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Automated SEM/EDS Analysis of Airbag Residue. II: Airbag Residue as a Source of Percussion Primer Residue Particles

ABSTRACT: Automated scanning electron microscopy with energy dispersive spectroscopy has been used to analyze airbag residue particles. Analysis of airbag residue from some passenger side airbags revealed some residue particles which are consistent with gunshot residue (GSR) samples. The source of these particles was determined to be percussion primers used to initiate the chemical reaction for deployment. This article identifies some vehicles which contain this type of airbag and demonstrates the types of particles which could be misidentified as being GSR. The low numbers of GSR particles in among the large particle populations of zirconium and/or copper–cobalt particles, which are clearly airbag residue, allow the trained analysts to distinguish the correct source of this residue. Particles containing high aluminum levels, elevated levels of allowable elements in GSR particles, or the presence of elements that are rare in GSR particles stand out as indications that the particles are not GSR in origin. This study serves as a guide to analysts who perform particle analysis in forensic investigations.

KEYWORDS: forensic science, scanning electron microscopy, energy dispersive spectroscopy, airbag, gunshot residue, backscatter electron detector system

Scanning electron microscopy with energy dispersive spectroscopy (SEM/EDS) has allowed the trace analyst the ability to detect and identify particles that were not visible with standard light microscopes. Automating this technique allows the analyst to quickly identify and categorize large populations of particles without having to manually operate the instrument. The implementation of this technique was critical for primer gunshot residue (GSR) testing and pyrotechnic residue testing (1). Particles formed when an airbag is deployed are also appropriate for this analytical technique (2).

During a research project attempting to detect and identify airbag residue using automated SEM/EDS, particles containing lead, barium, and antimony were detected. The source of these particles was in question. The potential impact on GSR testing was enormous.

Several patents for airbag inflators have been issued which call for the use of percussion primers. Breed Corporation (Lincoln Park, NJ) designed an inflator system that used a firing pin to activate a stab primer that was aligned with a percussion primer. When a crash sequence was detected, the percussion primer ignited the gas generating material (3). This mechanism was never put into production (4).

Autoliv ASP, Inc. (Ogden, UT) called for percussion primers in patents for hybrid generator systems (5,6). Figure 1 is one of the patent drawings and the predicted residue from the deployment of such devices corresponds to the population of particles recovered from the airbag standards.

Methods

Analysis of airbag residue standards identified airbags in which lead, barium, and antimony composed a portion of the particles detected in their residue standards (2). These standards had been analyzed during the course of the study and while the search criterion which was written for GSR analysis was being modified for the detection of airbag residue. This study was done using several automated SEM/EDS systems (Aspex Instruments, Delmont, PA). The software purchased with the instruments needed the additional categories of ''zirconium rich'' and ''cobalt'' to be added in order to accurately analyze airbag residue samples.

For this study, these airbags standards were rerun with the airbag search criterion with the emphasis on total particle population and the identification of particles that might be categorized as unique or consistent GSR particles. The particles which might be mistaken for GSR were examined by analysts to determine which particles they would identify as GSR if the particles were present on typical casework samples.

Results

Table 1 lists 12 airbag standards from which suspect GSR particles were recovered. All of the airbags are passenger side models with hybrid inflators. The inflator systems originated from two manufacturers: Autoliv ASP, Inc. and Ordnance Engineering Associates, Inc. (OEM) (Arapahoe County, CO). Both companies used percussion primers in their ignition systems (personal communications with Dr. Chris Erickson, a chemist with Autoliv). Autoliv acquired certain assets, including inflator technology, of OEM in 2000 (7).

Two different populations of particles were detected in the 12 airbags with suspect GSR particles. One population had high numbers of copper/cobalt particles and copper and cobalt present in several of the suspect GSR particles. If a hybrid inflator like that in Fig. 1 has an initiator that is a blend of zirconium and potassium perchlorate (ZPP), a lower atomic mass ignition material, such as boron potassium nitrate, a primer that has lead, barium, and antimony compounds, and a gas generant that is hexamine cobalt (III)

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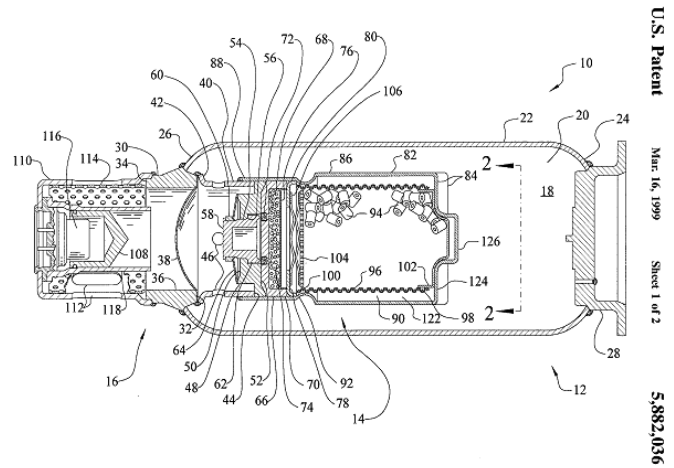

FIG. 1—*The actual drawing for the patent application for the hybrid gas generator system. The compressed gas (18) is stored in the pressure vessel (12). The pyrotechnic gas generant (94) is stored in its housing (82). When a signal to deploy is sent, the initiator (116) combusts to produce gas which propels the projectile (108) down the barrel (118). The projectile then ruptures the burst disc (38) that allows the compressed gas to escape through the central opening (36) and exit ports (112) and through the diffuser cap (110). The projectile continues until it strikes the head (60) of the piston (58). The base end of the piston impacts the primers (72) like firing pins and produces a small quantity of hot combustion gas. This ignites the ignition material (74) that ruptures the igniter cap (76). This ultimately ignites the generant that produces the hot gas that mixes with the cool compressed gas and inflates the bag completely. If this sequence occurs, the particles formed by the initiator would be formed first, without the presence of residue from the ignition material or the generant. Any particles that are not captured by the filter system would be blown into the airbag before the generant ignites. Residue from the ignition material and generant would be formed secondly and, if not captured by the filter, deposited in the airbag.*

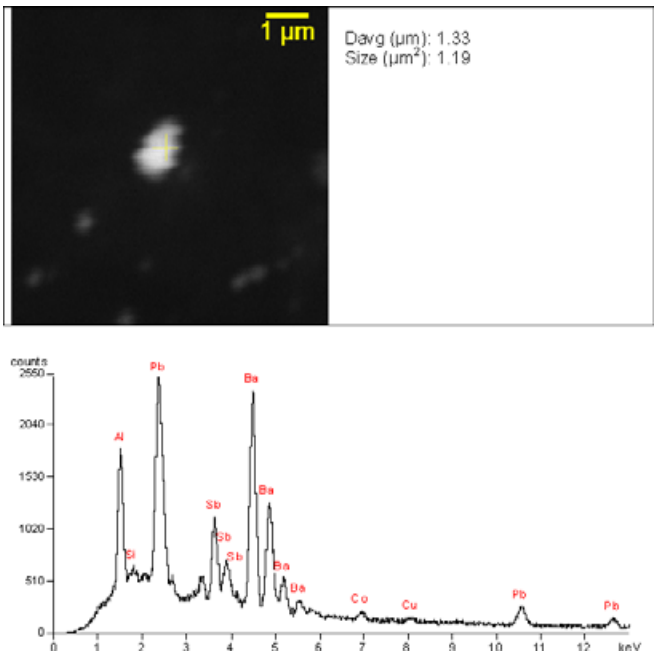

FIG. 2—*This particle was recovered from a 1999 Volkswagen Golf. The trace amount of cobalt was allowed.*

trinitrate (HACN) with copper (III) trihydroxynitrate as called for in the patent (5), then some of the particles formed by this overall reaction would be zirconium particles, copper/cobalt particles, and a few GSR particles, which may have trace amounts of copper and cobalt. None of the ignition material residue would be detected by SEM/EDS except for potassium. This is consistent with the test results.

The other population had high aluminum levels in various particles and high aluminum levels in several of the suspect GSR particles. Another Autoliv patent called for a similar hybrid inflator housing that uses their FN 1061-10 propellant which contains mostly potassium perchlorate with polyvinyl chloride, sodium oxalate, dioctyl adipate, and trace amounts of carbon black, lecithin, and stabilizer. The percussion primers ignite a mixture of hexahydrotrinitrotriazine (RDX) and aluminum powder that ignites the gas generant (6). Some of the particles formed by this overall reaction would be zirconium particles, particles containing high aluminum levels, and a few GSR particles that may have high aluminum levels. This is also consistent with the test results.

At the time of this study, changes in the titles used to categorize GSR particles have been discussed without unanimous agreement (8). This laboratory uses the terms "unique" and "consistent" to classify GSR particles.

A unique GSR particle should possess a molten appearance in origin. These particles may retain their shapes when deposited and collected. If not, their appearance should be irregular, but not crystalline (8). Their primary elemental composition should be lead, barium, and antimony. Many other elements (Si, Ca, Al, Fe, Sr, Cu, Zn, S, Sn, K, Cl, Na) may be present in trace amounts without affecting the identification. Other elements (Ni, P, and Co) are rarely found in primer formulations and may affect identification.

A consistent particle may be a combination of the primary elements or particle types produced from other primers that use

TABLE 1—*Airbag standards that contain lead, barium, and antimony.*

Model year	Make	Model	Major Particle Types Detected (by Percentage of Total Particles)	Percentage of Consistent GSR Particles	Unique GSR Particles Fig(s)
1999	Volkswagen	Golf	Co-76 Cu-9 Ti/Zr-7 Fe-2	0.11	2–4
2000	Chevrolet	Monte Carlo	Co-44 Zr-43 Cu-5 Fe-2	0.02	5
2001	Dodge	Dakota	Zr-75 Co-15 Cu-5 Fe-2	0.04	6
2002	Chevrolet	Cavalier	Zr-77 Fe-12 Zr/Zr-5 Al-2	0.46	7–8
2002	Chevrolet	Monte Carlo	Co-54 Zr-33 Cu-5 Fe-5	0.02	9
2003	Mercury	Sable	Co-46 Zr-44 Cu-4 Fe-2	0.02	10
2003	Ford	Van	Co-52 Zr-37 Cu-7 Fe-1	0.08	11–13
2003	Buick	Rendezvous	Zr-71 Cu-20 Fe-3 Zn-1	0.17	14–15
2003	Pontiac	Grand Am	Zr-87 Fe-4 Al-2 Zn/Zr-1	0.28	16–17
2004	Pontiac	Grand Am	Zr-82 Fe-7 Zn-1 Al-1	0.07	18–20
2004	Jeep	Cherokee	Zr-58 Cu-25 Fe-5	0.04	21
2005	Ford	Escape	Zr-81 Cu-10 Fe-5	0.09	22

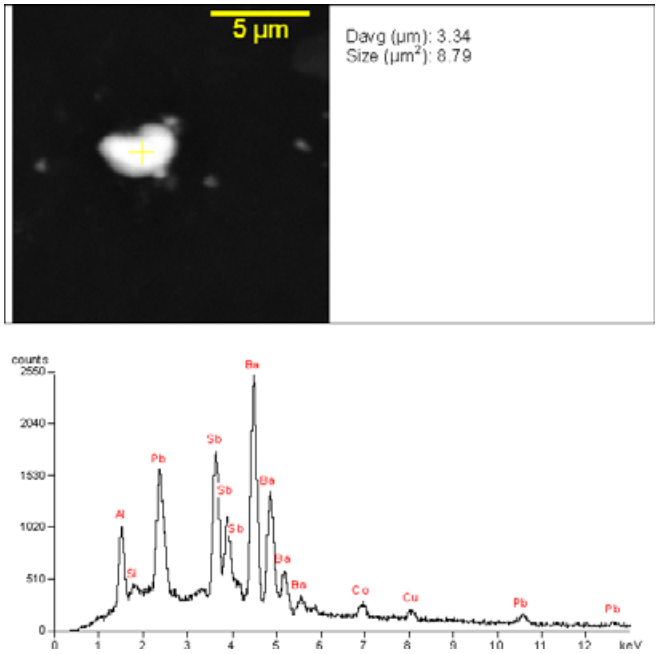

FIG. 3—*This particle was recovered from a 1999 Volkswagen Golf. The trace amount of cobalt was allowed.*

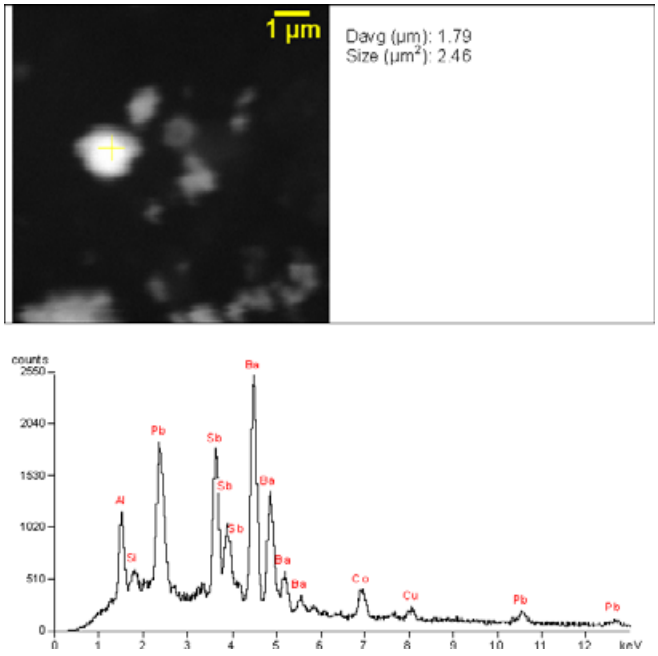

FIG. 4—*This particle was recovered from a 1999 Volkswagen Golf. This amount of cobalt is allowable, but it is close to becoming considered more than just a trace amount.*

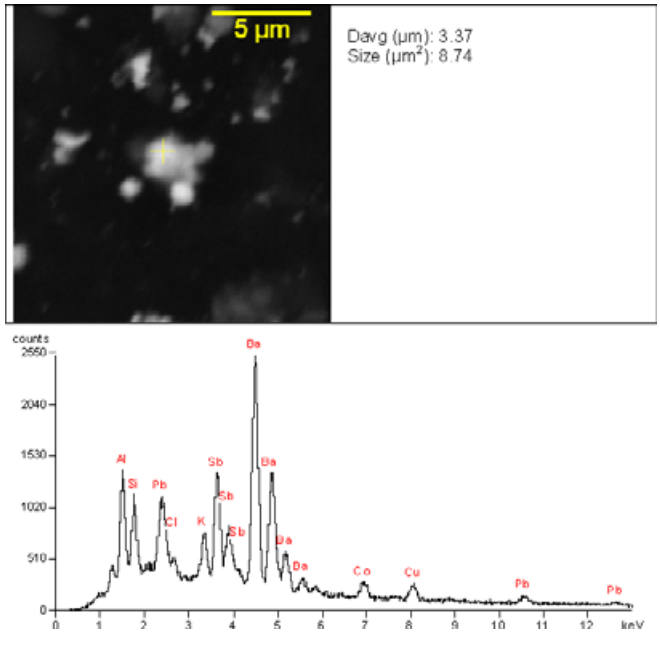

FIG. 5—*This particle was recovered from a 2000 Chevrolet Monte Carlo. The cobalt and potassium levels are allowable.*

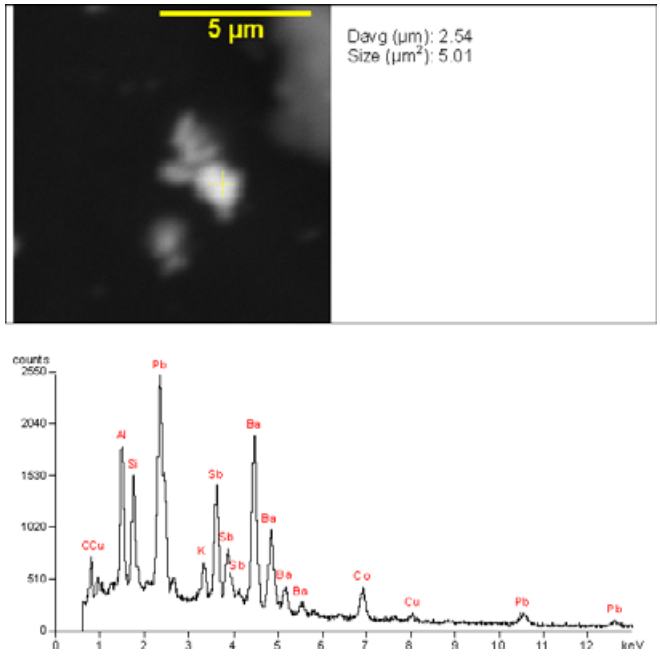

FIG. 6—*This particle was recovered from a 2001 Dodge Dakota. The cobalt level is allowable, but it is close to becoming considered more than just a trace amount.*

alternate priming formulations. Titanium and zinc or strontium particles may fall into this category.

With this strategy in place, the particles that were categorized as GSR by the instrument during the automated runs were evaluated. Several analysts who routinely analyze GSR evidence were asked to classify the particles that were detected. The population of particles produced by those airbags and references to the unique particles that were confirmed are represented in Table 1.

Discussion

The analysts who reviewed the suspected GSR particles knew that these particles were recovered from airbag standards. The morphology of the particle, the presence of the primary elements, and the levels of allowable elements in the particle are the typical factors used to determine GSR particle classification.

Because of the formation of these particles during an exothermic reaction and the selection criteria, the morphology and the presence

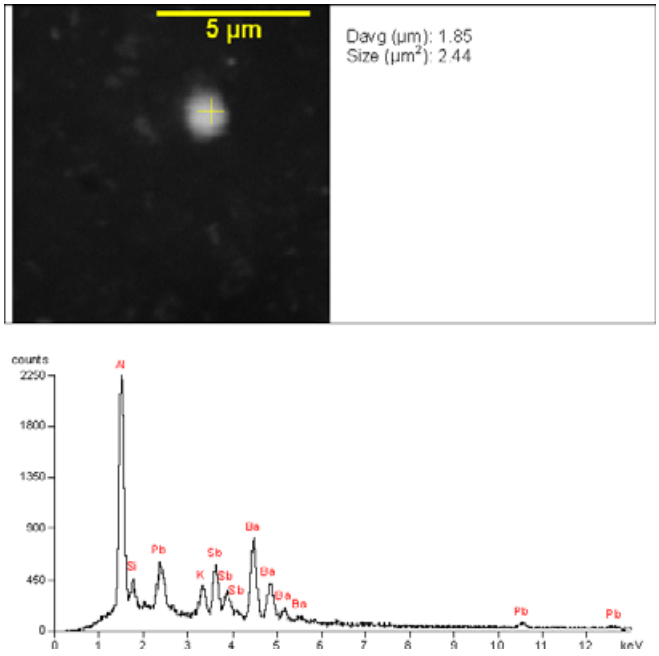

FIG. 7—*This particle is from a 2002 Chevrolet Cavalier. The elevated Al peak keeps the remaining peaks small, but still detectable. The amount of aluminum in the spectrum caused some of the analysts to exclude this particle.*

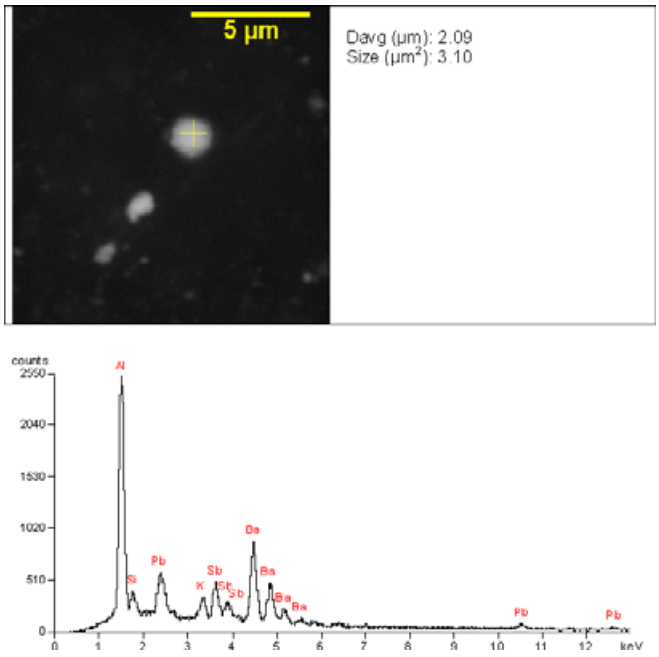

FIG. 8—*This particle is from a 2002 Chevrolet Cavalier. As with the preceding particle, the amount of aluminum in the spectrum caused some of the analysts to exclude this particle.*

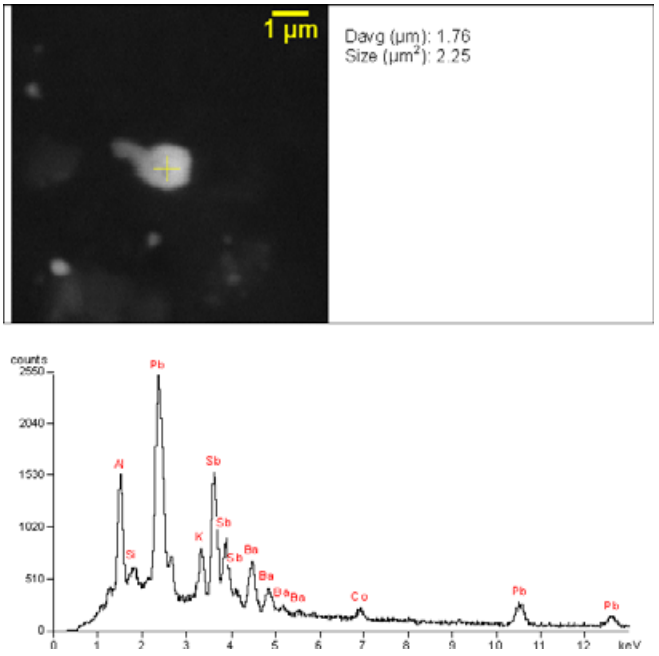

FIG. 9—*This particle is from a 2002 Chevrolet Monte Carlo. The cobalt and potassium levels are allowable.*

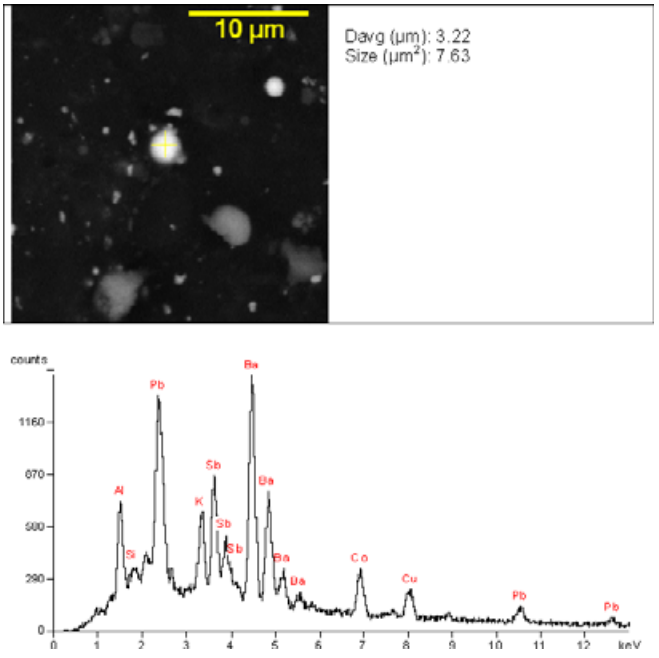

FIG. 10—*This particle is from a 2003 Mercury Sable. The levels of cobalt and potassium are allowable, but they are close to becoming considered more than just a trace amount.*

of the primary elements were not the main factors in classifying these airbag residue particles. Elevated levels of the allowable elements and the presence of rare elements were usually the main factors in classifying the suspect particles as not being GSR.

The cobalt levels in numerous particles caused them to be rejected as GSR. The presence of cobalt in percussion primer formulation is rare. Federal (Anoka, MN) produces Nyclad ammunition in which the bullet is jacketed with nylon to reduce airborne lead. The nylon is impregnated with cobalt blue pigment so that discharging this ammunition may produce GSR particles that contain cobalt (9).

Phosphorous is rare in GSR particles. The presence of zirconium is not allowed. Since the K alpha line for phosphorous (2.013 KeV) and the L alpha line for zirconium (2.042 keV) overlap, it is difficult to distinguish trace amounts of these elements in

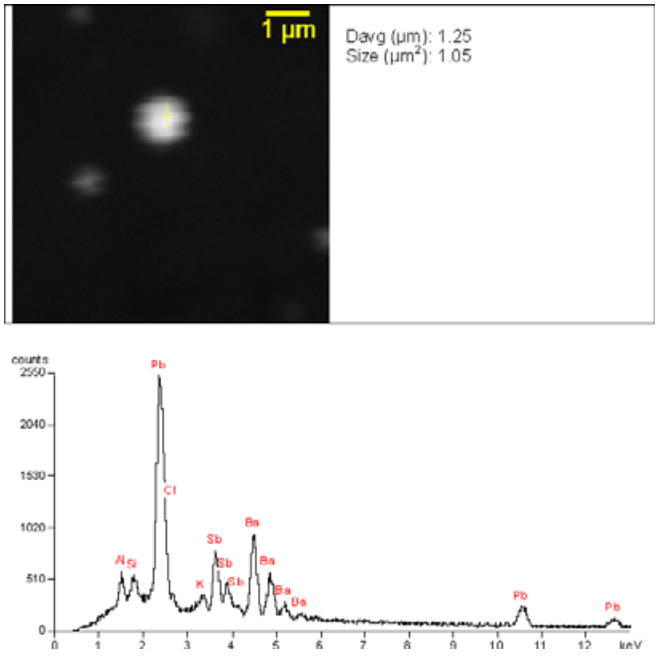

FIG. 11—*This particle was recovered from a 2003 Ford Van. Its morphology and elemental composition yield no indication that it is airbag residue and not gunshot residue.*

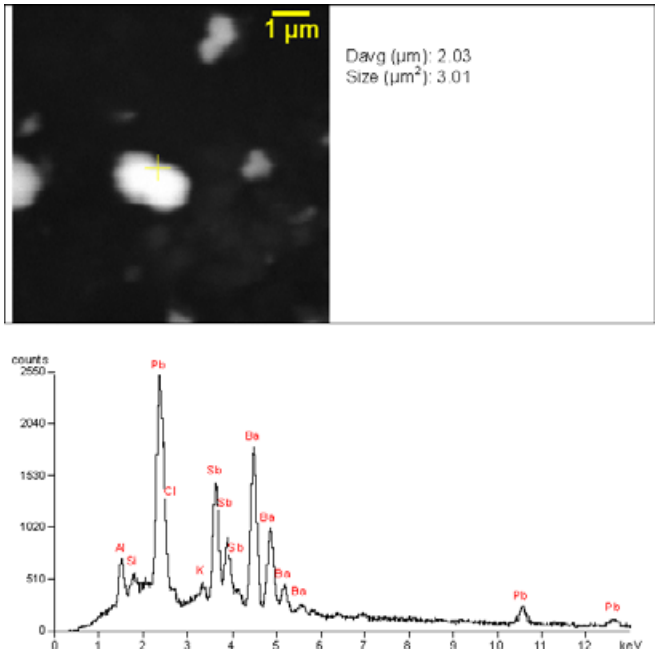

FIG. 12—*This particle was recovered from a 2003 Ford Van. Its morphology and elemental composition yield no indication that it is airbag residue and not gunshot residue. A trace amount of cobalt is detected (not listed in spectrum).*

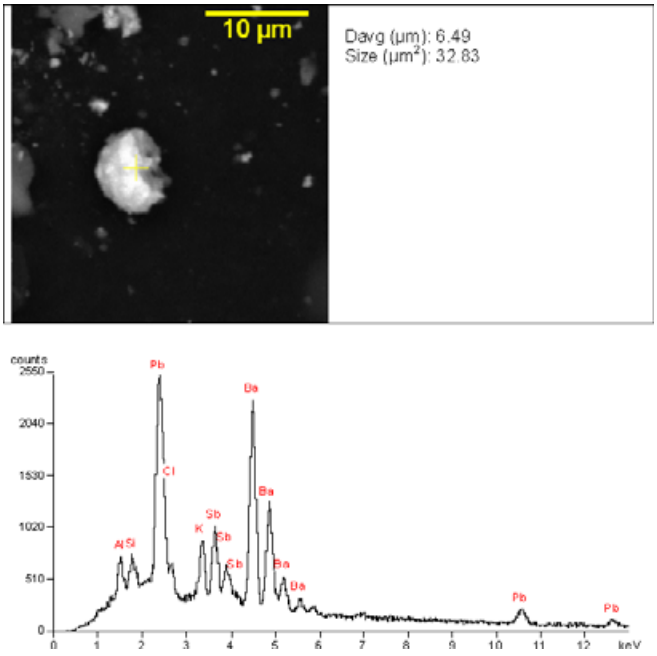

FIG.13—*This particle was recovered from a 2003 Ford Van. The potassium level is allowable.*

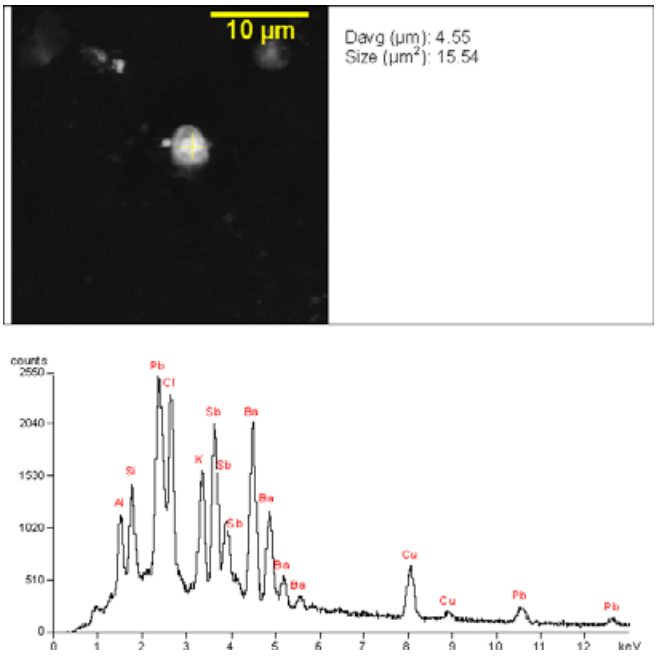

FIG. 14—*This particle was recovered from a 2003 Buick Rendezvous. The chlorine and potassium levels are allowable.*

a particle. For this reason, particles that contained a phosphorous/zirconium peak were classified as not being GSR particles.

Aluminum is an allowable element. However, if high amounts of aluminum are present in a particle, the height of the aluminum peak causes all other peaks to be diminished. High aluminum levels in suspect GSR particles caused disagreement among the analysts interpreting the data.

Conclusion

Some airbags use percussion primers in their chemistry. The residue produced when these airbags deploy creates particles that cannot be distinguished from the particles produced when a firearm is discharged. While evaluating data from one of these airbag samples, GSR analysts might report false-positive GSR results if they simply define GSR by the presence of a single particle containing lead, barium, and antimony.

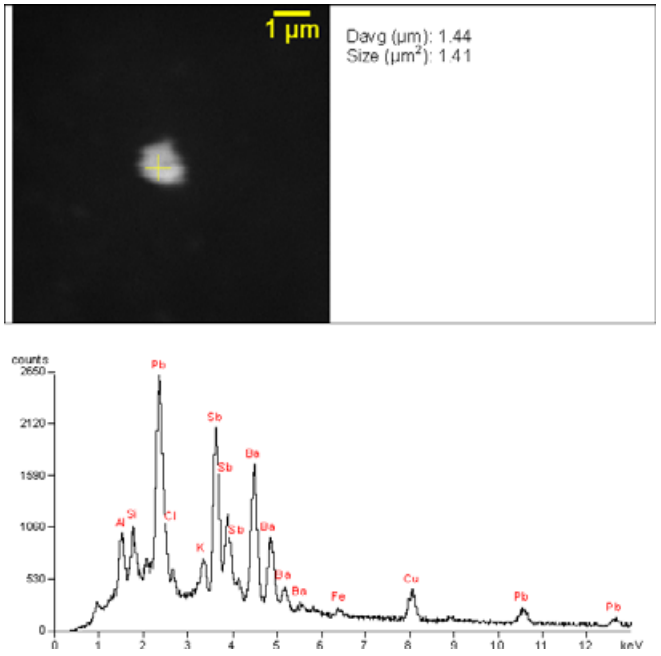

FIG. 15—*This particle was recovered from a 2003 Buick Rendezvous. The potassium level is allowable. The zirconium/phosphorous peak (not listed in spectrum) is not defined enough to exclude this particle.*

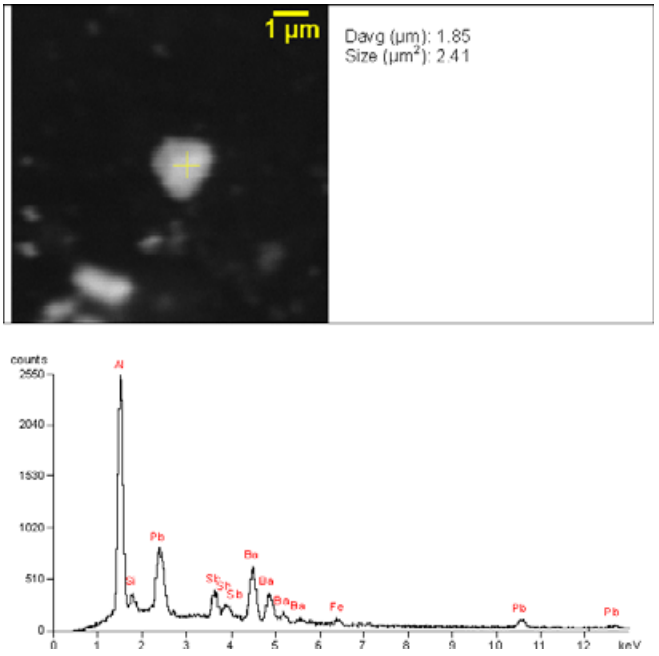

FIG. 17—*This particle was recovered from a 2003 Pontiac Grand Am. The elevated aluminum caused some of the analysts to exclude this particle.*

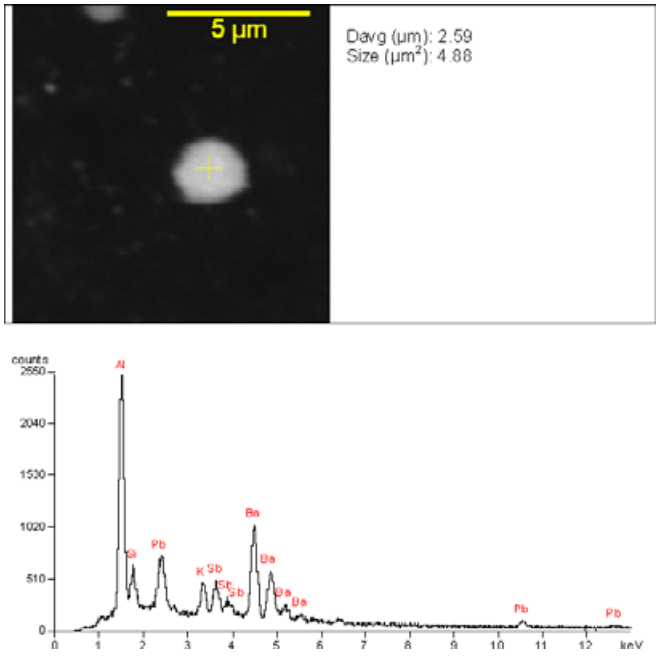

FIG. 16—*This particle was recovered from a 2003 Pontiac Grand Am. The elevated aluminum caused some of the analysts to exclude this particle. The potassium level is allowable, but it is close to becoming considered more than just a trace amount.*

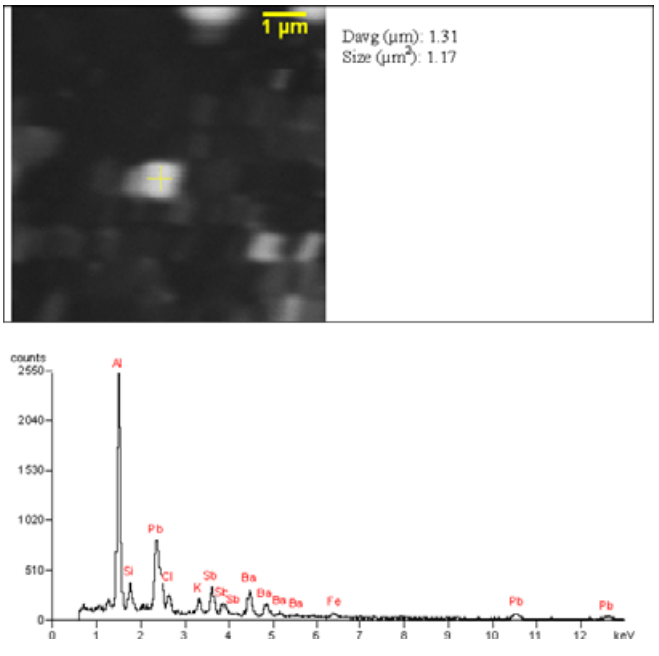

FIG. 18—*This particle was recovered from a 2004 Pontiac Grand Am. The amount of aluminum in the spectrum caused some of the analysts to exclude this particle.*

The percussion primer which is used in centerfire ammunition ignites a small quantity of single or double based smokeless powder and produces residue which is mostly lead, barium, and antimony particles. No additional fuels, oxidizers, or explosives are necessary. The residue from the nitrocellulose-based explosive is not detected by the automated SEM/EDS technique.

However, the percussion primer which is used in some airbags is part of a much larger chemical equation. Squibs, ignition material or boosters, secondary explosives, gas generants, additional oxidizers, or metallic fuels may add to the population of residue particles and may be detected by the SEM/EDS technique. If the analysts look to the whole population of particles that is recovered, they should see indicators that the material is actually airbag residue. As shown in Table 1, high numbers of zirconium or copper/cobalt particles should be present in the sample. Analysis of the particles that have been categorized during the automated analysis as GSR reveal either high aluminum levels, elevated levels of allowable elements,

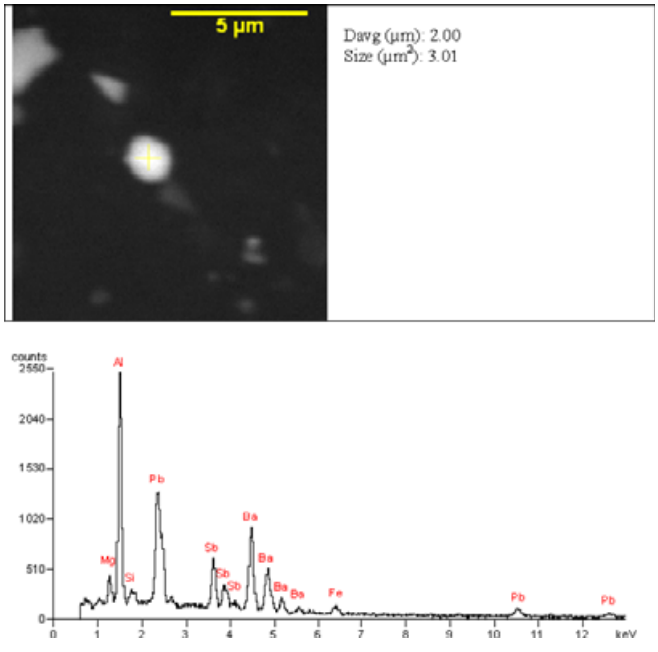

FIG. 19—*This particle was recovered from a 2004 Pontiac Grand Am. The amount of aluminum in the spectrum caused some of the analysts to exclude this particle. The trace amount of magnesium was not considered to be significant.*

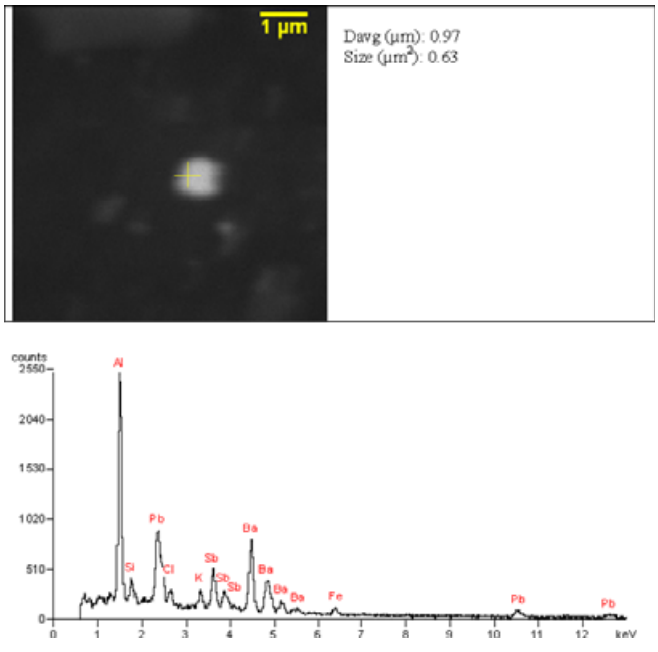

FIG. 20—*This particle was recovered from a 2004 Pontiac Grand Am. The amount of aluminum in the spectrum caused some of the analysts to exclude this particle.*

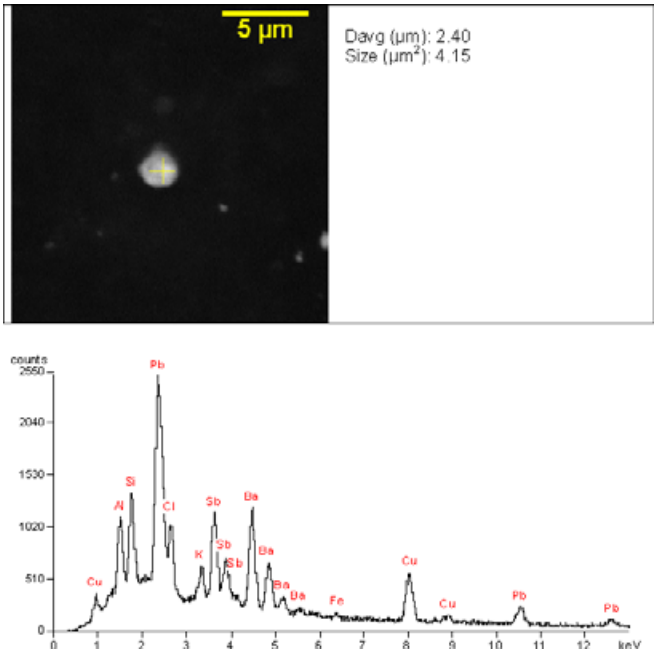

FIG. 21—*This particle was recovered from a 2004 Jeep Cherokee. Its morphology and elemental composition yield no indication that it is airbag residue and not gunshot residue.*

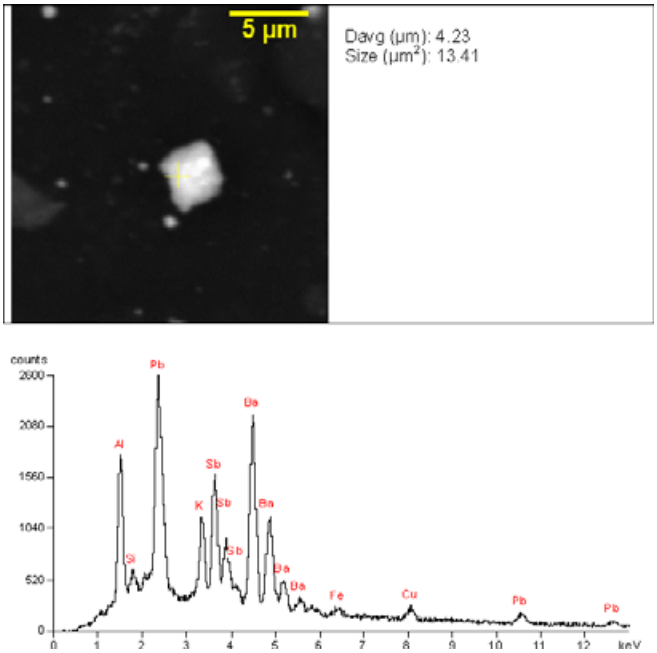

FIG. 22—*This particle was recovered from a 2005 Ford Escape. The potassium level is allowable.*

or the presence of elements that are rare to GSR. Few consistent particles are recovered from a relatively large overall particle population. As seen in Figs. 2–22, most particles give some indications that they are not typical GSR particles. Aluminum/silicon microfibers may be present in the sample. The indicators are there, if the analyst knows what to look for.

In an accident investigation, test results from the airbags themselves would indicate whether percussion primers were used and would identify the main particle types that were produced. This information gives the analyst an idea of what materials to look for on the suspect samples. Even if the airbag produced unique and consistent GSR particles, the lab report should indicate the presence of airbag residue particles on the suspect's hands or clothing.

In a shooting investigation in which a traffic accident has also occurred, the collection of the airbags is essential. Proper examination of the airbags would allow the examiner to determine if any recovered particles containing lead, barium, and antimony can be

associated with airbag and/or GSR. If unique GSR particles are produced by the airbag and the analysis of the suspect's hands or clothing reveals unique and consistent GSR particles, laboratory results would have to indicate the presence of percussion primer residue that originated from the airbag deployment and/or the discharge of a firearm.

This investigation was intended to increase the awareness of GSR analysts and aid in their interpretation of particle populations.

Acknowledgments

Verification of the suspect GSR particles was conducted by the Forensic Scientists at the Forensic Science Center—Chicago who perform gunshot residue testing: Michael Kopina, Mary Wong, Scott Rochowicz, and Ellen Connolly. I am grateful for their help in this study.

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