NARRATIVE

Refrigerant used in automotive applications (R-134a) is a colorless compressed gas that traditionally does not get verification of composition beyond the label on the outside of the cylinder. This reliance on packaging labels and difficulty in inspecting, coupled with the high commercial prices lend the R-134a refrigerant to be counterfeited using various other compressed gases. These gases and the equipment used to mix and fill cylinders are very inexpensive. The high profitability and weak punitive consequences make this a growing issue.

Photo 1 - Counterfeit refrigerant cylinder (left); legitimate refrigerant cylinder from reputable company (right).

The refrigeration industry has tracked counterfeit refrigerants for several years. Most gases used posed low to moderate safety risks from flammable gases being used. Many of these gases are also ozone depleting substances (ODS). These chemicals damage vehicle air conditioning (A/C) system seals, causing the contents to leak from vehicle systems or equipment. This loss of refrigerant damages the environment and will lead to system failure, resulting in costly repairs.

In 2011 industry identified the introduction of counterfeit refrigerants containing mixtures of R-40, a refrigerant discontinued from use. R-40 is flammable, toxic to humans, and harmful to the environment. In addition R-40 reacts with aluminum to form trimethylaluminum (TMA) which is pyrophoric, or will burn when exposed to air. TMA will explode if it comes in contact with water, carbon dioxide, halon, and many others. Release of the gases and byproducts can occur from seal or hose failure, inside or outside the vehicle, or during servicing. This poses a significant safety risk to the Soldiers using the vehicle as well as when the vehicle is serviced. In the shipping container industry three deaths were attributed to this mixture in 2011.

Program Management

The U.S. Army Research, Development and Engineering Command's (RDECOM's) Tank Automotive Research, Development and Engineering Center (TARDEC) ground systems engineers began responding to counterfeit refrigerant concerns following the release of a Department of the Army (DA) G4 All Army Action (ALARACT) message titled *Counterfeit R-134A of 021415ZMAR12*. This ALARACT highlighted the discovery and dangers of the R-40 present in counterfeit R134a supplies. Officials at the TACOM Life Cycle Management Command (LCMC) formed an Integrated Process Team (IPT) to assess counterfeit R-134a in U.S. Army ground combat and tactical vehicles and equipment. TACOM LCMC maintenance and safety personnel, along with TARDEC subject-matter experts (SMEs), formed the core IPT. TARDEC was designated as the IPT technical lead for the counterfeit refrigerants research and process development. IPT members collaborated with industry and academia, Society of Automotive Engineers (SAE), American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) and Defense Logistics Agency (DLA) SMEs, depot personnel, DA G4 staff and Department of Defense (DOD) multi-service representatives to determine problem extent, and to develop solutions for identifying, containing and mitigating contaminated refrigerants in U.S. military vehicles and equipment.

The IPT quickly developed a comprehensive project process plan which included an aggressive schedule with major milestones, including detection, understanding the issue and mitigation. The initial project plan called for:

- Determining if U.S. Army vehicles/equipment and bottles contained a pure R-134a refrigerant or contained R-40 (methyl-chloride) or other chemical contaminants that pose safety risks.
- Evaluating R-40 effects on air conditioning (A/C) systems, to include impacts to system operation; determining if Trimethylaluminum (TMA) is being produced; and evaluating immediate TMA contamination risks and impact severity on vehicles, equipment, crew members and maintenance personnel.
- Determining risks involved with operating/servicing A/C systems containing counterfeit refrigerants.
- Disseminating safety-related information to all IPT members as quickly and accurately as possible for subsequent release to their respective organizations.
- Conducting regular meetings/discussions with industry SMEs and academia researchers to develop long-term solutions.
- Providing status reviews/updates regularly to IPT members and key stakeholders.
- Developing electronic field testers and procedures to allow Soldiers and maintenance personnel to test refrigerants prior to use or during routine servicing of vehicles.
- Developing proper disposal procedures for special hazardous materials (HAZMAT) and contaminated byproducts.

In many cases, these steps were conducted simultaneously, where practical, to expedite timely information flow to the field and reduce overall environmental impacts. By reducing ozone depleting substances (ODS) and green house gases released from systems with counterfeit refrigerant, compliance is ensured with the *Clean Air Act*. As new information became available, frequently because of to the nature and speed of the effort, this information was discussed within the IPT and courses of action were decided. Several major tasks were modified and developed through this process and include:

- Providing status reviews regularly to an overarching IPT including DOD, DLA, depot personnel, DA G4 staff, PMs and DOD multi-service officials.
- Determining extent to which U.S. Army ground vehicles and equipment have counterfeit refrigerant in their A/C systems. A primary concern with the suspect refrigerants is the “source of supply.”
- Determining long-term impact to A/C system integrity from other counterfeit refrigerants not containing R-40.

Electronic test devices indicated significant contaminant levels in the vehicles tested and the two refrigerant reclaiming machines tested. Refrigerant samples were sent for Gas Chromatography (GC) testing to determine chemical compositions. Lab results confirmed that R-40 was present in the samples tested. As a result an initial information release, *Safety of Use Message* (*SOUM) 12-009*, was developed and released by TACOM LCMC officials. The *SOUM* included some technical information on the issue, along with interim precautionary measures to ensure the safety of maintenance personnel and vehicle operators.

The technical path forward included using electronic refrigerant test sets to isolate vehicles/equipment contaminated by counterfeit refrigerants.

- The IPT is working with Michigan Technological University (MTU) researchers to assess R-40 effects on system components, determine if TMA forms and how much, and how the compound interacts with refrigerant oil. The research evaluates the severity of reactions from TMA when mixed with various refrigerant oil quantities.
- Additional screening of refrigerant in U.S. military vehicles, leveraging Science Applications International Corporation (SAIC) experts, is being performed to determine the extent of counterfeit refrigerant infiltration.
- Follow-on research with MTU and Alion Science and Technology subject matter experts, (SMEs), includes proper system handling and decontamination/cleaning of those systems confirmed to have R-40 contamination.
- Ongoing work includes developing extensive procedures to check A/C systems and refrigerant canisters for content purity. Teaming with Letterkenny Army Depot (LEAD) and Red River Army Depot (RRAD) technicians, TARDEC engineers used electronic testers to evaluate military vehicles returning from Southwest Asia operations.

The IPT conducted multiple cross-functional meetings, reviews, briefs and presentations to inform, coordinate efforts and determine next steps/best overall forward path. Key technical Program/Project Management (PM) personnel, Army depots and various support teams were integrated into the process from the outset. To date, Army depots supporting field maintainers and logisticians include: LEAD, RRAD, Sierra Army Depot (SIAD) and Anniston Army Depot (ANAD).

The IPT technical leads initiated the effort to develop procedures to check A/C systems and canisters for content purity. Technical evaluations using the electronic refrigerant testers were conducted by LEAD, RRAD and TARDEC engineers/technicians. Based on their initial test results/findings, Army officials directed that all combat and tactical vehicles, engineer/construction vehicles, materiel handling and ground-support equipment that use R-134a be identified — including those in storage or reset. Those vehicles and equipment were to be tested and tracked for future refrigerant sampling; especially vehicles deployed OCONUS (Overseas-–Continental United States) within the last 36 months. Vehicles returning from overseas have been identified as the most “at risk” vehicles in the fleet. TACOM LCMC safety officials and TARDEC engineers are estimating that 25 percent of military vehicles per brigade-sized element (or roughly 300 vehicles per brigade) returning from OCONUS are suspected to be contaminated to some extent. Based on these estimates and other data collected to date, the approximate cost to replace refrigerant in contaminated vehicles is $106.00 per vehicle, or approximately $31,800.00 per brigade.

The process included crucial reviews of current, relevant counterfeit refrigerant information and details obtained from the Shipping and Container industry. Next, IPT members queried a variety of suppliers to determine how and where military ground vehicle refrigerant content was procured. Following this research, IPT members then met with academic researchers to further investigate dangers, safety and toxicity concerns and impact to the A/C systems themselves. Questions addressed were:

- How much reactive material could be formed with each gram of R-40?
- How do we determine if vehicles and bottles are pure R-134a or not?
- How do we evaluate the effects of R-40 in A/C systems?
- How do we determine if TMA is being produced?
- How do we evaluate the severity of TMA contamination and potential impacts?
- How do we contain the contaminants and then safely dispose of the hazardous materials?

Technical Merit

Through the extensive, integrated vehicle screening initiatives emplaced Army-wide by TARDEC, the TACOM LCMC and PMs for identifying counterfeit refrigerants, more than 18 different refrigerants have been found in U.S. military vehicles to date. These refrigerants include Class I ODS, Class II ODS and flammable refrigerants, along with the toxic and reactive R-40 refrigerant that initially sparked the controversy. Research has shown that many of these refrigerants destroy the seals used in R-134a A/C systems over time. If the refrigerants are left in the vehicles, they will leak or "vent" out into the atmosphere, contributing to ozone layer depletion. In addition, they may leak during vehicle operation, due to o-ring failure, exposing Soldiers to toxic and flammable gases. O-ring failure is caused by the chlorinated refrigerants found in counterfeit mixes. These refrigerants soften the seals, causing them to swell and lose their ability to contain the high pressure inside an air conditioning system. Capturing these refrigerants from inside vehicles before they leak out or identifying new bottles before they are used, allows safe and environmentally friendly containment and/or recycling of these refrigerants.

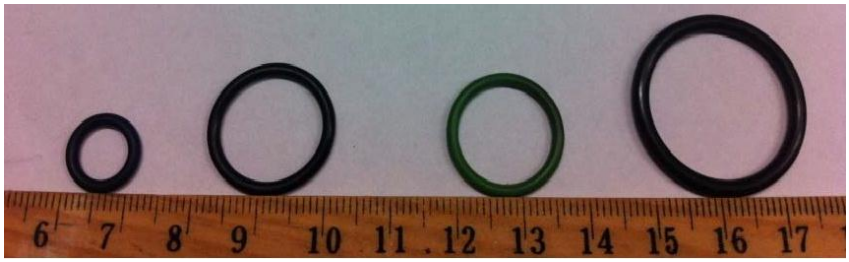

Photo 2 – Air conditioning o-ring seals new on left; exposed to counterfeit refrigerant on right.

Another issue is the presence of flammable refrigerants in systems not designed to handle/suppress them. Further, the systems are serviced with equipment not rated for flammable refrigerants. This may cause the service equipment to catch fire or explode during or after servicing. Also, the pyrophoric byproduct, TMA, would be exposed to air during a routine service, posing a significant safety risk to A/C system technicians. Procedures are being continuously updated to mitigate/eliminate potential service, storage and disposal risks.

An integral research element, IPT members worked with MTU researchers to assess R-40 effects on system components to determine:

- Does TMA form on system components?
- If so, how much TMA forms?
- How does this compound interact with refrigerant oil and other contaminants?

Photo 3 - Corroded laboratory vessel from reactions of counterfeit refrigerant with air conditioning system materials.

The research effectively evaluated the severity of reactions from TMA when mixed with various refrigerant oil quantities. The different oils present in military vehicle A/C systems further complicated the issue as each one reacts slightly differently with TMA. Upon discovery that additional refrigerants are present in A/C systems, further research was conducted to validate that no other refrigerants found in U.S. military vehicles pose significant health or safety risks, and verify that the risks for those known compounds are

being properly mitigated.

A typical scenario for a vehicle A/C system containing counterfeit refrigerant is, that one day, either idle or operating, the A/C system's seals or hoses will leak. Most, if not all, of the refrigerant will be released. This causes vehicle use issues in hot climates as interior temperatures quickly rise above safe operating levels for Soldiers. From a maintenance perspective, the system leak has to be located, components disassembled and then repaired or replaced. Upon returning the vehicle/system to operating status, it is likely that further leaks will develop under high-load conditions due to additional weakened parts, causing the system to fail when it is needed most. Many of these costly repairs can be significantly reduced, along with operating down time.

To allow the field to safely and effectively detect counterfeit refrigerants, TARDEC is leveraging its automotive industry relationships to develop the electronic tester for R-134a. Current state-of-the-art refrigerant electronic testers were modified and updated to accommodate counterfeit refrigerant issues and identify contaminated vehicle systems and equipment. The electronic refrigerant testers were developed via Cooperative Research and Development Agreement (CRADA) 12-11 between TARDEC and Neutronics, Inc. To evaluate the electronic refrigerant testers on Army military vehicles returning from theater, IPT associates worked closely with LEAD and RRAD technicians. Together, associates screened and sampled vehicle refrigerants. They also trained depot personnel on proper electronic tester use. TACOM leveraged existing operations in Kuwait to perform an initial field test for the electronic refrigerant identifiers. Several production representative testers were positioned at the depots to allow for further vehicle/equipment screening, data collection and user feedback on electronic test procedures and devices.

Photo 4 - Pictured is the refrigerant identifier test kit, including adapters, needed for common A/C service connections.

The IPT is transitioning the tester technology to the field, including procedures and personnel instruction on refrigerant tester use. Refrigeration tester effectiveness is being monitored through government, DLA, depot, DA G4 and DOD multi-service teams to address any new counterfeit refrigerant issues as they emerge. TARDEC and SAE are establishing new industry-wide automotive procedures and warning messages for isolating/identifying counterfeit refrigerants to mitigate future counterfeit refrigerant issues.

After the electronic tests are conducted, the refrigerant is assessed as "good" R-134a via an acceptable purity percentage or assessed as contaminated due to an unacceptable purity percentage. If the refrigerant is contaminated, a lab analysis is performed to determine the exact content of refrigerant mixtures. Based on these results, the refrigerant is then placed into one of four categories, with each category requiring different handling and disposal techniques. In fact, some HAZMAT mixtures require *special* handling/disposal equipment.

Categories of contamination based on refrigerants found in U.S. military vehicles.
CC1 - Good Refrigerant: R-134a
CC2 - Non-Hazardous: R-115, R-12, R-124, R-125, R-22, R-143a, R-123, R-133a, R-114, R218
CC3 - Flammable: R-152a, R-142b, R-290, R-600, R-600a, R-161

CC4 - Reactive or toxic: R-40

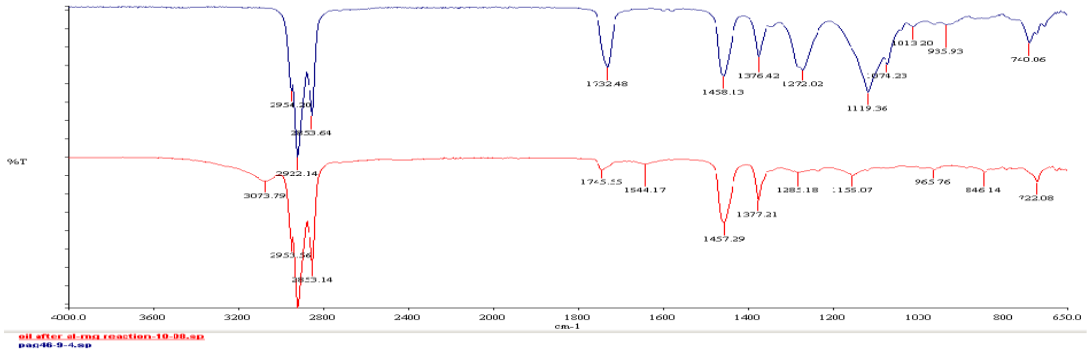

Photo 5 – Graphs of refrigerant lubricating oil signature from laboratory analysis. Top graph is oil used with pure R-134a refrigerant. Bottom graph is oil used with counterfeit R-134a refrigerant mixture.

Orientation to Mission

The overarching IPT included LEAD and RRAD personnel, DA G4, DLA and the DOD multi-service team. Regular updates regarding technical progress were provided, as available, to ensure the most up-to-date information was rapidly disseminated. The ability to safely service U.S. military vehicle A/C systems is keeping operational readiness rates high in inhospitable arid/extreme temperature environments, and keeping Soldiers and maintenance personnel safe from potentially toxic or hazardous chemicals.

Because of these new initiatives to identify counterfeit refrigerants in military vehicles and equipment, contaminated refrigerants can be properly captured, contained and then safely disposed. Once the refrigerants are removed from the vehicle, the refrigerant can be recycled. Commercial recycling centers separate the various refrigerants from each other through a distillation process, allowing the good R-134a to be reused, and other refrigerant chemicals reused or properly disposed. Through refrigerant recycling, logisticians are able to ensure vehicle and operator safety, and significantly reduce operating costs across DOD's combat and tactical vehicle fleets.

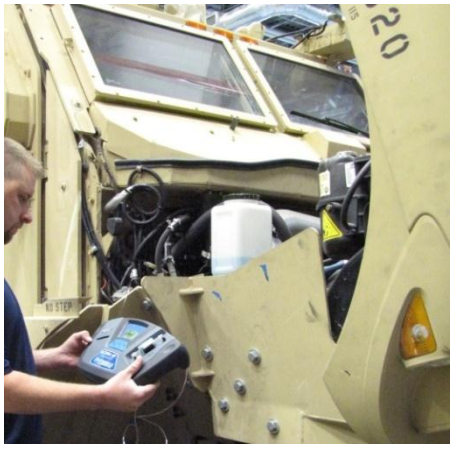

Photo 6 – Tester being used on a tactical vehicle to analyze refrigerant purity.

Transferability

Procedures and information about counterfeit refrigerant is being distributed through the overarching IPT organizations. Fielding efforts are being coordinated by the TACOM LCMC. A follow-on *SOUM* will be released in late April or early May 2013, detailing the most recent information and procedural updates. Some adaptations for military vehicles and equipment are expected for certain applications that differ from the automotive sector, but any military use of R-134a will incorporate advanced warning information and electronic test devices being developed and updated. In addition, the TARDEC/Neutronics, Inc. CRADA provides Neutronics with the commercial rights to the efforts performed under the CRADA. Neutronics is currently working with the automotive and shipping industries to use electronic testers for screening for counterfeit refrigerants before they hit the U.S. supplier system.

With the growing problem of refrigerant counterfeiting, the groundwork laid during this program is expected to continue to provide a valuable framework. Costs of new industry replacement refrigerants are even higher than currently seen for R-134a, increasing the risk of counterfeit refrigerant being sold in the future. This proactive posture will eliminate counterfeit refrigerants from getting into U.S. military vehicle systems and supplier channels. This prevents significant costly maintenance repairs and logistics impacts due to non-mission capable (NMC) vehicles and potentially unsafe mixtures of refrigerants in A/C systems.

Stakeholder Interaction

Throughout the program, the IPT worked closely with SAE, the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) and National Refrigerants, Inc. members to keep up-to-date on the latest counterfeit refrigerant developments and information. TARDEC engineers addressed SAE World Congress April 2012 attendees to initiate widespread communication with SAE members and associated automotive company engineers and technicians, manufacturers and suppliers. The IPT coordinated with ASHRAE on an initiative to validate the specification utilized for R-134a purity. The specification allows for 0.5% of any gas to be mixed in with a new refrigerant cylinder. With the advent of R-40 counterfeiting, even the low percentage of 0.5% has caused concern. This initiative will validate that the current specification that allows 0.5% R-40 will not generate a potentially hazardous TMA byproduct when it reacts with aluminum, refrigerant oils or other chemical compounds. Ongoing laboratory analysis and crucial experiments are being conducted to determine the potential reactions and volatility of counterfeit refrigerants with components inside a vehicle's A/C system, and determine the corrective procedures for mitigating any further potential risk so the refrigerant can be categorized and properly disposed of using current HAZMAT protocols.

Procedures for the electronic testers were developed to properly conduct the refrigerant screening for contaminants in vehicles, supply bottles/canisters and equipment stands. The procedures were used to educate and train depot and field personnel on electronic tester usage and results interpretation.

Potential Cost Liabilities

Based on the following assumptions made by IPT members, further assessments can be made for identifying costs associated with potential "at risk" vehicles and equipment. Each returning brigade includes an average of approximately 1,200 vehicles. Below is a summary of potential cost liabilities per brigade:

- 25 percent of vehicles (300 per brigade) returning from OCONUS are suspected to be contaminated to some extent, based on data collected.
- Recurring costs for each air conditioning service cycle are:
    - Approximately 1,800 pounds of pure refrigerant will be needed to recharge affected vehicles. The cost to replace refrigerant is $106.00 per vehicle or $31,800 total.
- 3.75 percent of all returning vehicles contain significant contamination, less than 90% pure R-134a refrigerant.
- Significantly contaminated vehicles may require parts to be replaced as a result; data currently being collected to determine what contamination requires which components to be replaced (i.e., compressors, hoses, condensers, evaporators, filter driers, seals, etc.).