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Subject

Review of results of emission tests by TNO on Mercedes diesel vehicles in relation to recent information on possible defeat devices

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Summary

Upon request of the Dutch Ministry of Infrastructure and Water management, TNO has reviewed all its previously performed laboratory and on-road emission measurements on passenger cars and vans from Mercedes Benz to check for possible indications of two types of defeat devices:

- one that switches off emission reduction systems after 26 km of driving, and
- one that detects whether the vehicle is undergoing a type-approval test or is driving on the road on the basis of speed and acceleration patterns.

From this review it is concluded that these on-road emission tests do not provide any indication of switching behaviour in the emission control software related to the driven distance after start of the trip.

For one vehicle a comparison of available roller bench tests showed large differences in the emissions measured on tests with a cold start on the NEDC type approval test cycle and the WLTC cycle, which is more representative for real-world driving. As in the execution of the tests the roller bench settings with respect to the simulation of mass and resistance were not the same, it cannot be concluded that this comparison provides an indication of cycle recognition. Moreover, significantly higher emissions on different real-world based test cycles compared to the NEDC are observed for many tested models of different brands, as already reported by TNO in 2016 and earlier.

Introduction

On February 17, 2018, Bild am Sonntag reported -on the basis of confidential documents- that U.S. investigators have found potentially illegal software in Mercedes-Benz diesel cars intended to help the vehicles pass emissions tests in the U.S.. One possible defeat device, named "Bit 15", was reported to switch off emission reduction systems after 26 km (16 miles) of driving. Another defeat device, named "Slipguard", would recognise on the basis of the speed and acceleration values whether a vehicle is tested in the lab or is driving on the road.

As TNO has tested several Mercedes-Benz vehicles in recent years, the Dutch Ministry of Infrastructure and Water management has requested TNO to review its test results for indications of switching behaviour as described above.

Tested vehicles and test programme

Table 1 lists all Mercedes Benz vehicles that in recent years have been subjected by TNO to emission testing in the lab (on the roller bench) and on the road (with SEMS or PEMS).

Vehicles tested on the road include two Euro 6 passenger car of the same model, six Euro 5 and 6 vans, and two vans which have an engine type approved under the Euro VI legislation for heavy duty vehicles.

In addition to the vehicles tested on the road, TNO has also tested a Euro 5 E220 (2010), a Euro 6 C220 (2015), a Euro 6 350 (2010), and a Euro 5 Sprinter (2014) in the laboratory. Due to the limited length of test cycles driven on the roller bench, these measurements are not relevant for the review related to a possible switching in emission behaviour at 26 km after start of a test. Some of the results, however, can be used for the review related to possible cycle recognition. Results of these tests can be found in [TNO 2016a] for the passenger cars and [TNO 2016b] for the Sprinter.

Table 1: Overview of Mercedes Benz vehicles tested in the lab and on the road by TNO

Model	Vehicle class	Euro-class	Fuel	Power [kW]	Displ. [cc]	EGR	LNT	SCR	Test date	Lab	Road
EC220 CDI	pass. car	5	diesel	125	2134	X			2010	X	
350	pass. car	6	diesel	155	2997	X		X	2010	X	
C220 Bluetec	pass. car	6	diesel	125	2143	X		X	2015	X	X
C220 Bluetec	pass. car	6	diesel	125	2143	X		X	2016		X
Citan	van	6b	diesel	55	1461	X	X		2017		X
Vito	van	5	diesel	70	2143	X			2014		X
Vito	pass. van	6b	diesel	100	2143	X		X	2017		X
Sprinter	van	5	diesel	95	2143	X			2014	X	
Sprinter	van	5	diesel	95	2143	X			2014		X
Sprinter	van	5b	diesel	95	2143	X			2016		X
Sprinter	van	6b	diesel	105	2143	X		X	2017		X
Sprinter	van	VI	diesel	120	2143	X		X	2014		X
Sprinter	van	VI	diesel	120	2143	X		X	2016		X

For the Euro 6 Mercedes C220 Bluetec test results have previously been reported in [TNO 2016a] and [TNO 2016d]. A more detailed review into the relation between ambient temperature and NO_x emissions of this vehicle model has been reported in [TNO 2016c]. In that report it was shown that the NO_x emissions of the Euro 6 Mercedes C220 Bluetec gradually increase with decreasing ambient temperatures. At temperatures above 15 ˚C NO_x emissions were found to be generally at or even below the type approval limit of 80 mg/km. Going from 15 ˚C

down to 5 ˚C the on-road NO_x emissions were found to increase on average by a factor of 7.

For the Euro 5 Mercedes Vito and Sprinter test results from 2014 have previously been reported in [TNO 2016b]. The results for the vehicles tested in 2017 are documented in [TNO 2017a].

General information on the test programmes for light duty vehicles, carried out by TNO under assignment of the Dutch Ministry of Infrastructure and Water management, can be found in [TNO 2016e].

Methodology of the review

Test cycles used in the lab are generally shorter than 26 km. For the review with respect to a possible defeat device switching off emission control software at 26 km after start of a trip therefore an in-depth assessment is made of the results of emission tests carried out with PEMS or SEMS on the road. In this assessment we have looked for indication of systematic increases in NO_x emissions after distances of around 26 km.

For the review with respect to a possible defeat device recognizing the type-approval test cycle a general comparison of emission test results obtained in the lab and on the road is not appropriate. There are too many differences in test conditions between these two types of vehicle tests. If a defeat device would switch on the basis of recognizing speed and acceleration values that are within or outside the boundaries of a type-approval test cycle, this could be detected by comparing the results of different emission test on a roller bench in the lab obtained on the type approval test cycle and other cycles that are more representative for real-world driving. For the European situation this would mean comparing the results obtained on the NEDC cycle with results obtained on the CADC and WLTC test cycles, which are both based on real-world driving patterns.

In the evaluation and interpretation of test results on individual vehicles the following considerations need to be taken into account:

- The tests performed by TNO are not intended for enforcement purposes and are not suitable for identifying or claiming fraud or other vehicle-related irregularities in a scientifically and legally watertight way.
- For each make or model, only a single vehicle or a small number of vehicles is/are tested a limited number of times. This means that it cannot be ruled out that the results correlate to the specific condition of the tested vehicles or to specific test conditions. The latter is especially the case in road-world testing on the road in which a large number of conditions, that have a strong influence on test results, vary from trip to trip (see e.g. section 5.2 of [TNO 2016a]).

Review with respect to a possible defeat device switching off emission control software at 26 km after start of a trip

Test trips used for on-road testing

For the purpose of systematic emission testing of passenger cars and light commercial vehicles (vans) on the road TNO has developed several well-defined test trips. These are characterised by a prescribed route containing a representative mix of urban roads, rural roads and motorway. Trips are generally driven with a “normal” driving style, but to test the impact of variations in engine load they can also be driven by a driver that is instructed to apply an “eco” (i.e. fuel efficient) or “sportive” driving style.

For the tests carried out in 2014 and 2015 TNO has used a so-called **reference trip**. The characteristics of this trip are plotted in Figure 1.

For the test programs carried out in 2016 and 2017 TNO has used a so-called **RDE-trip**, which has been developed in compliance with the Real Driving Emission legislation adopted by the European Union in 2016. This legislation has entered into force for new passenger car type approvals on September 1, 2017, and will be in force one year later for the large vans described here. The characteristics of this trip are displayed in Figure 2.

More details on both on-road test cycles can be found in [TNO 2016e].

Note: In the graphs below the plotted NO_x emissions as function of distance driven are averaged over a distance of 1 km.

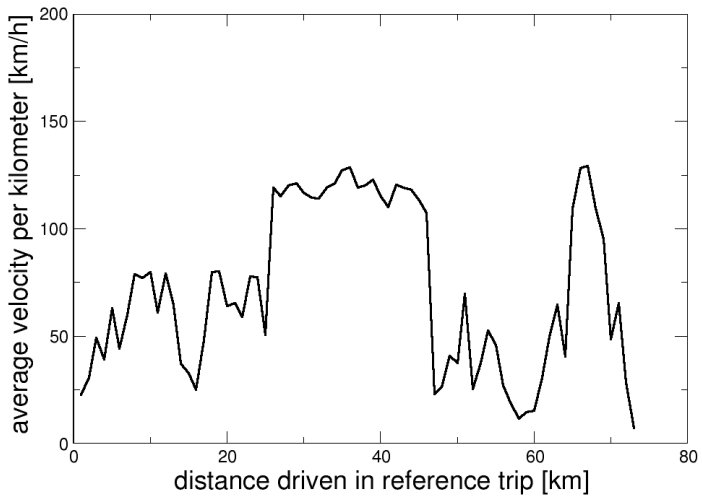

*Figure 1: Speed as function of distance driven after start of the trip for the **reference trip** used in the 2014 and 2015 test programs.*

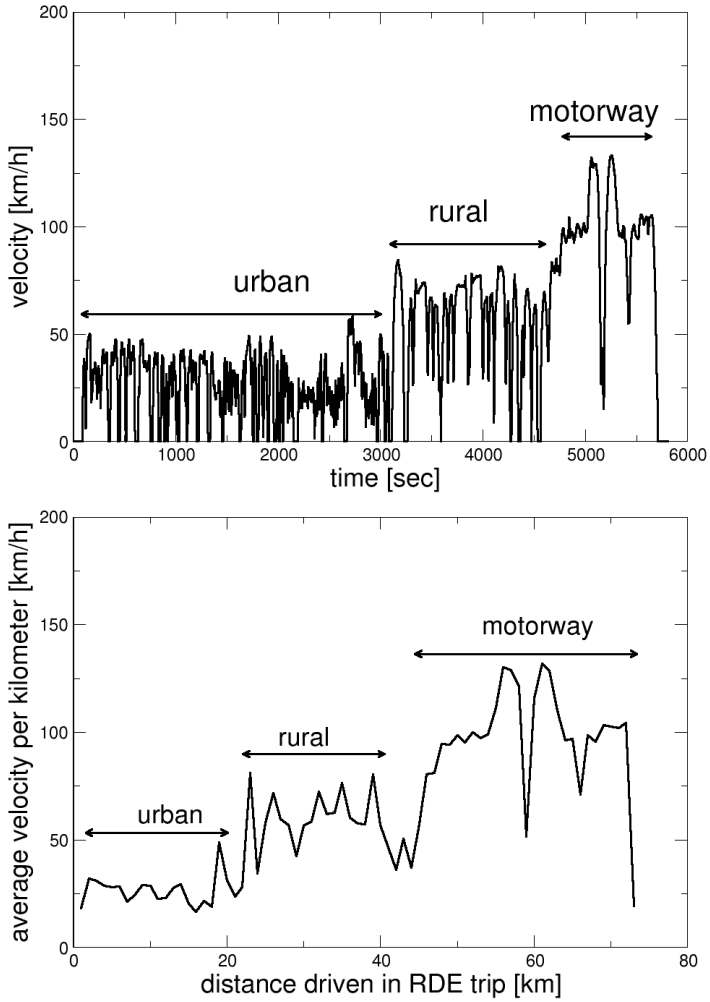

*Figure 2: Speed as function of time (upper) and distance driven after start of the trip (lower) of **RDE trip** used in the 2016 and 2017 test programs.*

Review of test results on passenger cars

Mercedes C220 Bluetec (Euro 6)
TNO has tested two Euro 6 Mercedes C220 with the same type approval, one in a test program run in 2015 (see [TNO 2016a]), and another in tests carried out in 2016 (see [TNO 2016d]).

Figure 1 shows the reference trip driven with the C220 in 2015. Emission measurement results for a number of tests on this reference trip, obtained with PEMS and SEMS measurement equipment, are plotted in Figure 3. The peak in NO_x emissions, observed in all four tests around 25 km is caused by the acceleration onto the motorway, associated with the transition from an urban part to a motorway part in the reference trip. After this peak emission go down again to levels that can be expected for driving at motorway speeds. The tests performed

in 2015, do not show indications of switching behaviour in the emission control software related to the driven distance after start of the trip.

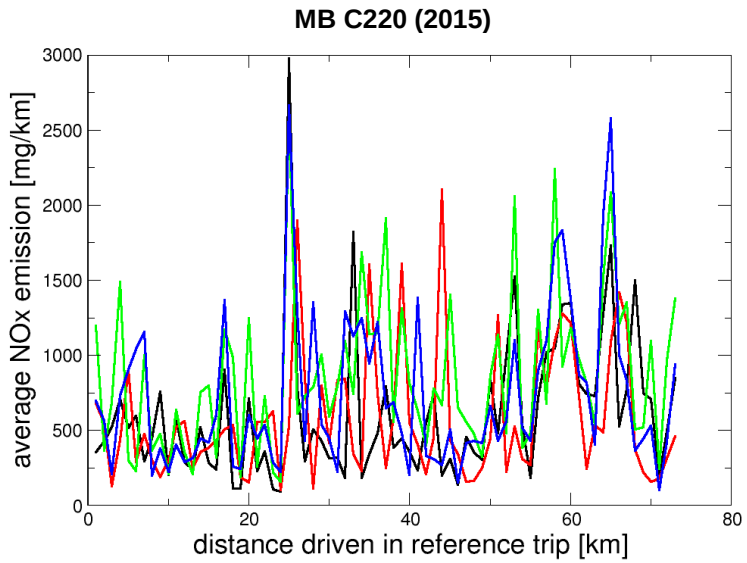

Figure 3: Overview of the NO_x emissions as function of the distance driven on a set of 4 comparable reference trips driven with the Mercedes C220 Bluetec in 2015.

The results reported in [TNO 2016c] and [TNO 2016d] have been obtained by testing a second Euro 6 Mercedes C220 Bluetec diesel vehicles with identical type approval on a total of 12 similar RDE trips in 2016. The characteristics of these trips are illustrated in Figure 2.

In Figure 4 for all RDE trips driven with the Mercedes C220 the NO_x emissions have been plotted as function of the distance driven after start of the trip. Most trips have consistently high or low emissions. One trip (the black line) has emissions that go down after a while. Only one trip (the red line) shows emissions that go up after a distance of slightly more than 26 km. This trip differed from the other RDE trips by the fact that the air conditioning was switched on during the entire duration of the trip. This was done to investigate the impact of higher engine loads, associated with the use of the air conditioning, on the overall emission behaviour.

In Figure 5 the emission results for trip at 20 ˚C with airco on are further highlighted and compared with test results obtained on two other RDE-trips carried out at similar ambient temperatures but with the airco switched off. All three traces show a peak around 23 km, which can be attributed to an acceleration at the transition from driving on urban roads to driving on a rural road (see Figure 2). After 26 km the red trace shows a marked increase in the emissions in mg/km. Emissions go down again after 50 km, which is some time after the start of the highway part of the trip.

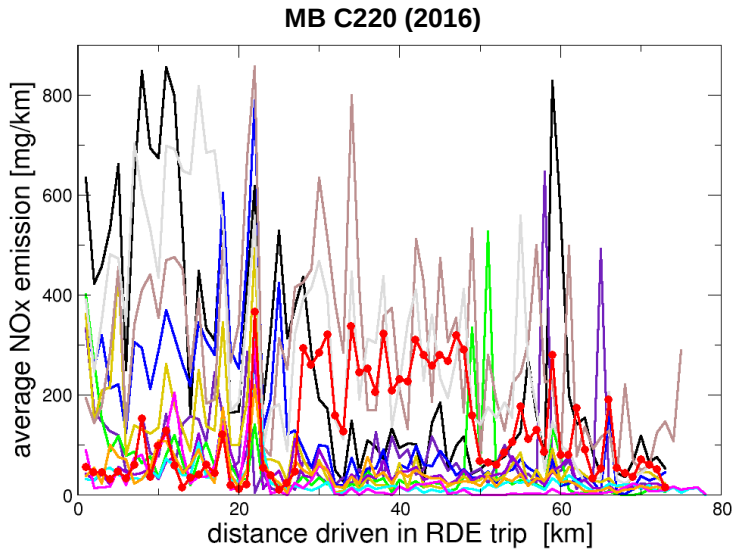

Figure 4: Overview of the NO_x emissions as function of the distance driven on a set of 12 comparable RDE trips driven with the Mercedes C220 Bluetec in 2016.

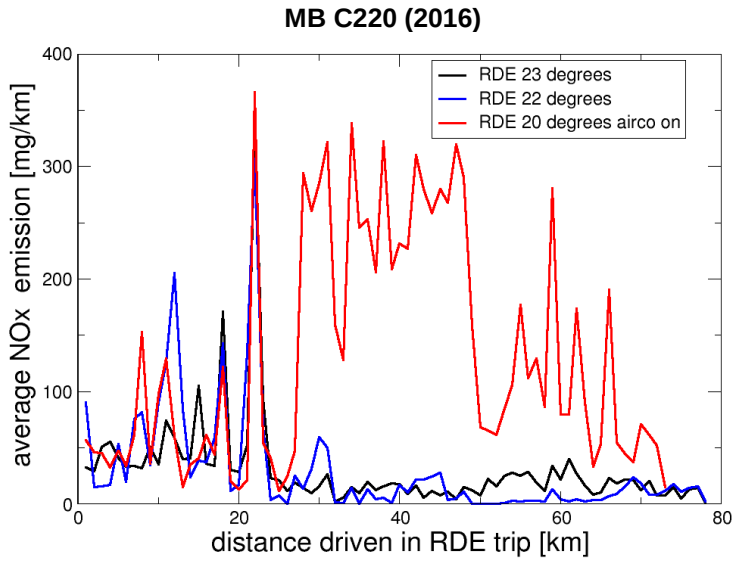

Figure 5: NO_x emissions of the Mercedes C220 Bluetec as function of the distance driven for three comparable RDE trips driven at ambient temperatures around 20˚C.

Detailed analysis of the test results shows that the increased emissions after around 26 km in the red trace from Figure 4 and Figure 5 are caused by a regeneration of the diesel particulate filter (DPF), which is triggered after the vehicle starts driving at higher speeds on the rural road part of the trip and stops before the vehicle enters the motorway. This can be seen from the exhaust temperature (Figure 6) and the CO_2 emissions (Figure 7), which are both temporarily elevated during the rural part of the trip. Compared to similar tests

without regeneration, the NO_x emission is seen to reduce slowly after the end of the DPF regeneration and to remain somewhat higher on the motorway part.

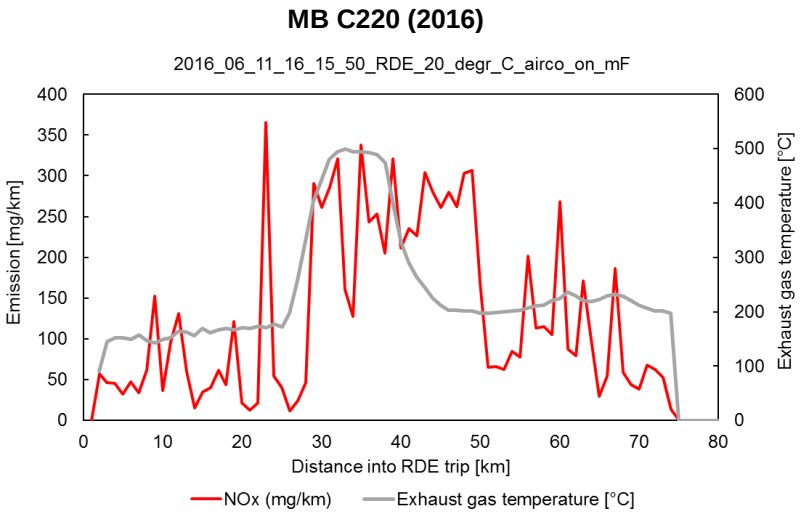

Figure 6: Exhaust temperature and NO_x emissions of the Mercedes C220 Bluetec as function of the driven distance driven for the test on the RDE trip carried out at ambient temperature around 20˚C with the airco switched on (red line in Figure 5).

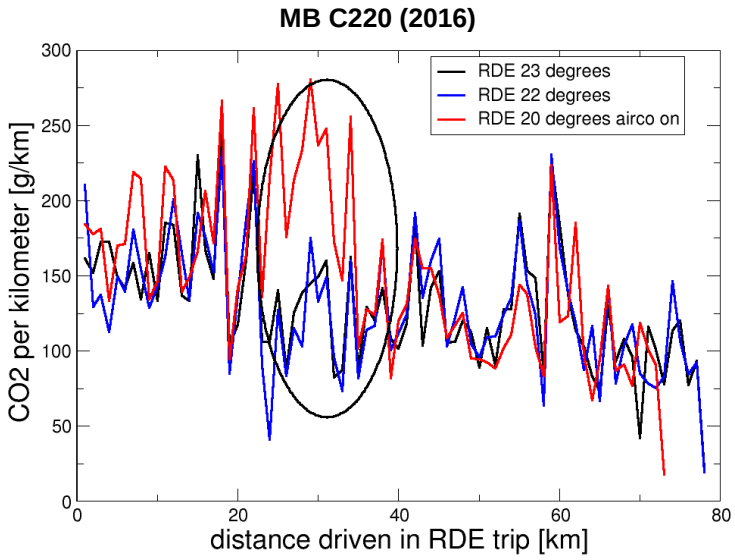

Figure 7: CO_2 emissions of the Mercedes C220 Bluetec as function of the distance driven for three comparable RDE trips driven at ambient temperatures around 20˚C (same trips as in Figure 5).

The second Mercedes C220 Bluetec, used in the tests reported in [TNO 2016c], has also been used for other on road test activities for an extended period [TNO 2017b]. During this period a wide range of real-world trips has been driven with widely varying trip characteristics. Figure 8 summarizes the NO_x emission behaviour observed over a total of 141 different trips by plotting the average NO_x emissions as function of the distance driven after start of the trip plus the spread

and maximum emissions per km driven. These traces do not indicate a switching behaviour in the emissions after 26 km or any other distance in the bandwidth shown. If such behaviour would occur in a significant share of the trips, one would expect this to lead to a noticeable increase in the average emissions after 26 km.

In the 141 consecutive trips the frequency of DPF regeneration was on average once every 400 kilometres. The distance between regenerations ranges from 200 to 600 kilometre. The periods of high exhaust gas temperatures, above 350˚C, associated with regenerations last typically eleven minutes.

Overall it is concluded that the tests performed by TNO on two Euro 6 Mercedes C220 Bluetec vehicles do not provide indications of a switch in the emission control software after 26 km or any other distance after start of a trip.

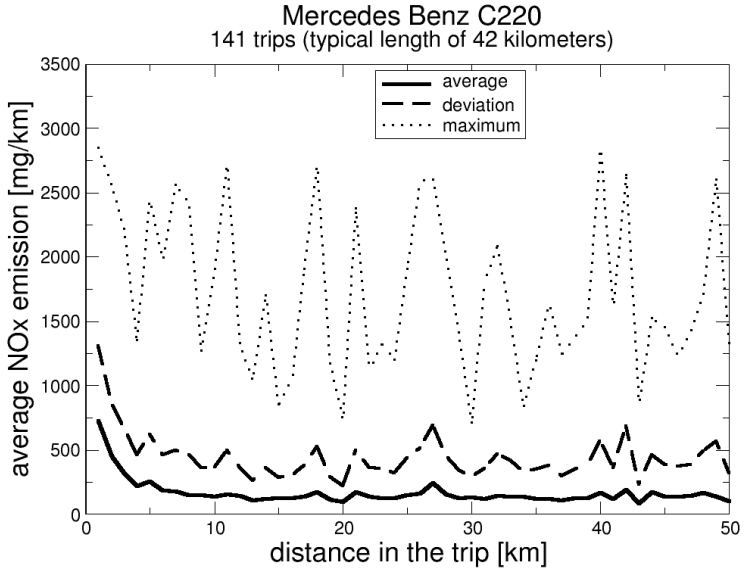

Figure 8: Average NO_x emissions plus spread and maximum emissions per km driven with the Mercedes C220 Bluetec, based on a total of 141 real-world trips driven under varying conditions during an extended period.

Results of the 2014 LCV test program

In the 2014 light commercial vehicle test programme a Euro 5 Mercedes Benz Vito as well as a Euro 5 Sprinter and a Sprinter with an engine type-approved under the HD Euro VI standard, have been tested on the reference trip (see Figure 1). Measured NO_x emissions are plotted in Figure 9. Test were carried out with different payloads, expressed as fraction of the maximum allowable payload.

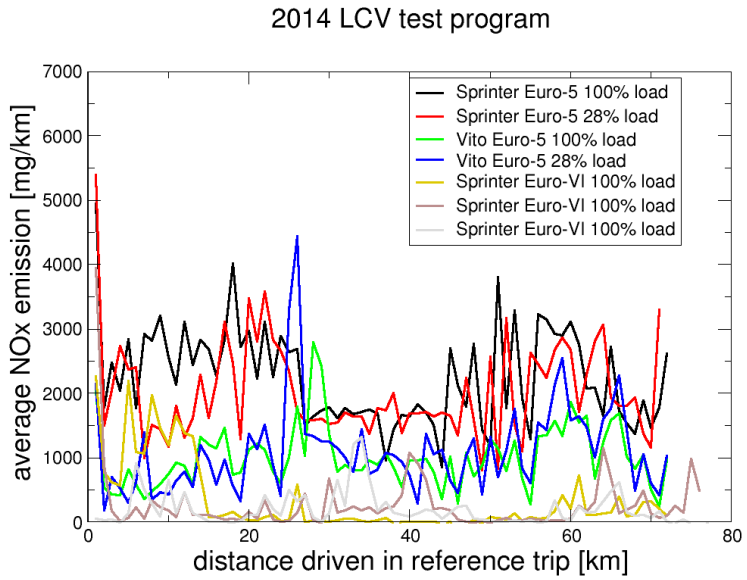

Figure 9: Overview of the NO_x emissions as function of the distance driven on a set of comparable RDE trips driven with the Mercedes vans tested in the 2014 LCV program.

In one test a peak in NO_x emissions is seen at the onset of the motorway part of the trip. For all vehicles, however, the emission levels after 26 km are similar to those in the proceeding part, albeit markedly more constant on the motorway for the two Euro 5 Sprinters. Variations later on in the trip are normal for the occurring speed dynamics. From these measurements it can therefore be concluded that the emission behaviour of the Mercedes vans tested in the 2015 program does not provide indications of a switch in the emission control software after 26 km or any other distance after start of a trip.

Results of the 2016/17 LCV test program

Mercedes Citan (Euro 6)

In Figure 10 the NO_x emissions of a Euro 6 Mercedes Citan van have been plotted as function of the distance driven after start of the trip for a total of five comparable RDE trips (see Figure 2). The peak in NO_x emissions around 55 to 60 km is associated with a subsequent accelerations and decelerations in the motorway part of the trip. From this overview it can be concluded that the tests performed by TNO on the Mercedes Citan do not provide indications of a switch in the emission control software after 26 km or any other distance after start of a trip.

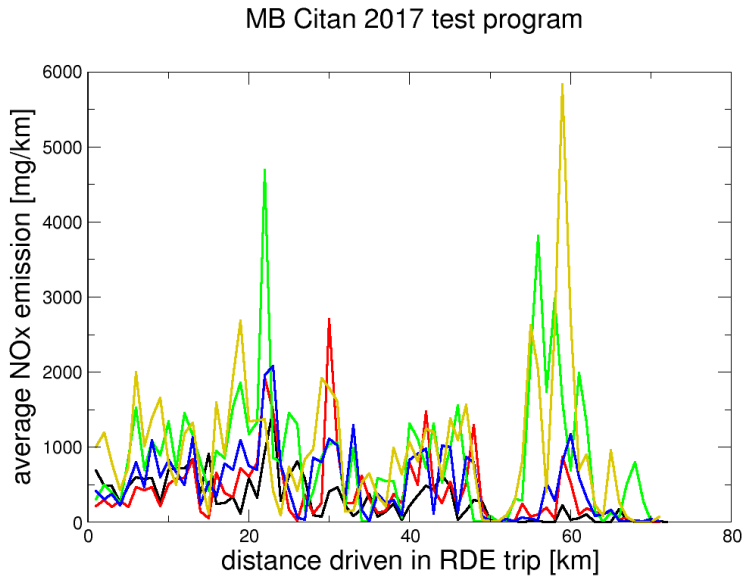

Figure 10: Overview of the NO_x emissions as function of the distance driven on a set of 5 comparable RDE trips driven with the Euro 6 Mercedes Citan.

Mercedes Vito (Euro 6)

In Figure 11 the NO_x emissions of a Mercedes Vito van have been plotted as function of the distance driven after start of the trip for a total of five comparable RDE trips (see Figure 2). From this overview it can be concluded that the tests performed by TNO on the Mercedes Vito do not provide indications of a switch in the emission control software after 26 km or any other distance after start of a trip.

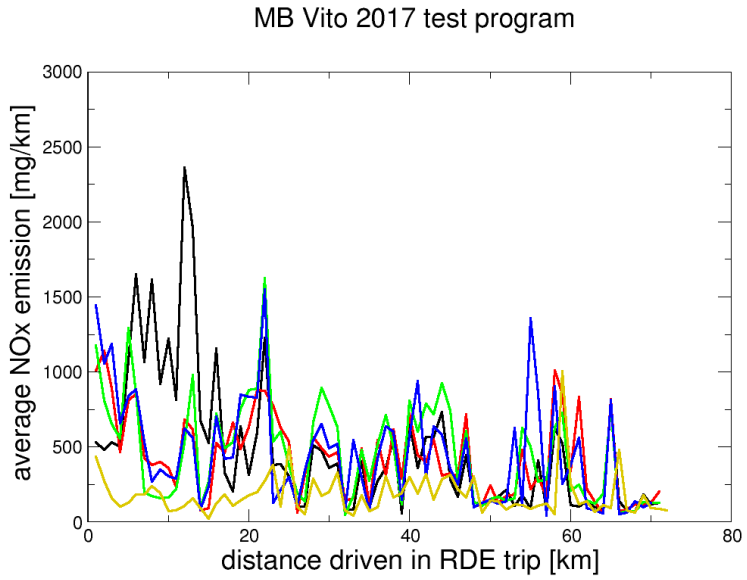

Figure 11: Overview of the NO_x emissions as function of the distance driven on a set of 5 comparable RDE trips driven with the Euro 5 Mercedes Vito.

Mercedes Sprinter (Euro 5, 6 and VI)
In Figure 12 the NO_x emissions of Euro 5, Euro 6 and Euro VI Mercedes Sprinter vans, tested on comparable RDE trips (see Figure 2), have been plotted as function of the distance driven after start of the trip. These tests do not provide indications of a switch in the emission control software after 26 km or any other distance after start of a trip.

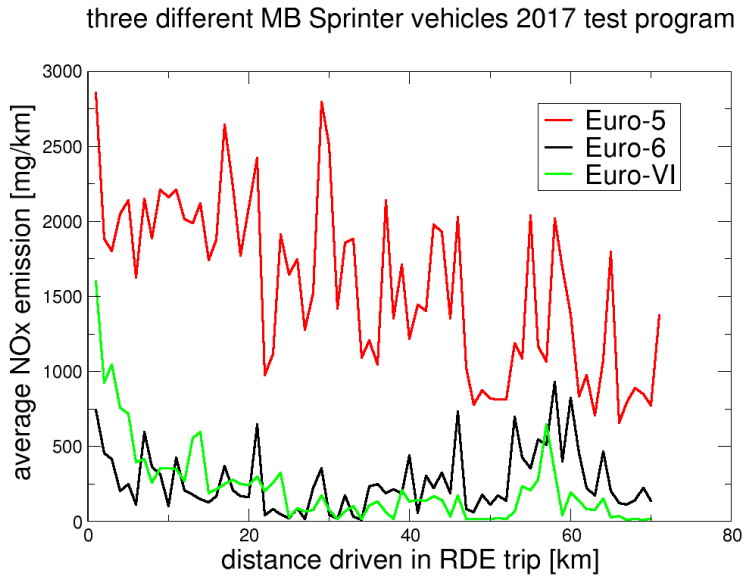

Figure 12: NO_x emissions as function of the distance driven on comparable RDE trips with a Euro 5 and a Euro 6 Mercedes Sprinter.

Review with respect to a possible defeat device recognizing the type-approval test cycle

To check for possible switching behaviour in the emission control software in relation to recognition of the vehicle undergoing formal testing, test results obtained on the type approval test need to be compared to results from tests under similar conditions but using a test cycle (speed-time profile) that is sufficiently different from the type approval cycle in terms of speed and acceleration values. For Europe the type approval cycle applicable to the vehicles under review is the NEDC.

As the focus of the test program carried out by TNO has in recent years been on measuring emissions on the road, only a limited number of vehicles have been tested in the lab. Table 2 shows an overview of relevant results for Mercedes Benz vehicles. Besides on the NEDC, these vehicles have also been tested on the CADC and/or WLTC. Both these cycles have been derived from real-world driving

profiles and therefore cover bandwidths of speed and acceleration values that are wider than those of the NEDC[1].

Table 2: Overview of NO_x emission test results of Mercedes Benz vehicles tested on the roller bench by TNO

		Euro class	NEDC cold [mg/km]	NEDC hot [mg/km]	CADC cold [mg/km]	CADC hot [mg/km]	WLTC cold [mg/km]	WLTC hot [mg/km]
passenger cars	E220 CDI	5	156			416		
	350	6	66			10		
	C220	6	34	27	27	15	47	51
LCV	Sprinter	5	287*	970			722	1082

*) Additional NEDC cold start tests, carried out by the manufacturer on the same vehicle within the same period at different test facilities, showed NO_x emissions well below the limit. As explained in section 5.1 of [TNO 2016b] the exceedance of the limit for this vehicle in the test carried out by TNO cannot be interpreted as noncompliance with the Euro 5 standard.

For the E220 (Euro 5) and 350 (Euro 6) no like-with-like comparison is possible on the basis of the performed tests, as the test on the NEDC is carried out with a cold start while the test on the CADC started with a warm engine. Differences in emissions may thus also be attributed to the difference in engine conditioning.

The Euro 6 version of the E220 shows similarly low emissions on all test cycles independent from the engine conditioning before the start. For this vehicle it can thus be concluded with certainty that its emission behaviour does not provide an indication of cycle recognition.

Comparing the test results for the Euro 5 Sprinter on the NEDC and WLTC, both with cold start, shows that emissions on the WLTC are significantly higher than on the NEDC. Whether this is an indication of cycle recognition, however, cannot be concluded with any certainty, as also this comparison is not exactly like-with-like. On the two cycles the test was carried out with roller bench settings for mass and resistance as prescribed by the associated formal test procedure. The current NEDC-based type approval procedure prescribes different roller bench settings than the new WLTP of which the WLTC test cycle is a part.

Emissions of the Euro 5 Sprinter in tests on the NEDC and WLTC with hot starts are of the same magnitude and therefore do not provide an indication of cycle recognition. The counterintuitive observation that emissions on an NEDC test starting with a warm engine are higher than on a test with a cold start has been reported for many vehicles of different makes and models (see [TNO 2016a] and [TNO 2016b]). The same is valid for the high emissions of the Euro 5 C220 on the CADC with hot start compared to the NEDC type approval test. Significantly higher emissions on different real-world based test cycles compared to the NEDC are observed for many tested models of different brands, as already reported by TNO in 2016 and earlier.

[1] See [TNO 2016a], [TNO 2016b] and [TNO 2016e] for more information on test cycles and test procedures.

Conclusions

Conclusions with respect to a possible defeat device switching off emission control software at 26 km after start of a trip

Of 12 similar RDE-trips driven in 2016 with a Euro 6 Mercedes C220 Bluetec one trip showed emission behaviour that could in principle be indicative of switching behaviour in the emission control software at a distance of around 26 km after start of the trip. From analysis of the exhaust gas temperature and CO_2 emissions during that trip it was clear, however, that the NO_x emissions were temporarily elevated due to a regeneration of the vehicle's DPF, triggered by the transition to the rural part of the trip after 23 km. Furthermore, no switching behaviour is apparent in the average emission behaviour of this vehicle as function of distance driven after the start for a total 141 different real-world trips, and from the analysis of the NO_x emissions of a similar vehicle measured in 2015 on four TNO reference trips. It is therefore concluded that the on-road emission tests carried out by TNO on the Euro 6 Mercedes C220 Bluetec do not provide indications of switching behaviour in the emission control software related to the driven distance after start of the trip.

Review of emission tests carried out on Mercedes Citan, Vito and Sprinter vans in 2014 and 2016/17 have revealed no striking emission behaviour. Also for these vehicle models we therefore conclude that on-road emission tests carried out by TNO do not provide indications of switching behaviour in the emission control software related to the driven distance after start of the trip.

Conclusions with respect to a possible defeat device recognizing the type-approval test cycle

A review with respect to a possible defeat device recognizing type-approval the test cycle was only possible for two Mercedes models tested on the roller bench.

For the Euro 6 E220 emissions are equally low on all test cycles, so that it can be concluded with certainty that its emission behaviour does not provide indications of switching behaviour in the emission control software in relation to recognition of the vehicle undergoing formal testing.

A Euro 5 Sprinter tested on the NEDC and WLTC, both with cold start, did show significantly higher emissions on the WLTC than on the NEDC. Whether this is an indication of cycle recognition, however, cannot be concluded from this comparison, as the roller bench settings were not identical on the two tests.

Euro 5 vehicles of all makes and models typically have much lower emissions on the NEDC-based type approval test than on other emission tests carried out in the lab or on the road. This is a commonly known phenomenon reported by TNO and other laboratories. The cause of this has not been investigated by TNO. The tests performed by TNO are not intended for enforcement purposes and are not suitable for identifying or claiming fraud or other vehicle-related irregularities.

References

[TNO 2016a] *NO_x emissions of Euro 5 and Euro 6 diesel passenger cars – test results in the lab and on the road*, TNO 2016 R10083, March 2016

[TNO 2016b] *NO_x emissions of Euro 5 diesel van – test results in the lab and on the road*, TNO 2016 R10356, May 2016

[TNO 2016c] *Review into the relation between ambient temperature and NO_x emissions of a Euro 6 Mercedes C220 Bluetec with a diesel engine*, TNO 2016 R11123, October 2016

[TNO 2016d] *NO_x emissions of fifteen Euro 6 diesel cars: Results of the Dutch LD road vehicle emission testing programme 2016*, TNO 2016 R11177, October 2016

[TNO 2016e] *Assessment of road vehicle emissions: methodology of the Dutch in-service testing programmes*, TNO 2016 R11178v2, October 2016

[TNO 2017a] *NO_x emissions of eighteen diesel Light Commercial Vehicles: Results of the Dutch Light-Duty road vehicle emission testing programme 2017*, TNO 2017 R11473, December 2017 (to be published)

[TNO 2017b] *Chase car study: driving behaviour in the Netherlands, Belgium, France and Germany - Technical report under the Assessment of the strengths and weaknesses of the new Real Driving Emissions (RDE) test procedure (TNO 2016 R11227)*, TNO 2017 R10436, March 2017

These reports can be found on:

https://www.tno.nl/en/focus-areas/traffic-transport/roadmaps/mobility/clean-mobility/overview-of-reports-measuring-the-emissions-of-passenger-cars-and-vans/

or

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