EVALUATION OF THREE LOW COST EXHAUST ANALYZERS

by

Charles Urban

for

U.S. ENVIRONMENTAL PROTECTION AGENCY

Ann Arbor, MI. 48105

May 1984

SOUTHWEST RESEARCH INSTITUTE

SAN ANTONIO HOUSTON

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Approved:

Karl J. Springer

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SUBJECT: Submittal of Test Results for work conducted under Work Assignment No. 18, Contract 68-03-3162, SwRI, Project 03-7338-018.

Contract Title: "Pollution Control Assessment for the Emission Control Technology Division, Ann Arbor, Michigan"

Assignment No. 18 Title: "Low Cost I/M Analyzer Study"

I. INTRODUCTION

Three "low cost" exhaust analyzers were provided to SwRI by the EPA for evaluation under a specific series of tests. This evaluation involved measuring various concentrations of CO in vehicle exhaust using a reference analyzer and the three "low cost" analyzers. The Statement of Work is given in Attachment A-1.

II. TEST PLAN

The test plan followed was the same as that given in the Work Plan for Work Assignment No. 18. A copy of the technical approach for that Work Plan is given in Attachment A-2. Some additional evaluations, over and above those given in the Work Plan, were conducted.

III. CAR, ANALYZERS, AND MISFIRE UNIT

The car used was a 1981 Ford Mustang with a 2.3 liter engine and a three-way exhaust catalyst. A commercial grade unleaded gasoline was used. The air pump was disconnected to enable attaining the higher levels of exhaust CO requested.

An Electronic Ignition Misfire unit that had been utilized in several previous EPA projects was used in this work assignment. This unit was described in the final report EPA-460/3-80-003.

The reference analyzer used was a Beckman 315A Infrared Analyzer appropriately configured for full scale ranges of 6,3 and 1.5 percent CO. It was determined at the start of the testing that use of the 6 percent range was adequate over all the test points. The use of a single range greatly facilitated the testing, and was felt to improve the overall integrity of the results. Use of a single range enabled concentrating on those items of greater importance and reduced elapsed time, which minimized drift for all analyzers used. The calibration curve for the reference analyzer is given in Attachment A-3.

The three exhaust gas analyzers tested included the following:

- KAL-EQUIP CO. Model 4089 (Part No. 97-3665)
- HEATHKIT Model CI-1080
- PEERLESS Model 600

Based on the copyright and other dates on the instructions provided, these analyzers are from the early 1970's. The sensing element in the Heathkit analyzer is a thermistor bead, and it is assumed that the other two analyzers also utilized thermistor beads. Such instruments using thermistors measure the overall thermal conductivity of the gas being sampled and compare those values with the thermal conductivity of air.

In the manuals provided, the accuracy of these analyzers was not given. However, with the Kal-Equip analyzer, a possible indication of accuracy was given. In a factory calibration, a tolerance of plus or minus three divisions of air fuel ratio (i.e., plus or minus 0.3 air fuel ratio) was allowed. Therefore, the tolerance on CO would be plus or minus one percent CO (e.g., 2.5 to 4.5 percent CO for a value of 3.5 percent).

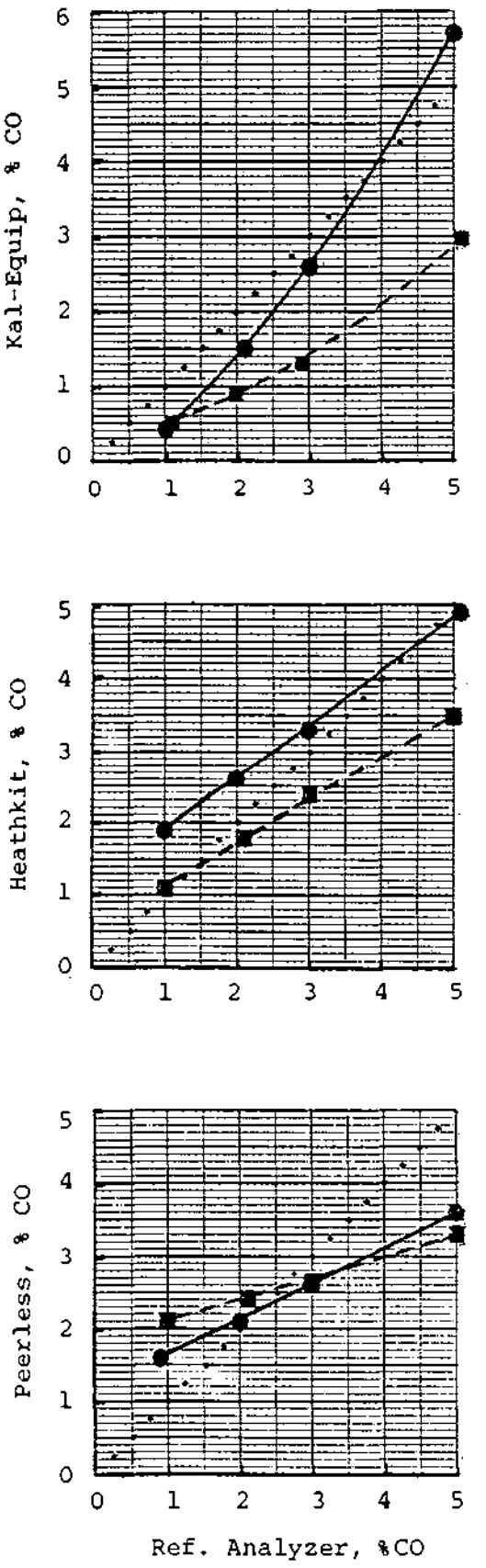
Copies of the data sheets developed and used for the evaluations conducted under this work assignment are given in Attachment A-4.

IV. TEST RESULTS

The specified exhaust CO concentrations of 1, 2, 3 and 5 percent were obtained by adjusting the carburetor idle air fuel mixture. The air pump was disconnected throughout these analyses, except when obtaining near zero concentrations of CO in the exhaust.

Results of the analyses are summarized in Attachments B-1 and B-2. The averages of the results are resummarized in Table 1 and are shown graphically in Figure 1.

The Kal-Equip analyzer was evaluated in one series of tests and the Heathkit and Peerless analyzers were evaluated simultaneously in a separate series of tests. The odd run number evaluations involved starting at the one percent CO value,and the even run number evaluations involved starting at the five percent CO values.



Legend: ● - W/O Engine Misfire ■ - 6% Engine Misfire

Figure 1. Performance of Low Cost Analyzers

TABLE 1. BRIEF SUMMARY OF RESULTS

Measured CO Values in Percent							
Ref. Anal.[a]		Kal-Equip		Heathkit		Peerless	
4"[b]	24"[b]	Base	Misfire[c]	Base	Misfire[c]	Base	Misfire[c]
0	0	--	--	1.5	--	1.5	--
1	1	0.4[d]	0.5	1.9	1.1	1.6	2.1
2	2	1.5[d]	0.9	2.6	1.8	2.1	2.4
3	3	2.6[d]	1.3	3.3	2.4	2.6	2.6
5	5	5.7[d]	3.0	4.9	3.5	3.6	3.3

[a] Set values were generally within plus or minus 0.2 of the values shown. There were no significant differences between the measured values at the two probe locations.
[b] Probe location from end of vehicle exhaust pipe.
[c] Six percent misfire setting.
[d] Next day repeat values were 0.2, 1.1, 2.1, and 4.7

For the analyses with the reference analyzer probes at 4 inches and 24 inches from the exit of the vehicle exhaust pipe, measurements of the initial position were repeated. The results were than compensated for any drift in the CO concentration. In no case was there any shift in the value when changing from one probe to the other. There was, of course, an initial blip with the first switch at each exhaust CO concentration.

The set point shifted or drifted as much as one percent CO with the Kal-Equip analyzer. A next day repeat evaluation with the Kal-Equip analyzer produced measured CO values of 0.2, 1.1, 2.1, and 4.7 percent for 1, 2, 3, and 5 percent exhaust concentrations After careful setting of the control on this analyzer, a 0.5 percent CO drift was observed after five minutes with the probe in room air.

Not shown on the summaries are the results of some added evaluations which were conducted. With essentially no CO in the exhaust, the average readings were 1.5 percent CO with the Heathkit and with the Peerless analyzers. With a calibration gas containing 9 percent CO in nitrogen, the CO readings on the Heathkit and Peerless analyzers dropped less than 0.5 percent CO from the room air set point of 3.5 percent CO (i.e., readings of about 3 percent CO).

It should be pointed out that with room air the analyzers are set to read 3.5 percent CO. With a 10.7 percent CO_2 calibration gas, the CO readings on these two analyzers were about 1 percent.

V. CLOSURE

This submission of the test results completes all of the requirements in Work Assignment 18.

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ATTACHMENTS

Statement of Work

The testing will consist of replicate measurements of vehicle exhaust at several tailpipe CO concentrations at idle, measuring simultaneously* with three low cost CO analyzers and a reference analyzer.** The CO exhaust concentrations should have values near 1%, 2%, 3%, and 5% CO such that each value can be replicated to within .03% CO (300 ppm) (the reference CO meter shall be used for determining the CO level). The low cost analyzer shall be operated per the manufacturers instructions. The reference analyzer shall measure CO at two locations; one at the same location as the shortest low cost analyzer probe, the other location shall be at least 20 inches upstream from the end of the vehicle tailpipe (to avoid tailpipe dilution). The vehicle shall have a 4- or 6-cylinder engine, and be capable of producing the CO levels indicated (more than one vehicle can be used if desired). The tests shall be run with a warmed-up vehicle. Replicate the concentrations serially, starting with ascending order, then with descending order, and so forth until five values are recorded at each level. Provide TSS with the upstream and downstream CO values for the reference analyzer; CO values from the low cost analyzers; average CO levels for each level, analyzer, and location; and the CO standard deviation for each level, analyzer, and location. Indicate the fuel type used, (Indolene or commerical). Repeat the above procedure using a misfire generator (6% misfire) and provide the same data.

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*If the tailpipe cannot contain all of the probes without distributing the flow, reduce the number of analyzers per test and repeat the test for the analyzers not tested in the first group.

**The reference analyzer shall conform to and be operated in accordance with 40 CFR 86 Subpart D (Heavy-duty raw exhaust).

II. STATEMENT OF TECHNICAL APPROACH

The approach to be taken is as follows:

- Receive the three low cost CO analyzers supplied by the EPA Technical Project Monitor.

- Check out the CO analyzers in accord with the manufacturers' instructions, which are to be provided by the EPA along with the analyzers. Analyzers meeting the requirements in the manufacturers' instructions will be used in this task; any analyzer not meeting the requirements will be dropped from further evaluation.

- Using a vehicle with a 4- or 6-cylinder engine, develop a method for obtaining tailpipe CO emissions of 1, 2, 3, and 5 percent by volume (±0.3%, or minimum variation practical). One of the following methods or a combination will be used:

  - Idle mixture adjustment

  - Intake restriction (i.e., choking)

  - Control of injected air (if and when a catalyst is used)

  It is anticipated that an oxidation catalyst-equipped car will be used for the initial evaluation.

- Tailpipe CO readings will first be taken with the low-cost analyzer having the shortest exhaust probe, and with the reference analyzer. The reference analyzer will have one probe located the same as that of the low-cost analyzer, and one probe located at least 20 inches upstream from the outlet of the tailpipe. The procedure will be as follows:

  - Warm-up the engine over an FTP, by operating at 40 mph for 15 minutes, or by equivalent operation.

  - Measure exhaust CO at idle mixtures producing approximately 1, 2, 3, and 5% CO, and then at 5, 3, 2, and 1% CO.

  - Clear the engine by operating at increased engine speeds for a few seconds, and check zero and/or spans on the instruments.

  - Repeat the measurement sequences of exhaust CO.

  - Clear the engine, zero, and span.

  - Repeat the measurement sequence of exhaust CO from the 1 through 5% values.

  - Zero and span the instruments.

  Note: Idle is generally not a stable condition, and therefore, does not generally produce stable or repeatable CO values, especially within ±0.3 at the higher CO setting.

If the CO values become more stable without clearing the engine, the clearing will be omitted. The engine idle speed will not be readjusted at the various CO levels as long as the speed remains within reasonable limits (i.e., within ±100 rpm). If found necessary, the order in which the idle CO values are measured may be altered.

- Repeat the tailpipe CO reading sequence with the remaining two low-cost analyzers (simultaneously, if practical to do so). These evaluations will include measurements with the reference analyzer at only one probe location: at least 20 inches upstream.

- Review the data to assure it appears reasonable and that there are at least four acceptable data points for each condition.

- Install the available misfire generator on a 4- or 6-cylinder engine that does not have a catalyst (can be a catalyst-equipped car on which the catalyst has been removed). With a 6 percent misfire setting, develop a method for obtaining the various tailpipe CO emission levels. Repeat the tailpipe CO reading sequence with the low-cost and reference analyzers, and review the data.

  Note: The level of effort assumes that the misfire generator still functions properly (it has not been used in approximately two years). Hydrocarbon readings may also be taken if it proves practical to do so, but any such reading will not be used in determination of validity of the data.

- Tabulate the CO data, and determine the averages and standard deviations for each combination of CO level-analyzer-probe location.

- Record identification data from the cars and the analyzers used, and determine the probe locations in the exhaust pipe. The fuel will be identified by type only; no analyses of the fuel will be conducted.

- Return or retain the low cost analyzers as subsequently requested by the EPA Tehcnical Project Monitor.

CALIBRATION CURVE FOR THE REFERENCE CO ANALYZER

CURVE FIT USING Y=X/(A+B*X+C*X**2+D*X**3)

C U G/D-2 NDIR CO S/N 201048 DANNY
5/04/1984 RANGE-1 0-6 %

A= .3140212E+02 B= -.1527510E+00 C= -.6650272E-04 D= .7999959E-07 FULL SCALE= 6.0
TABULATION USING EQUATION

METER	CONC	METER	CONC	METER	CONC	METER	CONC	METER	CONC
.50	.02	20.50	.73	40.50	1.61	60.50	2.76	80.50	4.30
1.00	.03	21.00	.75	41.00	1.64	61.00	2.79	81.00	4.35
1.50	.05	21.50	.77	41.50	1.66	61.50	2.82	81.50	4.39
2.00	.06	22.00	.79	42.00	1.69	62.00	2.86	82.00	4.44
2.50	.08	22.50	.81	42.50	1.71	62.50	2.89	82.50	4.49
3.00	.10	23.00	.83	43.00	1.74	63.00	2.93	83.00	4.53
3.50	.11	23.50	.85	43.50	1.77	63.50	2.96	83.50	4.58
4.00	.13	24.00	.87	44.00	1.79	64.00	2.99	84.00	4.63
4.50	.15	24.50	.89	44.50	1.82	64.50	3.03	84.50	4.68
5.00	.16	25.00	.91	45.00	1.84	65.00	3.06	85.00	4.73
5.50	.18	25.50	.93	45.50	1.87	65.50	3.10	85.50	4.77
6.00	.20	26.00	.95	46.00	1.90	66.00	3.13	86.00	4.82
6.50	.21	26.50	.97	46.50	1.92	66.50	3.17	86.50	4.88
7.00	.23	27.00	.99	47.00	1.95	67.00	3.21	87.00	4.93
7.50	.25	27.50	1.01	47.50	1.98	67.50	3.24	87.50	4.98
8.00	.27	28.00	1.03	48.00	2.01	68.00	3.28	88.00	5.03
8.50	.28	28.50	1.06	48.50	2.03	68.50	3.32	88.50	5.08
9.00	.30	29.00	1.08	49.00	2.06	69.00	3.35	89.00	5.13
9.50	.32	29.50	1.10	49.50	2.09	69.50	3.39	89.50	5.19
10.00	.33	30.00	1.12	50.00	2.12	70.00	3.43	90.00	5.24
10.50	.35	30.50	1.14	50.50	2.15	70.50	3.47	90.50	5.29
11.00	.37	31.00	1.17	51.00	2.17	71.00	3.51	91.00	5.35
11.50	.39	31.50	1.19	51.50	2.20	71.50	3.54	91.50	5.40
12.00	.41	32.00	1.21	52.00	2.23	72.00	3.58	92.00	5.46
12.50	.42	32.50	1.23	52.50	2.26	72.50	3.62	92.50	5.52
13.00	.44	33.00	1.26	53.00	2.29	73.00	3.66	93.00	5.57
13.50	.46	33.50	1.28	53.50	2.32	73.50	3.70	93.50	5.63
14.00	.48	34.00	1.30	54.00	2.35	74.00	3.74	94.00	5.69
14.50	.50	34.50	1.32	54.50	2.38	74.50	3.78	94.50	5.75
15.00	.52	35.00	1.35	55.00	2.41	75.00	3.83	95.00	5.81
15.50	.53	35.50	1.37	55.50	2.44	75.50	3.87	95.50	5.87
16.00	.55	36.00	1.39	56.00	2.47	76.00	3.91	96.00	5.93
16.50	.57	36.50	1.42	56.50	2.50	76.50	3.95	96.50	5.99
17.00	.59	37.00	1.44	57.00	2.53	77.00	3.99	97.00	6.05
17.50	.61	37.50	1.47	57.50	2.57	77.50	4.04	97.50	6.11
18.00	.63	38.00	1.49	58.00	2.60	78.00	4.08	98.00	6.18
18.50	.65	38.50	1.51	58.50	2.63	78.50	4.12	98.50	6.24
19.00	.67	39.00	1.54	59.00	2.66	79.00	4.17	99.00	6.30
19.50	.69	39.50	1.56	59.50	2.69	79.50	4.21	99.50	6.37
20.00	.71	40.00	1.59	60.00	2.73	80.00	4.26	100.00	6.43

CURVE FIT USING Y=X/(A+B*X+C*X**2+D*X**3)

C U G/D-2 NDIR CO S/N 201048 DANNY
5/04/1984 RANGE-1 0-6 %

A= .3140212E+02 B= -.1527510E+00 C= -.6650272E-04 D= .7999959E-07
X Y-G.S. Y-CALC. PCT. OF PT. PCT.FULL SCALE

X	Y-G.S.	Y-CALC.	PCT. OF PT.	PCT.FULL SCALE
25.300	.920	.920	-.014	-.002
53.100	2.300	2.297	.124	.044
73.700	3.700	3.719	-.524	-.301
83.700	4.630	4.599	.660	.475
93.000	5.560	5.574	-.247	-.213

LOW COST I/M ANALYZER STUDY
SwRI Project 03-7338-018

Date _____ By _____

ANALYZERS:

Calibration Check O.K.:

KAL-EQUIP ☐
. Connect to Battery
. Adj. Set Control
Yes ☐ No ☐

HEATHKIT ☐
. Connect to Battery
. Balance Meter
Yes ☐ No ☐

PEERLESS ☐
. Balance Meter
. Adj. Set Pointer
. Turn ON and Balance
. Adj. Set every 15 min.
Yes ☐ No ☐

AUTOMOBILE:

Year 1981 Make Ford Model Mustang
Engine CID 2.3 Liter Catalyst: None ☐ Oxid. ☐ 3-Way ☒
Fuel Used: Unleaded Gasoline

CO MEASUREMENTS IN PERCENT:

Misfire Setting: None ☐ 6% ☐

. Warm-up engine - 15 minutes at 40 mph, or equivalent.

Set % CO*	Ref. Anal. 4"	Ref. Anal. 24"	Kal-Equip	Ref. 24"	Heath-Kit	Peer-less			
1									
2									
3									
4									
5									
5									
4									
3									
2									
1									

* ±0.3%, or minimum variation practical.

Continued

- Misfire Setting: None ☐ 6% ☐

. Clear Engine at increased speed.
. Check calibration of all instruments

Set % CO*	Ref. Anal. 4"	Ref. Anal. 24"	Kal-Equip.	Ref. 24"	Heath-kit	Peer-less			
1									
2									
3									
4									
5									
5									
4									
3									
2									
1									

. Clear Engine at increased speed.
. Check calibration of all instruments.

Set % CO*	Ref. Anal. 4"	Ref. Anal. 24"	Kal-Equip.	Ref. 24"	Heath-kit	Peer-less			
I									
2									
3									
4									
5									
5									
4									
3									
2									
1									

. Check calibration of all instruments.

*± 0.3%, or minimum variation practical.

RESULTS WITHOUT IGNITION MISFIRE

LOW COST I/M ANALYZER CO RESULTS

Misfire Setting: None [X] 6% [ ]

	Ref. Anal. at 4"					Ref. Anal. at 24"					Kal-Equip.				
Set % CO	1	2	3		5	1	2	3		5	1	2	3		5
Run 1	1.1	2.0	3.1		4.8	1.1	2.0	3.1		4.8	0.7	1.8	3.0		6.0
Run 2	0.9	2.1	3.0		4.8	0.9	2.1	3.0		4.8	0.9	2.2	3.1		5.9
Run 3	1.0	2.2	3.0		5.1	1.0	2.2	3.0		5.1	<0.0	1.2	2.1		5.1
Run 4	0.8	2.0	3.1		5.0	0.8	2.0	3.1		5.0	<0.0	1.0	2.3		5.0
Run 5	1.1	2.2	3.1		5.2	1.1	2.2	3.1		5.2	0.0	1.2	2.6		6.0
Run 6	1.0	2.0	2.8		5.2	1.0	2.0	2.8		5.2	0.5	1.6	2.7		6.2
Average	1.0	2.1	3.0		5.0	1.0	2.1	3.0		5.0	0.4	1.5	2.6		5.7
Std. Dev.	0.1	0.1	0.1		0.2	0.1	0.1	0.1		0.2	0.4	0.5	0.4		0.5

	Ref. Anal. at 24"					Heathkit					Peerless				
Set % CO	1	2	3		5	1	2	3		5	1	2	3		5
Run 1	0.8	1.8	3.0		5.0	2.0	2.7	3.4		4.7	1.5	1.5	2.5		3.5
Run 2	0.9	2.1	3.0		5.3	1.9	2.6	3.4		5.0	1.6	2.3	2.7		3.7
Run 3	1.1	2.0	2.9		5.0	1.9	2.4	3.1		4.7	1.6	2.0	2.5		3.5
Run 4	0.9	1.9	3.0		5.1	2.1	2.6	3.6		5.4	1.8	2.3	2.8		3.8
Run 5	1.1	2.1	3.2		5.2	1.6	2.4	3.2		4.7	1.6	2.1	2.6		3.5
Run 6	0.8	2.0	3.0		5.1	2.0	2.7	3.3		4.7	1.6	2.1	2.5		3.4
Average	0.9	2.0	3.0		5.1	1.9	2.6	3.3		4.9	1.6	2.1	2.6		3.6
Std. Dev.	0.1	0.1	0.1		0.1	0.2	0.1	0.2		0.3	0.1	0.3	0.1		0.2

RESULTS WITH IGNITION MISFIRE

LOW COST I/M ANALYZER CO RESULTS

Misfire Setting: None [ ] 6% [X]

	Ref. Anal. at 4"					Ref. Anal. at 24"					Kal-Equip.				
Set % CO	1	2	3		5	1	2	3		5	1	2	3		5
Run 1						1.2	2.1	2.9		5.0	0.0	0.6	1.0		3.0
Run 2						1.0	2.0	3.0		4.9	0.8	0.8	1.0		2.9
Run 3						1.2	2.1	2.8		5.2	0.1	0.3	0.8		2.7
Run 4						1.1	1.9	2.9		5.2	0.5	0.9	1.5		3.0
Run 5						1.2	2.0	2.9		5.2	0.8	1.0	1.2		3.1
Run 6						1.0	1.9	2.8		5.1	1.0	1.7	2.0		3.2
Average						1.1	2.0	2.9		5.1	0.5	0.9	1.3		3.0
Std. Dev.						0.1	0.1	0.1		0.1	0.4	0.5	0.4		0.2

	Ref. Anal. at 24"					Heathkit					Peerless				
Set % CO	1	2	3		5	1	2	3		5	1	2	3		5
Run 1	1.1	2.1	3.1		5.0	0.6	2.5	3.0		3.8	2.0	2.4	2.7		3.3
Run 2	1.0	2.0	3.0		4.8	0.5	1.2	2.5		3.4	2.0	2.3	2.6		3.3
Run 3	1.0	2.1	3.1		5.1	0.9	1.6	2.2		3.5	2.0	2.4	2.6		3.2
Run 4	1.0	2.0	3.1		5.1	2.0	2.2	2.5		3.5	2.1	2.4	2.7		3.2
Run 5	1.0	2.0	3.0		5.1	1.0	1.8	2.2		3.3	2.2	2.3	2.6		3.2
Run 6	1.1	2.1	2.9		5.1	1.3	1.5	2.0		3.5	2.1	2.4	2.6		3.3
Average	1.0	2.1	3.0		5.0	1.1	1.8	2.4		3.5	2.1	2.4	2.6		3.3
Std. Dev.	0.1	0.1	0.1		0.1	0.6	0.5	0.4		0.2	0.1	0.1	0.1		0.1