State of California
AIR RESOURCES BOARD

SUBJECT:
Certification Procedure for Direct Ozone Reduction (DOR) Technologies

APPLICABILITY:
2001 and subsequent model-year passenger cars, light-duty trucks, and medium-duty trucks for which non-methane organic gas (NMOG) exhaust emission reduction credit is requested as a result of the use of a DOR technology on a motor vehicle radiator, air conditioning assembly, or other appropriate substrate.

REFERENCES:

1. Title 13, California Code of Regulations (CCR) sections 1960.1, 1961, 1968.1, 1976, 2037, and 2038 as amended or adopted August 5, 1999.
2. "California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles," adopted August 5, 1999.
3. "California Evaporative Emission Standards and Test Procedures for 2001 and Subsequent Model year Motor Vehicles", adopted August 5, 1999.
4. "Malfunction and Diagnostic System Requirements: 1994 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines" (OBDII), amended August 5, 1999.
5. "Staff Report: Initial Statement of Reasons; Proposed Amendments to California Exhaust and Evaporative Emission Standards and Test Procedures for Passenger Cars, Light-Duty Trucks and Medium-Duty Vehicles," Section II-B-8, September 18, 1998, Mobile Source Control Division, California Air Resources Board.
6. "Characterization of Driving Patterns and Emissions From Light-Duty Vehicles in California," dated November 12, 1993. Report prepared for the Air Resources Board by Sierra Research under agreement No. 932-185.
7. "Estimation of the Effects of a Vehicle-Based Ozone Scavenging Process on Ambient Concentrations," prepared by Systems Applications International (SAI), August 1998.
8. "Ozone Exposure within Motor Vehicles - Results of a Field Study in Cincinnati, Ohio," presented at the June 18-23, 1995 meeting of the Air & Waste Management Association, in San Antonio, Texas, by T. Johnson and others.

9. Code of Federal Regulations, Title 40 Part 86, Subpart S, (64 Federal Register, 23906, May 4, 1999).

BACKGROUND AND DISCUSSION:

Title 13, CCR, sections 1960.1 and 1961 as adopted or amended August 5, 1999 [Reference 1], and the incorporated "California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles," as adopted August 5, 1999 [Reference 2] allow a vehicle manufacturer to receive NMOG credits for the use of DOR technologies on motor vehicles (hereafter referred to as DOR devices). These NMOG credits may be applied to the exhaust emissions of motor vehicles to demonstrate compliance with the applicable exhaust emission standards. These credits may also be used to offset evaporative emissions for those vehicles for which the manufacturer is seeking partial zero-emission vehicle credit (PZEV) under the provisions in Title 13, CCR, section 1976 [Reference 1] and the incorporated "California Evaporative Emission Standards and Test Procedures for 2001 and Subsequent Model Year Motor Vehicles" [Reference 3].

DOR devices involve special coatings on radiators or other surfaces in such a way that the amount of ozone in the ambient air, which crosses through or across such surfaces, is reduced. The Air Resources Board (ARB) considers these devices to be emission control devices since the NMOG credit accrued by such devices is used to offset the exhaust or evaporative emissions of motor vehicles. Therefore, the manufacturer must demonstrate the performance and durability of such devices for the full useful life of the vehicle, provide an onboard diagnostic (OBD) system to monitor the performance of the device, and provide the appropriate emission control warranty. While this MAC is drafted to address the certification of vehicles equipped with an ozone reducing catalytic coating applied to the vehicle radiator, a manufacturer seeking to certify other DOR devices must submit similar data demonstrating the effectiveness of such devices over the full useful life of the vehicle. The general requirements of this MAC are that the manufacturer shall submit the following:

(1) Data demonstrating the airflow rate through and ozone-reducing efficiency of the DOR device;
(2) Data demonstrating the deterioration factor of the DOR device;
(3) Data demonstrating the durability of the DOR device over the full useful life of the vehicle; and
(4) An OBD strategy for monitoring in-use performance of the DOR device.

Using the above information, an appropriate credit is to be calculated using a photochemical modeling analysis of the impacts of a DOR strategy on 1-hour peak ozone levels in the South Coast Air Basin (SCAB). In general, the NMOG credit will be based on the relationship between the ozone air quality benefits calculated by the photochemical modeling analysis for vehicles with the DOR technology versus the ozone air quality benefits calculated for an NMOG reduction strategy. The value of the NMOG credit will depend on the specific vehicle application considering such factors as vehicle radiator airflow rate, ozone reduction efficiency, deterioration factor, durability, and other factors.

The purpose of this MAC is to describe (i) the photochemical modeling analysis that will serve as the basis for these comparisons, (ii) the data and testing procedures needed to verify the airflow rate through, ozone reduction efficiency, deterioration factor, and durability of the DOR device, and (iii) the elements needed in the OBD strategy.

POLICIES:

(1) Modeling Analysis

An automobile manufacturer has the following two basic options in calculating and demonstrating to ARB the appropriate NMOG credit for specific vehicle applications of a DOR:

(i) The manufacturer may conduct its own photochemical modeling analysis of the air quality benefits (i.e., the impacts on 1-hour peak ozone levels in the SCAB) of a DOR strategy versus an appropriate NMOG reduction strategy to determine the equivalent per vehicle NMOG reductions for its specific DOR application. The manufacturer shall use the specific characteristics of its DOR application (e.g., ozone reduction efficiency and deterioration factor, radiator airflow or airflow across other applicable surfaces, etc.) and an NMOG reduction strategy approved by ARB. ARB must also approve the photochemical model and the ozone episode and key assumptions used in the analysis.

(ii) The manufacturer may submit appropriate data, collected in accordance with the test procedures and other requirements described in this document, that demonstrate the airflow rate through, the ozone reduction efficiency, deterioration factor, and durability of its specific application of the DOR device. This information will allow the results obtained in ARB’s base case analysis (as described below) to be scaled appropriately to determine the NMOG credit available for the manufacturer’s specific application of the DOR device.

The discussion that follows is directed at option (ii) in which ARB uses a base case analysis to determine an NMOG credit for an assumed vehicle DOR application and the manufacturer then compares key parameters of its specific DOR applications with those of the vehicle in the ARB analysis to determine an appropriate NMOG credit. This discussion, however, can also be used as guidance for the manufacturer that wishes to conduct its own base case modeling analysis.

<u>General approach</u>

ARB intends to base its determination of NMOG credit for DOR devices on an analysis that uses the Urban Airshed Model (UAM) to compare the ozone benefit when all vehicles in the fleet are assumed to be equipped with a DOR device to the benefits of an NMOG reduction strategy. The UAM model, which is used in the California State Implementation Plan and other analyses of ozone problems and control strategies, is a three dimensional photochemical air quality grid model used to predict ozone concentrations using time and space varying emissions, meteorology, photochemistry and other parameters. Hourly and cell-by-cell grid emission data for mobile, stationary, and area sources are input into the model. Systems Applications International (SAI) has documented [Reference 7] how the UAM model can be modified to accept information based on the volume of air swept by the vehicle fleet radiators which, when combined with a negative source term incorporating an ozone scavenging efficiency factor and cell volume, can calculate the hourly removal rate for ozone per grid cell. Basically, the removal of ozone is implemented as a negative source term in layer one of the model in a manner similar to the surface deposition term.

ARB’s UAM analysis of the base case will incorporate certain assumptions as discussed below pertaining to both the DOR strategy and the NMOG reduction strategy. ARB may use other airshed models if they are deemed more appropriate for this purpose. The manufacturer will be allowed to compare certain parameters of its DOR applications with the assumptions used for the corresponding parameters in the DOR base case modeling analysis to determine the appropriate scaling factors to calculate the NMOG credit for their applications. For example, if the NMOG credit calculated for the base case DOR vehicle is 0.01 grams per mile and airflow rate through the radiator for a manufacturer’s application is 20% greater than that used for base case analysis DOR vehicle, then the NMOG credit for the specific application is 20% greater than the base case credit, which yields an NMOG credit of 0.012 grams per mile in this case, assuming the values for all other parameters are the same (the modeling for the base case analysis will assume that airflow speed through the vehicle radiator is 40% of the vehicle speed – the ratio of airflow speed through the radiator to vehicle speed will vary between vehicle models, however, data suggests that 40% is a reasonable assumption). The other parameters affecting the credit calculation for specific applications are the ozone reduction efficiency adjusted by the deterioration factor of the DOR device and the size of the radiator surface coated with the catalytic material. In a specific application, these efficiencies are functions of the radiator size, radiator structure, vehicle structure, vehicle speed, deterioration of the catalytic coating and other factors. The value of these parameters over the full useful life of the vehicle should be measured and then compared with the parameters assumed in the base case since the base case does not explicitly take into account these factors. The procedures that must be followed to demonstrate the ozone reduction efficiency, the deterioration factor, radiator effective airflow rate and durability are described below.

Base case analysis

The following is a discussion of the modeling analysis and specific assumptions ARB will use in the base case analysis of the DOR technology.

(a) Ozone episode

The modeling analysis will be based on the August 27-28, 1987 episode in the SCAB. This episode was derived from the Southern California Air Quality Study (SCAQS) conducted in 1987 that focussed on both hot summertime ozone episodic conditions and late fall stagnation conditions and continues to be a major episode evaluated in the South Coast Air Quality Management Plan (AQMP). The 1987 SCAQS characterized the meteorological and air quality conditions throughout the basin over a total of five special intensive study days (episodes) during the summer months. The episode for August 27-28, is noted for the highest ozone maximum of any SCAQS (29 pphm on the 28th) and, therefore, provides the most appropriate data available for modeling the SCAB when meteorological conditions are conducive to ozone formation. ARB will use this episode for conducting the base case analysis. However, ARB will conduct the analysis assuming full implementation of the AQMP by the year 2010. Therefore, the initial and boundary conditions for pollutants and the emission inventory used for the analysis will be adjusted to reflect emissions in the SCAB when attainment of the federal 1-hour ambient standard is projected. In this way, the NMOG credit for DOR technologies will be determined when ozone levels have been reduced to the level of the ambient standard, thereby assuring that any credit assigned to DOR technologies will not adversely affect attainment in the SCAB. ARB will use this episode for the base case analysis until better information is available.

(b) Radiator Airflow Rate

The amount of air that passes through the radiator and can be treated by the DOR device is a function of the size of the radiator, and the airflow rate through the radiator. The radiator airflow rate is a function of operation of the vehicle cooling and/or air conditioning fan(s), the radiator structure, the vehicle structure, vehicle speed, and other factors. For the base case modeling analysis, ARB believes it is reasonable to address these variables through two basic assumptions concerning an average radiator size and an average radiator airflow rate. ARB will assume an average cross-sectional size for the radiator of 0.29 square meters and that the airflow speed through the radiator is on average 40% of the vehicle speed. Thus, if a vehicle’s average speed for 1 minute of travel is 30 miles per hour, the airflow through the radiator is equal to about 3300 cubic feet per minute, considering a 40% relationship between the vehicle speed and the airflow speed through the radiator, a radiator size of 0.29 square meters, and converting units.

For a specific application, the radiator cross section area and the radiator airflow speed at different vehicle speeds will need to be measured experimentally by the manufacturer according to the procedures described below.

(c) Ozone reduction efficiency (ORE) base case

The overall ORE for the DOR device is a function of the radiator structure, the deterioration of the coating over the full useful life of the vehicle, and other factors. A typical ozone reduction efficiency of 80% can be assumed for the base case modeling simulation. The ORE for specific applications must be measured experimentally, accounting for the deterioration factor over the vehicle's full useful life as well as any variation of the ORE at different vehicle speeds.

(d) NOx scavenging efficiency in the roadway

Studies in California and elsewhere have demonstrated that elevated concentrations of nitric oxide (NO) in the roadway due to vehicle exhaust emissions can cause roadway ozone concentrations to be lower than ambient ozone levels away from the roadway. In general, heavily traveled, high-speed roadways tend to have higher NO concentrations and, therefore, reduced ambient ozone levels available for destruction by a DOR device than do less traveled roadways. Limited data appear to be available to quantify the NO titration effects under a variety of conditions. The SAI report [Reference 7] used data from road tests conducted by Engelhard and data from an extensive study in Cincinnati, Ohio [Reference 8]. The Cincinnati study presents an overall average impact of about 40%. That is, roadway ozone concentrations were on average about 40% less than ambient ozone levels.

ARB will use a 40% factor to account for the impacts of NOx scavenging until better information is available.

(e) NMOG reduction

Equivalent vehicle NMOG reductions cannot be derived from the UAM when it is used to calculate the reduction in peak ozone from the DOR device. Therefore, the impact of the DOR device on 1-hour peak ozone levels must be compared to the ozone impact from an vehicle NMOG emission reduction strategy applied to a separate UAM model run. Previous simulations by SAI have used NMOG emission reductions of 8 tons per day in vehicle NMOG emissions to achieve air quality benefits of the same order as those achieved by the DOR strategy. ARB proposes the use of a similar level of emission reductions for calculating NMOG reductions for a DOR device, as outlined below.

(f) Equivalent NMOG grams per mile for the base case DOR application

The 8 ton per day (tpd) NMOG reduction (from the previous paragraph) will result in a reduction of the 1-hour peak ozone concentration (calculated peak ozone concentrations will be affected linearly by changes in the emission inventory of this order). Comparing the impact from the NMOG 8 tpd reduction to the reduction of the 1-hour peak ozone concentration from the DOR device will produce a ratio that will be applied to the 8 tpd to determine the equivalent NMOG reductions for the DOR device in the base case. For example, if the DOR device has an impact on the 1-hour peak ozone level that is 75% of the impact from the 8 tpd NMOG reduction, then the DOR device will be said to be equivalent to a 6 tpd NMOG reduction (8 tpd x 75%). Since the fleet vehicle miles traveled (VMT) is known from the UAM simulation, dividing the 6 tpd by the VMT will yield the equivalent NMOG grams per mile credit for the DOR device for the base case scenario. The NMOG gram/mile credit for the base case scenario will be termed the base case NMOG Credit (NC_{BC}).

(2) Calculation of NMOG credit for specific vehicle applications
In general, the NMOG credit for a specific vehicle application of the DOR device will depend on the relationship between the radiator performance characteristics for this vehicle versus the radiator performance characteristics assumed for the vehicles in the base case modeling analysis. The performance characteristics of primary concern are the radiator cross section area, the radiator airflow rate and the ozone reduction efficiency adjusted by the deterioration factor over the full useful life of the vehicle.

To relate the effective airflow rate of a specific DOR application to the effective airflow rate used in the base case, the manufacturer must compare the radiator air speed/vehicle speed ratio for the specific vehicle application with the 40% ratio used in the base case. The manufacturer must also account for the different sizes of the radiators for the specific application versus the base case by determining a ratio based on the size differences.

The effective radiator airflow rate (AFR) is to be calculated by using the radiator cross-sectional size and the measured air speed through the radiator over a specified driving cycle. Comparing the AFR for a specific vehicle application with the AFR for the vehicle used in the base case analysis is a key step in calculating the NMOG credit. The manufacturer must provide data (in accordance with test procedures discussed below) for its particular vehicle applications.

The ozone reduction efficiency (ORE), that is, the percent destruction of ozone by the DOR device is a function of both the airflow speed (depending on the fin structure of the radiator or DOR device, conversion breakthrough may occur, whereby the ORE would decrease at high airflow speeds) and the deterioration factor of the DOR device over the full useful life of the vehicle. The manufacturer must provide information (in accordance with test procedures discussed below) that demonstrates the ORE and the deterioration factor for its particular vehicle applications.

Once the AFR and ORE for a particular vehicle application are determined the NMOG Credit (NC) for the application can be calculated using the following equation:

$$NC_{SV} = NC_{BC} \times (AFR_{SV}/AFR_{BC}) \times ((ORE_{SV} \times DF)/ORE_{BC}) \times (RCS_{SV}/RCS_{BC}) \qquad (1)$$

Where:
NC_{SV} = specific vehicle NMOG credit
NC_{BC} = base case NMOG credit
AFR_{SV} = airflow rate of specific vehicle application
AFR_{BC} = airflow rate of base case vehicle used in the airshed model
ORE_{SV} = ozone reduction efficiency of specific vehicle application
ORE_{BC} = ozone reduction efficiency of base case vehicle used in airshed model
DF = deterioration factor of specific application
RCS_{SV} = radiator size of specific application
RCS_{BC} = radiator size of base case

Test procedures and data requirements to demonstrate DOR performance

The test procedures and data requirements are directed at certifying the performance of the DOR device through the use of reasonable and reliable methods. The basic approach will require the manufacturer to evaluate and document the performance of the DOR device on its specific vehicle applications using procedures based on the Unified Cycle (UC) (the UC is more representative of contemporary driving patterns in the SCAB than other test cycles). The following discussion describes those methods and procedures ARB believes are appropriate for the manufacturer to follow in providing the necessary information for their specific vehicle applications. The manufacturer, with prior approval of the Executive Officer, may propose alternative methods or procedures to provide this.

(a) Radiator airflow rate

Although the test procedure and data needed regarding the radiator airflow should be based on the UC, ARB recognizes that the UC test does not actually provide a means for collecting information regarding such data. That is, the UC is a dynamometer-based test that does not reflect vehicle movement through the ambient air. Therefore, the manufacturer will need to conduct appropriate on-the-road driving or wind tunnel testing to develop data demonstrating the airflow through the radiator that can be used in calculating the radiator airflow were the vehicle to actually travel the UC in a real-world setting. The primary consideration will be the ability to ensure that the vehicle travels for at least ten minutes in each of the specified speed ranges. (See discussion below concerning speed ranges.)

The manufacturer may use other methods to determine the effective air speed through the radiator with prior approval of the Executive Officer.

(i) Vehicle speed ranges

Measurements of vehicle speed and radiator air speed must be taken for all the speed ranges used in the UC as shown in the following table:

TABLE 1: Vehicle speed ranges for measurements to determine DOR device airflow rate

Speed code	Vehicle Speed (mph)	% of UC test cycle
1	idle (0 mph)	16%
2	0.01 to 5.01 mph	8%
3	5.01 to 10.01 mph	5%
4	10.01 to 15.01 mph	8%
5	15.01 to 20.01 mph	7%
6	20.01 to 25.01 mph	9%
7	25.01 to 30.01 mph	11%
8	30.01 to 35.01 mph	7%
9	35.01 to 40.01 mph	6%
10	40.01 to 45.01 mph	6%
11	45.01 to 50.01 mph	4%
12	50.01 to 55.01 mph	1%
13	55.01 to 60.01 mph	5%
14	60.1 to 65.7 mph	7%

(ii) Measurement methodology

There are three components to the measurement methodology: the equipment used for measuring and recording vehicle and air speed, the location of measurement probes on the radiator, and the frequency of measurements.

(1) Equipment for measuring vehicle speed and air speed through the radiator

(a) Air speed transducers (e.g., hot wire anemometer) capable of measuring the point speed over the range of interest and mountable on the front face of the radiator.

(b) Temperature transducer (e.g., thermocouple) for measuring ambient temperature of the air entering the radiator.

(c) Access to vehicle speed transducer output.

(d) Data recording equipment, such as chart recorder, data logger or computer-based acquisition system for producing tapes, strip charts and/or electronic data files that can be provided to ARB as evidence of driving and measurements.

(2) Location of measurement probes

The manufacturer must measure the radiator air point speed at a sufficient number of locations with one location being as close to the center of the radiator as practicable. The other locations are at the discretion of the manufacturer as long as sufficient information is obtained to accurately assess the average airflow speed through the radiator. These measurements must reflect the airflow through the radiator as installed on the specific vehicle model for which the NMOG credit is to be determined. These measurements may be conducted with the radiator installed in the vehicle or on a bench test as long as the installation of the DOR device in the vehicle is adequately simulated to account for the effects of radiator fin density, vehicle front end design, seals, and dams, etc. The manufacturer shall also include a discharge box or other means to simulate engine-bay pressure when using a bench test to measure airflow through the radiator. The manufacturer must provide ARB data to support their measurement location selections, bench test setup and procedure, the methodology used to calculate the average airflow speed through the radiator, and address any technical issues associated with the above requirements.

(3) Frequency of measurements

Sufficient measurements must be taken to represent a minimum of 10 minutes of travel in each of the speed ranges noted above. Travel within a speed range does not have to be continuous; however, the summation of one second intervals associated with each speed measurement must be at least 10 minutes for each speed range. Measurements of vehicle speed and air speed through the radiator should be taken on a frequency of approximately one per second or collected in a manner that enables the measurements to be summarized to one-second intervals. Thus, for each speed range there will be a minimum of 600 measurements (10 minutes times 60 seconds per minute). The manufacturer is encouraged to collect additional measurements to add further rigor to the results. Furthermore, to promote consistency between measurements and to reflect conditions associated with elevated ozone levels (high ambient temperatures and stagnant meteorological conditions), measurements should occur when ambient temperatures are relatively high, when winds are calm or mild, and when the radiator fan and air conditioner are operating.

(ii) Calculation of the airflow through the DOR device

Calculation of the airflow through the DOR device over the Unified Cycle is as follows:

$$AF_{SV} = RCS \times UC_{SEC} \times 1.47 \times \Sigma(AS_i \times PF_i) \qquad (2)$$

(summed over i=1 to 14 for each of the speed ranges from Table 1)

Where:

AF_{SV} = total airflow across the DOR device for the specific vehicle application during a UC driving cycle, in cubic feet.

RCS = cross sectional area of the radiator (or DOR device), in square feet

UC_{SEC} = total seconds in the UC

1.47 = factor to convert from miles per hour to feet per second

AS_i = average measured air speed through the radiator (or DOR device) for speed code i, in miles per hour

PF_i = percent of UC with vehicle speed in range i

The calculated value for AF_{SV} shall be compared to the value for the maximum volume of air (AF_{MAV}) that could flow through the DOR device in order to determine the value for AFR_{SV}. AF_{MAV} shall be calculated using equation (2) by substituting vehicle speed for AS_i. The effective airflow rate for the specific vehicle application is defined as the ratio of the measured airflow rate through the DOR device to the airflow rate through the DOR device assuming no obstruction to the passage of air through the device. AFR_{SV} is calculated as follows:

$$AFR_{SV} = AF_{SV} / AF_{MAV} \qquad (3)$$

The value for AFR_{SV} shall be used in equation (1) to calculate the NMOG credit (see section (4) below).

(b) Specific vehicle ozone reduction efficiency (ORE_{SV})

Similar to the radiator airflow, a specific vehicle application could have a different ozone reduction efficiency than the efficiency assumed in the base case modeling analysis. In addition, this efficiency could vary to some degree over the different speeds encountered in typical urban driving.

Measuring the ORE_{SV} by requiring each manufacturer to conduct roadway tests for each vehicle configuration would be burdensome and prone to considerable variation (e.g., ozone levels vary considerably at any time and place, ozone monitoring equipment in a mobile operation introduces numerous measurement variables, etc.). Therefore, the manufacturer may conduct appropriate bench tests to determine the ORE_{SV} across a reasonable range of airflow speeds.

The manufacturer shall measure the ORE_{SV} for each unique radiator design based on features such as fin density, depth, etc. If the same radiator design will be used for multiple vehicle applications, then the manufacturer's data submission may be applied to all such vehicles, as long as the manufacturer can demonstrate that these applications will not modify the ORE_{SV}.

For the bench tests, the manufacturer must demonstrate percent reduction of the ozone concentration of the air passing through the radiator. ARB expects that this demonstration can be accomplished in two different ways. First, the full size radiator can be placed in a test rig such as utilized by manufacturers to assess radiator performance characteristics (e.g. heat rejection and pressure drop). Bulk air sampling locations should be chosen upstream and downstream of the radiator so that sufficient mixing of the air enables sound ozone conversion measurements to be taken.

Alternatively, a number of probes can be appropriately placed directly in front of and behind the radiator to measure ozone levels before and after passing through the radiator to determine the ozone concentrations in the bulk air up and down stream of the radiator. The manufacturer must develop a correlation between the point ozone concentrations measured and the ozone concentration in the bulk air up and down stream of the radiator. For both methods the air speed through the radiator must be varied to simulate the range of air speeds through the radiator likely to be encountered in the UC. Manufacturers must provide sufficient data validating the methodology used to determine the ORE of the DOR device.

For the first method, ozone should be introduced and dispersed sufficiently upstream of the radiator upstream sampling location to insure complete mixing in the air prior to the sampling point. ARB suggests that upstream measurements be taken two feet in front of the radiator front face and that downstream measurements be taken four feet after the radiator rear face and at least two feet from the end of the ductwork. The temperature of the radiator should be at its typical operating temperature. The ozone level entering the radiator should be between 100 and 300 ppb.

For the alternative method (i.e., individual probes), the manufacturer must measure the catalyst efficiency at a sufficient number of locations to assure an accurate measurement and in accordance with the following:

(1) At least one of the probes should be located at the point on the surface of the DOR device where the highest airflow speed occurs. The other probe locations are at the manufacturer's discretion as long as the average ORE of the DOR device is accurately demonstrated.

(2) The sampling locations are to be sufficiently shrouded to insure the upstream and downstream measurements are taken from the same air mass and that no cross mixing has occurred.

(3) The ozone concentration introduced into the radiator should be between 100 ppb and 300 ppb.

(4) The temperature of the radiator should be at its typical operating temperature.

The manufacturer may use the following equation to calculate the ORE for its specific vehicle application.

$ORE_{SV} = \Sigma(ORE_i \times PF_i)$ (4)
(summed over i=1 to 14 for each of the speed ranges from Table 1)

Where: ORE_I = measured ORE of DOR device for speed code I, in percent
PF_i = percent of UC with vehicle speed in range i

The manufacturer shall determine the DF of its specific applications for the full useful life of the vehicle, 120,000 miles. The ORE_{SV} shall be adjusted by the DF when calculating NC_{SV}. The manufacturer may repeat the above procedure with an appropriately aged radiator, or submit engineering data substantiating the DF.

(4) Sample calculation of NMOG credit for a specific vehicle application
Following is a example showing the calculation of the DOR NMOG credit for a specific vehicle application.

From equation (2) $AF_{SV} = RCS \times Sec_{UC} \times 1.47 \times \Sigma(AS_i \times PF_i)$

Assuming for the specific vehicle application:

AF_{SV} = volume of air passing through radiator over the unified cycle in cubic feet
RCS = .29 square meters
Sec_{UC} = 1435 sec
1.47 = factor to convert from miles per hour to feet per second
$\Sigma(AS_i \times PF_i)$= 7 mph

therefore: $AF_{SV} = .29 \times 1435 \times 1.47 \times 7$
$= 4282.1$ cubic feet

From equation (2):

$AF_{MAV} = .29 \times 1435 \times 1.47 \times 24.6$
$= 15048.8$ cubic feet

From equation (3):

$AFR_{SV} = (4282.1/15048.8) \times 100$

$= 28\%$

From equation (1):

$$NC_{SV} = NC_{BC} \text{ x } (AFR_{SV} / AFR_{BC}) \text{ x } ((ORE_{SV} \text{ x } DF) / ORE_{BC}) \text{ x } (RCS_{SV} / RCS_{BC})$$

for the specific vehicle application in a test group:

$NC_{BC} = 0.1$ g/mi NMOG
$AFR_{BC} = 40\%$ from base case
$AFR_{SV} = 28\%$ from equation (3)
$ORE_{BC} = 80\%$ from base case
$ORE_{SV} = 70\%$ from equation (4)
$DF = 0.80$
$RCS_{BC} = 0.29$ from base case
$RCS_{SV} = 0.20$ from specific vehicle application

therefore: $NC_{SV} = 0.01 \text{ x } (.28/.40) \text{ x } (70 \text{ x } 0.80/80) \text{ x } (0.20/0.29)$
$= 0.003$ g/mi NMOG

(5) Onboard diagnostic (OBD) requirements for DOR devices

Title 13, California Code of Regulations, Section 1968.1, “Malfunction and Diagnostic System Requirements – 1994 and Subsequent Model-Year Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles and Engines,” requires all passenger cars, light-duty trucks, and medium-duty vehicles to be equipped with an on-board diagnostic system that monitors the function or performance of all emission control devices. Since DOR technologies are considered emission control devices, the manufacturer must demonstrate its approach for monitoring the function or performance of such devices in use. The manufacturer must demonstrate that the OBD system will directly monitor ozone conversion or a surrogate parameter (for example, manufacturers infer catalyst efficiency by monitoring the oxygen storage capability of the catalyst). In designing the OBD system the manufacturer may target a specific location(s) of the DOR device as long as sufficient data is submitted demonstrating that such an approach provides an adequate assessment of the overall performance of the DOR device in-use. Furthermore, the mechanism used for monitoring must be designed such that replacement or proper repair of the DOR device is assured when a malfunction is detected. The criteria for MIL illumination are outlined below.

(i) For applications where the NMOG credit assigned to the DOR device is less than half of the applicable exhaust emission standard (50,000 or full useful life in-use) to which the vehicle is certified, the OBD system shall perform only a functional check of the DOR device. Accordingly, the OBD system shall indicate a malfunction when some degree of ozone conversion is not detectable.

(ii) For applications where the NMOG credit assigned to the DOR device is greater than half the applicable exhaust NMOG emission standard (50,000 or full useful life in-use) to which the vehicle is certified, the OBD system shall monitor the performance of the DOR device. Accordingly, the OBD system shall indicate a malfunction when the ozone conversion rate falls below the manufacturer’s specified conversion limit such that the difference between the calculated NMOG credit at that limit and the NMOG credit assigned to the DOR device exceeds half of the applicable exhaust NMOG emission standard to which the vehicle is certified.

(6) Durability

Consistent with the durability requirements for emission control devices, the manufacturer shall submit data demonstrating the durability of the DOR device. The manufacturer shall submit data demonstrating the effects of time, road grime, temperature variations to which the DOR device is subjected, vibration, and weather and any other condition which may affect the operation of the device over the full useful life of the vehicle.

(7) Emission Warranty

As noted above, DOR devices are to be classified as emission control components. Therefore, the manufacturer shall provide the appropriate emission warranty for such devices.

(i) If the replacement cost of the DOR device, including the substrate on which the ozone reducing material is coated, exceeds the applicable high cost parts limit, then the manufacturer shall warrant the DOR device for seven years or 70,000 miles, which ever occurs first (eight years or 100,000 miles for vehicles certifying to the optional 150,000 mile NMOG emission standards, and 15 years or 150,000 mile for vehicle certifying to the applicable PZEV standards).

(ii) If the replacement cost of the DOR device, including the substrate on which the ozone reducing material is coated, does not exceed the applicable high cost parts limit, then the manufacturer shall warrant the DOR device for three years or 50,000 miles, which ever occurs first. For vehicles certifying to the applicable PZEV standards, the manufacturer shall warrant the DOR device for 15 years or 150,000 miles.

(8) Certification Information Requirements:

Under the provisions of CAP 2000 [Reference 9] manufacturers are required to submit an Application for Certification (Application) for each durability group and their associated test groups. Furthermore, any information within the Application which is unique to a specific test group must be submitted for each test group. As noted above, ARB considers DOR devices to be equivalent to an emission control technology since the NMOG credits accrued by such devices are used to offset motor vehicle exhaust or evaporative emissions. Therefore, manufacturers shall include the relevant information pertaining to the DOR device with their Part 1, Part 2, and Part 3 Applications.

Since the application of this technology is unique, ARB will allow the manufacturer in the early years of application of this technology, subject to prior approval of the Executive Officer, to determine the criteria for defining DOR durability groups and DOR test groups within a certification (exhaust) durability group and its certification (exhaust) test groups. However, in defining durability groups and the associated test groups the manufacturer shall take into account the relative sizes of the vehicle radiators, the loading of the ozone reducing material, the composition of the ozone reducing material, the structure of the radiator (fin density and depth), the radiator/vehicle front end configurations, and any other parameters that may affect the operation of the DOR device when installed on different vehicle models. An analogy is the grouping of evaporative families among several exhaust durability groups and test groups. The ARB may issue more detailed guidelines for determining durability groups and test groups when more experience is gained in the application of this technology.

(9) Conditions for Certification

If a certification exhaust test group includes different DOR applications that yield different calculated NMOG credits and, if the test group’s exhaust NMOG certification value (from testing the “worst case” test vehicle) exceeds the NMOG standard after applying the lowest calculated DOR NMOG credit, the manufacturer shall remove the vehicle model associated with the lowest DOR NMOG credit from the test group.

Where an exhaust certification test group includes different DOR applications that yield different DOR NMOG credits and the conditions in above paragraph have been met, the DOR NMOG credit will be sales weighted among the DOR applications within the test group.