KBA Kraftfahrt-Bundesamt
(Federal Motor Transport Authority)

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Interims Report
On tests with vehicles concerning Flammability and HF-exposure with vehicle air-conditioning systems when using R1234yf

1. Introduction

The Kraftfahrt-Bundesamt (KBA, Federal Motor Transport Authority) is responsible for both the issuing of type-approvals and market monitoring, and consequentially, product safety for road vehicles in Germany. In this capacity, it has monitored information provided by leading institutions since 2009 indicating that the use of R1234yf as a refrigerant in mobile air-conditioning systems may lead to the occurrence of new hazards in vehicles. The KBA has previously provided information on this topic several times at the regular meetings of the European type-approval authorities (TAAM), to which representatives of the European Commission were always invited. Furthermore, in April 2012, the KBA has requested the European Commission to include safety requirements concerning air-conditioning systems in the type-approval process.

Subsequent to the publication of vehicle tests by Daimler AG in September 2012, followed by those of the VDA, detailing a clear hazard occurrence (vehicle fire and HF-exposure), reinforcing grounds for suspicion were provided, which resulted in the KBA initialising a product safety investigation, informing the Commission accordingly. This investigation initially resulted in contradictory statements from different manufacturers regarding the occurrence of flammability incidents and the likelihood of it taking place. An increase in the risk of fire due to R1234yf was generally acknowledged in discussions with the car industry, however, even though different views on the likelihood of it occurring exist. The continued existence of the contradictory statements and the lack of investigations contracted by neutral agencies occasioned the KBA to carry out its own risk assessment tests.

In this context a project group was assembled with experts from the specialist authorities of the federal government. The parties involved were the Federal Institute for Materials Research and Testing (BAM) whose specialist department for gases and gas systems has been completing tests on the flammability of refrigerants for many years; the Federal Highway Research Institute (BASt) in its role as a research institute with its prominent

expertise in crash research and passive vehicle safety, and as a specialist advisor, the Federal Environment Agency (UBA), which has also accompanied tests of this kind for a long time. The project management was provided by the product safety department of the KBA, which contracted the Technical Service of the TÜV Rheinland, which is designated by the KBA, for the actual execution of the test. This technical service has crash test systems as well as expertise that has been proven to the KBA in all of the vehicle type-approval scope, and is also able to demonstrate in-depth experience in the completion of flammability tests on refrigerants in vehicles.

For reasons of transparency, the European Commission and the affected vehicle manufacturers were continuously involved in the progress of the tests.

2. Selection of the test scenario

It was necessary for the test scenario to depict an accident scenario, as happens in reality, as accurately as possible. The Daimler tests demonstrated a reproducible flammability in the B Class and on other vehicles. They therefore provided the starting point for the suspicion of a product safety deficit, in the context of which after the occurrence of a leakage of refrigerant in a vehicle with a hot engine, it would be possible for a fire to occur which could put the vehicle occupants and first aid personnel at risk. As a consequence of a fire involving refrigerant R1234yf hydrogen fluoride also develops, which could pose a further hazard to the vehicle occupants and first aid personnel. The most likely scenario for the occurrence of such a damage pattern is to be seen as being a crash such as a tail end rear impact collision on the motorway.

Accordingly, it was necessary that the proven damages from crash tests needed to be observed during the investigation.

To this end, on the basis of the actual accident data gathered by the BASt in the GIDAS database (GIDAS = German In-Depth Accident Study), the collision configurations conceivable for such a damage pattern were described and evaluated and a test setup was identified. This was tested for relevance in the total population of the accidents and evaluated with regard to the likelihood of occurrence.

As a setup, a crash test was selected on the basis of ECE R94 with a reduced speed of 40 km/h, which in an initial test phase with a running engine at operating temperature,

brought about a realistic damage pattern. For this scenario, on the basis of the evaluated accidents in Germany, the likelihood of occurrence was assessed at $2.9*10^{-4}$ per vehicle and year, and is therefore a relevant event in terms of the observation of the product safety of vehicles.

In a second test phase, refrigerant was then emitted by the damaged system components and tested for flammability and the exposition of hydrogen fluoride. As it is known from tests by the automotive industry that only very high temperatures in the engine bay can lead to refrigerant combustion, the test vehicles were rebuilt to a drivable state again after the test, and brought to the high – yet realistic – operating temperatures through driving with a towing dynamometer. The vehicle was then brought to a stop and refrigerant from the air-conditioning system was emitted by the components damaged during the crash. The formation of flames and hydrogen fluoride was then monitored using technical testing methods and recorded by using cameras.

3. Selection of the test vehicles

In accordance with the basic principles of product safety, with regard to the question requiring clarification, the vehicles were initially selected which represented the greatest apparent risk in German road traffic. The only vehicles that were therefore considered were those to use R1234yf as an air-conditioning system refrigerant stated in their type-approval. A risk discrimination of the vehicles subsequent to their construction was not possible, as tests by vehicle manufacturers and the VDA had shown that a refrigerant flammability is not limited to individual power train concepts. Accordingly, all correspondingly equipped vehicles to be registered in Germany were observed, and one vehicle from each of the four most popular vehicle types in terms of registration was chosen. As required, in the context of the chosen type, that version was chosen for which the highest operating temperatures were to be expected due to its engine configuration, meaning a low volume petrol engine with a turbocharger if possible. Two turbo charged vehicles were chosen, and two normally aspirated vehicles.

4. Actual test

After the selection of the vehicle types the individual test vehicles were purchased on the market in the customary way by the Technical Service. The affected vehicle manufacturers were then notified and invited to an information briefing seminar and presentation of the

vehicles on 24th of May 2013 in Cologne. In addition to the project participants and affected manufacturers, the associations representing them (VDA and VDIK), as well as a representative of the European Commission attended that meeting. They were informed about the objective and motivation for the tests, the choice of vehicle, the choice of the crash scenario, the test sequence and the execution of the HF measurements. The presentation of the vehicles also served the purpose of guaranteeing that the vehicles requiring testing do not have any abnormal particularities.

The vehicles were prepared for the pending tests by TÜV Rheinland, the temperature sensors were installed, and temperature profiles were measured on the motorway at full throttle, to be used again as the basis for the refrigerant outflow test.

On 10th and 11.06.2013 the crash tests with the four selected vehicles took place at the facilities of TÜV Rheinland. After the tests, the vehicles were examined and disassembled to determine the damage to the air conditioning systems. On 28.06.2013 the vehicle manufacturers were then informed about the damage patterns and the way forward in the context of the planned outflow tests.

Depending on the damage pattern of the crash tests, the vehicles were assigned to different categories for the outflow test, with levels 1 and 2 being of relevance within the product safety investigation (refer to no. 2):

1st level – empirically proven damages
2nd level – minimal extrapolation of the damage within the known results scatter
3rd level – greater extrapolation of the damage for the verification of the knowledge

During the tests at the **first level**, the refrigerant is only emitted by the components which had leaked during the previous crash test. In the **second level**, components for the refrigerant outflow were also used which were damaged in the crash test but had remained leak-tight, but for which it is known – also through manufacturer tests – that in the context of the results scatter they leaked, either through component tolerances or similar during comparable tests. The **third level** serves the verification of the results. Here,

- damage to the refrigerant lines is observed, for which it is assumed that they will remain leak-tight if they are new during the chosen crash conditions, but for which it is assumed that during more stringent conditions such as
  - the ageing of the pipe material and / or

- higher impact speeds
  they will be destroyed and / or

- higher temperatures in the engine area are taken as the basis in the expectation of the engine development to be expected in the future.

The test conditions in the third level do not allow any conclusive statement to be made on possible risks concerning the evaluation of the product safety. These tests serve the purpose, however, of the general evaluation of the test result in the direction of serious accidents, the likelihood and significance of which has not, however, yet been determined. It is possible that a further need for investigations can be derived from this.

In this context levels 1 and 2 can be used for the evaluation of a possible hazard in terms of the legally specified tasks as a product safety authority (evaluation of the specific product). Level 3, in contrast, serves the purpose of a more general risk assessment which among others makes it necessary to allow the safety requirements to be included in the type-approval process for air conditioning systems.

The outflow tests took place at the BAM testing site in Baruth/Mark during the 28th calendar week. A total of 22 tests took place in the individual levels. With the hooked towing-dynamometer, the vehicles were brought up to the operating temperatures (measured during the previous high speed motorway tests), reduced by 50 Kelvin, and brought to a standstill at the test site. The solenoid operated vents were then immediately opened on the stationary vehicles.

5. Results

During the tests at levels 1 and 2 inflammations did not occur in any of the tested vehicles; with some of the measurements at these levels, small, non-critical concentrations of pyrolitically caused hydrogen fluoride were measured.

With the tests at level 3, in one case, a full inflammation in the engine bay occurred, with the measurement of considerable quantities of hydrogen fluoride. In two further cases on other vehicles, measurements of hydrogen fluoride concentrations were made in non-negligible magnitudes without any evidence of flame formation. An evaluation of the hydrogen fluoride

exposures according to their temporal and spatial distribution as their expected medical effect can first be carried out in the final report.

6. Preliminary conclusion and next steps

Due to the ongoing evaluation of the test results, the presentation of the results is not yet complete and the conclusion is therefore to be viewed as being preliminary. The project group will draw its final conclusions after the complete evaluation of the detailed results. So far the following conclusion can be summarised:

- Due to the results of levels 1 and 2 (no inflammation and no critical hydrogen fluoride exposure) there is no sufficient proof which substantiates the suspicion of the occurrence of a serious hazard on the vehicle types tested here in terms of the Product Safety Law (ProdSG), that would occasion the announcement of direct interventional measures according to the ProdSG by the KBA. The responsibility of the manufacturers for the safety of their products continues to apply.

- On the basis of the comparative measurements with the previous refrigerant R134a in level 3, it is ascertained that the safety level of motor vehicles tends to deteriorate through the use of R1234yf, since no critical event of damage occurred with the use of R134a during the tests. To this extent, with R1234yf, a new technology is brought in use in motor vehicles which conflicts with the intended European goals for the reduction of hazards in road traffic.

As the conditions under which, and the factors with which, a refrigerant flammability and hydrogen fluoride exposure may occur in motor vehicles are not yet completely, but that the occurrence of such an event directly leads to a serious hazard for the health and safety of vehicle occupants and first aid personnel, further research into these circumstances is highly recommended. The subject of this investigation should also be whether these findings are included in the approval process for vehicles in the future, and safety requirements for vehicle air conditioning systems should be legally specified. This preliminary conclusion is, however, subject to the express proviso of supplementation and specification by further as yet outstanding test evaluations and the final report, which is expected to be ready in the autumn of 2013.

7. Summary

In the scope of the product safety investigation on possible hazards due to air conditioning systems in motor vehicles, prior to the completion of its own tests, the KBA (Federal Motor Transport Authority) was not able to exclude the possibility of the existence of a general safety problem with the use of the refrigerant R1234yf. With the objective of gaining further knowledge, the KBA initiated and managed its own investigations. The independent investigations and tests were carried out by a Technical Service designated by the KBA and supported by federal authorities and research organisations. On this basis, a detailed evaluation of the safety risk with the use of the refrigerant R1234yf in car air conditioning systems was carried out.

For the tests, initially, one vehicle was chosen from each of the four most popular vehicle types in terms of registration, which were type-approved with the refrigerant R1234yf. The vehicles were crashed in a realistic test setup on the basis of ECE regulation 94 at an impact speed of 40 km/h and their refrigerant circuits were then investigated for signs of damage. Subsequent to this, occurring damage was simulated in separate outflow tests of refrigerant on a vehicle with a hot engine and investigated for the occurrence of fire and EF-exposure. In result, the tests did not provide sufficient proof to substantiate the suspicion of the occurrence of a serious hazard on the vehicle types tested here in terms of the Product Safety Law (ProdSG), that would occasion the announcement of direct interventional measures according to the ProdSG by the KBA.

Despite this, however, during further tests carried out by the KBA in addition to the product safety investigations, flammability and hydrogen fluoride exposures were determined. This provides clear evidence of an ongoing problem concerning the use of R1234yf as a refrigerant in motor vehicle air conditioning systems. On the basis of over-arching safety considerations, it is therefore highly recommended that this is investigated in more detail to be able to better evaluate the potential risks.