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# Note to DG ENTR

# JRC technical and scientific support to the research on safety aspects of the use of refrigerant R1234yf on MAC systems

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## Executive Summary

Directive 2006/40/EC on mobile air conditioning (MAC) bans, de facto, the use of current refrigerant R134a in newly type-approved vehicles because of its impact on Climate Change. The automotive manufacturers have decided, in 2009, to use refrigerant R1234yf as the technical solution to comply with the Directive's targets.

In the summer of 2012 one manufacturer indicated a safety problem in the use of the abovementioned refrigerant R1234yf in some of its vehicles. In view of the OEM's (Original Equipment Manufacturer) deviating statements on the safety of the new refrigerant, the KBA (Kraftfahrt Bundesamt, German authority responsible for market surveillance and product safety for road vehicles) launched a series of vehicle tests.

To provide clarity with the shortest delay about the testing plans, procedures and results carried out by the KBA, DG Enterprise and Industry (DG ENTR) proposed a review of the KBA testing procedures by the JRC. The JRC was asked to provide an in-depth analysis of the report elaborated by KBA, in order to ascertain whether the results stemming from the tests are well founded and supported by a rigorous and scientific methodology. In particular, the JRC should clarify if, in the view of the aforementioned report, there is a reason to believe that refrigerant R1234yf may not operate in the vehicles with the appropriate level of safety, in the sense of the General Product Safety Directive (Directive 2001/95/EC) and the Framework Directive 2007/46/EC.

After a first analysis of the final KBA report and bilateral discussions with involved stakeholder, the JRC organized three public meetings of the *Working group on safety aspects of the use of refrigerant R1234yf on MAC systems* on 20st November 2013, 11th December 2013 and 24th January 2014. A first draft report was provided by the JRC on 10th December, and discussed in detail on 24th January.

The present final report includes, where appropriate, the comments and suggestions received form the working group members. This final report however has been entirely drafted by the JRC, and has not been presented for final approval to the working group.

Assessment of the KBA report:

The KBA performed a series of tests at three different levels, considering levels 1 and 2 for their assessment of possible risks within the scope of the statutory tasks as product safety authority, and level 3 tests as general risk appraisal.

The KBA report concludes after level 1 and level 2 tests that "… results do not provide sufficient supporting evidence of a serious risk within the meaning of the Product Safety Act (ProdSG) with the vehicle types tested here…" This view is in general shared by the JRC. The level 1 and level 2 testing showed no ignition of refrigerant R1234yf and no release of hydrogen fluoride (HF) despite the very high temperatures in the engine compartment. Consequently the results as such with the vehicles tested under the conditions as described for level 1 and level 2 testing provided **no** evidence of a serious risk.

The refrigerant release tests under level 3 were not taken into account by the KBA as relevant input "… for the assessment of a possible risk within the scope of the statutory tasks as product safety authority…"

The KBA states also that "… (only) the levels 1 and 2 were considered relevant for a risk assessment with respect to the product safety regulations, as only these can be associated with the necessary concrete probability of occurrence." This approach taken by the KBA is supported by the JRC because it reflects JRC's understanding of Article 2(b) of the General Product Safety Directive 2001/95/EC in which is stated *"...'safe product' shall mean any product which, under normal or reasonably foreseeable conditions of use (...) does not present any risk or only the minimum risks compatible with the product's use..."*.

Therefore drawing of conclusions from level 3 tests, further than the ones already drawn from level 1 and level 2 tests regarding the safe operation of the refrigerant R1234yf in MAC systems, is not appropriate, considering the definition of "safe product" in the General Product Safety Directive 2001/95/EC.

## 1. Background

Directive 2006/40/EC on mobile air conditioning (MAC) bans, de facto, the use of current refrigerant R134a in newly type-approved vehicles because of its impact on Climate Change. The automotive manufacturers have decided, in 2009, to use refrigerant R1234yf as the technical solution to comply with the Directive's targets.

However, on 25th September 2012 one Original Equipment Manufacturer (OEM) announced that in-house testing procedures carried out in the summer of 2012 indicated a safety problem in the use of the abovementioned refrigerant R1234yf in some of its vehicles.

In view of the OEM's deviating statements on the safety of the new refrigerant, the KBA (Kraftfahrt Bundesamt, German authority responsible for market surveillance and product safety for road vehicles) launched a series of tests, for which a preliminary report has been sent to the European Commission on the 8th of August 2013. The final report has been submitted on 31st of October 2013.

In the current market situation, and considering that vehicles are put on the EU market, which are in non-conformance with the MAC Directive's requirements, the European Commission is strongly pressed to provide clarity with the shortest delay about the testing plans, procedures and results carried out by the KBA.

DG Enterprise and Industry (DG ENTR) considered that this could best be achieved through a review of the KBA testing procedures by the JRC, considering also the risk assessment performed by the SAE CRP (Society of Automotive Engineers Cooperative Research Program) and testing procedures developed by the suppliers, manufacturers and associations. DG ENTR presented this possibility to the Member States as a confidence-building measure, and this was welcome by all involved parties.

## 2. Objective of the work

The objective of the work carried out by the JRC was to provide an in-depth analysis of the report elaborated by KBA, in order to ascertain whether the results stemming from the tests are well founded and supported by a rigorous and scientific methodology. In particular, the JRC shall clarify if, in the view of the aforementioned report, there is a reason to believe that refrigerant R1234yf may not operate in the vehicles with the appropriate level of safety, in the sense of the General Product Safety Directive (Directive 2001/95/EC) and the Framework Directive 2007/46/EC. The JRC may also give an opinion, if the issue so requires, regarding possible improvements to the MAC systems to adapt to the specificities of the refrigerant, in the framework of the relevant standardisation procedures and/or the mandatory regulatory framework (notably under the New Approach Pressure Equipment Directive or mandatory automotive regulation/UNECE).

The JRC was requested, during the assessment, to hold discussions with relevant stakeholders and institutions, which have undergone relevant testing procedures and risk assessments and may provide further information useful for the process, and to review existing literature in the field. This consultation process is essential to provide for transparency and confidence in the process, but does not entail the approval of the JRC's report by the stakeholders.

## 3. Process followed by the JRC

After high-level contacts and technical discussions with DG ENTR, the JRC confirmed in July 2013 its availability to provide scientific/technical support to the research on safety aspects of the use of refrigerant R1234yf on MAC systems in a transparent and open process, including the involvement of all concerned parties. The preliminary KBA report, submitted on 8th August 2013, and the final KBA report submitted on 31st October 2013, were studied in-depth by the JRC. Before calling for a first working group meeting, JRC discussed the various aspects, tests and analysis related to the use of refrigerant R1234yf in MAC systems with different stakeholder from Industries and Associations. The final KBA report was also discussed in-depth with the KBA before the first working group meeting was held. The tested vehicles as well as additional video material were presented by KBA to the JRC and to DG ENTR on that occasion.

The JRC organized three public meetings of the *Working group on safety aspects of the use of refrigerant R1234yf on MAC systems* on 20 November 2013, 11th December 2013 and 24th January 2014 [1]. All documents presented during these meetings and considered as public available input to the discussion and to this assessment were published on the DG ENTR MAC web-site [2].
The outcome of the assessment carried out by the JRC is gathered in this final report addressed to DG ENTR.

## 4. Major elements of the KBA report and JRC analysis [3]-[4]

In spring 2013 the KBA carried out a series of tests <u>for the purpose of product safety investigations</u> with road vehicles being type approved for the use of air conditioning systems with refrigerant R1234yf. The work presented in the KBA report and its annexes [3]-[4] was not intended to be a full risk assessment but a safety check in the sense of Article 8.1(a) of the Directive 2001/95/EC of the European Parliament and of the Council on general product safety. Results can therefore not be directly compared or confronted with results from a risk assessment study or fault tree analysis, such as those presented during the working group meetings [5]-[10].

In this report the JRC links where appropriate the KBA test results with elements from other risk assessment work, keeping in mind the above described purpose of the KBA tests.

An objectives of the work is to ascertain whether the results stemming from the tests are well founded and supported by a rigorous and scientific methodology. At this point it is essential to note that there are no European or international "Standard" or "Regulatory" testing procedures available that could have simply been followed by KBA for these investigations. Therefore experts' judgements and engineering judgements have - by nature of the tests - to play a strong role when the test conditions are selected.

In the following sections the JRC summarises its understanding of the testing carried out by the KBA, and of the analysis and conclusions provided by the KBA. Where appropriate the JRC provides its comments on the descriptive sections.

## 4.1 Vehicle selection [3]

- Only vehicles using according to their type approval the new R1234yf refrigerant were selected, taking into consideration their representativeness on the German market. The four vehicle types with highest registrations (until 1st April 2013), were selected and bought on the market, choosing where appropriate the variant which was expected to have the highest operation temperatures.

## 4.2 General test setup [3]-[4]

- The vehicle testing was divided in 3 different steps (see below for more details):
  - Pre-test on motorway to determine the maximum temperature of the vehicles $T_{max}$, measured at the exhaust manifold or turbocharger by driving at the vehicles' maximum speed (about 180 to 190 km/h).
  - Crash test under "warm and wet" –but not hot – conditions. The purpose of the crash tests was to generate real damages in the air conditioning system for the release of refrigerant in the later test levels 1-3.
  - Refrigerant release tests at 3 different levels, with engine target temperatures set to $T_{max}$-50°C, except for one test at level 3
    - Under level 1 testing the leakages were those observed after the crash test
    - Under level 2 testing additional leakages were introduced in the air conditioning systems in those positions where damages without leakage were already observed after the crash test
    - Under level 3 testing further leakage modifications and configurations in the refrigerant release setup were introduced to verify if the worst case was met before under level 1 and level 2 testing

## 4.3 Pre-test to determine refrigerant release test target temperatures [3]-[4]

- All vehicles were driven on the German motorway at maximum speed until the highest temperatures measured at the vehicles' exhaust manifold or turbocharger remained stable.

- The maximum temperatures $T_{max}$ reached by the cars were 667 °C, 756 °C, 784 °C and 710 °C respectively, calculated from the target temperatures provided in table 3 of the KBA report's annex [4]. The target temperature derived from the high speed tests, and to be used for the refrigerant release tests, was defined as T = $T_{max}$ - 50 °C. This is based on the assumption that a car in a crash cools down by 50 °C when braking and bringing the vehicle's speed down to 40 km/h at the moment of the impact.

**JRC COMMENTS on the pre-tests:**

Pre-tests have been carried out to determine the desired test temperature for the refrigerant release tests. During these tests the four cars were driven at maximum speed (the report states "at full load") to reach "very high but realistic" temperatures at the exhaust manifold or turbocharger.

The maximum speed of the four vehicles, derived from public available information, ranges between 180 km/h and 190 km/h.

Speed/temperature data obtained from these pre-tests were not provided with the KBA report. These data could have been helpful for the analysis of experimental conditions during the refrigerant release tests discussed later.

If vehicles need to run at highest speed (or full load) in order to reach such high temperatures, these temperatures are not typical but extreme values. With respect to average European conditions it can be questioned that these temperatures are occurring frequently. However, since the KBA is the German type approval authority, this approach is understandable and acceptable to describe a possible scenario in the German market, covering at the same time also the extreme cases with very high engine temperatures.

It should be noted as well that from a European point of view the probability of reaching the maximum speed driving conditions to achieve these temperatures is low. An estimate based on the European real-drive database can be found in the text box below.

*European countries impose speed limits typically in the range of 110-130 km/h, and Germany recommends 130km/h as the maximum speed on those highway sections without speed limits. The actual average highway speed can be expected to be comparable in all regions, and mainly governed by traffic density. The actual average highway speed therefore is much lower than the assumed top speed range 180-190 km/h of the four tested vehicles.*

*A European real-drive database was generated in support to the development of a new worldwide harmonized test procedure for light-duty cars (WLTP). Analysis of the European drive data shows:*

- *Motorway driving at speed levels higher than 180 km/h accounts for about 0.03% of the total time driven at extra high speed; this is equivalent to about 0.06% of the total driven distance on motorways at speed levels higher than 180 km/h*
- *Motorway driving, or extra high speed driving, contributes with 15% to 20% to the total distance travelled in Europe.*
- *Therefore in Europe the distance travelled at speed levels higher than 180 km/h amounts to about 0.01% of the total travelled distance.*

It was suggested during discussions at the first working group meeting that such temperatures could also be reached when towing a trailer or a caravan whilst driving uphill. Under these conditions the very high temperatures are not reached because of the maximum speed, but due to high engine load at moderate speed. This is also a reasonable scenario. The probability for getting involved in an impact at the critical collision speed, potentially by collision with another vehicle, driving either uphill or downhill, was not quantified, and can be expected to be lower than the probability of collisions on flat roads and under interurban or rural driving conditions.

Another suggested option discussed at the working group meeting was that critical temperatures could be reached during aggressive urban driving, through sequences of fast speeding up and braking. Also this third scenario is reasonable, desired high temperatures can be reached under such conditions. As before, also under this scenario the probability of getting involved in a collision at the critical collision speed was not determined.

In summary, the way to determine the engine temperature for testing the vehicles followed the need to reach highest possible temperatures. This is justified with different scenarios, which all are not quantified in terms of their probability to occur. Nevertheless, the scenarios are reasonable ones, covering urban, extra-urban and highway driving conditions. But, although not quantified, the probability of being involved in a collision at 40 km/h with 40% offset **and** at extreme engine temperatures is lower than the probability determined in the KBA report for the selected and described crash scenario [4]. This however does not imply that the selected combination of test conditions (damage profile **and** very high engine temperatures) were unrealistic: the test conditions were extreme, but fully justified within the scope of the vehicle testing for the purpose of product safety investigations (see text box below).

*Extract from the DIRECTIVE 2001/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 3 December 2001 on general product safety [11] (text highlighted by the JRC)*

*Article 2*
*For the purposes of this Directive:*
*(…)*
*(b)* ***'safe product' shall mean any product which, under normal or reasonably foreseeable conditions of use…***

*Article 8*
*1. For the purposes of this Directive, and in particular of Article 6 thereof, the competent authorities of the Member States shall be entitled to take, inter alia, the measures in (a) and in (b) to (f) below, where appropriate:*
*(a) for any product:*
*(i)* ***to organise, even after its being placed on the market as being safe, appropriate checks on its safety properties****, on an adequate scale, up to the final stage of use or consumption;*
*(ii) to require all necessary information from the parties concerned;*
***(iii) to take samples of products and subject them to safety checks;***

### 4.5 Crash tests [3]-[4]

- To generate a realistic damage profile in the engine compartment, the crash tests have been carried out following the Regulation No. 94 of the Economic Commission for Europe of the United Nations (UN/ECE) - Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision (ECE-94). Reported and fully justified deviations from ECE-94 were the reduced vehicle speed of 40 km/h (instead of 56 km/h) and the overlap of 40% positioned on the vehicle's front side where most air conditioning system components were placed (instead of the steering wheel side).

- The crash test setup was determined based on the evaluation of the vehicle accident data base GIDAS (German In-Depth Accident Study). The impact speed of 40 km/h was selected to represent an accident resulting in damage to the air conditioning system, while leaving sufficient air space in the engine compartment to create the air/refrigerant mixture needed for ignition.

- Crash tests were performed under "warm and wet" conditions: all liquids were on board, the cars were heated up by running the (load free) engine at higher speed, reaching temperatures between 340°C and 400 °C at the moment of impact at turbocharger or exhaust manifold, with the coolant temperatures slightly above 100 °C.

- Two out of four vehicles showed damages but no leakages of the air conditioning system components, the other two vehicles had leaking air conditioning systems. All vehicles showed damages to the condenser.

**JRC COMMENTS on the crash tests**

The deviations from ECE-94 are reasonable because they are based on statistical data from an accident data base, as well as on the assumption that the target speed of 40 km/h would not only create damages to the air conditioning systems, but also leave sufficient space in the engine compartment to generate an inflammable mixture of air and refrigerant.

The impact velocity of 40 km/h is critical in the sense that two vehicles showed no leakages of the air conditioning system after the impact, although the systems showed damages, mainly at the condenser. An impact at slightly higher velocity might have caused leakages also on these two vehicles. Therefore the approach to artificially create these leakages at damaged components for level 2 testing is fully justified.

### 4.6 Refrigerant release tests (levels 1 and 2) [3]-[4]

- All vehicles were repaired after the crash test, and damaged parts were replaced. Care was taken to minimise changes regarding the components' positions after the crash and the free space in the engine compartment.

- The originally leaking components were re-installed, as representative as possible, in their post-crash position. Solenoid valves were used to release the refrigerant through these leakages.

- Engine coolant was released in a similar way during the test.

- Before starting the release tests, the vehicles were heated up with a trailer brake to reach the target temperature ($T_{max}$ - 50 °C).

- After the temperatures were reached, the cars were parked in the test area, and the refrigerant was released through the observed leaks (level 1: two vehicles, four tests).

- The same approach was taken when testing components with leakages thoroughly derived from the damage patterns observed after the crash tests, and manufactured from the original vehicle parts (level 2: four vehicles, six tests)

- All of the 10 refrigerant release tests at high temperature, carried out under level 1 and level 2, showed no refrigerant ignitions and no HF release above 1 ppm.

**JRC COMMENTS on the refrigerant release tests (levels 1 and 2)**

The KBA report concludes that level 1 and level 2 test results "…do not provide sufficient supporting evidence of a serious risk within the meaning of the Product Safety Act (ProdSG) with the vehicle types tested here…" [3]. This view is in general shared by the JRC.

The level 1 and level 2 testing showed no ignition of refrigerants and no HF release above 1 ppm, despite the very high temperatures in the engine compartment. Consequently the results as such with the vehicles tested under the conditions as described for level 1 and level 2 testing provided **no** evidence of a serious risk, which goes further than the statement "not … sufficient supporting evidence", considering the definition of "safe product" in the General Product Safety Directive (Directive 2001/95/EC, see text box at the end of chapter 4).

Beyond that it should be noted that tests with the two vehicles that were brought only to level 2 and level 3 testing were carried out at temperatures significantly higher than the target temperatures. The measured temperatures in these test were at average 22 °C and 34 °C higher than the respective target temperature, or 28 °C and 16 °C less than the maximum temperatures achieved during the full load motorway testing (instead of being 50 °C lower) [4]. Therefore the two vehicles were tested under conditions even worse than planned.

Discussions at the working group meetings revealed that towing of a trailer at lower speed might not have the same engine compartment cooling effect than driving at highest speed. Consequently the engine compartment temperatures of certain components or in certain compartment zones might have been already higher than "realistic ones" or those measured during the motorway pre-tests.

On the other hand it must be noted that the towing tests were performed with the damaged and buckled hoods. This opening in the upper part of the engine compartment of the cars might have allowed for heat release during towing, and might have reduced the engine compartment temperature. In the case of testing with damaged hoods, having data comparing the high speed engine compartment temperatures from the pre-tests versus those reproduced with the trailer on the test track would be useful for the verification of the temperature distributions under hood.

### 4.7 Refrigerant release tests (level 3) [3]-[4]

- Three out of four vehicles were tested further at level 3. The remaining fourth vehicle was not tested because no further changes in ignition behaviour and HF generation were expected.

- Level 3 testing comprises test at different temperatures and with different – not observed – damage profiles, in order to verify if the worst case was met with previous tests.

- One car was tested in two configurations, (i) with the leak inserted for a level 2 test, but turned by 90° towards the engine and the condenser not leaking, and (ii) as before but with condenser leak and an additional plate in front of the leak to change flow direction.

- The second car was tested in four configurations, (i) with the observed condenser leak and an additional leak in a tube on the low pressure side, (ii) with the additional leak in a tube and the condenser not leaking, (iii) with the additional leak as before but turned 90° towards the engine and the condenser not leaking, and (iv) with the additional, 90° turned leak, the condenser leak and an additional plate in front of the condenser leak to change flow direction. For the latter test the test temperature was about 80 °C higher than the target temperature. This is about 30 °C above the maximum temperature measured during maximum speed motorway driving. The reason for this was that the vehicle was equipped with a non-charged engine, coming already with lower engine temperatures that the others. The vehicle is today available with a turbo engine, and it can be assumed that the new vehicle, if tested under similar conditions, would have higher engine temperatures.

- The third car was tested in total six times under 3 different configurations, (i) two times with the observed condenser damage and an additional oval shaped leak in a tube connector, (ii) three times only with the additional oval shaped leak, and (iii) once with the additional oval shaped leak, but using R134a as refrigerant. Test temperatures were between 18 °C and 45 °C higher than the target temperature, the latter one being almost at the maximum temperature measured during maximum speed motorway driving.

- Under level 3 testing the first and second car released in 3 out of 6 tests elevated HF concentrations under hood (18, 133, 150 ppm).

- Under level 3 the released refrigerant R1234yf ignited in the third car, combined with higher measured values of HF in the engine compartment (3300, 5400 ppm). This happened in two out of three identical tests that were carried out without the leaking condenser but with the additional oval shaped leak.

- Under level 3 the comparative test with refrigerant R134a did not result in ignition; HF concentrations under hood were at about 3 ppm.

*Exposure to HF concentrations:*

*The Acute Exposure Guideline Levels (AEGL) are internationally accepted as tolerable concentration level for once-in-a-life-time or rare exposure to airborne chemicals.*

*AEGL-2 is the concentration value "...above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other, long-lasting adverse health effects or an impaired ability to escape." (http://www.epa.gov/oppt/aegl/pubs/define.htm)*

*The AEGL-2 value for HF is 95 ppm for an exposure period of 10 minutes. AEGL-2 was derived from the No Observed Effect Level (NOEL) for serious lung damages in rats, which is 950 ppm over a period of 10 minutes. To consider the different sensitivity of rats and humans, the NOEL was divided by 10 to obtain the AEGL-2 value. Therefore no irreversible or long lasting effects should be expected when being exposed to an HF concentration of 95 ppm for not longer than 10 minutes.*

**JRC COMMENTS on refrigerant release tests (level 3)**

The refrigerant release tests under level 3 were not taken into account by KBA as relevant input "… for the assessment of a possible risk within the scope of the statutory tasks as product safety authority…" [3]. The KBA states also that "… (only) the levels 1 and 2 were considered relevant for a risk assessment with respect to the product safety regulations, as only these can be associated with the necessary concrete probability of occurrence" [3]. This approach taken by the KBA is supported by the JRC because it reflects the JRC's understanding of Article 2(b) of the General Product Safety Directive 2001/95/EC in which is stated *"…'safe product' shall mean any product which, under normal or reasonably foreseeable conditions of use (...) does not present any risk or only the minimum risks compatible with the product's use…"*[11]

Therefore drawing of conclusions from level 3 tests, further than the ones already drawn from level 1 and level 2 tests regarding the safe operation of the refrigerant R1234yf in MAC systems, is not appropriate, considering the definition of "safe product" in the General Product Safety Directive 2001/95/EC.

Supporting details are given in the following paragraphs.

**Concrete probability of occurrence of level 3 tests**
Level 3 testing is mainly research driven, to explore what could happen under assumed extreme conditions not yet covered in the level 1 and level 2 testing. The level 3 research character is also confirmed (i) by going with these tests beyond the boundaries and limitations set for level 1 and level 2 tests, in order to verify if the worst case was chosen in the test setup, and (ii) by considering in level 3 also the *"…development of engines which can be expected for the future…"* as stated in the KBA report [3].

Whilst level 1 and level 2 tests were realistic and were considered by the KBA for the conclusions on risks with respect to the product safety regulations, the level 3 tests could not be associated with the necessary concrete probability of occurrence, but serve for a general appraisal of the risk [3].

Level 3 test temperatures were very high, approaching almost always the maximum temperature measured during the motorway high speed pre-test, and exceeding once that maximum temperature by +30 °C. These tests were carried out to understand if ignition might occur under higher engine temperatures that might be achieved with future vehicle technologies and future engine designs.

**Test resulting in ignition of the refrigerant**
Test conditions under which ignition was observed were extreme, and combined elements that very unlikely appear at the same time: a condenser not leaking after front collision and a side intrusion entering sufficiently deep into the engine compartment to generate the leaking refrigerant line, together with high engine temperatures and a special leak shape at the refrigerant line that is considered typical for a high speed crash scenario.

When combining these elements, the necessary conditions to ignite the refrigerant – sufficient refrigerant in an ignitable mixture, high temperatures and enough free air space for an ignition – can be created.

The damage profile in the test cases where the ignition of the refrigerant in the third vehicle was observed was challenged by some participants of the working group meeting.

The damage profile is based on a crash scenario that combined a front crash with no leakages to the condenser with a side intrusion leading to the simulated leakages in the damaged refrigerant lines. After discussions about the relevance of such a crash scenario, the Bundesanstalt für Straβenwesen (BaSt) carried out an additional GIDAS accident database analysis [12], presented by KBA during the third meeting of the working group.

The BaSt report concluded that the GIDAS database gave evidence of such a damage profile for 27 vehicles out of a subsample of 4400 vehicles extracted from the database. Purpose of the analysis was to find out how often such damage profiles occur. Therefore the BaSt report states also very clearly, that it was not considered important to know whether actually refrigerant lines passed through the damaged zone, and whether actually refrigerant lines were damaged or not. In other words, no evidence was given that under this scenario the refrigerant lines in one or more of the 27 vehicles were damaged and leaking.

As consequence the calculated relevance given in the BaSt report are indicative for an upper limit of vehicles involved in accidents and having the desired damage profile. But it is the relevance for only one element of the scenario, the damage profile. It does not include the probability of having leaking refrigerant lines in a relevant area, nor does it include the high test temperatures or the high speed character of the accident needed for the specific leak.

In summary: Each of the different single test conditions combined under level 3 testing reflect a situation which occurrence can't be excluded. The combined probability of occurrence for the combination of several single conditions into one scenario was not determined. Compared to the scenarios for the realistic level 1 and level 2 testing, the probability of level 3 scenarios must be assumed to be far lower, and not reflecting *"normal or reasonably foreseeable conditions of use"* [11] under which the General Product Safety Directive 2001/95/EC applies.

**Tests with Refrigerant R134a**

One refrigerant release test configuration was repeated 3 times, showing 2 times ignition of the refrigerant R1234yf and the release of HF at higher concentrations. The same test configuration was repeated once with the refrigerant R134a, showing no ignition and only low HF release.

Recalling that the KBA tests were designed for the purpose of product safety investigations with road vehicles being type approved for the use of air conditioning systems with refrigerant R1234yf [3];

and recalling that the objective of the JRC assessment is to clarify if, in the view of the aforementioned report, there is a reason to believe that refrigerant R1234yf may not operate in the vehicles with the appropriate level of safety, in the sense of the General Product Safety Directive (Directive 2001/95/EC);

and considering Article 2 of the General Product Safety Directive 2001/95/EC stating that *"The feasibility of obtaining higher levels of safety or the availability of other products presenting a lesser degree of risk shall not constitute grounds for considering a product to be 'dangerous'"*[11]

makes it inappropriate in this context to analyse and compare the risk levels of the two different products and to draw further conclusions.

*Extracts from the DIRECTIVE 2001/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 3 December 2001 on general product safety [11] (text highlighted by JRC)*
*Article 2*
*For the purposes of this Directive:*
*(…)*
*(b)* ***'safe product' shall mean any product which, under normal or reasonably foreseeable conditions of use including duration and, where applicable, putting into service, installation and maintenance requirements, does not present any risk or only the minimum risks compatible with the product's use, considered to be acceptable and consistent with a high level of protection for the safety and health of persons,***
*(…)*
***The feasibility of obtaining higher levels of safety or the availability of other products presenting a lesser degree of risk shall not constitute grounds for considering a product to be 'dangerous';***

## 5. Further elements that were discussed and considered

**Ignition temperature of refrigerant R1234yf**

It is a well-known fact that refrigerant R1234yf is a flammable product, with an auto-ignition temperature (AIT) of 405 °C (see for example the Material Safety Data Sheet for the refrigerant R1234yf [13]).
It is also well-known that refrigerant R1234yf forms corrosive and toxic hydrogen fluoride (HF) in case of thermal decomposition [14].
The two KBA tests resulting in ignition of the refrigerant and HF formation have been carried out at temperatures of 693 °C and 705 °C. This is in good agreement with the test data presented by SAE CRP suggesting that ignition of refrigerant R1234yf in the engine compartment can occur at temperatures above 700 °C [8].
For their fault-tree analysis (FTA) the SAE CRP assumes that refrigerant R1234yf causes fire in all vehicle accidents with damaged air conditioning system, when the hottest engine temperature is at or above 700 °C [5]. In a not published report on alternative FTA, the authors worked with a temperature of 525 °C for almost immediate ignition.
A presentation made by the Bundesanstalt für Materialwissenschaft und –prüfung (BAM) reviewed different tests for ignition temperatures of the refrigerant R1234yf [15]. BAM concluded that ignition temperatures depend strongly on test conditions, and suggests as most conservative approach to use the AIT for risk assessments [15].
The 700 °C temperature threshold for refrigerant ignition was also challenged by a vehicle manufacturer, suggesting that in the own tests ignition of the refrigerant R1234yf in vehicles was observed at temperatures down to 635 °C [10].
However, KBA tests showed also no ignition in 12 tests carried out at temperatures very near or above 700 °C (range 696 °C to 770 °C), and no ignition in 20 tests carried out at temperatures above 500 °C (range 615 °C to 770 °C) [4].
But by nature of the problem, it is impossible to prove for any of the above mentioned tests that hottest spot for temperature measurement was identified.

**Safety, liability and acceptable risk**

The KBA report states clearly: "…the manufacturers still remain liable for the safety of their products…" [3]
It was discussed in another context during the working group meetings whether or not the terms "safety" and "acceptable risk" are understood in the same way buy all participants. The text box below informs about the definition of safety and risk according to an ISO

standard. The text box in the previous chapter informed already about the definition of a "safe product" according to the General Product Safety Directive 2001/95/EC.

| |
|---|
| *ISO26262-1:2011 defines safety and risk as follows:*<br><br>*Safety:* *absence of unreasonable risk*<br>*Unreasonable risk:* *risk judged to be unacceptable in a certain context according to valid societal moral concepts*<br>*Risk:* *combination of the probability of occurrence of harm and the severity of that harm* |

**Pressure Equipment Directive**
According to Guideline 1/46 of the Directive 97/23/EC of the European Parliament and the Council on the approximation of laws of the Member States concerning pressure equipment (PED: Pressure Equipment Directive) "an item of pressure equipment not contributing directly to the functioning of the vehicles is covered by the PED (e.g. air conditioning system,…" [16].
The PED provides in Annex 1 Essential Safety Requirements, applicable also for the mobile air-conditioning systems. The Article 1.1 states: "Pressure equipment must be designed, manufactured and checked, and if applicable equipped and installed, in such a way as to ensure its safety when put into service in accordance with the manufacturer's instructions, or in reasonably foreseeable conditions" [17].

**Measures to further improve safety**
Although not being part of the working group's mandate, some measures to further improve MAC safety have been presented to the working group [14]-[15]. For example a list of three explosion protection concepts has been presented by BAM [15], modified to adapt to the MAC. Most of these measures, such as release valves in MAC circuits, fire extinguisher, reducing hot surfaces (thermal insulation) and additional ventilation were discussed in different occasions during the working group meetings.

## 6. Literature


[1] Call for expression of interest: Participation in the working group on safety aspects of the use of refrigerant 1234yf on MAC systems, accessed on 03.03.2014 under http://ec.europa.eu/enterprise/newsroom/cf/itemdetail.cfm?item_id=7053

[2] MAC working group documents, accessed on 03.03.2014 under http://ec.europa.eu/enterprise/sectors/automotive/environment/macs/index_en.htm

[3] Kraftfahrt-Bundesamt: Report on flammability and HF exposure trials with vehicle air conditioning systems using R1234y, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/72417c70-4487-46e4-a4c8-86ba613b9839/MAC%20KBA%20report%20summary-EN.pdf

[4] Kraftfahrt-Bundesamt: Annexes to the Technical Report - Investigations into the possible flammability of refrigerant R1234yf in motor vehicles, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/321c58e4-da1f-4c03-a682-11c595c34de9/Annexes_to_KBA_MACreport.pdf

[5] SAE CRP: Coolant Behavior Consideration, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/250819aa-22f8-4834-8d44-d950889ae6b1/SAE_Coolant_Behavior_Consideration_Stakeholder(11_20_2013).pdf

[6] SAE CRP: Location of Refrigerant in A/C System, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/e014124d-54f1-47fd-a6af-949e2c5d23df/SAE%20presentation%20refrigerant%20location_Stakeholder(11_20_2013).pdf

[7] SAE CRP: Effects of flammable fluids on propagation from GIDAS, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/e3f48ddb-7def-4031-8d66-4f59404dde16/SAE_GIDAS_flammable_fluids.pdf

[8] SAE CRP1234-4: Additional information from the SAE CRP-1234-4, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/8cd088c2-49ba-43b9-9e2d-826486b92386/SAE%20CRP1234-4%20second%20stakeholders%20meeting%20presentation.pdf

[9] SAE CRP1234-4: Clarifications to questions raised at 2nd Stakeholders Meeting on Fault Tree Analysis, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/40b868f1-3680-4ff0-bb07-ecad01268bdd/2.a.%20Presentation%20by%20SAE.pdf

[10] Daimler AG: Daimler’s Observations on Risk Assessments of R1234yf, 11.12.2013, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/6ea2b30c-a0ce-41b5-92a9-e1fd37354eb4/DAG%20Observations%20on%20Risk%20Assesments%20of%20R1234yf.pdf

[11] Directive 2001/95/EC of the European Parliament and of the Council of 3 December 2001 on general product safety, OJ L 11, 15.1.2002, p. 4, accessed on 03.03.2014 under http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:011:0004:0017:en:PDF

[12] Bundesanstalt für Straßenwesen, GIDAS-Unfalldatenanalyse, Teil II für „R1234yf-Projekt“ “Analyse – Frontbeschädigungen mit Intrusionen im Bereich der Kältemittelanlage“, 07 Januar 2014, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/305ee501-70aa-4b73-b698-eb7ed0730dda/5.b.%20Presentation%20by%20KBA%20of%20BASt%20GIDAS%20report.pdf

[13] Material Safety Data Sheet for the refrigerant R1234yf, accessed on 03.03.2014 under http://msds-resource.honeywell.com/ehswww/hon/result/result_single.jsp?P_LANGU=E&P_SYS=1&C001=MSDS&C997=C100;E%2BC101;SDS_US%2BC102;US%2B1000&C100=*&C101=*&C102=*&C005=000000011078&C008&C006=HON&C013

[14] Honeywell: Safety Aspects of Use of 1234yf, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/81e62b68-373b-4531-8b25-e41d86667dbe/JRC%20Stakeholders%20meeting%20Honeywell%20Presentation%2020%20Sept%202013.pdf

[15] Bundesanstalt für Materialforschung und -prüfung: Ignition Temperatures of R1234yf, accessed on 03.03.2014 under https://circabc.europa.eu/sd/a/43214d70-c128-4510-8b50-7e556e16d21d/4.%20Presentation%20by%20BAM%20Ignition%20temperatures%20of%20R1234yf.pdf

[16] Guideline 1/46 of the Directive 97/23/EC of the European Parliament and the Council on the approximation of laws of the Member States concerning pressure equipment (PED: Pressure Equipment Directive) accessed on 03.03.2014 under http://ec.europa.eu/enterprise/sectors/pressure-and-gas/files/ped/ped-guidelines_en.pdf

[17] Directive 97/23/EC of the European Parliament and the Council on the approximation of laws of the Member States concerning pressure equipment (PED: Pressure Equipment Directive), OJ L 181, 9.7.1997, p. 1, consolidated text accessed on 03.03.2014 under http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1997L0023:LATEST:EN:PDF