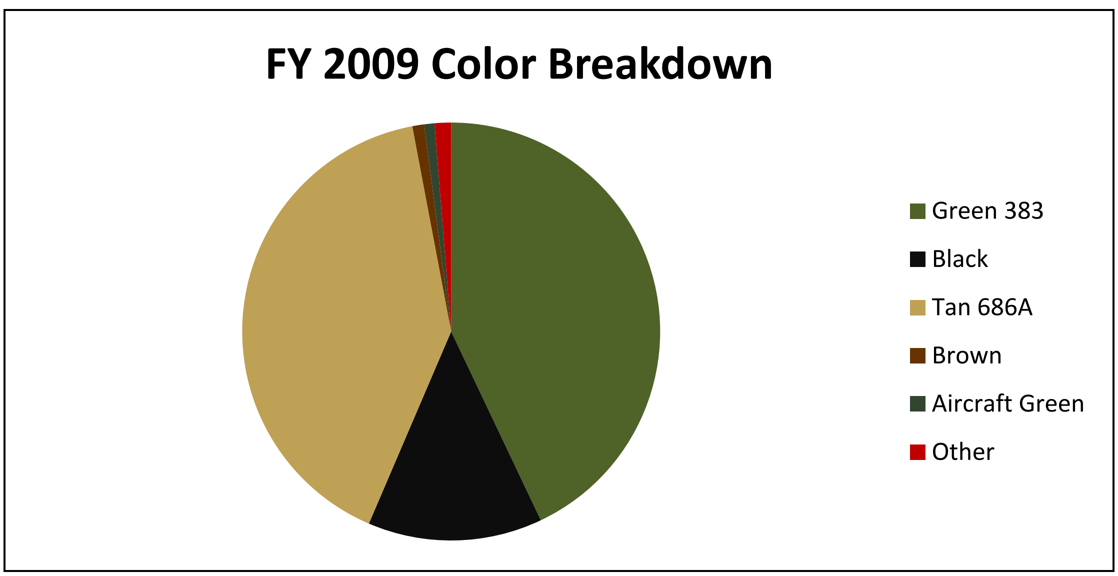

Figure 9. Color approvals and usage in FY 2009.

Tan 686A no. 33446 replaced Green 383 no. 34094 as the most mass-produced color in FY 2010 (see figure 10).

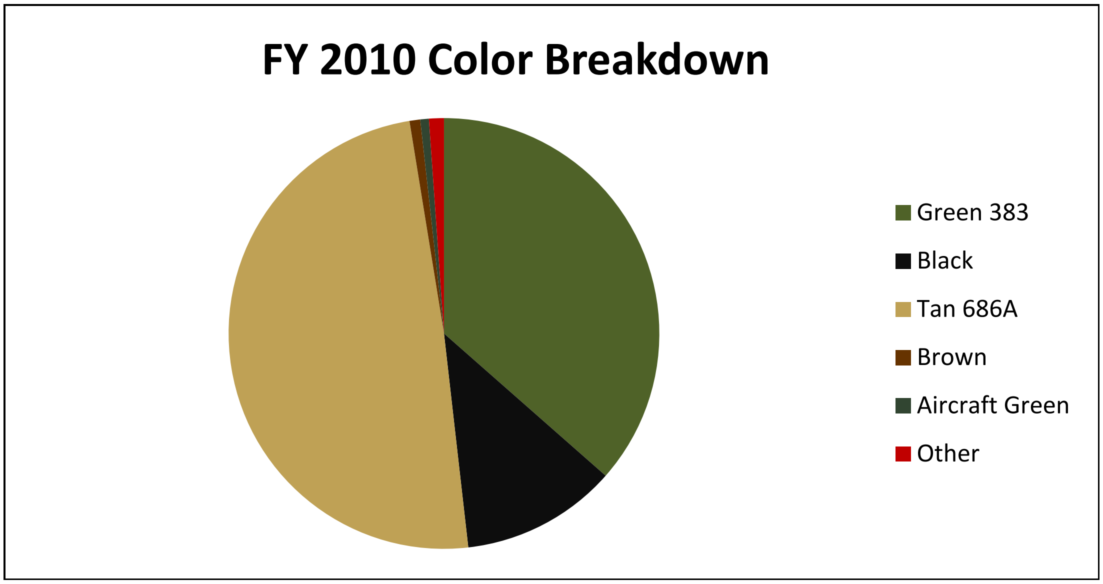

Figure 10. Color approvals and usage in FY 2010.

Tan 686A no. 33446 had a narrower lead over Green 383 no. 34094 as the dominant color by a 6% difference in FY 2011, as opposed to a 13% difference in FY 2010 (see figure 11).

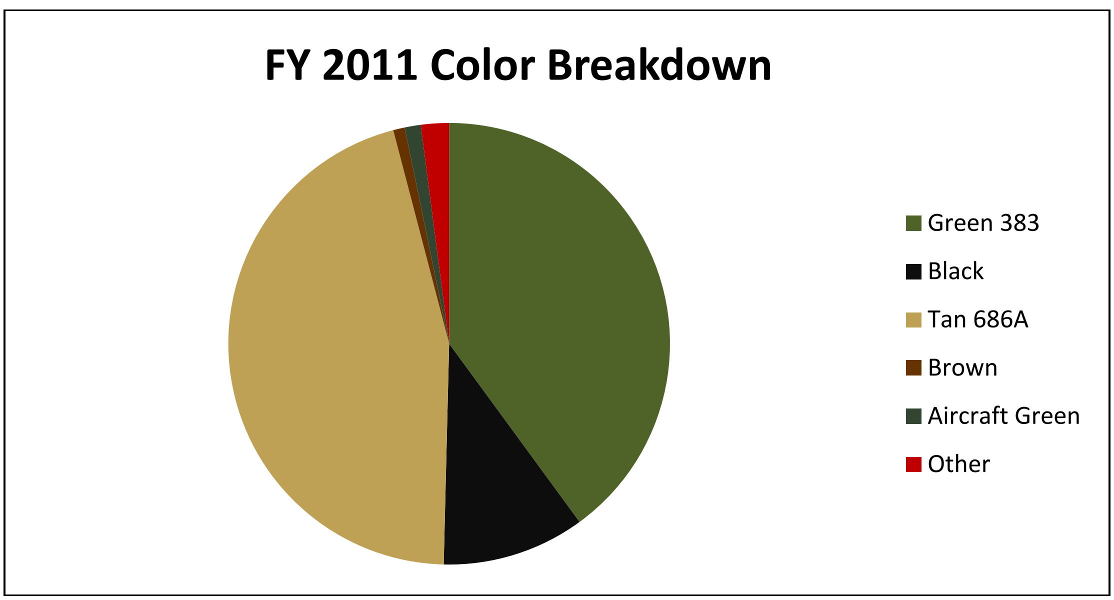

Figure 11. Color approvals and usage in FY 2011.

The total CARC volume peaked in FY 2008. This is reflected in the increase of VOC emitted during painting operations (table 2 and figure 12). Despite this, the VOC in each gallon of paint has been on a steady decline, dropping from 2.7168 lb/gal in FY 2007 to 2.3155 lb/gal in FY 2011 (table 2 and figure 13). New products with lower VOC have been tested and approved by ARL. These lower VOC products are placed in the supply system with national stock numbers for General Services Administration procurement.

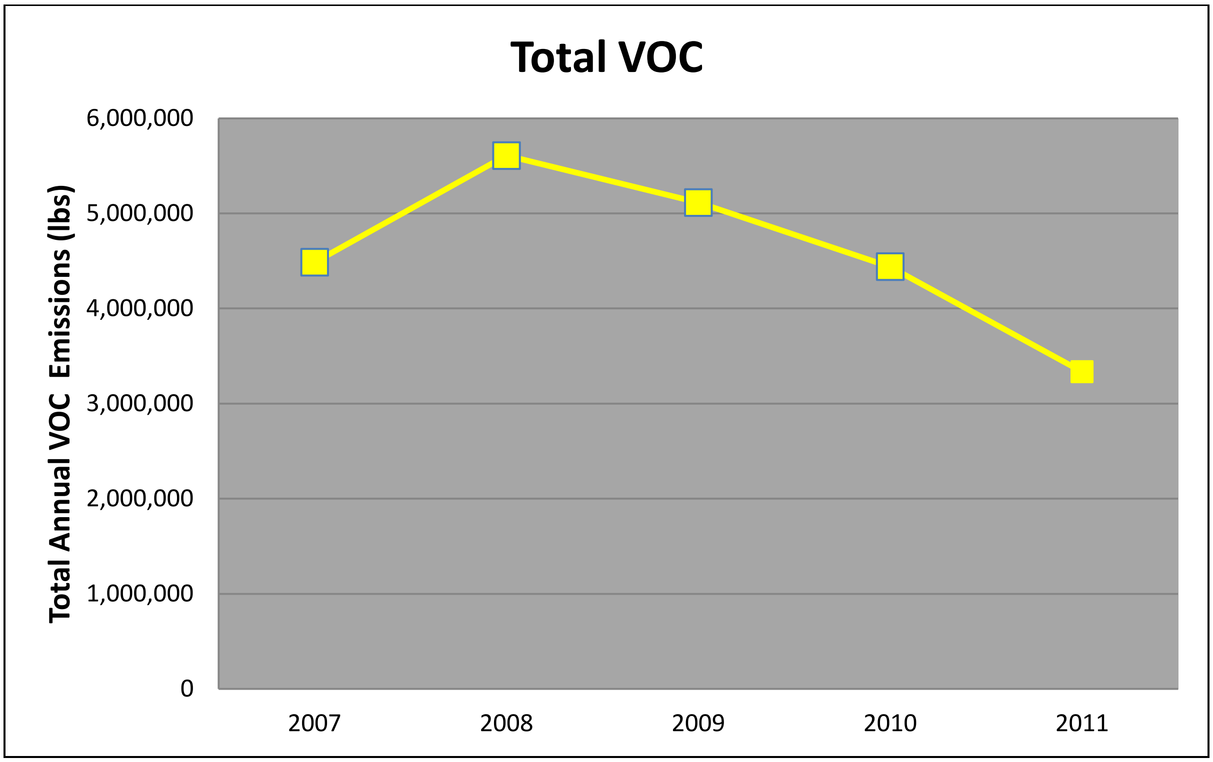

Figure 12. Total VOC emissions in pounds per year by fiscal years.

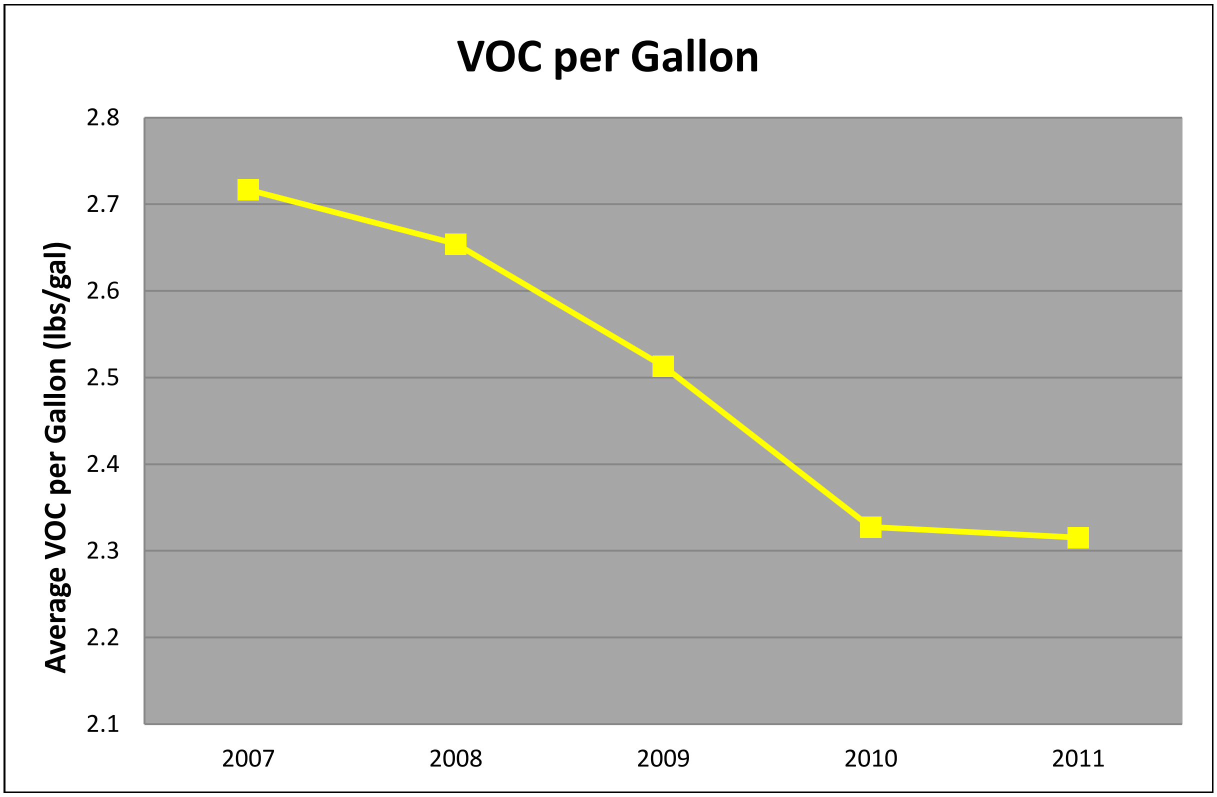

Figure 13. Average VOC (lb/gal) from FY 2007 to FY 2011.

It is predicted that the amount of VOC per gallon of paint will continue to drop over the next few years. An average VOC of 2.1 lb/gal in a few years is possible by projecting the trend.

Only polymeric flattening agents are cited in the current specifications, while silica types are being phased out. Overall, the polymeric-flattening agents provide improved weatherability and durability relative to silica flattening agents, and produce superior paints. A polymeric vs. silica weathering study was conducted and cited in the Q-Lab Arizona UAR-21 (*8*) accelerated outdoor weathering summary during April 2011. After 1400 MJ/m^2 of ultraviolet exposure (equivalent to about 5 years of outdoor exposure), two CARC topcoats with polymeric flattening agents did the best. All manufacturers were thus required to follow suit in producing these new products. As a result, the market experienced a huge shift in usage and sales in changing from silica- to polymeric-flattened materials (see table 4). The decline in usage of silica-flattened products is in volume and percent. The reduction in silica usage will also continue in the next few years, probably to the point of minimal usage.

Table 4. Volume in gallons and percentages of silica- and polymeric-flattened products.

Volume	FY 2010	FY 2011
Silica	1,418,798 (74.38%)	834,801 (57.95%)
Polymeric	488,735 (25.62%)	605,665 (42.05%)

This breakdown by specification and type shows that MIL-DTL-53039C/type I, which is a silica-flattened, 3.5 lb/gal-VOC product, has 29.9% of the total batch approval in FY 2011 (table 5 and figure 14). MIL-DTL-53039C/type II is a silica-flattened, 1.5 lb/gal-VOC product, and type III is a polymeric-flattened, 1.5 lb/gal-VOC product. Type IV is a polymeric-flattened, 1.0 lb/gal-VOC product, and type IX is a polymeric-flattened, 3.5 lb/gal-VOC product. Thus, the silica-flattened MIL-DTL-53039D is still used predominantly relative to the polymeric bead flattened MIL-DTL-53039D. MIL-DTL-64159/type I is silica-flattened product, and type II is a polymeric-flattened product. Both products are 1.8 lb/gal in their VOC content. Clearly, almost all use of MIL-DTL-64159B is the type II, which uses polymeric-flattening agents. The reason MIL-DTL-64159B has transitioned almost entirely to the polymeric-flattening agent while the MIL-DTL-53039D has not is because MIL-DTL-64159B polymeric-flattened paints were developed and implemented first in 2002, while MIL-DTL-53039D specifications for polymeric-flattening agents were not implemented until 2009 for types III, IV, and IX.

Table 5. Percentages of product approval by specification and type for FY 2011.

Specification Type	Percentage	Flattening Agent	VOC (lb/gal)
53039C TI	29.9	Siliceous	3.5
53039C TII	28.6	Siliceous	1.5
53039C TIII	5.5	Polymeric	1.5
53039C TIV	10.2	Polymeric	1
53039C TIX	10.4	Polymeric	3.5
64159 TI	0.5	Siliceous	1.8
64159 TII	14.9	Polymeric	1.8

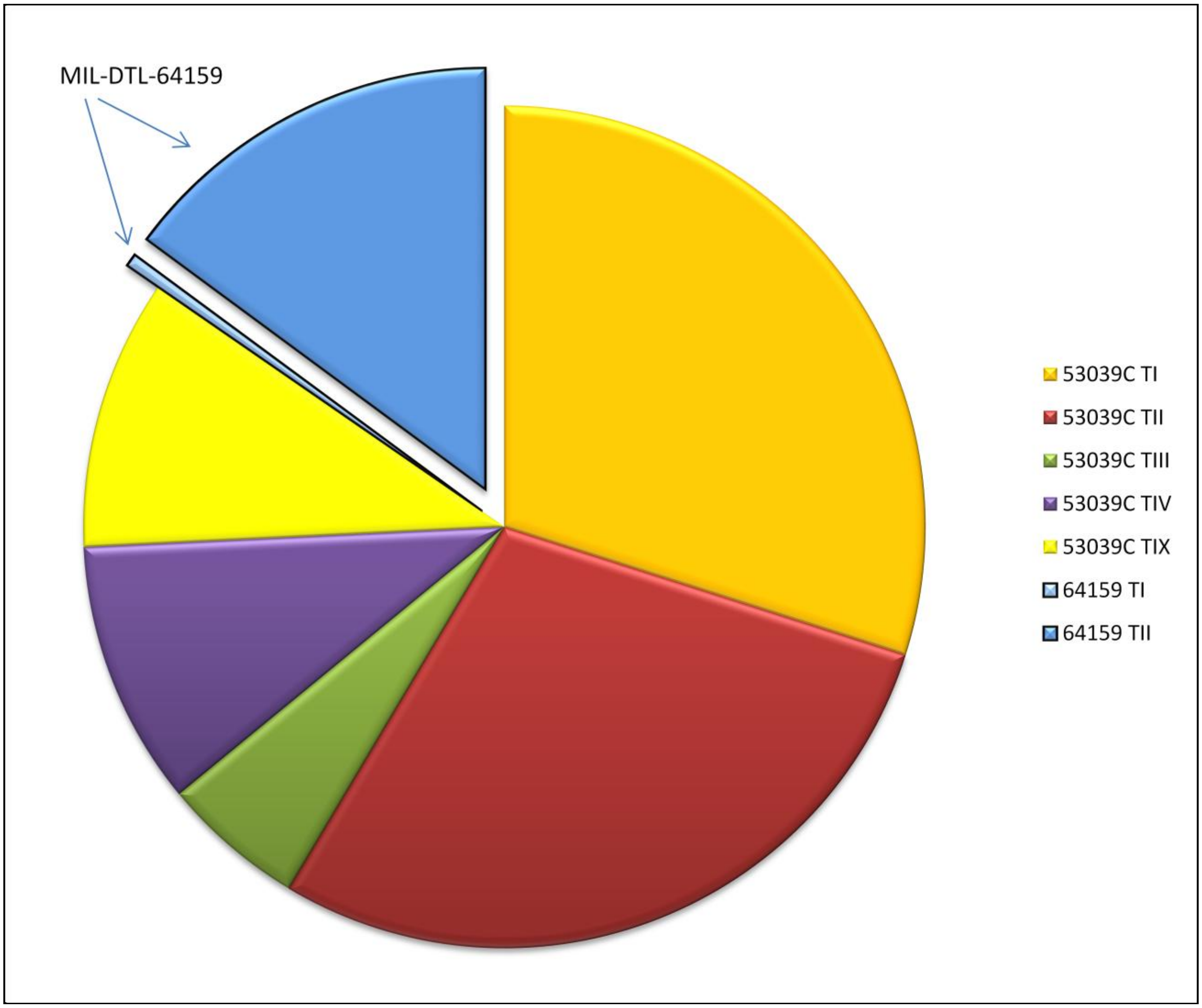

Figure 14. Product approval by specification and type for FY 2011.

MIL-DTL-53039D/type V coatings are 0.5 lb/gal VOC and polymeric-flattened products, and type VI paints are 0 lb/gal VOC and polymeric-flattened materials. Type VII is an aerosol touch-up, 3.5 lb/gal, polymeric-flattened product. Type VIII is a self-contained portable kit such as a brush, roller, or cartridge applicator; this type is a 1.5 lb/gal VOC and polymeric-flattened paint. Types V–VIII have few products available as qualified in the Qualified Products Database population.

Table 6 shows the total in gallons by company, specification, and type. The particular companies are omitted to protect their privacy. Table 7 outlines the percentage breakdown by company of that specification and type. Some companies are progressive in reducing VOCs and improving weatherability.

Table 6. Batch volume in gallons produced by company and the percentage breakdown of each specification and type.

Year Total	Company A	Company B	Company C	Company D
53039C TI	153373 (10.647%)	235309 (16.336%)	45085 (3.130%)	0 (0.000%)
53039C TII	20866 (1.449%)	360914 (25.055%)	7366 (0.511%)	0 (0.000%)
53039C TIII	74770 (5.191%)	0 (0.000%)	280 (0.019%)	0 (0.000%)
53039C TIV	17371 (1.206%)	114108 (7.922%)	7125 (0.495%)	0 (0.000%)
53039C TIX	109359 (7.592%)	40674 (2.824%)	100 (0.007%)	0 (0.000%)
64159 TI	10150 (0.705%)	1362 (0.095%)	0 (0.000%)	376 (0.026%)
64159 TII	182137 (12.644%)	29090 (2.020%)	18359 (1.275%)	12290 (0.853%)

Table 7. Total failure in batches and gallons by fiscal year.

Fiscal Year	Total Failed Batches	Total Failed Gallons	Total Batches	Total Volume	Batch Failure Percentage	Volume Failure Percentage
2008	121	162,508	1433	2,144,242	8.444	7.579
2009	42	51,884	1324	1,995,931	3.172	2.599
2010	30	16,029	1305	1,907,530	2.299	0.840
2011	54	60,161	1161	1,440,465	4.651	4.176

Failure or rejection rate calculation is part of the monthly batch tally stemming from the batch validation form. For the most part, the rejection rate has remained steady year after year, ranging from 2% to 5% on average. For some of the months, the rate is as low as 1%, while up to 10% in another month. FY 2008 is the fiscal year with the highest number of total batches and volume that led to the highest batch and volume failure rates—8.444% and 7.579%, respectively. FY 2010 numbers show the lowest batch failure rate at 2.299% and volume failure rate at 0.840%.

The main reason for the rejection is primarily because of the color and then the gloss. Color would be off slightly, but not by much. Resistance to STB has not been a failure reason. When a failure letter is issued from ARL to the manufacturer, it states that the product is typically too light in color for a visual color checking. In these cases, the manufacturer simply adds a small amount of tinting paste to the batch to correct the color. After the adjustment, the manufacturer resends the batch back to ARL for a retest. After validation retesting, the batch passes color and is reconfirmed in passing other tests. For gloss failures, the gloss is generally too high. We send a rejection letter to the company indicating the gloss's failure. The company then fixes this deficiency by simply adding some flattening agents. In reworking these batches, the additional cost is minimal to the manufacturer for not getting the batch correct the first time. In all cases after manufacturer modification, the batch then passes gloss and color and is approved by ARL for Government use.

Overall, this type of batch validation saves the Government in two ways: First, it prevents failed batches of paint from making it to U.S. Department of Defense use. This ensures proper protection of our assets and Soldiers. In addition, without a validation process, the amount of out-of-specification paints would likely rise to well above the highest rate of 8.4% because there would be no checks and balances of the paint vendors. In general, companies seek to increase profits, which would likely mean minimizing the addition of expensive components and maximizing the use of inexpensive products, resulting in an inferior product. Secondly, this batch validation, which indicates reports on what failure is occurring, allows the company to modify the batch to meet specifications at minimal cost. Although the Government cannot be charged for a batch that has not sold, if batches were not allowed to be adjusted in this way, higher CARC costs would result.

FY 2010 is the best year in terms of total failed batches and total failed gallons at the lowest level, 30 and 16,029, respectively (see table 7). The failure rates of batches for the most recent 4-year period illustrate the amount of rework and coordination with companies to resolve acceptance testing issues.

4. Summary and Conclusions

The results have shown significant CARC usage over the past years ranging from as much as 2.1 million gallons of CARC topcoat in FY 2008 to as little as 1.4 million gallons in FY 2011. Due to the war effort, the predominant color used was Tan 686A. Generally, the solvent-based MIL-DTL-53039D was used at approximately a 4:1 ratio relative to the MIL-DTL-64159B water-based coatings.

The future will bring many cutting-edge products through current formula improvements. HAPs-free materials are already in the CARC system specifications and procurement supply streams. Lowering the VOC has been secondary in priority to HAPs-free efforts; however, it has gained prominence as local and state jurisdictions have tightened their air standards. Different solvent packages present new alternative blends to be environmentally friendly. Current formulation efforts will improve emissions for tomorrow.

Polymeric-flattened coatings have better durability than silica-flattened products. This substitution will extend the life cycle of U.S. Army and Marine Corps equipment. Full impact of benefits, such as lengthened durability of equipment, will be felt as silica is worked out of the acquisition system.

Failure rates are monitored continuously both by volume and number of batches. They are big factors in the International Organization for Standards' (ISO) continuous improvement and calibration reset at our facility in meeting ISO 9001 standards. Also, the failure rates are a tracking tool for production quality control and ARL feedback. We believe that monitoring the failure rates can flag any potential maintenance and calibration problems with the color analysis instrument. This problem only occurred once when the failure rate hit 24%. With the continuous quality monitoring and improvement program in place, we fixed the situation as it occurred.

Failure rates, which are at an all-time low from all the fine tuning and feedback, are not a major concern. This proves that validation testing is necessary, and feedback to companies is well-coordinated. There is no additional pass-on cost to the Government, and the Government is not paying more for reworked batches.

The acceptance testing has a quick turnaround time, usually the same day. There is a 48-h turnaround time to provide manufacturers with the test results and approval letters. In the case of rejected batches, the manufacturers would decant the material into holding tanks, so production is not stopped. After receiving ARL feedback, adjustments would be made by putting the blade down to mix the tinting paste or flattening agent and resubmitting to ARL for acceptance request.

We predict a similar trend in the next few years. The paint volume will continue to drop as the drawdown of U.S. forces continues. Coupled with probable pending cuts in the Defense budget, many weapon programs and procurement will be affected in the next decade. The slowdown in acquisition of ground weapons systems will result in further drops in paint volume.

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