

Worldwide Pollution Control Association

WPCA-Duke Energy

Is Your Precipitator Ready for MATS?

Aug. 28, 2012 – Plainfield

Sept. 11, 2012 - Charlotte

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Fuel Effects on ESP Performance



By
Tom Lugar

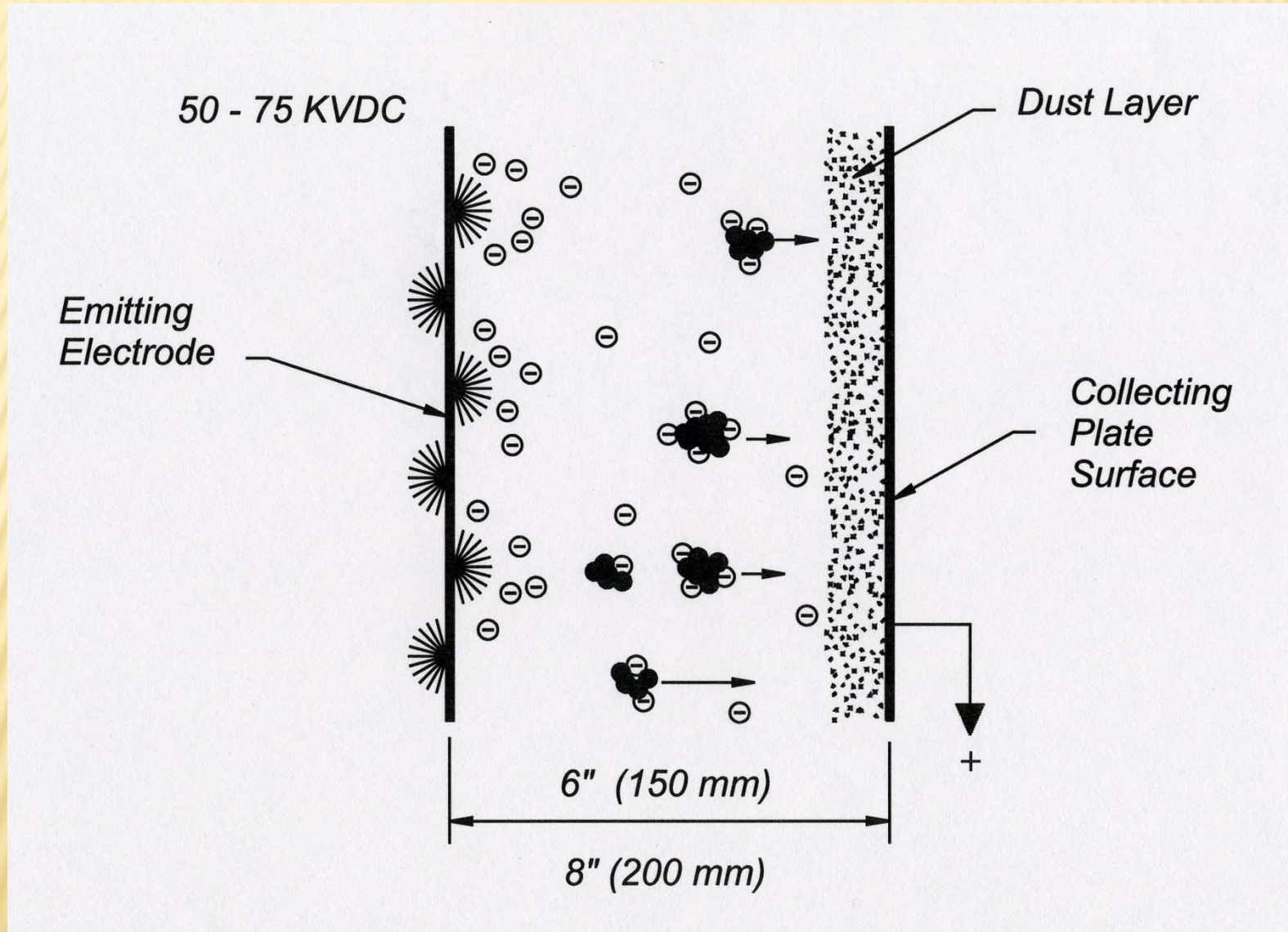
MET 
Marsulex Environmental Technologies

**Fundamentals
of
Electrostatic Precipitator
(ESP) Operation**

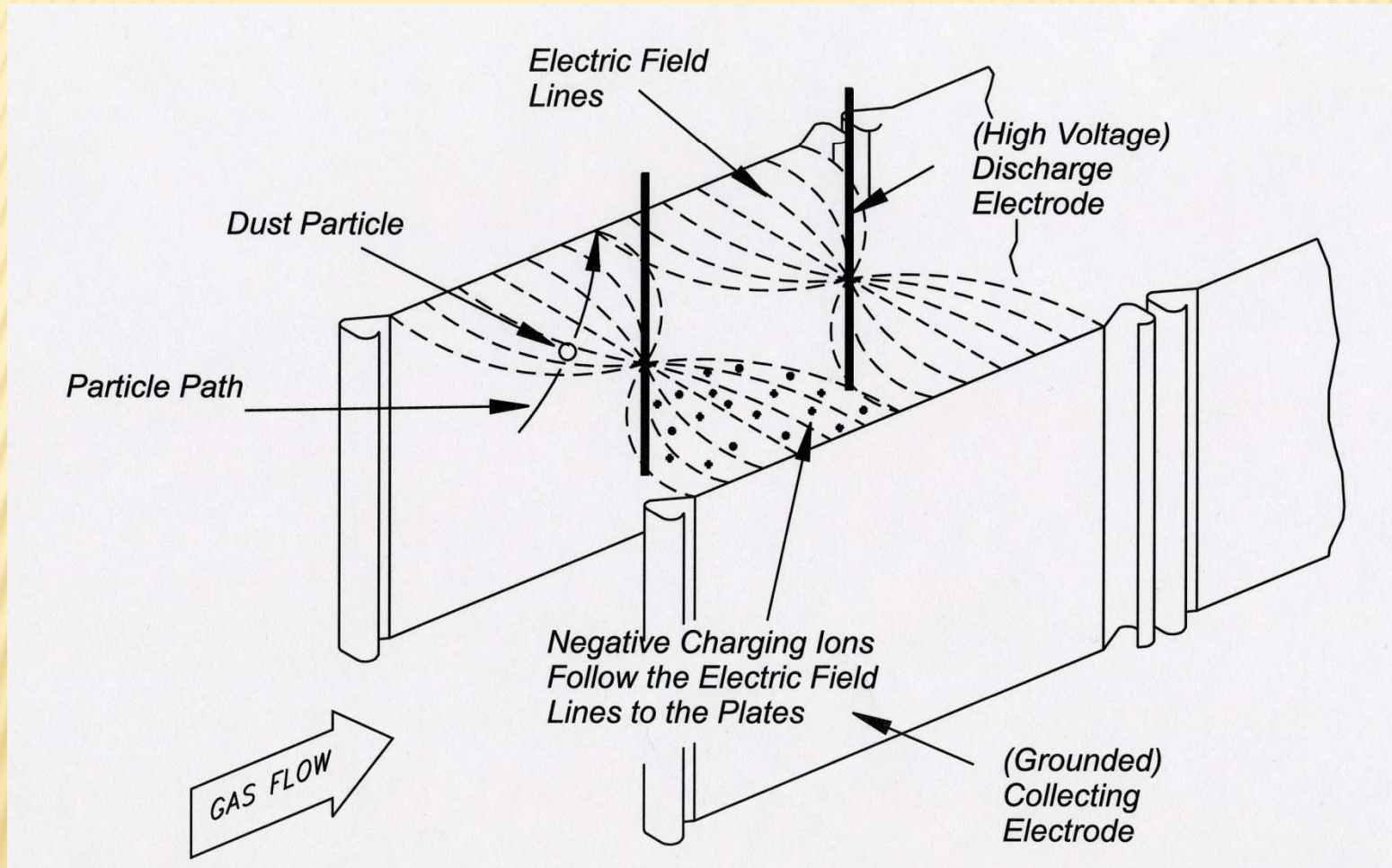
The Process in Electrostatic Precipitation

- **Particle Charging**
- **Particle Collection**
- **Removal of Collected Particulate**

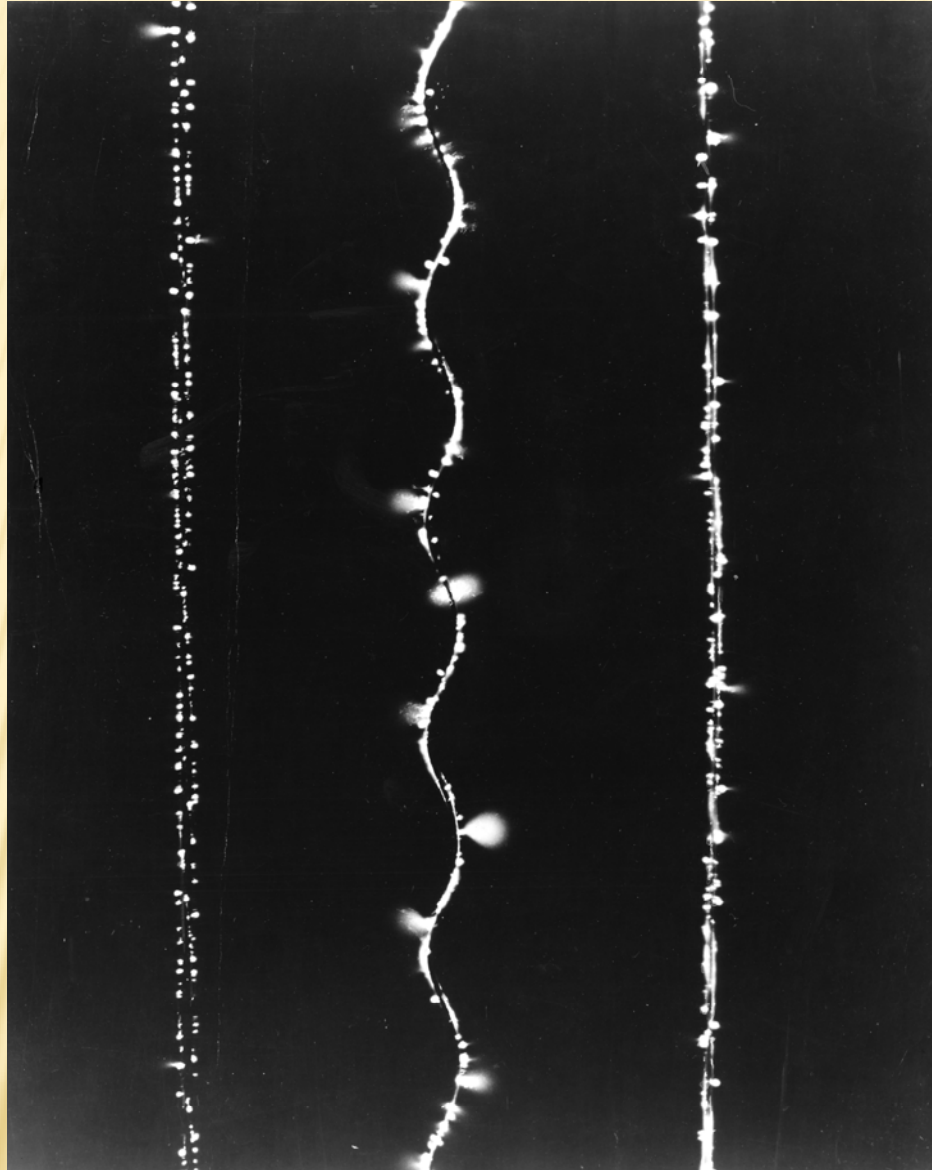
Particle Charging and Collection



ESP Gas Passage – Particle Charging & Collection



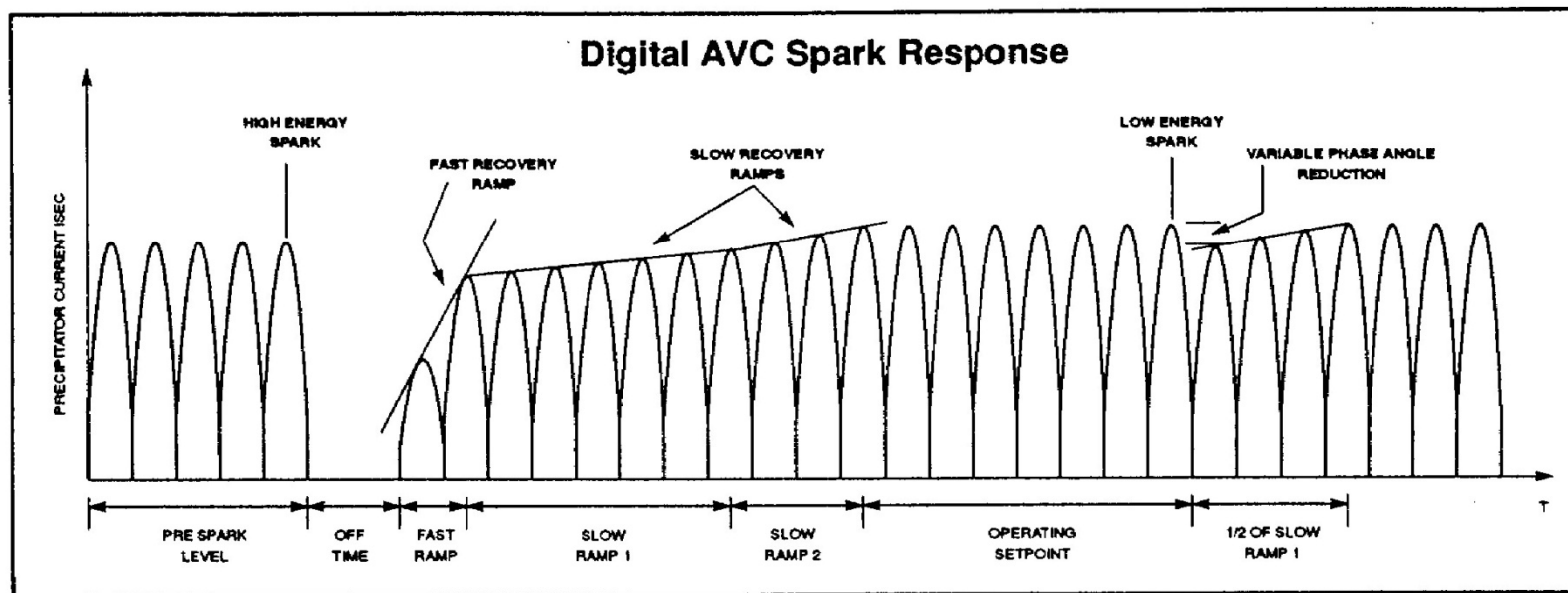
Emitting Electrodes Corona Emission

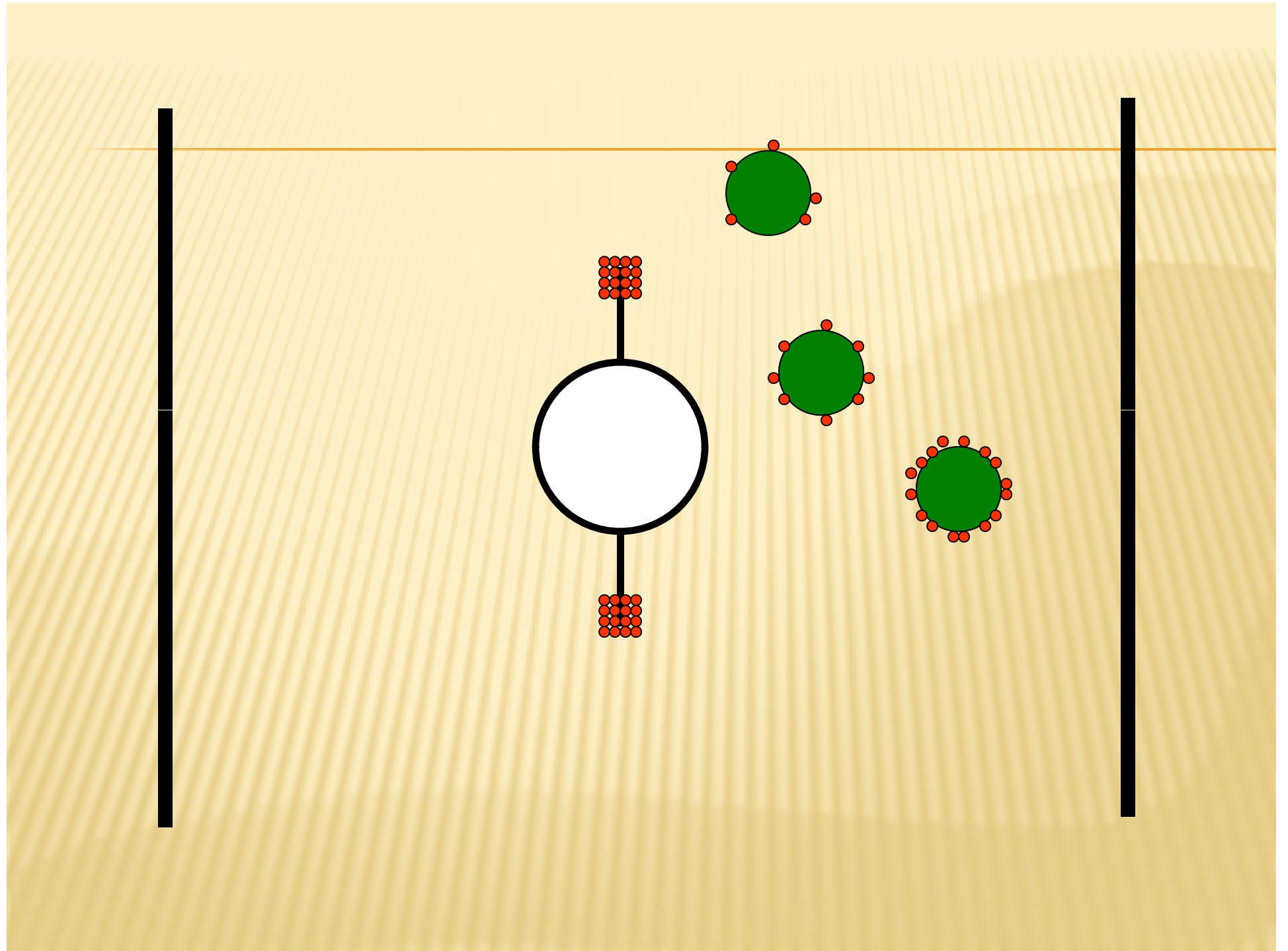


Emitting Electrodes Corona Emission



Automatic Voltage Control (Typical)





Factors Affecting ESP Sizing and Performance

Precipitator Sizing

Deutsch Equation for ESP Collection Efficiency

$$\eta = 1 - e^{-(Aw/Q)}$$

Where: η = Collection Efficiency, fraction

A = Collecting Plate Area, ft²

Q = Flue Gas Volume, ft³/sec (actual)

W = Charged Particle Migration Velocity, ft/sec

The migration velocity of the charged particulate is roughly proportional the precipitator voltage.

$$W \propto V^2$$

It is therefore critical that a high voltage level be maintained in the precipitator for optimal charging and collection.

Specific Collecting Area - SCA

$$\text{SCA} = \frac{\text{Collecting Plate Area ft}^2}{1000 \text{ ft}^3/\text{min. flue gas treated}}$$

Example: 400,000 ft² plate area
1,000,000 ACFM Gas Flow

$$\text{SCA} = 400$$

Fuel Effects on ESP Performance

Ash Content and Chemical Properties, Resistivity

For a given gas volume, precipitator sizing and performance are dependent on the following specified or assumed parameters:

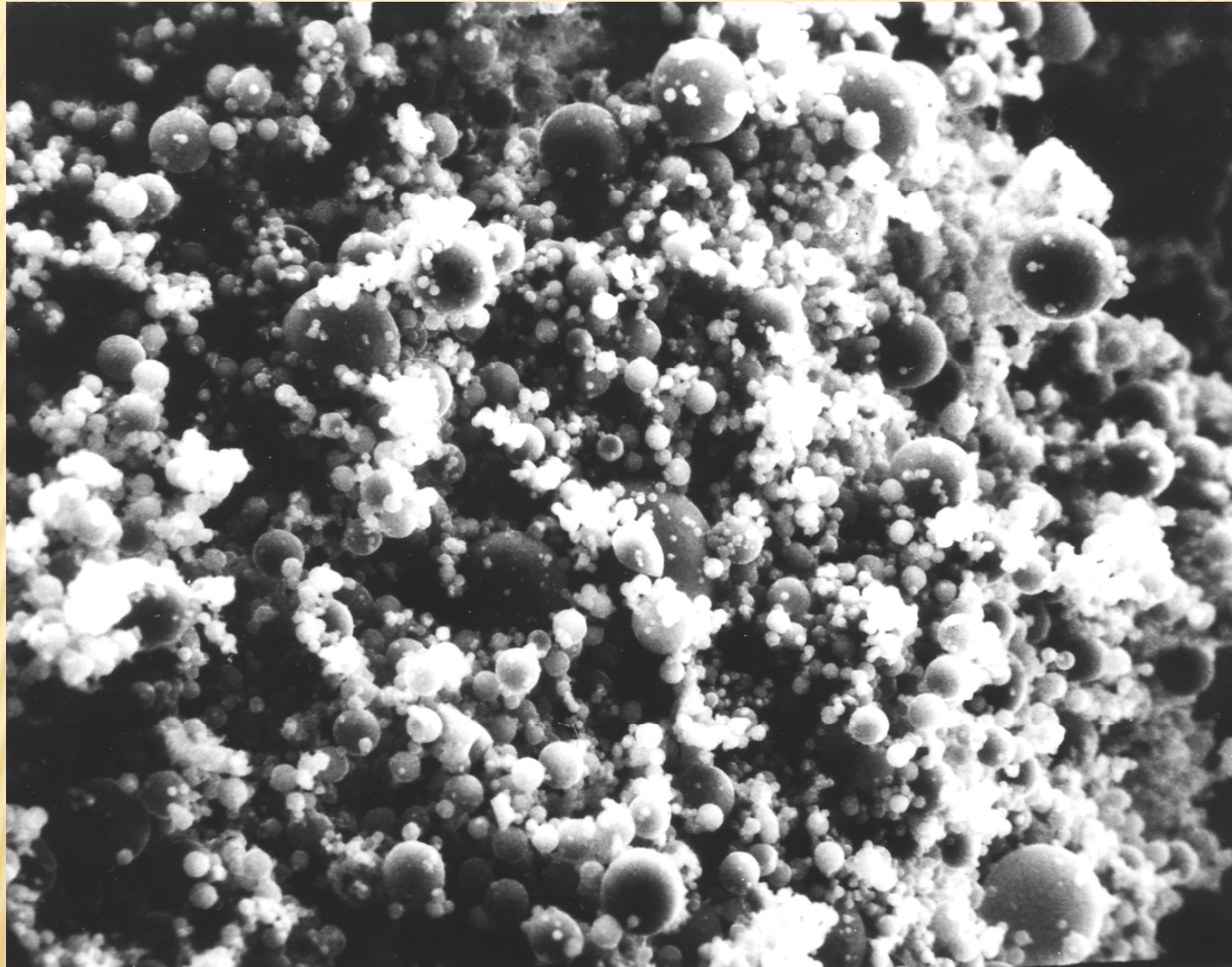
- **Ash Particle Size**
- **Ash Loading**
- **Ash Resistivity**

The above parameters vary depending on the type of boiler, fuel, flue gas temperature and flue gas constituents.

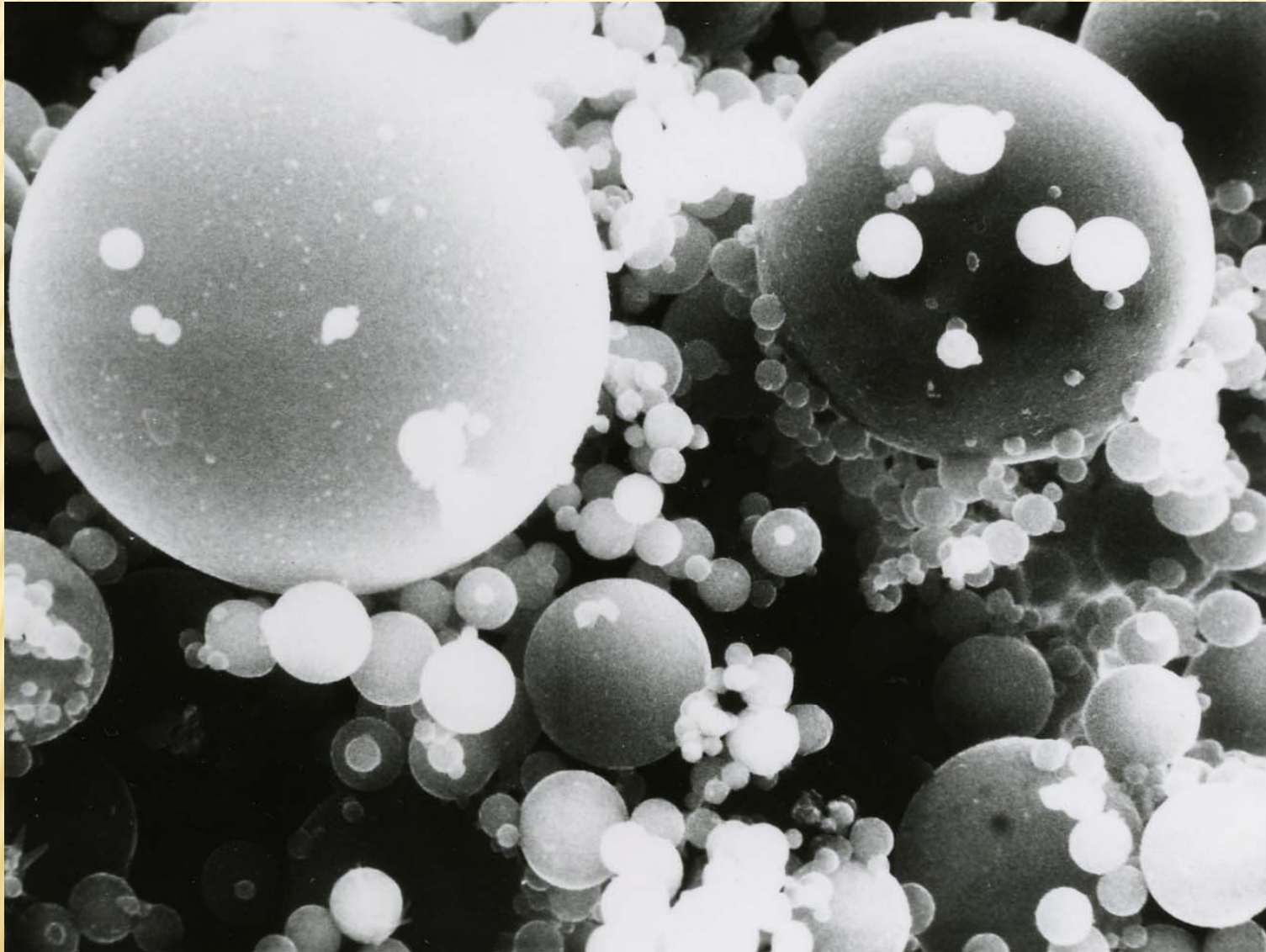
Particle Size Considerations

- **Very fine particles, less than one micron diameter, provide small cross sections or targets for capture of negative ions.**
- **Fine particles require more treatment time to capture a sufficient number of ions to attain an adequate charge.**
- **Charged particles less than 1 micron travel to the grounded plates in a random motion instead of a more direct path as taken by larger ash particles.**
- **The particulate removal efficiency of the outlet electrical fields of an ESP will be less than that of the inlet fields.**

**ESP Collecting Plate Flyash Layer
Scanning Electron Microscope Image – 500X**



**ESP Collecting Plate Flyash Layer
Scanning Electron Microscope Image -2000X**



Ash Loading Considerations

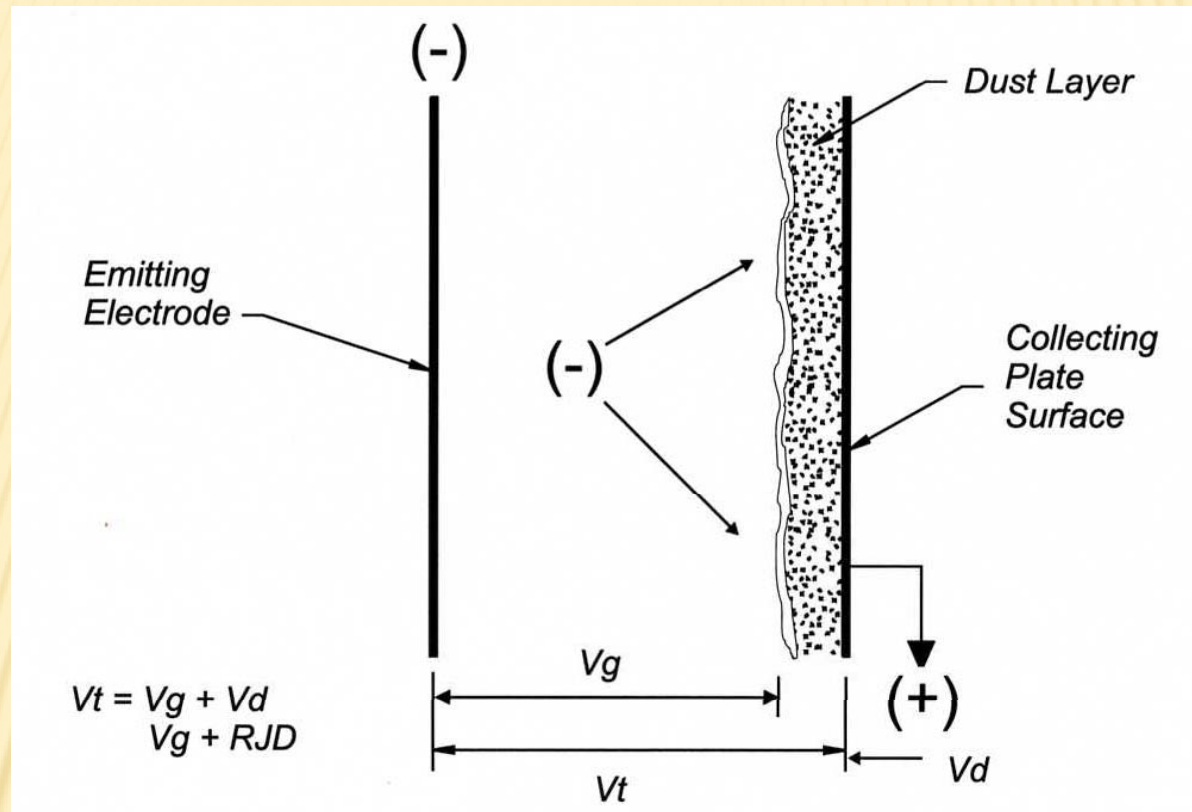
- **High ash loadings interfere with particle charging by suppressing the corona from the emitters and thus the negative ions generated for charging.**
- **The effect of suppression becomes significant if the higher ash loading has a large population of fines.**

Ash Resistivity

Definition: The degree of electrical conductivity of the ash expressed in ohms-cm.

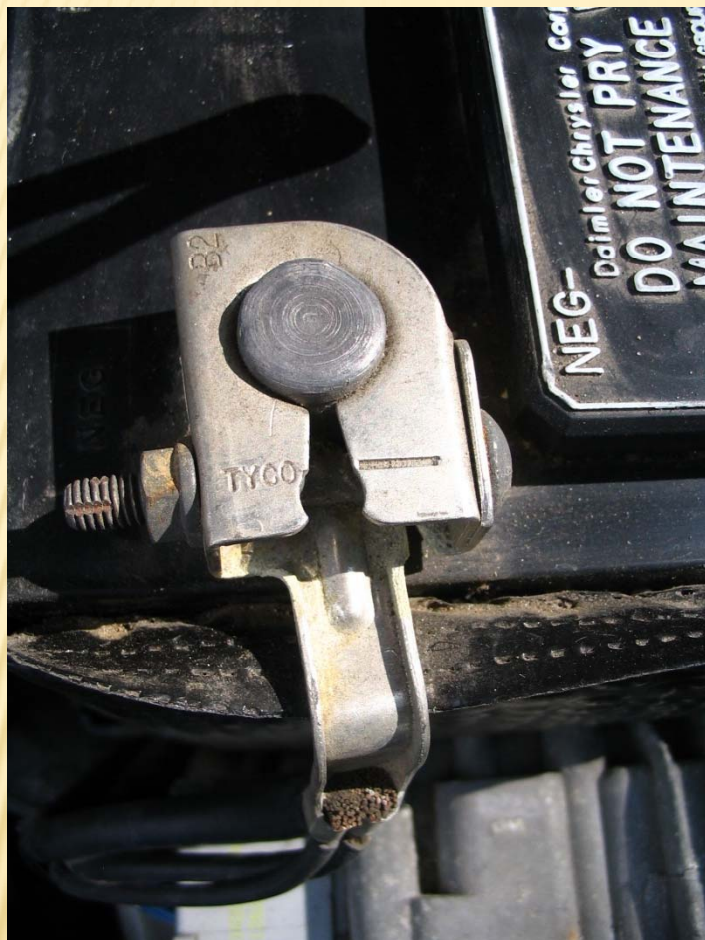
Typical Range: 1×10^9 - 1×10^{13}

The value of resistivity depends on the flue gas temperature, gas constituents, and chemical composition of the flyash.



- Due to the resistive ash layer on the collecting plate, ionic charge is stored on the ash layer surface and only a small amount of current flows through the ash layer to the grounded plate.
- Most of the voltage drop is in the ash layer and not in the gap where particle charging occurs.

Car Battery Analogy



Current flow is reduced due to the resistivity of the corrosive layer between the battery clamp and terminal.

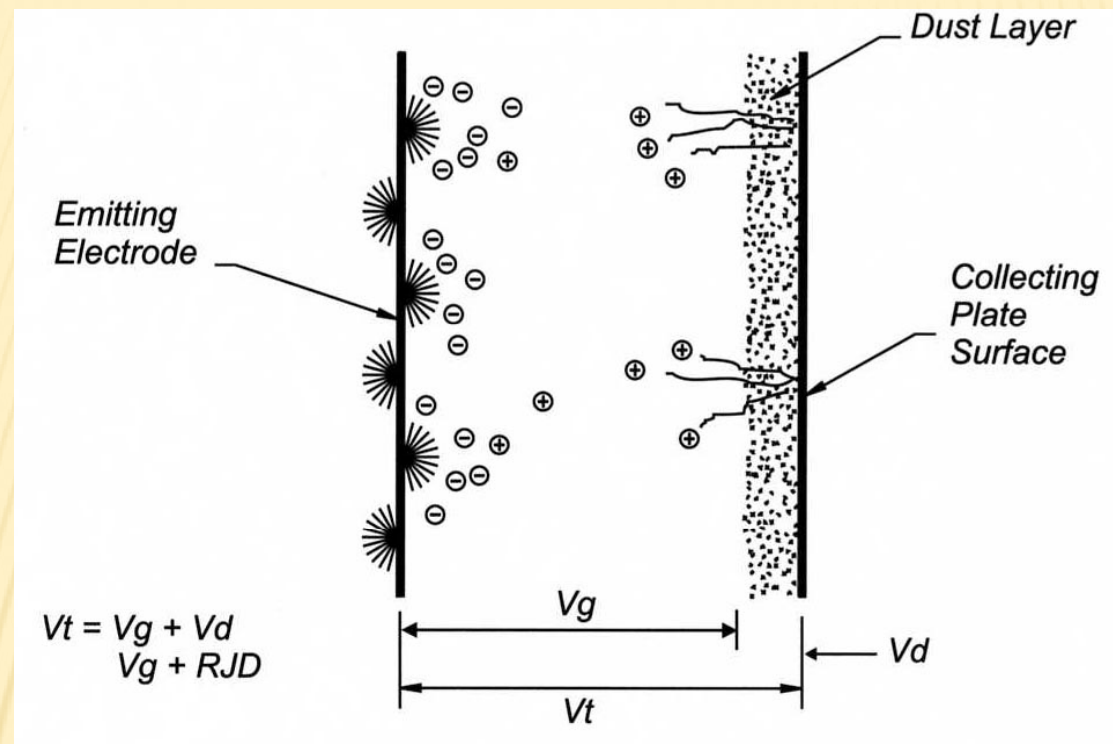
Effect of Low Ash Resistivity, $<1 \times 10^8$

- Collected ash particles lose their charge quickly and become re-entrained into the gas stream.

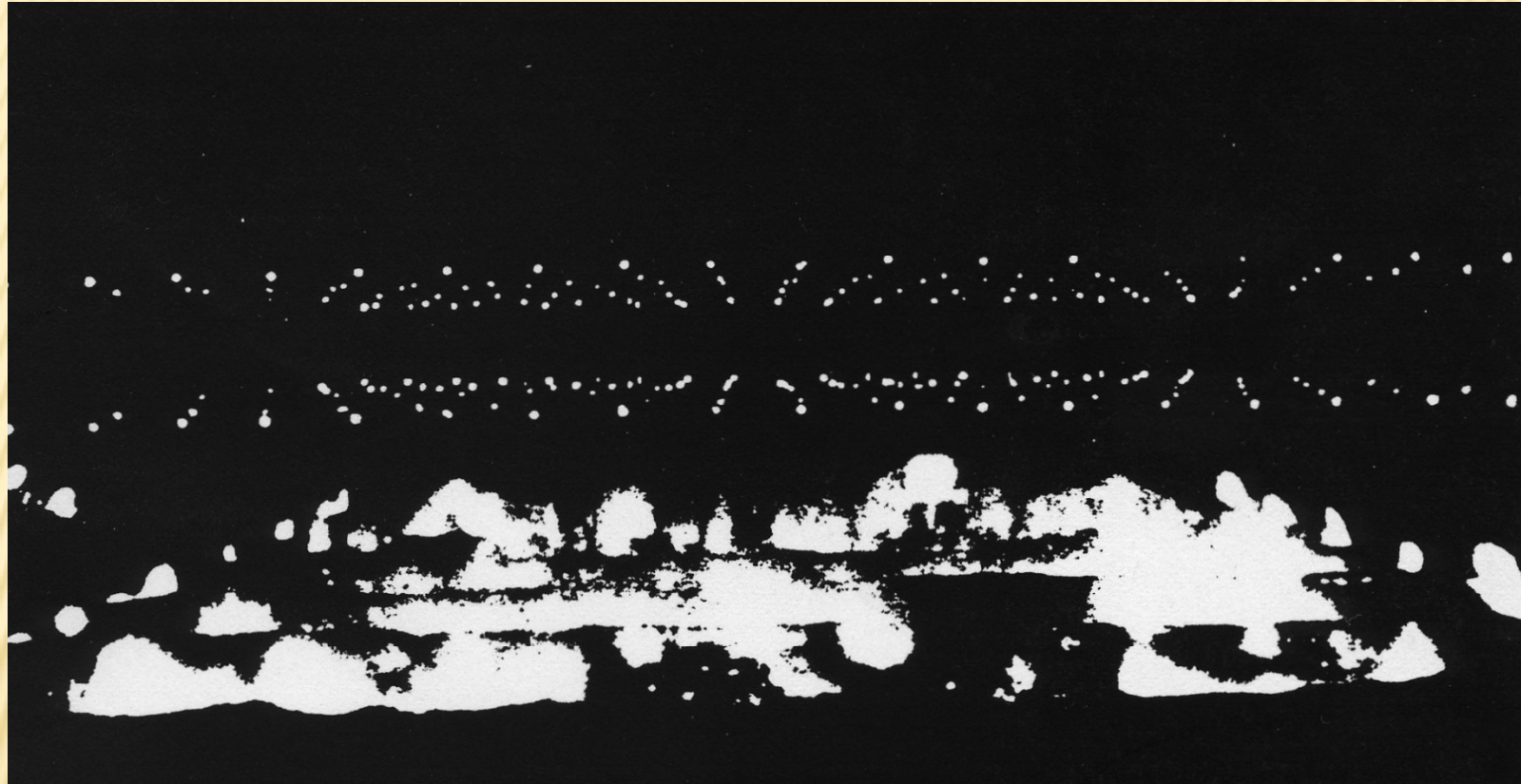
Effect of High Ash Resistivity, $10^{12} - 10^{13}$

- Low power levels, low voltage sparking, back corona formation.

Back Corona

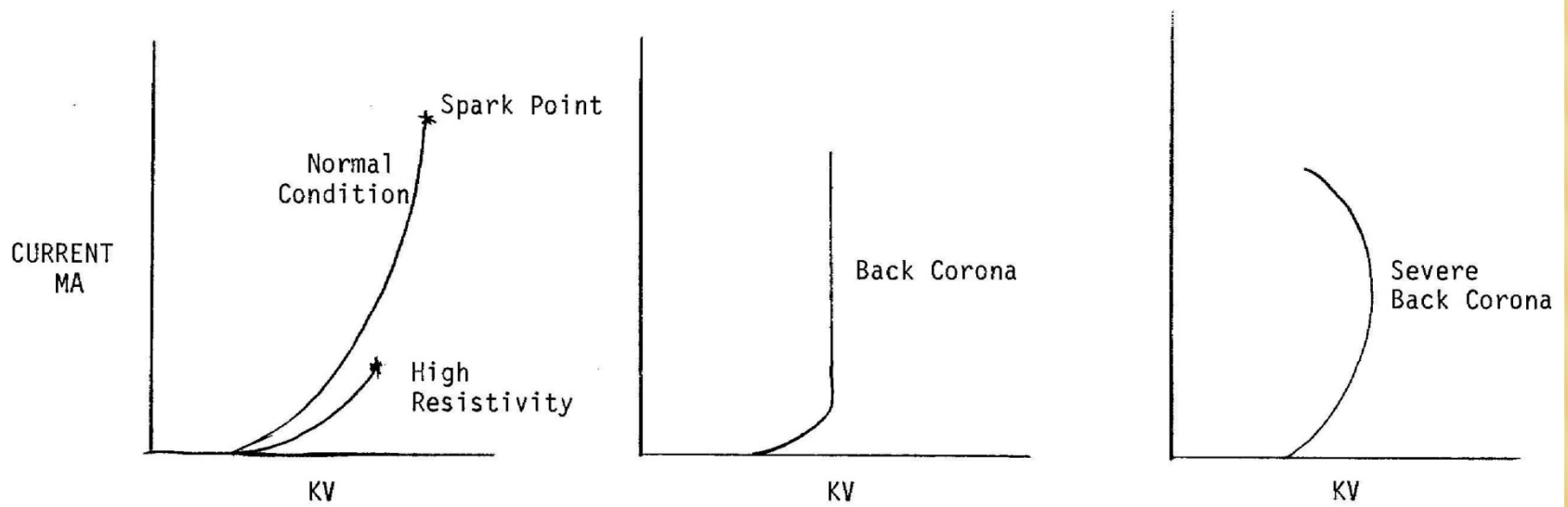


- If the ash layer voltage drop is very large due to very high resistivity, Back Corona will form when the ash layer breaks down and the total voltage, V_t , is not sufficient for sparkover.
- With Back Corona, positive corona occurs on the ash layer surface forming positive ions that are attracted to the negative polarity emitters. Positive ions encounter negative ions effectively canceling their contribution to the particle charging process.

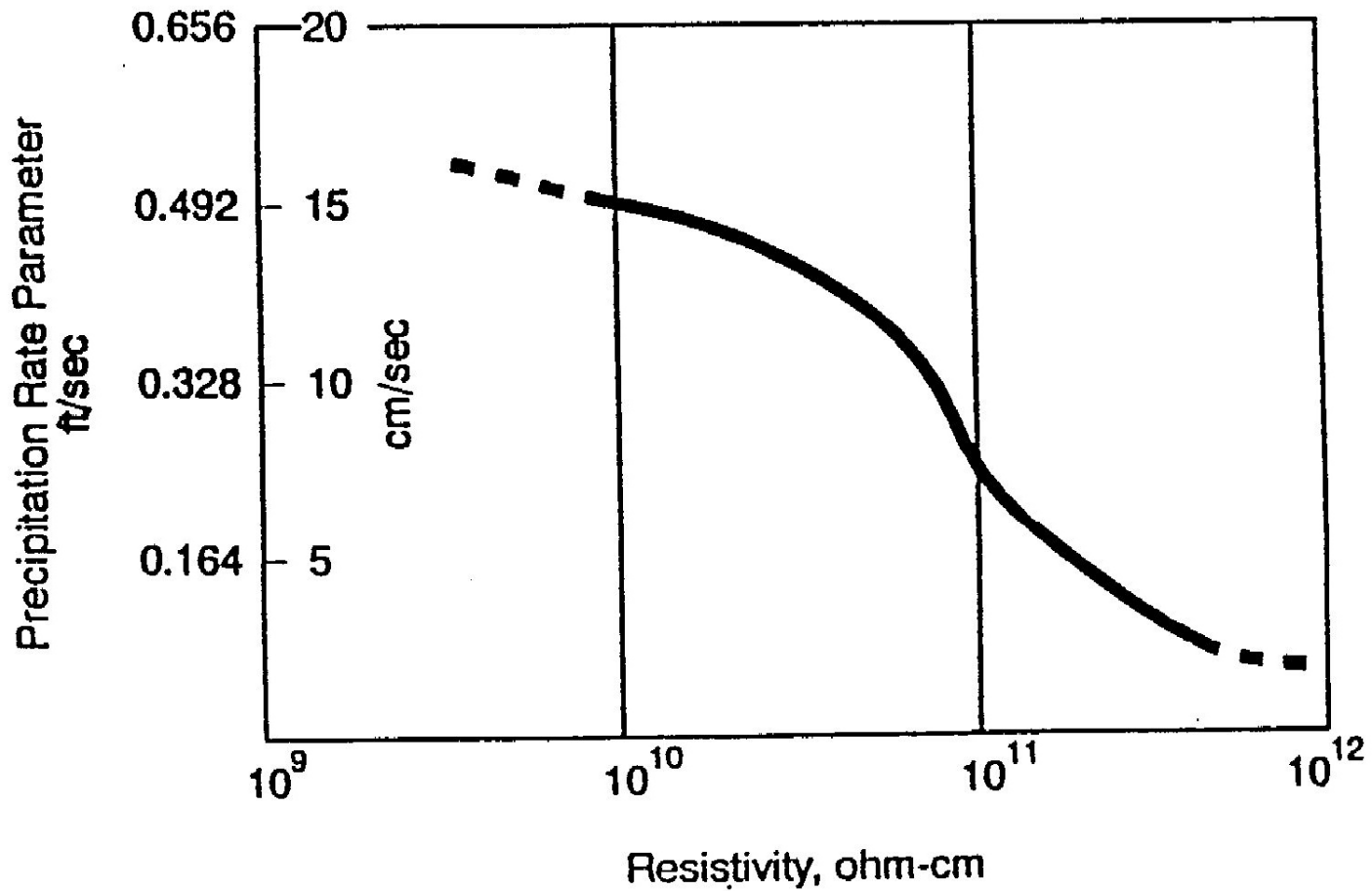


Back Corona Glow Regions on Collecting Plate Ash Surfaces
Plan View – Looking Down Into a Gas Passage

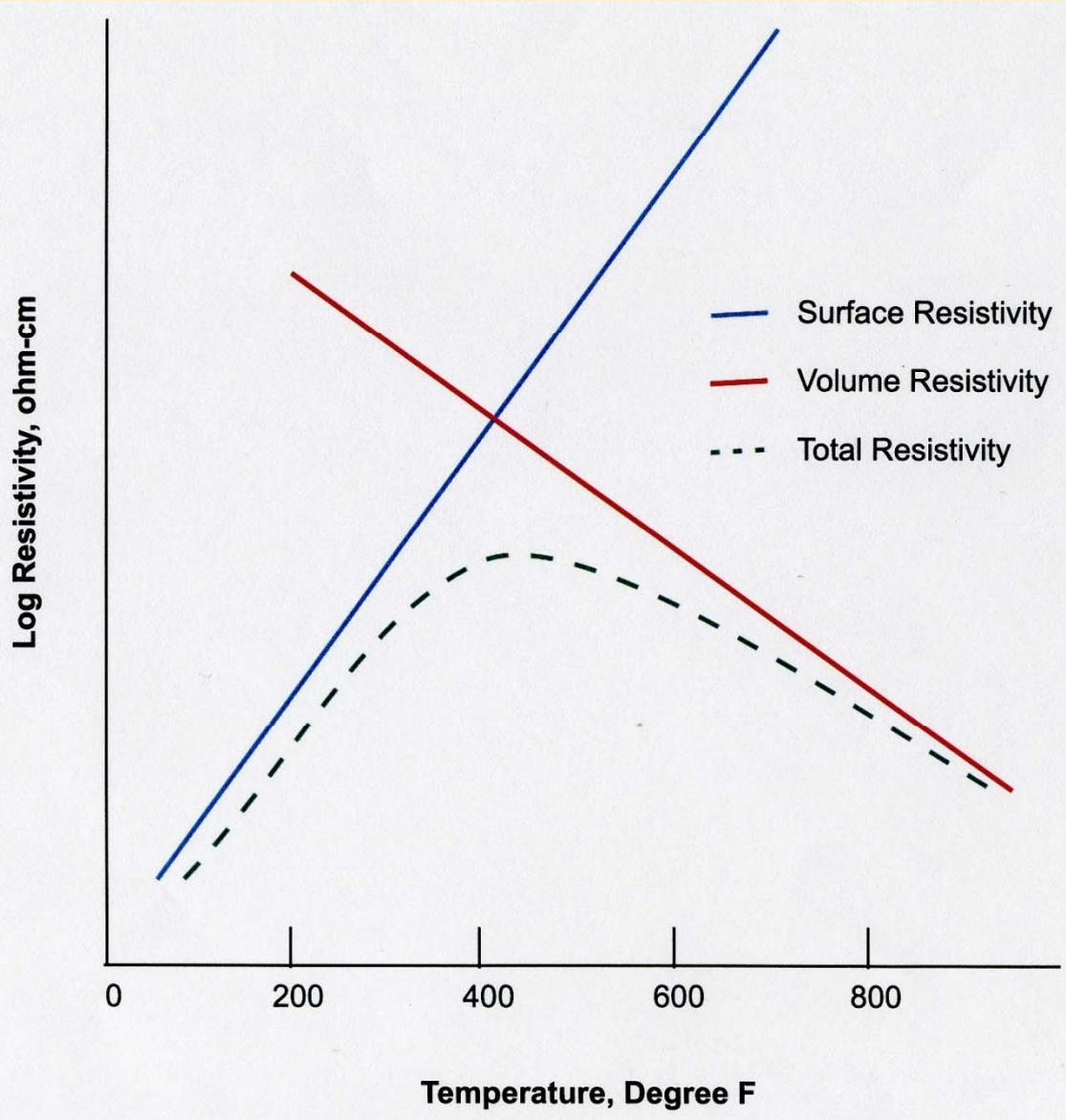
SAMPLE VOLTAGE-CURRENT CHARACTERISTIC CURVES



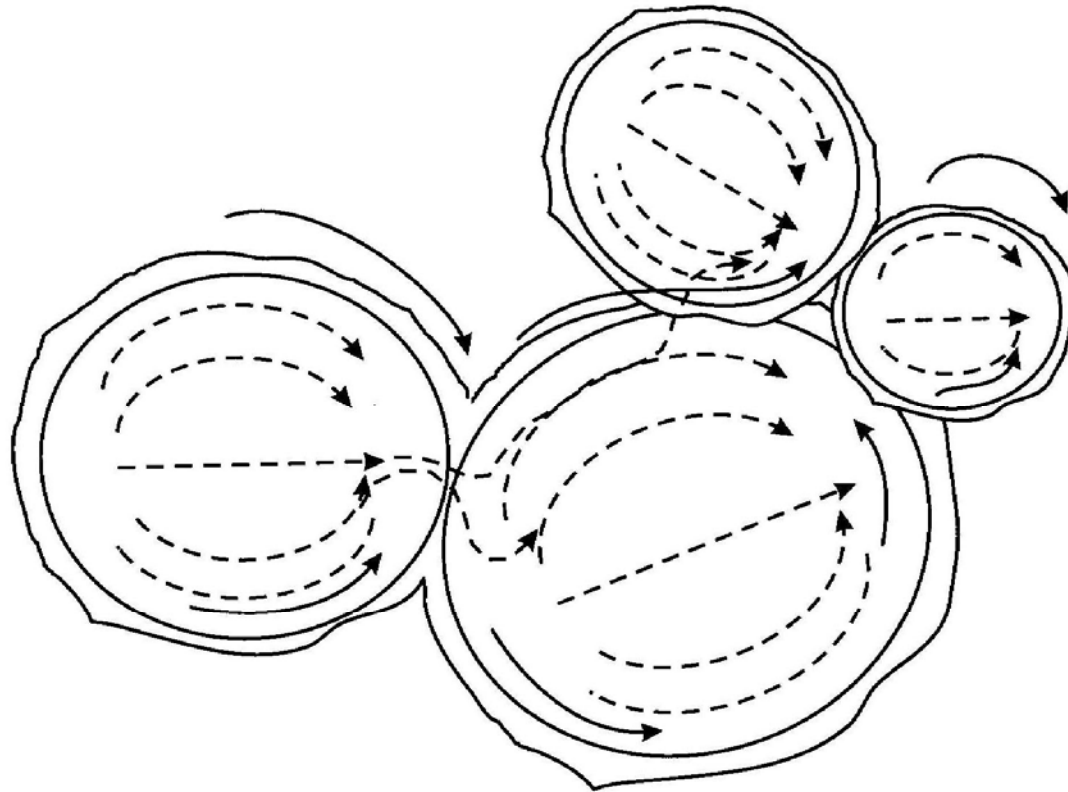
Effect of High Ash Resistivity on Charged Particle Migration Velocity



Factors Affecting Flyash Resistivity



Surface and Volume Conduction

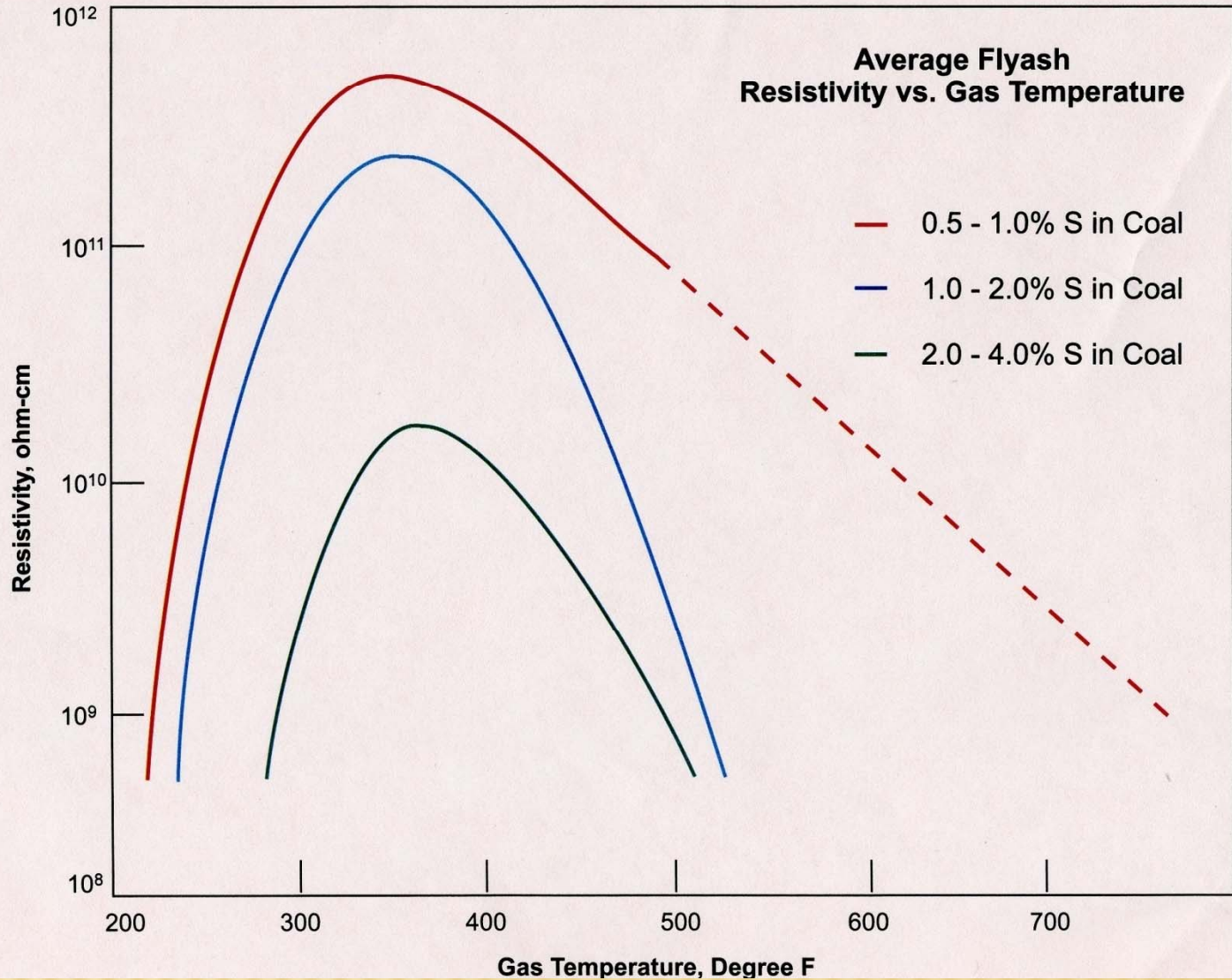
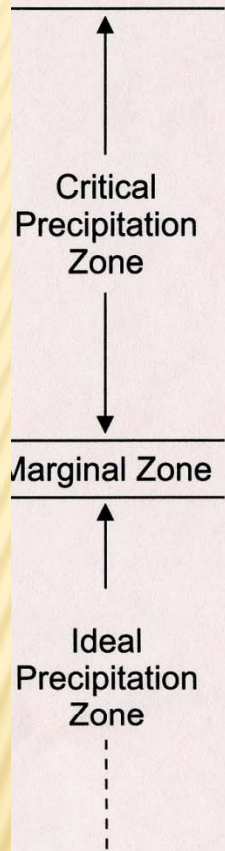


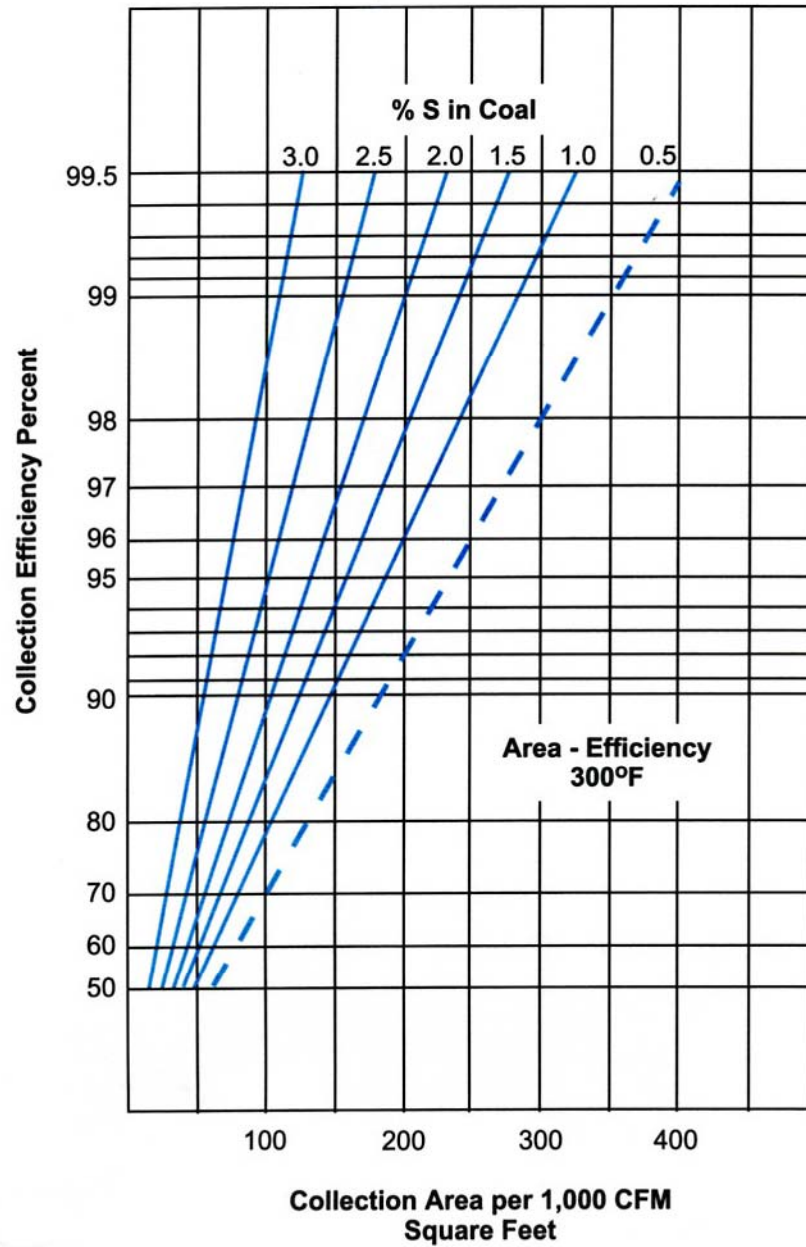
Surface Conduction \longrightarrow

Volume Conduction $\text{-----}\longrightarrow$

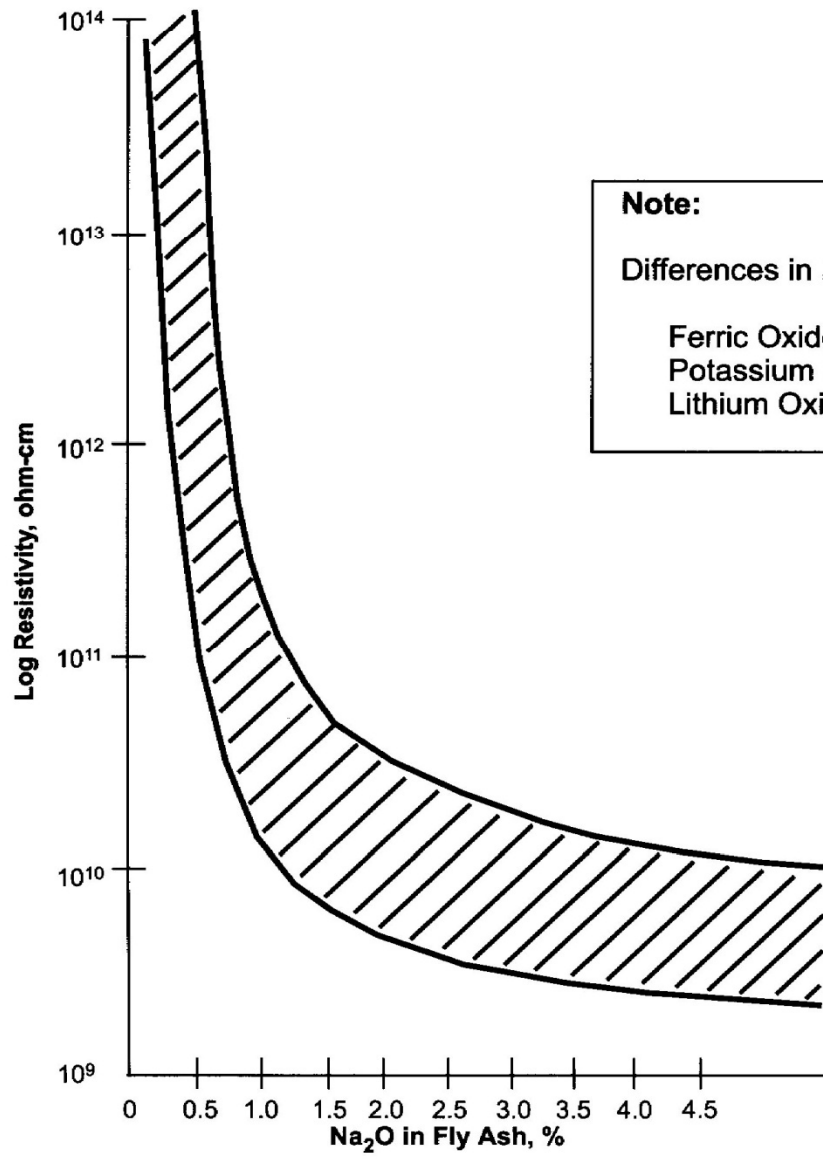
Surface Conduction Charge Carriers: H^+ , OH^- , Na^+ , K^+ , Li^+ , HSO_4^- , SO_4^{2-} Ions

Volume Conduction Charge Carriers: Na^+ , K^+ , Li^+ Ions





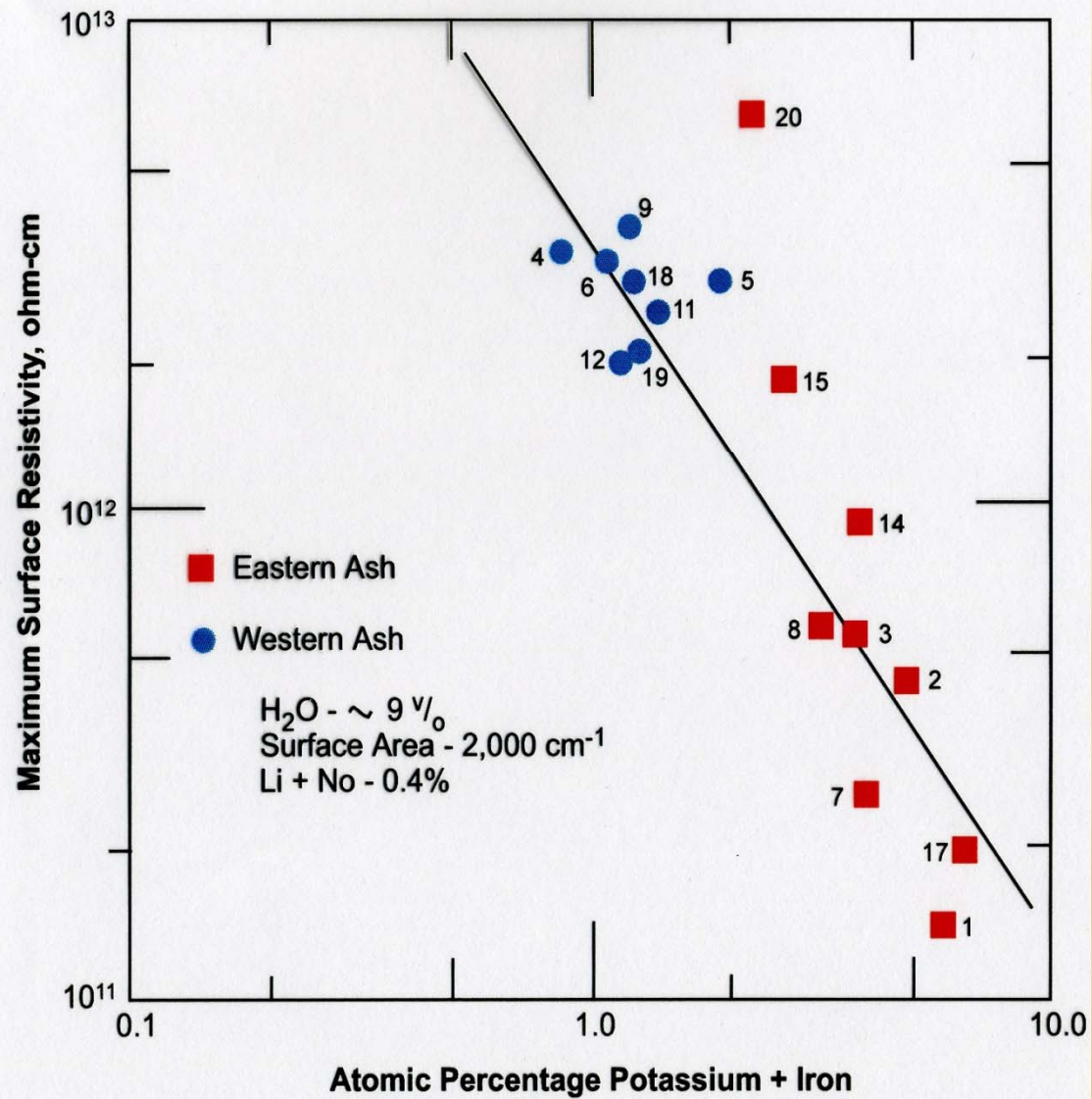
Resistivity of Flyash from Low Sulfur Coal @ 300°F



Note:

Differences in resistivity due to other elements:

Ferric Oxide	Fe_2O_3
Potassium Oxide	K_2O
Lithium Oxide	Li_2O



Elemental Analysis of Flyash

Typical Range of Constituents

<u>Component</u>	<u>Maximum %</u>	<u>Minimum %</u>
SiO ₂	61.00	41.20
Al ₂ O ₃	31.00	17.90
Fe ₂ O ₃	23.70	3.90
CaO	23.50	0.30
MgO	5.50	0.90
Na ₂ O	2.66	0.13
K ₂ O	3.90	0.28
Li ₂ O	0.07	0.01
TiO ₂	2.30	0.80
P ₂ O ₅	1.00	0.16
SO ₃	1.83	0.07

The Major Ash Resistivity Effects Due to Mineral Compounds in the Ash are:

SiO_2 , Al_2O_3 , CaO , MgO - Increases Ash Resistivity

Na_2O , Li_2O - Reduces Ash Resistivity

A Most Difficult Combination of Ash and Coal Constituents For ESP Operation:

$\text{SiO}_2 + \text{Al}_2\text{O}_3 > 80\%$

$\text{Fe}_2\text{O}_3 < 5\%$

$\text{Na}_2\text{O} < 0.5\%$

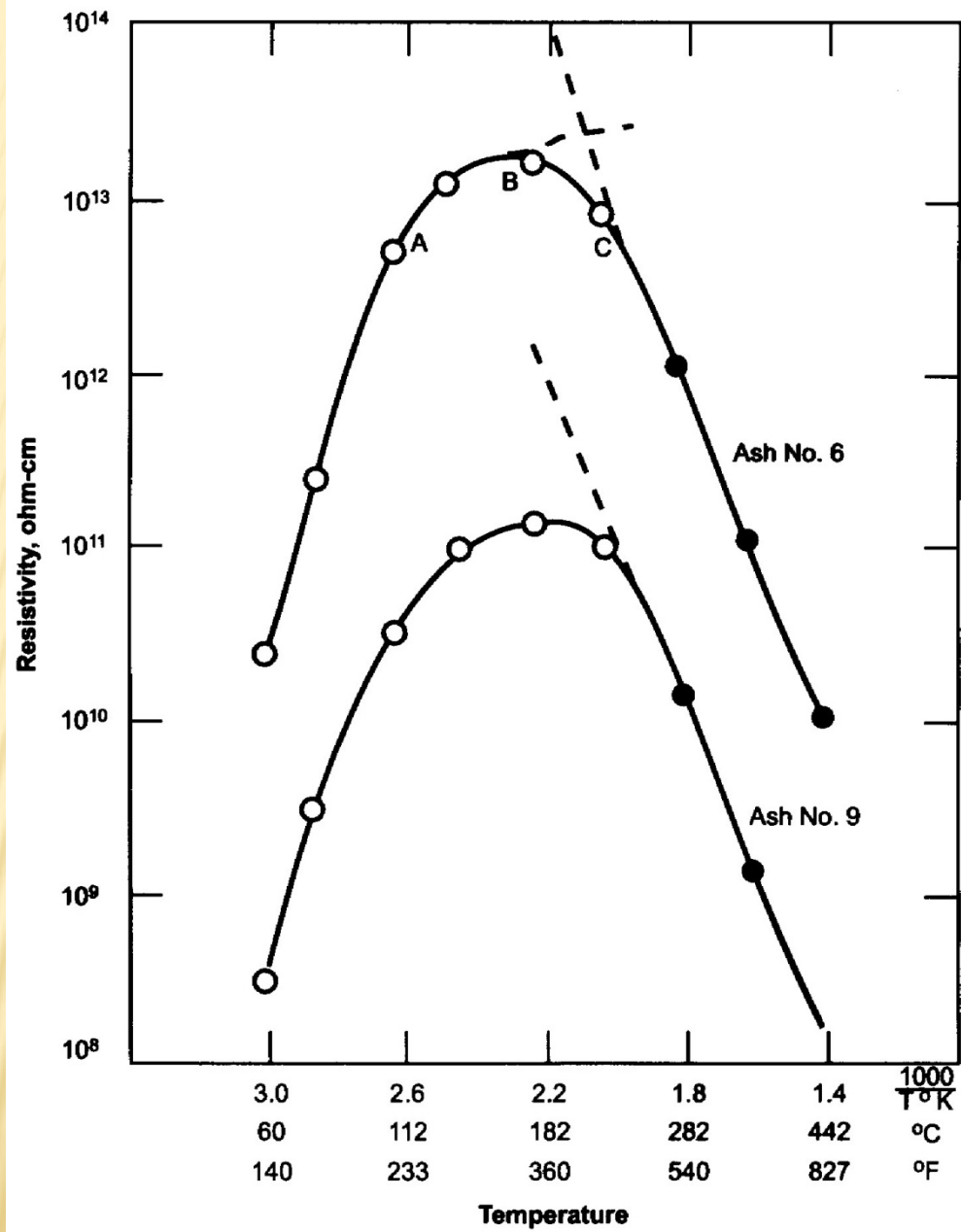
Coal Sulfur Content $< 1\%$

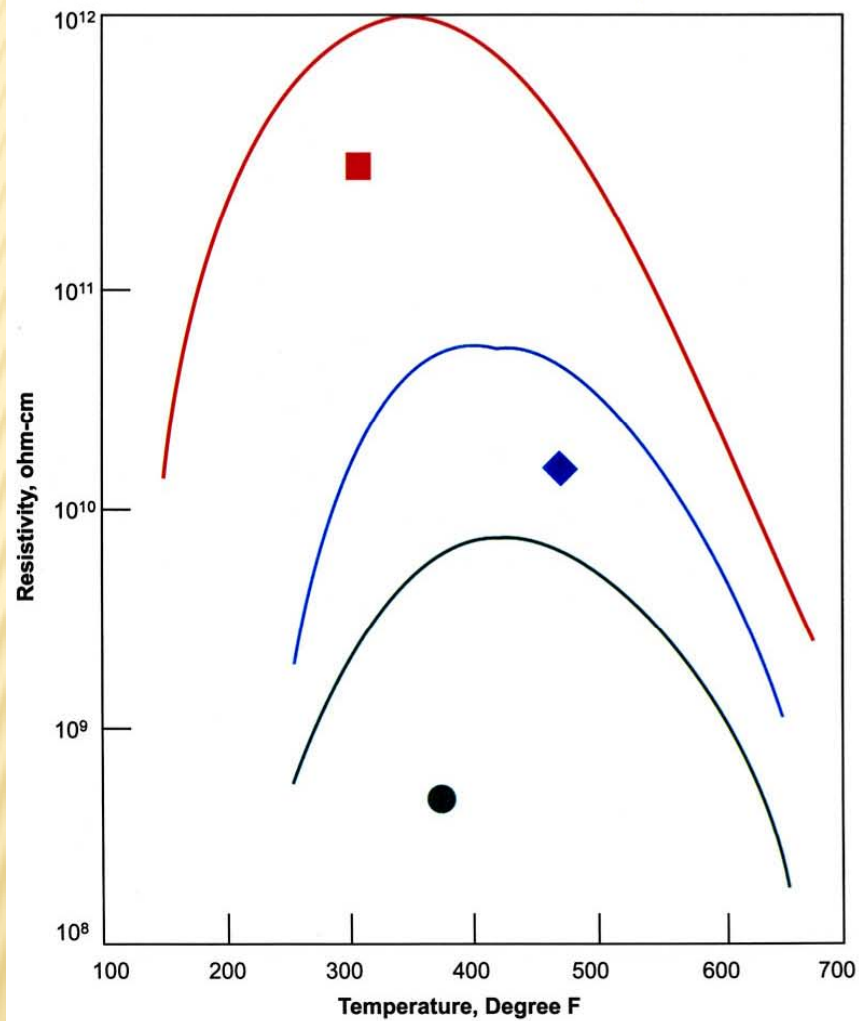
ESP Flue Gas Temperature 330 to 350°F

Chemical Analyses of Ashes in Weight Percent

Ash No.	Li ₂ O	Na ₂ O	K ₂ O	MgO	CaO	Fe ₂ O ₃	Al ₂ O ₃	SiO ₂	TiO ₂	P ₂ O ₅	SO ₄ ^a	Loss on Ignition
1	0.02	0.32	3.10	1.04	2.62	20.50	19.60	46.40	1.69	0.60	1.56	2.10
2	0.01	0.35	2.36	1.66	3.72	16.10	17.80	43.30	1.27	0.36	0.93	10.30
3	0.03	0.38	3.34	1.29	1.04	9.70	25.90	49.90	1.98	0.32	0.29	4.40
4	0.03	0.20	0.26	5.76	22.60	4.25	21.00	38.80	1.19	0.32	0.97	0.33
5	0.01	1.84	0.20	12.75	31.00	11.20	14.80	22.00	0.60	0.39	2.19	0.41
6	0.01	0.25	0.89	1.88	11.10	3.71	23.60	55.60	1.56	0.14	0.22	0.74
7	0.04	0.33	3.88	1.57	0.77	10.01	27.50	51.40	1.79	0.32	0.25	1.50
8	0.04	0.29	2.69	0.98	0.64	9.12	29.10	52.00	2.55	0.42	0.15	1.40
9	0.01	2.31	0.91	1.04	12.10	4.23	25.10	49.60	1.39	0.19	0.21	0.45
11	0.02	1.77	1.13	1.93	6.36	4.61	24.60	53.70	1.49	1.06	0.75	1.49
12	0.01	0.25	0.81	2.57	13.30	4.66	23.60	53.60	0.88	0.19	0.19	0.00
14	0.05	0.38	2.99	1.42	1.00	10.91	26.70	49.10	1.87	0.41	0.29	3.20
15	0.03	0.43	2.58	1.00	0.62	5.63	28.10	49.60	2.29	0.39	0.44	0.58
17	0.04	0.28	2.25	1.04	4.55	24.70	21.20	39.80	1.24	0.31	0.43	5.49
18	0.02	1.28	0.78	3.22	9.14	4.85	19.50	55.10	1.79	0.35	0.72	0.93
19	0.02	1.83	1.19	0.94	5.18	3.81	27.16	57.27	1.05	0.17	0.40	0.60
20	0.07	0.27	2.72	0.76	0.38	3.88	29.78	52.74	1.88	0.18	0.28	7.08

a) soluble sulfate





- High Resistivity : Typical of low-sulfur, low-sodium western coals
- ◆ Moderate Resistivity: Typical of eastern coals with 2 - 3% sulfur
- Low Resistivity: Eastern coals with more than 3.0% sulfur, western coals with low-sulfur, high-sodium content

WESTERN SUB - BITUMINOUS COALS

PERCENTAGES	MONTANA	WYOMING		UTAH
	Cold Strip Rose Bud	Decker	Kemmerer	Huntington
Ash	9.7	4.5	7.0	11.79
Sulfur	0.84	0.26	0.4	0.45
SiO ₂	35.4	25.4	56.9	52.08
Al ₂ O ₃	19.0	15.6	18.4	19.01
Fe ₂ O ₃	5.6	6.1	6.7	9.90
TiO ₂	0.8	0.8	4.7	1.29
P ₂ O ₅	0.3	0.3	0.24	0.88
CaO	17.8	19.4	8.3	10.58
MgO	4.4	4.5	2.4	2.57
Na ₂ O	0.3	8.4	0.2	1.41
K ₂ O ₃	0.1	0.4	0.84	0.7
SO ₃	16.3	19.3	4.7	0.82
SiO ₂ + Al ₂ O ₃	54.4	41	75.3	71.1
CaO + MgO	22.2	23.9	10.7	13.25
Resistivities	1.3x10 ¹¹	2.0x10 ⁹	8x10 ¹¹	5x10 ¹⁰
Predicted Range	1.0x10 ¹²	2.8x10 ⁹	1x10 ¹⁴	3x10 ¹¹
Measured @ 300° F	2.6x10 ¹²		5.5x10 ¹³	2x10 ¹⁰

11.9

EASTERN & MIDWEST COALS

	W.Va Arkwright	Ky Eastern	Ill BB Reserve	Ind Ayrshire Wright
Ash	6.9	6.34	6.46	9.71
Sulphur	2.1	0.69	1.47	3.75
SiO₂	44.8	46.69	45.75	35.35
Al₂O₃	29.4	31.11	22.71	16.66
Fe₂O₃	15.4	9.27	19.26	33.37
TiO₂	0.5	4.15	1.11	0.83
P₂O₅	0.3	0.26	0.61	0.19
CaO	4.2	2.81	3.77	6.76
MgO	1.0	1.16	0.36	0.84
Na₂O	0.8	1.53	1.43	0.51
K₂O₃	0.5	0.22	2.27	0.99
SO₃	3.7	3.02	1.79	2.86
SiO₂ + Al₂O₃	74.2	77.8	68.46	52.01
CaO + MgO	5.2	3.97	4.13	7.6