

# Integrated Duty Cycle Protocol

12/11/2017

# Overarching Goals

- Protocol Goals
  - Reflect typical loading patterns
  - Reflect typical operating patterns
  - Address variability by completing multiple runs of the same protocol
- Meeting Goals
  - Timeline development
  - Identify areas that need data from research runs
  - Identify areas of consensus

# Protocol Overview

- Compress entire protocol into a single day test
  - Burn phases: startup, high, medium, medium-low transition, and low
    - Phases attempt to reflect common daily user practices such as start-up and reloads.
    - Phases end when 90% of fuel charge is burned.
    - Three reloads during the protocol, with different coal bed weights.
  - Piece sizes vary with phase:
    - Start-up kindling and starter – 4 lb/ft<sup>3</sup>
    - High-fire: small pieces – 5 lb/ft<sup>3</sup>
    - Medium-fire: large pieces – 7 lb/ft<sup>3</sup>
    - Low-fire: mix of small and medium pieces – based on firebox capacity – min of 9 lb/ft<sup>3</sup>

# Changes from last iteration

- Operational protocol limited changes
  - Provide a range for coal bed weights for reload. Need to discuss what a reasonable range is and how to apply.
- Fueling protocol – major changes
  - Addressed typos that changed meaning in last iteration
  - Created draft fueling calculator
    - De minimus kindling for small stoves of 1 lb. Thoughts on maximum amount?
    - Changed target load piece sizes based on density of fuel used.

# Testing/Research at HLS

## Six stoves

1. High mass construction, large firebox, tube/non-cat emission controls
2. High mass construction, small firebox, catalytic emission controls
3. Steel construction, large firebox, catalytic emission controls
4. Cast iron construction, small firebox, tube/non-cat emission controls
5. Cast iron construction, medium firebox, non-cat/non-tube emission controls (this is likely a top loading unit)
6. Steel construction, medium firebox, tube/non-cat emission controls



Birch – start-up, high and medium fuel charge





Maple – start-up, high and medium fuel charge





Oak – start-up, high and medium fuel charge



# Issues Raised on IDC test method

- Fuel loading parameters
  - Configuration laid out in test method or manufacturers instructions?
- Is it really one day, does it save time? Need to consider time for pre-burns that are used in M28
  - Timing analysis for medium stove
    - M28 ~1780 minutes of burning – one preburn
    - 3 runs of IDC ~1300 minutes of burning
- What is the passing grade?
  - Ending test at 90% cuts test run at each phase by 30-50%
- How do measure efficiency?
  - Move in the direction of ASHRAE standards or use TCC methods

# Start Up Phase





Start-up load, large firebox – Washington State Protocol





Start-up load, medium firebox – Washington State Protocol

A photograph showing a firebox filled with kindling. The kindling consists of various thin, light-colored wooden sticks and branches, some with bark, piled together. The firebox is dark, and the background is dark. The text "Kindling – 2 lb/ft³" is overlaid at the bottom.

Kindling – 2 lb/ft<sup>3</sup>



# Comparison of Start Up Phase Data

Run Species	Burn Rate (g/kg)	Time (min)	PM (g)	Load (#)	PM (g/hr) @90%	PM EF (g/kg) @90%
4/7 –Maple	<u>3.5</u>	38	2.7	7.9	4.26	1.22
4/25 – Maple	2.3	58	6.65	7.8	6.88	2.99
4/26 – Maple	2.6	48	3.05	7.8	3.81	1.47
4/18 – Birch	2.0	65	5.47	7.7	5.05	2.52
4/29 – Birch	1.8	72	3.99	7.8	3.33	1.85
5/4 – Birch	2.4	55	6.57	7.8	7.17	2.99
Oak	<u>3.4</u>	40	11.6	7.9	<u>16.9</u>	<u>3.7</u>
Ash	2.9	44	4.4	7.6	6.2	2.1
Range	1.8 - 3.5	38 - 72	2.7 - 11.6	7.6 - 7.9	3.33 - 16.9	1.22 - 3.7
3 ft maple	3.7	57	9.98	12.3	10.51	2.84
3 ft ash	4.5	44	10.3	11.7	14.05	3.12



# Start Up Phase Discussion Items

- Loading density
  - Amount of kindling
  - Starter fuel
  - Capacity to use in a wide variety of stoves sizes and configurations
- Load configuration
  - Manufacturers instructions
  - Prescribed conditions
- End of Phase
  - Questions about size of coal bed to light off high fire

Integrated Duty Cycle Test Method

# **HIGH FIRE PHASE**





# High Fire Discussion Items

- Timing of placing the high fire load
  - It appears that wood could loaded earlier
- Amount of wood loaded
  - 5lbs per ft<sup>3</sup> - is it enough? What happens to timing?

# Comparison of High Fire Phase Data

Run Species	Burn Rate (g/kg)	Time (min)	PM (g)	Load (#)	PM (g/hr) @90%	PM EF (g/kg) @90%
M28/10 Doug Fir	2.47	144	9.58	15.68	3.99	1.62
M28/90 Doug Fir	3.48	93	9.58	15.68	6.18	1.78
4/7 –Maple	3.0	61	6.0	9.3	5.90	1.97
4/25 – Maple	2.4	78	3.17	9.5	2.44	1.02
4/26 – Maple	3.3	55	4.17	9.8	4.55	1.38
4/18 – Birch	3.3	59	6.08	9.8	6.18	1.87
4/29 – Birch	3.6	54	7.15	9.9	3.33	1.85
5/4 – Birch	<u>4.1</u>	47	5.96	9.8	<u>7.61</u>	1.86
Oak	3.6	52	5.7	9.4	6.2	1.7
Ash	3.0	69	<u>8.0</u>	<u>10.2</u>	6.9	<u>2.3</u>
Range med stove	2.4 - 4.1	47 - 78	3.17 – 8.0	9.3 – 10.2	2.44 – 7.61	1.02 – 2.3
3 ft maple	3.9	74	2.98	15.0	2.42	0.62
3 ft ash	3.4	84	6.02	14.7	4.30	1.26

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# **MEDIUM FIRE PHASE**



# Medium Fire Phase

Run Species	Burn Rate (g/kg)	Time (min)	PM (g)	Load (#)	PM (g/hr)	PM EF (g/kg)
M28 Doug Fir	2.49	154	4.85	15.66	1.89	0.76
	2.08	155	4.79	15.64	1.86	0.89
4/7 Maple	2.9	88	6.2	13.3	4.23	1.46
4/25 Maple	2.3	117	<u>12.7</u>	13.6	6.51	<u>2.83</u>
4/26 Maple	2.1	<u>125</u>	7.77	14.0	3.73	1.78
4/18 Birch	2.9	90	4.45	13.0	2.97	1.02
4/29 Birch	2.8	95	5.34	13.6	3.38	1.2
5/4 Birch	3.4	82	5.18	14.0	3.79	1.11
Oak	<u>3.6</u>	52	5.7		6.2	1.7
Ash	3.0	69	8.0		<u>6.9</u>	2.3
Range	2.1 – 3.6	52-125			2.97 – 6.9	1.02 – 2.83
3 ft maple	3.9	74	2.98	15.0	2.42	0.62
3 ft ash	3.4	84	6.02	14.7	4.30	1.26

# Medium Fire Discussion Items

- Transition to low burn
- Fuel adjustments

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# **LOW FIRE PHASE**



Coal bed before load low added





Birch – low load pile, all but two small pieces were loaded

# Low Fire Phase Data

Stove size	Species	Rate (kg/h)	Time (Min)	PM (g)	Load (#)	PM (g/hr)	PM EF (g/kg)
2 ft <sup>3</sup>	M28 doug fir – 100%	1.13	315	24.0	15.6	4.57	4.05
2 ft <sup>3</sup>	M28 doug fir – 90%	1.55	208	24.0	15.6	6.92	4.46
2 ft <sup>3</sup>	Oak	1.9	209	NA	20.5	13.7	6.4
2 ft <sup>3</sup>	Ash	1.5	364	NA	28.0	7.1	4.6
2 ft <sup>3</sup>	Birch	1.8	223	35.6	20.4	9.58	5.32
2 ft <sup>3</sup>	Birch	2.0	193	59.8	20.6	18.57	9.30
2 ft <sup>3</sup>	Birch	1.7	200	17.6	17.7	5.28	3.11
2 ft <sup>3</sup>	Maple	1.8	219	31.4	20.1	8.60	4.78
2 ft <sup>3</sup>	Maple	2.0	168	12.8	17.0	4.57	2.29
2 ft <sup>3</sup>	Maple	1.5	208	32.3	17.7	9.32	6.21
2ft	Range	1.5 – 2.0	168 – 364		17.0 – 28.0	4.57 – 18.57	2.29 – 9.30
3ft <sup>3</sup>	Maple	1.5	479	156	36.5	19.54	13.03
3 ft <sup>3</sup>	Ash	1.8	484	121	44.0	15.0	8.33

# Comparison of Low-Fire Phase

## 90 vs 100

Run Species	Burn Rate (g/kg)	Time (min)	PM (g)	Load (#)	PM (g/hr) @90%	PM EF (g/kg) @90%
M28 Doug Fir	1.55	208	24	15.6	6.92	4.46
	1.33	315	24	15.6	4.57	4.05
4/7 Maple	1.8	219	31.4	20.1	8.60	4.78
	1.1	411	31.4	20.1	4.58	4.17
4/25 Maple	2.0	168	12.8	17.0	4.57	2.29
	1.1	340	12.8	17.0	2.26	2.05
4/26 Maple	1.5	208	32.3	17.7	9.32	6.21
	1.1	321	32.3	17.7	6.04	5.49
4/18 Birch	1.8	223	35.6	20.4	9.58	5.32
	1.1	420	35.6	20.4	5.09	4.62
4/29 Birch	2.0	193	59.8	20.6	18.57	9.30
	1.1	404	59.8	20.6	8.89	8.07
5/4 Birch	1.7	200	17.6	17.7	5.28	3.11
	1.1	342	17.6	17.7	3.09	2.57

# **FULL RUN ANALYSIS**



# Analysis Full Runs

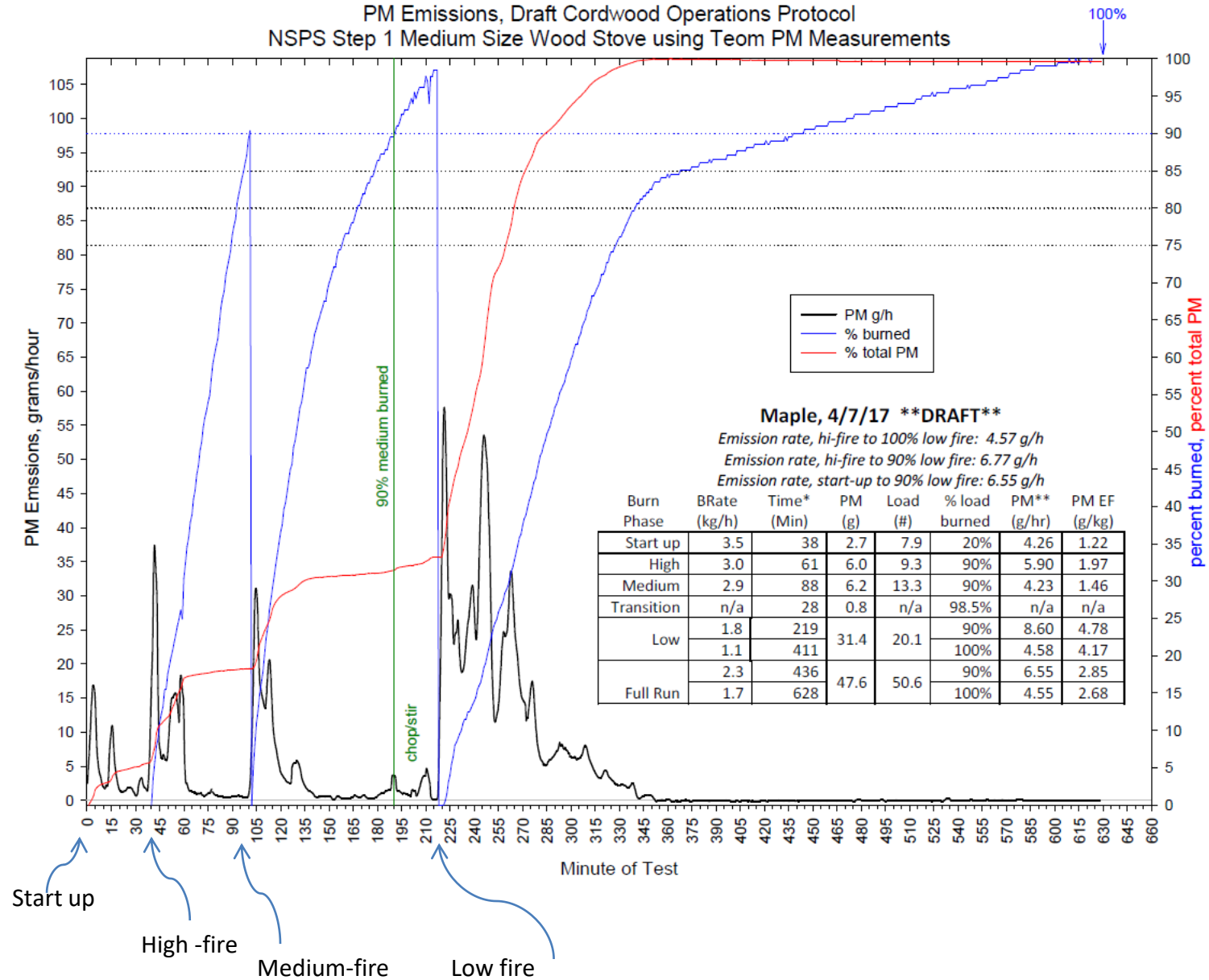
## Birch

Run	Burn Rate (g/kg)	Time (min)	PM (g)	Load (#)	PM (g/hr)	PM EF (g/kg)
4/18	2.2	460	51.7	50.9	6.74	3.07
4/29	2.3	430	76.6	51.8	11.38	4.95
5/4	2.5	392	35.3	49.3	5.40	2.16

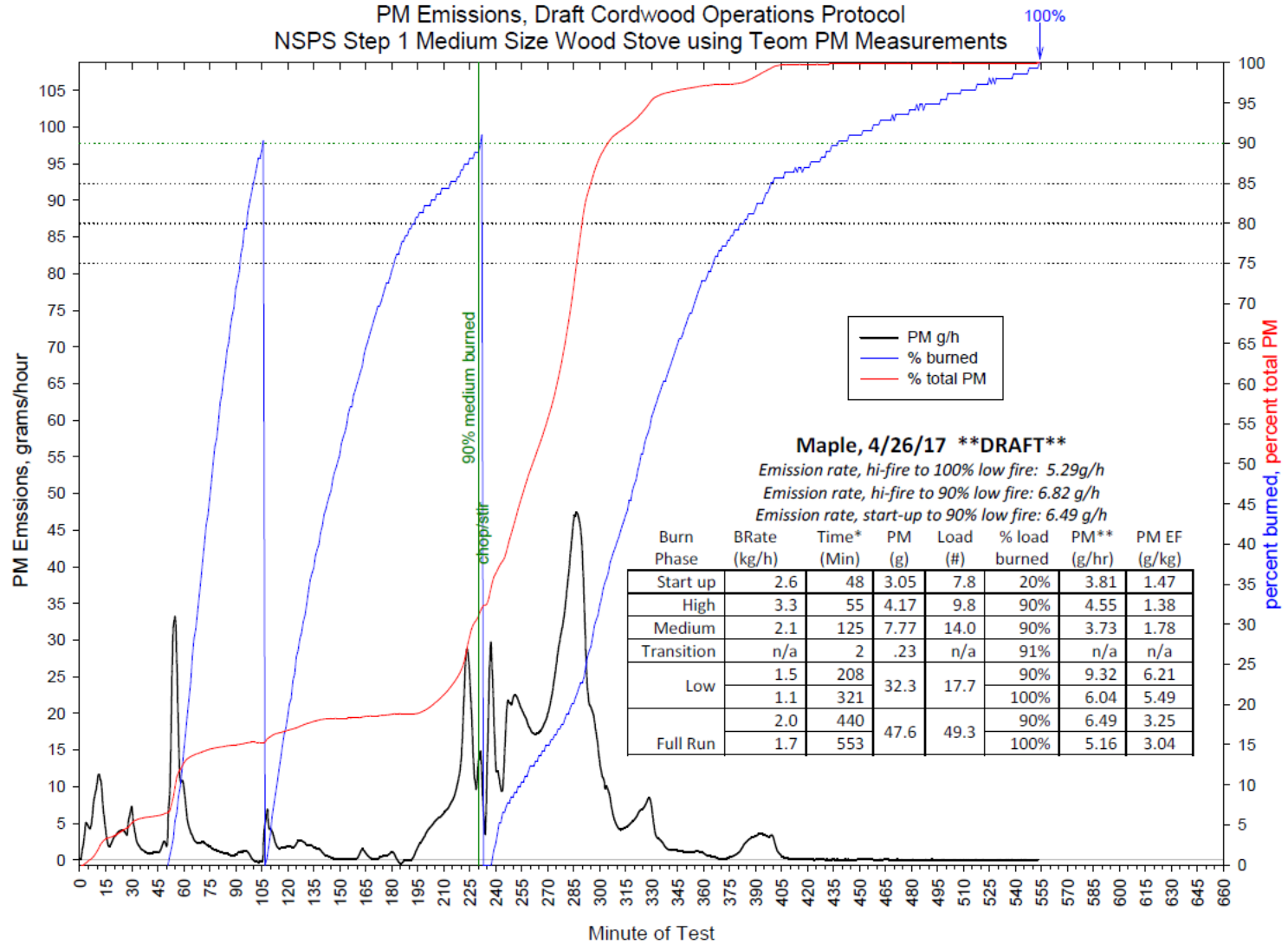
## Maple

Run	Burn Rate (g/kg)	Time (min)	PM (g)	Load (#)	PM (g/hr)	PM EF (g/kg)
4/7	2.3	436	47.6	50.5	6.55	2.85
4/25	2.2	432	35.6	47.9	4.94	2.25
5/4	2.0	440	47.6	49.3	6.49	3.25

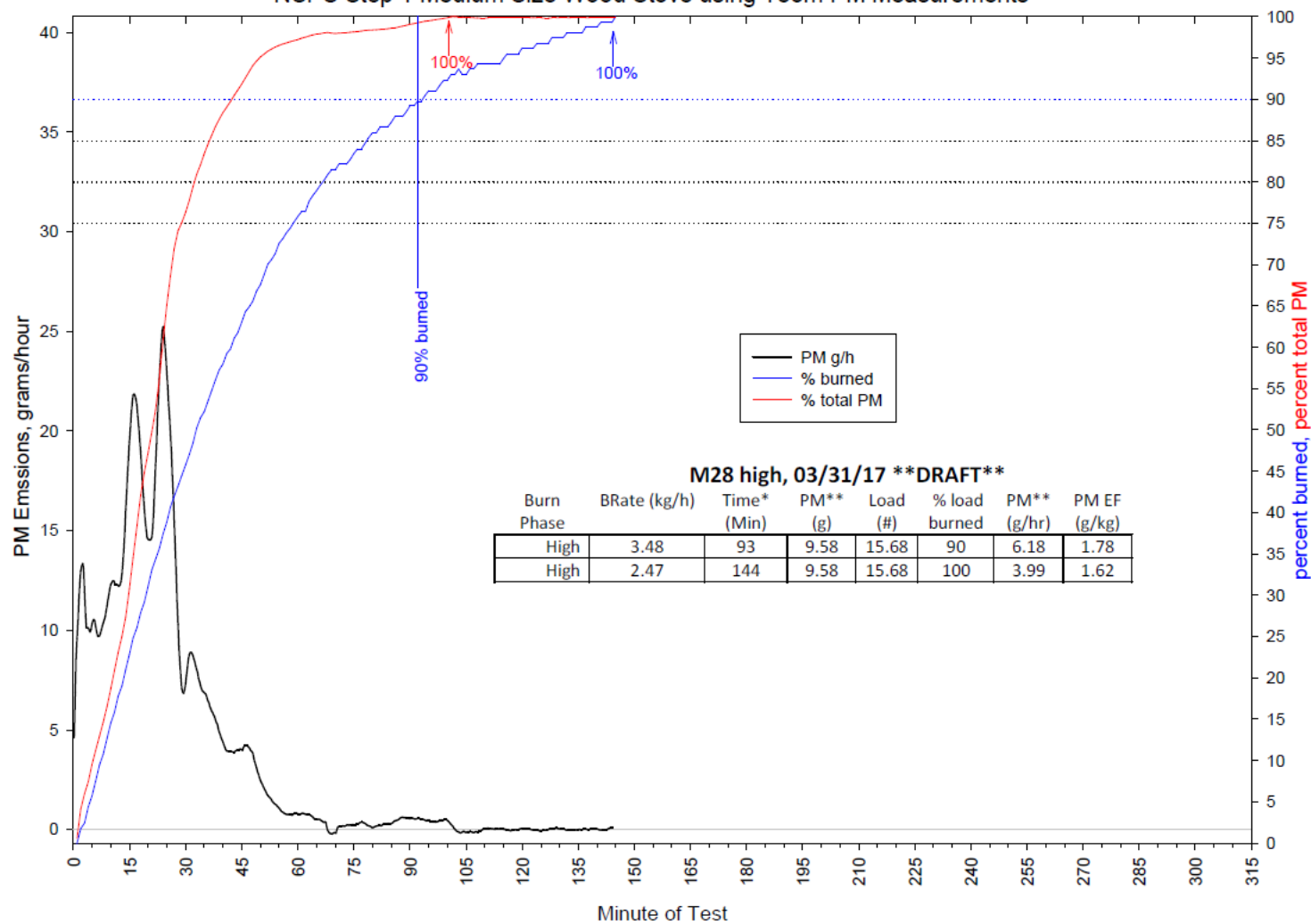
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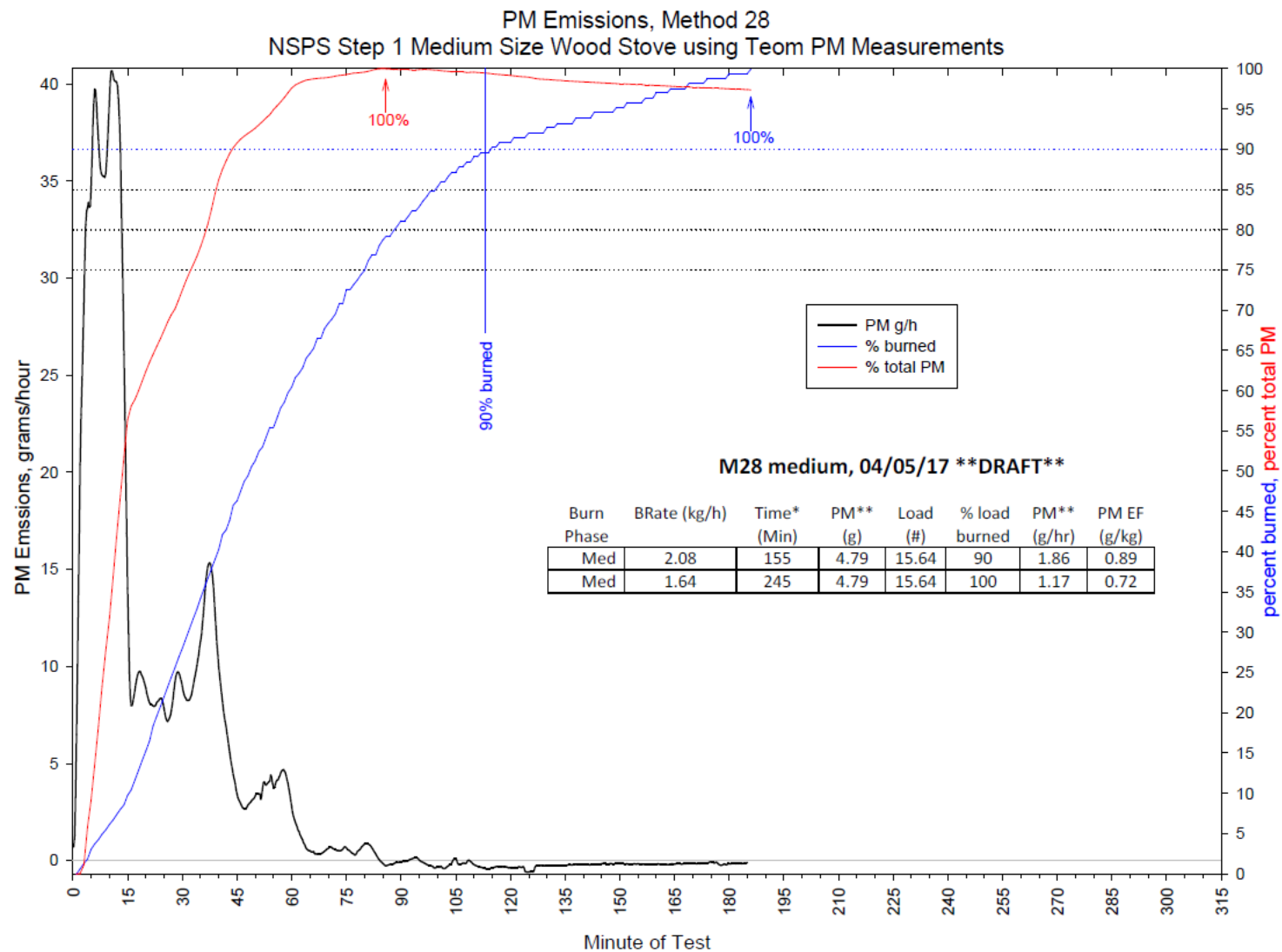
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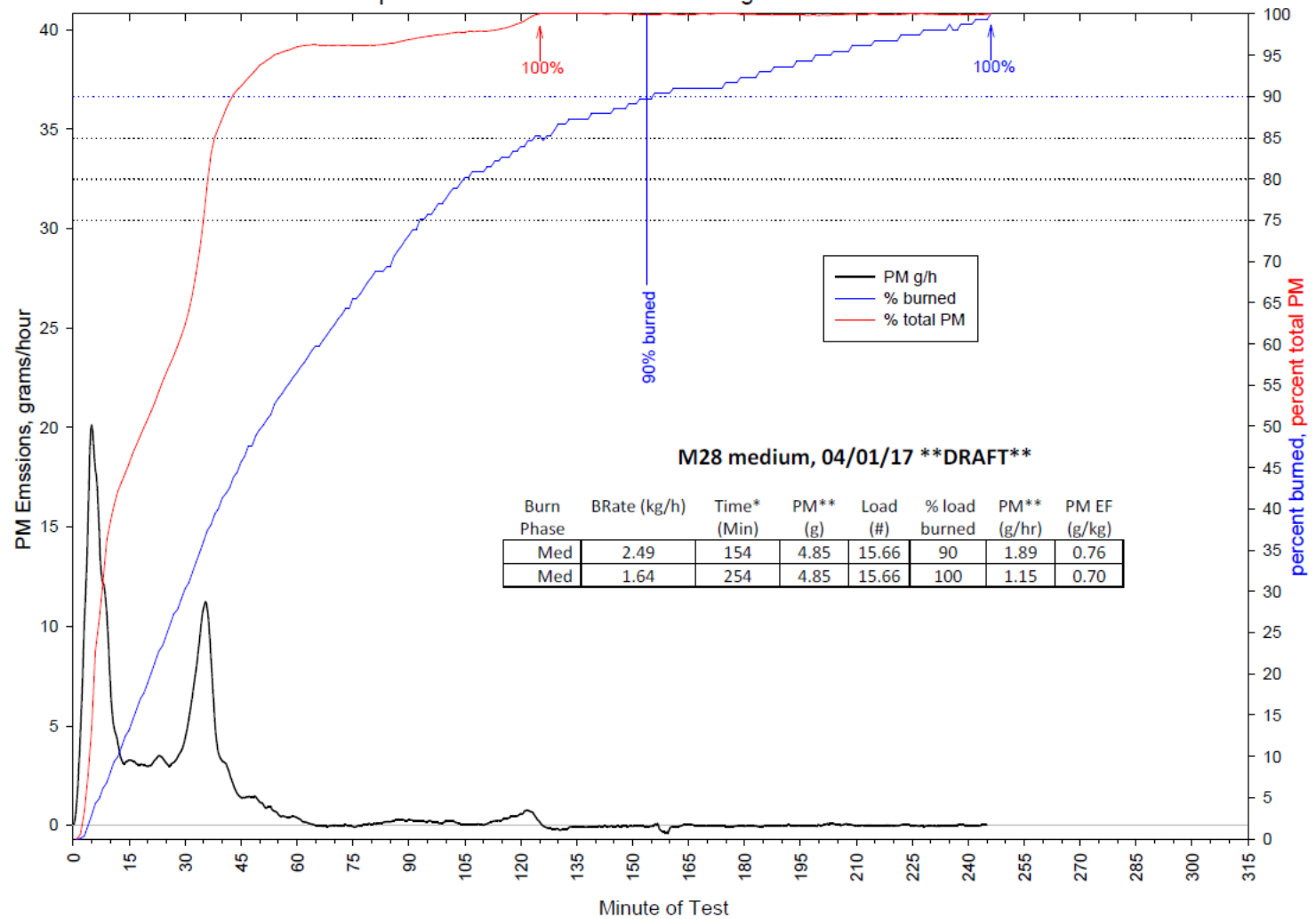
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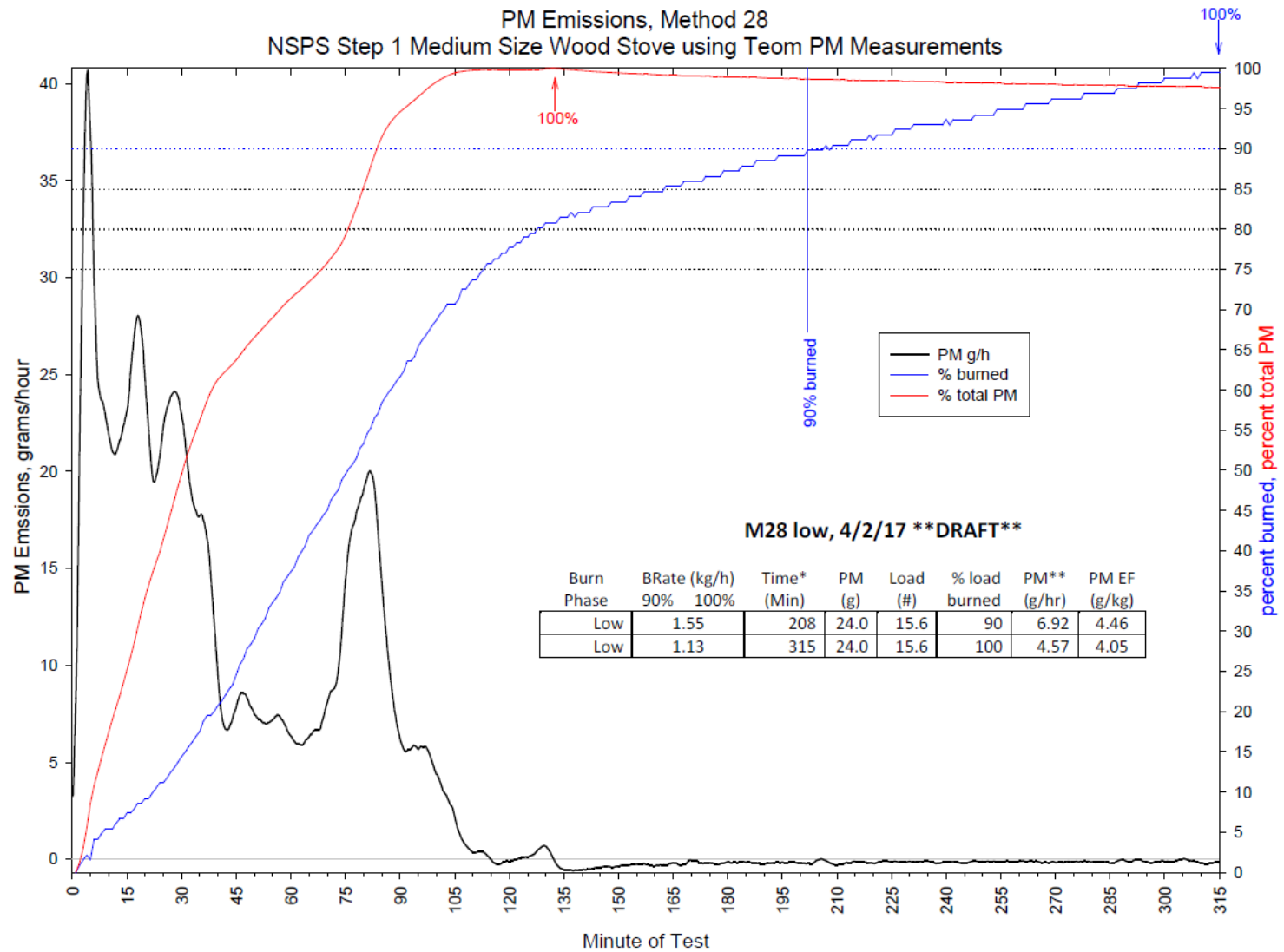




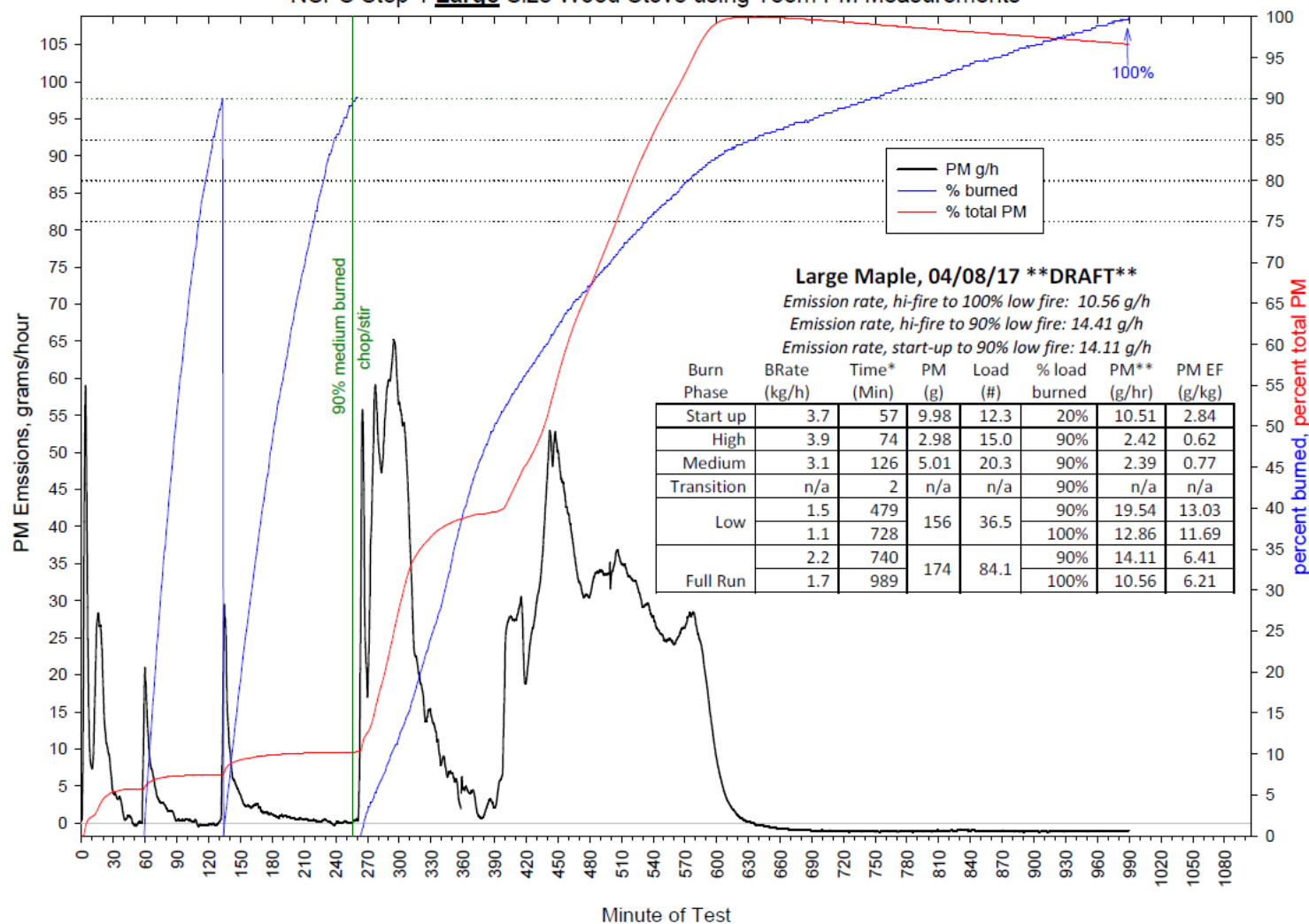


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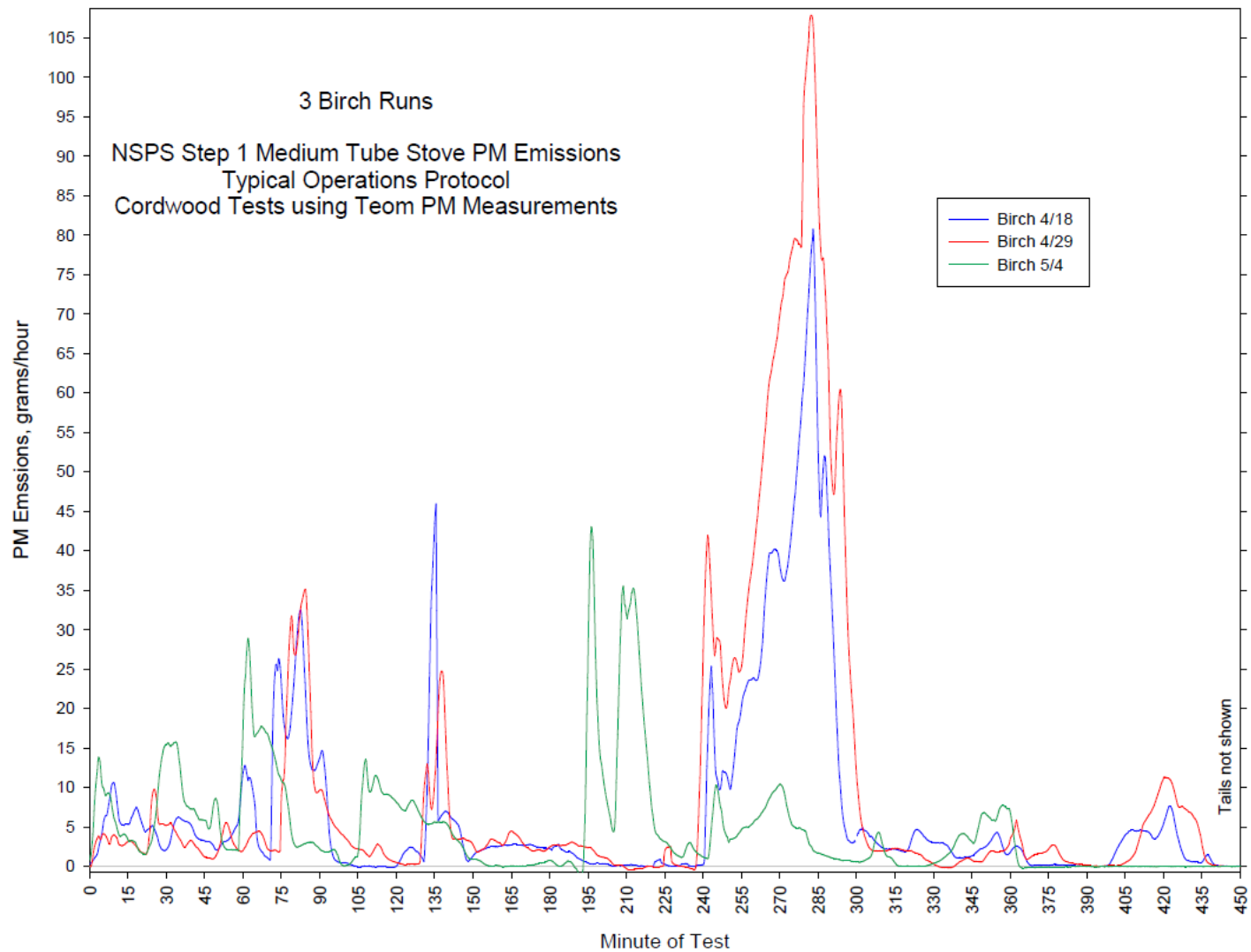


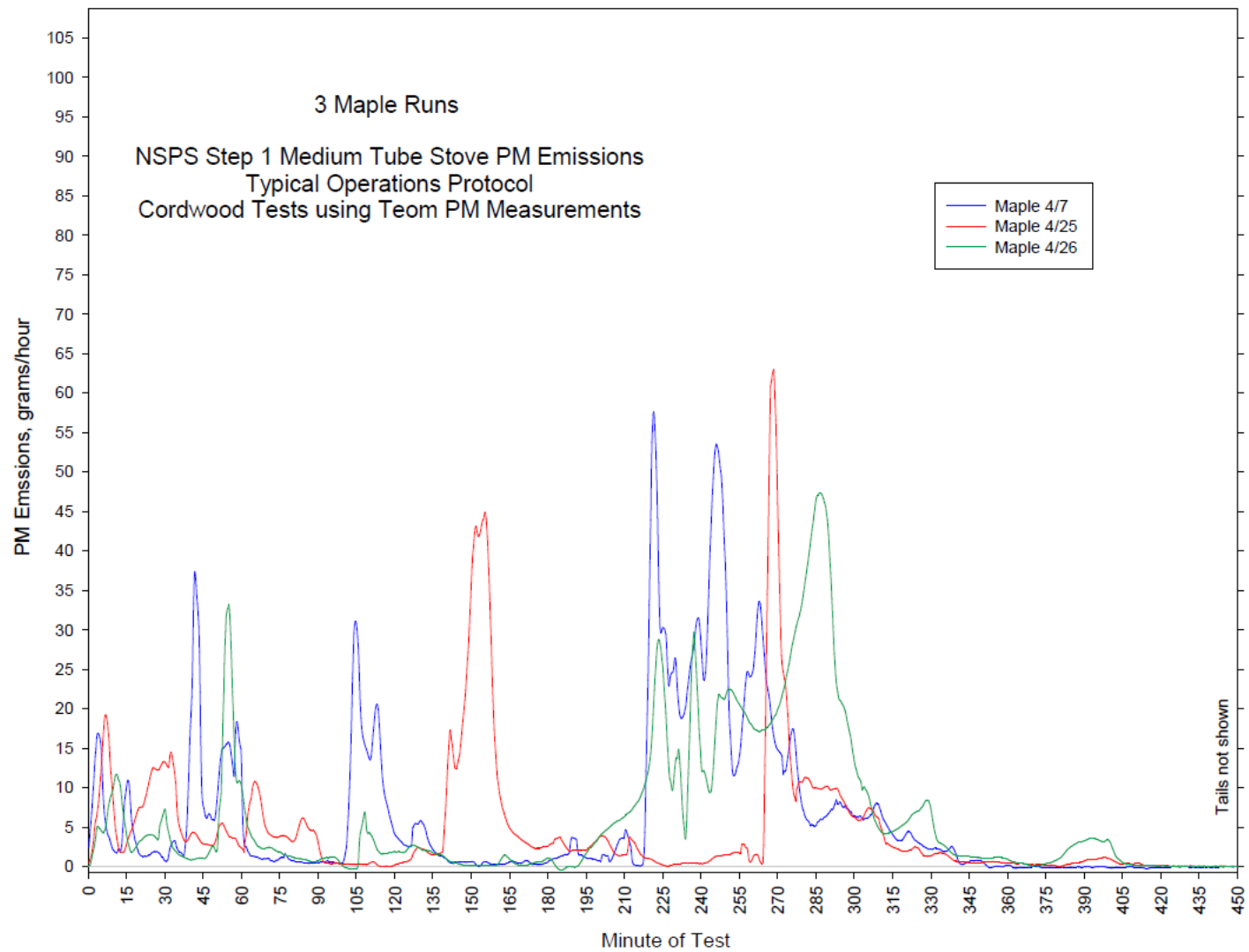


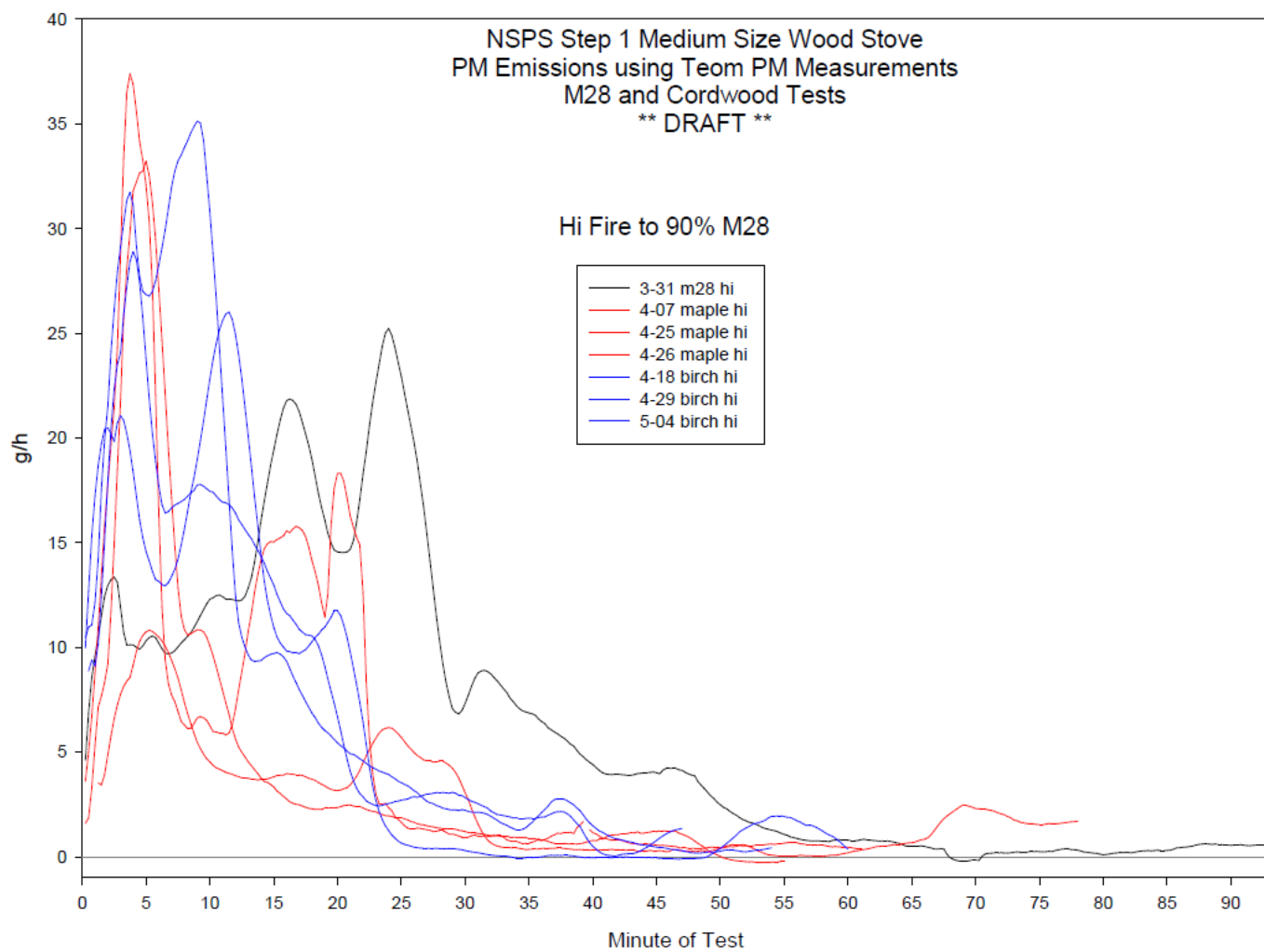
PM Emissions, Draft Cordwood Operations Protocol  
NSPS Step 1 **Large** Size Wood Stove using Team PM Measurements

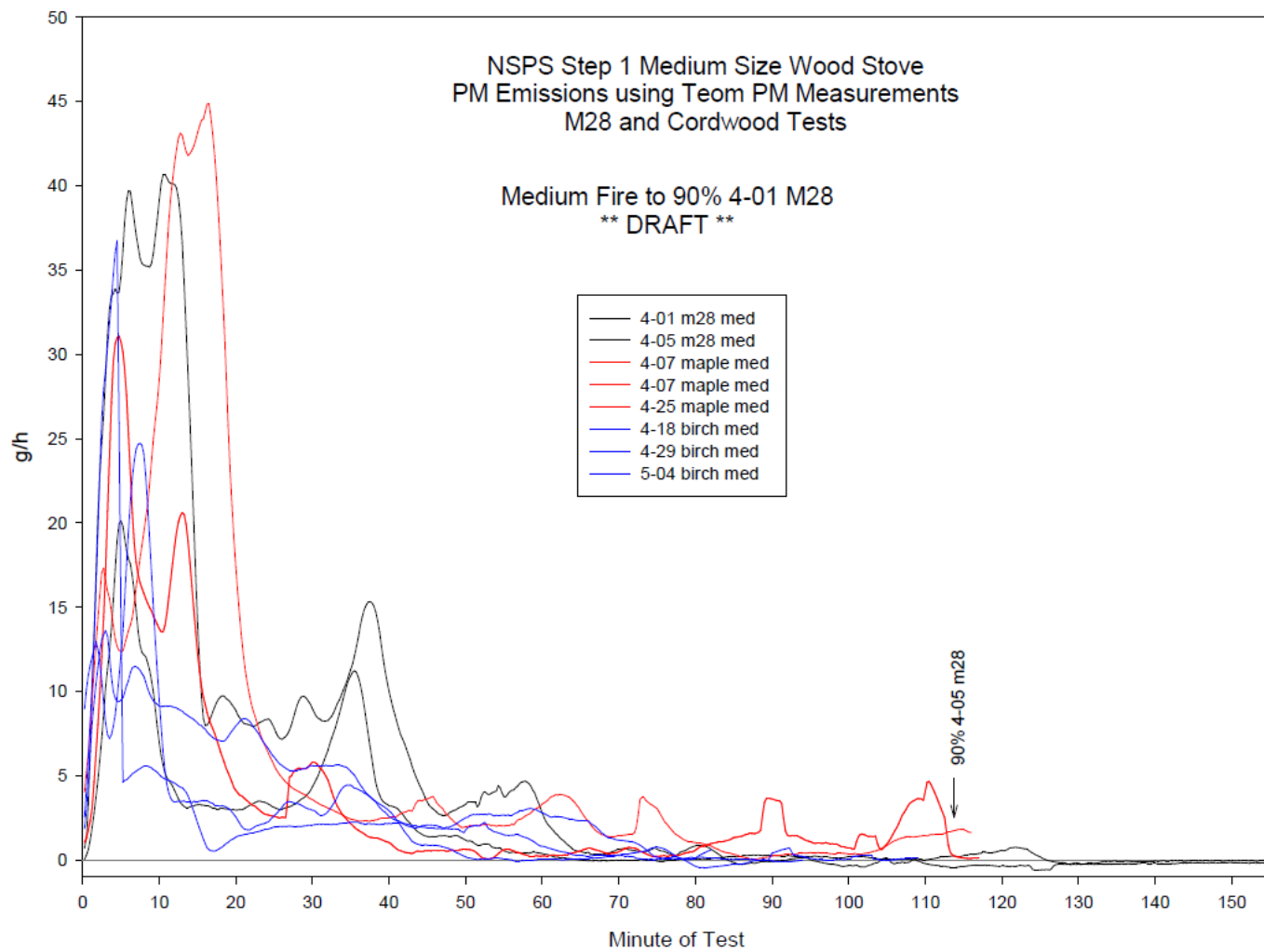




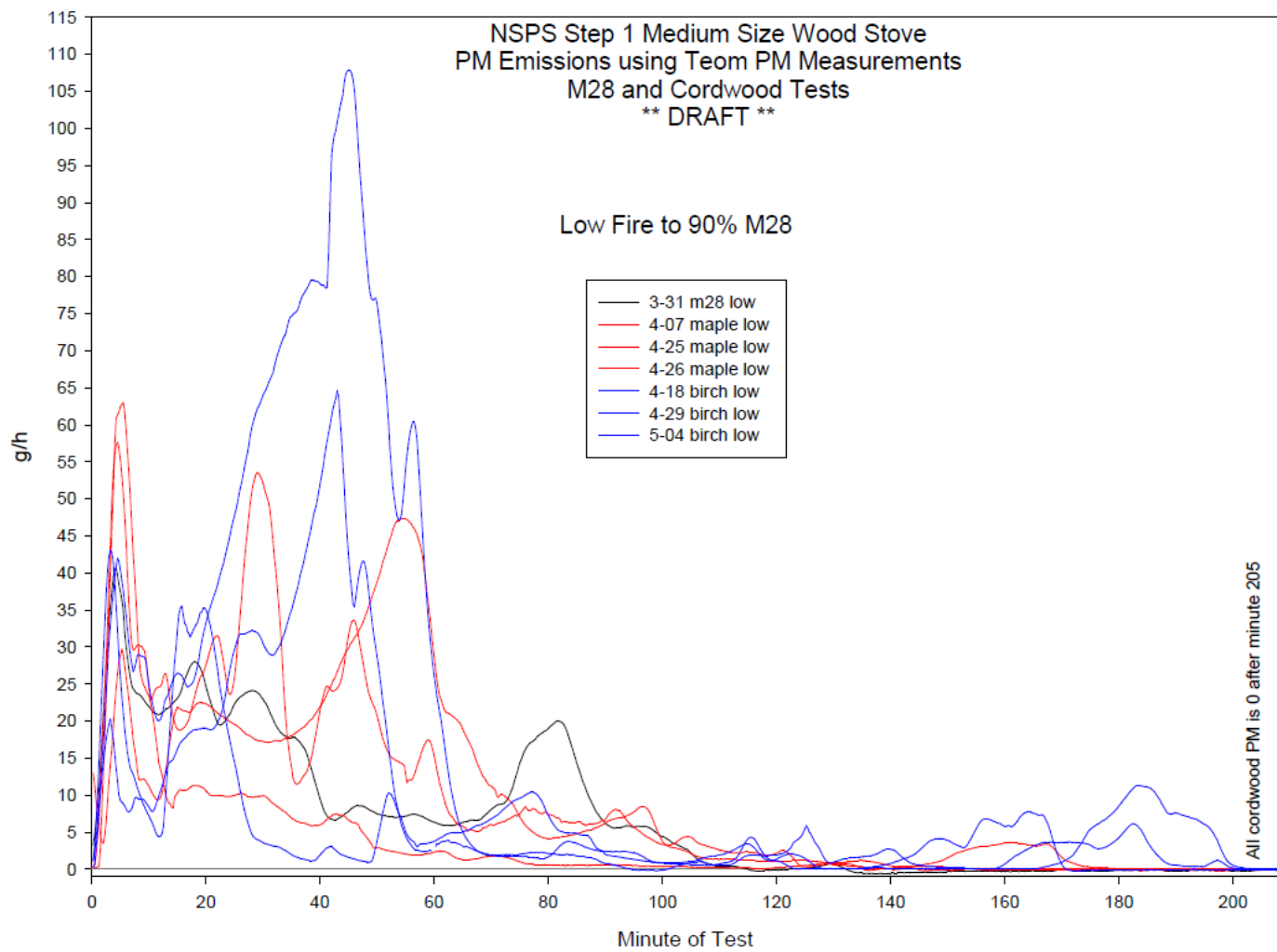




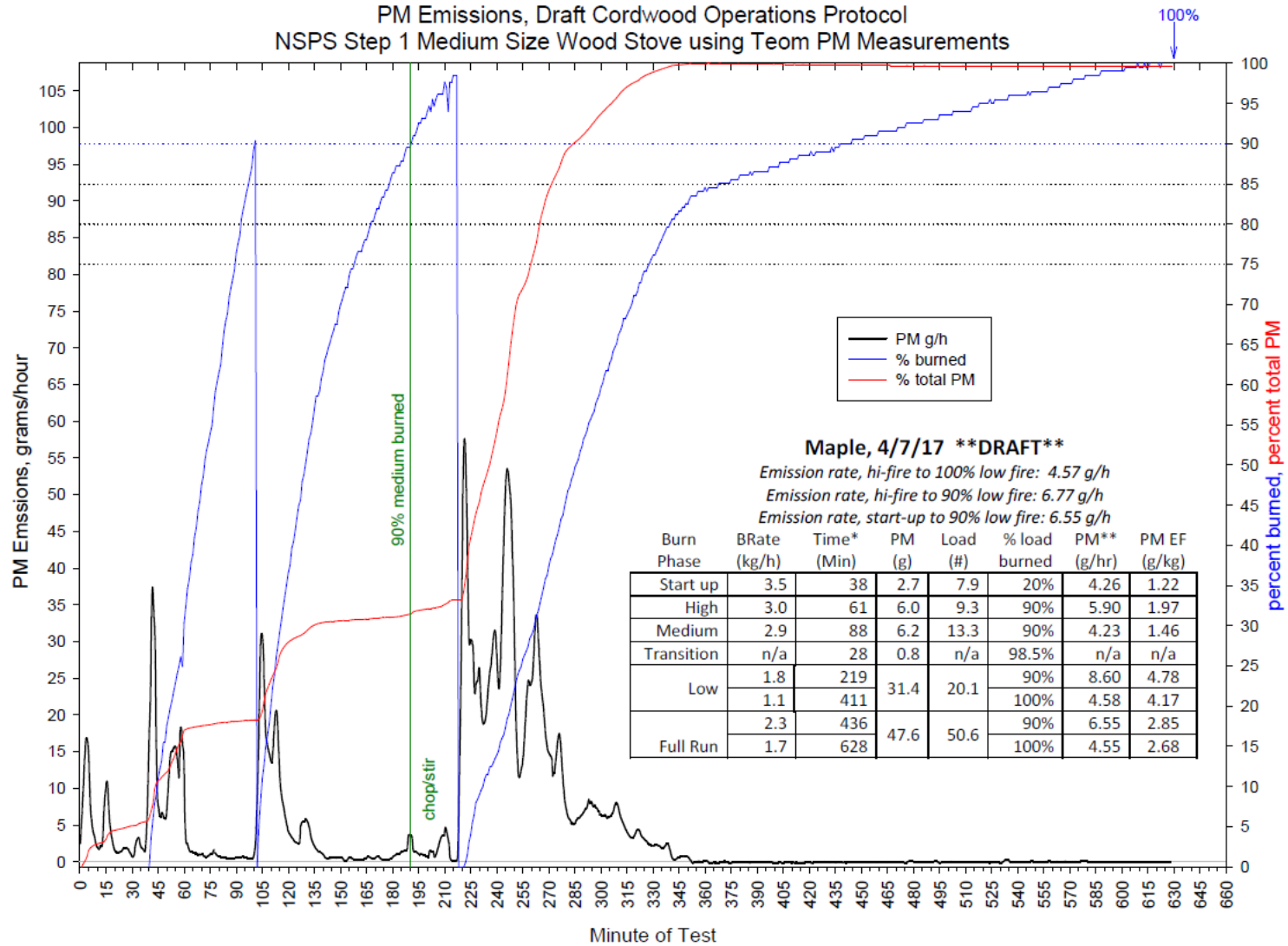






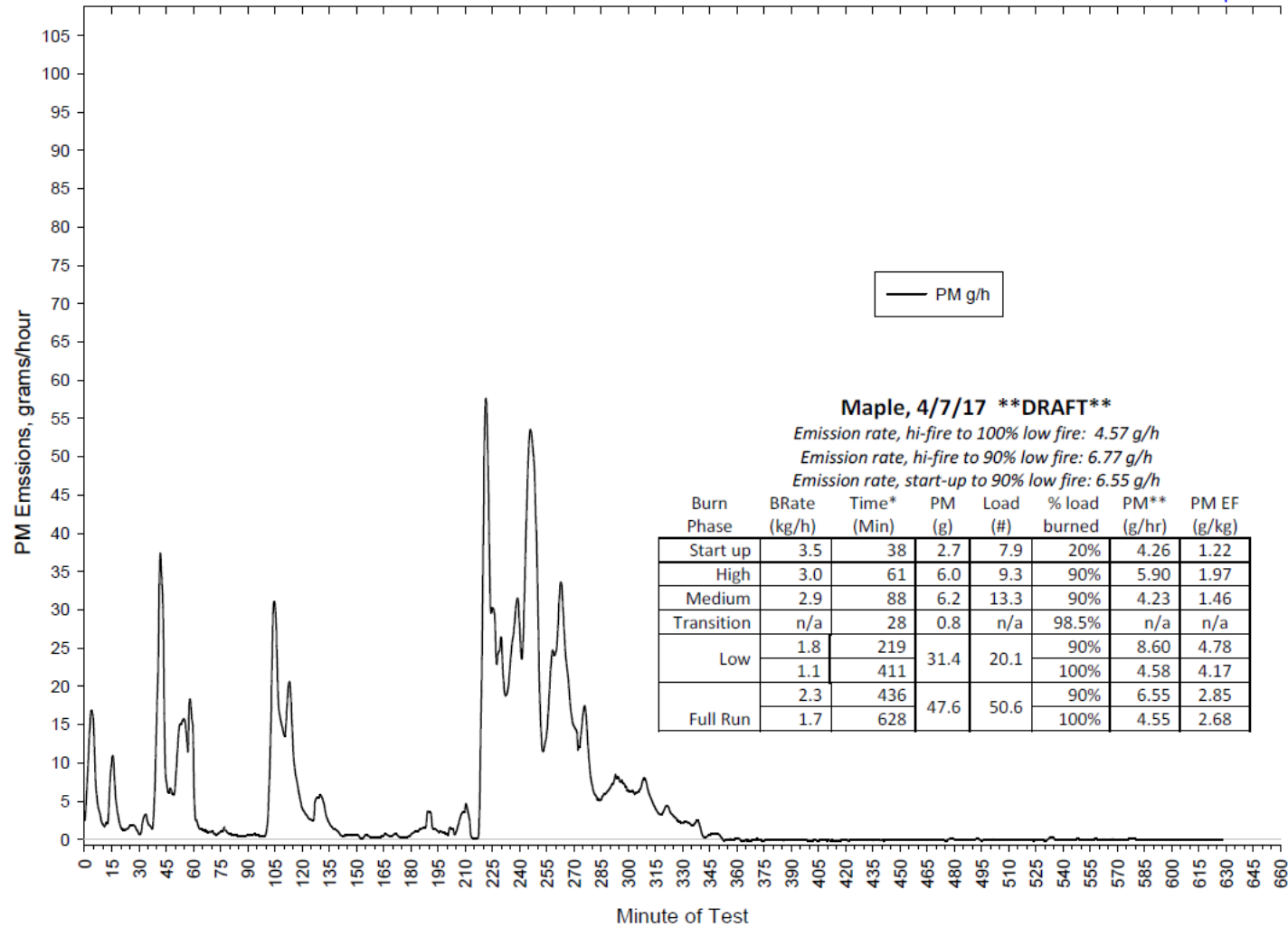


PM Emissions, Draft Cordwood Operations Protocol  
NSPS Step 1 Medium Size Wood Stove using Team PM Measurements

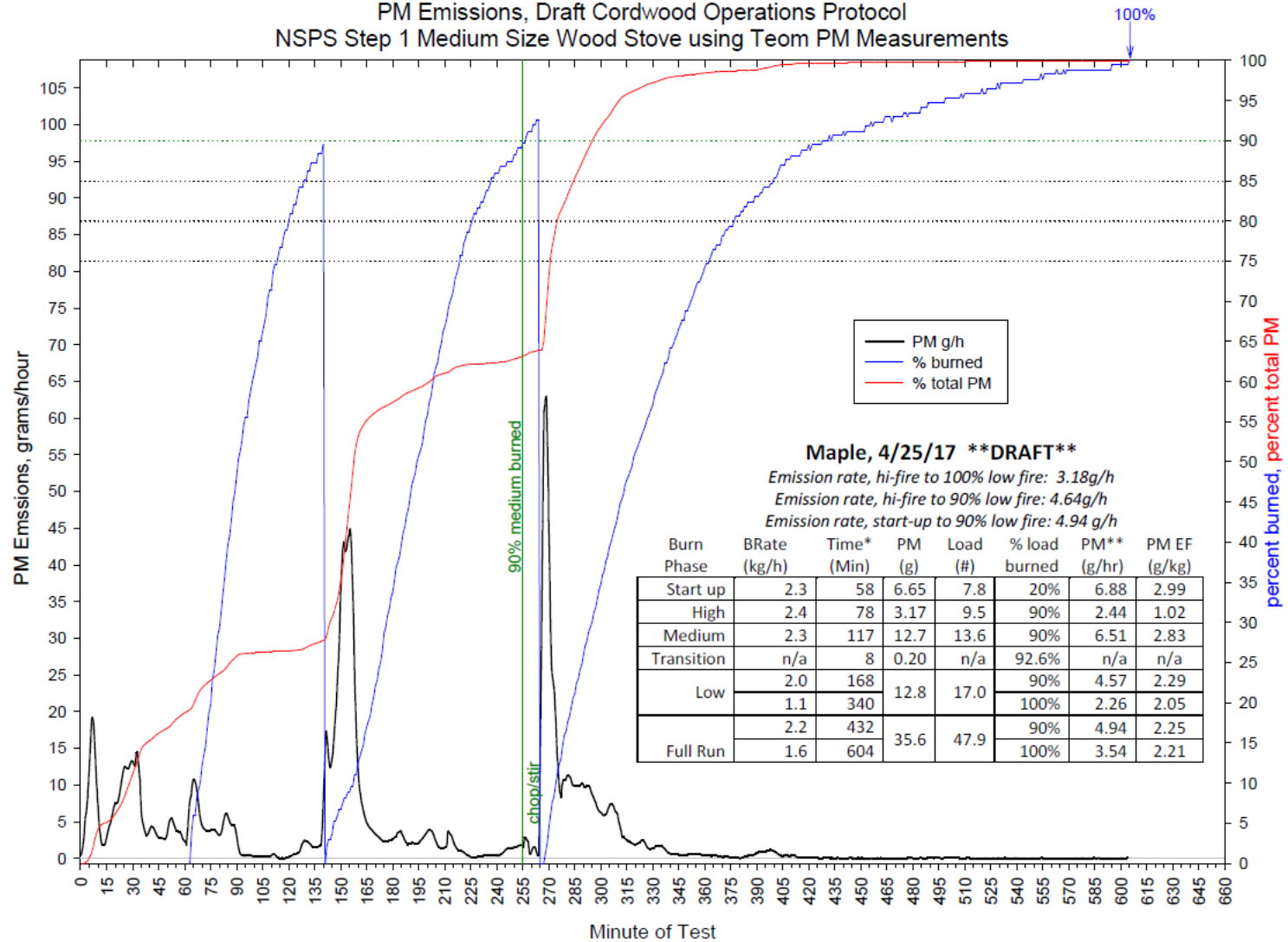


PM Emissions, Draft Cordwood Operations Protocol  
NSPS Step 1 Medium Size Wood Stove using Teom PM Measurements

100%  
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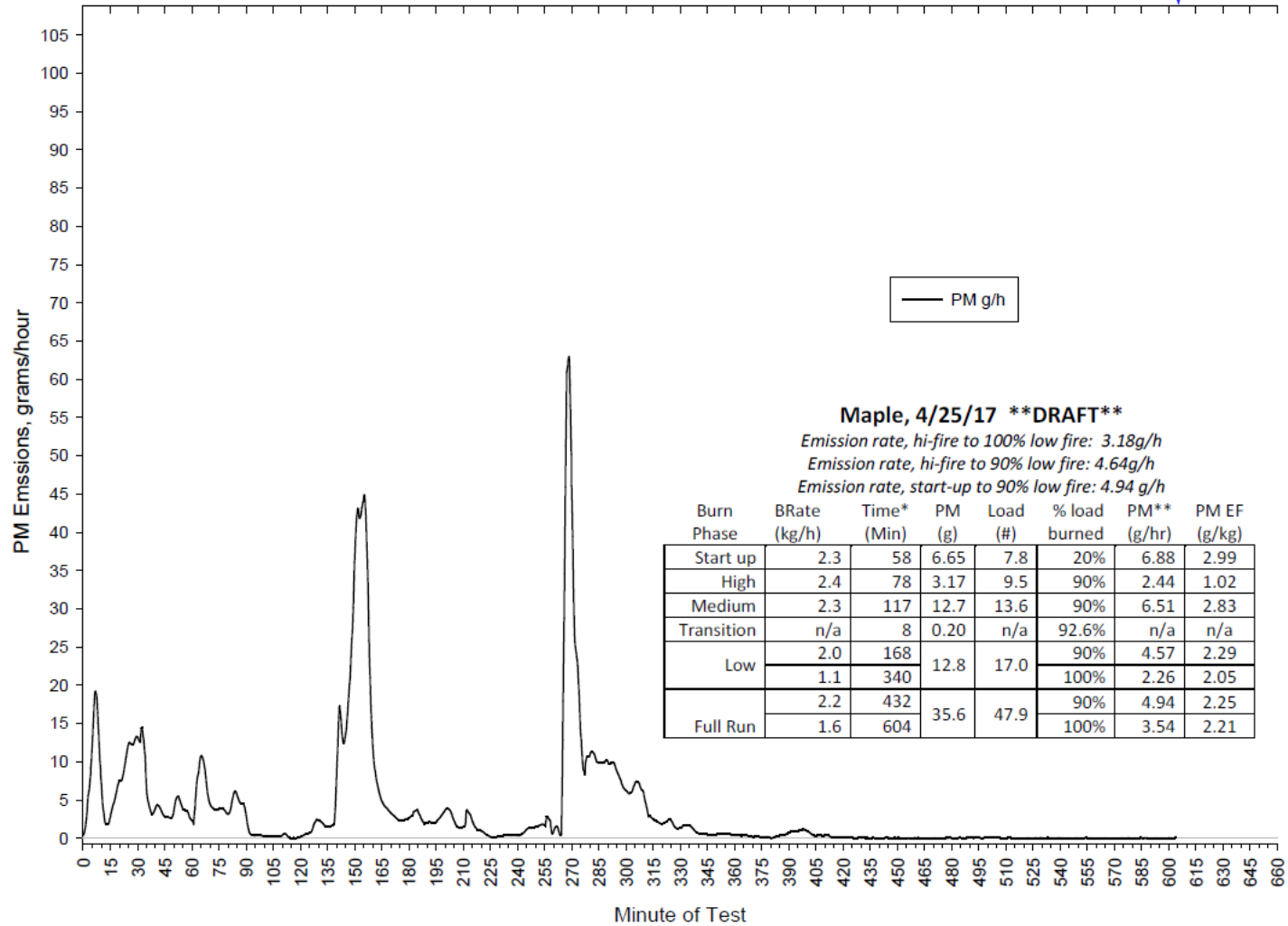
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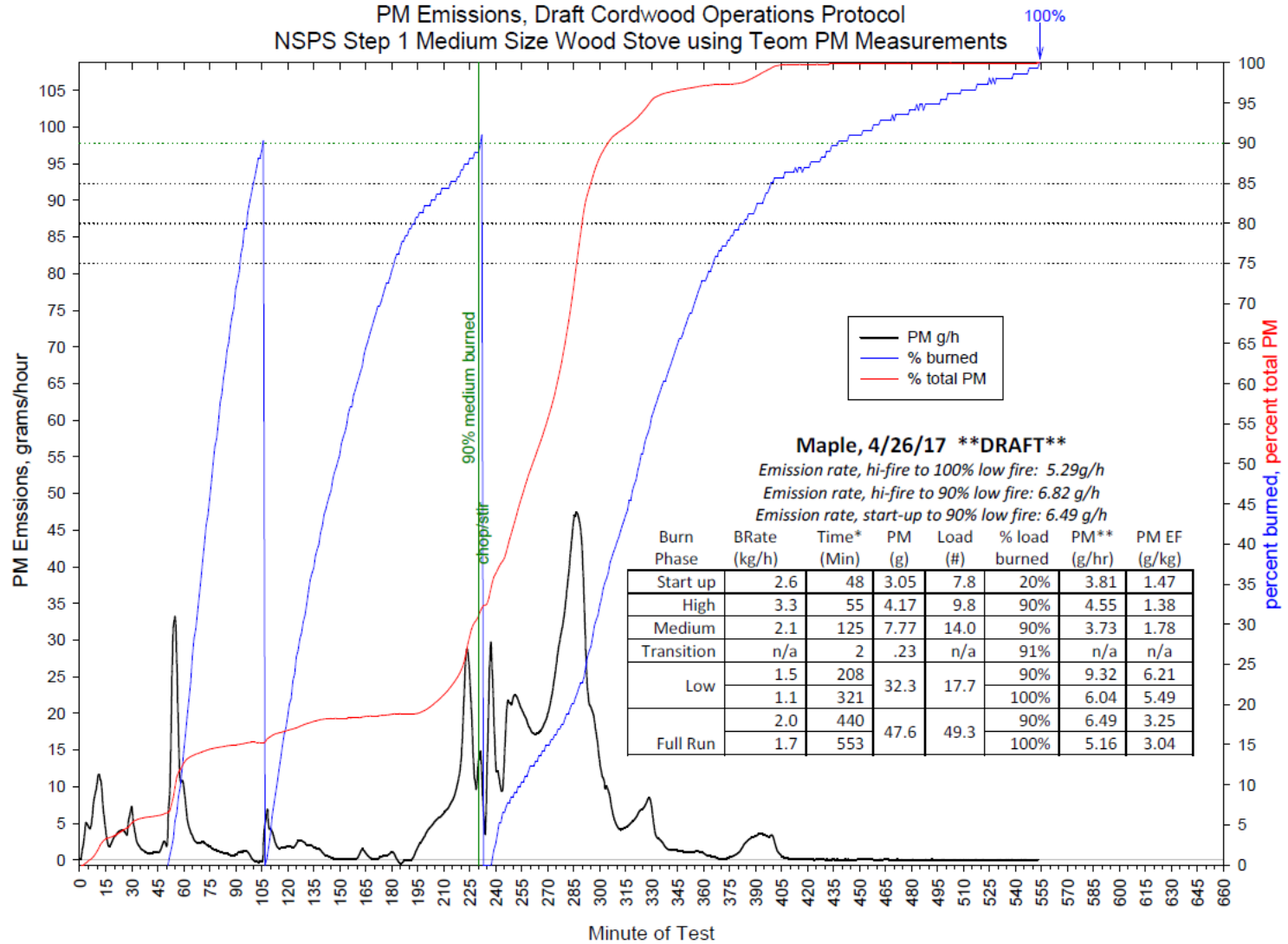


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NSPS Step 1 Medium Size Wood Stove using Team PM Measurements**

100%  
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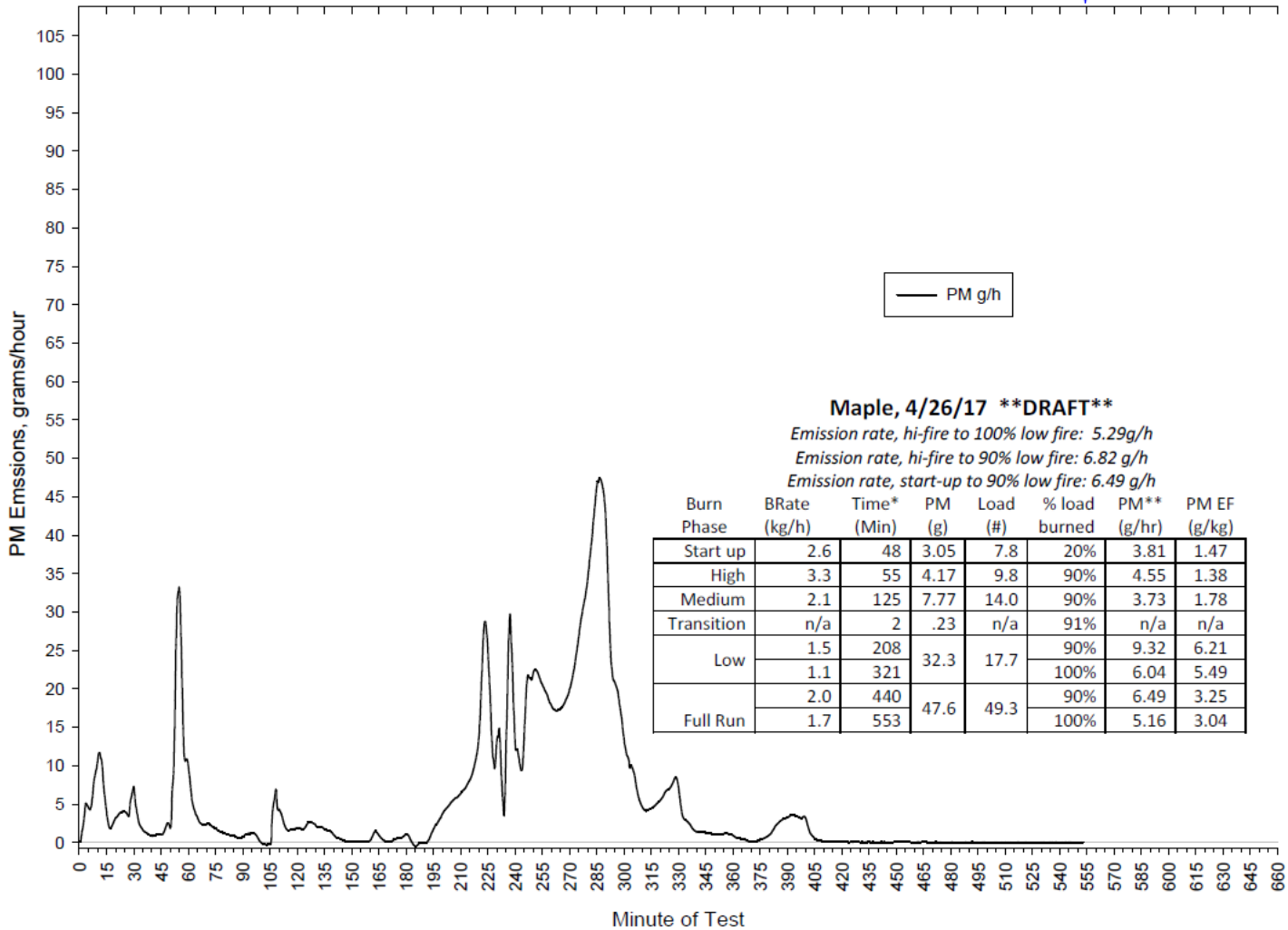


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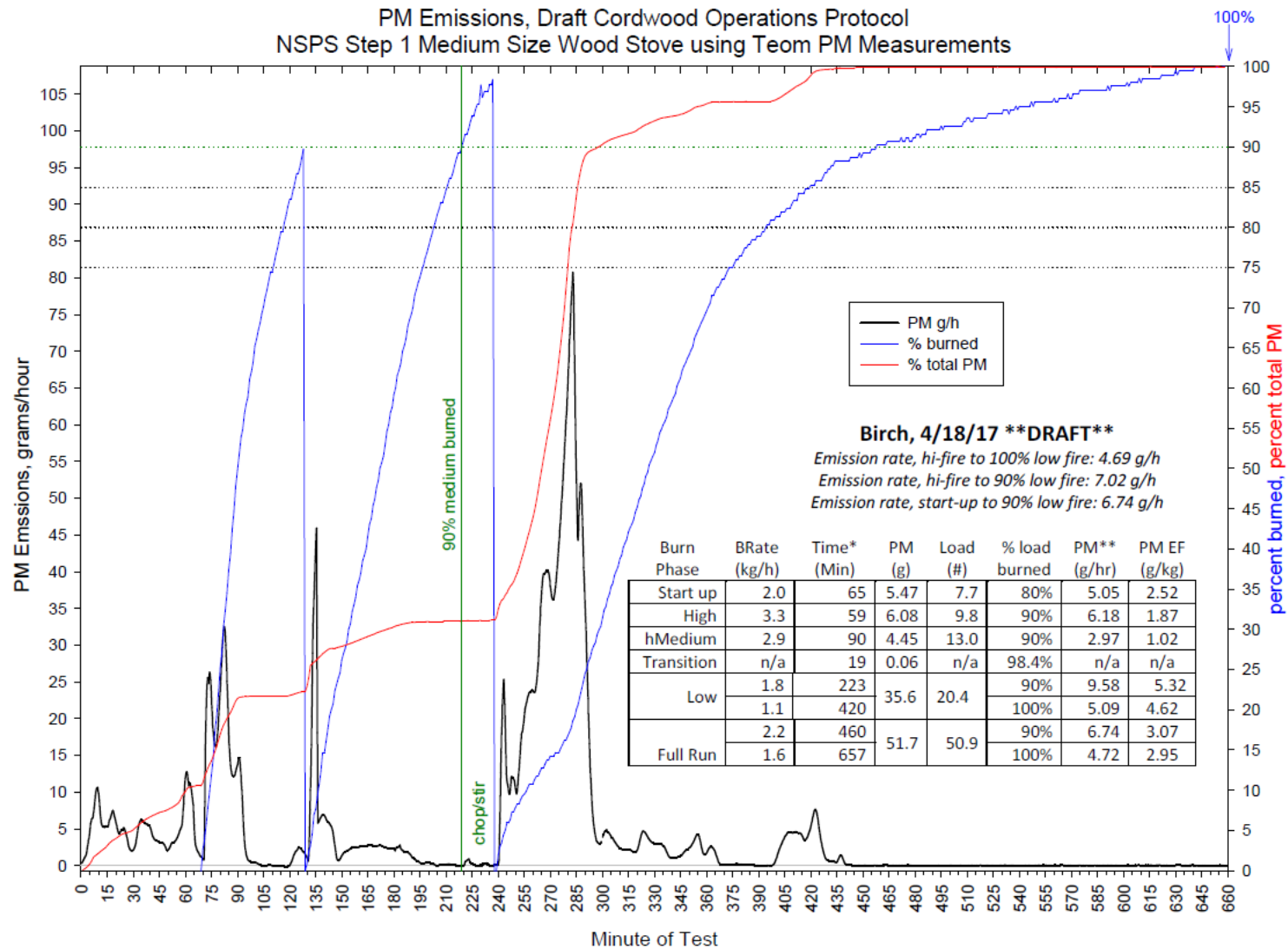


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100%



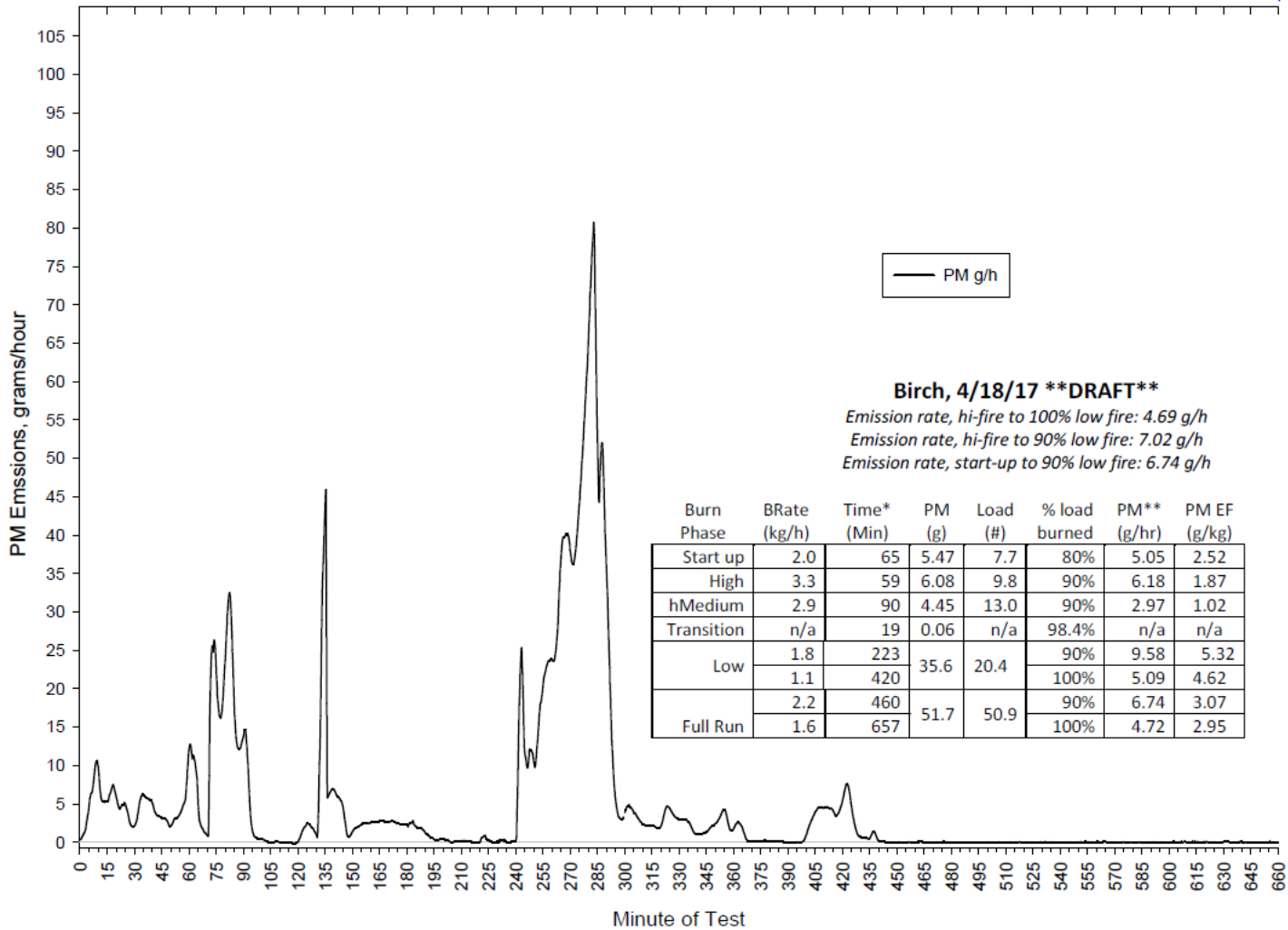
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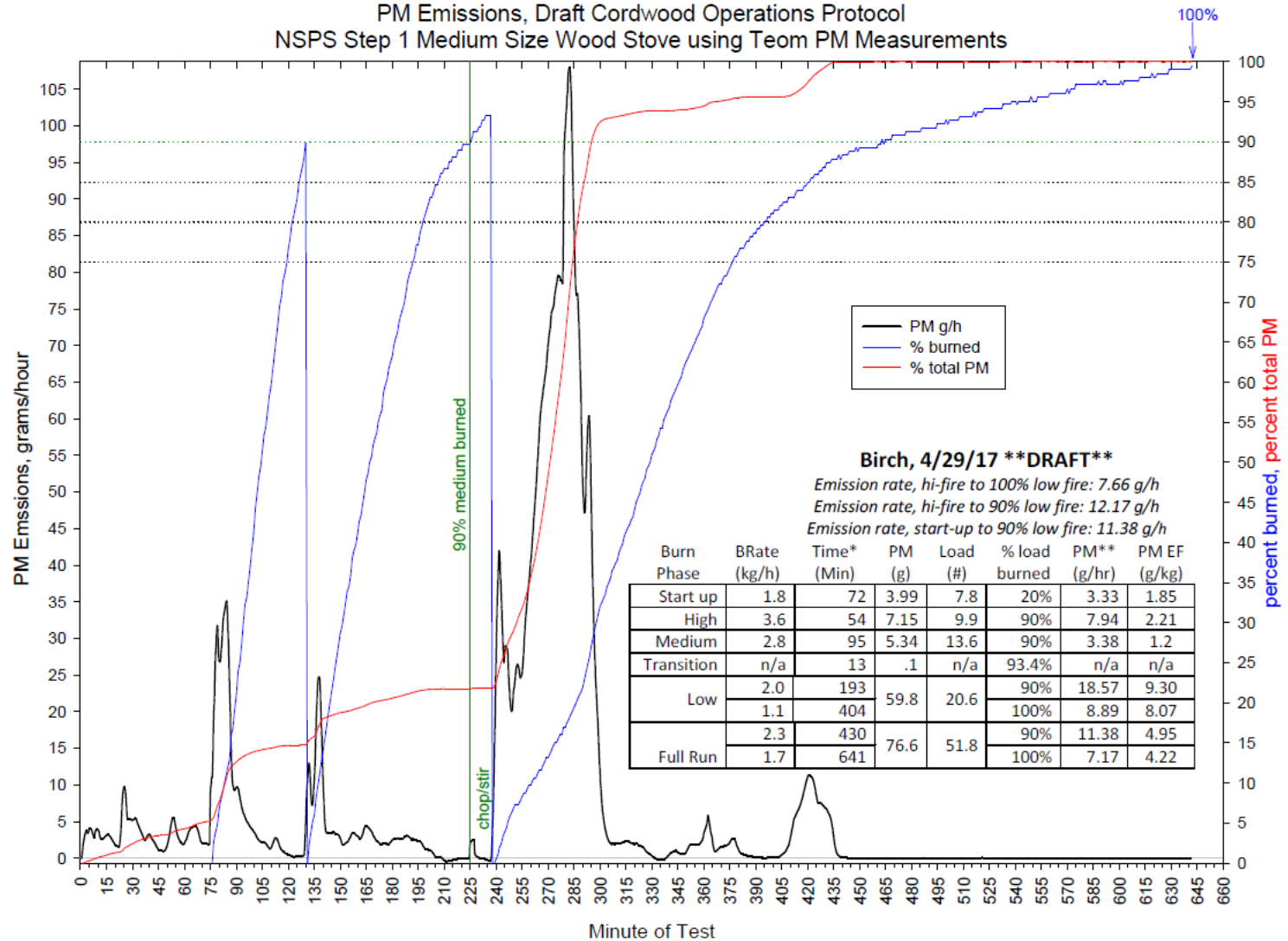


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100%  
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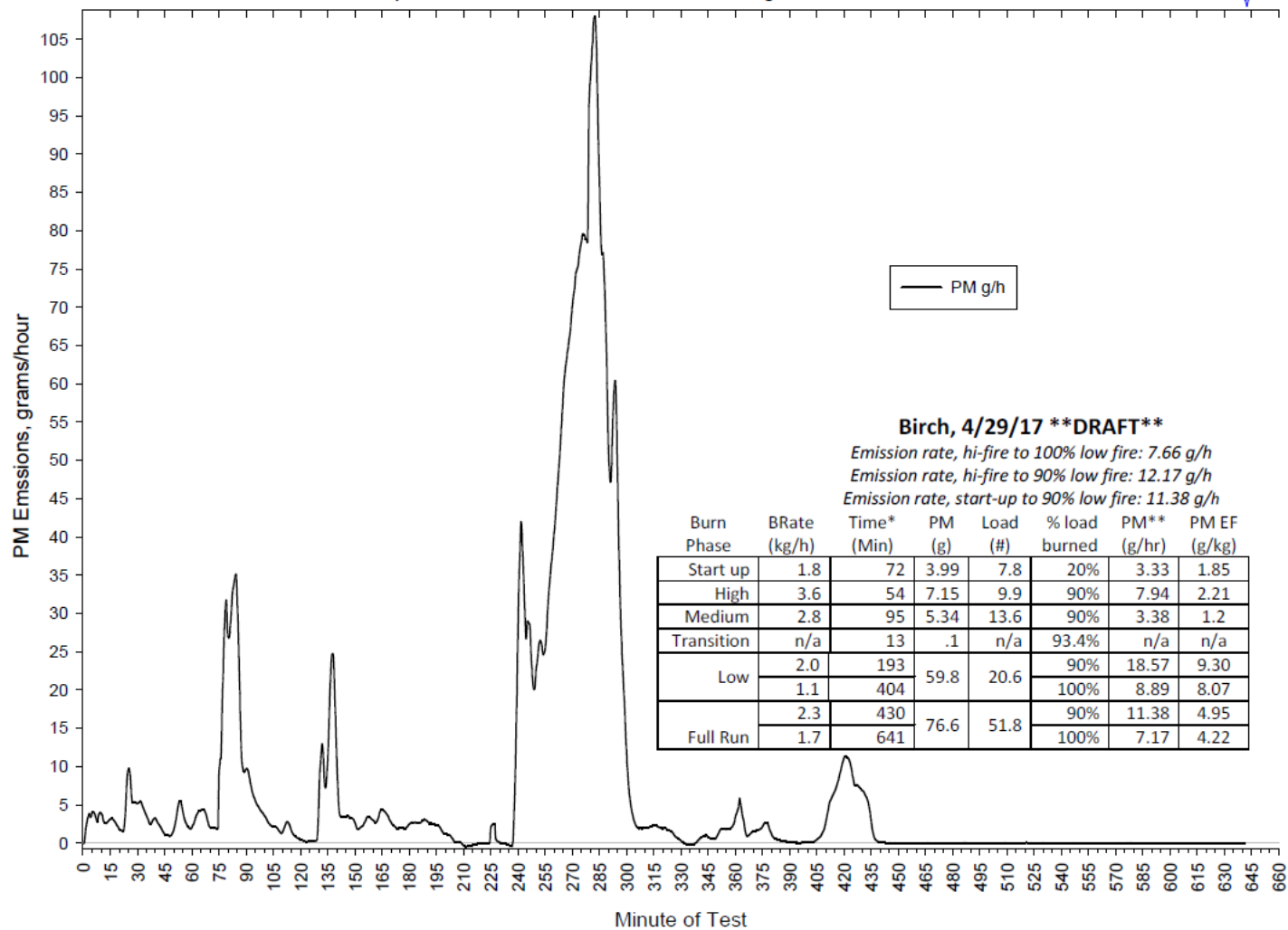


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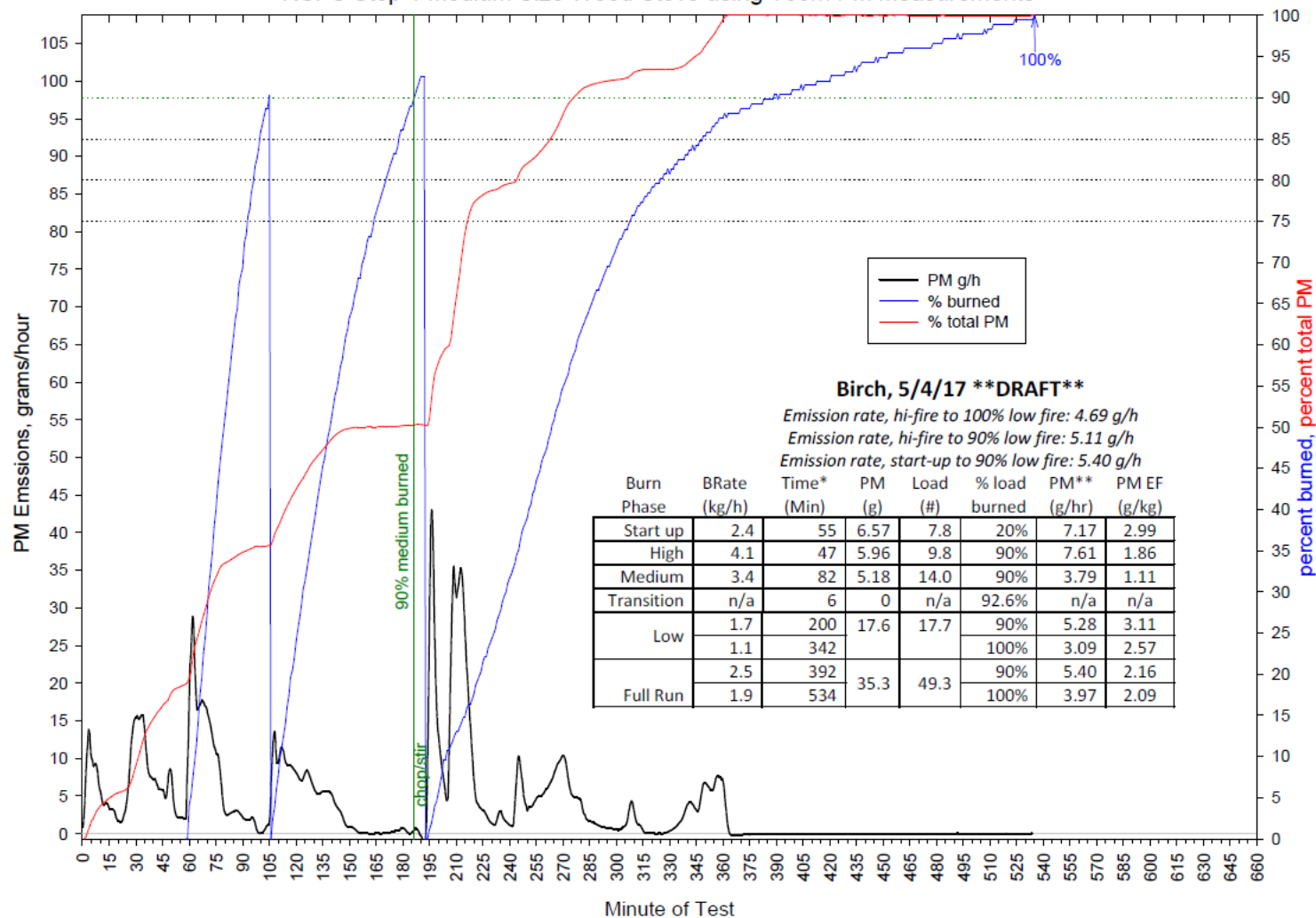


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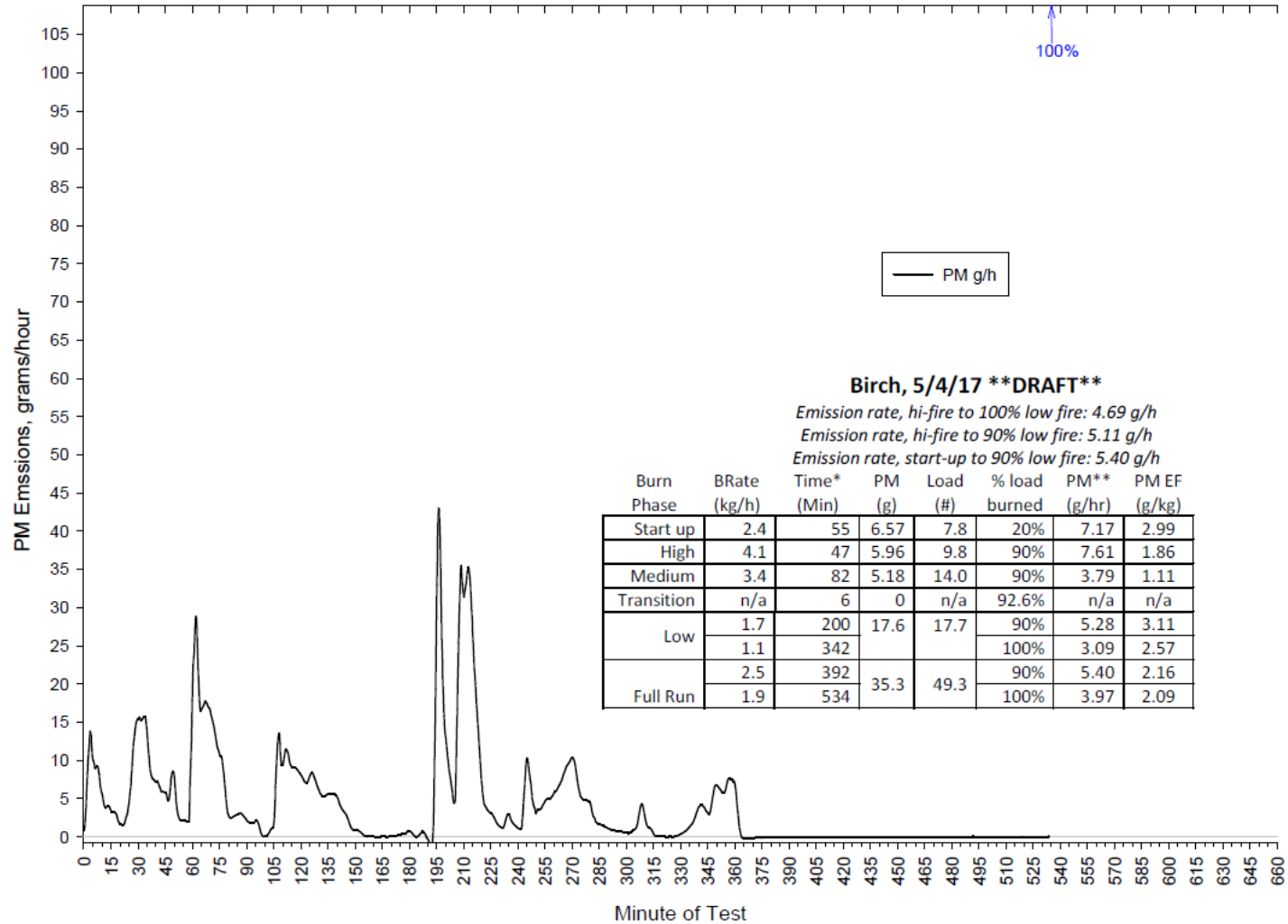
100%



**PM Emissions, Draft Cordwood Operations Protocol  
NSPS Step 1 Medium Size Wood Stove using Team PM Measurements**

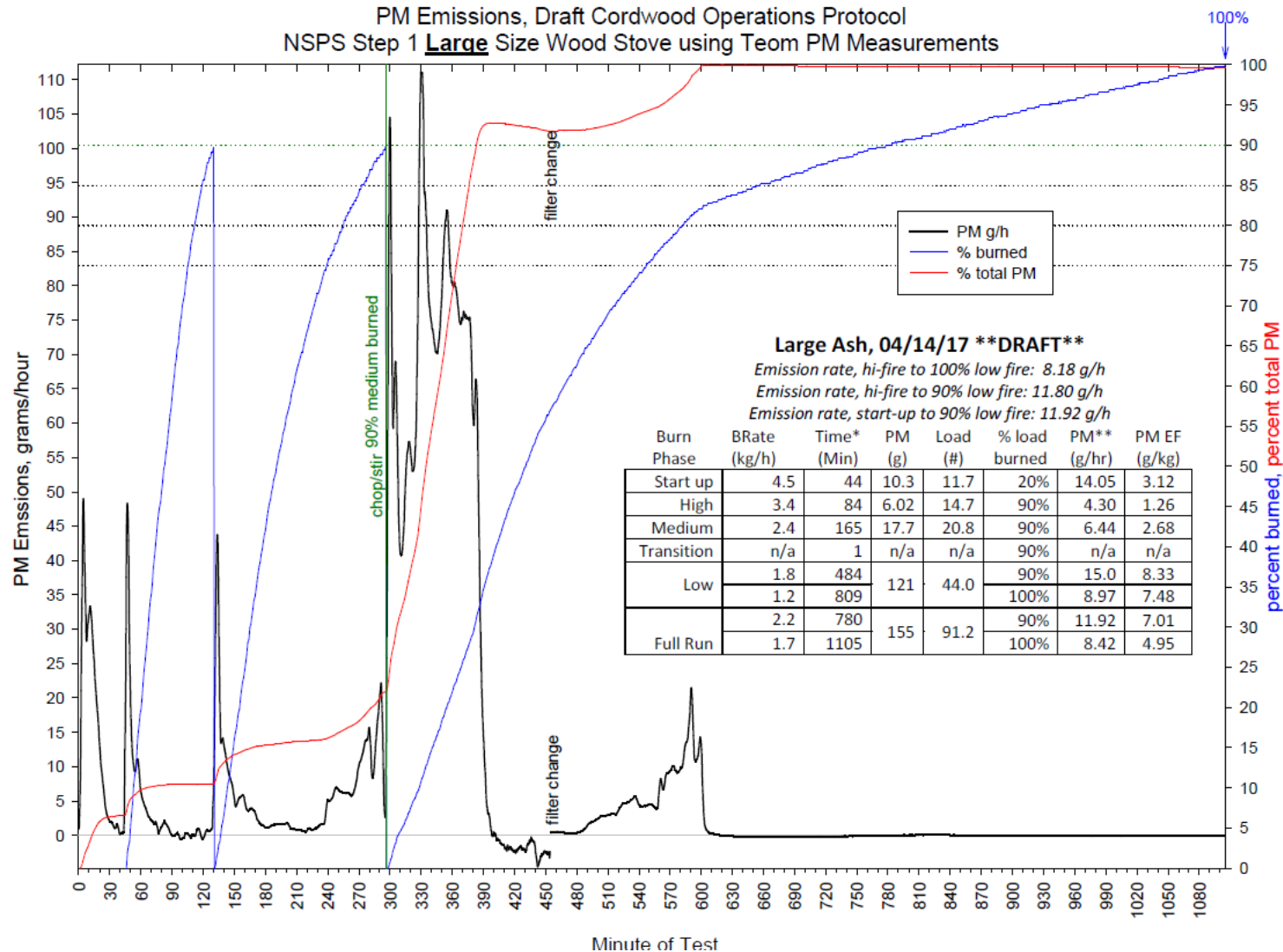


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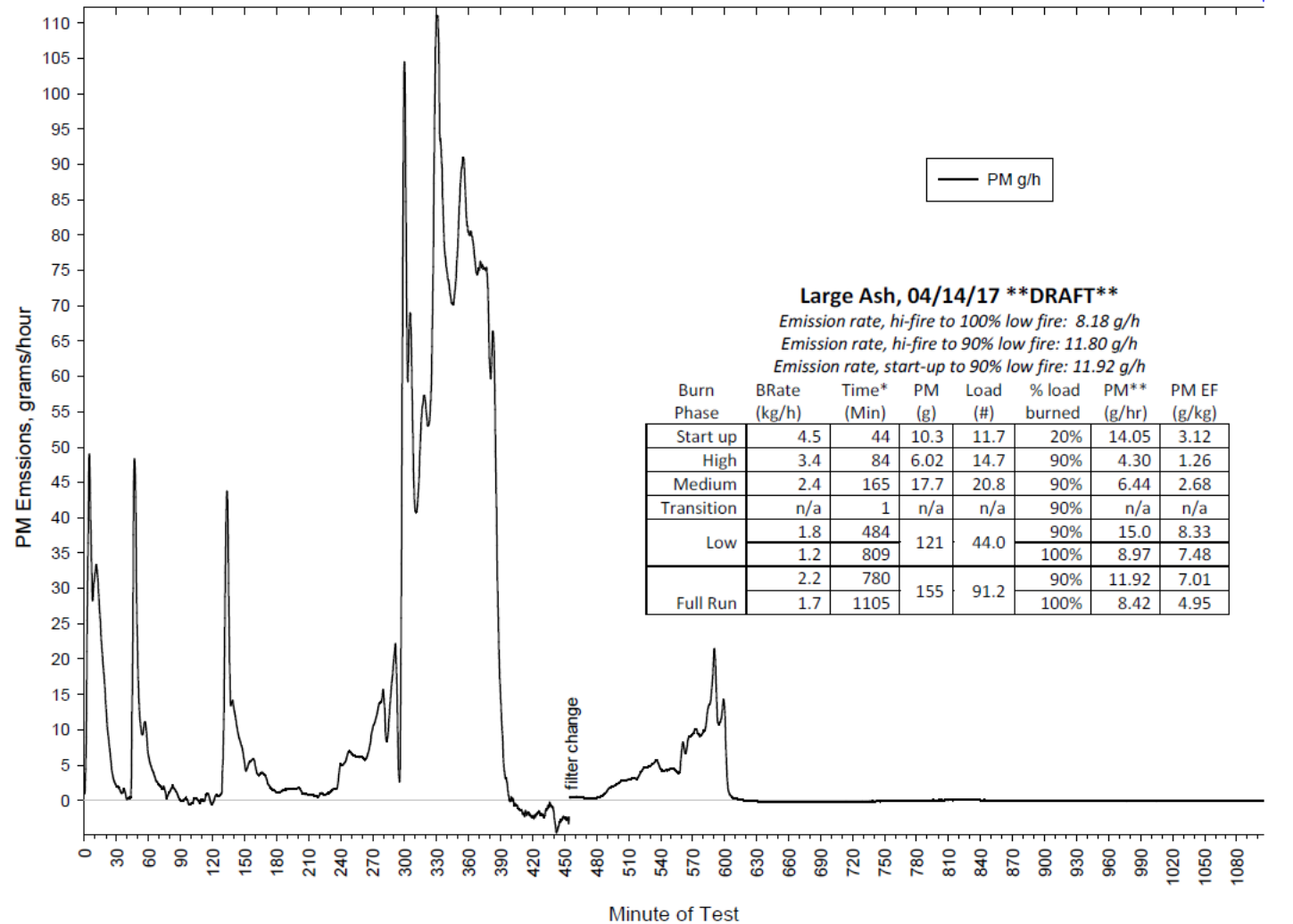




PM Emissions, Draft Cordwood Operations Protocol  
NSPS Step 1 **Large** Size Wood Stove using Team PM Measurements



PM Emissions, Draft Cordwood Operations Protocol  
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**Large Ash, 04/14/17 \*\*DRAFT\*\***

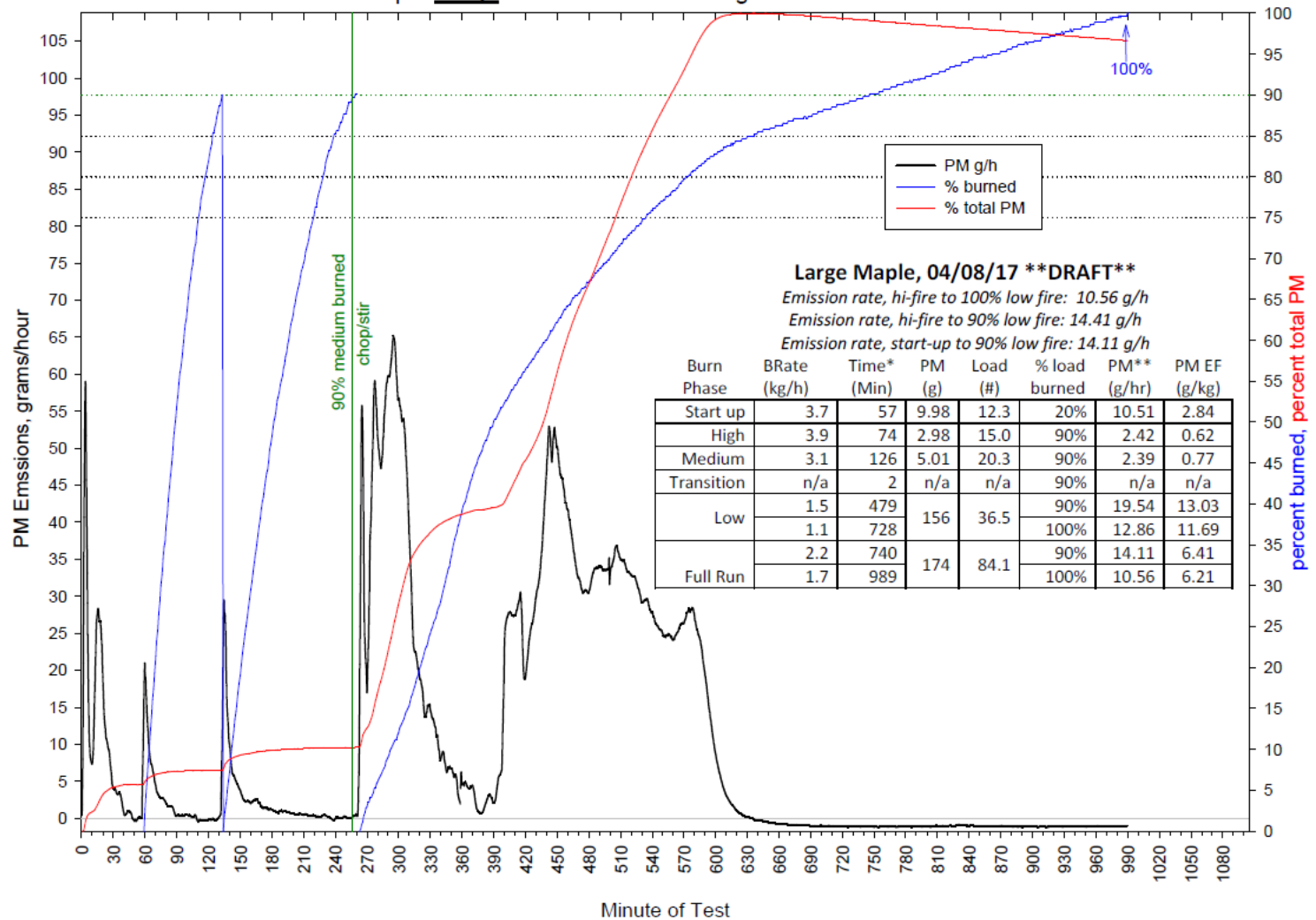
Emission rate, hi-fire to 100% low fire: 8.18 g/h

Emission rate, hi-fire to 90% low fire: 11.80 g/h

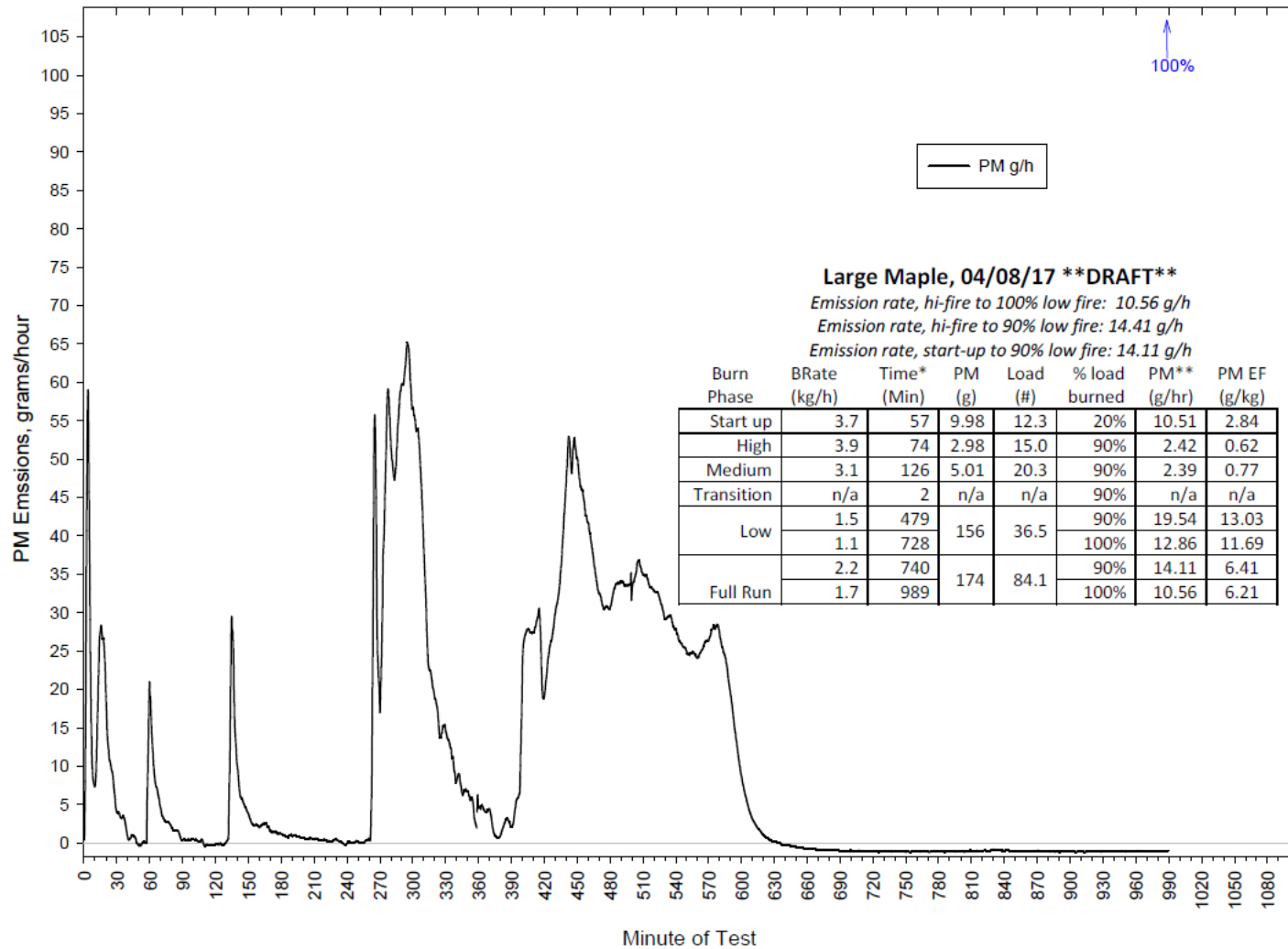
Emission rate, start-up to 90% low fire: 11.92 g/h

Burn Phase	BRate (kg/h)	Time* (Min)	PM (g)	Load (#)	% load burned	PM** (g/hr)	PM EF (g/kg)
Start up	4.5	44	10.3	11.7	20%	14.05	3.12
High	3.4	84	6.02	14.7	90%	4.30	1.26
Medium	2.4	165	17.7	20.8	90%	6.44	2.68
Transition	n/a	1	n/a	n/a	90%	n/a	n/a
Low	1.8	484	121	44.0	90%	15.0	8.33
	1.2	809			100%	8.97	7.48
Full Run	2.2	780	155	91.2	90%	11.92	7.01
	1.7	1105			100%	8.42	4.95

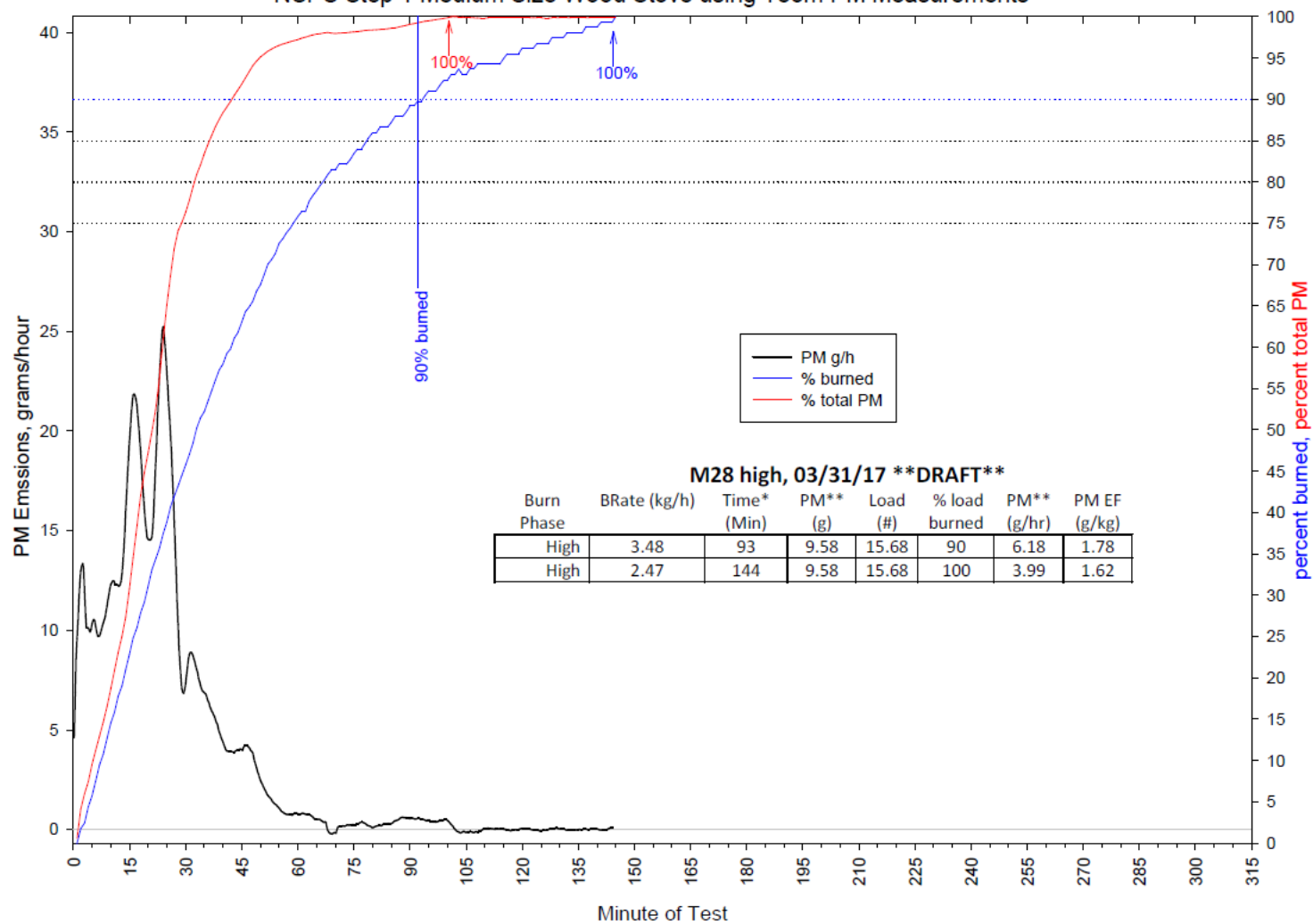
PM Emissions, Draft Cordwood Operations Protocol  
NSPS Step 1 **Large** Size Wood Stove using Team PM Measurements



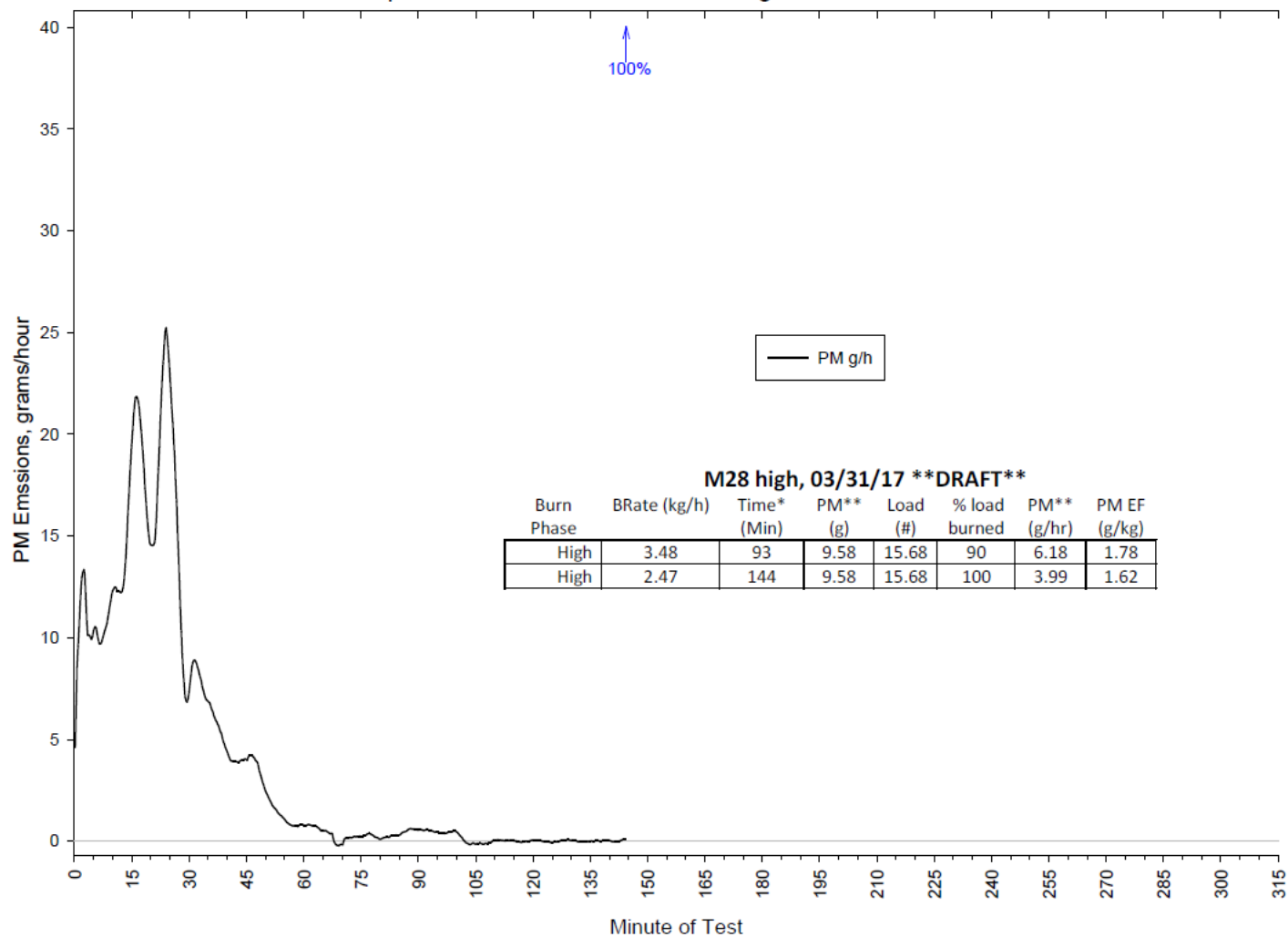
PM Emissions, Draft Cordwood Operations Protocol  
NSPS Step 1 **Large** Size Wood Stove using Teom PM Measurements



# PM Emissions, Method 28 NSPS Step 1 Medium Size Wood Stove using Team PM Measurements



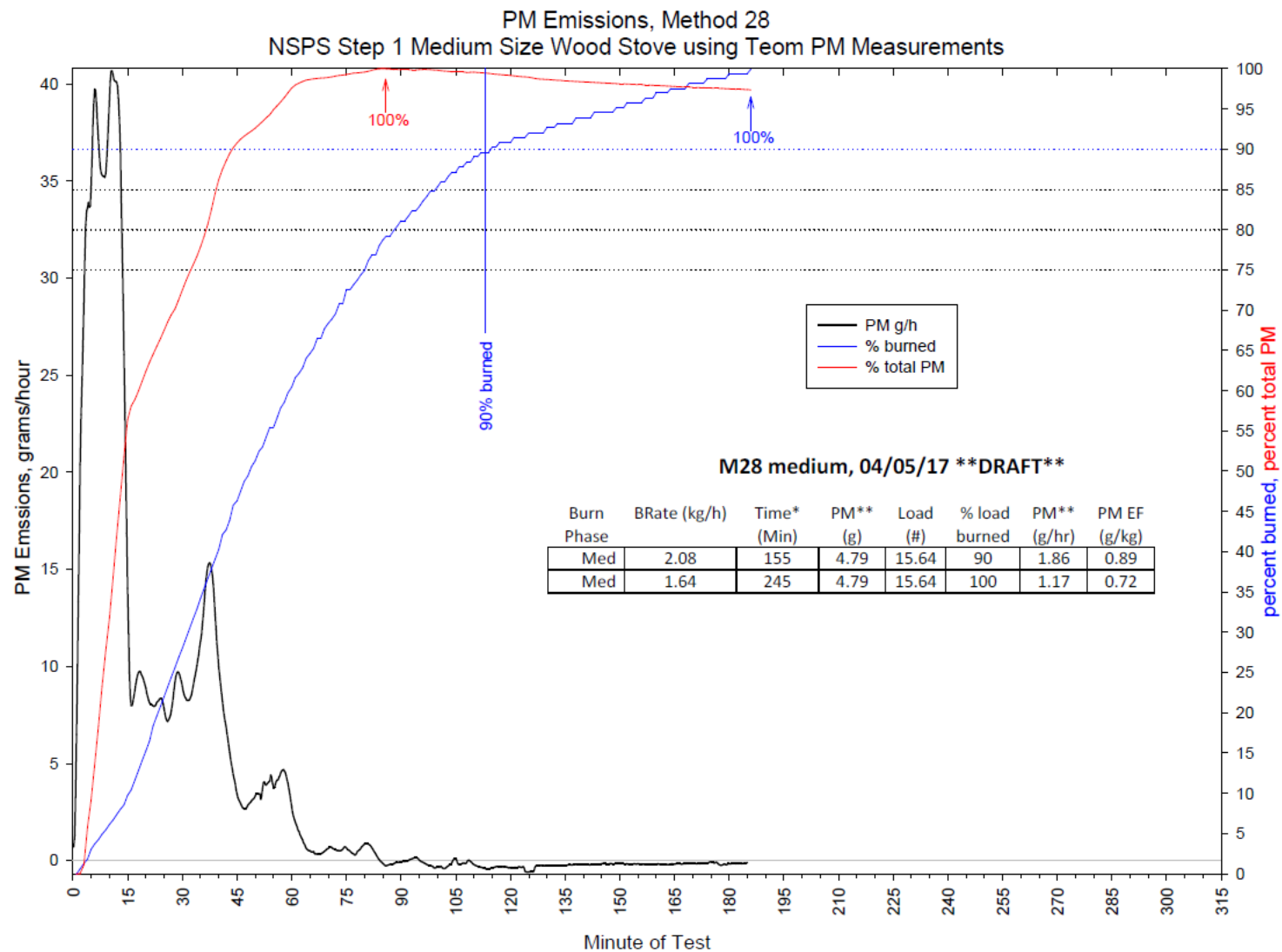
# PM Emissions, Method 28 NSPS Step 1 Medium Size Wood Stove using Teom PM Measurements



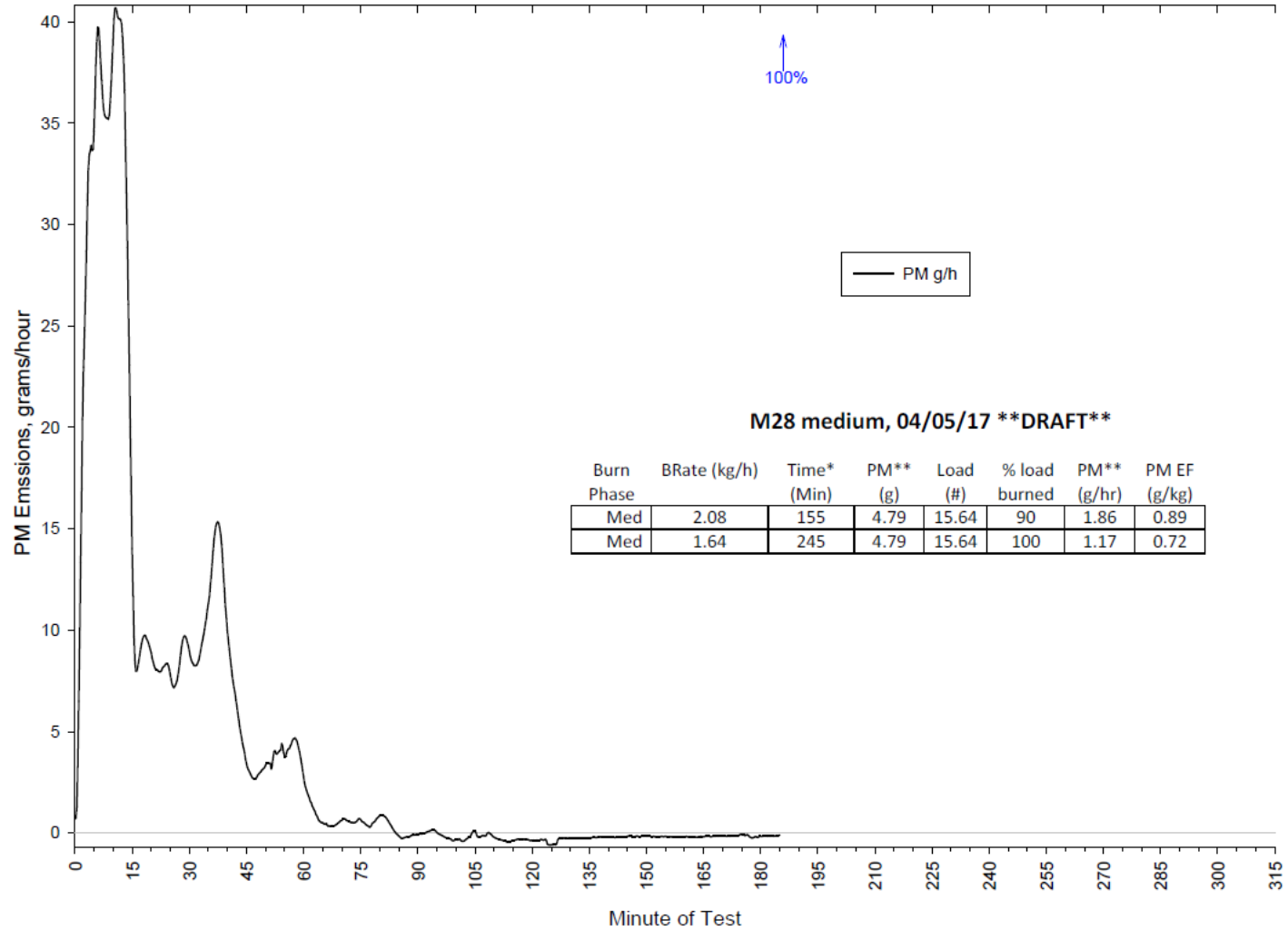
M28 high, 03/31/17 \*\*DRAFT\*\*

Burn Phase	BRate (kg/h)	Time* (Min)	PM** (g)	Load (#)	% load burned	PM** (g/hr)	PM EF (g/kg)
High	3.48	93	9.58	15.68	90	6.18	1.78
High	2.47	144	9.58	15.68	100	3.99	1.62





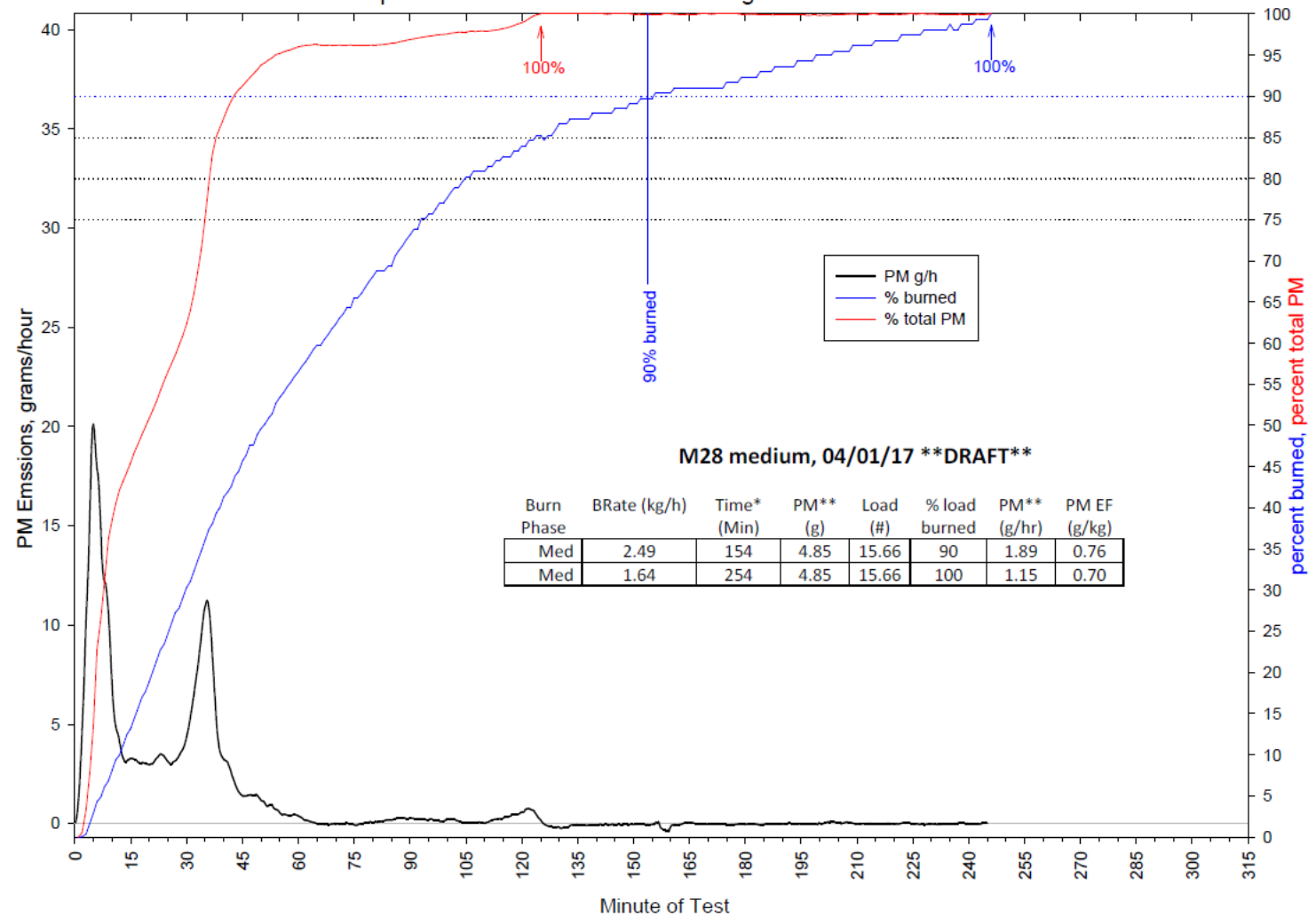
PM Emissions, Method 28  
NSPS Step 1 Medium Size Wood Stove using Teom PM Measurements



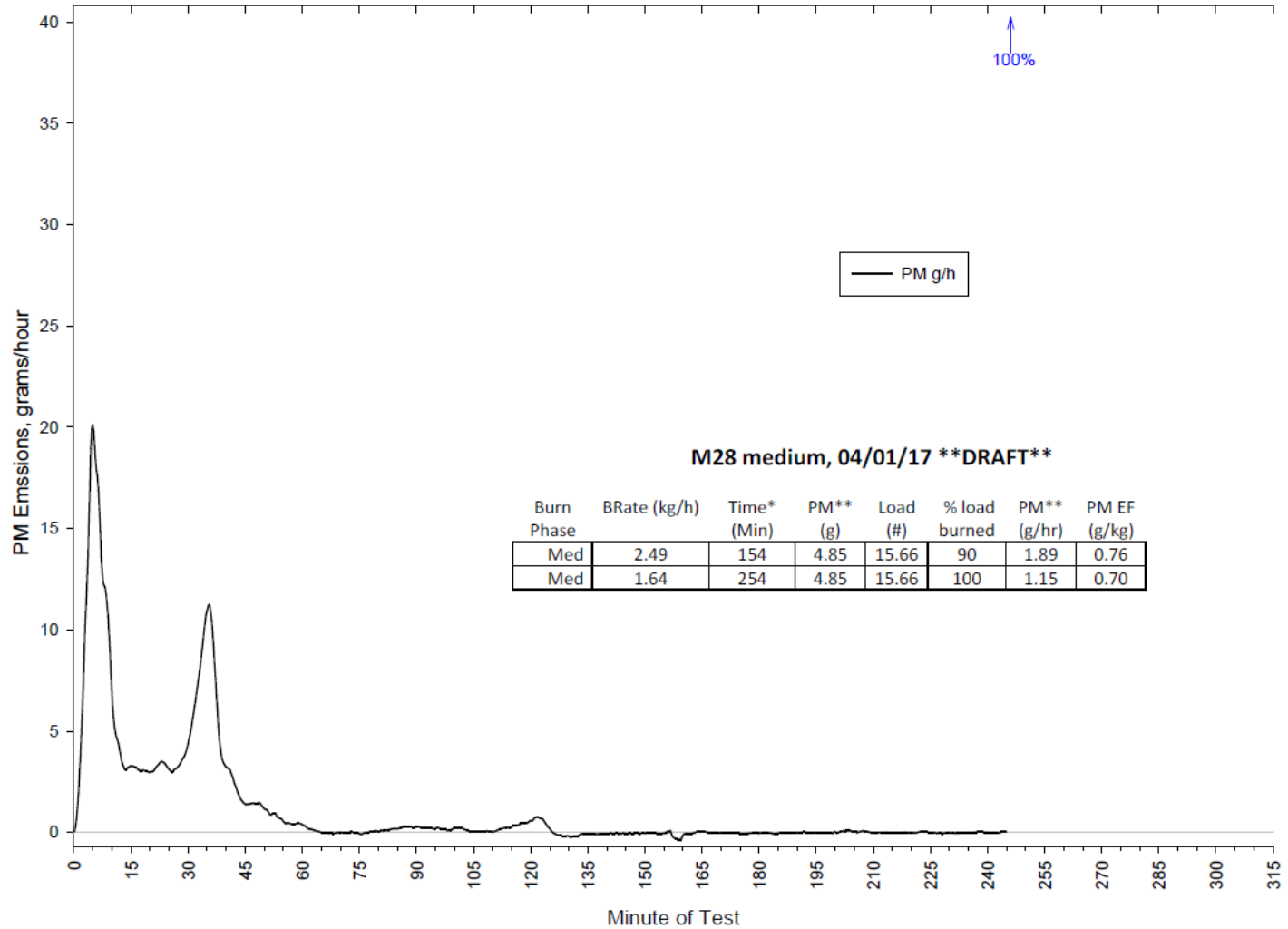
M28 medium, 04/05/17 \*\*DRAFT\*\*

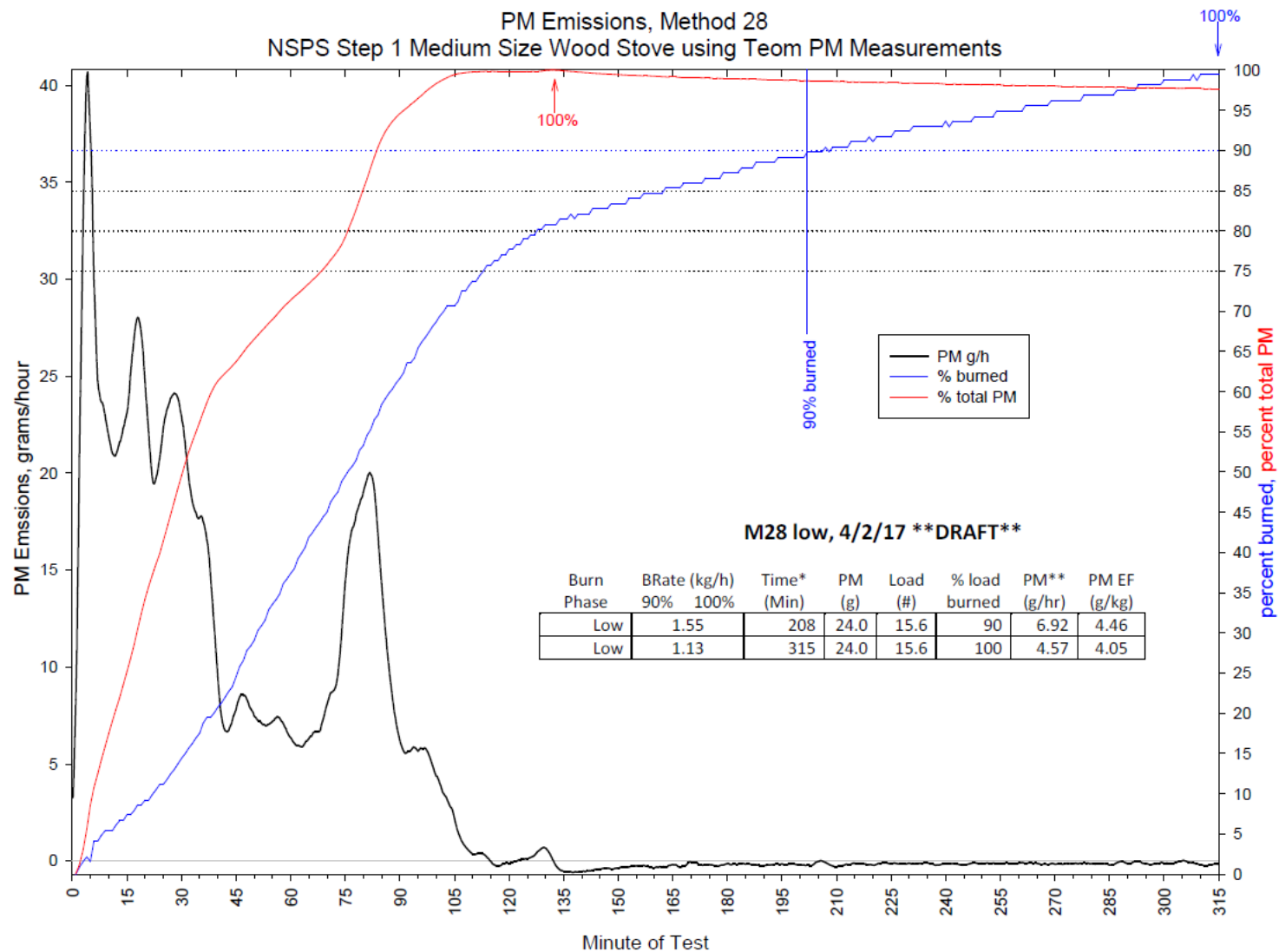
Burn Phase	BRate (kg/h)	Time* (Min)	PM** (g)	Load (#)	% load burned	PM** (g/hr)	PM EF (g/kg)
Med	2.08	155	4.79	15.64	90	1.86	0.89
Med	1.64	245	4.79	15.64	100	1.17	0.72

# PM Emissions, Method 28 NSPS Step 1 Medium Size Wood Stove using Team PM Measurements

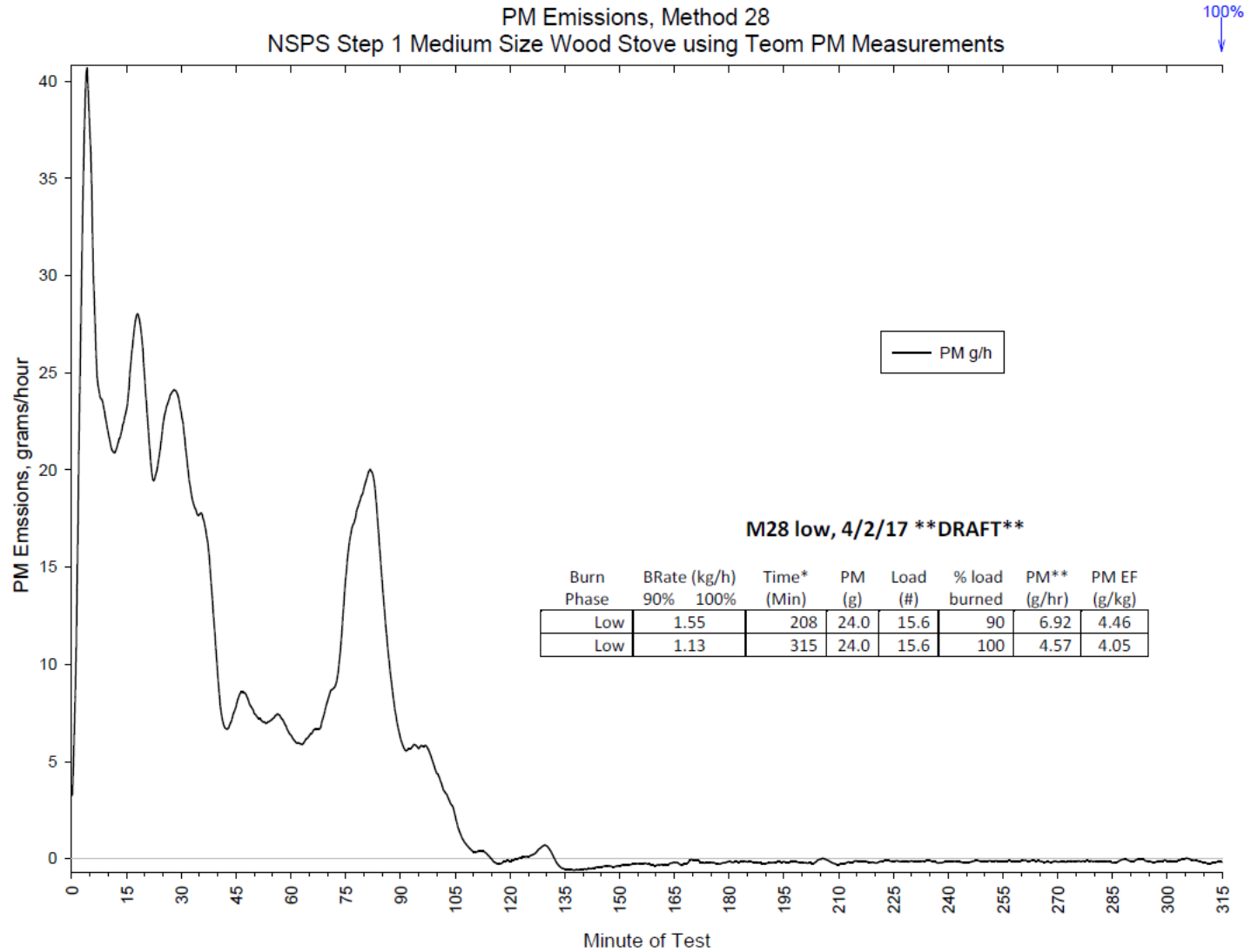


PM Emissions, Method 28  
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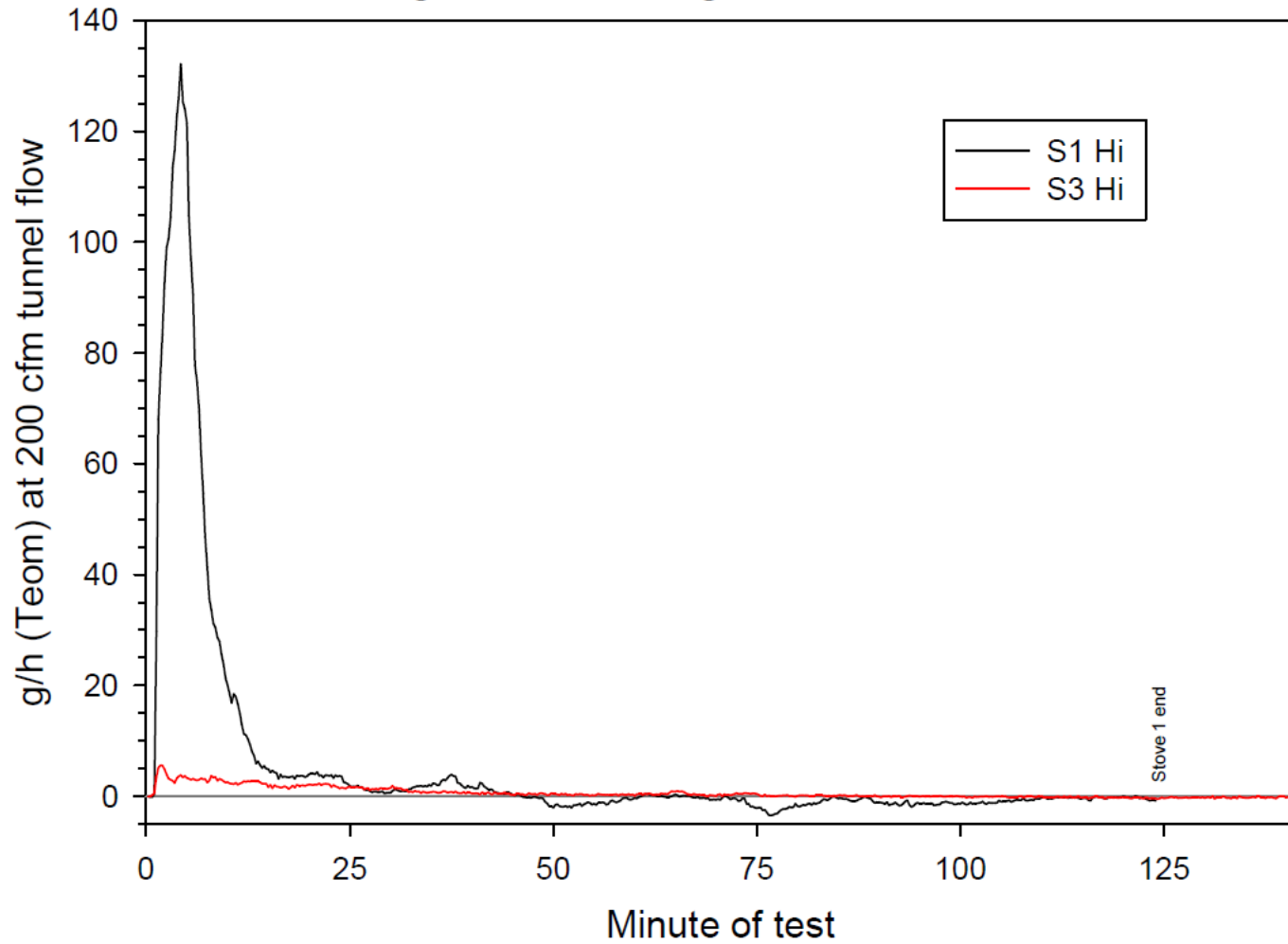


PM Emissions, Method 28  
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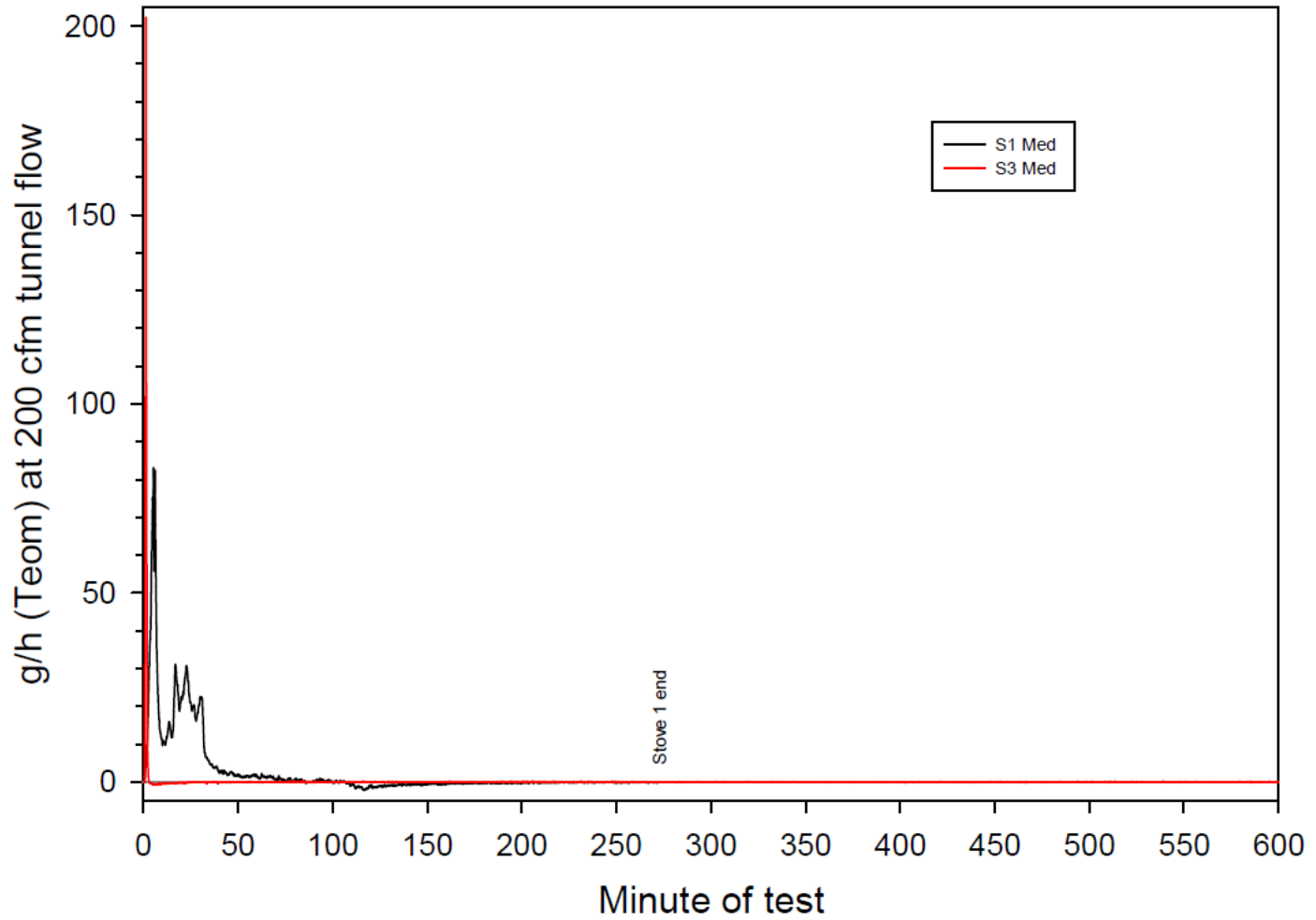




## M28 High Fire, Teom g/h, October 2017 HLS



## M28 Medium Fire, Teom g/h, October 2017 HLS



## M28 Low Fire, Teom g/h, October 2017 HLS

