<u>JRC technical and scientific support to the research on safety aspects of the use of refrigerant 1234yf on MAC systems</u>

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, the use of refrigerant HFO 1234yf as the technical solution to comply with the Directive's targets.

However, on 25 September 2012 one 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 HFO 1234yf in some of its vehicles.

In view of the OEM's statements on the safety of the new refrigerant, the KBA (German type-approval authority) and the German Ministry of Transports launched a series of testing procedures, which preliminary report has been sent to the Commission the 7th of August 2013. The final report has been submitted on 31st of October 2014.

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

DG Enterprise and Industry (DG ENTR) considers that this can best be achieved through a review, by the JRC, of the KBA testing procedures, considering also the risk assessment performed by the SAE (review of 2012/2013) and testing procedures developed by the suppliers, manufacturers and associations (e.g. VDA). DG ENTR presented this possibility to the Member States as a confidence-building measure, and this was welcome by all involved.

2. Objective of the work

The objective of the work to be carried out by DG JRC is to provide an in-depth analysis of the report elaborated by KBA, permitting to ascertain whether the results stemming from the tests are well founded and supported by a rigorous and scientific methodology. In particular, DG JRC shall clarify if, in the view of the aforementioned report, there is a reason to believe that refrigerant R-1234yf 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).

DG JRC is requested, during the assessment, to hold discussions with relevant stakeholders and institutions (indicative list: KBA; ACEA; CLEPA; Honeywell; DuPont; SAE), 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 by the stakeholders of JRC's report.

The process and outcome of the assessment carried out by DG JRC is gathered in this final report addressed to DG ENTR.

3. JRC analysis

In spring 2013 the KBA carried out test for the purpose of product safety investigations with road vehicles being type approved for the use of air conditioning systems with refrigerant R1234yf. It must be clearly stated that there is no Standard or regulatory testing procedure available that can simply be followed for these investigations! Therefore experts and engineering judgements play a strong role when selecting the test conditions.

Vehicle selection

- Vehicles with R1234yf refrigerant were selected according to their representativeness on the German market. The four vehicle types with highest registrations, choosing the variant which was expected to have the highest operation temperatures, were selected and bought on the market.

General test setup

- The vehicle testing was divided in 3 different steps (see below for more details):
    - Pre-test on motorway to determine the maximum (or highest?) temperature of the vehicles (Tmax, measured at 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 Tmax - 50°C except for one test at level 3; level 1 leakages were those observed after the crash test, level 2 additional leakages were introduced in the air conditioning systems where damages without leakage were observed after the crash test; for level 3 specific leakage systems and other modifications were introduced

Pre-test to determine refrigerant release test target temperatures

- 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.
- From public available information the maximum speed of the four vehicles ranges between 180 and 190 km/h.
- Maximum temperatures Tmax reached by the cars were 667 °C, 756 °C, 784 °C and 710 °C respectively, calculated from the target temperatures given in table 3 of the report's annex. The target temperature derived from the high speed tests, and to be used for the refrigerant release tests, was defined as T = Tmax – 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.

Speed/temperature data obtained from these pre-tests should be made available to better analyse experimental conditions during the refrigerant release tests!

If vehicles need to run at highest speed (or full load) in order to reach such high temperatures, the conclusion that these temperatures are "realistic" can be seriously questioned as statement regarding average European conditions. Speed limits exist currently all over Europe, except on some highways in Germany and on the Isle of Man. All other countries impose speed limits typically in the range of 110-130 km/h, which is much lower than the assumed 180-190 km/h top speed of the four tested vehicles.

It was argued during discussions that one could reach such temperatures also when towing a trailer/caravan whilst driving uphill. This is a reasonable scenario, but under such conditions it is likely also not very likely to reach the assumed impact speed of 40 km/h in a collision when driving uphill. Consequently the damage profile might be completely different, and air conditioning system components might be fully operational and not leaking.

Another option was that these temperatures can be reached during aggressive urban driving, through fast speeding up and braking sequences. Here again the scenario is reasonable. However, also in this scenario, being typical for urban driving, the reaching of the assumed collision impact speed of 40 km/h is not very likely.

Crash tests

- To generate a realistic damage, the crash tests have been carried out following Regulation ECE-R94 with reduced vehicle speed of 40 km/h (instead of 56 km/h) and an overlap of 40% on the vehicle's front side where most air conditioning system components were placed (instead of steering wheel side).
- The crash test setup was chosen after analysis of the vehicle accident data base GIDAS. The impact speed of 40 km/h was chosen to represent an accident resulting in a damage of the air conditioning system, but leaving sufficient air space in the engine compartment to create the air/refrigerant mixture needed for ignition.
- Crash tests were performed at "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 on the condenser. The latter seems logical, because the condenser is installed in front of the engine, and was exposed to the crash structure because the vehicles' impact zone was selected accordingly.

JRC COMMENTS on the crash tests

The deviations from R94 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 at the air conditioning systems, but leave also sufficient space in the engine compartment to generate a mixture of air and refrigerant that could ignite.

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.

Refrigerant release tests (levels 1 and 2)

- 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.
- Also the original leaking components were installed, as good 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 (Tmax – 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 the artificially created leaks (level 2, four vehicles, six tests)
- None of the 10 level 1 and level 2 refrigerant release tests at high temperature showed refrigerant ignitions.

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

The 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…". This view is in general shared by JRC.

Nevertheless, it must be noted that the level 1 and level 2 testing showed no ignition of refrigerants and no HF release despite the very high temperatures in the engine compartment. Consequently the results as such with the vehicles tested under the conditions as described provided **no evidence** of a serious risk, which goes further than the statement "not … sufficient supporting evidence".

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). Therefore the two vehicles were tested under conditions even worse than planned.

Discussions 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 made with the damaged and buckled hood. This opening in the upper part of the engine compartment might have allowed for heat release during towing, and might have reduced the engine compartment temperature. Without comparison of the engine compartment temperatures from the motorway pre-test and the refrigerant release tests no further conclusions can be drawn.

Refrigerant release tests (level 3)

- Three out of four vehicles were tested further at level 3. The remaining 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.
- 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.
- A 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.
- A 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 third car showed ignition of the release refrigerant, combined with higher measured values of HF in the engine compartment. This happened in two out of three tests that were carried out without leaking condenser but with the additional oval shaped leak.

JRC COMMENTS on refrigerant release tests (level 3)

The refrigerant release tests under level 3 were not considered by KBA as relevant input to their conclusions regarding the risk within the meaning of the Product Safety Act (ProdSG). This approach is supported by JRC.

The driving force behind the tests carried out under level 3 is engineering curiosity, test show a strong research character by going clearly beyond the boundaries/limitations set for level 1 and level 2 testing (and assumed to be realistic).

Test temperatures were very high, approaching almost always the maximum temperature measured during the motorway high speed pre-test, exceeding once that maximum temperature by 30 °C. These tests were (probably) carried out to understand if under higher engine temperatures, that might be expected for future technologies, ignition might occur.

Test conditions under which ignition was observed were extreme, and combined elements that not likely would appear at the same time: a condenser not leaking, together with high temperatures and a special oval leak typical for a high speed crash in a very hot engine compartment that is almost not crushed. With these elements the three necessary conditions to ignite the refrigerant – sufficient refrigerant, high temperatures and enough free air space for an ignitable mixture – can be created.

In summary, the test conditions under level 3 testing reflect situations that in principle might occur (occurrence can't be excluded). But these situations were not derived on basis of a real-life accident data base. Therefore the probability of such accident scenarios should be by far lower and not comparable with the scenarios considered for level 1 and level 2 testing.

All products used in cars should be treated/tested/dealt with equally. Other fluids and other solid materials might burn and might release as well harmful substances when burning. Level 3 testing as such, by picking just one specific fluid used in cars, is not appropriate because it is not compliant with the before mentioned principle.

Due to the assumed clear research nature of level 3 tests the drawing of further conclusions regarding future safe operation of the refrigerant seems therefore not appropriate / not advisable / questionable.

To be added for final version:

KBA experimental results in the light of SAE fault tree analysis and other work (consider different purpose; KBA tests not meant as risk analysis; confirm ca. 700 °C needed for ignition; risk of person in car to be exposed vs. risk of vehicle to catch fire?) and other work

Existing legislation, regulations, directives and standards