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Final Technical Report on Intermediate Soak and Start Driving Behavior for the Revised Federal Test Procedure Notice of Proposed Rulemaking

U.S Environmental Protection Agency

Office of Air and Radiation

Office of Mobile Sources

Certification Division

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I.Terminology

Soak Period - Duration for which vehicle is not operational.

Hot Soak - Soak duration less than or equal to 10 minutes. Soak preceding bag 3 of FTP generally referred to as hot soak

Intermediate Soak - Soak duration between 10 minutes and overnight (nominally less than 3 hours)

Overnight (Cold) Soak - Soak duration longer than 12 hours. Soak preceding bag 1 of FTP generally referred to as cold soak

Tier 0 - LDV/LDT Tailpipe emission standards in place prior to Model Year 1994. Vehicles certified to these standards are referred to as "Tier 0" vehicles.

Tier 1 - LDV/LDT Tailpipe emission standards beginning phase-in Model Year 1994. Vehicles certified to these standards are referred to as "Tier 1" vehicles.

Tier 2 - LDV/LDT Tailpipe emission standards proposed to be in place by Model Year 2004. Vehicles certified to these standards are referred to as "Tier 2" vehicles.

LEV/ULEV - State of California's Low Emission Vehicle and Ultra-Low Emission Vehicle standards. Vehicles certified to these standards referred to as "LEV" or "LEV/ULEV" vehicles.

505 - Driving cycle used for Bags 1 and 3 of the FTP with a duration of 505 seconds.

Closed-loop fuel control - period for which vehicle is operating in continuous feedback loop to ensure optimum fuel calibration.

SFTP - Supplemental Federal Test Procedure: proposed addition to the Federal Test Procedure encompassing aggressive driving behavior, air conditioning and intermediate soak control

Additional Note on Terminology: For convenience, tailpipe emissions which are generated following a soak period are generally referred to as being emissions "on", "over" or "following" the soak.

II.Introduction

The Federal Test Procedure (FTP) currently represents all vehicle soak periods with an overnight "cold" and a 10 minute "hot" soak. The Agency's study of driving behavior found that vehicle soak periods of duration between those represented on the FTP, termed "intermediate" soaks, occur frequently in-use. Agency testing has shown that tailpipe emission levels increase significantly as soak duration is extended beyond hot soak periods. Due to concern that potentially important emission modes are not represented by the current test procedure, EPA is proposing the inclusion of an intermediate soak component as part of revisions made to the FTP. This document presents EPA's findings on the in-use occurrence of intermediate soaks and related emission impacts, discusses technical elements of potential control strategies, and details the proposal for inclusion of an intermediate soak requirement in the FTP. In addition, this document addresses EPA's findings on in-use driving behavior following vehicle startup and the subsequent proposal to include representative start driving as part of the intermediate soak requirement.

III.In-use behavior and emission impacts

A.Intermediate soak

1.In-use soak behavior

The FTP includes one overnight soak and one 10 minute hot soak meant to represent the range of in-use soak durations. The Agency's study of in-use driving behavior found that although soak periods of less than 10 minutes and greater than 8 hours have the highest frequency of occurrence in-use, a significant portion of vehicle soak times were of a duration in between the soak periods represented by the FTP. Table 1 shows the overall in-use distributions of soak periods from the Baltimore survey(1); nearly 40% of vehicle soak times recorded were between 10 minutes and 2 hours. The Agency hypothesizes that the significant occurrence of soaks periods of intermediate duration is the logical result of the continued decentralization of urban and suburban areas. As population and road networks continue to spread, there is an increased dependence on the vehicle for performing day-to-day tasks. The result is a larger variation of trip lengths and soak periods than is represented on the FTP, which was designed to represent a typical commute to work. By not representing soaks of intermediate duration, the FTP currently excludes a mode of in-use driving which is already significant and will likely increase as the trend towards population decentralization continues.

2.Emission impact of intermediate soaks

In order to assess the emission impact of intermediate soaks and start driving, EPA conducted the Soak/Start test program in two phases between July 1993 and June 1994. Because it was hypothesized that the primary contributor of emission increases over intermediate soaks is the rapid cooldown of the catalytic convertor, the test program was designed to investigate this phenomena. The vehicle sample for the program consisted of 3 Tier 0 and 4 Tier 1 vehicles, including one Light-Duty Truck (Table 2). Because the Tier 0 vehicles were equipped with multiple light-off catalysts and/or main catalysts of similar placement, size and loading representative of what is being used to comply with Tier 1 standards, the relative emission performance of these vehicles over intermediate soaks was considered representative of Tier 1 vehicles. The vehicles were tested over EPA's Soak Compliance Cycle (2) following soaks of 0

The Baltimore dataset was determined as the best representation of the cities surveyed as part of the in-use driving survey. The methodology which determined this is discussed in the FTP Preliminary Technical Report, pp. 83-87

EPA's Soak Compliance Cycle, or SC01, is described in Section 7.1.4. For simplicity, both the cycle which was tested in EPA's Soak/Start program and the cycle being proposed are referred to as SC01. However, the version being proposed was (no soak), 10, 20, 30, 45, 60, 90, 120 and 720 (overnight) minutes in length; this sample of soak periods was chosen to highlight the period for which the rate of catalyst cooldown is most rapid. The vehicles were also run over the 505 following no soak and soaks of 10 and 720 minutes in duration.

Results from the Soak/Start test program show that tailpipe emission levels increase significantly following intermediate soaks of relatively short duration. The primary reason for the observed emission increase is the rapid cooldown of the catalytic convertor below properly operating temperatures after the vehicle is shut off, and the subsequent delay in catalyst warmup upon restart. In addition, the data indicate that a lack of optimized fuel control calibration on start-up following intermediate soaks has a significant emission impact on some vehicles. A detailed discussion of the observed causes of intermediate soak emissions is contained in the following sections.

a.Catalyst cooldown

Data from the Soak/Start test program indicate that catalytic converters cool down rapidly after the vehicle is shut off, in a short time falling below the temperature required to function properly ("light-off" temperature) when the vehicle is restarted. Figure 1 shows a cooldown profile for the catalyst on a Tier 1 1994 Ford Escort over a two hour soak. After 10 minutes, the catalyst is well above light-off temperature (nominally defined as 600 degrees F). However, the catalyst begins to cool down

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modified from the test version by removing extended idle periods between bags 1 and 2 and following the bag 2, which had been in place for sample delay purposes. It is also important to note that SC01 was tested as a two bag cycle, while it is being proposed as a one bag cycle. In order to represent start driving fully, SC01 was tested with varying initial idle times, depending on whether the start was hot, warm or cold (with initial idles of 12, 18 and 28 seconds, respectively); the version being proposed contains an 18 second initial idle. The start driving portion of SC01 (the first 258 seconds following startup) is referred to as the Start Cycle (ST01), bag 1 of the test version.

rapidly past 10 minutes, falling below light-off temperature within 25 minutes following vehicle shut-off. The catalyst has dropped to well below light-off temperature after two hours. When a vehicle is restarted following a soak of 10 minutes, the catalyst is above the temperature necessary for proper conversion. However, when this soak is extended to 30 minutes or longer, the catalyst is typically below the temperature necessary for proper operation. Because of the sensitivity of tailpipe emissions to the conversion of the catalyst, a relatively small increase in soak duration can result in a disproportionately large emission increase.

Compounding the impact of rapid catalyst cooldown is the observation that despite higher catalyst temperatures upon startup following intermediate soaks, the time required to achieve light-off of the catalyst following an intermediate soak is similar to that for cold starts. This is contrary to the expectation that the light-off time of a catalyst following an intermediate soak will be less than that for a cold start in accordance with the increased startup catalyst temperature. The reason for this appears to be the dependence of catalyst temperature rise on exhaust temperatures. Exhaust temperatures upon startup are typically lower than catalyst temperatures observed following intermediate soaks; when the vehicle is restarted following the soak, the catalyst temperature will stay stable or even decrease until the exhaust temperature surpasses the catalyst temperature, at which point the temperature rise in the catalyst will begin. This is illustrated in Figure 2, which shows a substantial drop in catalyst temperature from startup levels while the exhaust temperature is below the catalyst temperature (approximately 90 seconds) following a 60 minute soak. This trend is apparent regardless of the startup temperature of the catalyst. However, it is of particular concern for catalysts whose temperatures at startup are below light-off temperature (as is the case with intermediate soaks), since there will be considerable delay before the catalyst is fully functioning. This point is highlighted in Figures 3 and 4, which show that light-off times following a soak of only 60 minutes are comparable with light-off times following cold starts.

Agency testing indicates that as a result of rapid catalyst cooldown and the subsequent delay in catalyst warmup upon restart, tailpipe emissions rise significantly in conjunction with increases in soak duration. This is particularly true between soak durations of 10 and 60 minutes. The data also indicated that although improvements in cold start performance on Tier 1 vehicles have reduced intermediate soak emissions relative to Tier 0 vehicles, there continues to be significant increases in intermediate soak emissions on these vehicles. Figures 5-7 show NMHC, CO and NOx tailpipe emission levels for all soak durations tested, averaged for all vehicles and for Tier 1 vehicles only(3). These emission results were generated over ST01 (the start driving portion of SC01), which is designed to represent in-use driving behavior following startup. These data indicate a sharp rise in emissions within an hour after the vehicle has been shut off, particularly for NMHC and NOx; the average NMHC emissions on the Tier 1 vehicles went from about 0.05 g/mi following the 10 minute soak to over 0.5 g/mi following the 60 minute soak, and from 0.2 g/mi to 0.6 for NOx. It is important to note that the profile of the emission increase coincides directly with the catalyst cooldown profile depicted in Figure 1. The emission results level out beyond soak periods of 90 minutes, when the catalyst has cooled significantly and the rate of cooling has slowed. At only two hours, although the engine is generally still warm, emissions are relatively high compared to overnight levels because the catalyst has already stabilized fairly close to ambient temperatures. The average two hour soak emission level is at approximately 65% percent of the cold start level for NMHC and 50% for CO. The level is above 100% for NOx, and in general NOx levels are higher over than intermediate soaks relative to the cold start. The combination of a warm engine and cool catalyst makes the intermediate soak a

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One Tier 1 vehicle, the Toyota Camry, was excluded from general analysis of emission impacts due to catalyst cooldown over intermediate soaks. As described in Section 3.1.2.2, this vehicle used an unusual calibration strategy which resulted in very high NOx values following certain soak periods. For this reason, it was not considered appropriate to include this vehicle in the analysis of emission levels resulting from rapid catalyst cooldown.

significant source of NOx emissions. These data demonstrate that there is a disproportionately large increase in emissions relative to soak duration, particularly for soak durations of one hour or less.

By including only the extremes of soak duration, the FTP provides no incentive to reduce emissions over intermediate soaks. Because catalyst temperatures remain above light-off temperatures after the 10 minute soak, and it is not practical to delay cooldown long enough to obtain a benefit after the overnight soak, no incentive is provided on the current FTP to address the issue of rapid cooldown of the catalyst. Although improved light-off performance would help to reduce emissions following intermediate soaks, these improvements are not occurring to the extent necessary since manufacturers are successfully controlling FTP emissions to Tier 1 levels without resorting to fast light-off catalyst technologies following the FTP cold soak. In this way, the FTP does not properly represent the in-use occurrence of intermediate soaks.

b.Calibration strategies

EPA test results indicated that an additional source of high emissions over intermediate soaks may be fuel calibration strategies which are not optimized for startups following intermediate soaks. The calibration strategy on a Tier 1 1994 Toyota Camry was such that NOx emissions over ST01 increased ten-fold (to over 2.0 g/mi) following soaks less than 90 minutes from levels following a 10 minute soak due to a lean air/fuel ratio at startup. This calibration strategy resulted in extremely low NMHC and CO emissions following the same soak durations. The vehicle resumed proportional NOx control as the soak duration approached cold start levels (Figure 8). The results from this vehicle indicate that significant emissions may be occurring in-use because of a lack of incentive to optimize start-up calibration over intermediate soak modes.

B.Start driving

Since the development of the FTP, large emission reductions have been achieved over hot stabilized driving through improved fuel system and catalyst technology. However, emissions shortly after startup have not been reduced to the same extent due to the combined factors of the delay in catalyst warmup and closed-loop operation. As a result, emission levels immediately following startup represent a greatly increased proportion of overall emissions, and how vehicles are driven shortly after they have been started is a much more important consideration than when the FTP was developed. EPA's study of in-use driving found several ways in which the FTP does not accurately represent driving following start-up. Three primary areas for which in-use startup driving were found to be different than the FTP are 1) driving behavior immediately following startup, 2) the length of initial idle periods, and 3) the proportion of driving which occurs following starts. These areas and the potential emission impacts are discussed in the following sections.

1.Driving behavior following startup

Data from EPA's in-use driving survey was used to analyze driving behavior following startup. The first step in this analysis was to develop a criteria for distinguishing "start" driving from hot stabilized driving. In order to facilitate this, the initial idle for in-use vehicle trips was stripped off and analyzed separately from the data after the vehicle had begun to move. This was done because of the substantial impacts of ambient temperature on the initial idle time; stripping off the initial idle allowed an equitable comparison across driving after cold, warm and hot starts. The analysis of EPA's in-use driving survey data from the 6-parameter component of the study (which monitored coolant temperature) found that most vehicles had reached stabilized engine temperatures (defined as 140° F coolant temperature) within 240 seconds after non-idle operation; data from previous work had concluded that the catalysts generally had reached hot stabilized temperatures within two minutes following startup. Hence, start driving was defined as the first 240 seconds of non-idle operation following startup, and this period was used to analyze start driving behavior. This period was subdivided into three 80 seconds phases in order to further distinguish the sequence of driving behavior following starts([4]).

U.S. Environmental Protection Agency, "Federal Test Procedure Review Project: Preliminary Technical Report" EPA

Two primary observations were made concerning driving behavior following startup. The first was that the length of the soak period (i.e. whether the vehicle is started cold, warm, or hot) does not significantly impact start driving behavior. The second observation was that there are differences between driving behavior following a start and hot stabilized operation. Table 3 shows average speed and positive power levels for each of the 80 second start phases and the hot stabilized phase (i.e., following start driving). The average speeds for all the start phases are lower than for the hot stabilized driving, particularly phase 1. Phase 1 has lower power values than all other phases, although phase 2 and phase 3 actually have higher average power values than the hot stabilized driving, which results in a slightly higher overall power level for start driving that for hot stabilized driving. In addition to speed and power characteristics, an important difference between in-use start driving behavior and the FTP is that in-use driving contains more throttle variation than is represented on the FTP.

In order to assess the emission impact of start driving behavior, EPA developed a cycle from in-use start driving behavior known as The Start Cycle, or ST01. The first element of this cycle was the development of a cycle component which provided a more accurate representation of the first 240 seconds of non-idle vehicle operation following startup. This was accomplished by using the first 240 seconds of non-idle operation on each trip from the Baltimore in-use survey dataset into three 80-second phases, developing a target speed-accel profile for each phase, and choosing microtrips from the data set to best match the target distributions(5). The second element of the cycle was the addition of an initial idle period. The duration of the initial idle period was set at 18 seconds, the average of in-use idle periods following "warm" starts from the Atlanta in-use survey (data from the Atlanta survey was used rather than Baltimore to

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Report # 420-R-93-007

Sierra Research, Inc., "Development of Driving Cycles to Represent Light-Duty Vehicle Operation in Urban Areas", Final Report prepared for EPA, September 1993.

mitigate concerns with the biasing effect of the cold weather conditions during the Baltimore survey on initial idle durations). ST01 encompassed the first 258 seconds of SC01, the cycle used for testing purposes in the Soak/Start test program (described in footnote 2) and shown in Figure 9.

The primary concern with start driving behavior emission impacts in relation to post-soak emissions is the impact of driving behavior on the rate at which the catalyst and engine warm-up(6). The lower speed and power levels of in-use start driving in the first 80 seconds of driving relative to the 505 result in less mass flow through the engine and exhaust system. This results in slower engine and catalyst warmup, which would result in higher emissions given other factors were equal. This is depicted in Figures 3 and 4, which show that in general light-off times were longer over the Start Cycle than over the 505. However, this factor is potentially offset due to higher mass flows (i.e., more engine-out pollutants) on the 505 during the catalyst warm-up phase. The Agency investigated this issue by comparing test results on SC01 and the 505 following an overnight soak. Emissions over 505 were higher by 11%, 9% and 25% for HC, CO and NOx, indicating that higher mass flows during the catalyst warmup phase are a greater contributor to emissions than the delay in catalyst and engine warmup. Thus, although catalyst and engine warmup are slower over in-use driving than represented by the FTP, the offset of higher mass flow on the FTP results in the current FTP not underrepresenting emissions over the warmup phase.

2.Initial idle

The FTP includes an idle period of 20 seconds following startup of the vehicle for both the cold and hot start. EPA data from the in-use driving survey found that the initial idle time is

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For analysis purposes, emission impacts over start conditions were considered separately from the impact of the characteristics of start driving behavior over warm operation. An emission assessment of the latter is contained in the technical document addressing aggressive driving.

dependent on whether the start is cold, warm or hot, with the length of idle time increasing with the length of soak time. The average initial idle time from the Atlanta in-use survey, which was conducted in the summer, was 28 seconds for cold starts, 18 for warm starts, and 12 for hot starts(7). The FTP initial idle time appears to be a good representation of the in-use results for warm starts, but is less representative of both the cold and hot start idles. The Agency did not directly assess the emission impact of in-use idle periods. However, EPA anticipates that the emission impact from in-use idle periods not being represented by the FTP is not significant.

3.Proportion of start driving

The FTP represents driving over two trips, each 7.5 miles in length. The EPA in-use survey found that the average trip length is approximately 4.9 miles, while the median trip length is only 2.5 miles(8). Since each trip includes a constant amount of "start" driving, the result is that by including no trips less than 7.5 miles, the FTP underestimates the amount of time vehicles actually spend in the initial portions of a trip. Because emissions generated over start driving make up a significant portion of overall emissions, the current structure of the FTP likely misrepresents in-use start emissions by underestimating the amount of start driving which occurs in-use. The Agency did not perform an evaluation of the emission impact of this area.

IV.Control of intermediate soak emissions

A.Catalyst-based strategies

U.S. Environmental Protection Agency, "Federal Test Procedure Review Project: Preliminary Technical Report" EPA Report # 420-R-93-007

U.S. Environmental Protection Agency, "Federal Test Procedure Review Project: Preliminary Technical Report" EPA Report # 420-R-93-007

As discussed, emission increases over intermediate soaks are primarily a function of rapid catalyst cooldown and the subsequent delay in catalyst temperature rise upon startup. Effective strategies in reducing emissions following intermediate soaks will focus on reducing the time required for the catalyst to reach light-off temperatures following an intermediate soak. There are two primary methods for achieving this: 1) controlling the rate for which the catalyst cools down after the vehicle is shut off, or 2) increasing the rate at which the catalyst warms up following startup. The Agency investigated both approaches to determine the effectiveness of each for reducing emissions following intermediate soaks. The Agency's work focussed on the use of catalyst insulation to retard catalyst cooldown since this approach showed promise from a cost/benefit perspective, and is currently not in production. The impact of improving light-off performance on intermediate soak performance was also judged by comparing vehicles with a variety of catalyst strategies. Both approaches are discussed in detail in the following sections.

1.Catalyst insulation

a.Emission results/available control

The Agency hypothesized that enveloping the catalyst with insulating material would prevent the loss of thermal energy stored in the catalyst over extended soak durations, thus reducing the rate at which the catalyst cools down. Upon startup following an intermediate soak, the catalyst would already be near or above light-off temperatures, resulting in decreased emissions over these modes. In order to evaluate this hypothesis, EPA performed testing with insulation at the proof-of-concept level. The catalysts on four vehicles (all three Tier 0 vehicles from the Soak/Start program and one Tier 1 vehicle, a 1994 Ford Escort) were wrapped externally with a layer of ceramic fiber insulating blanket with a pre-compression thickness of 1 inch. The material was affixed with heat resistant tape and/or wire so that the post-compression thickness, although not measured, was reduced likely to 1/2 to 3/4 of an inch. Each catalyst on a vehicle was wrapped with the insulation, including the cones of the catalyst shell. The vehicles were then tested over the sequence of soak periods detailed in Section 3.1.2 in order to assess the ability of the insulation to retard catalyst cooldown and the resultant emissions benefits derived from this. The data indicated that insulation was effective in keeping the catalyst near or above light-off temperatures up to 60 minutes, and above temperatures without insulation for at least 120 minutes, resulting in significant emission benefits over intermediate soaks up to this duration. Figures 10 through 12 show average HC, CO and NOx emission results over ST01 for the four vehicles in EPA's program tested over the full range of soak times with and without insulation. Emission levels with insulation were lower for HC and NOx for all soaks except the overnight soak, whose duration is beyond the capacity for the insulation to retain heat in the catalyst([9]). The emissions benefits derived from even this level of proof-of concept testing were significant, particularly for HC and NOx. For example, following the 60 minute soak, average HC emissions dropped from 0.7 g/mi to 0.3 g/mi with insulation, while NOx emissions dropped from 0.9 g/mi to 0.55 g/mi. It is important to note that small emission benefits were derived over soaks as short as 10 minutes, indicating that there is some emission impact of the cooldown of the catalyst even following short durations.

The objective of catalyst insulation is to maintain catalyst light-off temperatures over soaks of longer duration than if no insulation were used. With no insulation, catalyst light-off temperatures are generally maintained over soaks of 10 minutes. The Agency defined the 10 minute soak without insulation as a basis for evaluating the effectiveness of insulation in maintaining catalyst light-off temperature over soaks of longer duration. Thus, soak durations for which emissions with insulation were comparable to those following 10 minute soaks

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CO emissions do not appear to exhibit as sharp a rise in emissions over intermediate soaks as HC and NOx, and (as shown in Figure 11) there appears to be no significant benefit from controlling it. In addition, control over aggressive driving is viewed as the primary strategy for reducing CO emissions, and is expected to incur reductions of a much larger magnitude. Thus, although there may be some incidental CO benefit from requiring control over intermediate soaks, it is not targeted for control over these modes.

without insulation were considered to be one for which insulation provided effective control. Based on the Agency's proof-of-concept testing, EPA believes that using catalyst insulation will enable this to be the case for intermediate soaks up to 1 hour in duration. Figures 13 through 15 show HC, CO and NOx emission results for each vehicle over SC01 following the uninsulated 10 minute soak and the 1 hour soak with and without insulation, as well as the 505 following a 10 minute soak (representing FTP Bag 3) without insulation. Without insulation, emission levels are substantially higher following the 1 hour soak compared to the 10 minute soak. With insulation, emission levels following the 1 hour soak are comparable to the 10 minute SC01 levels on the majority of vehicles. The Agency anticipates that insulation systems in production will be improved to allow superior performance to EPA's proof-of-concept insulation system. Based on Agency data and anticipated technology improvements, EPA considers holding emissions following 1 hour soaks with insulation to emission levels following a 10 minute soak without insulation to be a feasible level of control. As detailed in Section 7.2.3, This level was extended to FTP bag 3 levels since observed emission differences between SC01 and the 505 are attributable to driving behavior characteristics which are not related to catalyst performance.

In addition to benefits derived over intermediate soaks, there may be emission benefits from insulation over hot stabilized operation. Higher catalyst temperatures incurred by insulation may result in increased catalyst conversion levels, particularly on in-use modes such as extended idles for which the catalyst temperature drops to levels which adversely impact conversion (the potential impacts of higher temperature on catalyst durability is discussed in Section 4.1.1.2.3). One manufacturer suggests that a potential advantage of higher temperatures from insulation could be useful in maintaining the downstream catalyst in a multiple catalyst system above light-off temperatures(10). Data over hot stabilized driving with insulation shows

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Hartsock, et al., Ford Motor Co., "Analytical and Experimental Evaluation of a Thermally Insulated Automotive Exhaust System", SAE Paper No. 940312

consistently lower emission levels than without insulation. Analysis of modal data over the 505 with and without insulation on a 1991 Honda Accord showed average improvements of absolute conversion efficiency of 1% for HC and 5% for NOx over stabilized portions of the FTP; given the high proportion of in-use hot stabilized driving, the emission benefits from conversion efficiency increases of this magnitude could be significant. This effect appears to be vehicle specific, however, since a 1992 Dodge Dakota showed no significant conversion efficiency improvement with insulation.

b.Feasibility

Feasibility issues surrounding two types of insulation systems were considered. External insulation systems, for which the majority of EPA's testing was performed on, involves the wrap of an insulating material around the exterior of the outer catalyst shell. Internal insulation systems place the insulating material between the catalyst substrate and outer shell. There are a number of issues surrounding the implementation of either catalyst insulation system in production. Of primary concern are the effects of insulation on the temperatures of the catalyst system when the vehicle and catalyst are fully warmed-up. The specific components for which EPA is aware of temperature concerns due to insulation are the catalyst shell, the intumescent mat material which holds the substrate in place, and the catalyst elements on the substrate itself. The impact of insulation on durability of the catalyst system as well as the relative merits of each insulating system are discussed in the following sections.

(1)Catalyst shell

Temperature increases in the outer casing of the catalyst system, or catalyst shell, are primarily a concern with external insulation systems. This phenomenon results from external insulation not allowing heat to radiate outward, effectively trapping heat in the shell. Manufacturers who have worked with external insulation have observed temperature increases in catalyst shell made from steel currently in production, causing permanent deformation over extended periods of time at elevated temperatures. Many current catalyst technologies use an intumescent (i.e., heat-expanding) mat between the shell and substrate which is constructed of a blanket of ceramic fibers though which vermiculite particles are distributed. Vermiculite expands when exposed to heat, imparting pressure on the substrate, thereby holding the substrate in place. Since the shell provides support for the mat, it is an important element in ensuring that the substrate is securely in place. Permanent deformation of the shell can alter the pressure placed on the substrate, and jeopardize the stability of the substrate.

Catalyst manufacturers have indicated that the best approach to reducing shell temperatures would be to use an internal rather than external insulation mount, since this system will insulate the shell from high catalyst temperatures and allow heat to radiate out from the shell. However, if an external insulation system were used, manufacturers have indicated that using a shell material which would not result in permanent deformation when exposed to higher temperatures would be a viable approach. Another approach suggested with an external system would be to increase the thickness of intumescent mat used. This would decrease the heat reaching the shell, thereby reducing shell temperatures.

(2)Intumescent mat

Adverse effects of high temperature on the intumescent mat which holds the substrate in place are also of concern, although primarily with external insulation. Since external insulation prevents heat from radiating out from the catalyst system, temperature rises are experienced in the mat. Manufacturers have indicated that the risk of decomposition of the intumescent mat may increase when exposed to elevated temperatures. Decomposition of the intumescent mat would have adverse effects on the holding force on the substrate, and is a serious durability concern. Again, catalyst manufacturers have suggested that use of an internal insulation system will help to mitigate this problem, since the increased thickness of the mat mount would reduce the overall average temperature of the mat. A similar strategy of increasing the thickness of the mat mount could also be used with an external insulation system. In addition, using an alternative mount material with a higher temperature threshold, such as vermiculite-free ceramic fiber, has been suggested for addressing this issue for both internal and external insulation systems.

(3)Catalyst performance

A primary concern with catalyst insulation is the potential impact on the durability and performance of the catalyst as a result of increased substrate temperatures. The Agency has generalized the effects of high temperature on the catalyst substrate into two areas, long-term effects and instantaneous severe damage. Long-term temperature effects stem from prolonged operation at temperatures which occur frequently in-use, and result in what would be considered normal in-use deterioration in conversion efficiency. Instantaneous damage results from exposure to extreme exhaust temperatures which occur much less frequently in-use; the catalyst may suffer irreparably severe loss in performance due to damage to the substrate or catalytic material. Agency data confirms that in general insulating the catalyst results in temperature increases in the substrate. The Agency gathered temperature data with and without insulation over SC01, the 505, and REP05 (a high speed/high accel cycle developed from in-use driving to represent off-FTP driving modes). Summaries of these temperature data are presented in Tables 4-6. These data show that the average temperature difference, regardless of the catalyst system and driving mode, was generally averaged about 40° C.

An important finding regarding the impact of insulation on catalyst temperature is variation in catalyst temperature increase as a function of catalyst temperature. Analysis of real-time data indicates that temperature differences become smaller as the baseline (non-insulated) temperature of the catalyst increases. Figure 16 shows the temperature difference with and without insulation over a drive cycle consisting of the 505 immediately followed by SC01 (labeled here as "Cycle A"). As the temperature of the catalyst increases, the temperature difference between the insulated and non-insulated cases decrease. This would indicate that temperature differences tend to drop as catalyst temperature increases, meaning that although adding insulation to the catalyst does cause a temperature increase, the increase may become smaller as temperatures of concern are achieved.

The real-time temperature data also indicates that difference in temperature is function of the time duration of the driving mode. Figure 17 shows the temperature difference with insulation over a drive cycle consisting of SC01 immediately followed by the 505 ("Cycle B"). Except for the ordering of the cycles, the primary difference between Cycle B and Cycle A (for which this pattern was not observed) is that Cycle B was run followed a 2 hour soak, while Cycle A followed a 10 minute soak. Although baseline catalyst temperatures had stabilized at comparable levels for both cycles, there is virtually no temperature difference between insulated and uninsulated initially on Cycle B; the temperature difference increased over the duration of the cycle, reaching levels comparable to that on Cycle A. The Agency theorized that this results from the temperature increase incurred by insulation being a function of heat stored in the insulation, so that there is no temperature difference when the insulation is "cold" (as it presumably is following a two hour soak) and maximum temperature difference when the insulation is "hot" due to extended vehicle operation and/or a start following only a short soak. Based on this theory it is likely that the temperature increase resulting from insulation will stabilize as the capacity of the insulation to retain heat is reached.

EPA data on more extreme test cycles (REP05 and HL07) show mixed results compared with SC01 and the 505 in terms of absolute average and maximum temperature differences. For the Saturn, average and minimum temperature differences are lower on REP05 than the less aggressive cycles, while the maximum delta is higher. For the Intrepid, all deltas are higher on the REP05. For the HL07, temperature deltas are higher than both the REP05 and the SC01/505 cycles. Analysis of the real time data shows the same inverse relationship between temperature and temperature difference seen on the less extreme cycles. For example, the temperature difference at the maximum uninsulated catalyst temperature event on the HL07 was approximately 20° C for the Saturn and 40° C for the Intrepid underbody catalyst; these temperatures are below the average differences seen on the cycle, and comparable to the average levels seen on the more moderate driving cycles. One potential contributor to the variation in temperature difference across cycles may be the level of preconditioning for each cycle. The SC01/505 cycles were started from a soak, while the REP05 and HL07 were preconditioned with a

505. As stated, the impact of "hot" insulation is theorized to lead to increased temperature differentials.

There is limited information publicly available concerning the impact of insulation on catalyst substrate temperatures. One manufacturer who conducted temperature testing with the entire exhaust system wrapped with external insulation observed increases in temperature differences with an increase in baseline catalyst temperature on a series of mostly high speed/high load steady-state tests(11). The range of temperature difference observed in this experiment was from 11 to 217° C over a variety of operating conditions; however, since the entire exhaust system was insulated, it is not appropriate to infer this temperature difference directly to a system where only the catalyst is insulated.

Since the magnitude of temperature increase incurred by adding insulation appears on a relative basis not to be large, and the temperature increase due to insulation appears to decrease as catalyst temperatures increase, EPA is less concerned that insulation will cause the catalyst to reach extreme temperatures which would cause severe instantaneous damage to the catalyst substrate and/or catalytic material (e.g. melting of the substrate). However, the fact that there is a consistent temperature increase resulting from insulation over all driving modes merits concern of long-term catalyst performance and durability, since the catalyst will generally be exposed to higher temperatures than without insulation. To investigate this, EPA performed an analysis to quantify the decrease in catalyst efficiency over the useful life of the vehicle which would result from insulation. Temperature data from SC01, 505 and REP05 on the Saturn and underbody catalyst on the Dodge Intrepid were combined with in-use weights of FTP and off-cycle warm driving behavior to develop projected in-use distributions of catalyst temperature with and without insulation, shown in Figures 18 and 19. Data relating catalyst efficiency loss to

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Hartsock, et al., Ford Motor Co., "Analytical and Experimental Evaluation of a Thermally Insulated Automotive Exhaust System", SAE Paper No. 940312

exposure at various temperature regimes was applied to the projected temperature distributions to predict the losses in efficiency (assumed to be the same for all constituents) which would occur over the full useful life of each vehicle (12). The result for both vehicles was an estimated loss in absolute conversion efficiency of 0.04% (e.g., 98% conversion to 97.96%) over full useful life. Since the catalyst deterioration information used for this analysis did not directly apply to either the Saturn of Intrepid catalyst, this analysis gives only a general idea of the magnitude of performance loss due to insulation. However, this analysis suggests that potential levels of efficiency loss appear significantly smaller than the increases in conversion efficiency observed over warmed-up operation discussed in Section 4.1.1.1. As a result, losses in conversion efficiency resulting from increased thermal severity may be offset by increases which occur over hot stabilized driving. Based on the observed data, EPA is assuming that the emission impact of efficiency losses due to increased thermal severity and efficiency increases due to higher operating temperatures are offsetting.

It is important to note that the Agency's analysis of catalyst degradation due to insulation was performed on two vehicles equipped with underbody catalysts. Based on this assessment, EPA believes that in general internal catalyst insulation will not pose a concern for significant catalyst degradation for underbody catalysts. It appears that temperature levels in underbody catalysts are at a low enough level where the additional temperature increment due to insulation will result in

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The information used for this analysis is based on methodology used to project catalyst deterioration over different durability cycles. This approach, known as the Arrhenius method, relates catalyst conversion efficiency loss to time spent in a given temperature regime. The Agency has obtained specific information from some manufacturers which quantify this relationship, for which EPA's analysis of conversion efficiency loss is based on. However, because of the confidential nature of this information, EPA is not including the specific quantities used in this analysis.

significant added deterioration. However, EPA has not reached a firm conclusion for catalysts which are close-coupled, and hence operation in higher temperature regimes. The Agency plans to perform further analysis in order to determine if this issue is of concern for the small number of Tier 1 vehicles which might need to insulate close-coupled catalysts.

There are some measures which could be taken to reduce the impact of higher temperatures on catalyst performance. One manufacturer suggests that higher temperatures resulting from insulation could be addressed by moving the catalyst further away from the engine, thereby reducing the temperatures seen by the catalyst. The decrease in light-off performance could be avoided by reducing the thermal mass in front of the catalyst using thin-walled exhaust pipe(13), or using a double-wall exhaust pipe. Another solution to higher temperature issues is the use of Palladium-only or other catalysts which have a higher capacity for operating under higher temperatures without adverse effect to catalyst performance. This technology is currently being used to handle higher temperatures which result when the catalyst is moved closer to the exhaust for better light-off performance.

c.Suggested means of implementation

Agency testing at the proof-of-concept level was performed with insulation wrapped externally around the catalyst. At the production level, catalysts may be insulated using an external insulation of some sort, or a system which incorporates internal insulation, i.e. insulation which is placed between the catalyst substrate and the outer shell. Catalyst manufacturers have indicated that external catalyst insulation may have adverse temperature effects on the catalyst shell and mat, and modifications to these components would likely be required to alleviate these concerns. As a way to avoid this, manufacturers have indicated to EPA that a system which incorporates internal

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insulation may be the best method for addressing these concerns.

The Agency conducted testing on a prototype internally insulated catalyst for the purposes of evaluating its performance relative to external insulation. The prototype was developed by recanning an existing catalyst substrate with an increased intumescent mat thickness of one inch, post-compression. A modified catalyst shell was developed in order to accommodate the increased mat thickness. Some insulation was placed in the cone area, but was not part of the substrate wrap. The catalyst was then put back on the vehicle and the vehicle run over the intermediate soak sequence in order to evaluate the performance of the catalyst. The catalyst cooldown performance of catalyst with no insulation, internal insulation and external insulation system are shown in Figure 20. While internal insulation did have a positive effect on delaying the cooldown of the catalyst, it was not as effective as the external insulation in the delay of catalyst cooldown.

Industry sources have since indicated to EPA that improvements could be made both to the design of the system and to the insulating material which would improve the performance of the system. From the design perspective, the system tested by EPA did not insulate the entire catalyst; the cones leading to the substrate were not fully insulated as with the external systems. Proper insulation of the cones leading and following the substrate will likely improve the performance of the system to comparable levels with external insulation. In addition, manufacturers have indicated that improved design of the shell to reduce heat loss through metal joints will likely also improve the effectiveness of the system. Another method of improving the performance of an insulated catalyst would be to move towards an improved insulating material. Manufacturers of catalyst mounting material have proposed to EPA the use of a vermiculite-free ceramic fiber material for replacement of vermiculite intumescent mat. This material has superior insulating properties to vermiculite mat and can withstand temperatures far higher than would be reached by the catalyst system. Based on the design of an internally insulated catalyst with the described improvements and use of a non-vermiculite mat with a post-compression thickness of 1 inch, a temperature simulation was performed by one manufacturer which indicated that the heat loss performance from this prototype system would be slightly better than on an external insulation system similar to that tested by EPA (Table 7). The temperature simulation also indicated that catalyst shell and mat mount temperatures were well below recommended maximum levels. These results support the use of an internally insulated system as a feasible method for complying the proposed requirement.

Although prototype assessment was performed using a post-compression insulation thickness of 1 inch, it is important to note that continued improvement of system design and insulating material will likely reduce the thickness of insulation needed for adequate performance. The Agency's proof-of-concept external insulation was performed with 1 inch thick insulation prior to compression; the compression necessary to affix the insulation around the catalyst reduced this thickness. Although the post-compression thickness was not quantified, it was likely 1/2 to 3/4 of an inch. With system design and material improvements, EPA anticipates that the post-compression thickness could be reduced, possibly to 1/2 inch. If this were the case, EPA anticipates that adding insulation of this thickness will not result in widespread concerns with exhaust system packaging.

d.Cost

As detailed in the overall cost/benefit analysis of the rulemaking, costs incurred by the manufacturer can be divided into fixed and variable costs. Fixed costs are those made prior to vehicle production and are relatively independent of production volumes. Fixed costs considered for this rulemaking include those for vehicle redesign, test facility upgrades, etc. Fixed costs associated with requiring the use of catalyst insulation are discussed in the cost/benefit analysis of the overall rulemaking. The remainder of the discussion for the costs of implementing catalyst insulation focusses on the incremental per-vehicle variable costs due to the addition of catalyst insulation. Variable costs are costs for the necessary emission control hardware and are, by nature, directly dependent on the production volume. For catalyst insulation, these costs include the insulating material, additional material required in construction of the catalyst shell, and per-unit production costs.

Estimates for incremental per-vehicle costs were developed from one catalyst manufacturer's proposal for an approach to an internal insulation system which would be viable in production and would meet the necessary performance standards. The cost estimates quoted were for a standard sized underbody catalyst. The prototype design would use an increased thickness of non-vermiculite mat mounted inside the catalyst shell, estimated to cost $3 per catalyst. In order to accommodate the increased thickness of mount, an estimate for additional can material was placed at $2. In addition, the catalyst design would require internal cones before and after the substrate in order to direct the flow of exhaust to the catalyst substrate, at an additional cost of $3. Although there is increased material involved in producing a catalyst, It was assumed that the production process would fundamentally be similar to current production processes, and therefore there would be no incremental cost due to production.

Potential cost savings from the use of insulation were taken into account in developing the overall estimate for per-vehicle catalyst cost. One manufacturer who has worked with exhaust system insulation states that "the costs of an insulation system could be offset by, among other things, the elimination of heat shields and cheaper material costs in adjacent components"(14). While this is stated for an exhaust system which is completely insulated, some of the potential for cost savings identified here are likely applicable to a system with catalyst insulation as well. The Agency believes that two primary cost savings could be brought about by the implementation of internal catalyst insulation - reduced need for external heat shielding, and potential cost savings in the material used for the catalyst shell.

In terms of cost reductions, there is uncertainty about the effect eliminating heat shields would have on the overall cost. Heat shielding methods vary significantly from vehicle to

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vehicle, and the costs savings would depend on the complexity of the system. Some heat shields consist of a single piece of metal which affixes to the vehicle frame and/or exhaust system. More complex systems consist of a heat shield which fully envelops the catalyst, effectively resulting in a second outer shell. Low end costs for heat shields have been estimated at $2 by industry sources. It was assumed that this savings could be incurred over 50% of the vehicles in production, resulting in a per-vehicle savings of $1 over the entire fleet. In addition, although the Agency has not included this cost savings in the cost assessment, industry sources have mentioned to EPA that cost savings may be available through the use of cheaper metal on the catalyst shell, since heat load on the shell would be reduced with internal insulation. Based on the scenarios for estimates of an internal catalyst system and potential savings incurred, the incremental per-catalyst cost estimate for insulating an average sized underbody catalyst is $7.

2.Enhancement of catalyst light-off

Agency data shows that emissions over intermediate soak modes can be reduced with technology which reduces start-up emissions through the enhancement of catalyst light-off, although these strategies will generally not result in emission reductions of the magnitude available from insulation. Rather than focus on retarding the cooldown of the catalyst when the vehicle is shut off, strategies of this type would seek to offset the rapid cooldown of the catalyst by reducing the time for which the catalyst lights off after the vehicle is restarted. Manufacturers are currently employing technologies which will allow the catalyst to light off quickly for the purpose of improving vehicle cold start performance to comply with recently tightened emission standards, such as the more stringent California LEV/ULEV program([15]). There are two general methods for improving light-off performance, designated here as conventional and advanced. Conventional technologies generally

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"Status of Control Technology Developments for the LEV Program", Presentation by The Manufacturers of Emission Controls Association (MECA) at MECA conference, Ann Arbor, MI, May 1994 seek to improve light-off performance through the use of thermal energy available in the exhaust. Advanced technologies seek to improve catalyst light-off by providing heat to the catalyst either through stored means or generation of heat by external source. Issues surrounding the use of these strategies for reducing emissions following intermediate soaks are discussed in the following sections.

a.Conventional approaches

Rather quickly after a "cold" engine is started, the exhaust gas mixture leaving the combustion chambers of the engine is at, or above, typical catalytic converter light-off temperatures. However, the radiation of thermal energy by the exhaust pipe results in a decrease of the temperature of the exhaust gas mixture as it flows toward the converter. By the time the exhaust gas mixture reaches an underbody converter which is located several feet away from the engine, the temperature of the mixture will be below light-off temperature of the converter. As long as this condition exists, the reduction of pollutant concentrations by the converter will be inadequate. Eventually, the rate at which thermal energy is provided by the exhaust gas will increase enough to raise the temperature of the converter above the level that results in adequate reductions in pollutant concentrations. The time required for the development of such an adequate temperature will depend on a number of variables, such the volumetric flow rate of the exhaust gas mixture, its initial temperature, the mass of the active element in the converter, the ambient air temperature, and the movement of the vehicle.

The effectiveness of the exhaust gas in raising the temperature of an underbody converter to its light-off temperature can be improved by any technique which results in a higher exhaust gas temperature at the point of entry into the converter. The desired effect can be accomplished by any means that results in a smaller decrease in the temperature of the exhaust gas before it reaches the converter, such as shortening the distance between the exhaust manifold and the catalyst and/or reducing the thermal radiation characteristics of the exhaust pipe. Manufacturers currently employ several techniques for reducing the time required for the catalyst system to light off. These include relocation of the main catalyst closer to the exhaust manifold and/or use of small volume light-off catalysts in front of the main catalyst located very close to the manifold. In addition, the start-up fuel calibration can be optimized to enhance the exothermic reaction in the catalyst. Strategies in use or being considered for reducing thermal losses in the exhaust pipe are wrapping of the pipe with an thermally insulating material or the use of a double wall construction which provides an annular insulating dead air space between inner exhaust pipe and an outer enclosing larger diameter pipe. Strategies which move the catalyst closer to the manifold, add a warm-up catalyst before the main catalyst, or insulate the exhaust pipe are currently being used in production to comply with Federal Tier 1 exhaust emission standards.

Comparison of Tier 0 and Tier 1 vehicle results from EPA's Soak/Start test program (Figures 5-7) indicate that an improvement in catalyst light-off through conventional technology will result in emission decreases over intermediate soaks. However, EPA has concluded from these results that this technology will inherently not deliver the same performance as insulation in reducing intermediate soak emissions. This appears to be the case because there is a significant delay in catalyst light-off time following intermediate soaks, even for vehicles with good cold start light-off performance. Investigation of catalyst light-off times and warm-up profiles indicate that the time required for catalyst light-off over intermediate soaks is generally not less than for cold starts, primarily because catalyst warmup appears to be largely a function of exhaust temperature rather then the temperature at startup. Although startup catalyst temperatures are higher following intermediate soaks than for cold starts, the catalyst temperature will stay constant or decrease slightly until the exhaust temperature exceeds the catalyst temperature, at which point the catalyst temperature begins to rise. This observation indicates that any strategy for compliance which utilizes thermal energy from the exhaust system to improve catalyst light-off performance will see a delay in catalyst light-off from startup. As a result, this strategy will not be as effective in reducing emissions over intermediate soaks as either catalyst insulation, which keeps the catalyst temperature above light-off, or some form of advanced catalyst technology which allows for near-instantaneous light-off.

b.Advanced approaches

Methods which provide heat to the catalyst instantaneously upon startup are also being investigated to comply with more stringent California emission standards(16). These methods include providing heat previously generated by the engine or catalyst through stored means, or generating thermal energy upon startup by electrical means. Since these approaches would allow for near-instantaneous light-off of the catalyst, they would likely result in no significant emission increase over intermediate soak modes and likely provide emission reductions comparable to catalyst insulation. However, one catalyst manufacturer placed cost estimates for this technology at adding from $100 to $800 per vehicle, which is substantially more than cost estimates developed for insulation(17). As a result, it is anticipated that these approaches will prove too costly to apply solely for the purpose of reducing intermediate soak emissions. However, some manufacturers may be moving towards this type of technology for the purposes of complying with lower emission standards. This would ultimately satisfy the objective of reducing emissions over intermediate soaks if the technology were applied to these modes. Since it is anticipated that this technology is not required for compliance with Tier 1 standards, this issue is more relevant to the issue of future emission standards. Further discussion of the impact of future emission standards on intermediate soak emissions is contained in Section 8.

3.Insulation as primary approach

Of the approaches considered viable for the control of intermediate soaks, EPA is focussing on catalyst insulation as the primary control strategy by proposing levels of control achievable through insulation. The Agency believes that catalyst

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"Status of Control Technology Developments for the LEV Program", Presentation by The Manufacturers of Emission Controls Association (MECA) at MECA conference, Ann Arbor, MI, May 1994

"Cleaner Starts for the Catalytic Converter", New York Times article, September 11, 1994 insulation will result in greater emission reductions over intermediate soaks than strategies which focus on improving catalyst light-off through conventional means, and provides more cost effective emission benefit than advanced cold start approaches. Although intermediate soak emissions will likely be reduced to some extent due to directional improvements in cold start performance, EPA believes that on Tier 1 vehicles intermediate soak emissions will continue to be relatively significant because the primary cause of intermediate soak emissions - rapid cooling of the catalyst - will remain unaddressed. Because catalyst cooldown is addressed directly through catalyst insulation, EPA anticipates that this approach will incur significant emission reductions over intermediate soaks on Tier 1 vehicles, including those which will incidentally reduce intermediate soak emissions through improved cold start performance (the impact of standards more stringent than Tier 1 on the need for a separate intermediate soak requirement is addressed in Section 8).

B.Engine-out calibration

An additional source of emission reduction over intermediate soaks for some vehicles is the optimization of calibration strategies to reduce engine-out emissions upon startup. Since intermediate soaks are not currently represented on the FTP, manufacturers have no incentive to optimize calibrations over this mode. This was apparent in EPA's Soak/Start test program, where one vehicle adopted a lean calibration strategy over soaks longer than 10 minutes and shorter than 2 hours which caused NOx emissions over SC01 to increase by a factor of 10. Reductions over intermediate soaks are possible through improved fuel calibration which both reduces engine-out emissions and facilitates faster catalyst light-off. It is difficult to quantify how much reduction could be obtained through improved calibration alone. The emission reductions from optimized calibration are vehicle dependent, with some vehicles likely seeing substantial benefit and some vehicles seeing little benefit.

V.Tier 1 fleet compliance

A.Tier 1 catalyst technology penetration

In order to develop cost and benefit estimates for the intermediate soak requirement, it was necessary to develop estimates for the Tier 1 fleet penetrations of catalyst technology, and how each technology would likely comply with an intermediate soak requirement. Four groupings of catalyst configuration were identified based on the number and location of catalysts: 1) close-coupled catalyst(s) only (nominally defined as within 8 inches of the exhaust manifold), 2) single underfloor catalyst only, 3) multiple exhaust banks with underfloor catalysts, 4) and multiple catalysts in series (including either close-coupled plus underfloor or multiple underfloor catalysts). In order to develop an estimate of the Tier 1 fleet penetration for each grouping, a sample of 1994 4 and 6 cylinder and 1995 8 cylinder LDV and LDT Tier 1 engine families was used. The results of this sampling are shown for each engine size in Table 8. Using an estimate of projected engine family percentages for 4,6 and 8 cylinders from the Cold CO rule of 65/23/12, the weighted average for each of the groupings was calculated. These percentages, also presented in Table 8, are 7% close-coupled, 56% underfloor, 7% multiple bank, and 30% multiple catalysts in series. These percentages were used for estimating the fleet penetration of compliance strategies, from which cost and benefit estimates were ultimately derived from.

B.Development of fleet compliance estimates

As stated in Section 4.1.1.1, EPA has determined that an achievable level of control over intermediate soaks is to reduce emissions following soaks of duration up to 1 hour to FTP bag 3 levels. There are two primary approaches to implementing this level of control. One approach is to require a demonstration of compliance on a "stand-alone" basis, i.e. require a direct comparison between intermediate soak emissions and bag 3 levels. The second is to composite intermediate soak emission results with bags 1 and 2 of the FTP. Although the level of stringency (and hence, the benefits) are not different from requiring bag 3 emission levels on the intermediate soak test procedure, manufacturers would likely comply differently under the composite scheme than under a stand-alone intermediate soak requirement.

It is important to develop an estimate for how manufacturers would comply under each scenario in order to gauge the cost effectiveness of each approach, and (for the stand-alone case) evaluate this level of control on an individual basis. Based on the estimates of fleet compliance and benefits developed in the following sections, cost and cost/benefit information for this proposal is presented in the overall cost/benefit analysis of the regulatory package.

1.Stand-alone approach

A pure stand-alone approach to the intermediate soak requirement would determine compliance by a direct comparison of emissions over the intermediate soak test procedure to bag 3 of the FTP. EPA data suggests that manufacturers would not be able to meet this level of control utilizing a close-coupled catalyst or other methods with use exhaust heat to improve catalyst light-off , since there is an inherent delay in light-off times from startup over intermediate soaks. Only technology which effectively results in instantaneous light-off of the catalyst will allow a vehicle to control to this level. Two viable technologies to achieve this are catalyst insulation and advanced light-off technology such as electrically heated catalysts. Based on the assumptions that insulation is the least costly of these technologies, manufacturers would need to use catalyst insulation on all vehicles to achieve this level of control. Thus, it is assumed that for a pure stand-alone intermediate soak requirement, 100% of vehicles would need to use catalyst insulation in order to comply.

One issue concerning the implementation of catalyst insulation on 100% of the fleet is how to account for vehicles which employ multiple catalyst systems. These vehicles were broken into two categories: multiple bank systems and multiple catalysts in series. For multiple bank systems, EPA is assuming that insulation of multiple catalysts will be required; this accounts for 7% of vehicles overall. For vehicles which use multiple catalysts in series, EPA believes that for most vehicles it is possible to achieve the required level of control by insulating only the last catalyst in the system. This is particularly the case with vehicles which employ a small close-coupled warm-up catalyst followed by a larger main underbody catalyst. EPA data on a Dodge Intrepid with two small warm-up catalysts and one main underbody catalyst show that using insulation on the warm-up catalysts was not effective in keeping the small catalysts above light-off temperature. Despite this, the 60 minute soak emissions on this vehicle were reduced substantially, indicating that only the insulation on the underfloor catalyst was necessary. However, for a minority of vehicles, it may be necessary to insulate multiple catalysts in series, particularly if the size of the multiple catalysts are relatively small and/or the first catalyst in the series is not close-coupled; EPA is estimating that this applies to 25% of vehicles which employ multiple catalysts in series, or approximately 8% of vehicles overall.

EPA is assigning the cost of two insulated catalysts for all vehicles requiring multiple catalyst insulation. Although a portion of these vehicles (particularly with multiple banks) may require insulation on more than two catalysts, it is assumed that the catalysts on these vehicles will be smaller than the standard size, and the per-catalyst cost of materials and production is reduced accordingly so that it is similar to the cost of insulating two catalysts of standard size. Using this assumptions and the estimates of fleet penetration developed in Section 5.1, it is estimated that 85% of vehicles will insulate one catalyst and 15% will insulate two catalysts to comply with the stand alone requirement.

2.Composite approach

Under the composite approach, compliance would be demonstrated by weighing the intermediate soak procedure with bags 1 and 2 of the FTP and comparing with FTP standards, effectively "replacing" bag 3 with the intermediate soak procedure. With this approach, an increase in emissions on the intermediate soak procedure would be allowable as along as it were offset by emission reductions over bags 1 or 2 of the FTP. Under this scenario, manufacturers would have the option of complying with the intermediate soak requirement using technology which would not be effective under a stand-alone requirement. Technology which affords some delay in light-off of the catalyst, such as improving light-off strategies and/or reducing engine-out emissions, would likely be sufficient for compliance. Manufacturers might opt for strategies which are in step with overall efforts to improve cold start emissions, and might be more cost effective than insulation. Since there is some benefit over intermediate soaks incurred by strategies which reduce cold start emissions, improving cold start performance will bring down intermediate soak emissions as well. The overall benefit from reduced cold and intermediate soak emissions under a composite approach would be comparable to incurring all emission reductions over the intermediate soak using catalyst insulation. Because manufacturers would have a broader range of strategies to comply with this requirement, the assumption that 100% of vehicles would use insulation to comply is not appropriate.

In order to develop an estimate of compliance strategies under the composite approach, EPA developed assumptions about how vehicles would comply with the composite requirement for each of the technology groupings designated in Section 5.1. It was estimated that 100% of vehicles employing only close-coupled catalysts would meet the requirement solely through optimized fuel calibration to reduce engine-out emissions and improve catalyst light-off. This estimate is based on the assumptions that for these vehicles 1) manufacturers would choose not to insulate close-coupled catalysts to avoid the risk of increased catalyst degradation, 2) no significant catalyst-based improvement could be made to reduce start emissions, and 3) less emission reduction would be needed in order to comply with the standard given the improved start emission performance of vehicles equipped only with close-coupled catalysts.

Unlike vehicles employing close-coupled only catalysts, vehicles equipped with underfloor catalysts will need to pursue a catalyst-based solution to either improving light-off performance or retarding catalyst cooldown through insulation. It is assumed that the most cost effective approach for improving light-off performance would be to move the catalyst closer to the manifold; in this case, recalibration would also be required. In some cases this might be an attractive alternative to insulation, since there would be no additional hardware costs. However, certain vehicles may favor insulation over this option (particularly if the catalyst temperature increase due to insulation is relatively small) due to packaging limitations and the potential for large catalyst temperature increases brought on by moving the catalyst closer to the exhaust manifold. It is assumed that improving cold-start performance through methods which are more expensive than insulation would not be pursued, such as the addition of catalysts or use of advanced technology such as electrically heated catalysts, since EPA believes that insulation is a feasible method for meeting the requirement. EPA does not have a good estimate for what percentage of manufacturers who would use a catalyst-based cold start strategy versus insulation to comply with the requirement. For the purpose of developing a compliance strategy breakdown, it was assumed that the tradeoffs between both approaches rendered each equally attractive, and hence it was estimated that for vehicles employing an underfloor only catalyst, 50% would choose to comply with the requirement by relocating the catalyst closer to the manifold and recalibrating, and that 50% would choose to insulate the catalyst. For vehicles employing a multiple bank system, it was estimated that 50% would relocate two catalysts and recalibrate, and 50% would insulate two catalysts.

EPA is assuming that 100% of vehicles equipped with multiple catalysts in series would need to comply with the requirement using insulation. Although the first catalyst in the system (particularly a warm-up catalyst) may light off quickly, the overall efficiency of the system following an intermediate soak is less than for a close-coupled only system, resulting in an emission increase over intermediate soak modes. Because of the impact of the second catalyst in the system, neither catalyst relocation nor recalibration will incur the necessary emission reductions. As detailed in Section 5.2.1, EPA believes that vehicles equipped with a small warm-up catalyst followed by a main underfloor catalyst will only require insulation on the underfloor catalyst. This may also be true for some vehicles equipped with multiple catalysts of similar sizing; however, it is anticipated that a minority of these vehicles will require insulation on multiple catalysts, particularly if the first catalyst in the series is not close-coupled. Consistent with the assumptions for this technology under the stand-alone scenario, it was assumed that 75% of vehicles equipped with multiple catalysts in series would require insulation on one catalyst, and 25% of vehicles would require insulation on two catalysts.

Based on the stated estimates for fleet penetration of technology groupings and the breakdown of compliance strategies, an overall fleet breakdown of compliance strategies was developed, presented in Table 9. It is estimated that under the composite scheme, 51% of the fleet will comply by insulating one catalyst, 28% will comply by relocating one catalyst and recalibrating, 11% will comply by insulating multiple catalysts, 7% will recalibrate only, and 3% will comply by relocating multiple catalysts and recalibrating. In order to separate recalibration for the purpose of cost estimation, the percentages for this strategy are summed in Table 9, resulting in 39% of vehicles overall requiring recalibration.

VI.Benefits

Estimated benefits for this proposal were developed using emission results on the 4 Tier 1(18) vehicles tested in EPA's Soak/Start Test Program. It was considered appropriate to use only Tier 1 vehicles in the analysis to best represent potential benefits which will be incurred on Tier 1 vehicles. The baseline results of these vehicles indicated that emission levels over intermediate soaks (and hence, benefits) are dependent on the technology type of the vehicle. Hence, an effort was made to

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It was considered desirable to include the Toyota Camry in the benefit analysis, since this vehicle was the only one in the test fleet equipped with a close-coupled and underfloor catalyst in series. However, because of unrepresentative intermediate soak emission levels due to poor calibration (as detailed in Section 3.1.2.2), a projection of how this vehicle would perform over intermediate soaks with good calibration was developed. The methodology involved calculating the ratio of emissions over intermediate soak period from 20 to 120 minutes to the cold start results from the Ford Escort (used because of the relative similarity of cold start emissions between the two vehicles), and (18, cont.) applying these to the Camry cold start results (which were not impacted by the calibration problem) to develop projections for each soak period. NMHC+NOx projections were developed to provide a more generally applicable estimate of overall emission levels.

weight the emission results from the sample to represent the technology penetration of the overall Tier 1 fleet. It was assumed that the Ford Escort was representative of vehicles equipped with close-coupled only catalysts, which (from Section 5.1) were estimated to make up 7% of the Tier 1 fleet. The Toyota Camry was assumed to represent vehicles equipped with a close-coupled light-off catalyst followed by an underfloor catalyst, which were estimated to make up 11% of the fleet. The Plymouth Voyager and Pontiac Grand Prix were both equipped with single underfloor catalysts, assumed to be representative of vehicles not equipped with close-coupled catalysts, which were estimated to be 82% of the fleet. Based on these assumptions, weighting factors where applied to the results of 7% to the Escort, 11% to the Camry, and 82% to the average of the Voyager and Grand Prix to develop the benefit estimates of the proposal.

Estimates for baseline and controlled emissions were calculated over the full range of soak durations for which emission reductions are anticipated using the primary control strategy of insulation. This time period was established to extend from 15 minutes to 3 hours, based on the projected performance of the insulation systems used to meet the proposed level of stringency. Baseline emissions for each vehicle were calculated by weighing ST01 emission results(19) following soak periods of 20, 30, 45, 60, 90 and 120 minutes by the in-use weighting factors for each soak period contained in Table 10, and summing the results. The summed result was then weighted by the in-use start driving factor of 24%, resulting in the per-vehicle baseline intermediate soak emissions shown in Tables 11-13. Weighing the per-vehicle results with the fleet penetration

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For the purposes of including the projected Toyota Camry results, expressed as NMHC+NOx emissions, baseline and controlled emissions for all vehicles were calculated using combined NMHC and NOx emission levels, and assigning each constituent 50% of the total when broken back down to individual constituents. This was considered an appropriate methodology because preliminary calculations of benefits which did not include the Camry resulted in equal results for NMHC and NOx when calculated on an individual basis.

factors developed above, the overall in-use baseline emissions over intermediate soaks were calculated to be 0.045 g/mi for both NMHC and NOx and 0.22 CO.

Controlled emissions for each vehicle were calculated by weighing ST01 emissions following the 10 minute soak by the weighting factors of the 20, 30, 45 and 60 minute soaks. Since control at the desired level is only required to 60 minutes, it is not appropriate to use the 10 minute control level from the period from 1 to 3 hours; however, it is reasonable to assign some benefit to soaks beyond 60 minutes, since insulation is effective beyond this point. The controlled levels for soaks longer than 60 minute were estimated using results from soaks longer than 60 minutes with insulation from the one Tier 1 vehicle (Ford Escort) tested over both the 90 and 120 minute soak with insulation. At 90 minutes, it was assumed that the controlled emissions would be 35% of the baseline for HC and NOx, and 50% for CO. At 120 minutes, it was assumed that the controlled emissions would be 75% of the baseline for HC and NOx, and 100% for CO. These percentage reductions were then applied to the baseline emissions on a per-vehicle basis over these soak periods to estimate the level of control, and weighted with the appropriate in-use soak period weightings and summed. The per-vehicle controlled levels, shown in Tables 11-13, were then weighted with the in-use start driving factor of 24% and the fleet penetration factors from Section 5.1 to result in estimates of overall in-use controlled intermediate soak emissions of 0.023 g/mi for both NMHC and NOx, and 0.20 g/mi CO.

The impact of controlling NOx emissions from air conditioning operation over intermediate soaks was also taken into account in determining baseline and controlled emission levels. Emission testing indicated that substantial NOx increases occur over warm stabilized operation with the air conditioning system on (see technical document addressing A/C operation). These increases are exacerbated over intermediate soaks because of the combination of a warm engine and a cool catalyst. A sample of Tier 1 vehicles tested as part of the joint EPA/Manufacturer A/C test program showed an average NOx increase of 0.63 g/mi following a 60 minute soak, while the average NOx increase over warm stabilized driving was only 0.18 g/mi. Although control of NOx emissions due to A/C operation is being proposed as part of this rulemaking, this control is targeted at reducing NOx emissions over warm stabilized operation, primarily through the improvement of catalyst conversion efficiency. Thus, there will continue to be substantial A/C NOx increases following intermediate soaks in the period prior to catalyst light-off. Because catalyst insulation will maintain the catalyst above light-off temperature following intermediate soaks, incremental A/C NOx emissions over intermediate soaks would be controlled though an intermediate soak requirement.

The estimates for the contribution of A/C operation to NOx emissions were developed according to the following methodology. Taking the results of A/C testing over Tier 1 vehicles discussed previously, it was assumed that the baseline A/C NOx increase between soaks of 15 and 60 minutes was the average of the increase over warm stabilized operation (0.18 g/mi) and following a 60 minute soak (0.63 g/mi), or 0.41 g/mi. For soaks in length from 60 minutes to 180 minutes, the A/C NOx increase was assumed to be that following the 60 minute soak, or 0.63 g/mi. To come up with overall in-use baseline NOx increase due to A/C operation over intermediate soaks, the baseline NOx increase from 15-60 minutes was weighted by the in-use weighting factor for this soak range of 28.2%, and summed with the baseline NOx increase from 60-180 minutes weighted by the in-use factor of 15%. This result was then weighted by the estimate for in-use AC usage of 65% and the in-use portion of start driving of 24%, resulting in an overall in-use baseline NOx increase due to A/C operation over intermediate soaks of 0.033 g/mi. The controlled in-use level was calculated by assuming that the A/C NOx increase from 15-60 minutes would remain at the warm stabilized level of 0.18 g/mi, and the control level from 60-180 minute would be the average of warm-stabilized control and no control (0.63 g/mi), or 0.41 g/mi. Using the same methodology for calculating the baseline levels, the in-use controlled level of A/C NOx increase was calculated to be 0.018 g/mi.

Overall benefits were calculated using the in-use baseline and controlled emissions from soak-only and from A/C operation over soaks. Incorporating the A/C factors developed above, the overall in-use baseline and controlled emissions over intermediate soaks are shown in Tables 11-13. From these, overall in-use benefits of 0.022 g/mi NMHC, 0.20 CO and 0.037 NOx were estimated. As stated in Section 4.1.1.2.3, it is assumed that potential additional benefits from insulation over warmed-up operation and potential losses in catalyst performance due to increased thermal severity over the useful life of the vehicle will be offsetting. Based on this assumption, neither factor was included in the overall benefit estimate.

VII.Discussion of requirement and options considered

A.Intermediate soak test procedure

1.Need for test procedure

The Agency considered the need for developing an intermediate soak test procedure for the purpose of determining compliance with an intermediate soak requirement. The primary alternative to this which was considered was to judge intermediate soak performance based on performance over elements of the existing FTP. The latter approach would involve judging the vehicles's intermediate soak performance through the vehicle's cold start performance, via either emission levels or catalyst light-off criteria. The advantage of this approach would be the elimination of an additional test procedure, although there would be additional data reporting requirements. The Agency has determined, however, that this approach would not be adequate for controlling intermediate soak emissions. As stated in Section 4.1.3, EPA believes that improving catalyst light-off as a primary approach to reducing intermediate soak emissions is less desirable because it is not effective in retarding catalyst cooldown. Under an approach which judged intermediate soak performance based on FTP cold start performance, intermediate soak performance would be tied to improving catalyst light-off. Manufacturers would be limited to improving light-off technology for complying with the intermediate soak requirement, and because there would be no incentive to control rapid cooldown of the catalyst, control of intermediate soak emissions would be compromised. As a result, EPA believes that using a representative test procedure is the best approach to controlling intermediate soak emissions, since it targets control at the primary cause of increased emissions over this regime.

2.Duration of soak period

The primary objective for establishing an intermediate soak requirement is to provide incentive for manufacturers to control emissions over driving following intermediate soaks. the Agency sought to do this by extending the control currently achieved over the FTP into the new regime. Because the primary cause of emission increase over intermediate soaks is the rapid cooldown of the catalyst, control centered on soak durations for which control of catalyst cooldown is achievable, determined to be between 15 minutes and 180 minutes (3 hours). In keeping with this objective, the primary factor involved in EPA's determination of the soak period length was the maximum soak duration for which control currently achieved over the FTP could be extended. The Agency's interpretation of this was to extend control currently incurred on the FTP hot start (following a ten minute soak) to soaks of intermediate duration. Thus, the Agency sought to require control over the maximum soak duration for which emission levels could feasibly be reduced to FTP Bag 3 levels. Agency test results using catalyst insulation found that the maximum duration for which this was the case was 1 hour; thus, EPA is proposing to set the soak period length at this duration. The Agency believes that one hour is an appropriate soak duration since establishing a shorter soak duration will compromise emission reductions gained over the full intermediate soak range, while establishing a longer period would not allow for an extension of current FTP control levels to the intermediate soak regime. In setting the soak duration at 1 hour, compliance is ensured for soaks between 15 minute and 1 hour, which account for approximately 28% of soaks in-use. It is anticipated that some measure of control will be experienced on soak longer than 1 hour, since strategies which are used to comply with the soak requirement will afford some benefit beyond 1 hour. For example, catalyst insulation will continue to retain heat in the catalyst beyond 1 hour which will be beneficial to catalyst performance. In addition, 1 hour was considered to be the minimum soak time which would allow utilization of the test site while the test vehicle underwent the soak period off the dynamometer.

Manufacturers who execute the test procedure will be required to test a soak period of minimum length 1 hour. The Agency will have the option of testing any soak of length between 10 and 60 minutes. The purpose of this is to allow EPA to ensure proportional calibration control within the target soak range and to give the option of reducing test length if it is determined that a 1 hour soak is unnecessary to ensure compliance.

3.Permissible activity during soak

It is essential that during the soak period, the vehicle is not subjected to unrepresentative cooling of the engine or catalyst. If the vehicle is to remain on the dynamometer during the soak period, cooling fans directed at the vehicle should be shut off for the duration of the soak period. In cases where the vehicle is removed from the dyno, the vehicle must be soaked in an environment which will not result in a different engine or catalyst cooldown profile as would be seen had the vehicle remained on the dynamometer.

4.Drive cycle

The Agency developed a new Soak Control Cycle, designated SC01, to be used for controlling emissions following intermediate soaks (Figure 9). Initial idles and start driving are addressed in SC01 by incorporating the EPA Start Cycle (ST01) in its entirety. The balance of SC01 is composed of two microtrips of moderate driving, selected from the in-use survey database in order to bring the total distance of the new control cycle up to match the 3.6-mile distance of the 505 Cycle; the resulting cycle is 568 seconds long(20). The purpose of matching the distance of the 505 was to allow evaluation of the emission performance over each cycle by providing a direct comparison of emissions between the SC01 and 505 cycles on a gram-per-mile basis. This construction also adds control capability for warm-stabilized moderate

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The severity of one SC01 acceleration was artificially modified to be less severe than in the original microtrip; this preserved the design objectives of matching the 505 trip distance and reflecting moderate, rather than aggressive driving. The representative level of microtransient behavior in the cycle was unaffected by this change driving, and provides added flexibility in constructing the Supplemental Federal Test Procedure([21]).

From a start driving perspective, the Agency considers the SC01 cycle preferable to the 505 following an intermediate soak because it has speeds and power levels that are more representative of in-use start driving behavior; in addition, because the cycle is comprised of in-use microtrips, microtransient operation (rapid speed fluctuation) is more properly represented. Emissions following startup are very dependent on the warmup profile of the engine and catalyst, which in turn are very sensitive to how the vehicle is driven after startup. In-use data indicates that the 505, whose period of highest speed and acceleration takes place during the startup phase, is not a good representation of real-world start driving behavior. SC01 is being proposed because the Agency believes it is important to represent how vehicles perform in-use following startup in a superior fashion than the 505.

5.Preconditioning

Prior to the 1 hour soak period of the test procedure, it is important the vehicle's engine and catalyst are warmed up sufficiently and have stabilized at the appropriate warmed-up temperatures for representative cooling to occur. If the vehicle has not been operational for longer than 2 hours prior to preconditioning, then the vehicle is required to run over EPA's Urban Dynamometer Driving Schedule (LA4) prior to the soak. If the vehicle has not been operational for less than the cutoff of 2 hours, the option is available to precondition the vehicle either over the 505 or the 866. The cutoff of 2 hours is based on EPA data showing that a 505 is sufficient to stabilize engine and catalyst temperatures following a soak of 2 hours.

B.Standards

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s with those which match power levels of the 505 more closely. The completed cycle, known as SC02, will replace SC01 and serve the same purpose.

1.Emission performance-based requirement

Several approaches were considered in developing the type of standard for the intermediate soak test procedure. As discussed in Section 3.1.2.1, the primary cause of increased emissions over intermediate soaks is the rapid cooldown of the catalyst once the vehicle is shut off. Since the control of this mode would involve either controlling catalyst cooldown or improving light-off performance once the vehicle is restarted, EPA considered a number of options for control which centered on catalyst-based solutions. One option considered was to establish a catalyst system design criteria. While this would eliminate the burden of a test procedure, this approach was rejected because it would be difficult to establish the proper design of the catalyst system, and affords the least flexibility for manufacturers. Another option considered was to establish a catalyst temperature performance criteria either for catalyst cooldown upon keyoff or catalyst warmup upon restart. Again, this approach was rejected because of the difficulty in establishing appropriate performance specifications across varying catalyst systems and the lack of flexibility for manufacturers.

In order to move away from solutions which centered on specific catalyst design or temperature performance criteria, an emission performance-based criteria is being proposed. This approach is being proposed to allow a straightforward method for determining compliance, and to allow manufacturers increased flexibility in complying with the requirement. Emission levels over intermediate soaks will meet the philosophical objective of representative in-use control over intermediate soaks without imposing specific design criteria. In addition, EPA believes that an emission performance-based standard is the most straightforward method to ensure that calibration strategies are optimized for performance following an intermediate soak.

2.Absolute vs. comparative standards

Standards for the intermediate soak requirement were developed from the dual objectives of providing FTP-like control over intermediate soaks and giving manufacturers increased flexibility in meeting the requirement. The Agency considered two general approaches in setting the level of the emission standard. The first option considered was to set absolute emission standards over an intermediate soak test procedure. This option would guarantee a certain level of control over the intermediate soak mode, and provide a straightforward method for determining compliance. However, this option was considered undesirable because it would be difficult to set absolute standards which were applicable to all vehicles based on existing test data. Figures 13-15 show the baseline emission levels on the 60 minute soak for all vehicles in the test program. For the Tier 1 vehicle sample (which does not include any engines larger than 3.0 liters), there is significant variation in absolute emission levels, particularly for NOx. Because of the variability in emission performance over intermediate soaks, setting an appropriate emission standard would be difficult. Setting an emission standard too high would allow many vehicles to comply without improving emissions, while setting a standard level too low would incur large cost for some vehicles to comply. An additional argument against setting absolute emission standards is that standard levels would need to be revisited when changes in overall FTP levels where changed.

The second general approach considered in developing the standard level was to use an approach which compares performance over the intermediate soak to existing elements of the FTP. This approach is considered more favorable than setting an absolute emission level because it imposes control over intermediate soaks in a consistent manner across vehicles, and assures that control over intermediate soaks will remain in proportion with decreases in emissions on the FTP. However, one potential problem with a direct comparison requirement is that it would offer some inducement for manufacturers to increase the FTP mode which is being used as a basis of comparison instead of reducing intermediate soak emissions. This risk is eliminated by including the intermediate soak requirement in an overall composite standard for all off-cycle requirements. Such a scheme is described in detail in the Preamble of this rulemaking.

3.Stringency

Based on the levels of control which EPA believes to be feasible and the stated objective of extending current levels of FTP control into intermediate soaks, EPA considered for proposal two standard level stringency options based on a comparison with bag 3 of the FTP. The first option would require no emission increase on the 1 hour soak from FTP bag 3 levels. EPA testing with insulated catalysts has demonstrated at the proof-of-concept level that control of emissions over SC01 following a 1 hour soak to 10 minute SC01 soak levels appears feasible. The Agency believes it is appropriate to extend the feasible level of control to bag 3 of the FTP because emission differences observed between SC01 and the 505 (Figures 13-15) are largely attributable to throttle microtransient effects, as detailed in Sections 3 and 4 of the technical document addressing aggressive driving, and the increased loading of SC01 relative to the 505 addressed in Section 7.1.4 of this document. It is anticipated that proposed control of microtransient emissions and the replacement of SC01 with a lower load cycle (see footnote 21) will result in comparable emissions between the 505 and the Soak Compliance Cycle. On a stand-alone basis, a requirement which is based on achieving this level of control would effectively require catalyst insulation or advanced light-off technology as a compliance strategy, since any approach which did not result in instantaneous or near-instantaneous light-off of the catalyst would result in an emission increase over intermediate soaks.

EPA considered putting forth a second stringency option which could be attained with conventional light-off technology, as well as catalyst insulation and advanced light-off technology. This option would allow an emission increase over the intermediate soak test procedure relative to bag 3. Under a stand-alone approach, manufacturers would have more available strategies for complying with the requirement, and would be able to comply with technology which has been proven effective in production. However, EPA considers this approach to be undesirable since the emission benefits from this approach would be less than would be incurred by a level of control available through catalyst insulation.

C.Compliance demonstration - options considered

The Agency recognizes that the addition of an intermediate soak requirement comprised on a 1 hour soak in the SFTP significantly increases the length of the overall test procedure, thereby increasing the test burden on both EPA and the manufacturers. As a result, EPA considered alternatives to the standard process for determining compliance at the time of certification - i.e., requiring manufacturer to perform the required test procedure and submit test data to EPA for the determination of compliance for each engine family. However, these alternatives were ultimately rejected either due to the reduced ability for EPA to determine compliance with the requirement, or additional burden placed on both the manufacturers and EPA in generating information in lieu of direct test data. The Agency believes that using the standard certification process for determining compliance with the intermediate soak requirement is preferable because it is the most direct and straightforward method to ensure compliance for the maximum number of vehicles. The alternatives considered to this approach and the rationale for rejecting each are discussed in the following sections.

1.Defeat device

The least burdensome of the alternatives considered was to structure the intermediate soak requirement solely as a defeat device policy. This would not require any up-front compliance demonstration from the manufacturer, but would give EPA the option to perform intermediate soak testing on any production vehicle for the purpose of ensuring adequate control over this mode. This option was rejected for two reasons. First, defeat device policy is generally implemented as a control measure against off-cycle calibration strategies which are not consistent with the on-cycle strategies. While this is of concern over intermediate soaks, the primary emission mode over intermediate soaks is the rapid cooldown of the catalyst and subsequent delay in the catalyst reaching light-off temperatures upon startup. The second argument against using only a defeat device approach to address intermediate soaks is that it will not provide an adequate level of enforcement from EPA's perspective. As demonstrated in EPA's test program, emission increases over intermediate soak modes occur on most vehicles in production. In order to ensure compliance over the entire production fleet, it is essential that EPA have more enforcement capability than afforded by the defeat device policy.

2.Self-Certification

A second alternative to the standard compliance determination considered was to allow manufacturers to self-certify over the intermediate soak test procedure. This would entail the manufacturers indicating to EPA that a given engine family was in compliance with the intermediate soak requirement without providing test data. This approach was rejected for two reasons: First, under this approach, burden would be reduced primarily on EPA, since manufacturer would still be required to perform the test procedure. Second, the self-certification approach would reduce EPA's ability to adequately check for compliance since no test data would be submitted.

3.Carryover across engine families

The final alternative to a standard compliance determination requirement considered was a "carryover" approach which allowed manufacturers to demonstrate compliance only on "worst-case" engine families, and use these results to infer compliance on remaining engine families without a direct compliance check. For example, a manufacturer might demonstrate compliance on a family whose catalyst system cooled down the most rapidly over the intermediate soak. Although this approach would reduce the test and data submission burden on the manufacturers, significant effort would be required to establish criteria determining which engine family would be considered the "worst-case", and to provide justification for compliance on the remaining families. Thus, this approach was not considered further.

D.Waiver provision

The Agency is considering the adoption of a waiver from running the intermediate soak procedure if a technical justification is provided that demonstrates a vehicle would clearly pass the requirement when run over the intermediate soak procedure. The Agency is considering a waiver provision due to the recognition that emissions over intermediate soaks will be reduced as manufacturers move towards technology which will improve light-off performance on cold starts; the purpose of such a waiver would be to prevent the intermediate soak procedure from being a redundant test procedure if improved cold start performance becomes more prevalent. For example, a vehicle equipped with an electrically heated catalyst may meet the intermediate soak requirement provided the heater was activated following intermediate soaks. A waiver under this scenario might comprise information in the application describing the technology, and a demonstration that the technology would be in effect over intermediate soaks. Under a waiver scenario, EPA would retain the right to access relevant information from the manufacturer, and to perform testing to verify compliance.

VIII.Impact of impending lower emission standards

The Agency's proposal for incorporating an intermediate soak requirement is based on the determination that the requirement is cost effective and technically feasible for vehicles certified under Tier 1 emission standards. However, the future of lower emission standards casts uncertainty on the effectiveness of a separate requirement addressing intermediate soaks. The Tier 2 study, scheduled for completion in 1997, will determine the need for standards more stringent than Tier 1 to be implemented between Model Year 2004 and 2006. In addition, the effort by the Ozone Transport Commission to adopt the State of California's Low Emission Vehicle (LEV) program for Northeastern states, and subsequent negotiations for the voluntary adoption of a Federal LEV program, may result in implementation of LEV-type vehicles in a timeframe which overlaps with implementation of the FTP rulemaking. As a result, there is a likely possibility that many vehicles will certify to emission standards lower than Tier 1 by the time a revised FTP would take effect.

Emissions over intermediate soak will be reduced by a move to lower emission standards. As a result, the cost effectiveness of controlling intermediate soak emissions will be reduced.   In order to comply with lower emission standards, vehicles will most likely be required to adopt strategies which will improve cold start emissions by enhancing catalyst light-off. As discussed in section 4.1.2.1, the enhancement of catalyst light-off through conventional means such as catalyst relocation or the addition of a small warmup catalyst will also incur benefits over intermediate soaks, although not to the degree as catalyst insulation. However, some vehicles may be required to comply with lower emission standards by adopting advanced light-off technology such as electrically heated catalysts. For these vehicles, emission increases over intermediate soaks will be reduced substantially, and additional control over intermediate soak modes would likely not be necessary. The effectiveness of a separate intermediate soak requirement would be reduced if a significant percentage of vehicles use this technology to comply with lower emission standards. For vehicles which do not employ electrically heated catalysts, there will likely continue be some emission increase over intermediate soaks relative to FTP bag 3 levels. However, there will be reduced benefit from controlling these emissions, and as a result the cost effectiveness of pursuing this benefit is in question.

The Agency performed a preliminary evaluation of the potential benefits and cost effectiveness of requiring control over intermediate soaks on vehicles certified to lower emission standards. The analysis was performed using emission results from a vehicle tested in EPA's Soak/Start test program. The Ford Escort was a Tier 1 vehicle equipped with a single close-coupled catalyst whose cold start emission results were in the range EPA anticipates will be necessary to comply with LEV/Tier 2 standards. FTP emission results for the vehicle were 0.11 g/mi NMHC, 1.2 g/mi CO and 0.09 g/mi NOx, while proposed Tier 2 standards are 0.125 NMHC, 1.7 CO and 0.2 NOx for LDV's at 100,000 miles. Although FTP (particularly NMHC) emissions would likely need to be reduced to comply with the in-use Tier 2 standards, it was observed that bag 2 emissions on this vehicle were relatively high (e.g. NMHC bag 2 emissions were 0.09 g/mi, approximately 4 times higher than the average of the other Tier 1 vehicles tested). The Agency hypothesized that because of high warm stabilized emissions and the fact that the vehicle is equipped with the most advanced level of cold start technology short of going to advanced technologies (such as an electrical heating), the vehicle would comply with LEV/Tier 2 standards by reducing emissions over warm stabilized operation rather than over cold start. Hence, EPA concluded that this vehicle was equipped with cold start technology which would be implemented for complying with lower emission standards, and that a preliminary sense of benefits incurred by an intermediate soak requirement on vehicles equipped with LEV/Tier 2 technology could be inferred from the results on this vehicle. Using a similar methodology for determining benefits detailed in Section 6, in-use benefits for this vehicle over intermediate soaks were determined to be .012

g/mi NMHC, .04 g/mi CO and .020 g/mi NOx, using an estimated AC benefit factor of 1/2 the AC NOx factor used for the Tier 1 analysis. Using a cost/vehicle estimate of catalyst insulation $11.42 ($7 per vehicle plus fixed costs) from the overall cost/benefit analysis of the regulation, the estimated cost/ton associated with this level of benefit is $5710 NMHC and $2855 NOx for this vehicle. While these numbers are less cost effective than those projected for Tier 1 vehicles, they are not outside the scope of what is considered cost effective by the Agency by means of comparison to other mobile source programs. This preliminary analysis indicates that on at least one technology which would likely comply with lower emission standards, there continue to be substantive benefits at a cost effective level of control. However, given the preliminary nature of this analysis, it is preferable to the Agency to perform further analysis on this issue before making a final determination as to the cost effectiveness of an intermediate soak requirement on vehicles certified to lower emission standards.

There are also concerns with the feasibility of implementing catalyst insulation on vehicles certified to lower emission standards. Vehicles which do not employ electrically heated catalysts or some other form of advanced technology will likely require at least one close coupled catalyst. Since the proximity to the engine elevates the temperature of these catalysts, the risk of additional catalyst degradation due to catalyst insulation will increase. This is of particular concern in cases where the vehicle is equipped with only one main close-coupled catalyst requiring insulation. As detailed in Section 5.1, EPA estimates that the percentage of the Tier 1 vehicles for which this is the case is small. However, EPA anticipates that a greater proportion of vehicles will employ this strategy to comply with lower emission standards. At this point, EPA is uncertain about the impact of catalyst insulation on the deterioration of close-coupled catalysts, and the ramifications of this issue on the viability of requiring control of intermediate soak emissions on vehicles certified to lower emission standards. Factors which go into this determination are 1) the proportion of vehicles which would employ only close-coupled catalysts to comply with lower emission requirements, 2) the risk of significant deterioration due to insulation on close-coupled catalysts, and 3) the possibility that improvements in catalyst formulation would allow vehicles which employ only close-coupled catalysts to insulate the catalyst without risk of substantial incremental deterioration.

As a result of the cost effectiveness and feasibility concerns of an intermediate soak requirement under lower emission standards, EPA believes it is appropriate to take into account the impact of such a requirement on vehicles which are certified to emission standards more stringent than Tier 1 before making the determination on whether or not to finalize the intermediate soak requirement. The Agency plans to evaluate the issues which have been raised regarding the cost effectiveness and feasibility of an intermediate soak requirement in the context of lower emission standards. The Agency believes it is only necessary to move forward with an intermediate soak requirement if a significant proportion of vehicles are certified to Tier 1 standards for a significant time period following implementation of the proposal, or if this is not the case, that it is cost effective and feasible to pursue control over intermediate soaks on vehicles certified to impending lower emission standards.