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March 23, 2005

TO: Power Research Inc.
6970 Portwest Drive, Suite 180
Houston, TX 77024

ATTN: Ms. Wanda E. Lewis

SUBJECT: Final Letter Report for SwRI Project No. 11211 under Proposal No. 03-41665, titled, "Emissions Testing to Quantify Emission Reductions for Alternative Diesel Fuels"

1.0 INTRODUCTION

This final report is submitted to document emissions testing of a candidate fuel over a protocol specified by the California Air Resources Board (CARB). The protocol is based on transient emission measurement procedures developed by the EPA for emissions regulatory purposes. The CARB protocol allows a 1991 Detroit Diesel Corporation (DDC) Series 60 engine to be used as the "test bench" for comparing exhaust emissions using a California reference fuel, "Fuel R," and a candidate fuel, "Fuel C." For this protocol, Power Research Incorporated (PRI) provided a type-2D diesel as Fuel R, and a PRI-treated 2D fuel as Fuel C. The CARB protocol requires fuel evaluations to be conducted using one of three alternative testing sequences, and this work used the RRR-CCC hot-start transient cycle testing sequence.

2.0 SCOPE OF WORK

Southwest Research Institute performed emission tests using a Type-2D fuel as Fuel R, which is understood to have been procured in Texas by PRI. The candidate fuel, Fuel C, consisted of Fuel R treated by PRI with PRI-D additive. Testing adhered to the CARB "Interim Procedure for Certification of Emission Reductions for Alternative Diesel Fuels," which was transformed into a test procedure for the purposes of this project. The "Alternative 3" CARB procedure was completed by running consecutive hot-start tests with the two fuels in an order of RRR, CCC, on Test Day 1, and then CCC, RRR on Test Day 2, and so on. The required 21 individual hot-start emission tests were completed with each fuel in seven test days. The average for individual regulated emissions from each triplicate series of hot-start tests (i.e., RRR or CCC) was considered a single emissions value for that fuel in statistically comparing fuel effects.

Emissions determined on each fuel included total hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_X), carbon dioxide (CO_2), and total particulate matter (PM). The original scope of work included analyzing gathered particulate samples to express the soluble organic fraction of the PM (SOF), sulfate (SO_4), the carbonyls (ALD), individual hydrocarbons (IHC), and polycyclic aromatic hydrocarbons (PAH). However, PRI halted planned work after the seventh test day, and directed SwRI to discard all of the samples to avoid expenses related to their handling and analyses.

Preparation of this report was funded by a grant to Power Research Inc from the State of Texas through the Texas Council on Environmental Technology and the Texas Commission on Environmental Quality

Work incorporated the procedure given in Table 2 for completing instrument and sample systems calibrations, changing fuels, determining engine performance, preparing and stabilizing emission measurement systems, and performing the multiple hot-start transient cycle testing work to obtain the needed exhaust samples.

TABLE 2. PROCEDURE FOR ACCUMULATING REGULATED EMISSIONS DATA USING ALTERNATIVE 3 OF THE CARB PROTOCOL

Step	Description
1	Perform emission instrument calibrations as required. Calibrate torquemeter and check signal conditioning systems. Validate CVS gaseous and particulate sampling systems using propane recovery techniques.
2	Check engine condition using in-house, low sulfur emissions type fuel, and note fault codes if any. Bring engine oil level to "full" using an approved lubricating oil.
3	At the beginning of the first test day, perform fuel change procedure to operate on Fuel R. Change filter, purge fuel supply, etc.
4	Warm up engine and operate at rated speed and load, then check performance.
5	Conduct transient "full-throttle" torque map from low- to high-idle. Compute and store resulting transient command cycle. This initial transient command cycle with Fuel R will be used for all subsequent emission tests in this test plan. Other torque-map information generated with either Fuels R or C during this test work will be stored for documentation purposes.
6	Load dummy sample media and run two 20-minute practice or conditioning transient cycles without a 20-minute soak between cycles, and adjust dynamometer controls to meet statistical limits for transient cycle operation.
7	During a 20-minute engine soak, load appropriate sampling media and set emission instruments to measure emissions. Run a hot-start transient test. Repeat the soak and run process until emission data for three hot-start transient cycles are accumulated. For each individual hot-start test, determine HC, CO, NO_X, PM, SO_4, and SOF. For ALD and IHC, accumulate a composite dilute exhaust sample and a background sample over all three runs by collecting a proportional sample of gases. For 1,3-butadiene, accumulate dilute exhaust and background samples over only the first hot-start test. As soon as practical, but no longer than one-hour after completing the first hot-start test, submit the dilute exhaust sample for analysis of 1,3-butadiene. On Day 1, load PAH sampling systems with dummy collection media for consistent operation of all sampling systems over the three runs. Distribute other samples as required for analysis.

TABLE 2 (Cont'd). PROCEDURE FOR ACCUMULATING REGULATED EMISSIONS DATA USING ALTERNATIVE 3 OF THE CARB PROTOCOL

Step	Description
8	Repeat Steps 3 through 7 with Fuel C.
9	On Day 2 of testing, repeat Steps 4 through 7 with Fuel C, but use appropriate sample media for PAH collection.
10	After completing Step 9 and distributing samples, operate the CVS with engine off for 15 minutes. Load PAH collection media, and with engine off, accumulate a blank, B-2, by sampling for one hour with the CVS running. After completing this process, continue to the next fuel.
11	Repeat Steps 3 through 7 with Fuel R.
12	On Day 3 of testing, repeat Step 9 with Fuel R and perform Step 10 for B-3.
13	Repeat Steps 3 through 7 with Fuel C.
14	On Day 4 of testing, repeat Step 9 with Fuel C and perform Step 10 for B-4. For this blank set only, load collection media to accumulate blanks for IHC and ALD. As soon as practical, but no longer than one hour after completing blank sampling process, submit the tunnel blank sample for IHC for analysis of 1,3-butadiene, then on to other analyses.
15	Repeat Steps 3 through 7 with Fuel R.
16	On Day 5 of testing, repeat Steps 9 and 10 for B-5.
17	Repeat Steps 3 through 7 with Fuel C.
18	On Day 6 of testing, repeat Steps 9 and 10 for B-6.
19	Repeat Steps 3 through 7 with Fuel R.
20	On Day 7 of testing, repeat Steps 9 and 10 for B-7.
21	Summarize data and prepare the final report.

Note: All analyses of SO_4, SOF, ALD, IHC, and PAH samples were canceled by PRI.

Table 3 illustrates the pattern of 42 hot-start transient runs made using Fuel R and Fuel C. On each of the 42 runs, HC, CO, NO_X, PM, SOF, SO_4, and CO_2 were determined. Hot-start transient emission tests were conducted as specified in the Code of Federal Regulations, Title 40, Part 86, Subpart N. Procedures for measurement of HC, CO, NO_X, CO_2, and PM are described in Subpart N.

TABLE 3. PATTERN OF RUNS FOR FUEL R AND FUEL C OVER SEVEN DAYS USING ALTERNATIVE 3

Test Day	Hot Start Transient								
	Fuel	Test Number			Blank	Fuel	Test Number		
1	R	1	2	3	-	C	4	5	6
2	C	7	8	9	B2	R	10	11	12
3	R	13	14	15	B3	C	16	17	18
4	C	19	20	21	B4[a]	R	22	23	24
5	R	25	26	27	B5	C	28	29	30
6	C	31	32	33	B6	R	34	35	36
7	R	37	38	39	B7	C	40	41	42

[a] One blank sample set included IHC and ALD tunnel blanks in addition to PAH tunnel blanks.

3.0 RESULTS OF EMISSIONS TESTING

All planned engine operations and emissions sampling was completed. However, despite collecting all samples, SwRI did not finish analyzing the numerous samples to quantify unregulated compounds. A work stoppage was issued by PRI immediately after they reviewed results shown in Table 4, as the regulated emissions information indicated PRI-treated fuel did not improve emissions or fuel economy. At that time, PRI opted to limit project expenditures, and directed SwRI to halt work related to post-test sample processing and analyses. Therefore, only the information on regulated emissions is presented in this report.

As specified in the CARB protocol, each triplicate set of hot-start tests gave a single data point per emission compound (or BSFC expression) on each fuel. The seven daily averages were then averaged to compare the base 2D fuel (Fuel R) effects to PRI-treated fuel (Fuel C) effects. Comparison of results over this seven-day protocol showed no significant difference or consistent trend in regulated emissions or fuel consumption.

TABLE 4. TRANSIENT CYCLE EMISSION RESULTS FOR 1991 DDC SERIES 60 ENGINE USING A TYPE-2D FUEL AND 2D FUEL TREATED WITH PRI ADDITIVE

Test Day	Fuel Identity	FTP Run	SwRI Test Number	Hot-Start Transient Cycle Emissions, g/hp-hr					BSFC, lb/hp-hr	Work, hp-hr	
				BSHC	BSCO	$BSNO_X$	BSPM	$BSCO_2$		Cycle	Ref.
1	R	1	0210-H1	0.07	2.58	5.045	0.198	542	0.379	25.16	25.00
	R	2	0210-H2	0.05	2.54	4.982	0.197	533	0.372	25.31	25.00
	R	3	0210-H3	0.05	2.55	4.960	0.197	527	0.368	25.16	25.00
	R		**Average**	**0.06**	**2.55**	**4.996**	**0.197**	**534**	**0.373**	**25.21**	**25.00**
	R		*Coefficient of Variation*	*13%*	*1%*	*1%*	*0%*	*1%*	*1%*	*0%*	*na*
	C	4	0210-C1	0.05	2.60	4.923	0.197	534	0.373	25.10	25.00
	C	5	0210-C2	0.05	2.62	4.983	0.200	527	0.368	25.14	25.00
	C	6	0210-C3	0.05	2.60	4.995	0.199	536	0.374	25.07	25.00
	C		**Average**	**0.05**	**2.61**	**4.967**	**0.199**	**533**	**0.372**	**25.10**	**25.00**
	C		*Coefficient of Variation*	*1%*	*0%*	*1%*	*1%*	*1%*	*1%*	*0%*	*na*
2	C	7	0211C-H7	0.08	2.59	4.993	0.199	534	0.373	25.15	25.00
	C	8	0211C-H8	0.05	2.53	5.013	0.200	536	0.374	25.13	25.00
	C	9	0211C-H9	0.05	2.56	4.949	0.203	538	0.375	25.14	25.00
	C		**Average**	**0.06**	**2.56**	**4.985**	**0.201**	**536**	**0.374**	**25.14**	**25.00**
	C		*Coefficient of Variation*	*26%*	*1%*	*1%*	*1%*	*0%*	*0%*	*0%*	*na*
	R	10	0211R-H10	0.04	2.49	4.740	0.190	517	0.361	25.11	25.00
	R	11	0211R-H11	0.05	2.58	4.854	0.192	541	0.378	25.16	25.00
	R	12	0211R-H12	0.04	2.55	4.858	0.196	543	0.379	25.31	25.00
	R		**Average**	**0.04**	**2.54**	**4.817**	**0.193**	**534**	**0.373**	**25.19**	**25.00**
	R		*Coefficient of Variation*	*12%*	*2%*	*1%*	*2%*	*3%*	*3%*	*0%*	*na*
3	R	13	0214R-H13	0.05	2.79	4.985	0.201	541	0.378	25.09	25.00
	R	14	0214R-H14	0.03	2.72	4.939	0.203	540	0.377	25.10	25.00
	R	15	0214R-H15	0.00	2.70	4.954	0.200	544	0.380	25.07	25.00
	R		**Average**	**0.03**	**2.74**	**4.959**	**0.201**	**542**	**0.378**	**25.09**	**25.00**
	R		*Coefficient of Variation*	*95%*	*2%*	*0%*	*1%*	*0%*	*0%*	*0%*	*na*
	C	16	0214C-H16	0.04	2.57	4.883	0.199	528	0.368	25.06	25.00
	C	17	0214C-H17	0.03	2.64	4.894	0.200	535	0.373	25.11	25.00
	C	18	0214C-H18	0.04	2.66	4.849	0.198	536	0.374	25.11	25.00
	C		**Average**	**0.03**	**2.62**	**4.875**	**0.199**	**533**	**0.372**	**25.09**	**25.00**
	C		*Coefficient of Variation*	*14%*	*2%*	*0%*	*1%*	*1%*	*1%*	*0%*	*na*
4	C	19	0215C-H19	0.03	2.68	4.957	0.208	541	0.377	25.06	25.00
	C	20	0215C-H20	0.07	2.73	4.958	0.205	556	0.388	25.17	25.00
	C	21	0215C-H21	0.03	2.70	4.963	0.208	541	0.378	25.08	25.00
	C		**Average**	**0.04**	**2.71**	**4.959**	**0.207**	**546**	**0.381**	**25.10**	**25.00**
	C		*Coefficient of Variation*	*54%*	*1%*	*0%*	*1%*	*2%*	*2%*	*0%*	*na*
	R	22	0215R-H22	0.01	2.66	4.829	0.201	536	0.374	25.10	25.00
	R	23	0215R-H23	0.03	2.63	4.798	0.206	531	0.371	25.07	25.00
	R	24	0215R-H24	0.03	2.66	4.862	0.203	534	0.373	25.02	25.00
	R		**Average**	**0.02**	**2.65**	**4.830**	**0.203**	**534**	**0.373**	**25.06**	**25.00**
	R		*Coefficient of Variation*	*43%*	*1%*	*1%*	*1%*	*0%*	*0%*	*0%*	*na*

Notes:

FTP Hot-Start Test over On-Highway U.S. FTP Transient Cycle, per CFR Title 40, Part 86, Subpart N (1200 seconds)
R SwRI Inventory Code EM-5418-F
C Candidate fuel prepared by mixing PRI-D in EM-5418-F, coded: EM-5423-F
COV Coefficient of variation, or the ratio of standard devation to the mean.

TABLE 4 (Cont'd). TRANSIENT CYCLE EMISSION RESULTS FOR 1991 DDC SERIES 60 ENGINE USING TYPE-2D FUEL AND 2D FUEL TREATED WITH PRI ADDITIVE

Test Day	Fuel Identity	FTP Run	SwRI Test Number	Hot-Start Transient Cycle Emissions, g/hp-hr					BSFC, lb/hp-hr	Work, hp-hr	
				BSHC	BSCO	$BSNO_X$	BSPM	$BSCO_2$		Cycle	Ref.
5	R	25	0216R-H26	0.05	2.66	4.971	0.207	552	0.385	25.08	25.00
	R	26	0216R-H27	0.06	2.61	4.996	0.204	563	0.393	25.12	25.00
	R	27	0216R-H28	0.06	2.66	4.932	0.204	544	0.380	25.08	25.00
	R		**Average**	**0.06**	**2.64**	**4.966**	**0.205**	**553**	**0.386**	**25.09**	**25.00**
	R		*Coefficient of Variation*	*7%*	*1%*	*1%*	*1%*	*2%*	*2%*	*0%*	*na*
	C	28	0216C-H29	0.06	2.70	4.802	0.204	535	0.373	25.29	25.00
	C	29	0216C-H30	0.04	2.68	4.887	0.201	550	0.384	25.17	25.00
	C	30	0216C-H31	0.05	2.63	4.884	0.196	534	0.373	25.24	25.00
	C		**Average**	**0.05**	**2.67**	**4.858**	**0.200**	**539**	**0.377**	**25.23**	**25.00**
	C		*Coefficient of Variation*	*16%*	*1%*	*1%*	*2%*	*2%*	*2%*	*0%*	*na*
6	C	31	0217C-H32	0.05	2.46	4.713	0.193	519	0.362	25.18	25.00
	C	32	0217C-H33	0.04	2.59	4.936	0.209	539	0.376	25.20	25.00
	C	33	0217C-H34	0.03	2.58	4.961	0.211	539	0.376	25.13	25.00
	C		**Average**	**0.04**	**2.54**	**4.870**	**0.204**	**532**	**0.371**	**25.17**	**25.00**
	C		*Coefficient of Variation*	*30%*	*3%*	*3%*	*5%*	*2%*	*2%*	*0%*	*na*
	R	34	R-H1	0.07	2.61	4.827	0.198	529	0.368	25.28	25.00
	R	35	R-H2	0.06	2.63	4.872	0.198	532	0.371	25.29	25.00
	R	36	R-H3	0.04	2.65	4.927	0.199	530	0.370	25.05	25.00
	R		**Average**	**0.06**	**2.63**	**4.875**	**0.198**	**530**	**0.370**	**25.21**	**25.00**
	R		*Coefficient of Variation*	*21%*	*1%*	*1%*	*0%*	*0%*	*0%*	*1%*	*na*
7	R	37	R-H1	0.02	2.59	5.006	0.200	534	0.373	25.28	25.00
	R	38	R-H2	0.03	2.62	4.991	0.204	545	0.380	25.27	25.00
	R	39	R-H3	0.00	2.58	5.021	0.203	542	0.378	25.30	25.00
	R		**Average**	**0.02**	**2.60**	**5.006**	**0.202**	**540**	**0.377**	**25.28**	**25.00**
	R		*Coefficient of Variation*	*92%*	*1%*	*0%*	*1%*	*1%*	*1%*	*0%*	*na*
	C	40	C1-H1	0.07	2.67	4.877	0.210	544	0.380	25.11	25.00
	C	41	C1-H2	0.03	2.60	4.849	0.214	533	0.372	25.09	25.00
	C	42	C1-H3	0.01	2.54	4.796	0.206	531	0.370	25.31	25.00
	C		**Average**	**0.04**	**2.60**	**4.841**	**0.210**	**536**	**0.374**	**25.17**	**25.00**
	C		*Coefficient of Variation*	*78%*	*3%*	*1%*	*2%*	*1%*	*1%*	*0%*	*na*
Mean of Seven Averages for R				**0.040**	**2.621**	**4.921**	**0.200**	**538**	**0.376**	**25.16**	**25.00**
			COV	*46%*	*3%*	*2%*	*2%*	*1%*	*1%*	*0%*	*0%*
Mean of Seven Averages for C				**0.045**	**2.615**	**4.908**	**0.203**	**536**	**0.374**	**25.14**	**25.00**
			COV	*20%*	*2%*	*1%*	*2%*	*1%*	*1%*	*0%*	*0%*
Percent Change for C vs. R				**13.3%**	**-0.2%**	**-0.3%**	**1.4%**	**-0.3%**	**-0.3%**	**-0.1%**	**na**

Notes:

FTP Hot-Start Test over On-Highway U.S. FTP Transient Cycle, per CFR Title 40, Part 86, Subpart N (1200 seconds)

R SwRI Inventory Code EM-5418-F

C Candidate fuel prepared by mixing PRI-D in EM-5418-F, coded: EM-5423-F

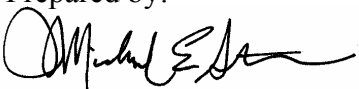
COV Coefficient of variation, or the ratio of standard devation to the mean.

4.0 SUMMARY

SwRI has attempted to address the need for conducting a test program to obtain transient cycle emissions data from a 1991 DDC Series 60 engine using a reference fuel, Fuel R, and a candidate fuel, Fuel C. Emissions data were accumulated using procedures outlined in Table 2 to conduct emission tests and fuel changes, with 42 hot-start tests run in an RRR-CCC, seven-day CARB protocol. Comparing the resulting levels generated using base 2D fuel (Fuel R) and those generated using PRI-treated 2D base fuel (Fuel C), there was no significant difference in regulated emissions or fuel consumption rates.

This final report is intended to meet the needs of PRI and the Texas Commission on Environmental Quality (TCEQ) for documenting this work. SwRI appreciates the opportunity to perform this study, and looks forward to meeting the future emissions research needs of PRI. As authorized by PRI, a copy of this report was sent by e-mail direct to the Grant Manager of TCEQ.

Prepared by:



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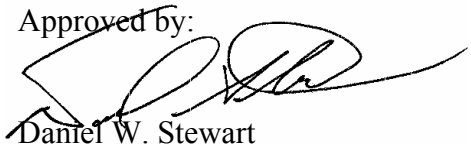

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