Technical Report

Effects of Idle Warm-up and Warm Idle Soak Periods on CO Emissions and Fuel Consumption at 20°F

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1.0 Summary

The effects of idle warm-up and warm idle periods on CO emissions and fuel consumption were studied on two vehicles at 20°F. Both vehicles were Ford vehicles which had air pump systems that routed pump air to the atmosphere after 1-2 minutes of engine idling, and as such, these vehicles are not representative of any particular fleet. The testing revealed that (1) there is a CO benefit and a fuel economy penalty associated with a short (less than 10 minutes) idle warm-up period which preceeds actual driving; (2) there is a fuel economy penalty associated with leaving a vehicle running for 5-15 minutes as compared to turning the engine off for the same period of time and restarting it, and (3) a different and more comprehensive test program would be needed to test the effects of warm idle periods on CO emissions.

2.0 Background

The 1975 Federal Test Procedure (FTP) requires vehicle exhaust emissions to be measured in three separate phases of a 31 minute typical urban driving cycle at 75°F. The distinction between phases is made to characterize the emissions produced from different modes of engine operation such as cold starting and engine warm-up, stabilized operation, and hot starting.

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As one would expect, the first phase, which includes engine starting and warm-up, is the phase that produces the most CO emissions during an FTP test. This effect becomes more pronounced as test temperature is decreased. There are several reasons for this phenomenon. First, at low temperatures, engine starting requires carburetor choking because of the low volatility of gasoline at low temperatures. Consequently, much of the gasoline entering the engine is not completely burned. Second, low temperatures also result in longer engine cranking times than would be experienced at warmer temperature. Like choking, long cranking times can add more low-volatility fuel to the engine, resulting in more incompleted burned combustion products than there would have been with a shorter cranking time. Third, the choke does not completely open up at the instant the vehicle is started. Depending on what other choke controls are present on a vehicle (electric assist, thermostatic coil, etc.) it may take several minutes for the choke to completely open up. This further exacerabates the incomplete combustion products problem. Finally, internal friction in the drive train and the power required to drive the accessories (heater, wipers) are higher, requiring greater power output from the engine during warm-up.

When these effects are coupled with the fact that during engine starting and warm-up the catalyst is cold and unable to operate effectively, high CO emissions at the tailpipe are typically the cold start and warm-up result.

The aforementioned reasons are usually given as an explanation of the causes of excessive low temperature CO emission from vehicles. However, driver behavior may also have some impact on the amount of CO emissions produced by

DRAFT

vehicles at cold temperatures. In extreme cold weather (i.e., 20°F or less) many people warm up their vehicles at idle prior to taking a trip (to work, shopping, etc.). Presumably people feel this increases driving comfort, but may also feel it increases fuel consumption. The 1975 FTP has only a 10 second cold idle warm-up included in the driving cycle. The question raised by this first aspect of cold weather driving is: What are the overall CO emission and fuel economy effects of this cold weather anomaly, i.e., are the total emissions produced and fuel used during an idle warm-up and a typical trip greater or less than the total emissions and fuel used from a typical trip without an idle warm-up?

The other aspect of cold weather vehicle operation is the extended warm idle. In extreme cold weather operation, many people leave their cars running instead of turning them off when performing a short errand that takes them out of their car (such as running into a grocery store for 10 minutes). People feel this increases driving comfort, and may also feel it saves a small amount of battery power for times when the vehicle really needs it -- during an extreme cold start. The 1975 FTP contains 252 seconds (out of 1371 total seconds or 18.4%) of idle time in the driving cycle. This accounts for idle time which is incurred at stop lights and stop signs. But it does not take into account the emissions produced during extended (5-15 minutes) warm idles which may be an integral part of cold weather driving habits. The question raised by this second aspect of cold weather driving is: Are total CO emissions produced during a warm idle plus a typical trip greater or less than the emissions produced from a typical trip without a prior warm idle?

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3.0 Program Description

The test program used to determine the effects of idle warm-up and warm idle periods on CO emissions and fuel consumption is presented in Figure 1.

Figure 1. Idle Effects Test Sequence

Figure A. Test Sequence

1. Check tune-up specifications on vehicle
2. FTP at 75°F
3. Cool to 20°F
4. Idle warm-up (2, 5, 10 minutes)
5. LA-4
6. Engine-off soak (5, 10, 15 minutes)
7. LA-4
8. Cool to 20°F
9. Cold start LA-4
10. Idle Soak (5, 10, 15 minutes)
11. LA-4
12. Repeat steps 3-11 for next idle warm-up and warm idle period.

Steps 1 and 2 were performed for the purpose of assuring that each vehicle was operating properly. Steps 3 through 11 are the core of the test program; emissions produced from the tests in Steps 4 and 5 were compared to emissions produced from the test in Step 9 to determine the overall effect of an idle warm-up period on a typical first trip of the day. Similarly, emissions produced from the tests in Steps 6 and 7 were compared to emissions produced in Steps 10 and 11 to determine the effect of warm idle period on a typical subsequent trip.

Idle warm-up periods were 2, 5, and 10 minutes in duration; warm idle periods were 5, 10, and 15 minutes in duration. These times were selected on the basis of a 1980 Alaska Department of Environmental Conservation survey which studied idle warm-up and warm idle times among people who participated in the 1979-80 Anchorage Free Emission Control Test. The results of this survey are presented in Attachment 1 of the Appendix.

Vehicles - The two vehicles used in this study were a 1978 Ford LDT (8 cylinder) and a 1978 Ford Pinto (4 cylinder - certified for California). Both vehicles had air pumps, and both vehicles had an air pump control system which routed pump air to the atmosphere (instead of to the exhaust manifold) after 1-2 minutes of engine operation at idle. Specifications for both vehicles are listed in Attachment 2 of the Appendix. Both vehicles were tuned to manufacturer specifications prior to testing.

Controlled Environment Test Cell - The vehicles were tested in the Controlled Environment Test Cell (CETC) located in EPA's Motor Vehicle Emission Laboratory in Ann Arbor, Michigan. The cell contains an electric dynamometer for simulating vehicle loads and inertia weights and a constant speed fan for engine cooling. A diagram of the cell is presented in Attachment 3 in the Appendix. The cell is capable of maintaining any temperature between 20°F and 100°F throughout the duration of a test.

The starting procedures used during testing were the manufacturers recommended cold start and warm start procedures. The cold start procedures for both vehicles required the driver to set the choke with the accelerator pedal prior to turning the key. The warm start procedures required the driver to turn the key without depressing the accelerator pedal.

Since a proportional fan control (where fan speed is coupled to dynamometer roll speed to simulate the actual velocity of cooling air passing over the vehicle) was not available at the time of testing, the fan speed was set to simulate a velocity of about 20 mph, which is the average vehicle speed of the driving cycle of the 1975 FTP. A divider was placed in front of the vehicle to prevent 20 mph cooling air from the fan from passing over the vehicle when idle emissions were sampled.

In most instances a vehicle was allowed to "soak" overnight at the test temperature (20°F) so that there was reasonable assurance that all components (tires, oil, etc.) of a vehicle were at the test temperature. However, in order to expedite testing, a "forced cool down" technique was sometimes employed. In this cooling technique, fan speed was increased to approximately 55 mph while cell air was maintained carefully at 20°F. This reduced the "soak time" necessary to cool all components (including engine crankcase oil, which is the slowest component to cool) to 20° from about 12 hours (with no fan cooling) to about 4 hours. Vehicles were determined ready for testing when their engine crankcase oil temperature reached a value of 20± 2°F.

4. Results

Equipment Modifications - When the first 2 minute idle warm-up bag was analyzed, it was discovered that the CO analyzer in its highest operating range was partially saturated at approximately 135 meter deflections (an adequate analysis can be obtained only up to about 125 meter deflections). A higher CO range (range 23, 0-25,000 ppm CO) was installed to alleviate this problem.

Emissions From Idle Periods - CO emissions from the test vehicles during the idle periods are summarized in Table 1. It should be noted that although CO emissions increased with longer idle warm-up periods, the same was not true with respect to the warm idle periods. Possible reasons for these results are discussed in the conclusions.

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Table 1. CO Emissions From Idle Periods

Test	Pinto	LTD
2 min. Idle Warm-up	79.4 grams	86.9 grams
5 min. Idle Warm-up	240.2	622.6
10 min. Idle Warm-up	286.3	734.9
5 min. Idle Warm-up	1.3 grams	.43 grams
10 min. Idle Warm-up	.24	.12
15 min. Idle Warm-up	14.8	.53

Idle Warm-up Effects on Emissions and Fuel Consumption - The average (of both vehicles) emissions produced and the average fuel consumed for the idle warm-up test as opposed to the cold start test are presented in Table 2. It is evident from this table that there is a CO benefit and a fuel economy penalty associated with a short (10 minutes or less) idle warm-up period which preceeds an LA-4. There also appears to be a small HC benefit to an idle warm-up of 2 minutes or less. The NOx results are inconclusive.

Table 2. Average Emissions (gms.) and Fuel Consumed (gals.) During Idle Warm-Up Sequence of Testing

Test Sequence	HC	NOx	CO	Fuel (gals.)
	Total Emissions (gms.)			
2 min. idle warm-up + LA-4	45.3	9.4	485.6	.55
5 min. idle warm-up + LA-4	71.1	11.9	567.3	.63
10 min. idle warm-up + LA-4	122.4	6.9	591.3	.74
Average of 6 cold start LA-4's (3 tests on 2 vehicles)	53.7	9.7	618.2	.54

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There is another way to interpret the data obtained from this phase of the test program. Although a CO benefit may accompany an idle warm-up coupled with an LA-4, how great is the benefit compared to the total FTP CO emissions (i.e., idle + FTP CO emissions)? Figure 1 provides the answer to this question. This figure was made by adding an actual Bag 3 CO result at 20°F to the tests which generated Table 2, and applying the appropriate weighting factors[1/] to each bag result to come up with an FTP CO gm/mile value for each idle warm-up test and cold start test. These values are listed in Table 3. The ratio of idle warm-up FTP CO to FTP CO (without idle warm-up) is plotted in Figure 1.

1/ The equation used was FTP CO (gm/mi) = [.57 (Idle + CT) + CS + .43 HT]/7.5 miles, (40 CFR 86.144-78, July 1, 1977, page 467)

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Figure 1. Idle Warm-up Factors vs. Idle Warm-up Time

Factor = (Idle + FTP) CO gm/mi divided by
cold start FTP CO gm/mi.

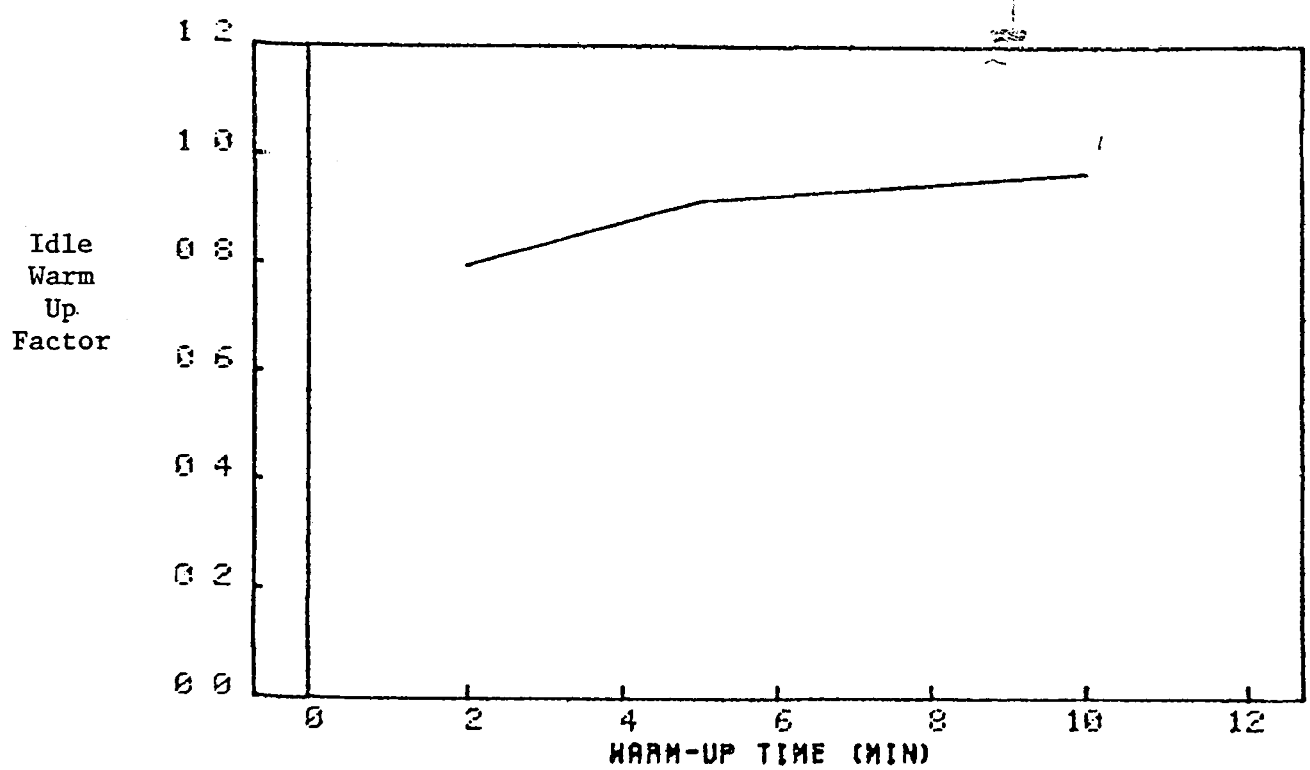

Table 3. FTP CO gm/mile

Calculated for Idle Warm-ups

and Cold Starts.

Idle Warm-up Time	FTP CO gm/mile
2 min.	33.7 gm/mile
5 min.	38.7 gm/mile
10 min.	40.8 gm/mile
No idle warm-up	42.2 gm/mile

Warm Idle Effects - The average (of both vehicles) emissions produced (in gms.) and the average fuel consumed for the warm idle test as compared to the engine-off test is presented in Table 4.

Table 4. Emissions and Fuel Consumption Comparisons Between Idle and Engine-Off Periods of the Same Duration

Test Sequences	Total Emissions (gms.) HC	NOx	CO[2]	Fuel (gals.)
5 min. Eng-off + LA-4	6.2	10.6	63.4	.43
10 min. Eng-off + LA-4	9.0	11.1	78.4	.43
15 min. Eng-off + LA-4	4.3	10.6	77.8	.43
5 min. Idle + LA-4	7.2	11.0	53.0	.47
10 min. Idle + LA-4	7.8	12.1	48.0	.52
15 min. Idle + LA-4	10.0	11.7	50.1	.58

2/ The CO emissions from the second bag of the LA-4 (Bag 4) were averaged with those from the other tests to reduce variation for comparison purposes. Theoretically, Bag 4 results should be very similar because the vehicles are well warmed-up at the time Bag 4 sampling begins.

Although it appears from Table 4 that there may be a CO benefit and a fuel economy penalty associated with allowing a warm engine to idle in cold weather for a short period of time instead of turning the engine off, several other considerations yield this result inconclusive. First, the data on the individual vehicles did not display the same trend as the average of the two. Table 5 lists the bag-by-bag CO emission results of each vehicle. One should notice that there is a CO reduction which accompanies a 10 minute warm idle on the 1978 Pinto, but there is a CO increase which accompanies a 10 minute warm idle on the 1978 LTD. Second, the idle percent of total emissions in five out of six cases is less than 1.7%. Third, the variation in Bag 4 CO emissions from each vehicle, although the vehicles are fully warmed up, is in most cases higher than the total CO emissions produced from each idle period. (For this reason, Bag 4 CO emissions were averaged, and the average was used in the calculation of Total Emissions, Idle % of Total Emissions, and the Total CO Emissions presented in Table 4.) In summary, this test procedure cannot be viewed as very effective in testing a phenomenon whose contribution to total emissions is so small as to be disguised by normal variations in the test procedure.

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Table 5. CO Emissions and Fuel Consumption Comparisons between Idle and Engine-Off Periods of the Same Duration

	1978 For LDT CO Emissions (gms.)				Idle %	Fuel	1978 Calif. Pinto CO Emissions (gms.)				Idle %	Fuel
Test Sequence	Idle	Bag 3	Bag 4	Total	of Total	(gals.)	Idle	Bag 3	Bag 4	Total	of Total	(gals.)
5 min Eng-off + LA-4		33.4	7.3	38.3		.51		53.9	22.4	88.5		.35
10 min Eng-off + LA-4		23.1	4.0	28.0		.52		94.3	32.2	128.9		.34
15 min Eng-off + LA-4		29.4	4.2	34.3		.51		86.8	43.4	121.4		.34
5 min Idle + LA-4	.43	23.1	2.0	28.4	1.5%	.56	1.3	43.0	42.0	77.6	1.7%	.38
10 min Idle + LA-4	.12	27.0	7.1	32.0	.4%	.62	.24	29.5	25.9	64.1	.4%	.42
15 min Idle + LA-4	.53	26.0	5.0	31.4	1.7%	.69	14.8	27.0	41.9	68.9	21.5%	.47
		Avg =	4.9					Avg =	34.6			

Notes:

(1) Both vehicles have air pumps which route air to the atmosphere after 1-2 minutes of engine operation at idle. Normally the air is routed to the exhaust manifold.

(2) Bag 3 is the cold transient driving cycle portion of the 1975 FTP. It covers a distance of 3.59 miles and lasts 505 seconds. Bag 4 is the cold stabilized portion of the 1975 FTP. It covers a distance of 3.91 miles and lasts for 867 seconds.

(3) Bag 4 results should be relatively insensitive to the preceeding test procedures, as the vehicles were fully warmed up before the Idle and Bag 3 tests were conducted. Consequently, Bag 4 results were averaged and used in the calculation of Total and Idle % of Total emissions in an attempt to reduce this source of variation.

5. Conclusions

Applicability of Results - Since the data obtained from this test program was from tuned-up vehicles, it cannot be used to predict the behavior of actual-in-use vehicles. In-use vehicles, on the average, exhibit significantly higher idle HC and CO concentrations than tuned-up vehicles, and therefore might exhibit very different idle warm-up and warm idle effects.

CO Emissions Produced From Idle Periods - It was mentioned that CO emissions increased as idle warm-up time increased, but that this was not the case for the warm idle period. One would expect that as the length of the warm idle period increases, CO emissions would increase also; all other things being equal. An explanation of this disparity could be in differing idle speeds of the vehicles. Although the vehicles were fully warmed up and the carburetors were thoroughly checked prior to testing for warm idle effects, it is possible that the fast idle cam did not consistently return to the same position each time a vehicle returned to idle. A higher idle speed would increase CO emissions from the warm idle period.

Idle Warm-up Effects - There are two competing factors which probably affect cold start and total emissions when an idle warm-up preceeds actual driving. Since the vehicle is warming up at idle, the warm-up time is longer than if the vehicle were immediately driven after it was started. This would seem to have the effect of increasing cold start and total CO emissions as compared to a situation where there was no idle warm-up. However, the volumetric flow rate of air and fuel through the engine is lower during idle than when the vehicle is driven. This would seem to have the effect of lowering cold start and total CO emissions, because the vehicle is warming-up in a low CO production mode (as compared to a vehicle which is warmed-up while it is driven). The results indicate that the second factor out-weighs the first.

Warm-Idle Effects - There are several factors which would affect the amount of CO emissions produced during either a warm idle period or a period in which the engine is turned off and restarted. First, increasing time would increase the amount of CO produced during a warm idle period. However, increasing idle speed would also increase CO emissions produced at idle. It is conceivable therefore that a vehicle which idles for five minutes at a high idle speed could produce the same amount of CO emissions as the same vehicle idling at a lower idle speed for ten minutes.

For a period in which an engine is turned off and restarted, there are two other factors which probably affect the quantity of CO produced. First, increasing the time which the engine is turned off has the effect of decreasing the temperature of the engine, thereby yielding higher restart emissions. Second, cranking time also probably has an effect on CO emissions. If a vehicle takes a long time to start, its emissions will be higher than if the engine immediately fires upon turning the key.

The variation in Bag 4 CO results, the insignificance of warm idle emissions when compared to total emissions, and the lack of correlation between warm idle time and CO emissions produced leads to some doubt on the effectiveness of the test procedure that was used in studying the warm idle phenomenon. It is possible that a test procedure that compared cranking (starting) emissions to warm idle emissions might be more effective. However, problems that would surface in designing and implementing this type of testing would center around (1) defining the cranking period, and (2) accurately analyzing cranking emissions.

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ATTACHMENT 1

The following questions, among others, were asked of 500 participants in the 1979-80 Anchorage Free Emission Control Test (AFECT), eliciting these responses:

How long do you let the vehicle warm up in the morning on cold mornings after starting the vehicle for the first time?

How long do you let the vehicle warm up after work during cold days?

When you are shopping and leave the store, how long do you warm up the vehicle before driving it?

MINUTES	WARM-UP TIME - AM %	CUMULATIVE %	WARM-UP TIME - PM %	CUMULATIVE %	WARM-UP TIME - POST SHOPPING %	CUMULATIVE
0	8.9	8.9	14.3	14.3	36.0	36.0
0.5	10.0		11.6		22.2	
1.0	8.9		15.8		17.3	
1.5	3.9		5.8		4.5	
2.0	9.0	41.1	10.7	58.2	8.1	88.1
2.5	3.5		3.0		0.6	
3.0	6.1		5.8		2.9	
3.5	3.8		2.6		0.4	
4.0	3.9		3.2		0.1	
4.5	0.2		0.2		6.2	
5.0	17.3	75.5	15.0	88.0	4.5	98.0
5.5	0.0		0.0		---	
6.0	0.2		0.2		---	
6.5	0.7		0.2		---	
7.0	0.0		0.2		---	
7.5	5.1		2.4		---	
8.0	0.0		0.0		---	
8.5	0.0		0.0		---	
9.0	0.4		0.4		---	
10.+	18.0		8.8		2.0	

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Attachment 2 Vehicle Specifications

	1978 Pinto (California)	1978 Ford LTD
I.D.	8R10Y131366	F8863F182034F
Mileage	20,392	35,739
EGR	Yes	Yes
Air Pump	Yes	Yes
Catalyst	Yes	Yes
Engine	In line - 4	V-8
Displacement	2.3L	302 C.I.D.
A.H.P.	10.7	10.9
I.H.P.	9.7	9.9
I.W.	2750	4500

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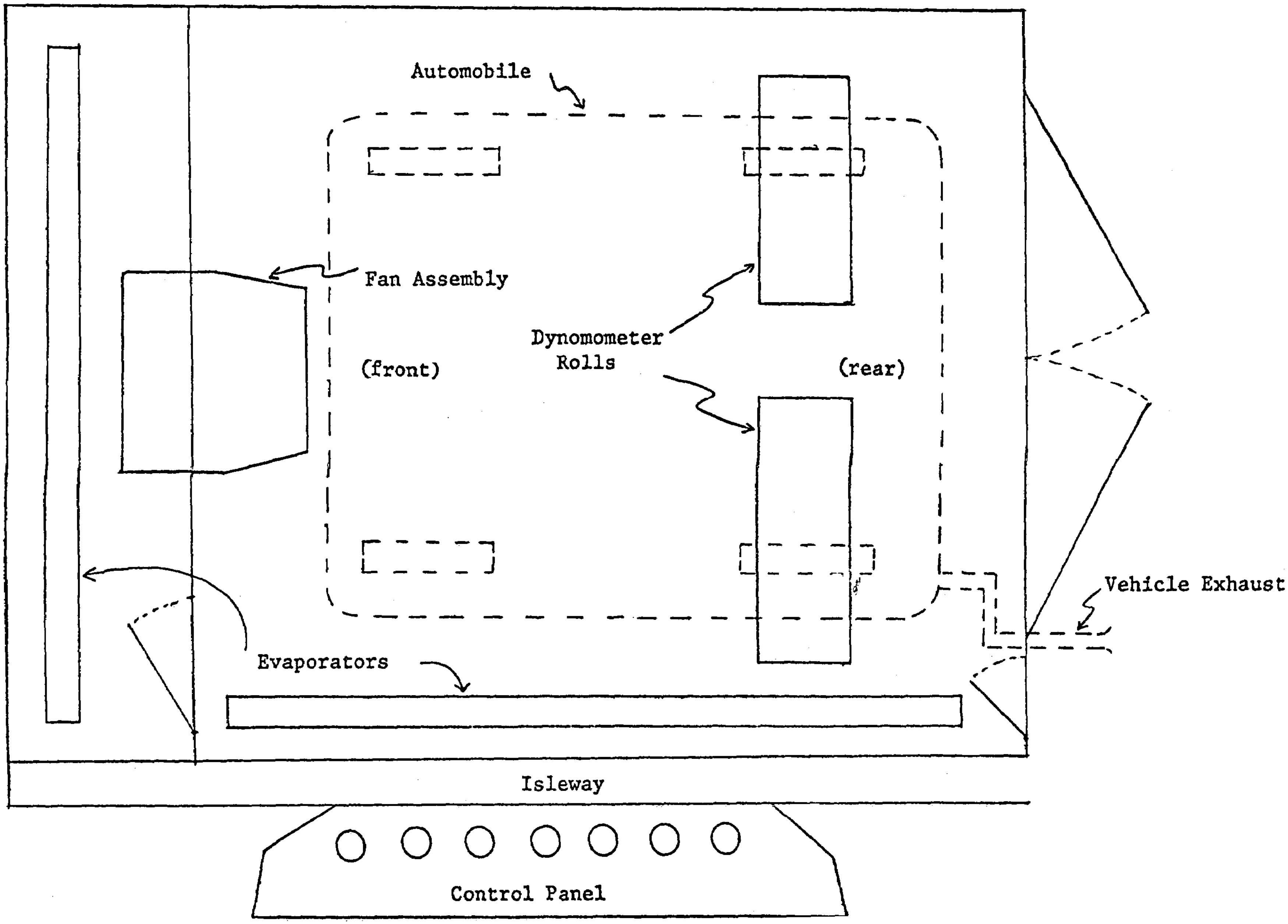
Attachment 3 Controlled Environment Test Cell
Environmental Protection Agency



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