**Solution K68360438**
**Wednesday, March 11, 2020 3:20:15 PM CET**

## ** SOLUTION **

| | |
|---|---|
| Title | To Be Published Description and Function - Premium Tech Tool (PTT) Operation 2589-08-03-18 Exhaust Aftertreatment System Analysis |

## Mack Models

| | |
|---|---|
| **Mack Model** | LR , TE - TerraPro , AN - Anthem , GR - Granite , PI - Pinnacle |

## Volvo Models

| | |
|---|---|
| **Volvo Model** | VN , VNL , VNR , VNX , VAH , VHD |

## Emission Standard

| | |
|---|---|
| Emission Standard | US17+OBD18 |

## Engine family

| | |
|---|---|
| Engine family | 11L Engine , 13L Engine , MP7 , MP8 |

## ** SOLUTION **

**Cause**

**Purpose:** To have a series of routines in Premium Tech Tool (PTT) to effectively evaluate and diagnose the NOx sensors, Urea (DEF) dosing system, and SCR efficiency. The routine is also captured in a .csv file and can be downloaded from Product History Viewer for later review if necessary. This document includes the list of Diagnostic Trouble Codes (DTC) that, when following Guided Diagnostics (GD), will list this operation as a step. This document will outline key details that the technician should be aware of when performing the operation. Currently this operation is only available for 11 and 13 liter engines with:

- US17+OBD18 Emissions
- A Variable Geometry Turbo (VGT)
- Engine Control Module (EMS) Main Software (MSW) Part Number 23766686 and newer.

For these vehicle configurations, the NOx Conversion Test (operation 2549-08-03-03) is replaced by this operation (2589-08-03-18 EATS Analysis). The NOx Conversion Test will remain available for all other variants except US17 emissions turbo compound engine configurations.

**Solution**

Current operations in Premium Tech Tool typically allow for activation of actuators with the engine off/key on or without control over other variables, and trying to record on-the-road data typically introduces too many variables to make an effective diagnosis. The Exhaust Aftertreatment System Analysis attempts to resolve many of these issues by testing engine and emissions components as a system with the engine running under more controlled operating conditions and without the requirement of removing engine components. The current operation consists of 4 subtests:

1. **Aftertreatment Hydrocarbon Injection (AHI) System**

- Verifies that the AHI system is properly working to warm the exhaust system at various levels of fuel dosing. Aids in clearing the SCR buffer.

**2. NOx Sensors**

- Checks NOx sensor readings during varying engine operating conditions.

**3. Diesel Exhaust Fluid (DEF) Dosing System**

- Verifies proper DEF flow, dosing valve operation, and pump function.

**4. SCR efficiency**

- Provides an objective evaluation of SCR efficiency under controlled, repeatable conditions.

Prior to these tests, there is a warm-up step to ensure proper exhaust/ aftertreatment temperatures and that the NOx sensors are warmed up/enabled:

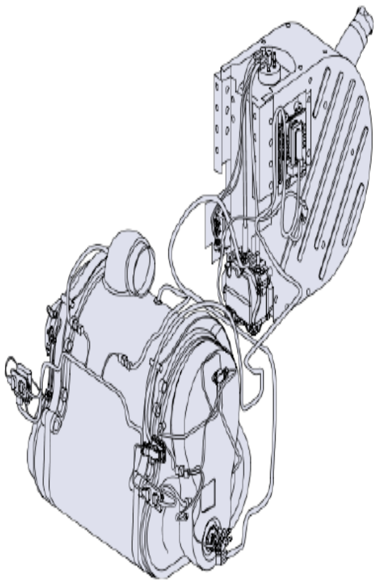
These routines can be run separately or in combination. By default, all of the subtests are enabled. Typical time to run all 4 subtests is 25-45 minutes. The test time is dependent on many factors: engine/coolant temperature and ambient temperature, for example.

# Operations screens for PTT

Tech Tool

Tech Tool | Links | Help

Product | Product History | Diagnose | Test | Calibrate | Program | Impact



## 2589-08-03-18 Exhaust Aftertreatment System Analysis

**Information** >> Conditions >> Execution >> Result

### Purpose

Comprehensive check of Exhaust Aftertreatment System (EATS)

**Note:** This operation should only be used in the following circumstances

- Reference fro.. ı diagnostic/service information or Technical support
- Relevant DTCs: **P103C, P20EE, P225E, P225C, P229F, P2201, P0422**

### Description

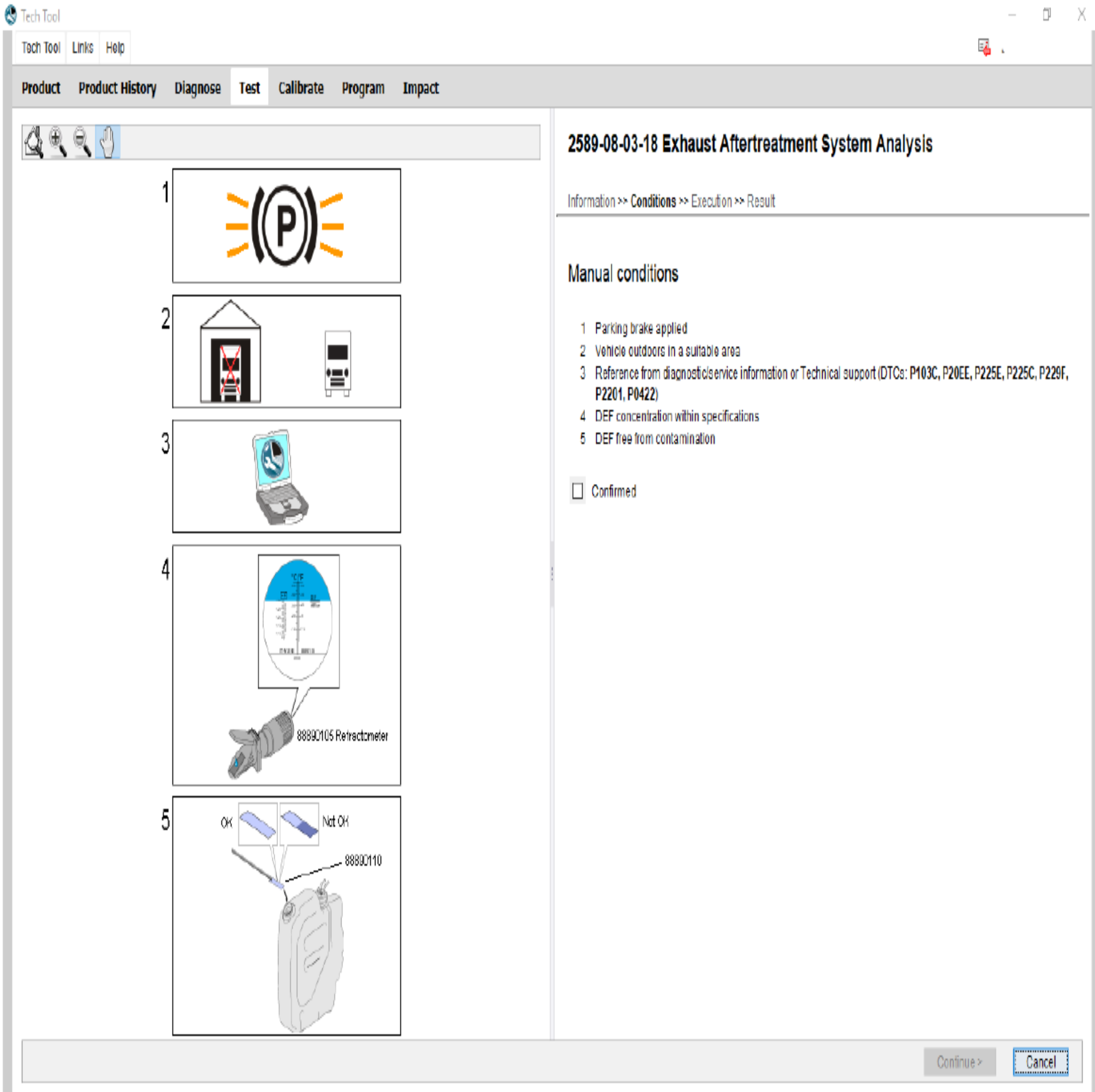
- The ECM routine will perform a self-evaluating system test on the Exhaust Aftertreatment System (EATS)
- All test can be performed in sequential order or specific sub-test that can be individually selected

Available sub-test that can be performed individually

1. Aftertreatment hydrocarbon injection (AHI) system
2. NOx sensors
3. DEF dosing system
4. SCR efficiency

Operation may take approximately 15 - 45 minute(s) to complete

Continue > | Cancel




## Diagnostic Trouble Codes

The Guided Diagnostic (GD) trees for the DTCs below will be updated to reflect this operation.

| Diagnostic Trouble Code | Description | Behavior |
|---|---|---|
| P20EE-00 | SCR NOx Catalyst Efficiency Below Threshold Bank 1 | All subtests should be performed |
| P103C-00 | SCR NOx Catalyst Efficiency Inducement | All subtests should be performed |
| P0422-00 | Catalyst 2 Efficiency Below Threshold Bank 1 (DPF NMHC conversion efficiency) | All subtests should be performed (only when DTC is confirmed) |

| | | |
|---|---|---|
| P225E-00 | NOx Sensor Performance Signal Stuck High Bank 1 Sensor 2 (NOx outlet) | All subtests should be performed (only when DTC is confirmed) |
| P2201-64 | NOx Sensor Circuit Range/Performance Bank 1 Sensor 1 / Signal Plausibility Failure (NOx inlet) | Only the NOx sensors subtest should be performed |
| P225C-00 | NOx Sensor Performance Signal Stuck High Bank 1 Sensor 1 (NOx inlet) | Only the NOx sensors subtest should be performed |
| P229F-64 | NOx Sensor Circuit Range/Performance Bank 1 Sensor 2 / Signal Plausibility Failure (NOx outlet) | Only the NOx sensors subtest should be performed |

## General Testing Conditions

The primary thresholds / enable and exit conditions are listed below:

| Parameter | Value | Behavior |
|---|---|---|
| Ambient Air Temperature | Between 11 °F and 104 °F (12 °C an 40 ° C) | |
| DPF Soot Level | Less than 69% | |
| DEF Tank Level | Greater than 10% | |
| Coolant Temperature | Greater than 140 °F (60 °C) | Vehicle will run in Heating EATS phase until minimum temperature is reached. |
| Diesel Oxidation Catalyst (DOC) Outlet Temperature (T2) | Greater than 734 °F (390 °C) | |
| SCR Average Temperature (Calculated Value) | Greater than 680 °F (360 °C) for at least 2 minutes. | Minimum temp must be maintained for minimum time period for test to begin. |

• When coolant and SCR average temp requirements are satisfied, and if NOx sensors have not come online, the routine allows 4 minutes for NOx Inlet and 5 minutes for NOx outlet to come online before it will abort test for NOx sensor quality (bad).
• Additionally, if the NOx sensors are the last to come online, there is a 60 second delay before it will enter the NOx sensor evaluation.
• If the conditions are not met within 1800 seconds (30 minutes) the test will abort.

• EGR position is commanded to zero (full closed) for warmup and currently every phase of the operation.

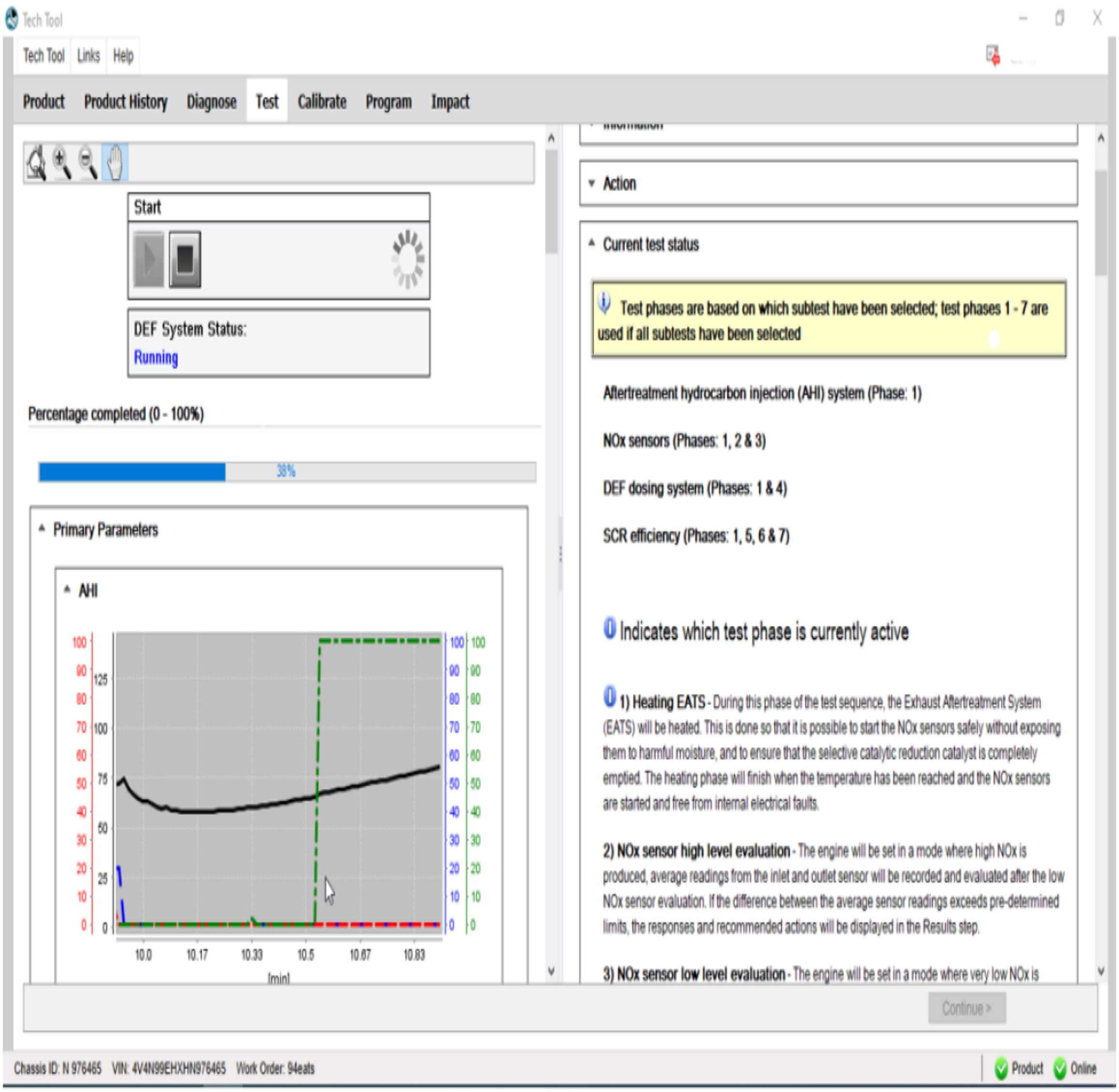
**NOTE: Test abort due to NOx Inlet or Outlet sensor quality bad is an unlikely scenario, however if this exception occurs, it is advisable to re-run test 1 more time.**

# Tests and Operations

## Heating EATS Phase (Warmup)

### Heating EATS Phase Operation Details

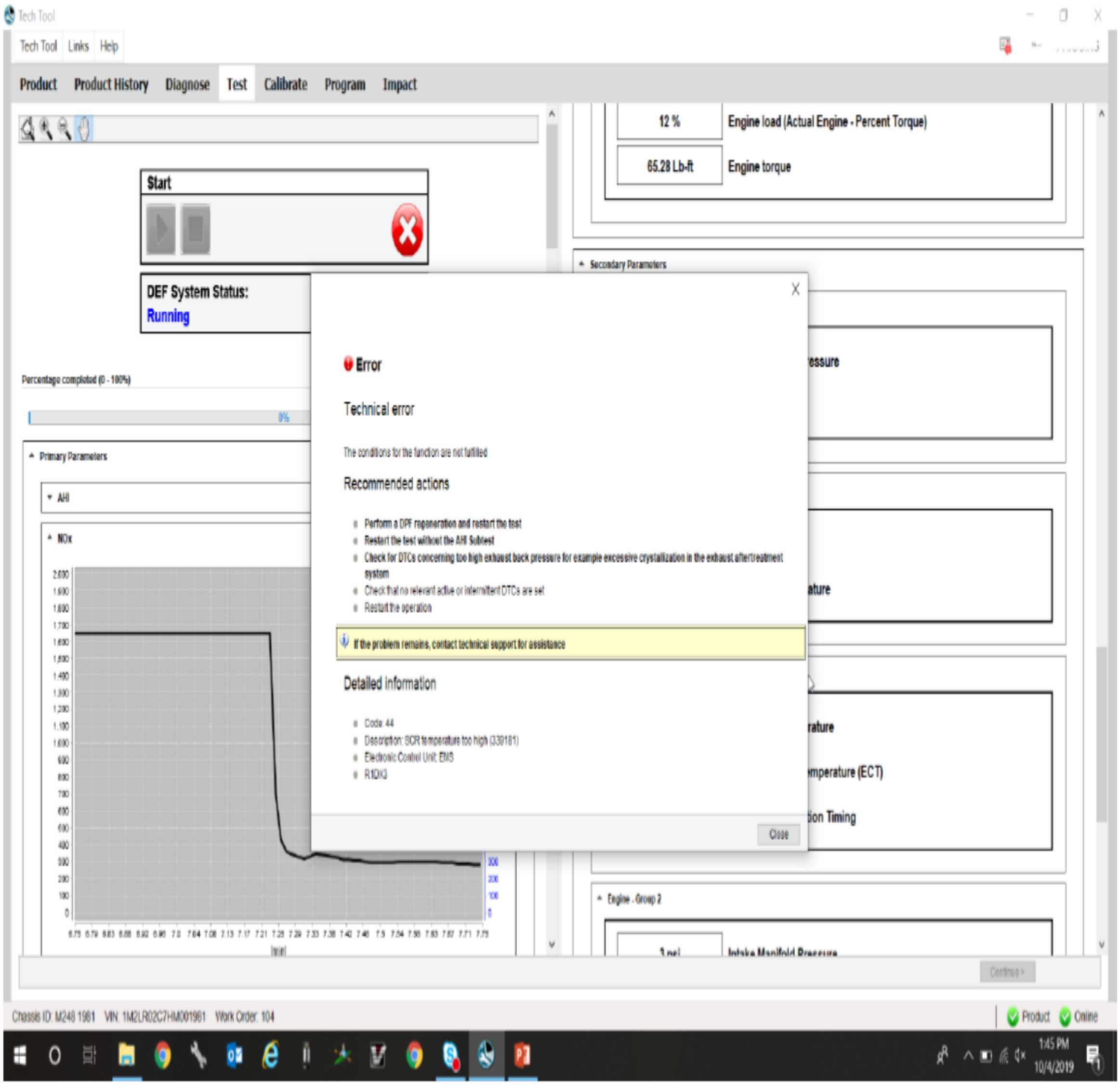
The purpose of the warmup phase is to stabilize engine and exhaust temperatures, bring the NOx sensors online, and clear the SCR buffer. During the Heating EATS phase (sometimes referred to as "warmup") the engine enters a state similar to regeneration and will vary engine speed between 1200 and 1250 rpm and control the VGT position to reach the target range for engine exhaust temperature (measured by the T1 temperature sensor). This phase will occur during <u>all</u> of the selected sub tests. AHI dosing will occur whether or not the AHI subtest is selected in order to meet target DOC outlet temperature (measured by the T2 temperature sensor) and SCR average temperatures and bring the NOx sensors online faster.




**Operation failure during Heating EATS phase:**

The screenshot below shows the current recommended actions for the scenario when criteria are met for the Heating EATS phase, except NOx outlet sensor came online just after the timeout period.

**The first recommended action in this scenario, specifically if the unit did not have NOx sensor DTCs, is to rerun the test.**




## AHI Subtest

The AHI subtest has the advantage of adding more heat to the system and aids in clearing the SCR buffer faster. When the AHI system subtest is selected, AHI dosing is added at 3 fixed dosing rates for 2 minutes at each step. When the AHI subtest is selected and the Engine exhaust temperature (T1) reaches 527 °F (275 °C), AHI dosing will begin.

### Subtest conditions:

| Condition | Value |
| --- | --- |
| Engine Exhaust Temperature (T1) | Minimum of 527 °F (275 °C) |

### AHI Subtest Failure

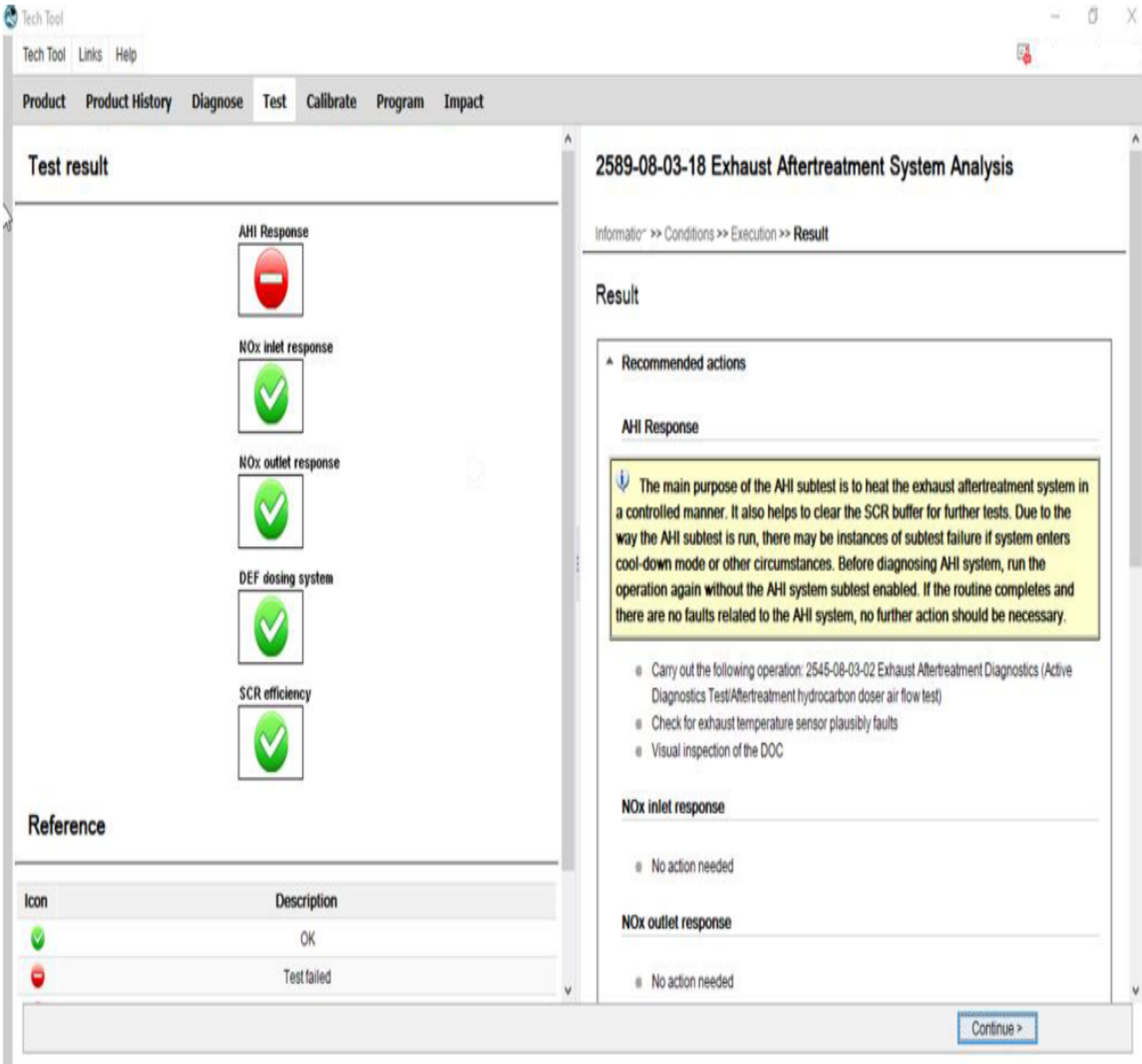
The following conditions will allow the AHI subtest to complete, but will show a “test failed” status for the results:

| DOC Outlet Temperature (T2) Threshold | Time Limit |
|---|---|
| T2 fails to reach 464 °F (240 °C) | First 2 minutes of dosing |
| T2 fails to reach 626 °F (330 °C) | Second 2 minutes of dosing |
| T2 fails to reach 734 °F (390 °C) | Third 2 minutes of dosing |

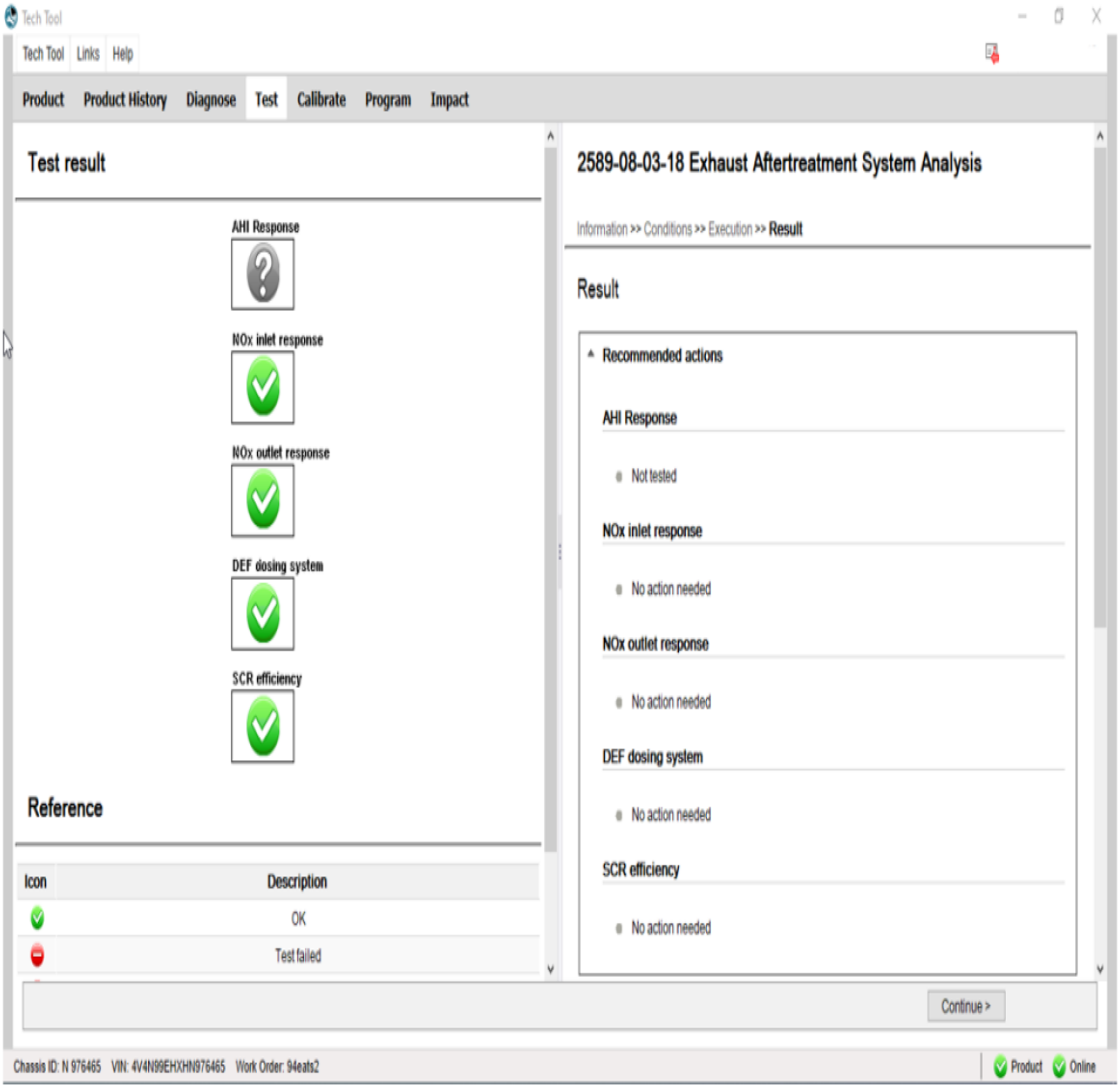
The conditions below will cause the AHI Subtest to abort or fail:

| Parameter | Condition | Effect |
|---|---|---|
| Engine, DOC, or DPF Outlet Temperature (T1, T2, OR T3) | Temperature exceeds 914 °F (490 °C) | Test aborts due to over-temperature |
| Engine Exhaust Temperature (T1) | Temperature falls below 527 °F (275 °C) after AHI dosing begins | Test result will show failed |

**If the AHI subtest fails as shown in the screenshot below,** the first recommended action is to uncheck the AHI system test and restart the test. This failure can result if the DOC Outlet Temperature (T2) does not reach the specified minimum temperature for each of the subtest's 3 steps.




The “Not tested” response shown under the AHI Response section in the screenshot below is the result of unchecking the AHI subtest.




## NOx Sensor Subtest

The primary purpose for the NOx high and low phase evaluation is to verify the plausibility of the sensors at two points in the measurement range where the readings should be within the manufacturers specified accuracy with the SCR buffer cleared, the readings should be within the “allowable difference” tolerance and the NOx level is not expected to exceed the Max/Min limits.

After conditions are satisfied for the warmup state, the routine enters the NOx sensor high and low evaluation phases. This phase replaces the current NOx Conversion test.

**IMPORTANT NOTE:** In the rare case that there are enough crystals in the urea (DEF) injection pipe to sublimate during the warmup, the Outlet NOx Value will read significantly lower than the Inlet NOx Value during the last part of the Heating EATS phase, typically when the DPF outlet temperature (T3) is above approximately 626 °F (330 °C). as T3 drops—which should occur during NOx sensor high and low evaluations—NOx outlet may rise as less sublimation occurs. This could cause the routine to abort immediately after the Heating EATS phase, or cause the NOx sensor evaluation to fail if this is suspected, a crystal sublimation should remedy the problem.

## Subtest conditions:

**High Evaluation**

| Condition | Value | |
|---|---|---|
| | **11 Liter Engine** | **13 Liter Engine** |
| Engine Speed | 1050 RPM | 1100 RPM |
| VGT (Turbo) Position | 10% | 7% |
| Injection Timing | 5° BTDC | 5° BTDC |
| Fan Speed | Max | Max |

The routine will stabilize for 40 seconds and then average the NOx sensor readings for 20 seconds before entering NOx low evaluation.

**NOx sensor low evaluation:**

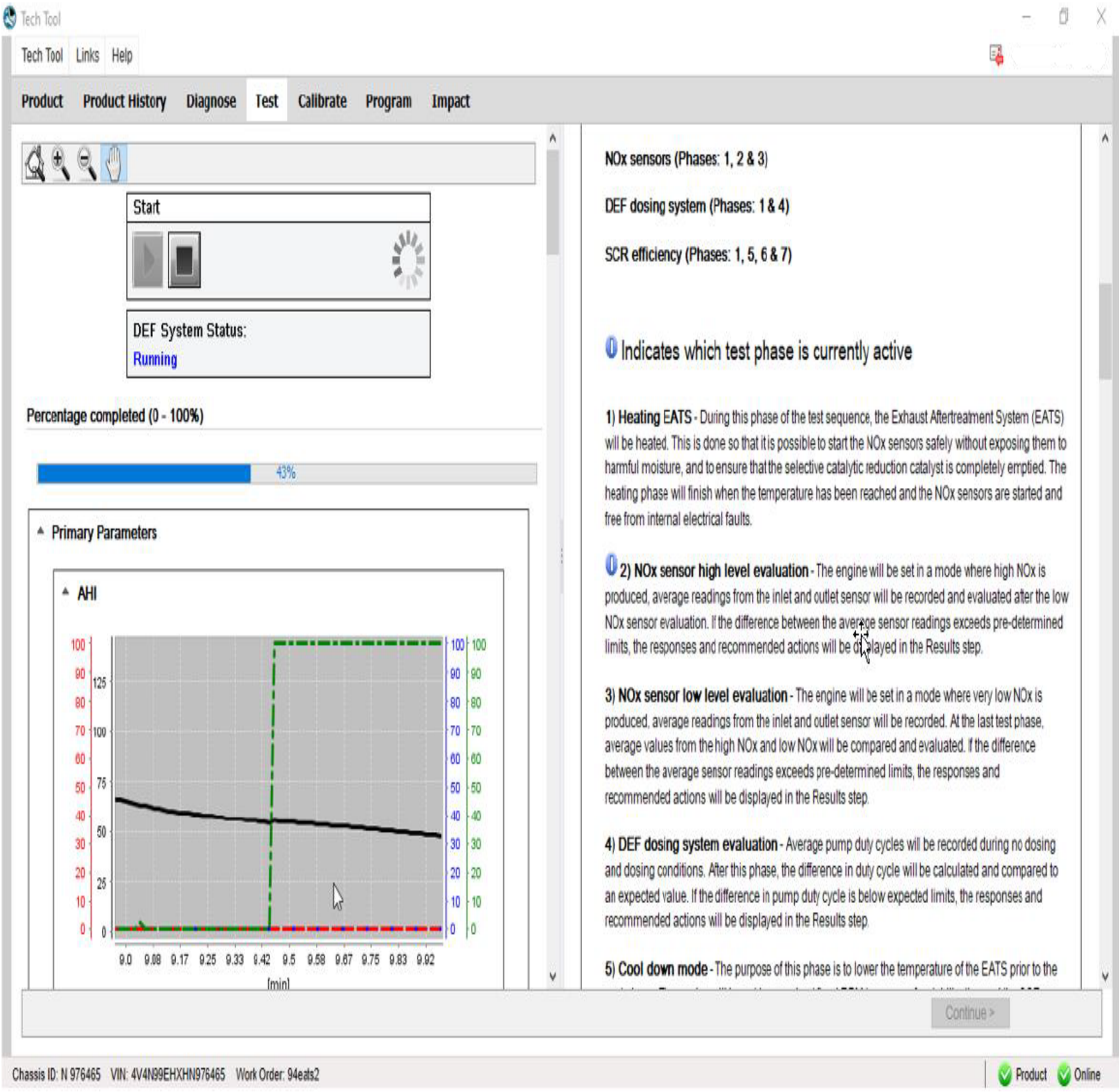
| Condition | Value | |
|---|---|---|
| | **11 Liter Engine** | **13 Liter Engine** |
| Engine Speed | 1050 RPM | 1100 RPM |
| VGT (Turbo) Position | 25% | 25% |
| Injection Timing | 0° (TDC) | 0° (TDC) |
| Fan Speed | Max | Max |

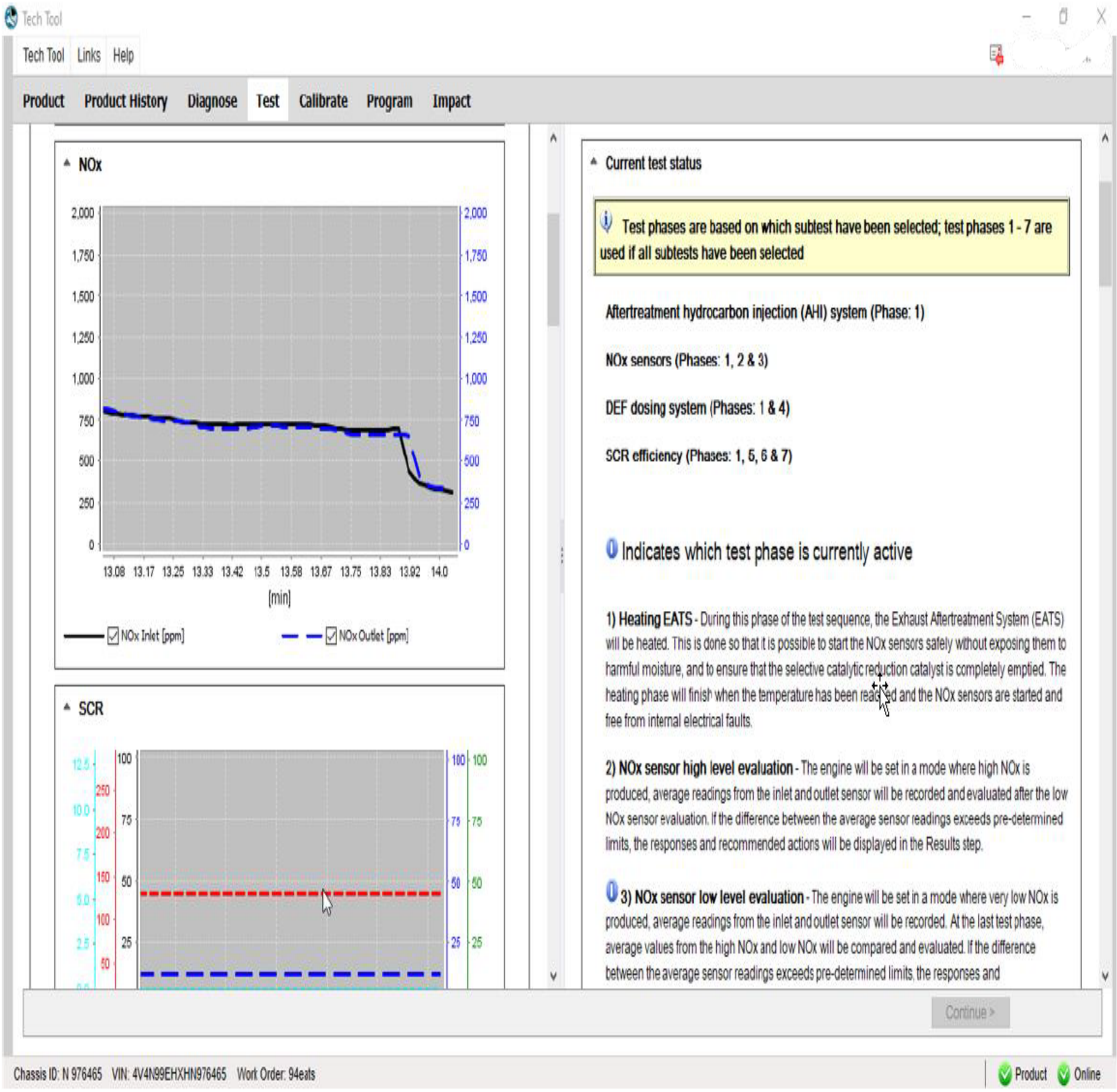
The routine will stabilize for 40 seconds and then average the NOx sensor reading for 20 seconds.

## Limits (For test to complete successfully)

| Phase | Maximum Difference between Inlet and Outlet NOx Values |
|---|---|
| High | 100 ppm |
| Low | 50 ppm |

## Operations Screens - NOx Sensor High Level Evaluation


Tech Tool
Tech Tool Links Help
Product Product History Diagnose Test Calibrate Program Impact
Start
DEF System Status:
Running
Percentage completed (0 - 100%)
43%
Primary Parameters
AHI
[min]
NOx sensors (Phases: 1, 2 & 3)
DEF dosing system (Phases: 1 & 4)
SCR efficiency (Phases: 1, 5, 6 & 7)
Indicates which test phase is currently active
1) Heating EATS - During this phase of the test sequence, the Exhaust Aftertreatment System (EATS) will be heated. This is done so that it is possible to start the NOx sensors safely without exposing them to harmful moisture, and to ensure that the selective catalytic reduction catalyst is completely emptied. The heating phase will finish when the temperature has been reached and the NOx sensors are started and free from internal electrical faults.
2) NOx sensor high level evaluation - The engine will be set in a mode where high NOx is produced, average readings from the inlet and outlet sensor will be recorded and evaluated after the low NOx sensor evaluation. If the difference between the average sensor readings exceeds pre-determined limits, the responses and recommended actions will be displayed in the Results step.
3) NOx sensor low level evaluation - The engine will be set in a mode where very low NOx is produced, average readings from the inlet and outlet sensor will be recorded. At the last test phase, average values from the high NOx and low NOx will be compared and evaluated. If the difference between the average sensor readings exceeds pre-determined limits, the responses and recommended actions will be displayed in the Results step.
4) DEF dosing system evaluation - Average pump duty cycles will be recorded during no dosing and dosing conditions. After this phase, the difference in duty cycle will be calculated and compared to an expected value. If the difference in pump duty cycle is below expected limits, the responses and recommended actions will be displayed in the Results step.
5) Cool down mode - The purpose of this phase is to lower the temperature of the EATS prior to the
Continue >
Chassis ID: N 976465 VIN: 4V4N99EHXHN976465 Work Order: 94eats2
Product Online




## Urea (DEF) Dosing System Subtest

The primary purpose for the urea dosing system check is to verify urea flow prior to evaluation of the SCR efficiency. While this test can be performed separately, and has the advantage over the flow test in that there is no dis assembly for some cases it may be good practice to also perform the standard dosing valve test, especially in any case when SCR replacement is considered. This would allow for visual inspection of the urea injection pipe for excessive crystal buildup. In any cases where excessive crystal buildup is observed , it may be advisable to perform a sulfur regeneration or crystal sublimation and then re run the operation.

After conditions are satisfied for the NOx Sensor Subtest, the routine enters the DEF dosing system check.

### Subtest Conditions

| Condition | Value (11L & 13L Engines) |
|---|---|
| Engine Speed | 1000 RPM |
| VGT (Turbo) Position | ~10% |
| | |

| | |
|---|---|
| Injection Timing | 20° BTDC |

The DEF Dosing Routine lasts approximately 30 seconds. The DEF pump duty cycle is first evaluated during a “no dosing” state at 131 psi (900 kPa) pressure. The ACM will then command .8 g/sec (0.028 oz/sec) urea flow. The urea dosing valve duty cycle will last approximately 10 seconds, and the change in pump duty cycle to maintain pressure is evaluated.

### Limits (For test to complete successfully)

| Parameter | Allowable change (.8 g/s flow, 10 second average) |
|---|---|
| DEF Pump Duty Cycle | Between 8% and 12% |

This range allowance, while appearing narrow is actually quite wide. Based on test data, typical pump duty cycle change is about 9-10%

## Cooldown Mode (Intermediate Phase)

The primary purpose for the cooling phase is to bring exhaust and SCR temperatures lower in order to expedite the stabilization step prior to efficiency evaluations. The target SCR temperature for the stabilization and SCR efficiency low evaluation steps is relatively low at 518.9 °F (270.5 °C) when compared to the temperature targets reached during the warmup phase. The SCR temperature reacts significantly slower than the other exhaust temperatures, and is usually elevated well above the target for SCR evaluation from the previous steps.

Both the NOx flow and Exhaust Mass Flow are recorded in the data (csv) file and displayed in the results of the test. These are not displayed during the test for initial releases of the EATS Health Check due to current Tech Tool limitations.

After conditions are satisfied for the Urea Dosing System check, the routine enters the Cooling step.

### Phase Conditions

| Condition | Value (11L & 13L Engines) |
|---|---|
| Engine Speed | 1600 RPM |
| VGT (Turbo) Position | Variable |
| Injection Timing | Variable |

This step will last approximately 30 seconds.

### Limits (For phase to complete successfully)

| Parameter | Condition |
|---|---|
| SCR Outlet Temperature | Temperature decreasing toward 518.9 °F (270.5 °C) |

# Stabilize Low SCR Temperature (Intermediate Phase)

The purpose of the stabilization step is to stabilize the SCR temperature, exhaust mass flow and NOx flow to begin the SCR efficiency evaluation.

After the cooling step, the routine enters the Stabilize low SCR temp step.

## Phase Conditions

| Condition | Value (11L & 13L Engines) |
|---|---|
| Engine Speed | 1550 RPM |
| VGT (Turbo) Position | 18% (At start of phase) |
| Injection Timing | 20° BTDC (At start, then retarding) |
| Intake Throttle Valve (ITV) Position | Closes from 87% to 20% |

After approximately 5 seconds, injection timing will retard from 20 BTDC to control NOx flow at 0.40 ± 0.01 g/s (.052 to .054 lb/min)

After approximately 1 minute, the routine will evaluate the exhaust temperature and exhaust mass flow routine will adjust the VGT to raise or lower the exhaust temperature between 518 and 536 °F (270 and 280 °C) and engine speed may be increased or decreased in 30 RPM increments as required to maintain exhaust mass flow between 0.21 and 0.26 kg/s (27.783 to 34.398 lb/min)

After the target exhaust mass flow and engine temperatures are reached, the routine will wait until the SCR average temperature falls within the range of 509-527 °F (265-275 °C) for 30 seconds to begin the SCR efficiency low step.

Additional condition for exiting stabilize low is the difference between NOx inlet and outlet doesn’t exceed 150 ppm (this is to ensure any SCR buffer accumulated during the UDS check is clear)

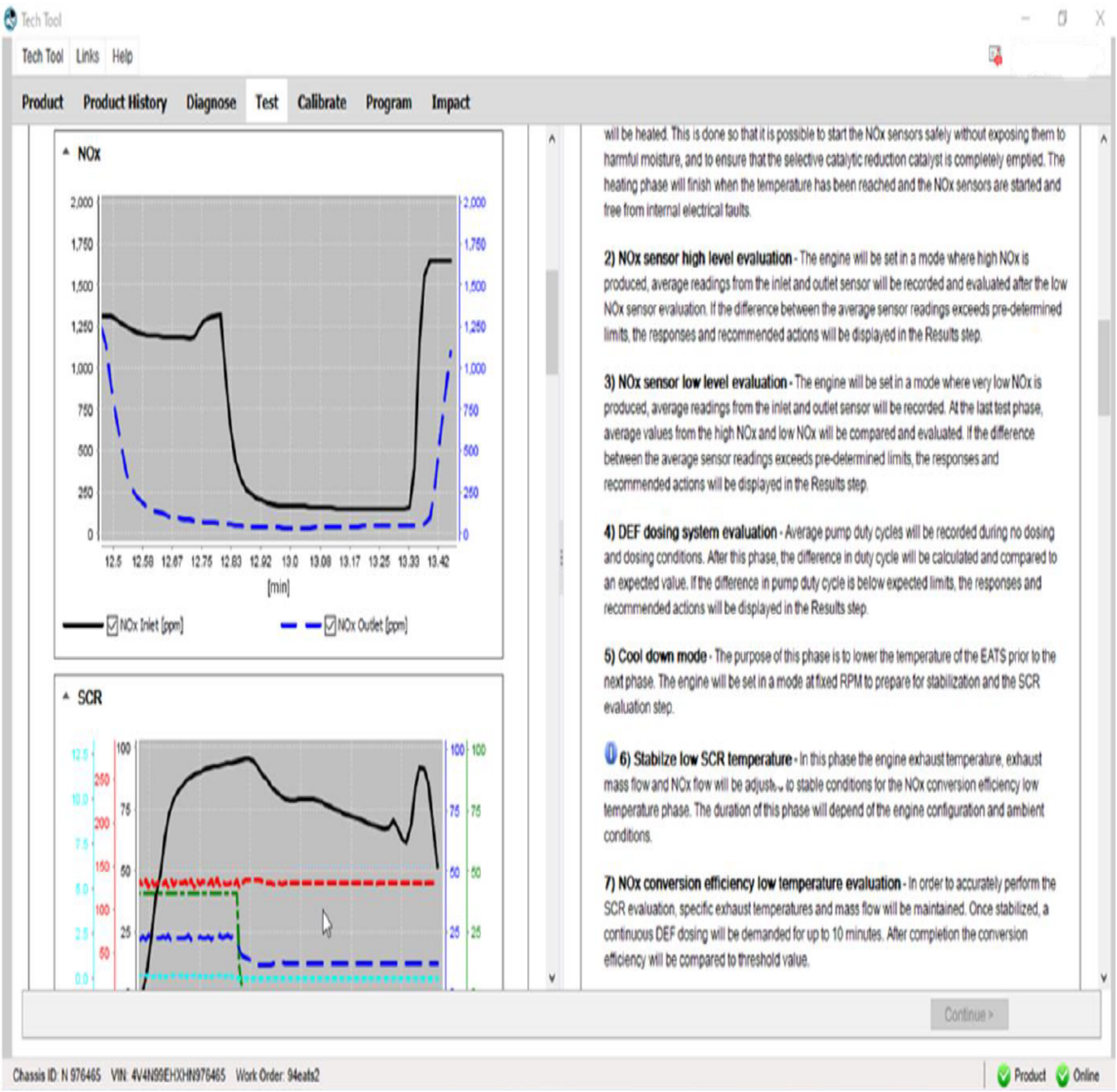
## Limits (For phase to complete successfully)

| Parameter | Condition |
|---|---|
| Engine Speed Variation | Maximum of 150 RPM for the duration of the phase |
| VGT (Turbo) Position Change | Maximum of 10% from the start position |
| Target Temperature Range | 509-527 °F (265-275 °C) for minimum of 30 seconds |
| NOx Values | Maximum difference of 150 ppm between inlet and outlet sensors |

**Operation failure during Stabilize Low SCR Temperature phase:**

The routine will timeout if target temperatures and exhaust flow are not met within 1800 seconds.

### Operations Screens - Stabilize Low SCR Temperature Phase




## NOx Conversion Efficiency Low Temperature Evaluation Subtest

The purpose for SCR efficiency evaluation is to evaluate SCR performance, and in most cases, assist in determination of whether the SCR is failed or still serviceable. The temperature and mass flow set points allow for evaluation under “less than ideal” conditions for the SCR (relatively low temperature and typical mass flow). There are cases in which the duty cycle of the vehicle allows for very optimum conditions during the On board diagnostic, (heavy loads and high average exhaust temperatures) and there may be only minimum instances of r elated fault codes, since this test evaluates at “less optimum” conditions the results of the test may indicate failure without setting related DTCs.

After the stabilize low SCR temperature conditions are satisfied, the routine enters the NOx conversion efficiency low temperature evaluation :

## Conditions

| Condition | Value |
|---|---|
| SCR Temperature Range | 509-527 °F (265-275 °C) |
| Exhaust Mass Flow Range | 27.8-34.4 lb/min (12.6-15.6 kg/min) |
| NOx Flow Range | 0.052-0.054 lb/min (0.0236-0.0245 kg/min) |

When conditions are met, urea (DEF) dosing will begin at a rate of 0.8 g/sec (0.028 oz/sec)

## Limits (For phase to complete successfully)

| SCR Efficiency Value | Time Limit | Behavior |
|---|---|---|
| Greater than or equal to 85% | Within first 5 minutes | Subtest will pass |
| Between 65% and 85% | Within first 5 minutes | DEF dosing continues for 5 more minutes |
| Does not reach 77% | After 10 minutes | Subtest will fail (See note below) |

### NOx Conversion Efficiency Low Temperature Evaluation Subtest Failure

In some cases where the efficiency is borderline (within 3-4% of the limit) consider the items below:

• There is possibility of aged SCRs that will finish the evaluation step a few percent below the failure limit after 10 minutes of evaluation. These instances should be handled on a case-by-case basis. For this reason, the test will be uploaded as a .csv file in case additional review is needed. It may be possible that SCR evaluation is borderline or slightly below the limit, but replacement may not be necessary. These cases will most often include vehicles that do not show frequent SCR related faults, and may operate in extreme enough conditions to allow average exhaust temperatures greater than 660 °F (350 °C).

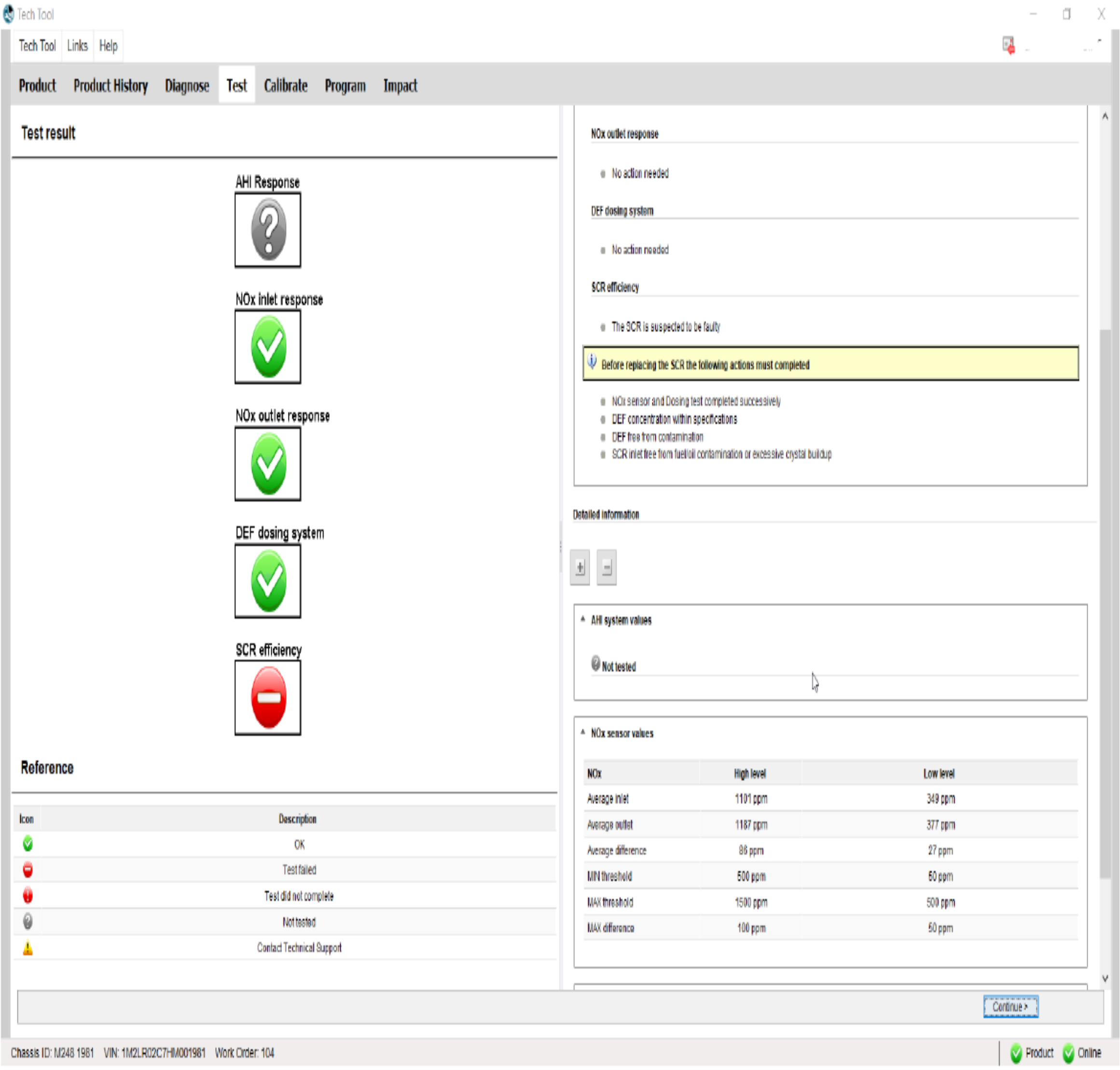
• **In all cases where the SCR shows efficiency at or below the passing limit**, the following checks should always be done prior to SCR replacement:

- Check the DEF quality with refractometer and test strips, and perform visual inspection of the tank for any contaminants
- Inspect SCR inlet for excessive crystal buildup, also inspect the SCR inlet for any indications of contaminants e.g. oil in exhaust from component failure upstream

# Post Test Results - Screenshots And Recommendations

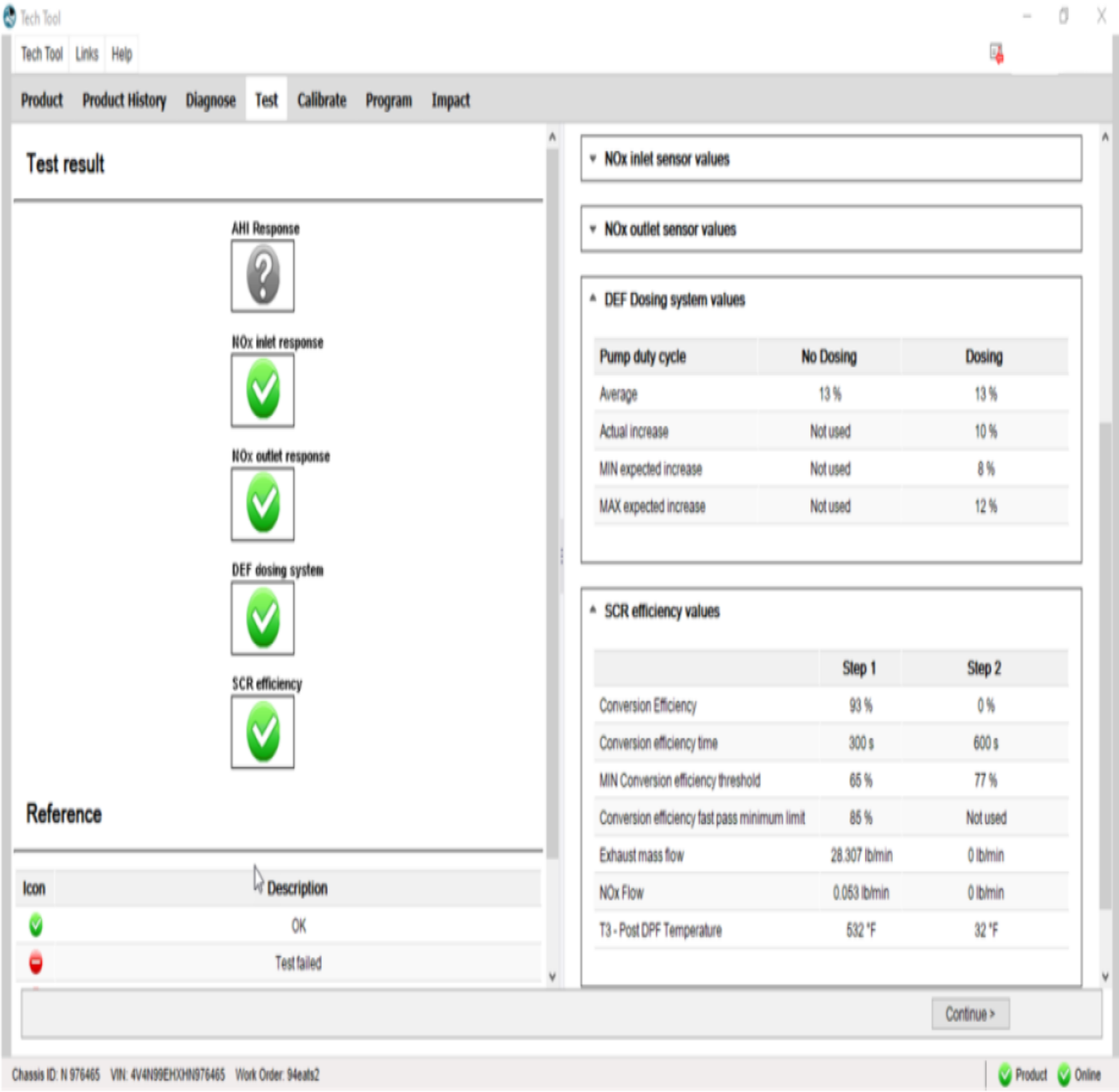
### NOx sensor evaluation results

The screen shows both High and Low phases with the difference and average value.

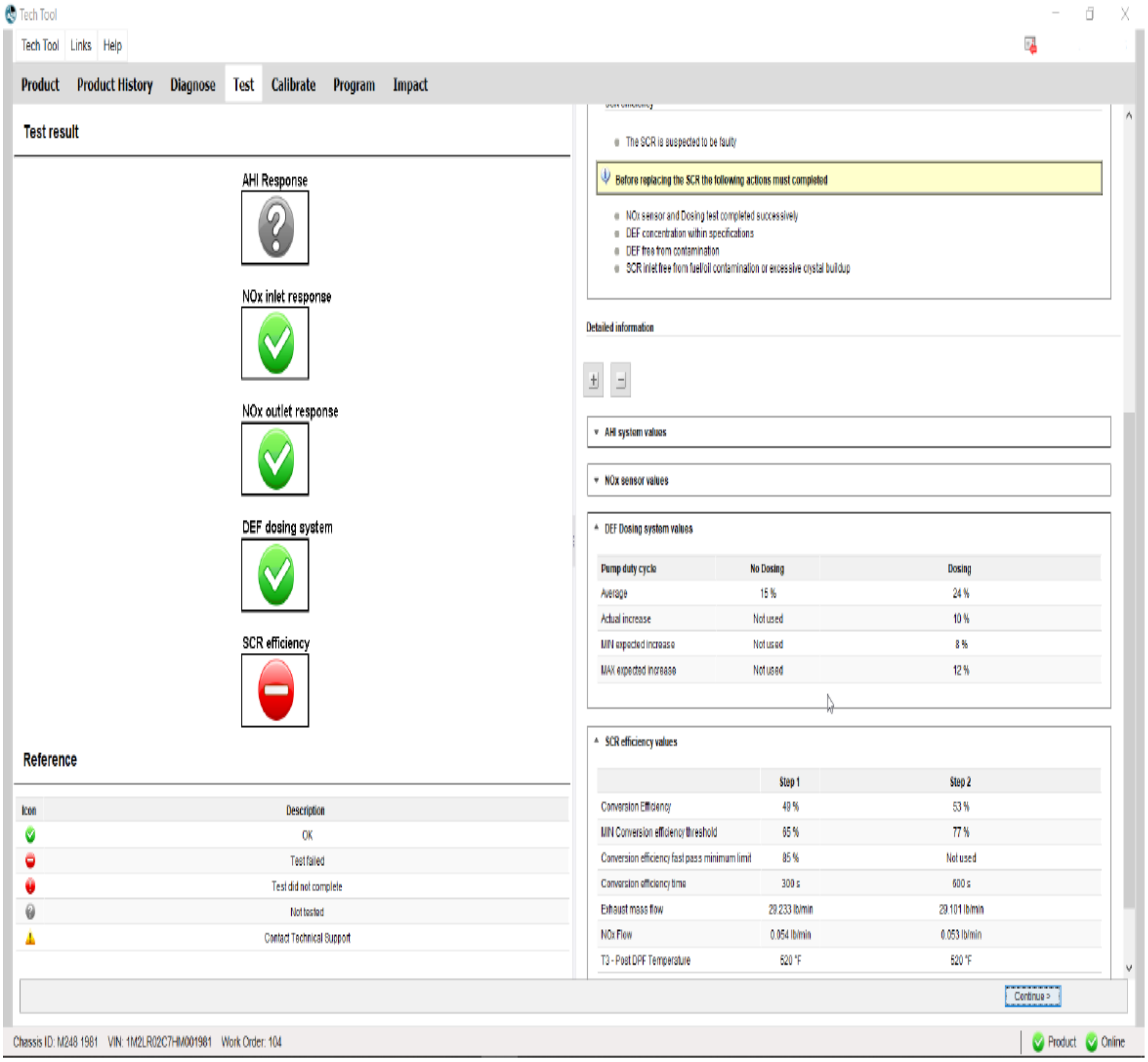


## DEF Dosing system and SCR Evaluation Phases

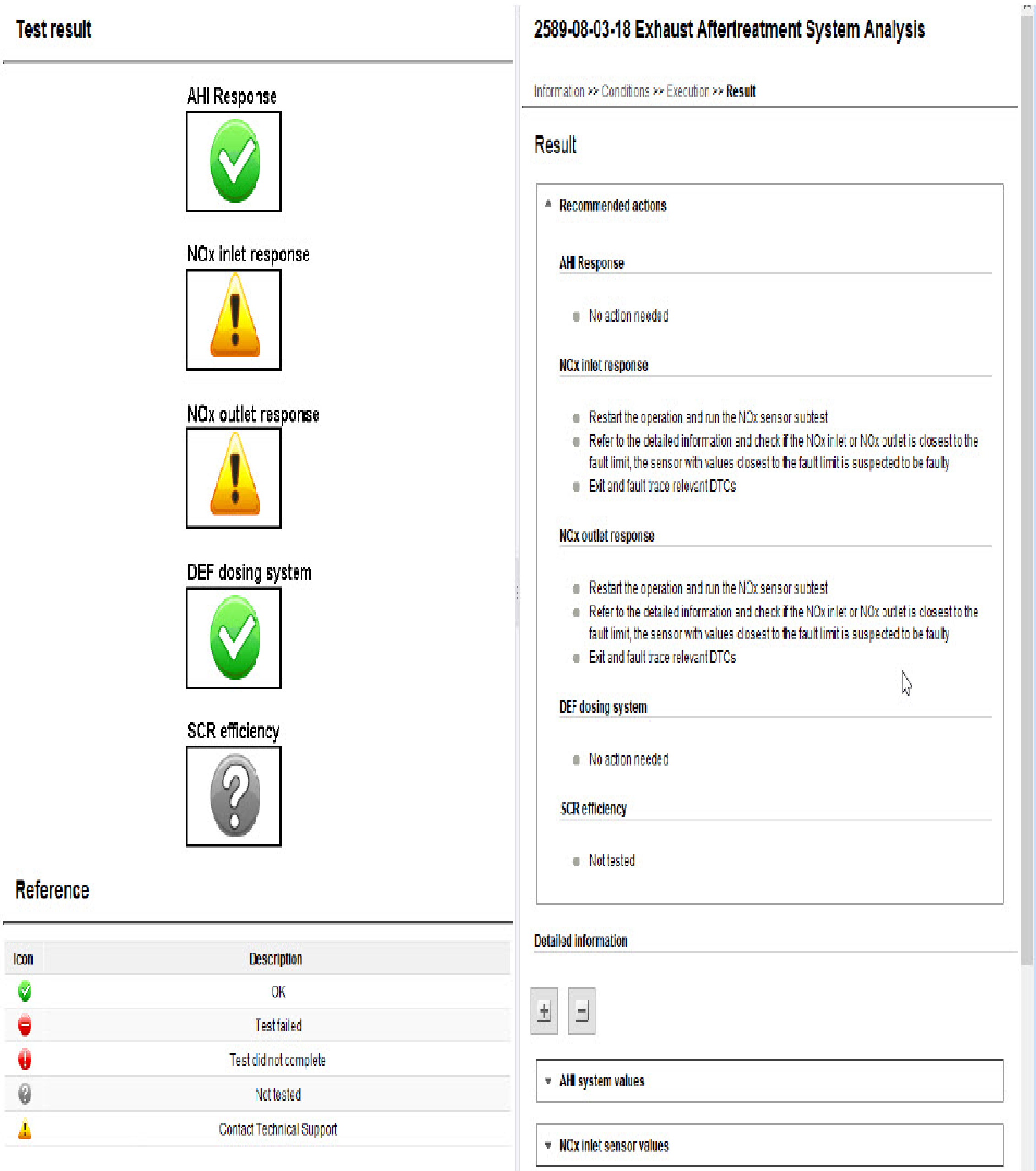
In the screenshot below, step 2 conversion efficiency is not shown because the “fast pass” limit is 85% (shown at 93% in step 1).




Step 2 conversion efficiency failed to reach the expected efficiency limits in both steps of the SCR evaluation in the screenshot below. The next test update will allow for a “fast fail” if SCR efficiency does not reach 65% in the first 5 minutes of evaluation.




The screen below shows the rare scenario when one or both sensors fail to reach a minimum value and also exceeds the allowable difference between the sensors.




| | |
|---|---|
| Internal comments (BO) | The attached pdf document is intended to assist the technician that is unfamiliar with this operation or has questions that may not be answered while performing the operation |
| Solution visibility | Dealer distribution |

## Function(s)/component(s) affected

| | |
|---|---|
| Function affected | SCR , DEF Dosing , DOC , DPF , Fuel Dosing |

## Function Group

| | |
|---|---|
| Function Group | 254 catalytic converter; exhaust emission control equipment , 258 emissions after-treatment |

## Customer effect

| | |
|---|---|
| Main customer effect | diagnostics/methodology , fault code/display |

## Fault Codes And Error Codes

| | |
|---|---|
| OBDII Diagnostic Trouble Codes (P, U, B Format) | P0422 , P0422-00 , P103C , P103C-00 , P20EE , P20EE-00 , P2201 , P2201-64 , P225C , P225C-00 , P225E , P225E-00 , P229F , P229F-64 |

## Administration

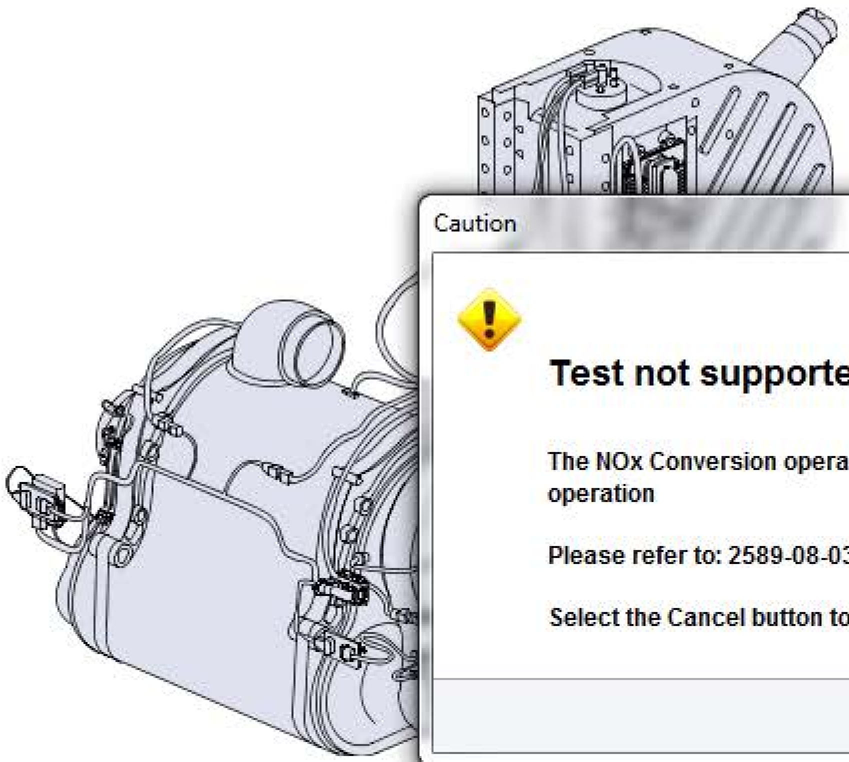
| | |
|---|---|
| Author | UT9246H |
| Dealer ID | UT9246H |
| Last modified by | A241298 |
| Creation date | 06-01-2020 15:01 |
| Date of last update | 11-03-2020 14:03 |
| Status | To be published |

Tech Tool

Tech Tool | Links | Help — JAMES JOHNSON

Product | Product History | Diagnose | Test | Calibrate | Program | Impact

Aftertreatment selective catalytic reduction (SCR) system



## 2549-08-03-03 NOx Conversion

Simulation

**Information** >> Conditions >> Execution

### Purpose

Caution

**Test not supported**

**The NOx Conversion operation is not supported with this ECM software, it has been replaced with a new Test operation**

**Please refer to: 2589-08-03-18 Exhaust Aftertreatment System Analysis**

**Select the Cancel button to exit the operation**

Close

...cumstances

...al support

- Verification - To compare system behaviour before and after repair

**Note:** Operation may take approximately 20 - 30 minute(s) to complete

▼ **Information**

Continue > | Cancel

Chassis ID: N 904837 VIN: 4V4WC9EH6KN904837 Work Order: 99999 — Product — Online

10:32 AM 3/11/2020