Appendix III – Supplemental Information for Aim 3

Particle Size – Cigarette Smoke vs. Wildfire Smoke

Data from many combustion studies have demonstrated that the particle size of combustion-generated particles is on the order of 300 µm. A typical size distribution for particles during a wildfire event is shown below (Figure 1). Thus, even though conventional occupational PM samples collect particles with aerodynamic cut size of 3.5 µm, most of the wildfire smoke exposure is to submicron particles. This compares well to smoke from burning cigarette tobacco. When the size distribution of particles from wildfire smoke was measured using both an optical particle counter and a differential mobility analyzer, the mass median particle diameter was about 300 nm. As shown in Figure 1, the median diameter of smoke from a conventional cigarette is about 250 nm, which is similar to that of wildfire smoke particles.

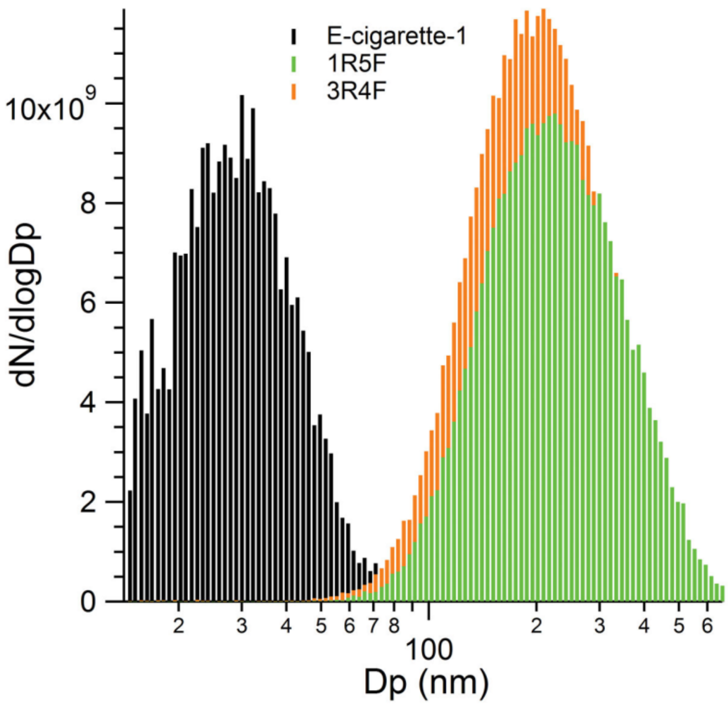


Figure 1 Particle size distribution observed after injecting a single puff of smoke from conventional cigarettes (1R5F, 3R4F) or an e-cigarette in a Teflon™ chamber filled with zero air.

Conclusion: Cigarette smoke exposure is comparable to wildfire smoke exposure with respect to particle size.

Breathing Rate Calculation for Wildland Firefighters

A survey of respiratory rates and heart rates were measured for wildfire fighters doing different tasks during operations. The data are summarized in Table 1. Activity codes were grouped into relevant tasks.

Table 1. Description of Activity Code groupings and number of wildland firefighters (WLFFs) and repeated measures in each grouping.

Task Code	Task Code Labels	Activity Codes	Activity Code Labels	Obs	WLFFs
1	Handline (direct)	1,3,6,7,13,31,55,56,57	handline direct scratch, handline direct swamper, handline direct squad, handline direct firefighter, improving direct line, initial attack, working with aviation, scouting hazard trees, grid the black	7064	75
2	Handline sawyer (direct)	2,53,54	handline direct sawyer, felling sawyer, felling swamper	2317	34
3	Pump Op	5,20,21	handline direct pump operator, engine pump operator, holding pump	495	13
4	Mop Up	8,12	mop up, cold trailing	10823	67
5	Handline (Indirect)	14,22,24,26,27,28,30,58,59,60	improving indirect line, handline indirect scratch, handline indirect swamper, handline indirect pump, handline indirect squad, handline indirect firefighter, Line prep, grid the green, structure protection, medical event	8384	59
6	Holding	15,16,17,18,19,37,40	holding direct line, holding indirect line, holding firefighter, holding squad, holding engine, rx holder, suppression holder	11028	59
7	Handline sawyer (Indirect)	23	handline sawyer indirect	1186	13
8*	Dozer Boss	29	handline indirect dozer boss	20	1
9	Lighting	36,39	rx lighter, suppression lighter	2466	18
10	Project	44,45,61,62,64	project saw, project stacking, staging, compound work, station/compound work	20328	109
11	Briefing	46	briefing	4770	176
12	Training	99	training (medical scenario)	213	2
13	ICP	32,35	ICP stationary, ICP other	3490	58
14	PT	43	PT	2652	36
15	Hiking	48	hiking	8711	158
16	Standby	49,50,51,52,63	lunch break, rest break, operational break, refurb tools, tool up/tool down	38212	208
17	Driving	47	driving	21859	199
Total				**144,018**	**208**

* Moved Task Code = 8 to Task Code = 5 since there was only one firefighter and 20 observations for "Dozer Boss".

Generalized estimating equations were used to estimate mean (95%CI) heart rate and respiratory rate, accounting for clustering of repeated observations on the same wildland firefighter. An exchangeable correlation structure was selected for this analysis although results were not sensitive to this decision.

Table 2. Mean heart rate and respiratory rate by task grouping.

	Heart Rate (beats / minute)				Respiratory Rate (breaths / minute)			
Task	Estimate	SE	lower 95% CI	upper 95% CI	Estimate	SE	lower 95% CI	upper 95% CI
1	107.27	1.85	103.65	110.90	30.22	0.73	28.79	31.64
2	120.73	2.69	115.45	126.00	34.20	0.84	32.55	35.85
3	92.38	3.06	86.38	98.39	24.46	1.15	22.22	26.71
4	103.30	1.72	99.93	106.66	29.23	0.59	28.08	30.39
5	109.71	2.88	104.06	115.37	31.75	0.72	30.35	33.16
6	90.07	2.04	86.07	94.06	23.13	0.67	21.82	24.44
7	126.25	2.44	121.46	131.03	35.35	0.87	33.64	37.06
9	113.79	4.06	105.83	121.75	31.77	1.37	29.09	34.44
10	91.30	1.71	87.95	94.65	25.07	0.62	23.85	26.29
11	88.00	1.01	86.03	89.97	23.40	0.39	22.64	24.16
12	111.90	6.99	98.20	125.59	31.47	3.64	24.34	38.59
13	85.52	2.18	81.24	89.79	24.07	0.76	22.58	25.57
14	127.10	3.21	120.82	133.39	37.29	1.20	34.93	39.65
15	123.51	1.47	120.63	126.39	35.59	0.59	34.44	36.74
16	89.86	0.95	88.00	91.72	23.81	0.30	23.22	24.40
17	83.00	0.97	81.10	84.91	23.35	0.44	22.48	24.21

Heart rate and respiratory rate are linearly related. For the purpose of this project we will use the measured RR, however for other studies where only HR data are available one could use the linear relationship developed here to estimate RR.

Table 3 Regression Analysis (HR vs. Ve)

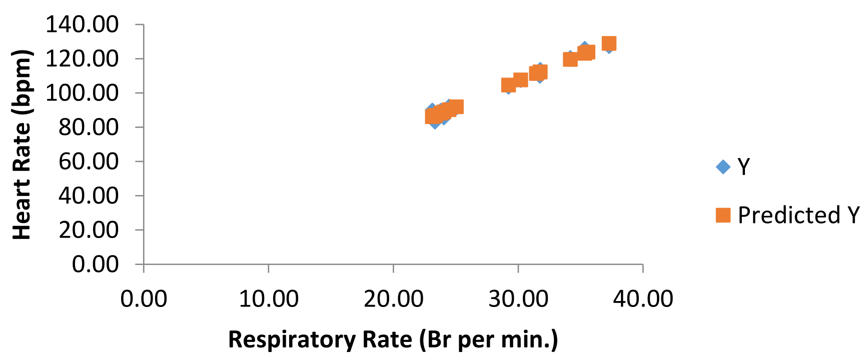
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.989379
R Square	0.97887
Adjusted R Square	0.977361
Standard Error	2.337428
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3543.56	3543.56	648.5798	3.98E-13
Residual	14	76.48996	5.463568		
Total	15	3620.05			

Fig. 2 HR and RR are Linearly Related



	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	16.24573	3.49422	4.649316	0.000376	8.751377	23.74009	8.751377	23.74009
X Variable 1	3.024298	0.118753	25.46723	3.98E-13	2.769599	3.278997	2.769599	3.278997

The reported heart and respiratory rates are lower than one would suppose for most individuals presumably performing reasonably heavy labor. By comparison they were comparable to those measured for a trained athlete performing exercise at a relatively mild level (e.g. walking on a treadmill at 10.8 km hr^{-1})[54]. However, firefighters are expected to work at these levels for the duration of a shift and they are conditioned to be able to perform under the conditions of the job. However, in order to calculate exposure amounts (exposure concentration x amount of air inhaled), it was necessary to develop an estimate of breathing rate (minute ventilation (Ve, L air inhaled per breath)). Although we have heart rate and RR data from actual measurements with firefighters, minute ventilation data was not measured. We have therefore developed a linear equation to estimate Ve from HR.

Table 4

Heart Rate	Ve	Data Source
60	6	1
70	7	1
75	11	1
100	20	1
125	31	1
150	43	1
175	56	1
75	12	2
80	18	2
100	20	2
120	25	2
130	28	2

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9789134
R Square	0.9582715
Adjusted R Square	0.9540986
Standard Error	3.187562
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2333.311151	2333.311	229.6441	3.1693E-08
Residual	10	101.6055156	10.16055		
Total	11	2434.916667			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-19.936451	2.984243834	-6.68057	5.5E-05
Heart Rate	0.4097122	0.027036548	15.15401	3.17E-08

Data source: 1=Wallaart (1997)[55]; 2=Vai et al. (1988)[56]

Table 5 Breathing Rate (Ve) by Task

Heart Rate (beats per minute)	Average Ventilation

Task	Estimate	SE	lower 95% Cl	upper 95% CI	Mean Ve (L min-1)	SE
1	107.27	1.85	103.65	110.90	23.97	0.76
2	120.73	2.69	115.45	126.00	29.48	1.10
3	92.38	3.06	86.38	98.39	17.88	1.25
4	103.30	1.72	99.93	106.66	22.34	0.70
5	109.71	2.88	104.06	115.37	24.97	1.18
6	90.07	2.04	86.07	94.06	16.93	0.84
7	126.25	2.44	121.46	131.03	31.74	1.00
9	113.79	4.06	105.83	121.75	26.64	1.66
10	91.30	1.71	87.95	94.65	17.43	0.70
11	88.00	1.01	86.03	89.97	16.08	0.41
12	111.90	6.99	98.20	125.59	25.86	2.86
13	85.52	2.18	81.24	89.79	15.07	0.89
14	127.10	3.21	120.82	133.39	32.09	1.32
15	123.51	1.47	120.63	126.39	30.62	0.60
16	89.86	0.95	88.00	91.72	16.84	0.39
17	83.00	0.97	81.1	84.91	14.04	0.40

Table 6 - Wildland Firefighter Estimated Shift Dose of $PM_{2.5}$

We used Eq. 1 from above to calculate a shift dose of $PM_{2.5}$ for each fire type across different career lengths.

Fire Event	**Duration (hrs)**	**Days worked per year**	**Shift Exposure (mg/m3)**		**Breathing Rate (L/min)**
	Shift		**Mean**	**95% UCL**	
Prescribed Burn	10.5	5	0.48	0.72	20
Prescribed Natural Fire	13.6	64	0.2	0.3	23
Fire Project Crew	13.6	64	0.51	0.64	24
Initial Attack	12.4	64	0.15	0.2	25
Project Fire Manager	14.5	64	0.16	0.21	16

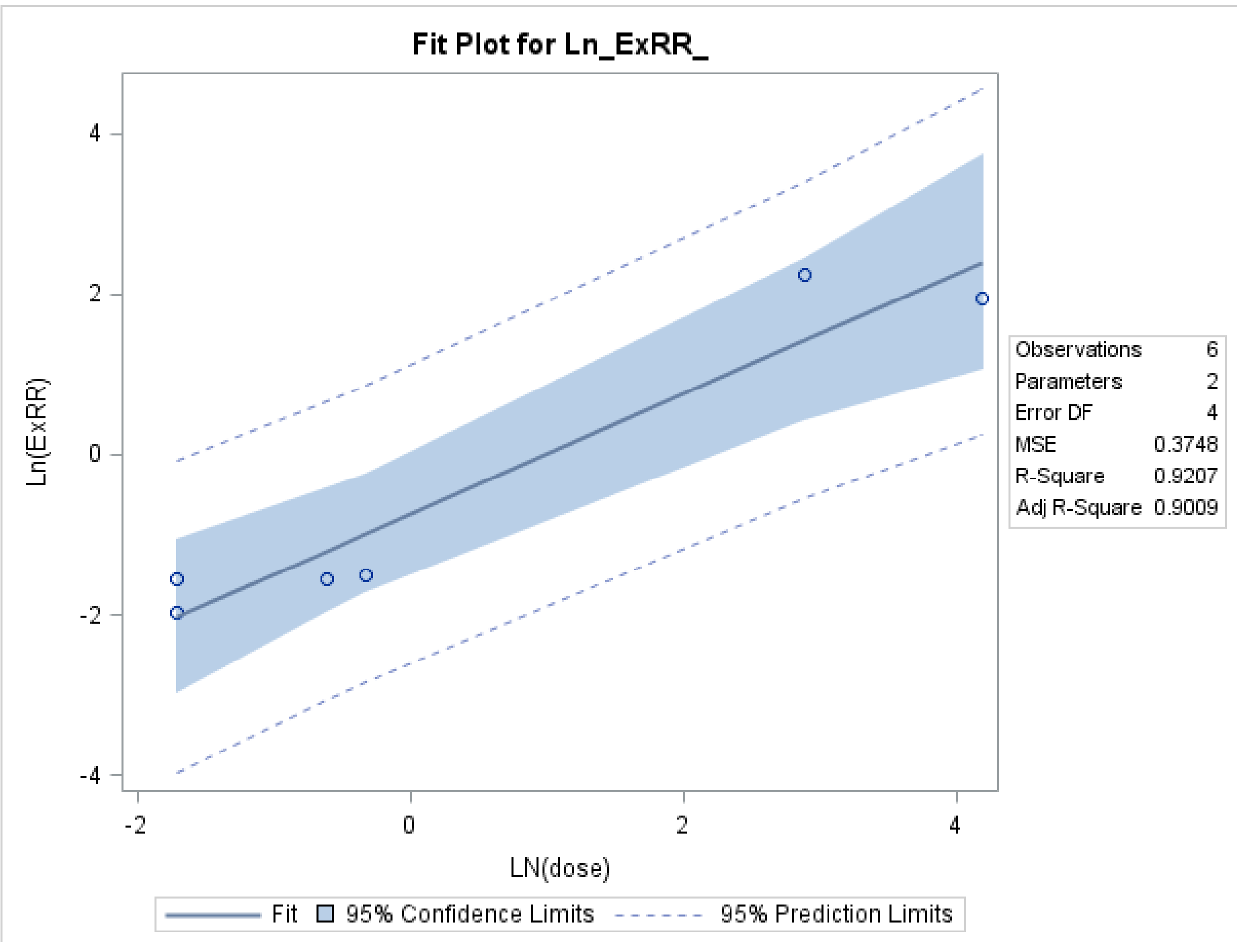
Derivation of Relative Risk Power Function

Lung Cancer

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	**1**	-0.73869	0.25481	-2.9	0.0442
LN_dose_	LN(dose)	**1**	0.74869	0.10986	6.81	0.0024

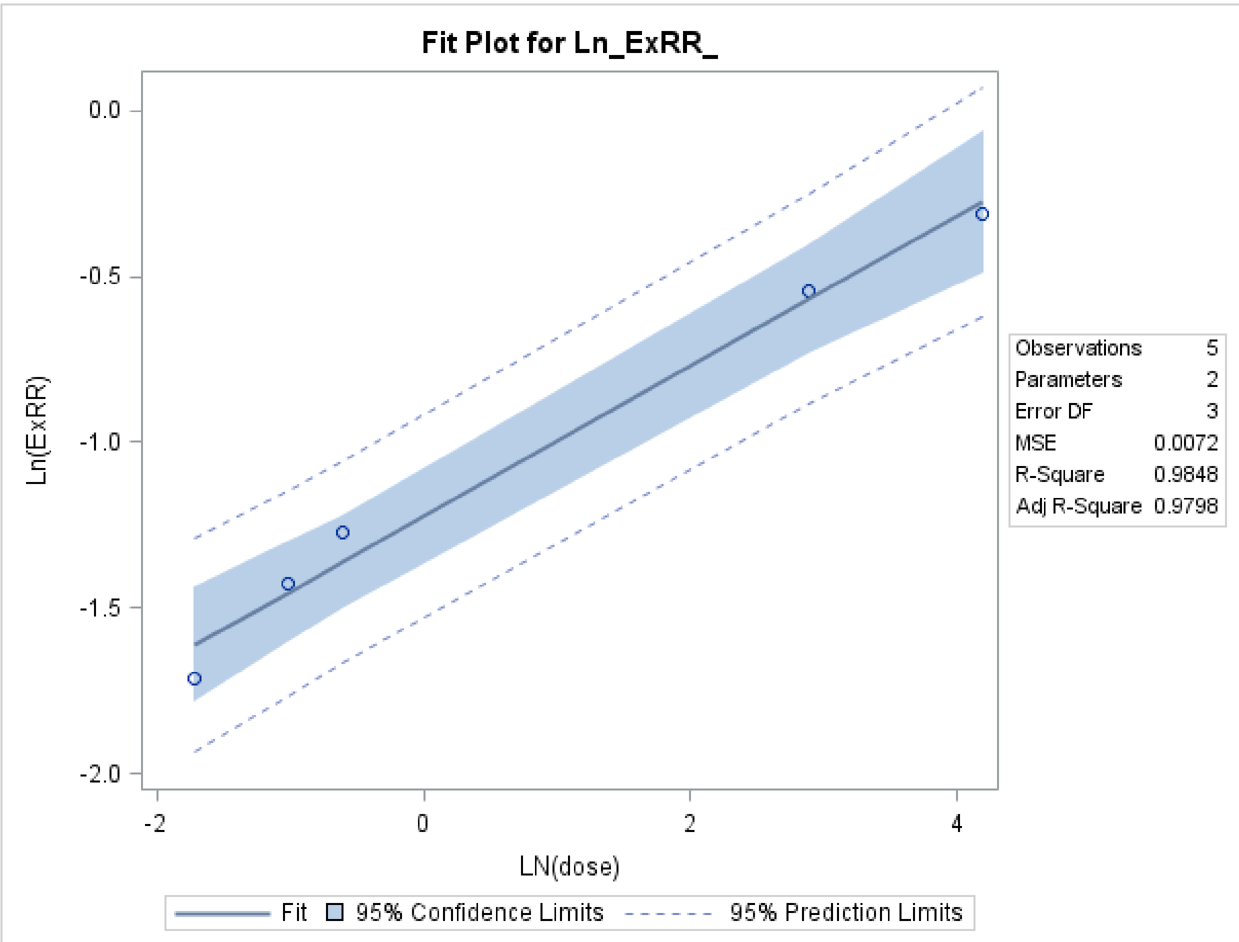
power	0.74869
constant	0.477739344



Ischemic Heart Disease

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	-1.22357	0.03988	-30.68	<.0001
LN_dose_	LN(dose)	**1**	0.22631	0.01621	13.96	0.0008

Power	0.22631
Constant	0.294178074



Cardiovascular Disease

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	-1.29286	0.12282	-10.53	0.0001
LN_dose_	LN(dose)	**1**	0.23565	0.05432	4.34	0.0074