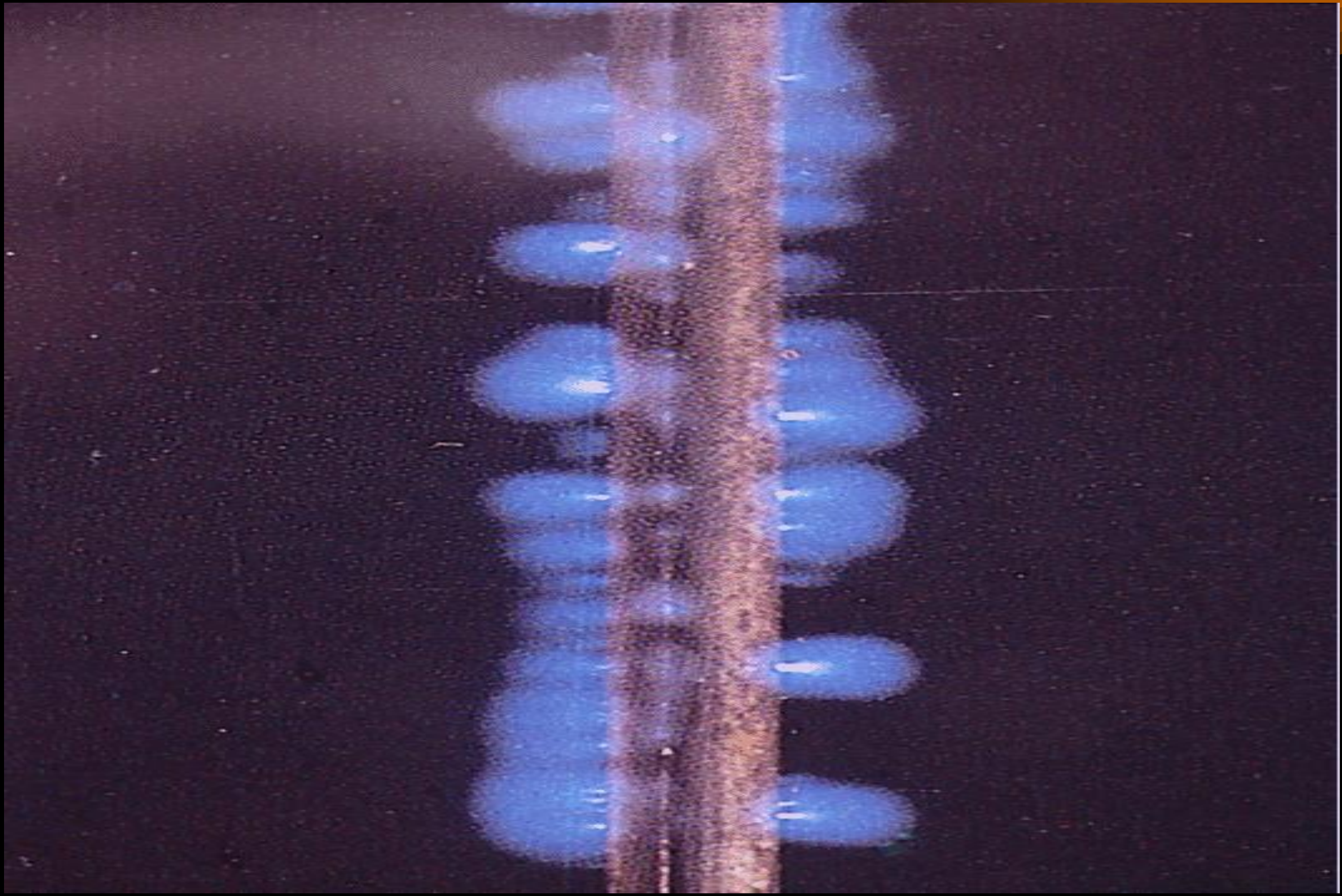
REINHOLD ENVIRONMENTAL ®

2023 Reinhold/PCUG Round Table Presentation

Cohosted by Duke Energy and Vistra in The Westin Hotel, Cincinnati, OH on June 26-27, 2023

Electrostatic Precipitation



Electrostatic Precipitation

Donora, PA

Electrostatic Precipitation

Donora, PA

Donora was incorporated in 1901.

Donora got its name from a combination of William Donner, the founder of Union Steel Company and Nora Mellon, banker Andrew Mellon's wife.

Electrostatic Precipitation

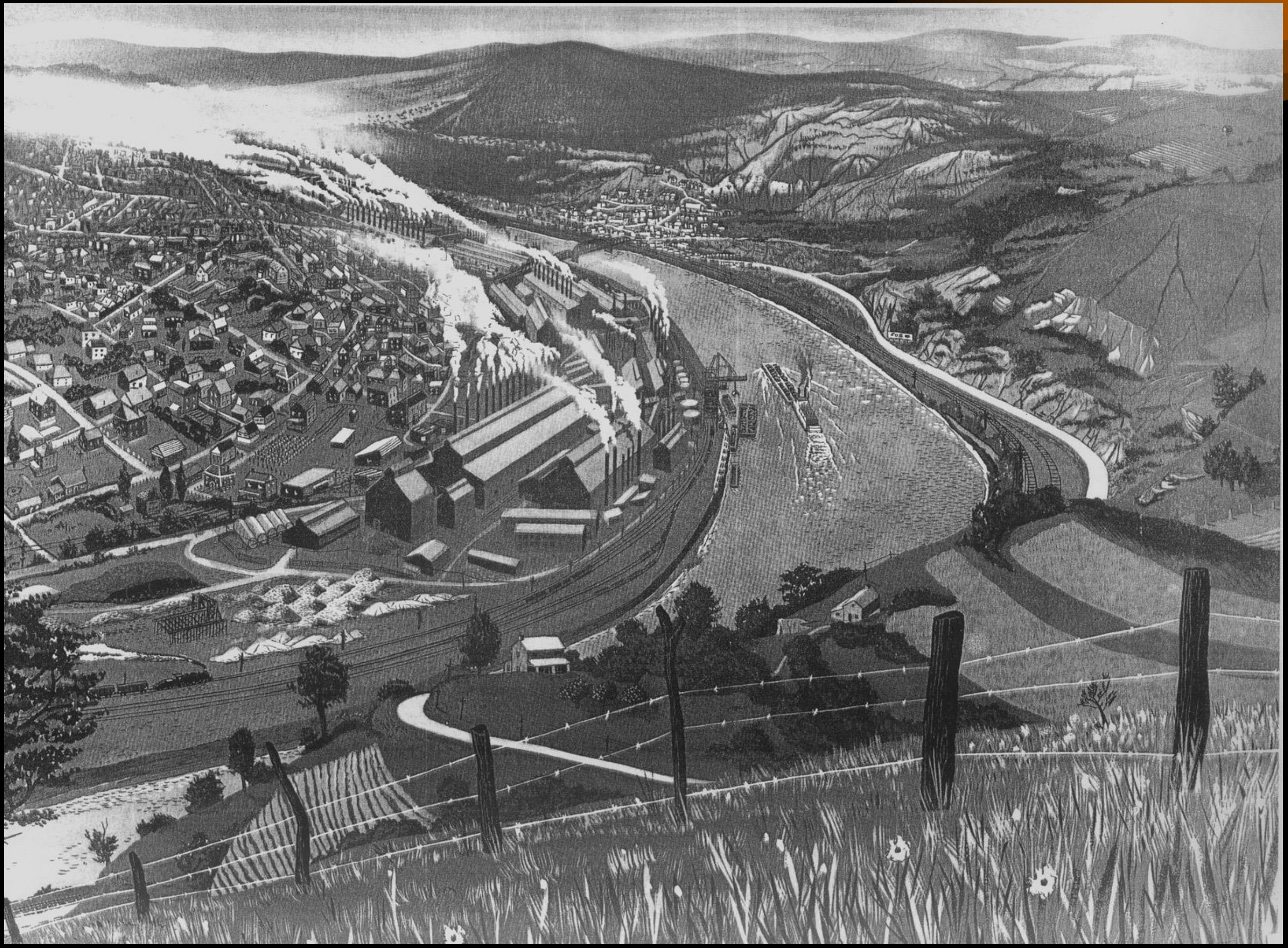
Donora, PA

Home of:

- *Stan Musial*
- *Ken Griffey, Sr.*
- *Ken Griffey, Jr.*

Electrostatic Precipitation

Donora, PA



Electrostatic Precipitation

The Zinc plant extends about 1 miles north of the bridge. This plant was built in 1915.

Components of the zinc plant:

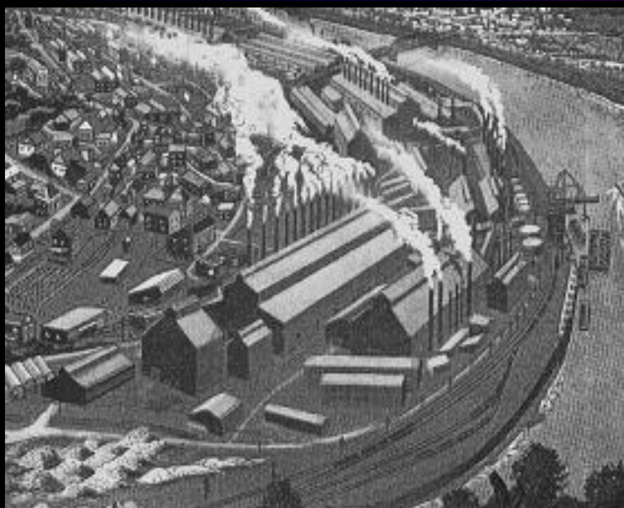
roasters
sintering plant
zinc smelters
waste heat boilers
Waelz plant
dross plant
sulfuric acid plant
cadmium plant

The products of the plant included:
zinc
cadmium
unrefined lead
sulfuric acid

Plumes of smoke from the zinc factory are carried by the wind. These plumes contained large amounts of sulfur dioxide, carbon monoxide and other particulate matter.

Electrostatic Precipitation

Donora, PA



The Steel and Wire plant extends about 2 miles south of the bridge. This plant was built in 1900. The plant made wire, nails, barbed wire, welding rods and other products.

The main components of the Steel and Wire plant were:

Blast furnace

Open hearth

Blooming and billet mills

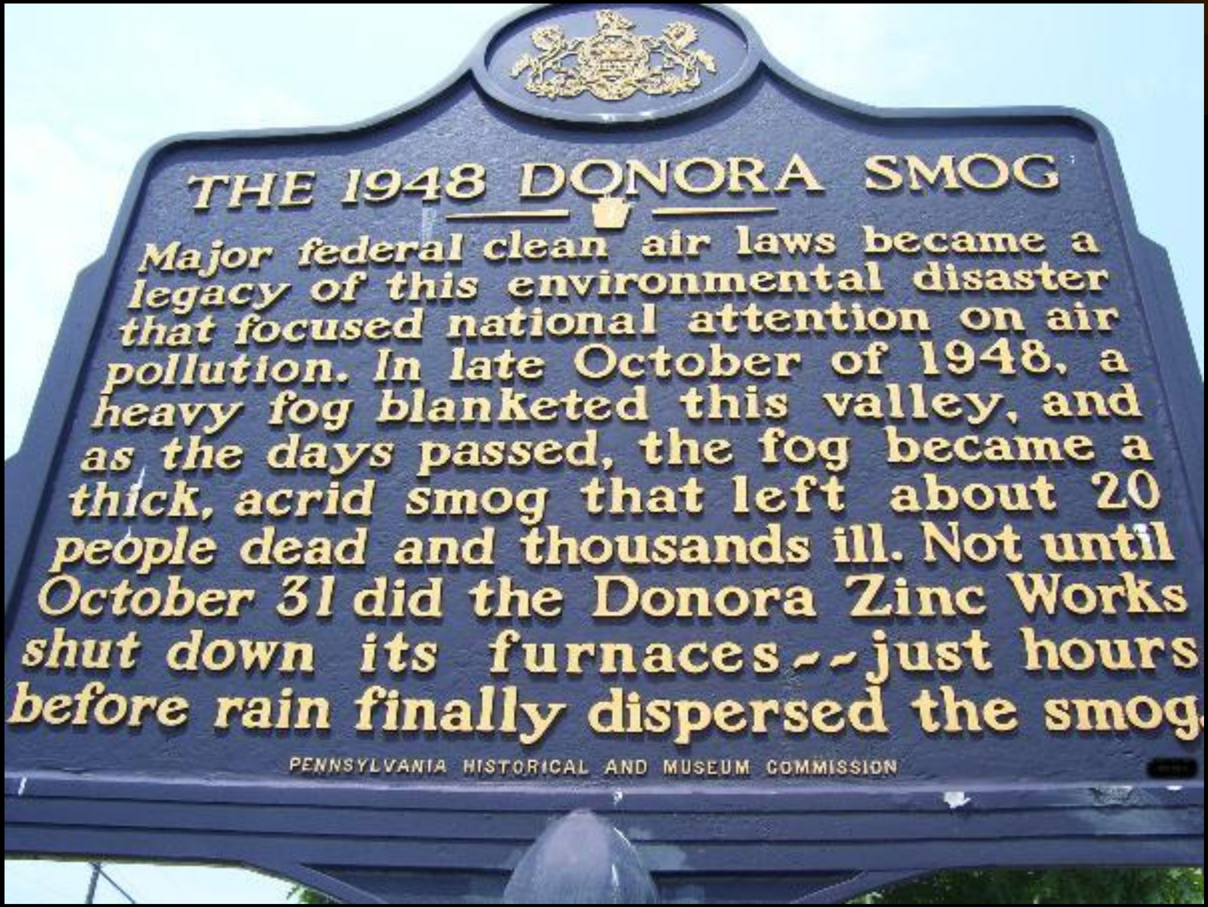
Rod mills

Wire mills

Plumes of smoke from the steel and wire factory are carried by the wind. Major pollutant in these plumes were sulfur dioxide and particulate matter.

Electrostatic Precipitation

Donora Death Fog



Who: 20 Deaths, 1000s Hospitalized, After the inversion lifted, 50 more died.
Where: Donora, PA
When: Oct 26-31, 1948
What: Death Fog
Why: Temperature inversion and pollution from American Wire and Steel plant and the Donora Zinc Works. Both are owned by the U. S. Steel

Electrostatic Precipitation

America's Worst Environmental Disaster

Electrostatic Precipitation

America's Worst Environmental Disaster

Donora at High-Noon

Electrostatic Precipitation

Disaster Account

From local accounts this is a description of the 1948 disaster.

By Friday evening (October 29), local residents were crowding into nearby hospitals and dozens of calls were made to the area's eight physicians. While Fire Department volunteers administered oxygen to those unable to breathe, Board of Health member Dr. William Rongaus led an ambulance by foot through darkened streets to ferry the dead and dying to hospitals or on to a temporary morgue.

On Rongaus' advice, those with chronic heart or respiratory ailments began to leave town late Friday evening, but before noon on Saturday, 11 people died. "Conditions had not improved by Saturday night, and with roads congested by smog and traffic, evacuation became impossible. The company operating the Donora Zinc Works finally ordered the plant shut down at 6 a.m. Sunday morning. By mid-day Sunday, rain had dispersed the smog.

The Donora Smog gained national attention when Walter Winchell broadcast news of the disaster on his national radio show.

Electrostatic Precipitation

Letter to Governor from Webster Resident

Webster, Pa.
Oct. 31, 1948.

Hon. James H. Duff.
Harrisburg, Pa.

Dear Sir:

I am writing for "Smoke Control" in Washington County. Pittsburgh has it, why can't Donora after the tragedy of Oct. 30. & 31st.

The Zinc Works has ruined Donora & Webster. The company has talked about moving it for years but nothing has been done about it. Perhaps this will awaken some of the high officials who have built beautiful homes outside of Donora in the surrounding country where vegetation will grow.

The towns of Monessen, Charleroi and Monongahela, adjacent to Donora & Webster had fog but there weren't 20 deaths as Donora & Webster had. There is something in the Zinc Works causing these deaths.

The Zinc Works is very old fashioned. It could be moved & electric furnaces installed. That would help consume the fumes & do away with that awful acid & smoke. It eats the paint off your houses. Even fish cannot live in the Monongahela River, the bank on which the mill is situated.

I would not want men to lose their jobs but your life is more precious than your job.

They closed the smeltering plant today. We found that you could breathe normally without having the air polluted with acid fumes.

Webster was here before the Donora Zinc Works was constructed, so why should we suffer? A once beautiful town is now almost a "Ghost Town".

I know you are quite a busy person but will you please consider this letter a little bit?

Thanking you, I remain,
Respectfully yours,
Mrs. Lois Bainbridge.
Box 254.
Webster, Pa.

GOVERNOR'S OFFICE
RECEIVED
NOV 2 1948
ADM. BUREAU

Electrostatic Precipitation

Death in Donora

Death in Donora

I have felt the fog in my throat --
The misty hand of Death caress my face;
I have wrestled with a frightful foe
Who strangled me with wisps of gray fog-lace.
Now in my eyes since I have died.
The bleak, bare hills rise in stupid might
With scars of its slavery imbedded deep;
And the people still live -- still live -- in the
poisonous night.

John P. Clark, area resident

Electrostatic Precipitation

Prior European Events

In 1873, a London pollution episode resulted in 700 deaths

In 1911, another London pollution episode resulted in 1150 deaths and the term “SMOG" was coined

In 1930, fog trapped pollution in the city of Liège, Belgium, killing dozens of people.

Electrostatic Precipitation

Killer Fog London 1952

In the 1952 London "killer fog," an atmospheric inversion created a "toxic mix of dense fog and sooty black coal smoke" lasting 4 days. On the second day of the fog, 500 people in London died; 900 people died on the last day. All told about 4000 people died.

The 1952 London event proved that Donora was not a fluke and that industrial air pollution was a serious threat to human health.

Electrostatic Precipitation

Clean Air Acts

Air Pollution Control Act of 1955

1. Department of Health
2. Allow state to establish air standards
3. Research and investigation

Clean Air Act of 1963

1. Investigation by Surgeon General - advisory only
2. Research and technical assistance to State and local government
3. Development of air quality criteria by the Secretary of HEW
4. Abatement actions (only one enforcement action ever brought)

1967 Air Quality Act

1. First comprehensive scheme for Federal control of air pollution
2. Designation of atmospheric regions by HEW
3. Designation of air quality regions, by HEW, based on jurisdictional boundaries and other factors
4. States required to adopt ambient air quality standards
5. State implementation plans
6. Preemption of stricter State air quality standards

Clean Air Act of 1970

1. Established the Environmental Protect Agency (EPA)
2. National Ambient Air Quality Standards (NAAQSs)
3. New Source Performance Standards
4. National Emission Standards for Hazardous Air Pollutants

Clean Air Act of 1977

1. Set new date to achieve NAAQS
2. Established Pollutant Standards Index (PSI)
3. Most of Act was ineffective

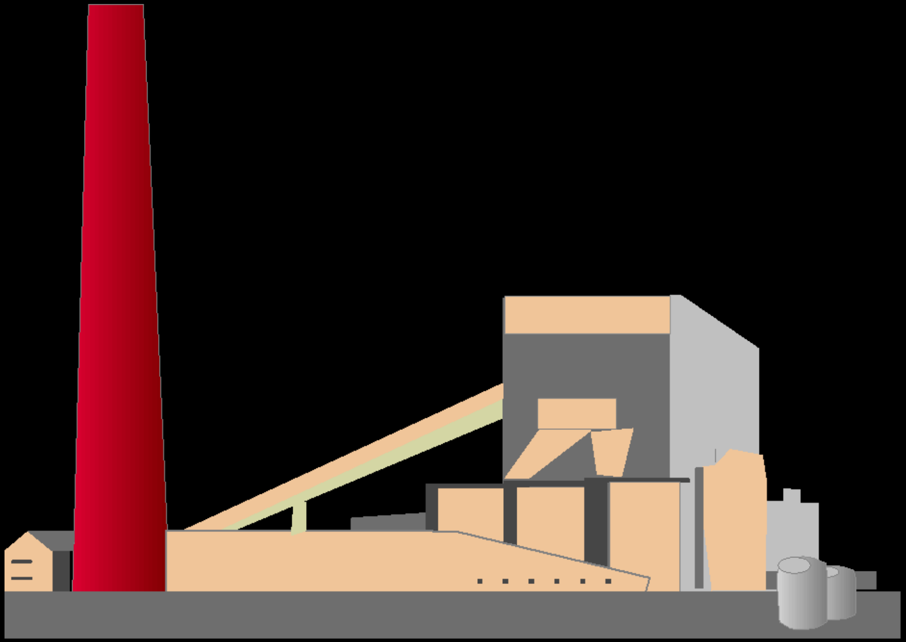
1990 Clean Air Act Amendments

1. Acid Rain Control
2. Enforcement

Electrostatic Precipitation

Required Efficiency

- COAL
  - 20% ASH
  - 11,500 BTU/lb
- 1,000,000 BTU / 11,500 X .20 = 17.4 LB/MMBTU
- Assume 80% of Ash is Fly Ash gives 13.9 LBS/MMBTU to ESP
- Emission Limit is 0.1 LB/MMBTU
- Required Efficiency is 99.3% to achieve.



Electrostatic Precipitation

Electrostatic Precipitation

Development of Electrostatic Precipitation

600 B.C. — First documentation of electrostatic attraction by Greek philosopher Thales.

1600's — DeMagnete-Work on Magnetism by William Gilbert was first observation of electrical attraction of smoke.

1700's — Charles de Coulomb discovery of Inverse Square Law which is starting point for electrostatic precipitation.

Ben Franklin's first work on corona discharge from a sharp point.

Gambattista Beccaria separation of particles from a gas.

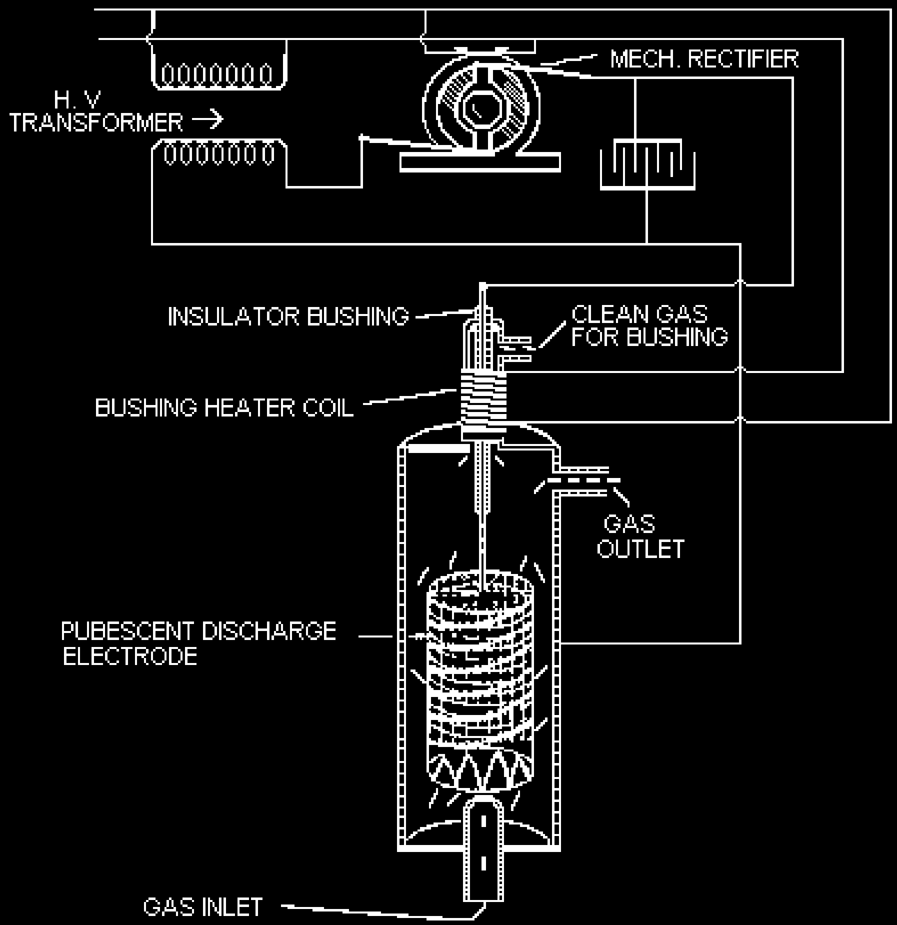
1884 — Sir Oliver Lodge published work on precipitating smoke from air, i.e., electrostatic precipitator.

1906 — Frederick Cottrell - A California chemist patented the first successful electrostatic precipitator.

1923 — Trenton Channel Plant First Utility ESP

Electrostatic Precipitation

First Patented Precipitator



Electrostatic Precipitation

TENTON CHANNEL POWER PLANT
FIRST UTILIY BOILER PRECIPITATOR 1923

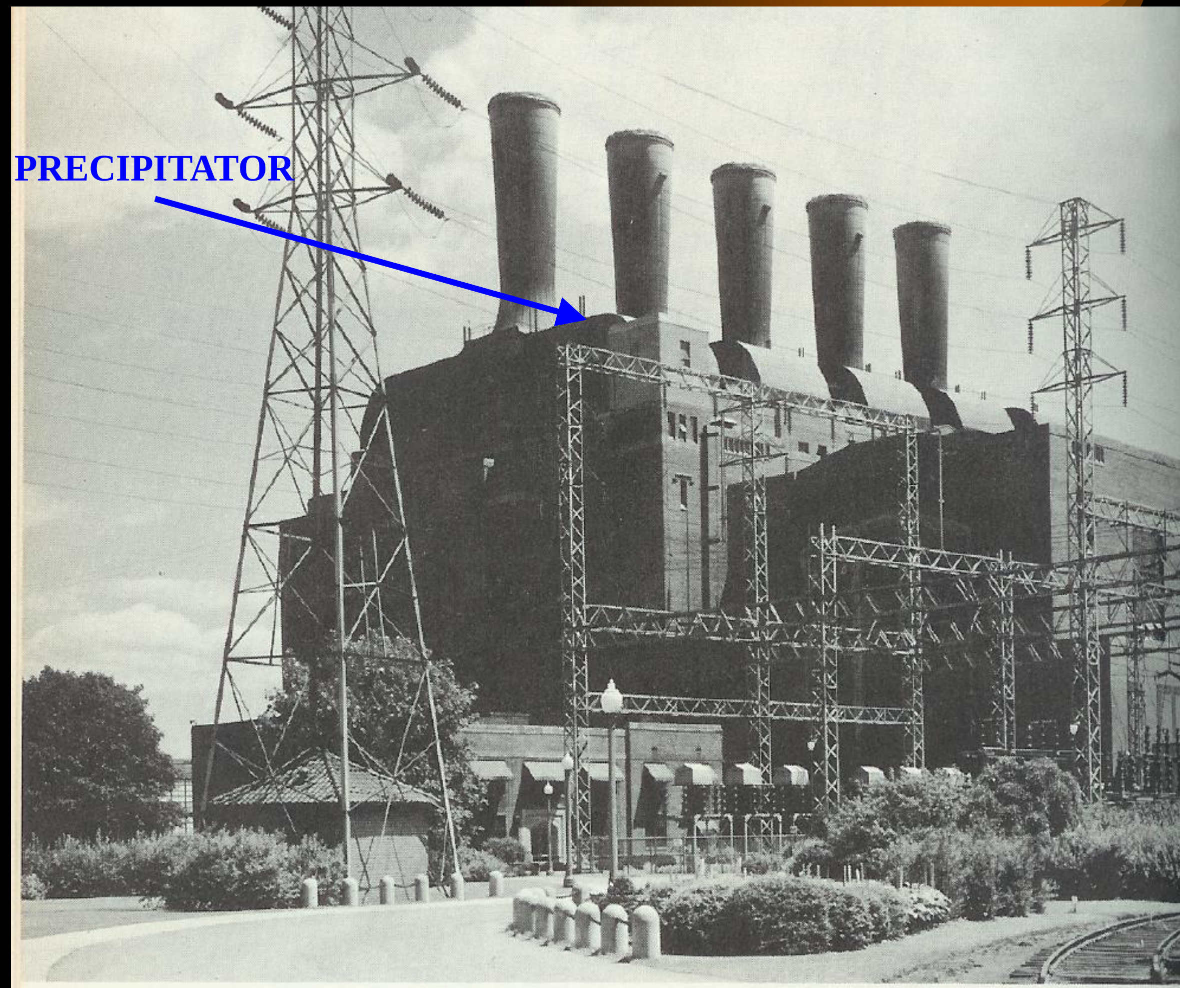
TRENTON CHANNEL PLANT

13 Units

Boiler:
- 360,000 lb/hr
- Pulverized coal

ESP Design:
- Efficiency 90 %
- 2 fields
- Corrugated plates on 4" centers
- Horizontal wire rods on 6' centers

Did not work.
- Converted to a concrete plate with vertical electrodes



Raymond C. Miller, Kilowatts at Work, A History of The Detroit Edison Company , Wayne State University Press, Detroit, 1957. Illustration title: "Trenton Channel, 1924" facing page 338.

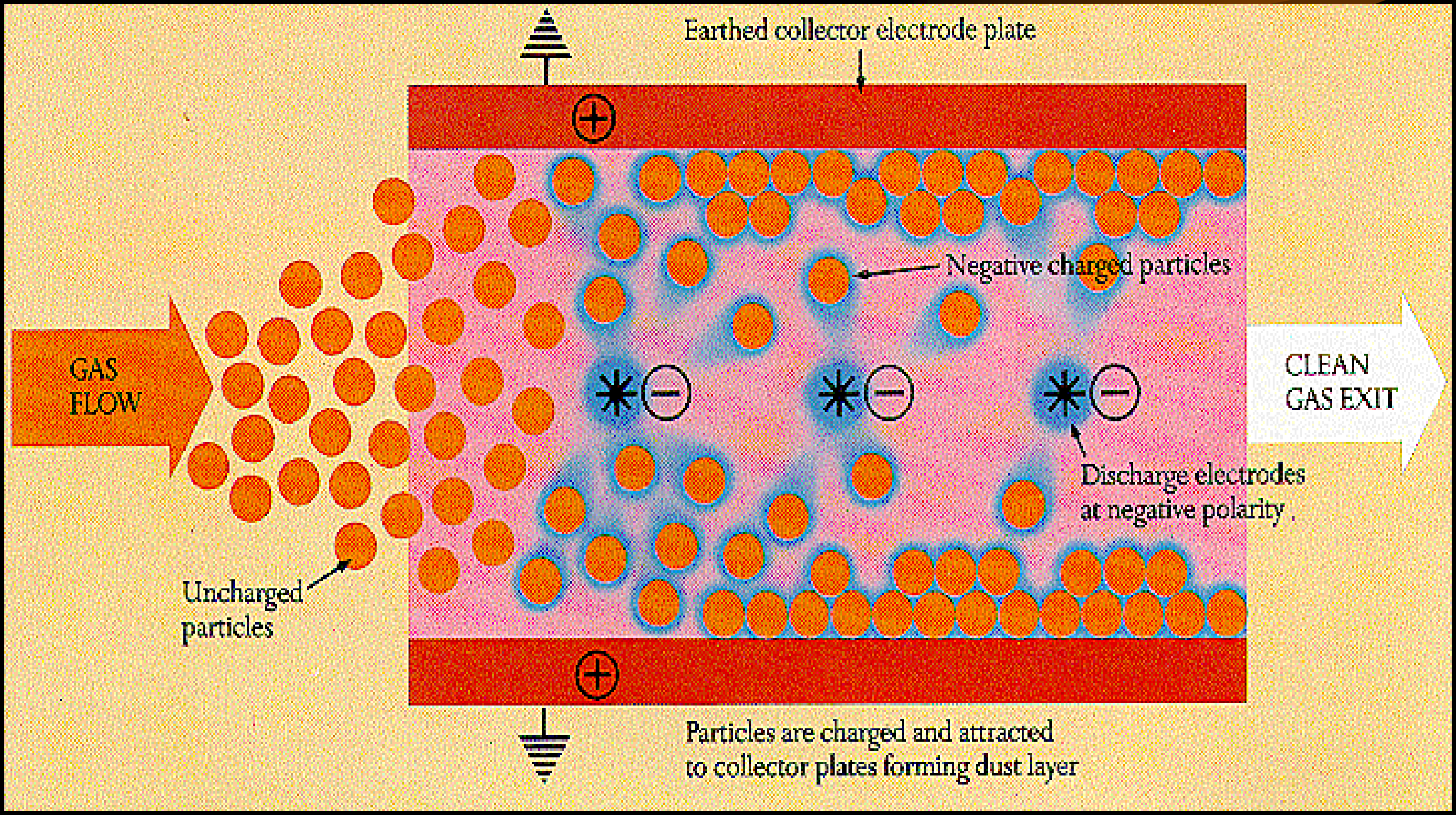
Electrostatic Precipitation

Steps of the Process

- Particulate Charging
- Particulate Collection
- Particulate Removal

Electrostatic Precipitation

Particulate Charging



Electrostatic Precipitation

DEUTSCH - ANDERSON EQUATION

$$N = 1 - e^{\frac{-A}{V} W}$$

N = COLLECTION EFFICIENCY

A = EFFECTIVE COLLECTING AREA - $ft.^2$

V = GAS FLOW RATE - $ft.^3$/min.

W = MIGRATION VELOCITY - ft./min.

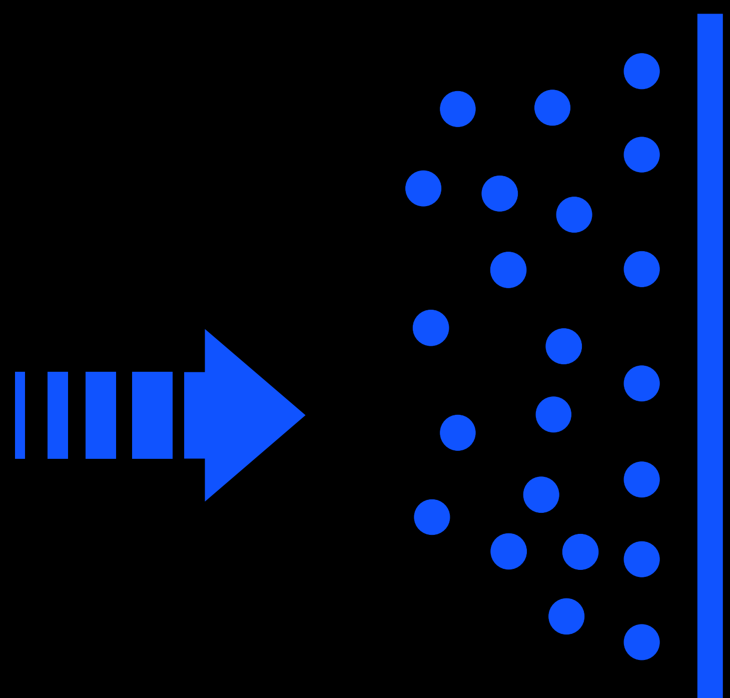
Electrostatic Precipitation

Collecting Particles

Requires

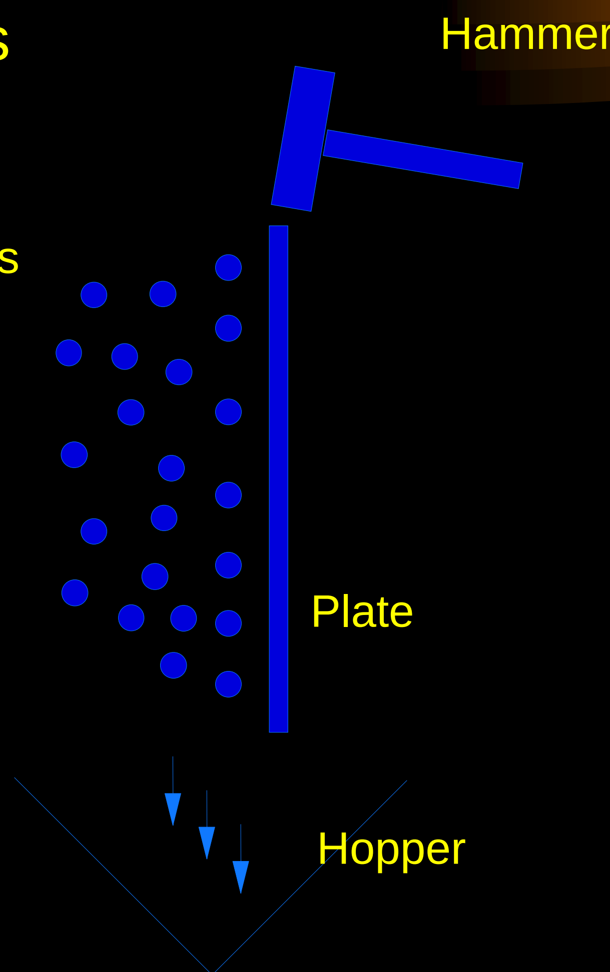
- Charged Particles
- Electric Field
- Low Gas Velocity

Results In Particles On Plate



Electrostatic Precipitation

Removing Particles

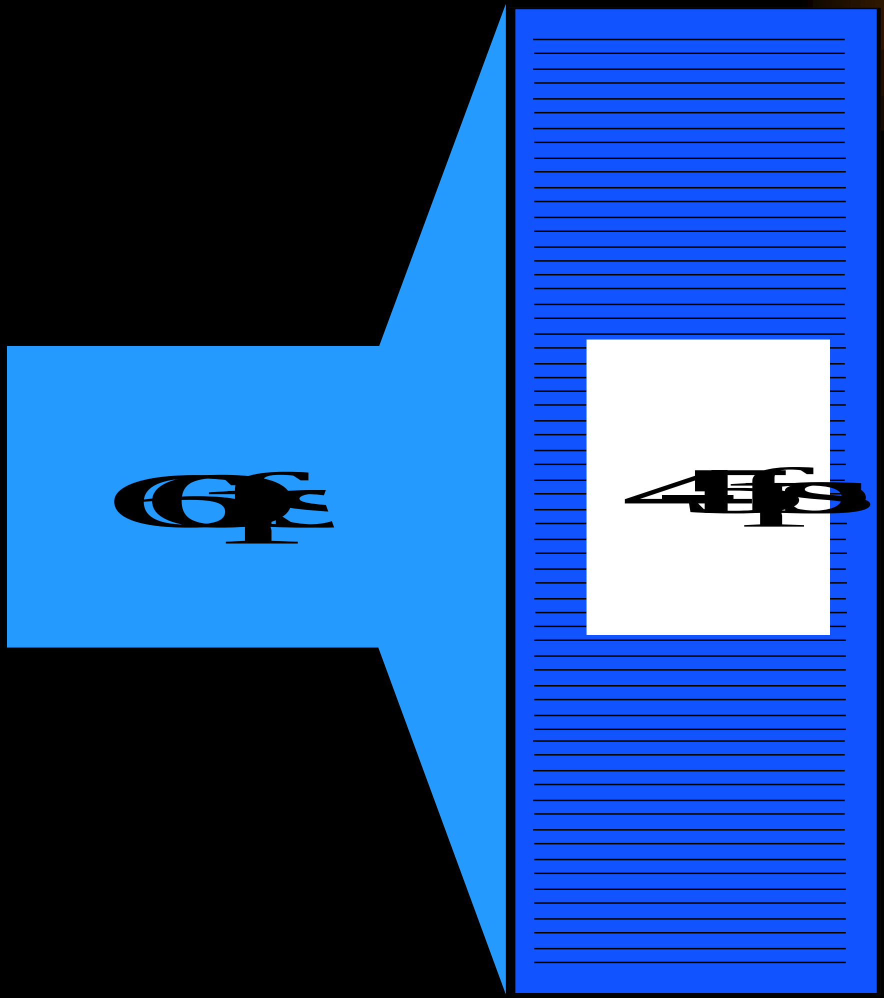


Requires
- Enough Particles On Plates
- Rapping System

Results
- Particles in Hoppers
- Reintrainment

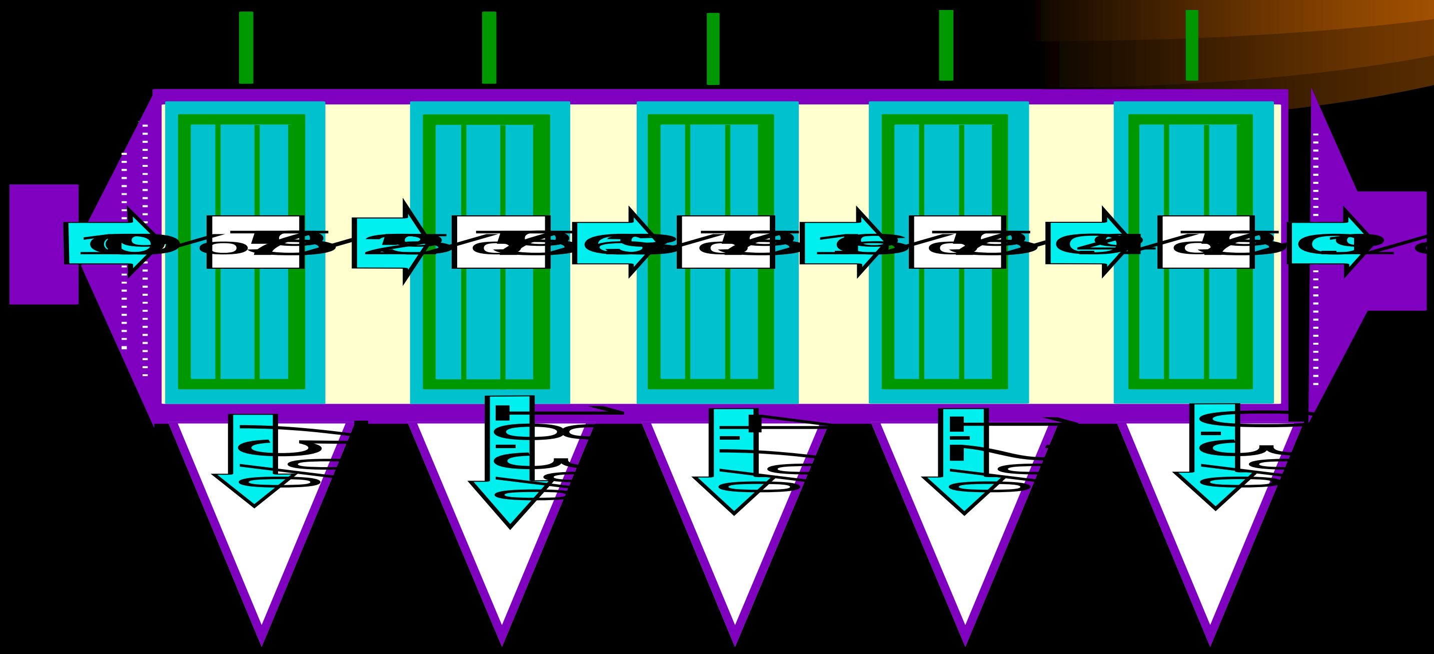
Electrostatic Precipitation

Parallel Paths

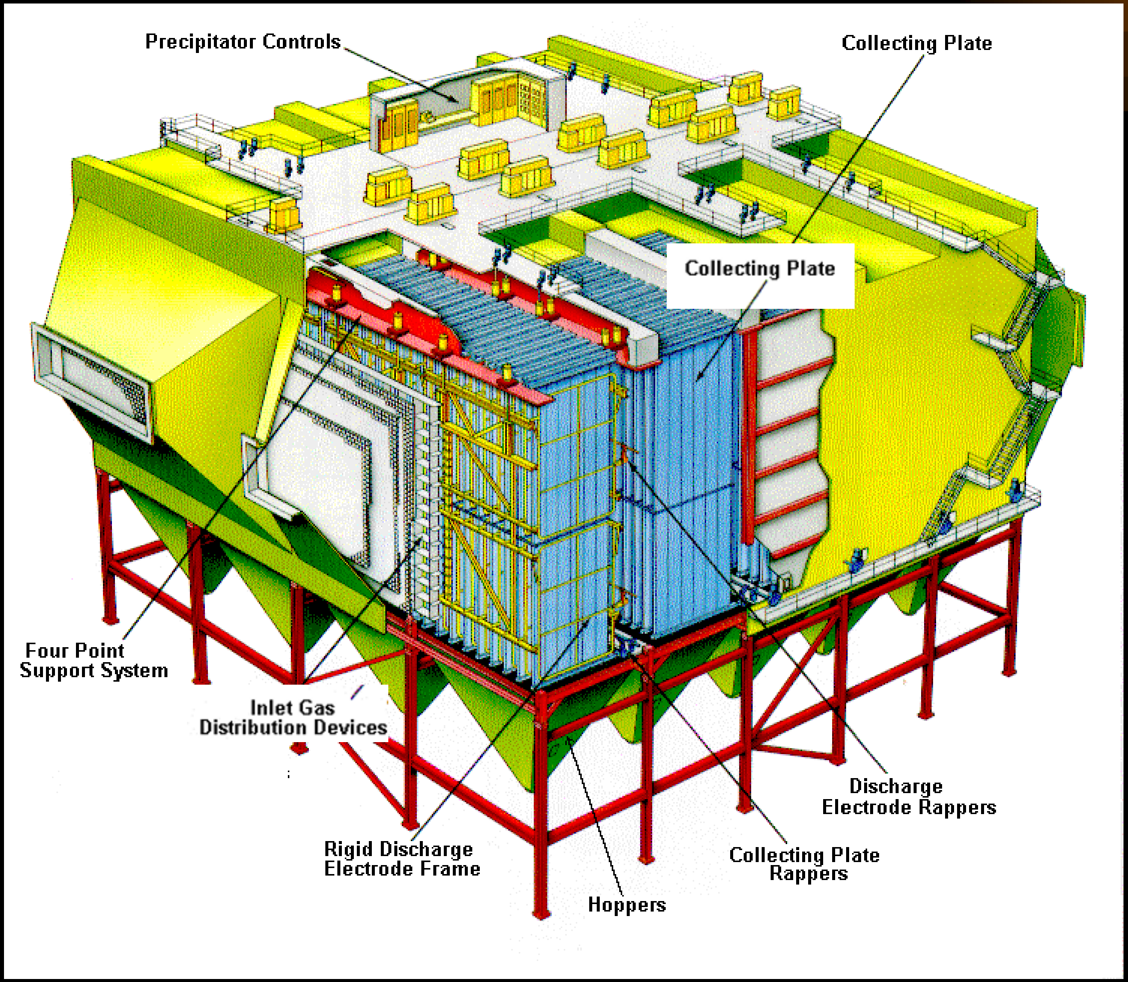


Electrostatic Precipitation

Series Configuration

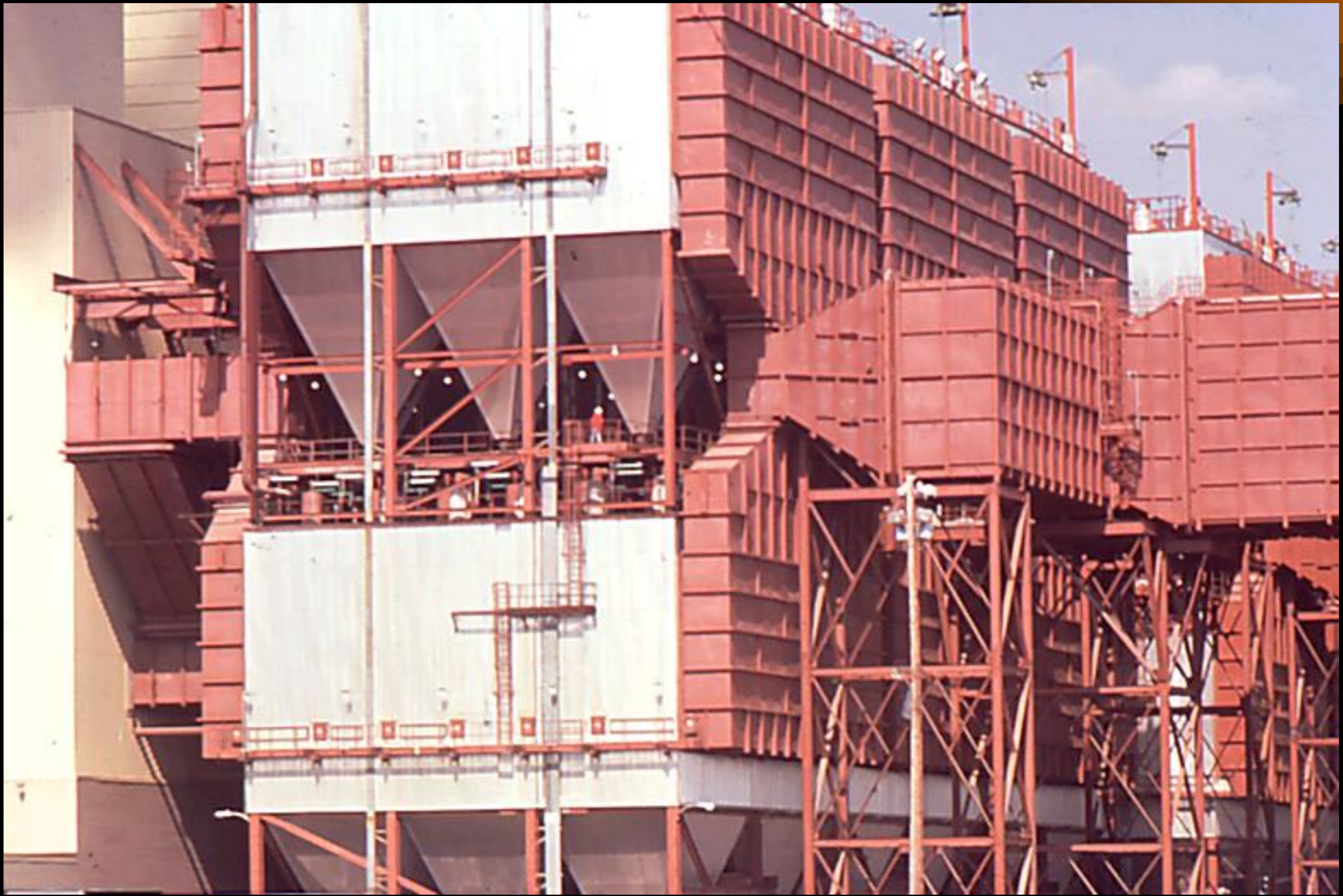


Electrostatic Precipitation



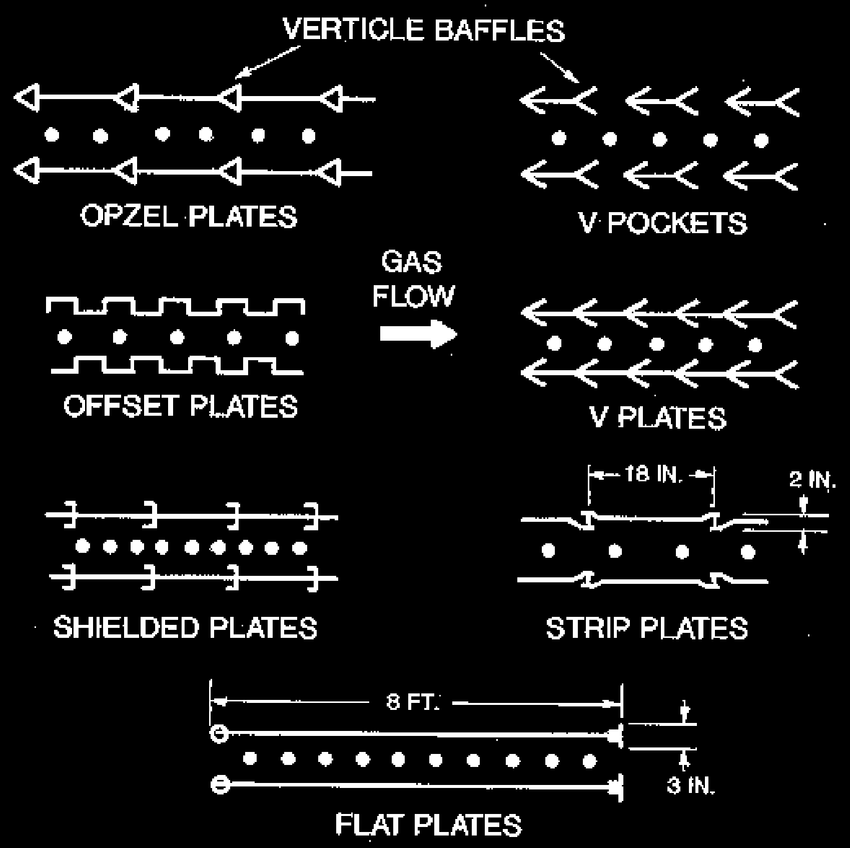
Electrostatic Precipitation

Gavin ESP

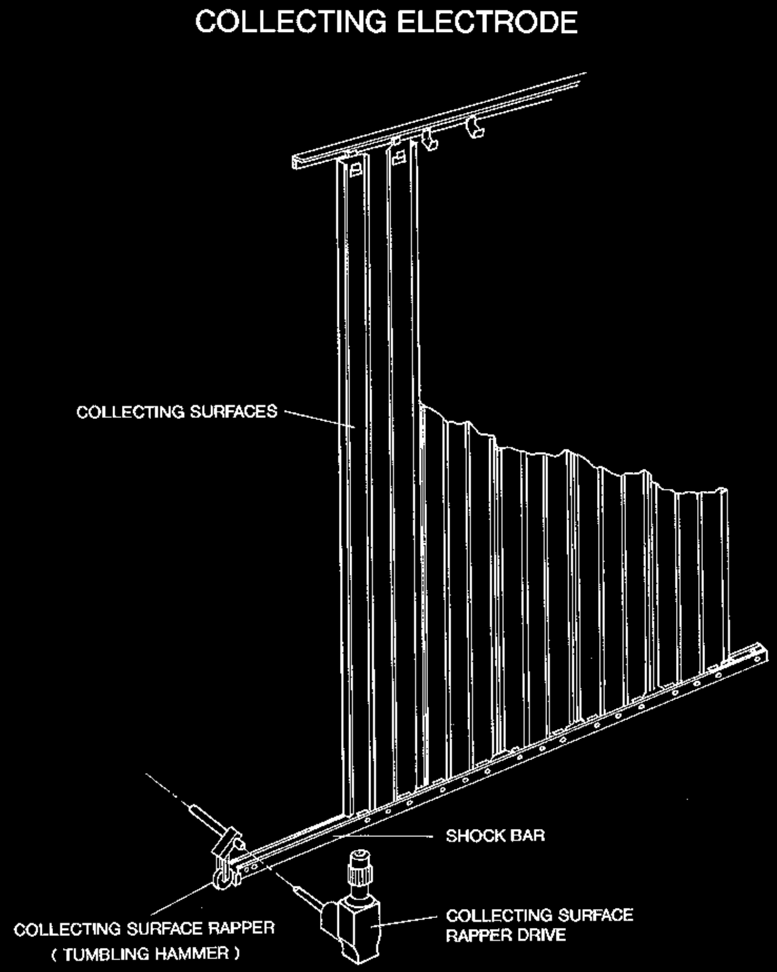


Electrostatic Precipitation

VARIOUS DESIGNS OF COLLECTING ELECTRODES



Electrostatic Precipitation



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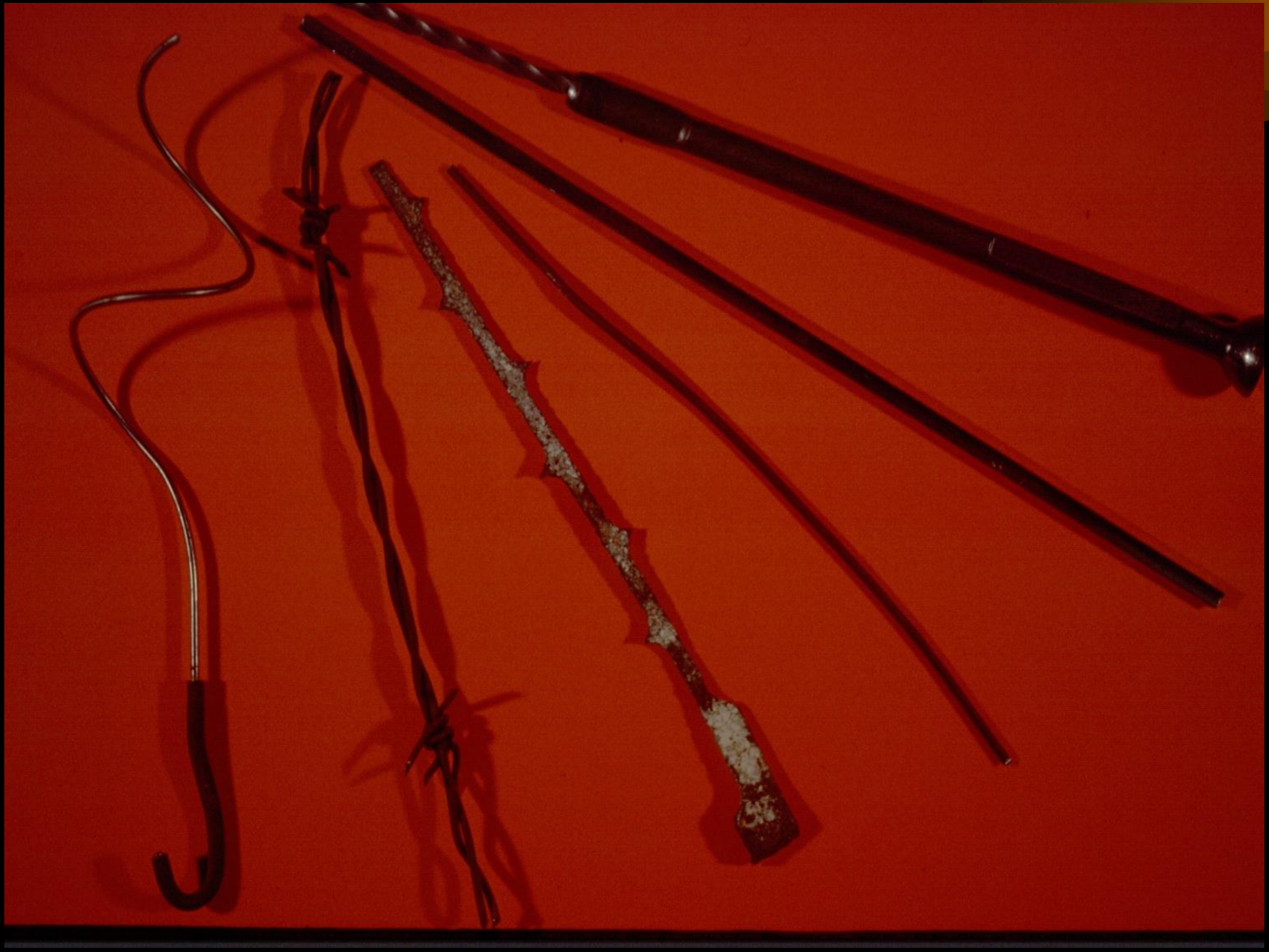
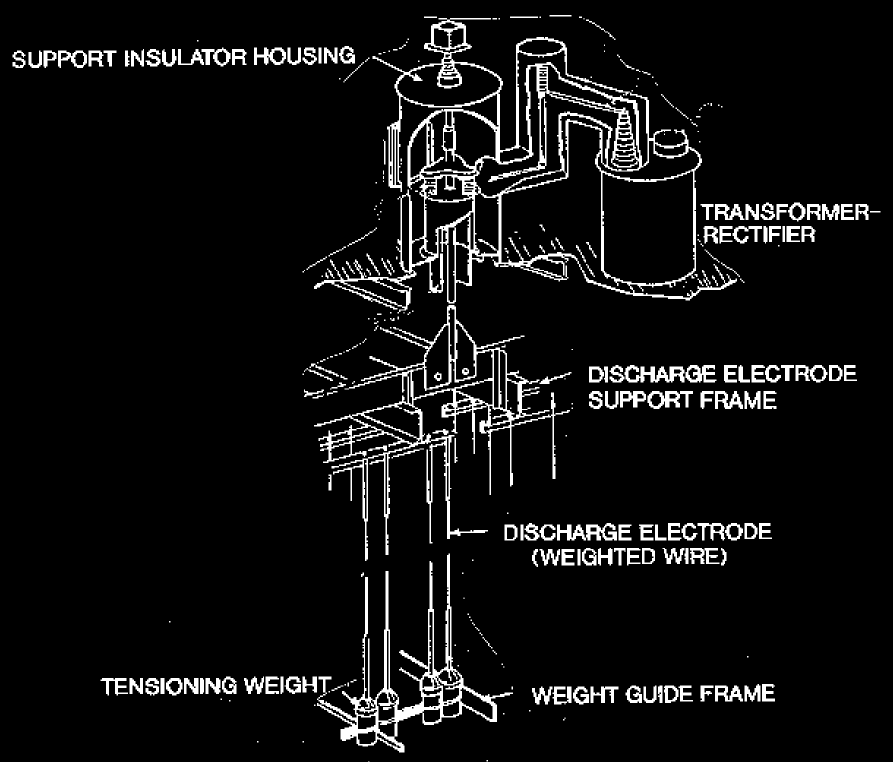


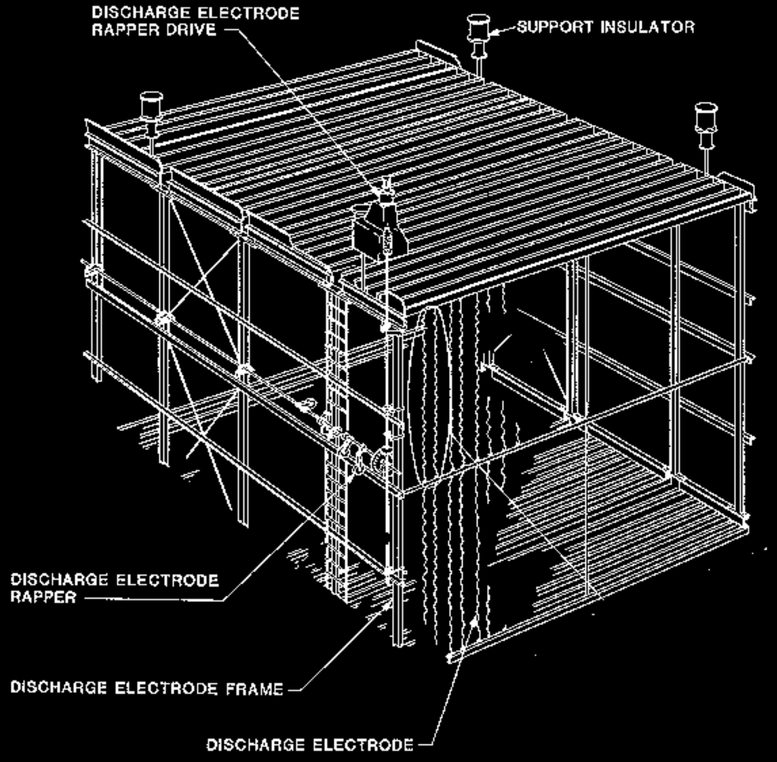
Electrostatic Precipitation

WEIGHTED WIRE
DISCHARGE ELECTRODE SYSTEM



Electrostatic Precipitation

RIGID FRAME
DISCHARGE ELECTRODE SYSTEM



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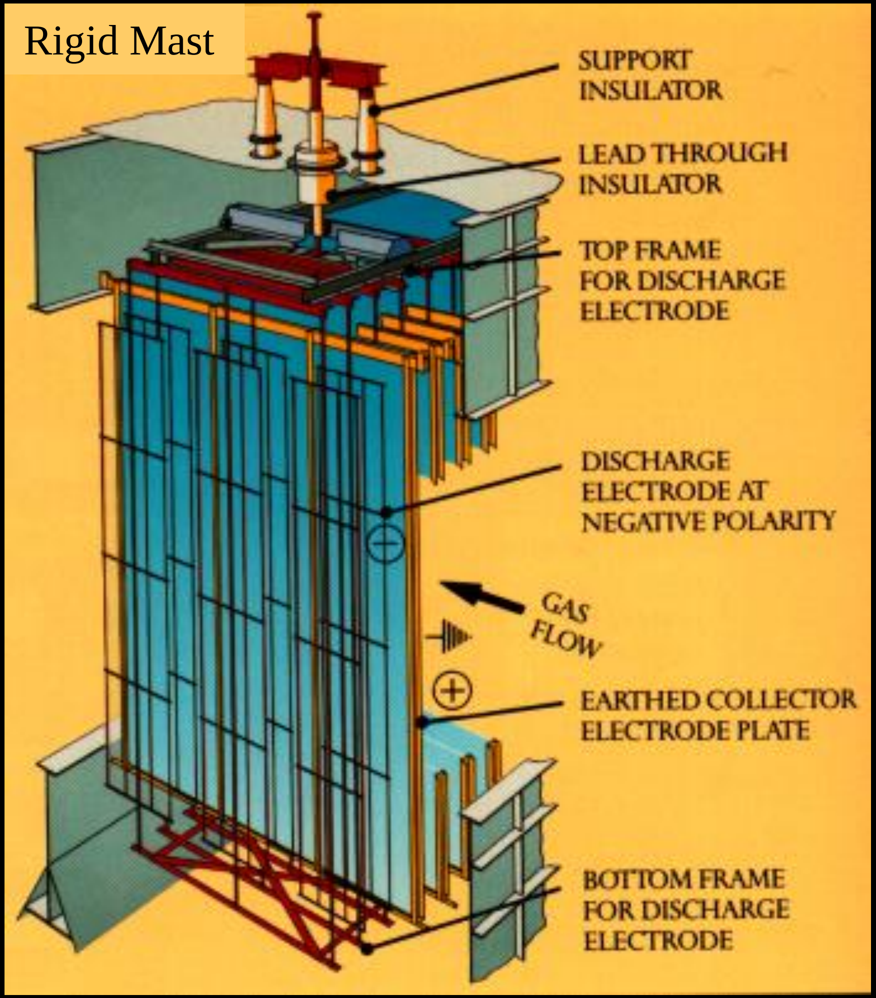

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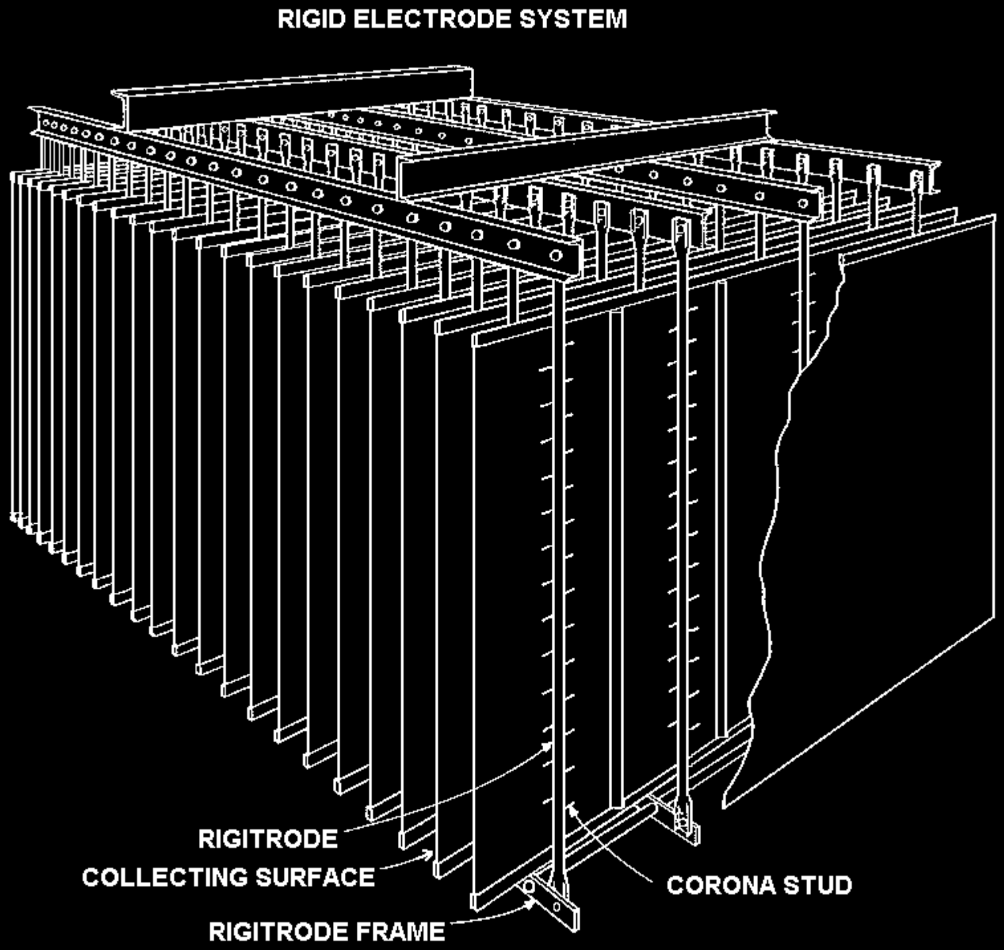


Electrostatic Precipitation

Electrostatic Precipitation

Electrostatic Precipitation

Wire-to-Plate Spacing

As a general rule, the applied voltage for an ESP is equivalent to 10KV per inch. Using this general rule the TR set rating for various ESP designs are as follows:

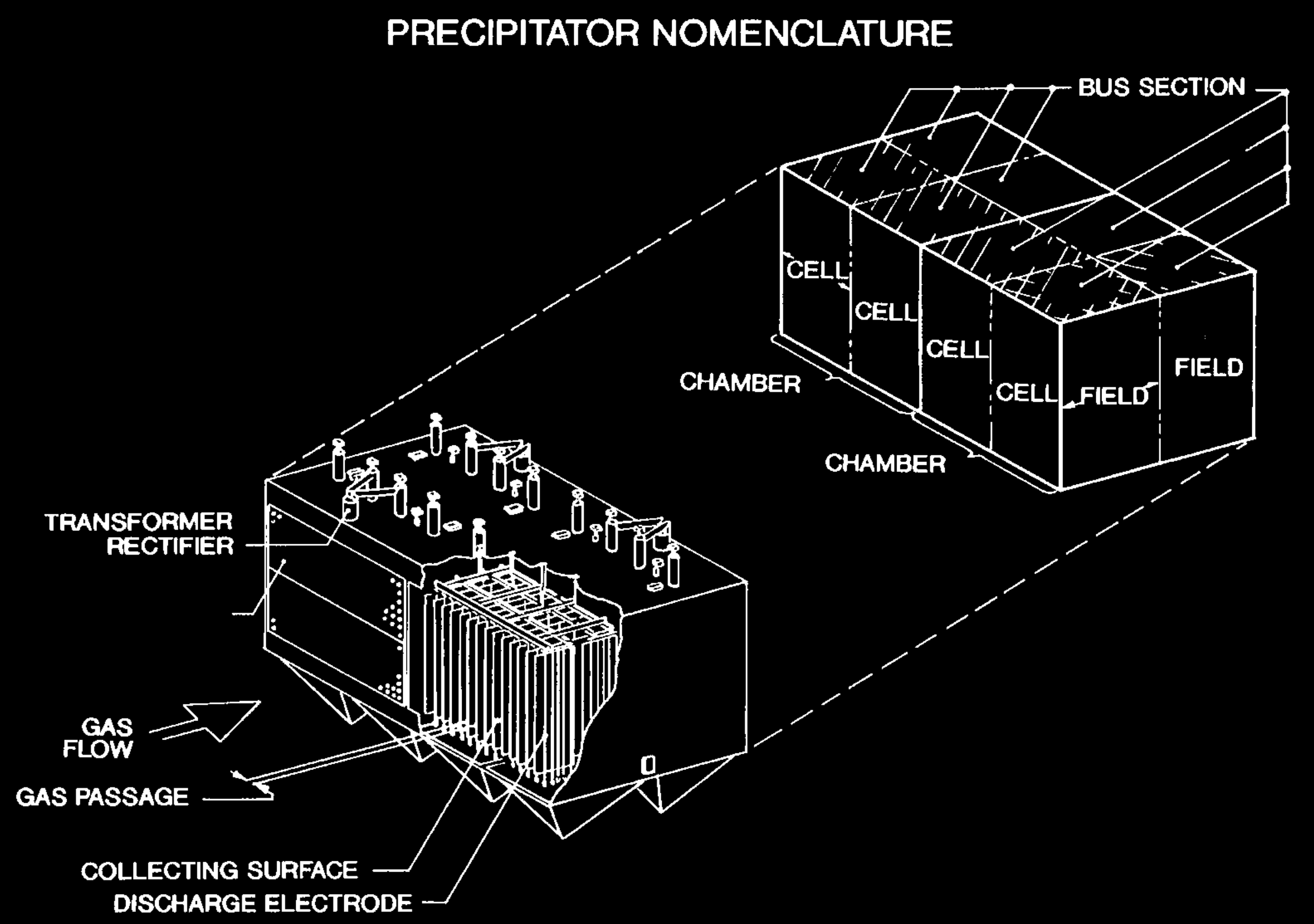
(Plate-to-Plate Width)		
9 - 10"	4.5 - 5"	45 KV
12"	6"	55 KV
16"	8"	80 KV

Electrostatic Precipitation

TERMS OF THE TRADE

- Precipitator - ESP
- Precipitator Box or Boxes
- Chamber
- Bus Section
- High Voltage Power Supply
- Field
- Cell or Lane
- Effective Length
- Effective Height
- Effective Cross-sectional Area
- Specific Collecting Area
- Collecting Surface Area
- Gas Passage
- Collection Efficiency
- Precipitator Gas Velocity

Electrostatic Precipitation



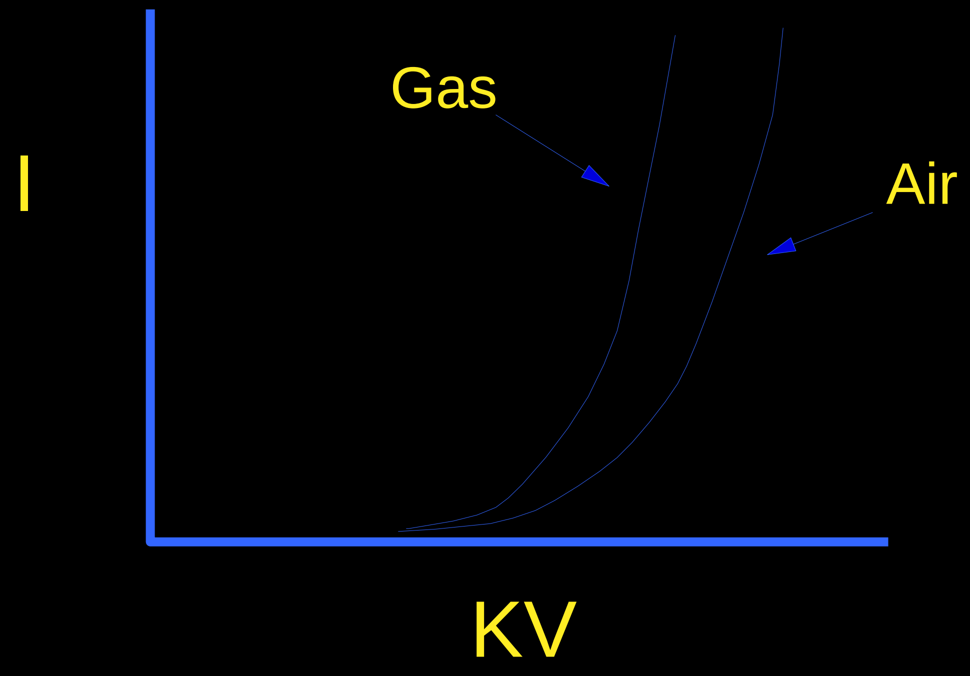
Electrostatic Precipitation

Where a control should operate

- TR set rating
- Artificial limit (manually or energy management)
- Spark limited
- SCR limited (full conduction of the SCRs)

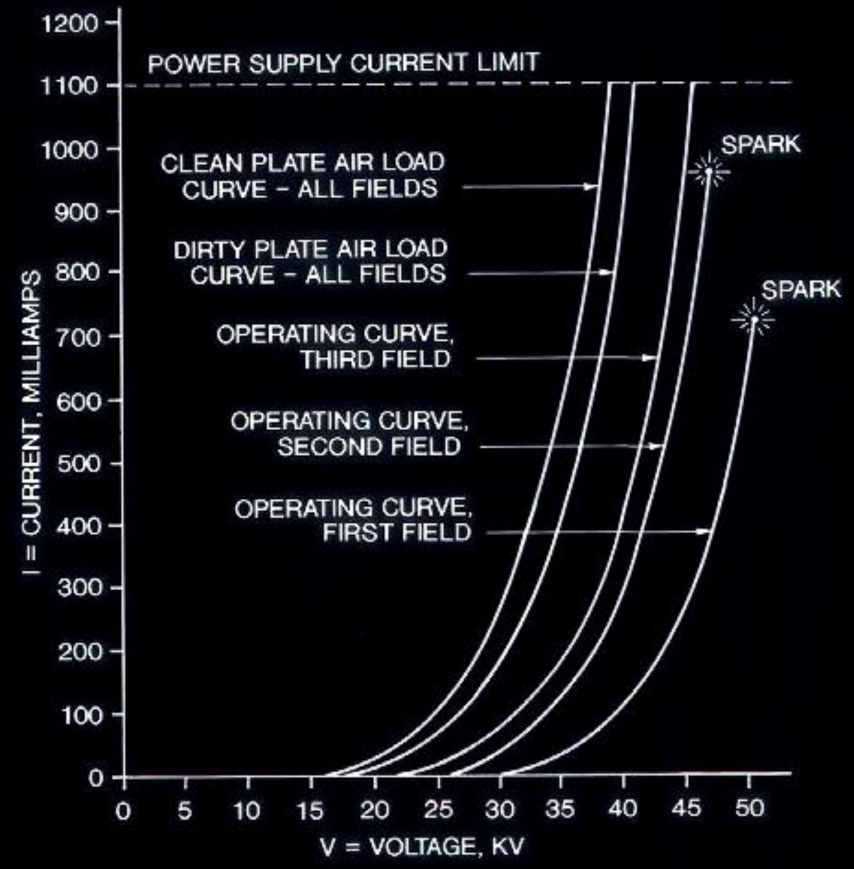
Electrostatic Precipitation

V-I Curves - Air vs. Gas



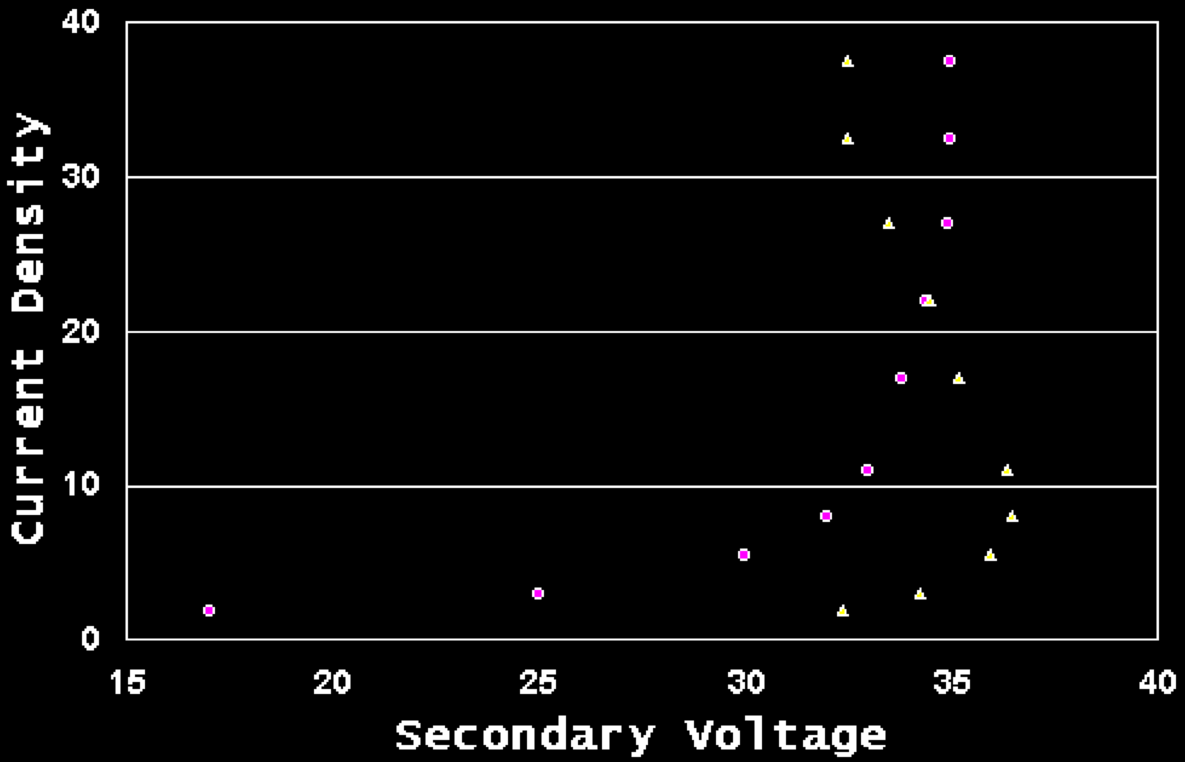
Electrostatic Precipitation

NORMAL PRECIPITATOR CURRENT VOLTAGE CURVES



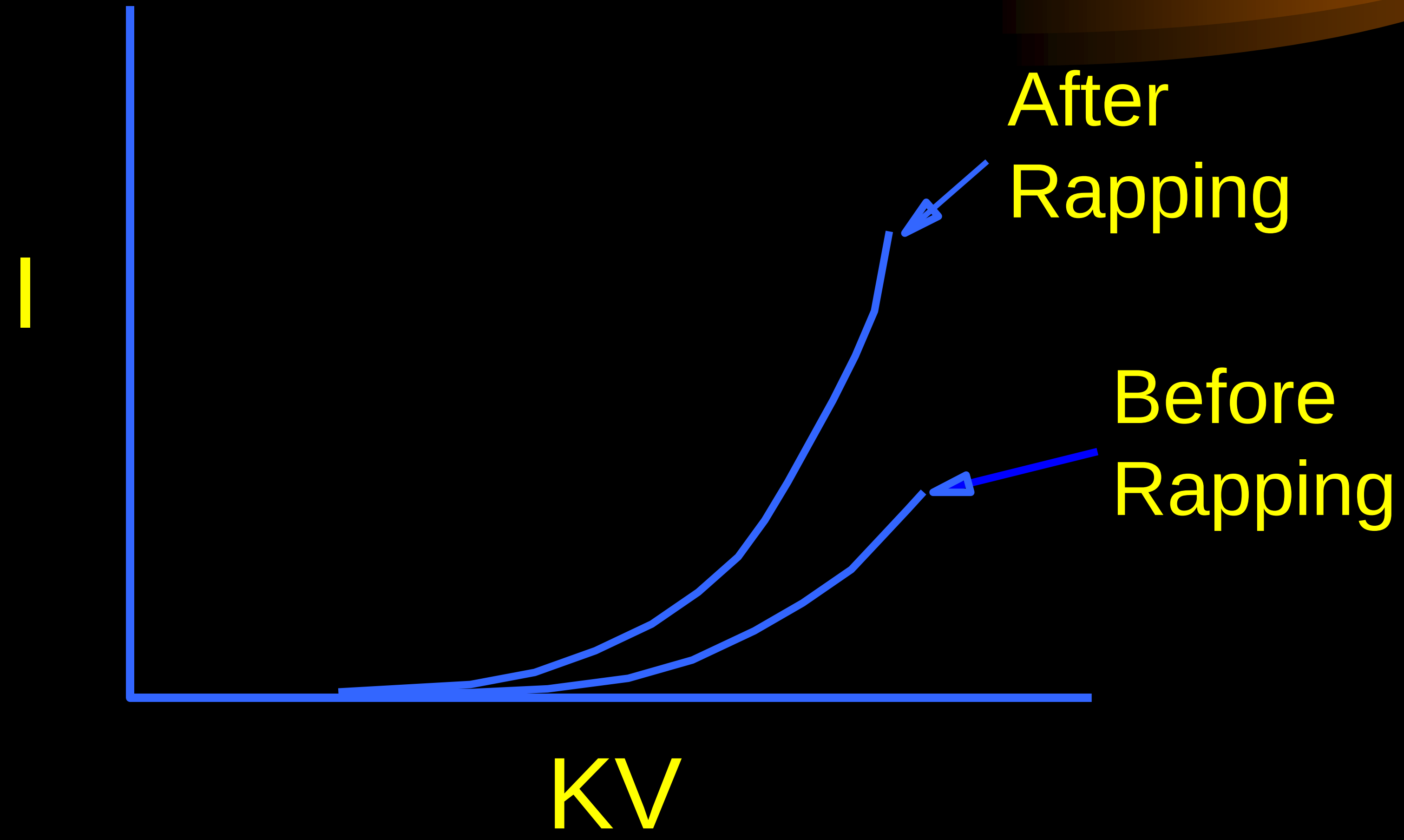
Electrostatic Precipitation

V-I Curves: Typical vs. Back Corona



Electrostatic Precipitation

Benefits of Rapping



Electrostatic Precipitation

Factors Affecting ESP Performance

1. Fundamental
2. Mechanical
3. Operational

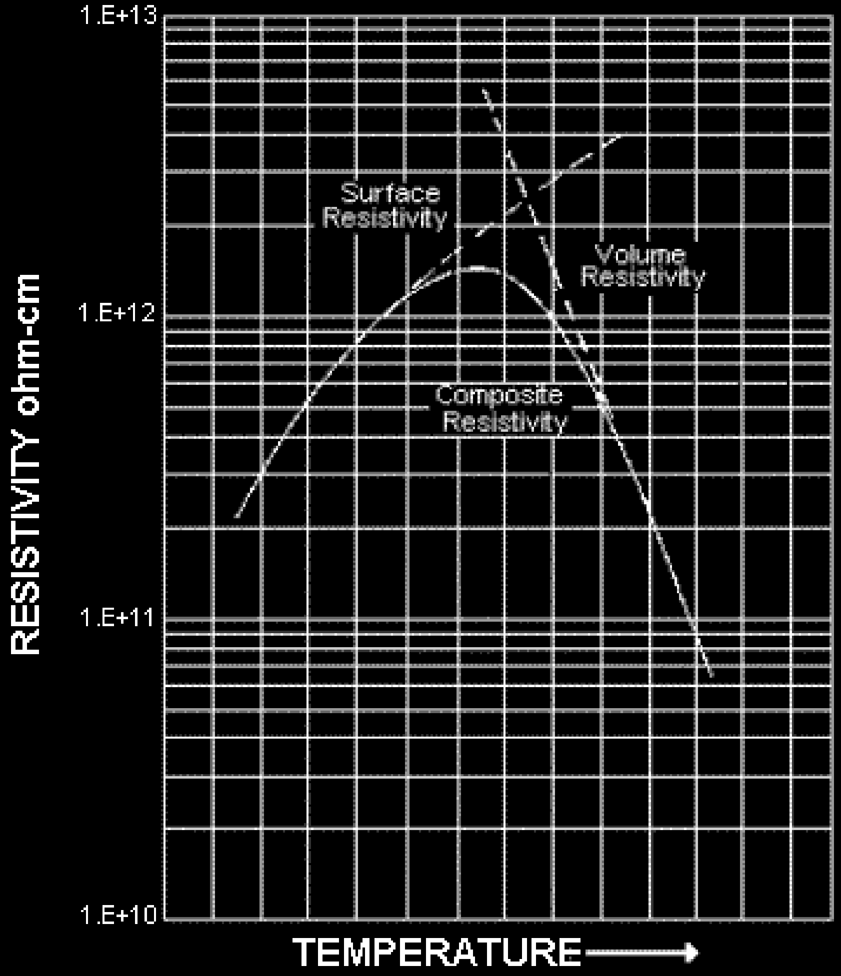
Electrostatic Precipitation

Fundamental Design Factors

- Fly Ash
  - Resistivity
  - Particle Size
  - Chemical Composition
- Inadequate Rapping System
- Insufficient T/R Sets
- Undersized Precipitator
- Unstable T/R Controls

Electrostatic Precipitation

Ash Resistivity



ash Resistivity/Conduction Mechanisms

- Flyash resistivity/conductivity determined by two independent mechanisms
  - Volume resistivity/conduction
  - Surface resistivity/conduction
- Volume resistivity due to conduction through the bulk of the flyash
- Volume resistivity dominates at higher temperatures

Electrostatic Precipitation

Flyash Resistivity/Conduction Mechanisms

- Surface resistivity due to conduction along the flyash particle surfaces
- Surface resisitivity dominates at lower temperatures
- Volume and surface resistivity represent parallel conduction paths

Electrostatic Precipitation

As Received Ultimate Coal Analysis	% by Weight	
	Typical Range	Optimum ESP Operation
Carbon, C	65 - 75	N/A
Hydrogen, H_2	3 - 6	N/A
Oxygen, O_2	4 - 9	N/A
Nitrogen, N_2	1 - 2	N/A
Sulfur, S	0.5 - 2.0	High Value is Better
Moisture, H_2O	2.8 - 12	High Value is Better
Ash	5 - 21	Low Value is Better

Electrostatic Precipitation

Ash Mineral Analysis % by Weight

	Typical Range	Optimum ESP Operation
Lithium Oxide, Li_2O	0 - 0.01	High Value is Better
Sodium Oxide, Na_2O	0.5 - 2.5	Greater than 1%
Potassium Oxide, K_2O	0.1 - 5.9	N/A
Magnesia, MgO	0.6 - 1.8	High Value is Better
Lime, CaO	0.9 - 5.8	High Value is Better
Ferric Oxide, Fe_2O_3	3.5 - 10.0	Greater than 6%
Alumina, Al_2O_3	24 - 35	Low Value is Better
Silica, SiO_2	40 - 62	Low Value is Better
Titania, TiO_2	1.1 - 2.3	N/A
Phosphate Pentoxide, P_2O_5	2.8 - 12	N/A
Sulfur Trioxide, SO_3	0.1 - 4.6	High Value is Better

Electrostatic Precipitation

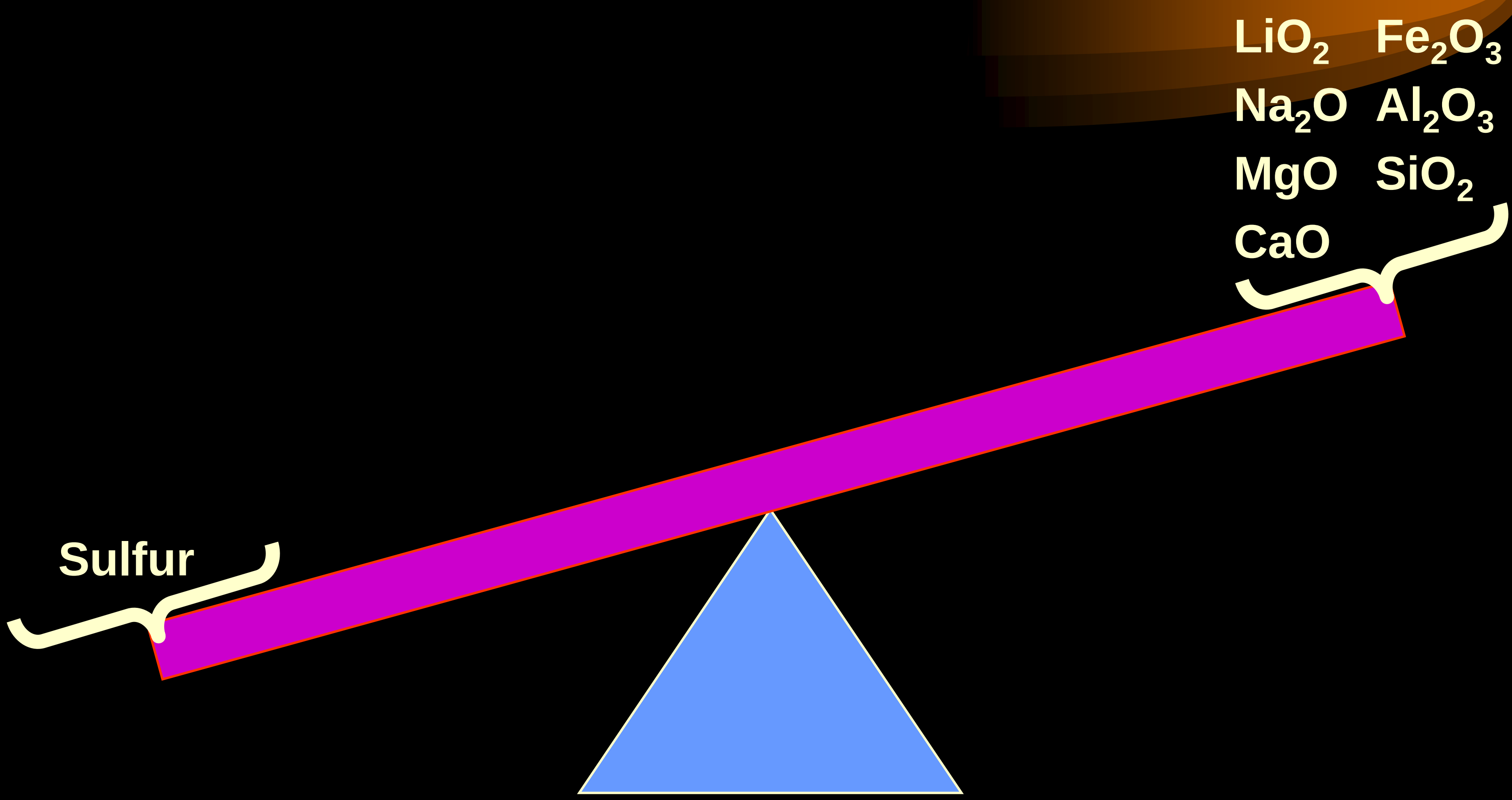
Recommended Fuel Procurement Guidelines for Optimum ESP Operation

Ash Mineral Analysis	% by Weight	
	Typical Range	Optimum ESP Operation
$Al_2O_3 + SiO_2$	64 - 97	Less than 85%
CaO + MgO	1.5 - 8.0	Greater than 5%

Electrostatic Precipitation

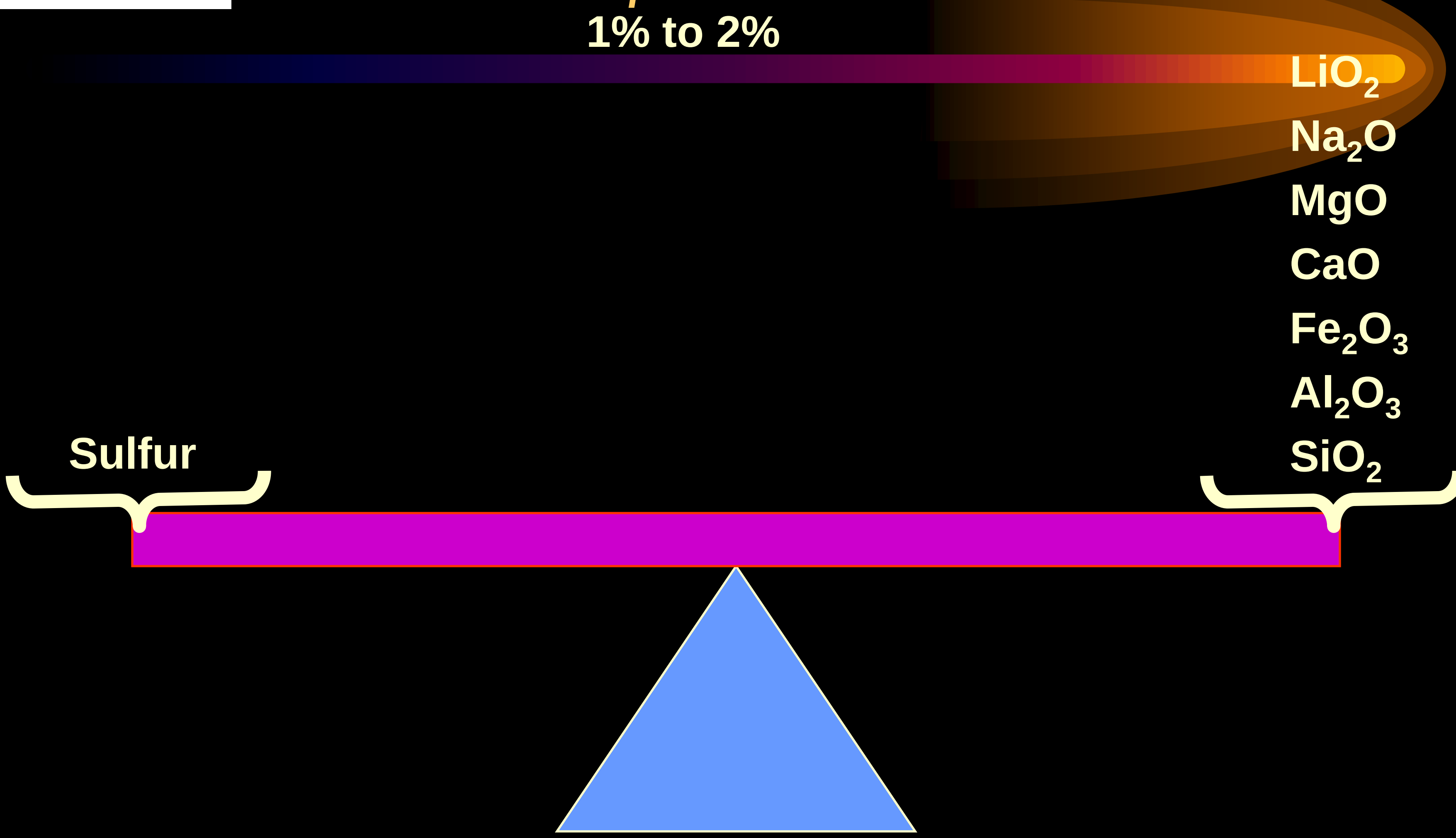
High Sulfur Coal vs. Ash Constituents

Greater Than 2%



Electrostatic Precipitation

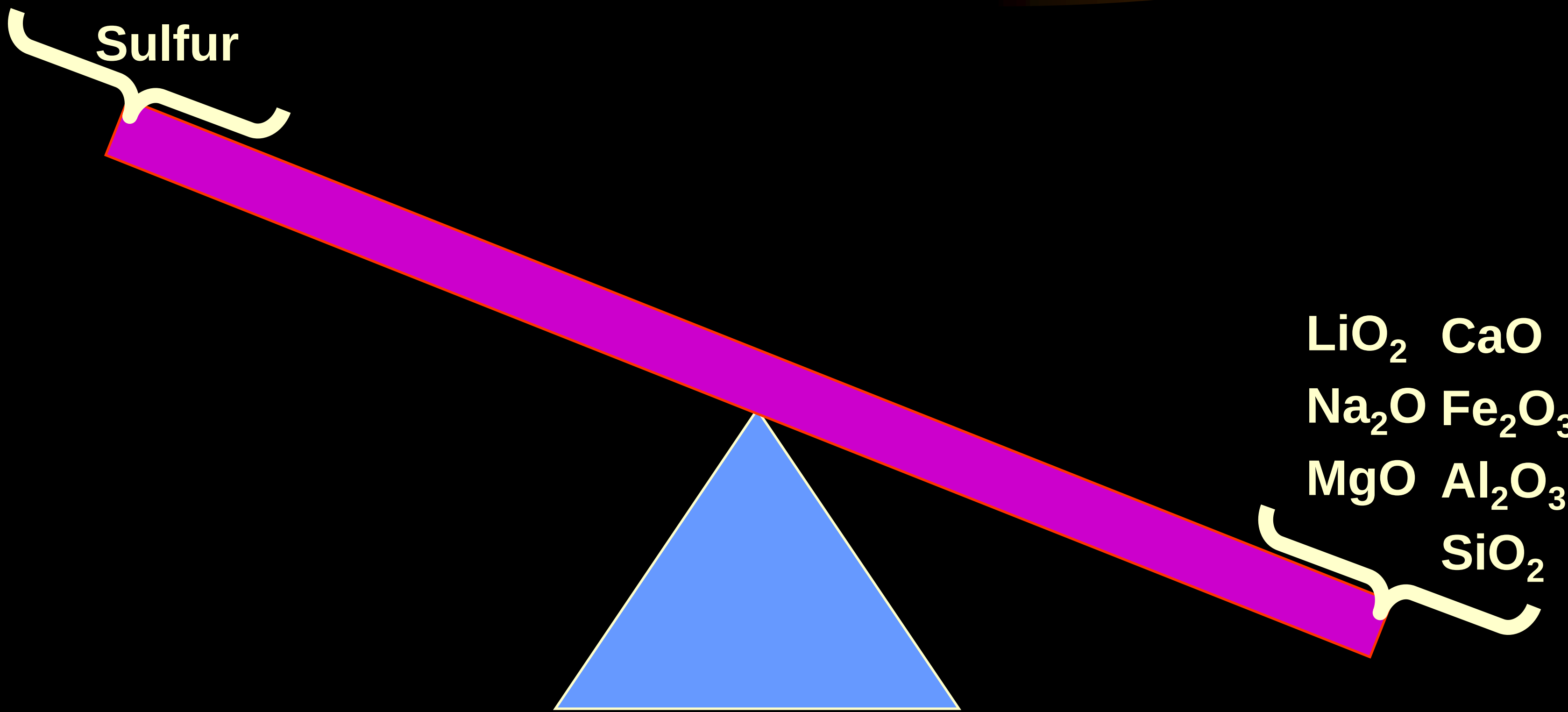
Medium Sulfur Coal vs. Ash Constituents



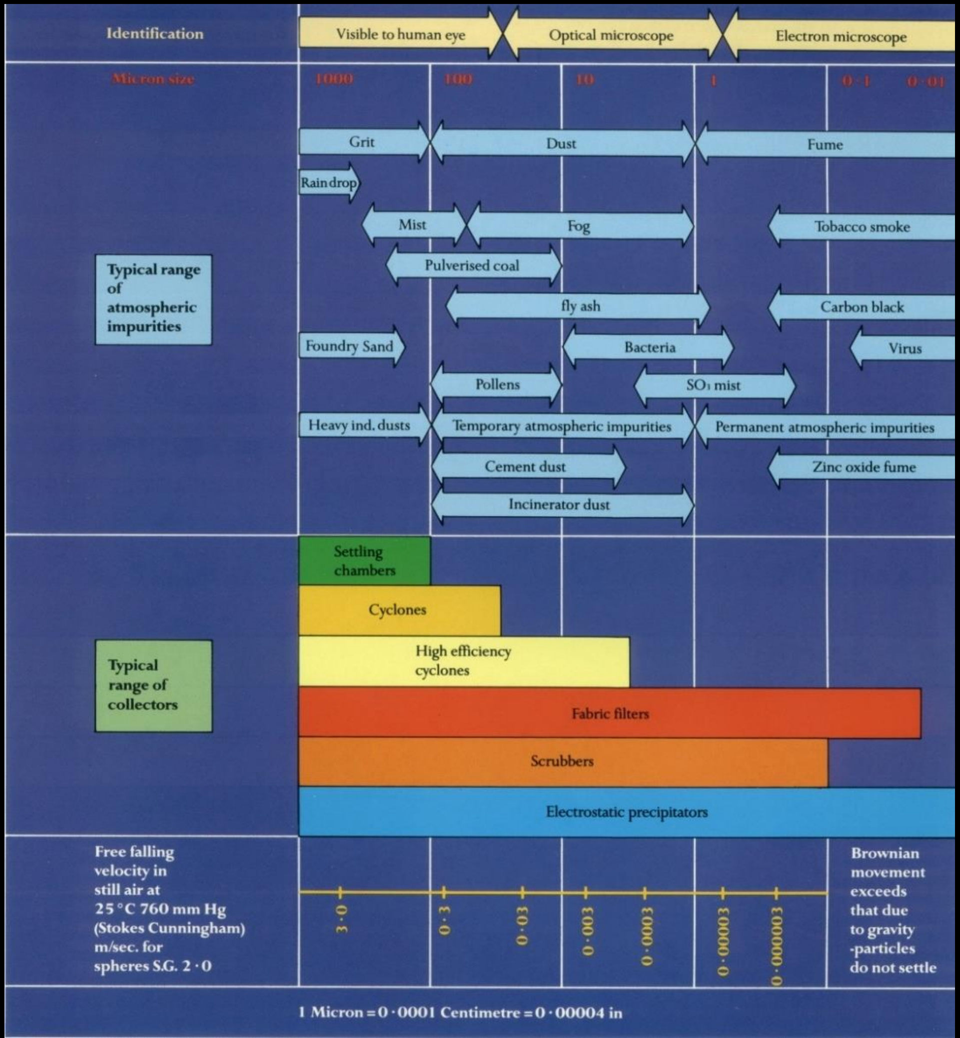
Electrostatic Precipitation

Low Sulfur Coal vs. Ash Constituents

Less Than 1%



Electrostatic Precipitation



Electrostatic Precipitation

Mechanical Factors Affecting Performance

- Poor Electrode Alignment
- Vibrating or Swinging Electrodes
- Distorted Collecting Plates
- Excessive Ash Deposits on Electrodes
- Full Hoppers
- Air Inleakage
- Ash Deposits on Gas Distribution Devices
- Gas Sneakage Through Hoppers and Around ESP Zones

Electrostatic Precipitation

Operational Factors Affecting Performance

- Improper T/R Control Adjustment
- Excessive Gas Flow Through Precipitator
- Improper Adjustment of Rapper Intensity or Frequency
- Process Upsets
  - Tube Leaks
  - Plugged Air Heater
  - Shut-Downs and Start-Ups