The following presentation was made available by Process Applications, Inc. The presentation was developed for the operator's workshop at the International Ozone Association meeting at Lake Lanier, Georgia, USA in October of 2005. It was presented by Kerwin Rakness and Glenn Hunter of Process Applications.

Process Applications is a preeminent international firm that specializes in facilitating the implementation of prioritized technical knowledge for the water and wastewater profession. The consultancy is led by Kerwin Rakness who is an established expert in the operation and maintenance of ozone systems for drinking water treatment. He is the author of the book "Ozone in Drinking Water Treatment" recently (2005) published by the American Water Works Association.

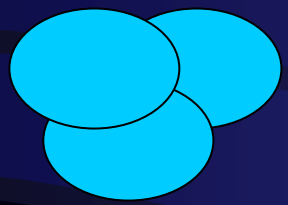
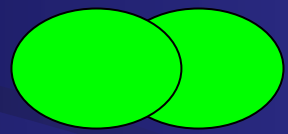
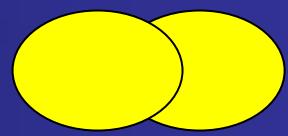
Process Applications specializes in providing operation and management services aimed at obtaining cost effective, improved performance and additional capacity from existing water and wastewater facilities. Their experience has shown that expensive plant upgrades can be reduced in cost, can be delayed, or can sometimes be avoided. They believe that their services are timely given the reduced funding available for new plant construction, the increasing cost of capital modifications, and the ever-increasing and more stringent regulations governing water and wastewater treatment practices. Services are offered to municipalities, special districts, industries, consulting engineers, state and federal agencies, and universities. A unique aspect of the Process Applications approach is the emphasis on facilitating the implementation of optimization approaches by their clients' personnel. This approach requires empowerment of local personnel such that improvements are accomplished and sustained.

Detailed information on Process Applications, their personnel and project history can be found by clicking on the following link:

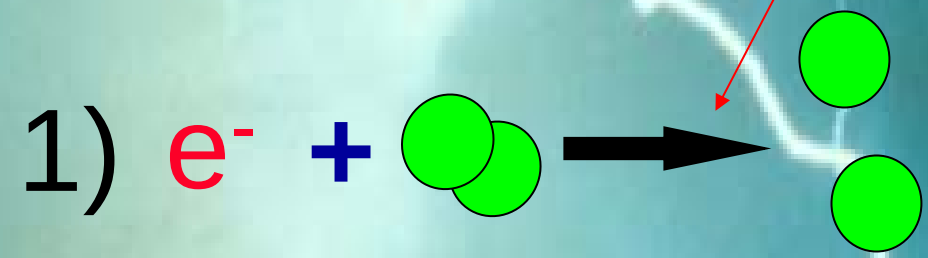
http://kerwin.rakness.com/Files/PAIQualificationsOzone2000.pdf


Ozone
Water Treatment Applications,
Equipment, and Safety

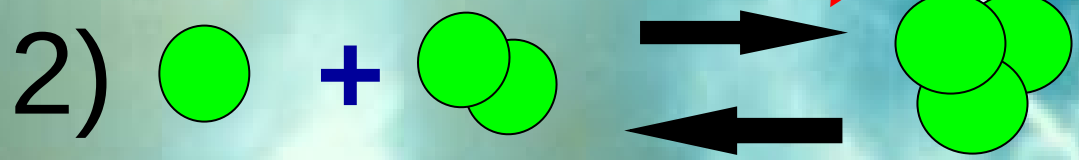
Ozone is an Unstable Odorous Gas

Ozone	Oxygen	Chlorine
O_3	O_2	Cl_2
		
Unstable	Stable	Stable
Odor	No odor	Odor

Oxygen + Electric Discharge Produces Ozone



One electron splits one oxygen molecule into two oxygen ions.



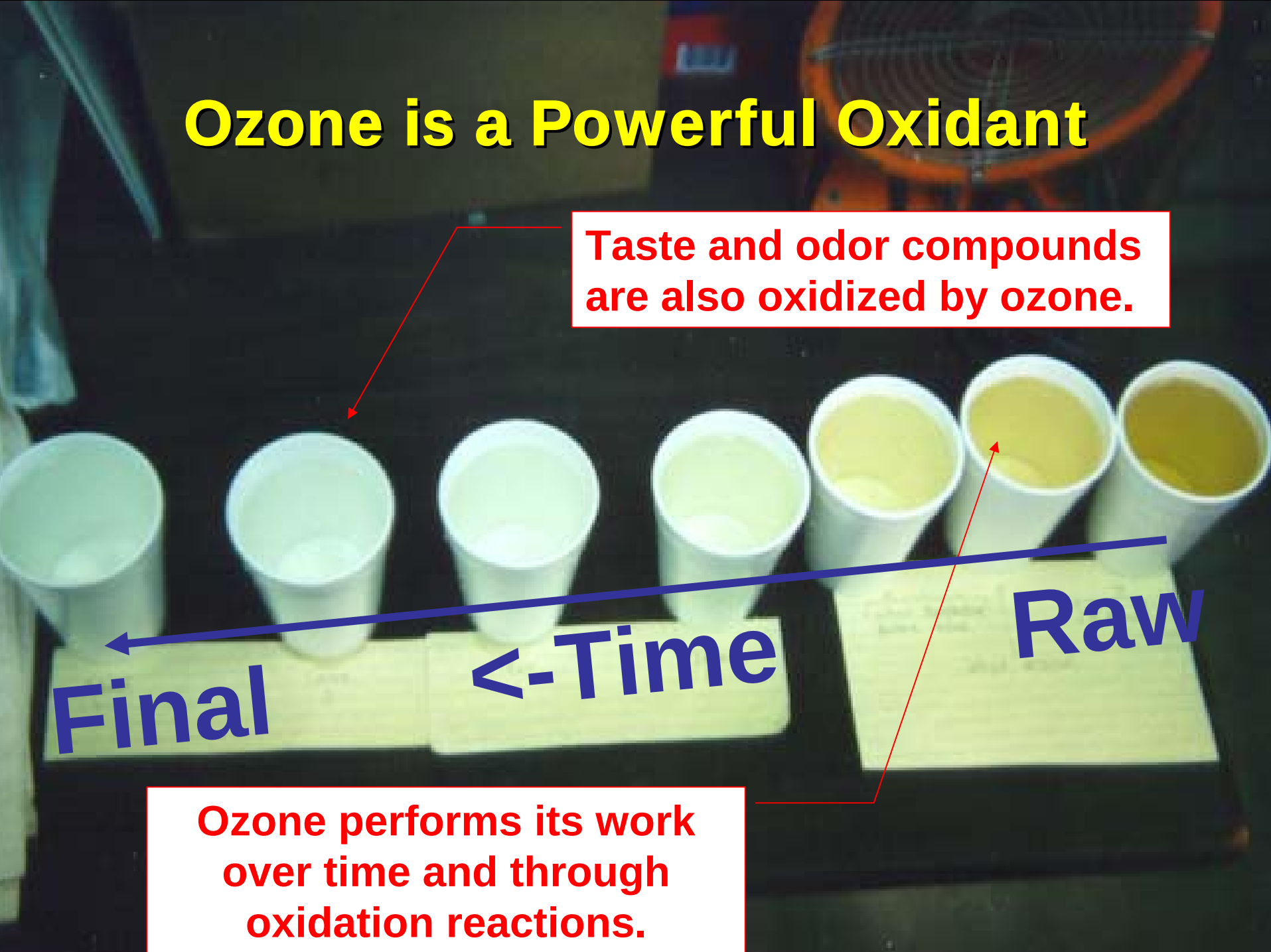
One oxygen ion combines with one oxygen molecule to form one ozone molecule.

NOTE: Ozone is unstable.

Water Ozone Application

- Disinfection (*Giardia*, virus, *Crypto*)
- Reduce disinfection by-products
  Chlorinate after filters to reduce THM/HAA
- Oxidation benefits
  - T&O and color
  - Micro-flocculation
  - Iron and manganese
  - Solvents, pesticides, etc.
- Disinfection usually controls dose

Ozone is a Powerful Oxidant



Ozone Oxidation Reactions

Inorganics

Iron

Manganese

Hydrogen Sulfide

Bromide

Organics

Pathogens

Bacteria

Virus

Giardia

Cryptosporidium

Other

Solvents – **HO·**

Pesticides - **HO·**

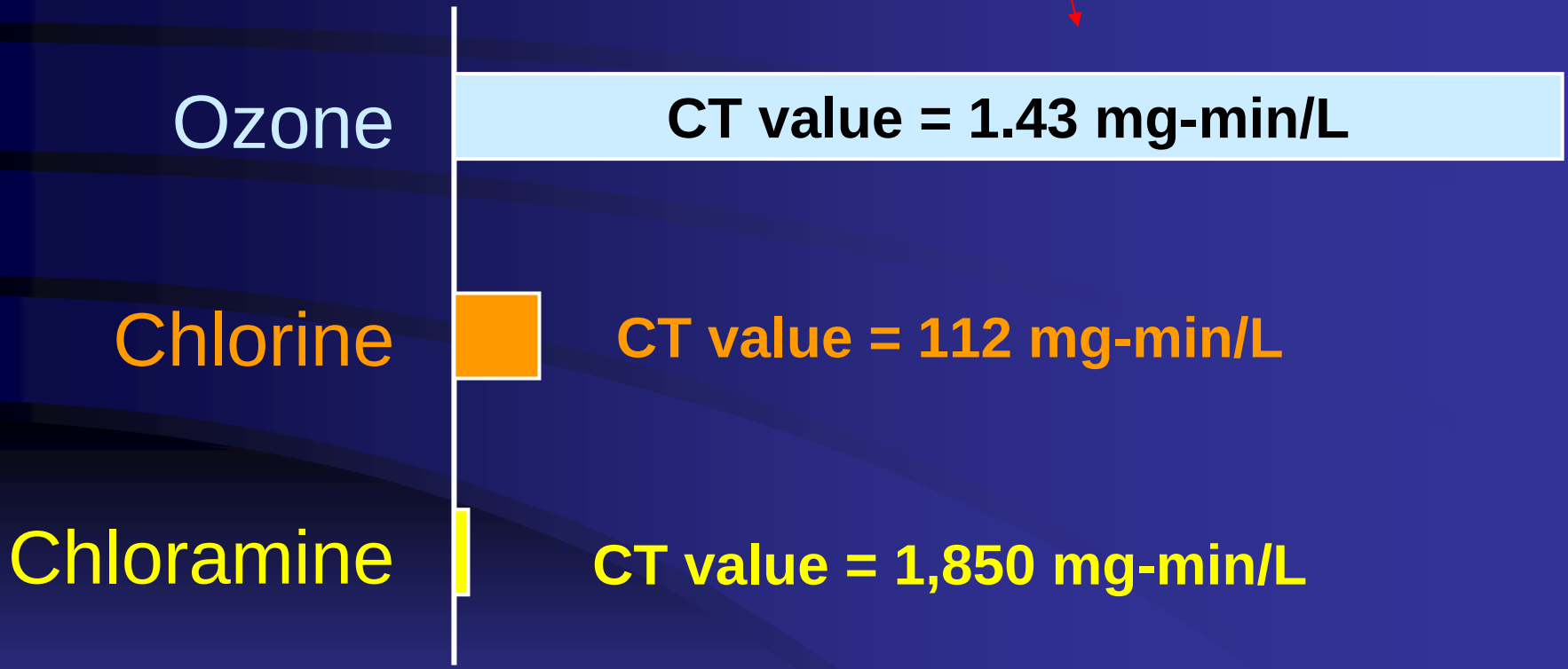
Color

Taste & Odor - **HO·**

HO· Some hydroxyl radicals (**HO·**) form naturally.
HO· formation is greater at elevated pH (>8.0 – more OH^-)
HO· formation is enhanced with hydrogen peroxide (PEROXONE).

Ozone is a Powerful Disinfectant

Ozone requires much lower CT value than chlorine or chloramine.



CT value for 3-log *Giardia* cyst inactivation @ 10°C and pH 7

Disinfection By-Products

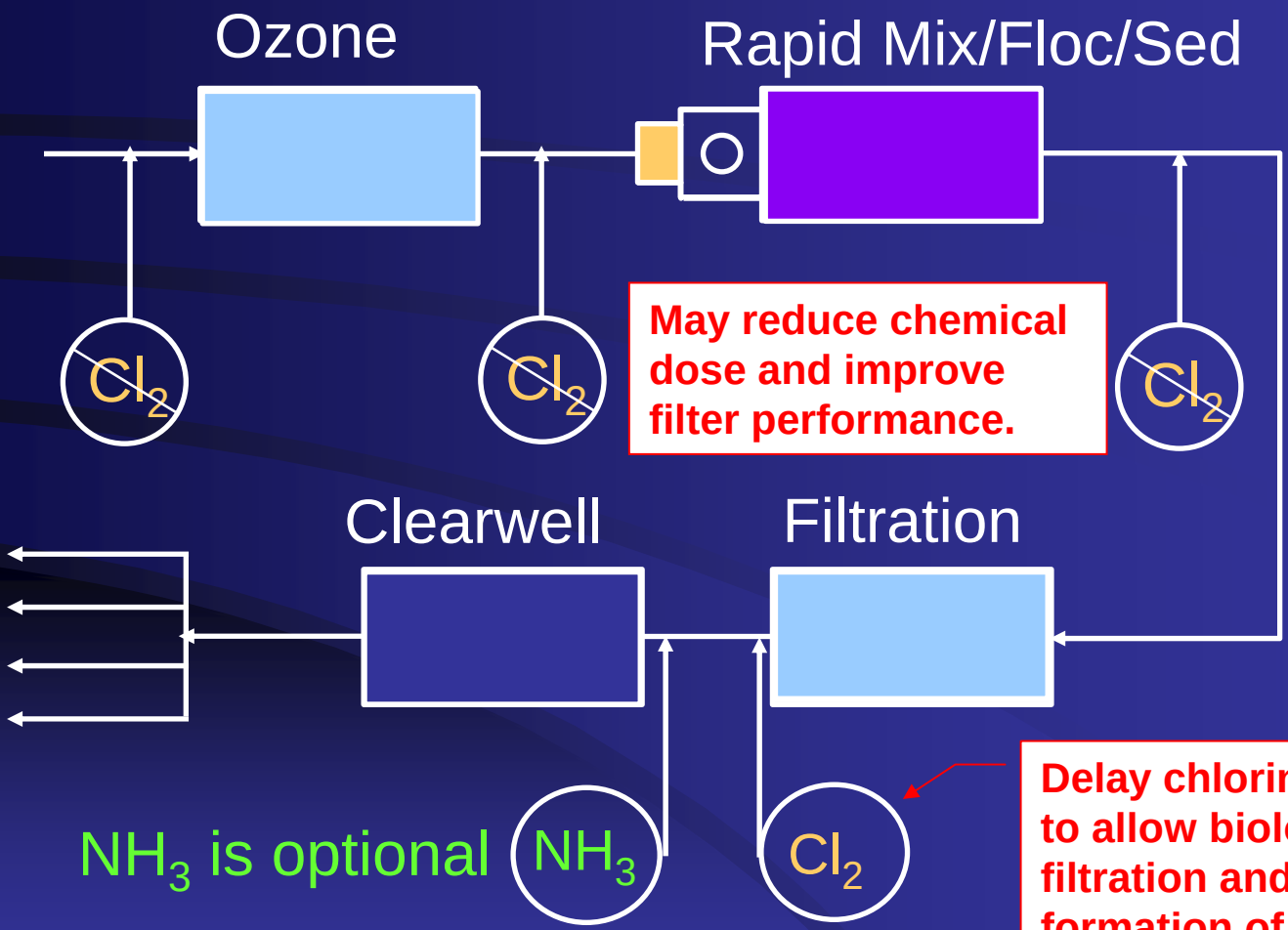
Chlorine	Ozone
Trihalomethanes (THM)	Bromate
Haloacetic Acids (HAA)	Assimilable Organic Carbon (AOC)

Ozone DBP Considerations

- Biodegradable organics
  - Ozonation increases AOC
  - Chlorinate after filters
  - Biological activity in filters consumes AOC
- Bromate
  - Bromide must be present
  - Bromate limit is 10 µg/L (annual average)
  - Minimize ozone dose is first control option
  - Other control options include
    - Lowering pH
    - Add pre-chlorine and ammonia or pre-chlorine dioxide

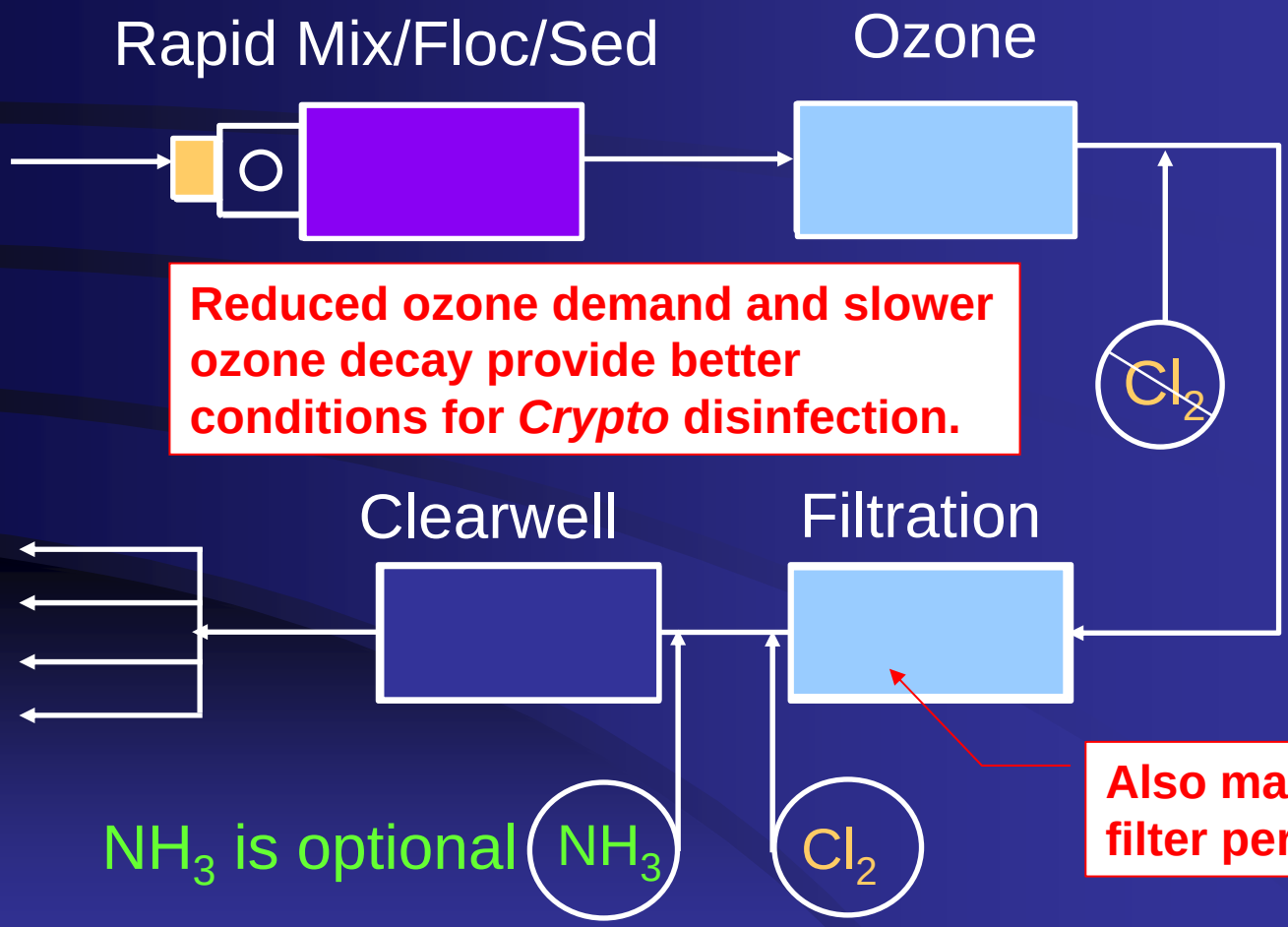
Pre-Ozone Application

Pre-oxidation, disinfection, and T&O removal



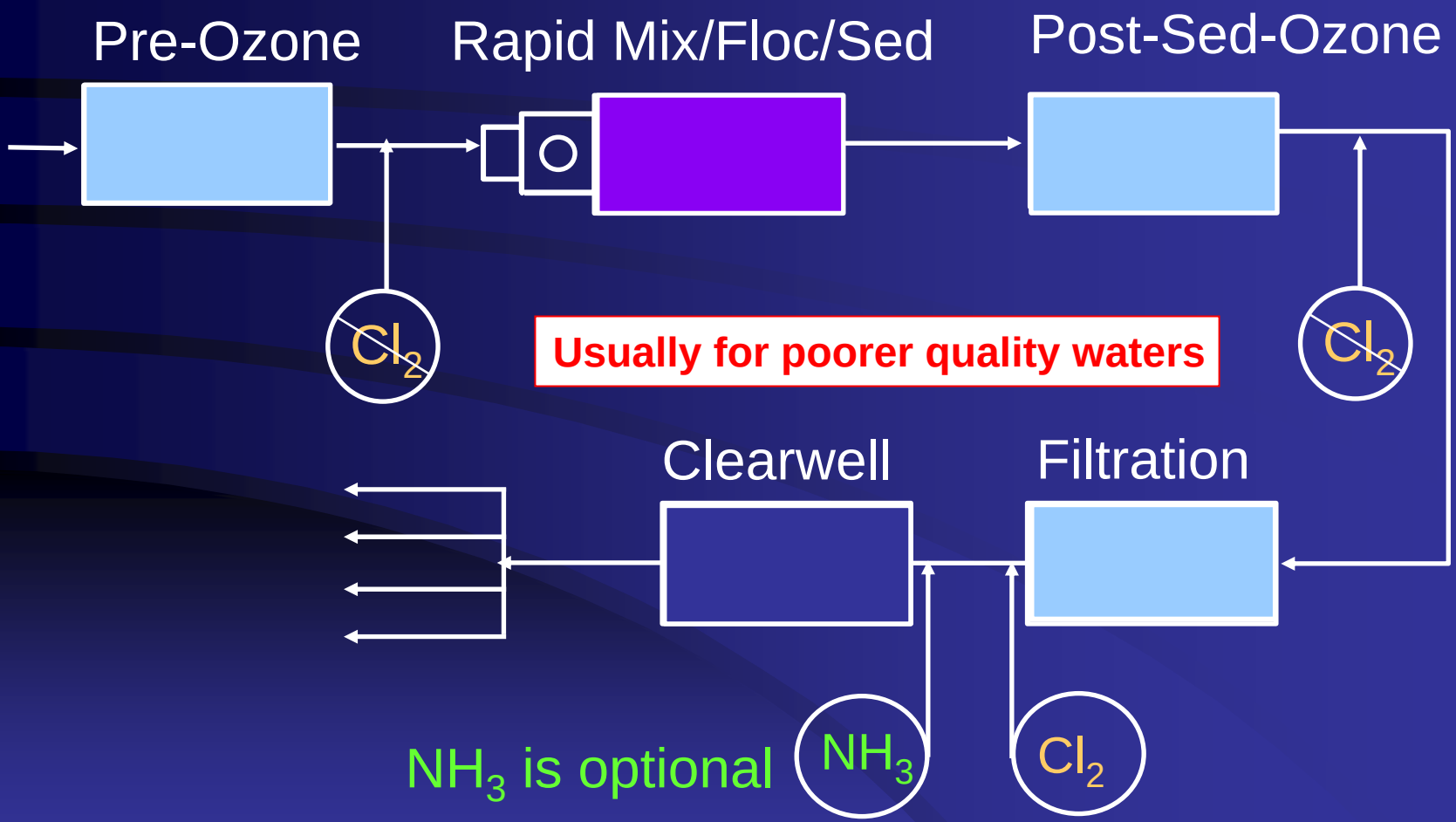
Intermediate Ozone Application

Disinfection, reduce ozone dose and T&O removal

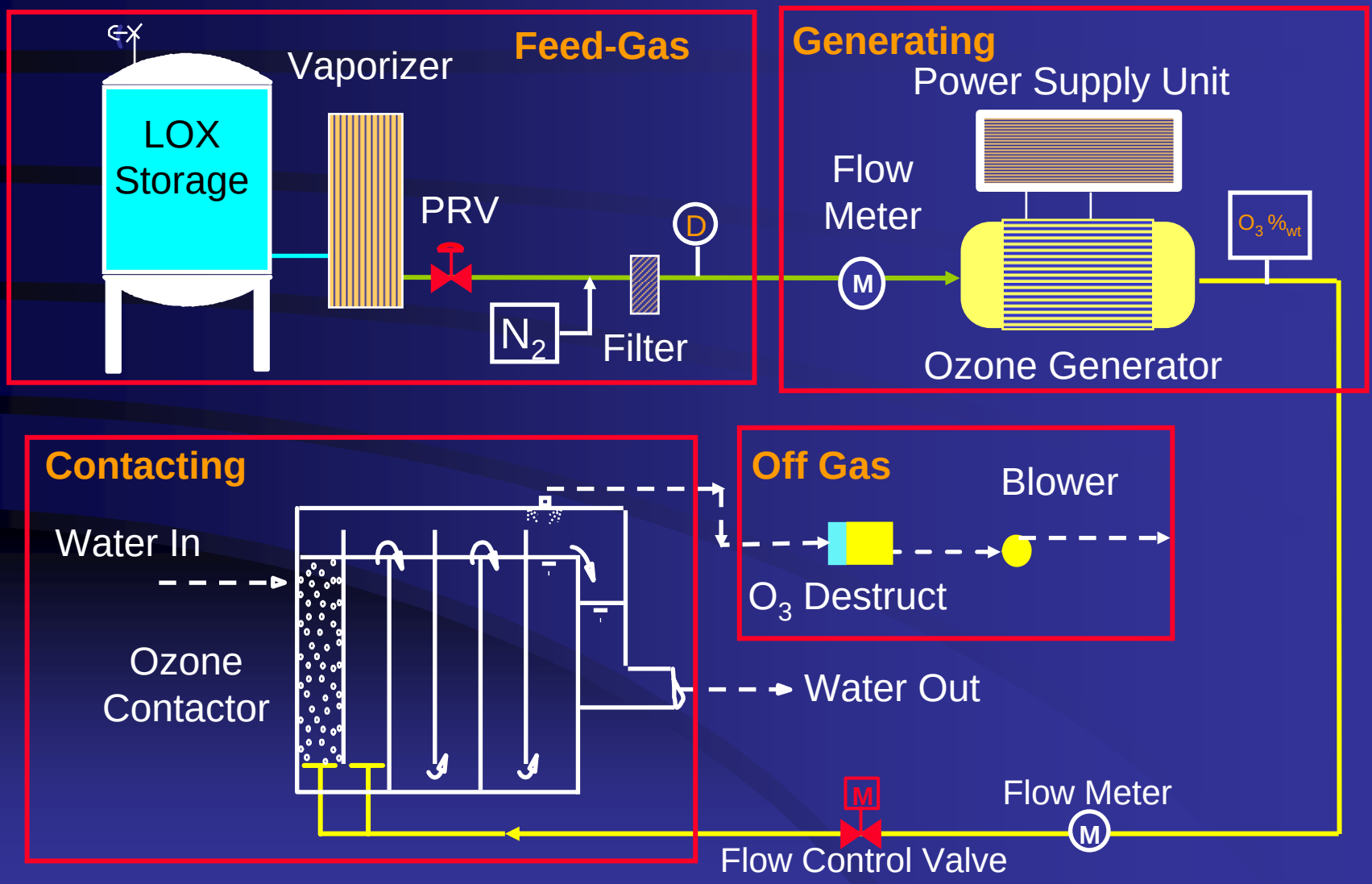


Two-Stage Ozone Application

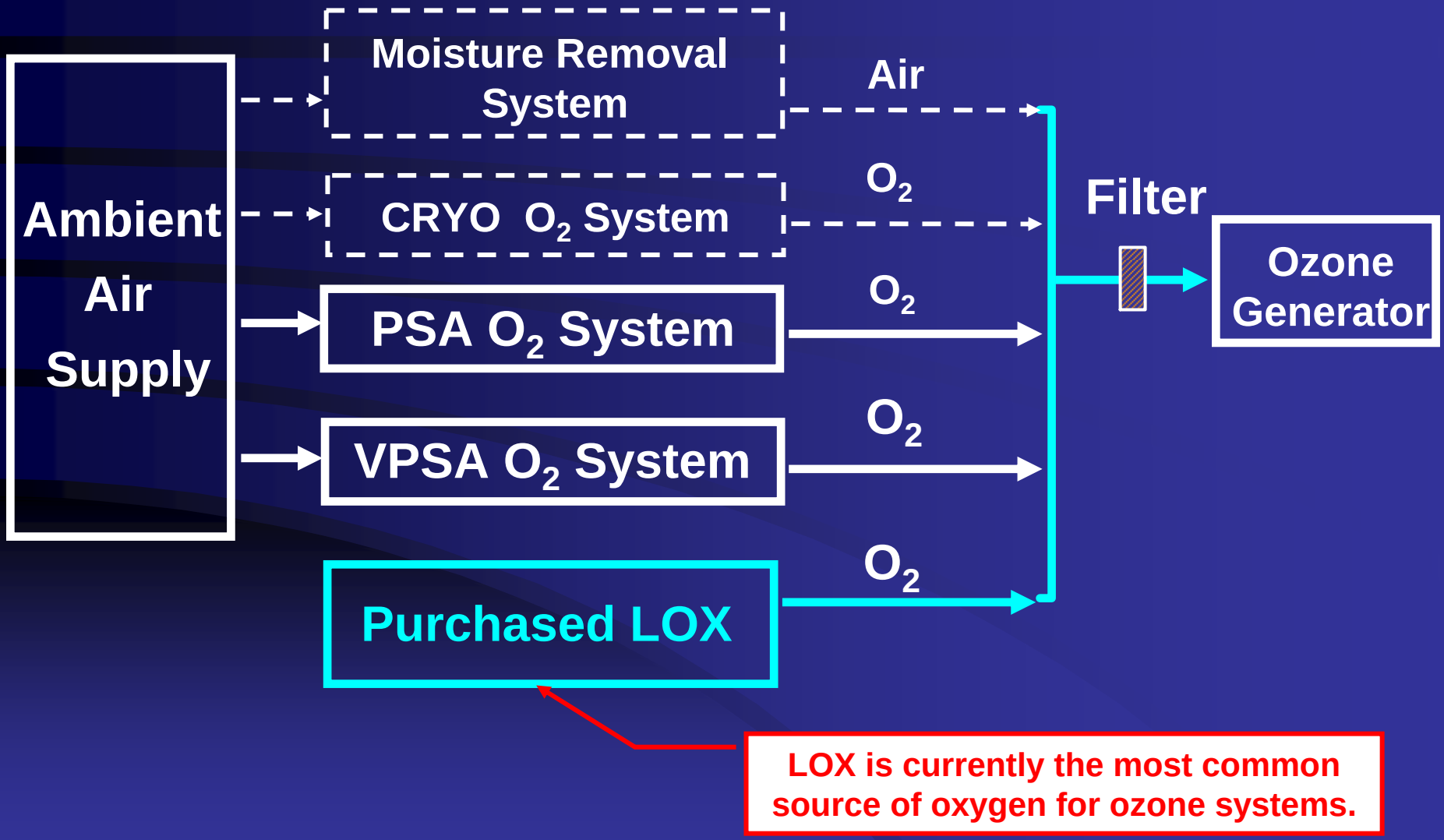
Pre-oxidation, disinfection, reduce dose and T&O removal



Four Components of an Ozone System



Ozone Feed-Gas Options



Ozone Equipment Has Been Simplified

Earlier air-fed ozone systems

Air Compressor

Refrigerant Dryer

Desiccant Dryer

Ozone Generator

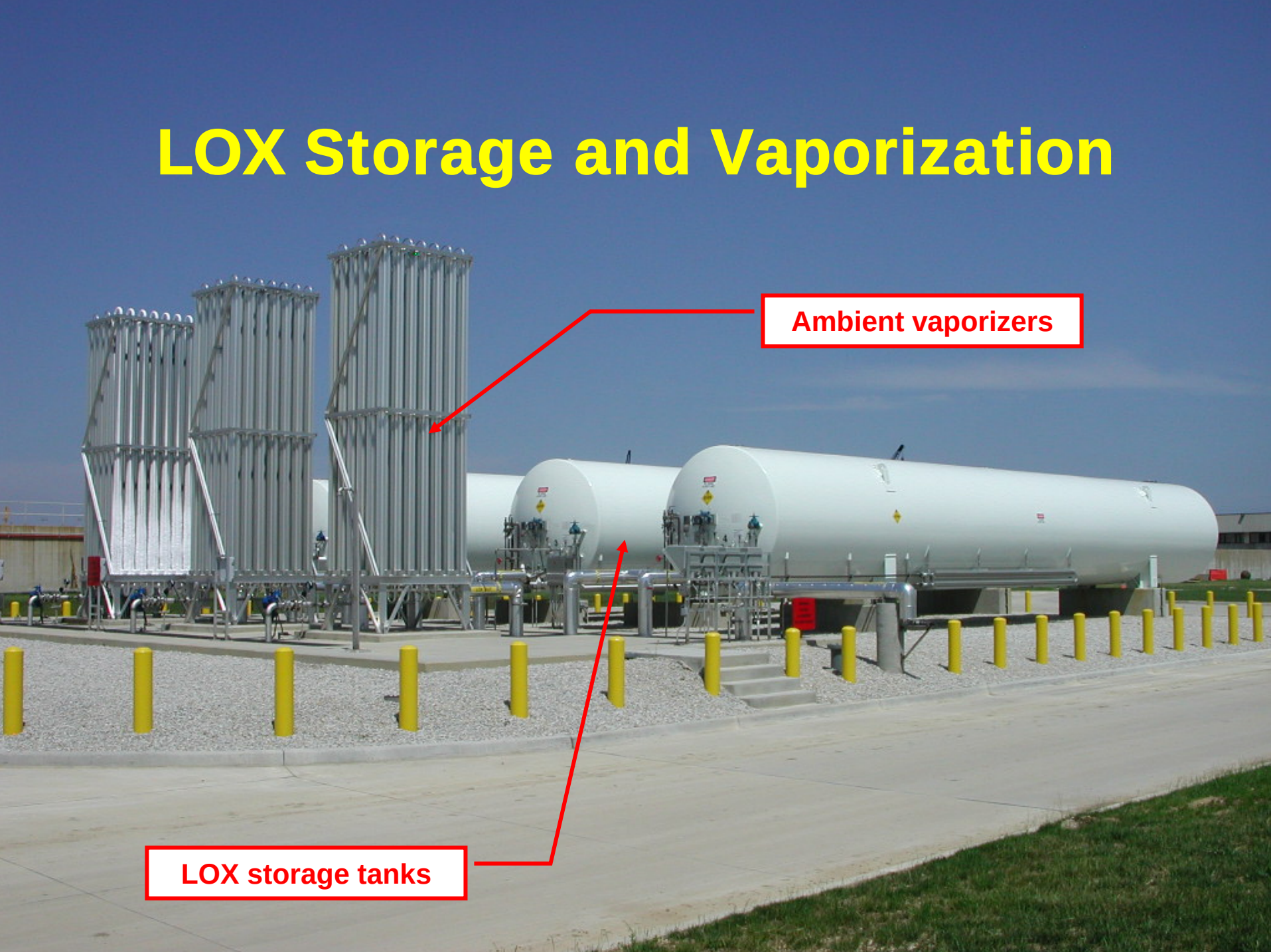
Less equipment = Lower maintenance, capital cost, and operating cost

Liquid Oxygen Storage & Ambient Vaporizers

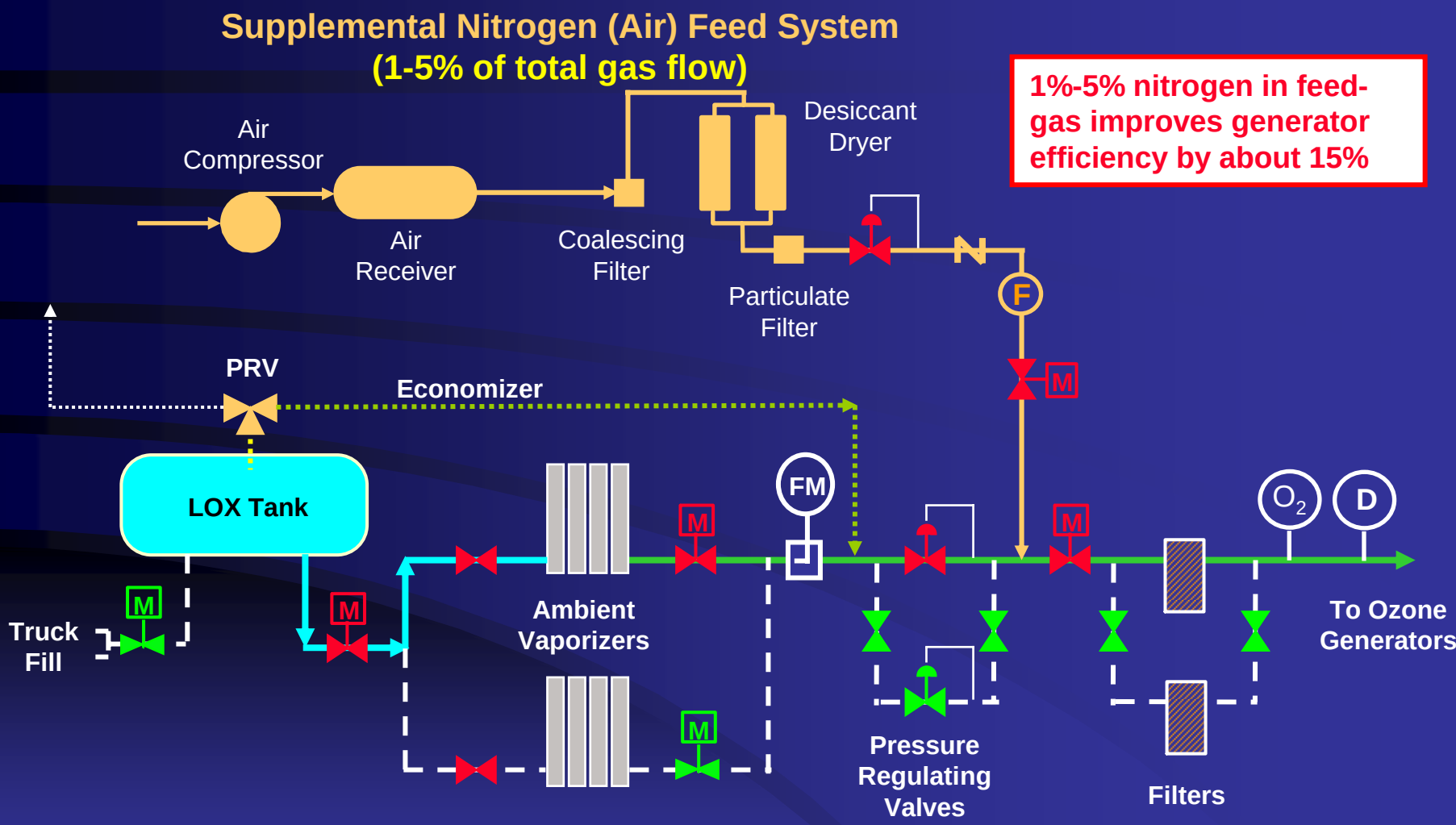
Ozone Generator

Current oxygen-fed ozone systems

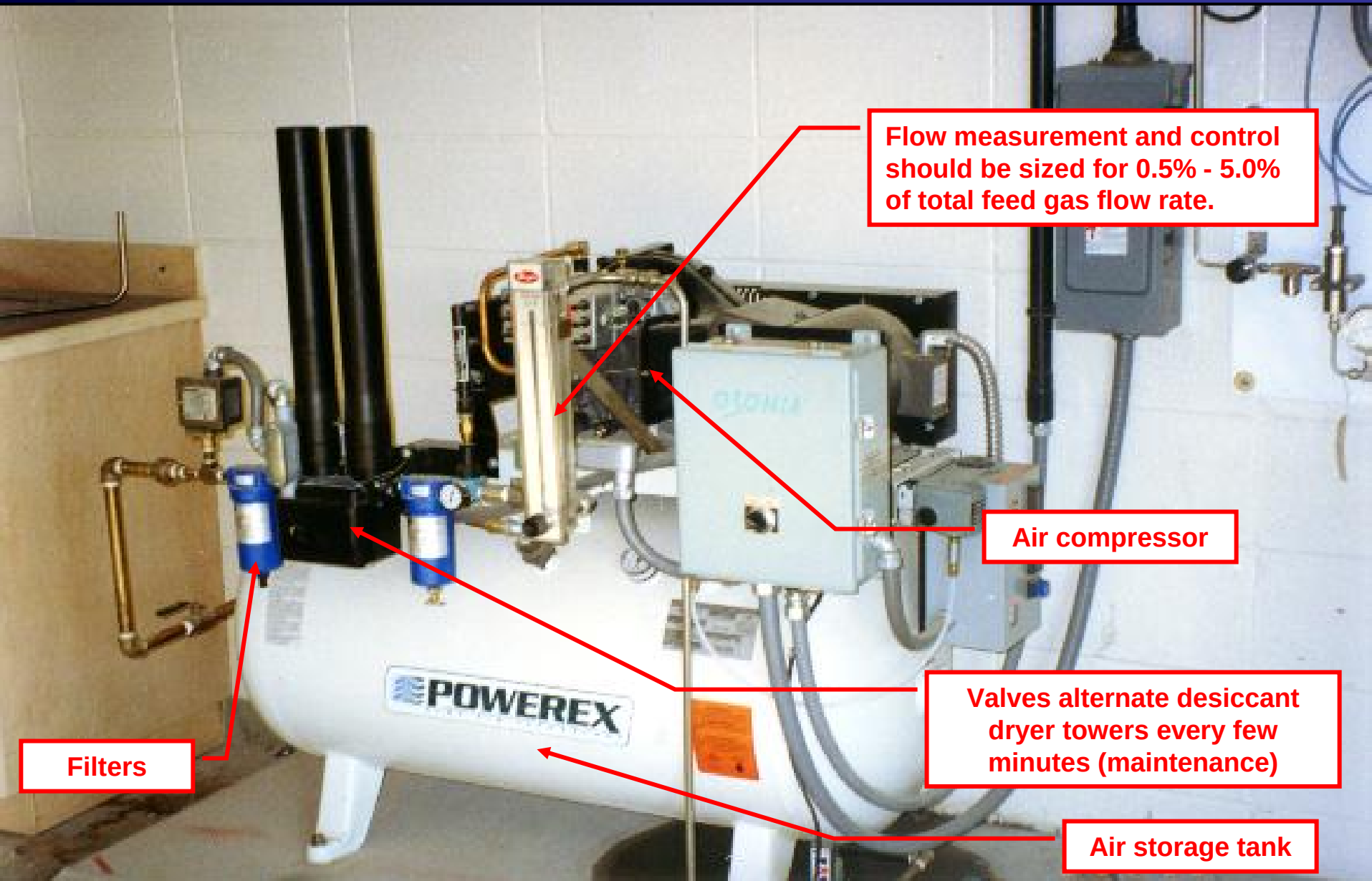
LOX Storage and Vaporization



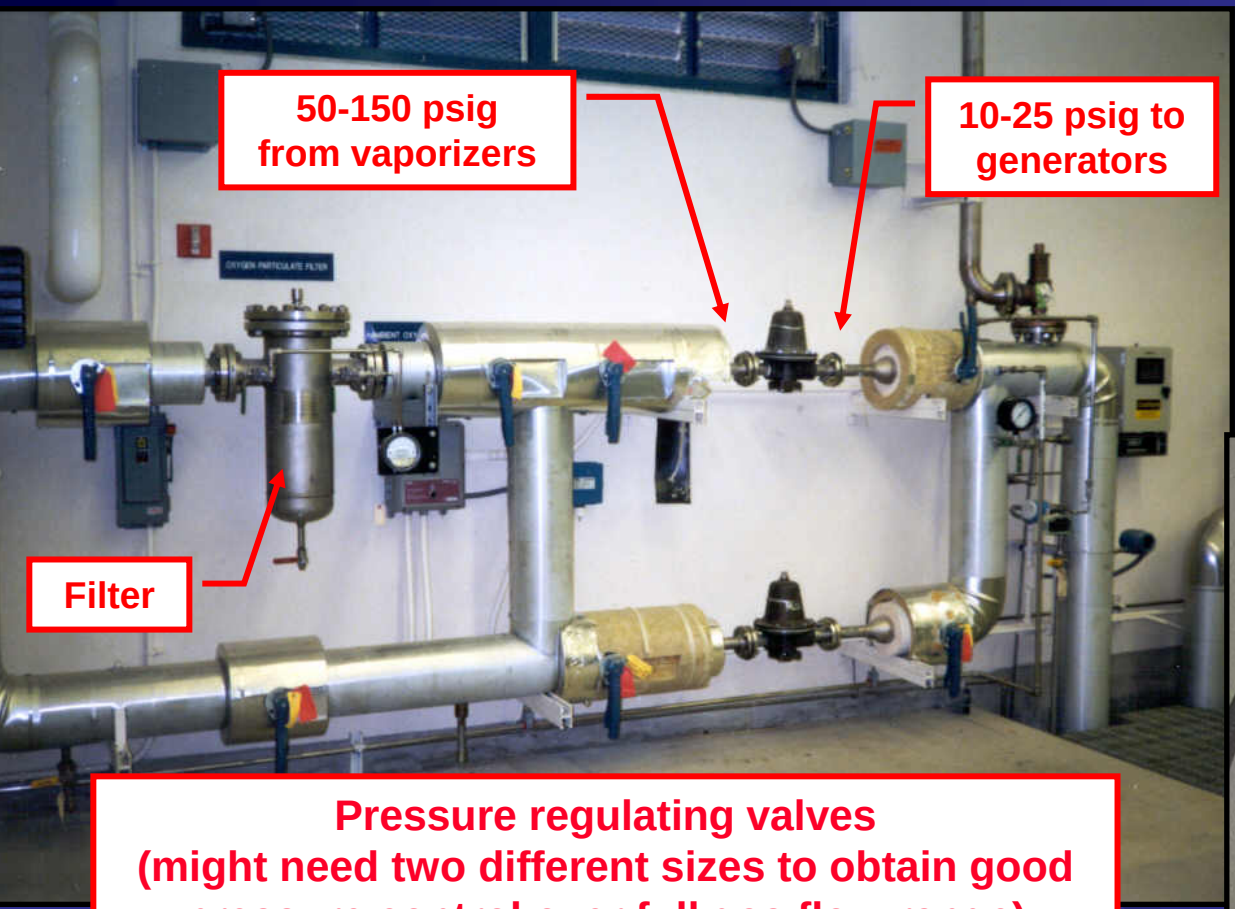
Oxygen Feed-Gas System



Nitrogen-Feed Air System



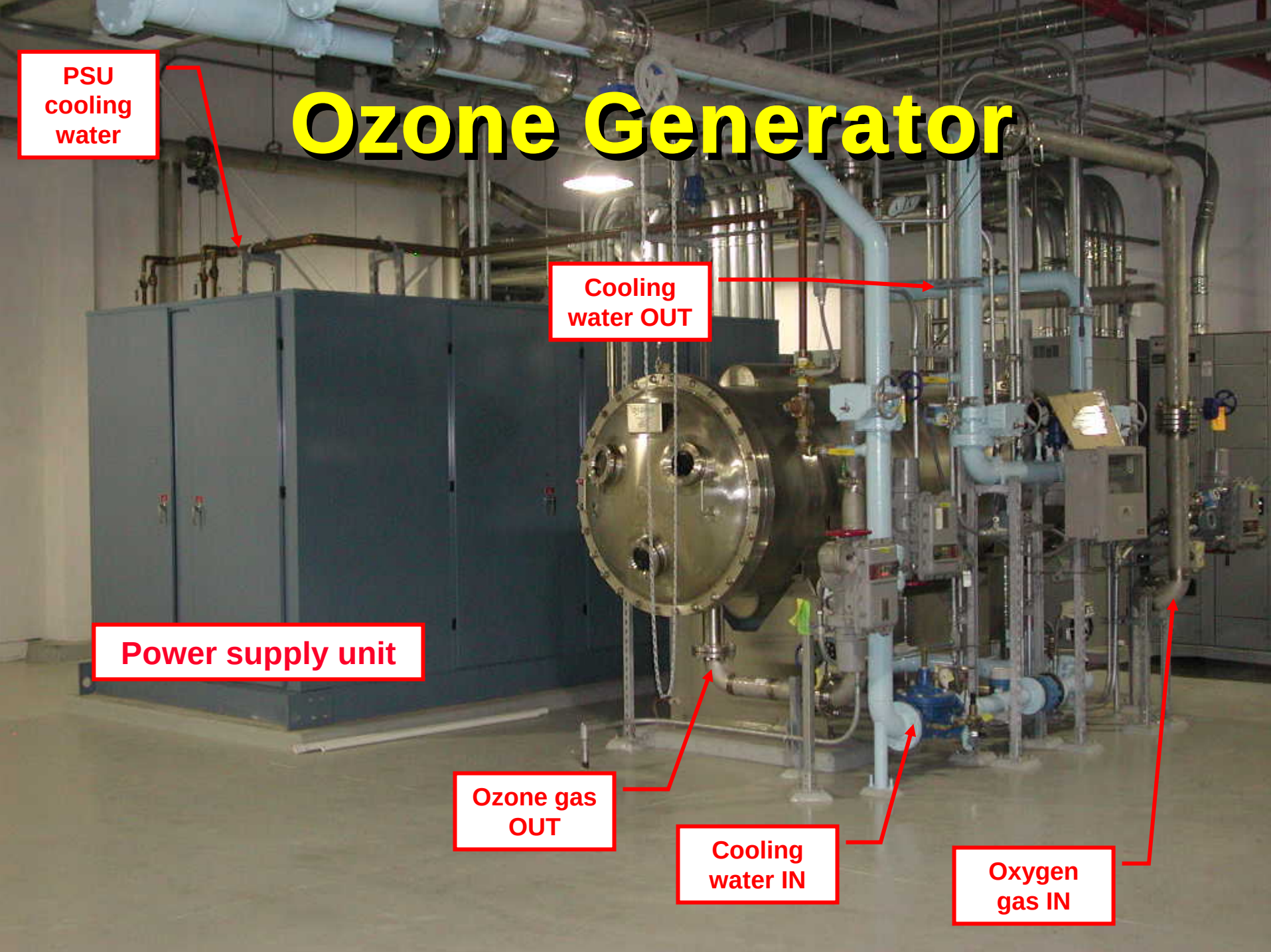
Oxygen Gas Filter, PRV, Purity and Dewpoint Monitor



Pressure regulating valves
(might need two different sizes to obtain good pressure control over full gas flow range)

Dewpoint monitor

Oxygen purity monitor


Ozone Generator
PSU cooling water
Cooling water OUT
Power supply unit
Ozone gas OUT
Cooling water IN
Oxygen gas IN

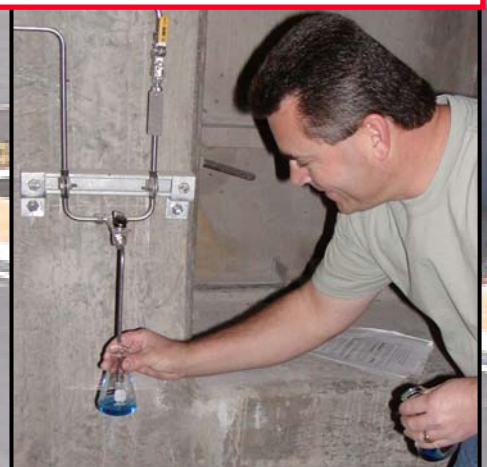
Ozone Contactor

Ozone off-gas destruct

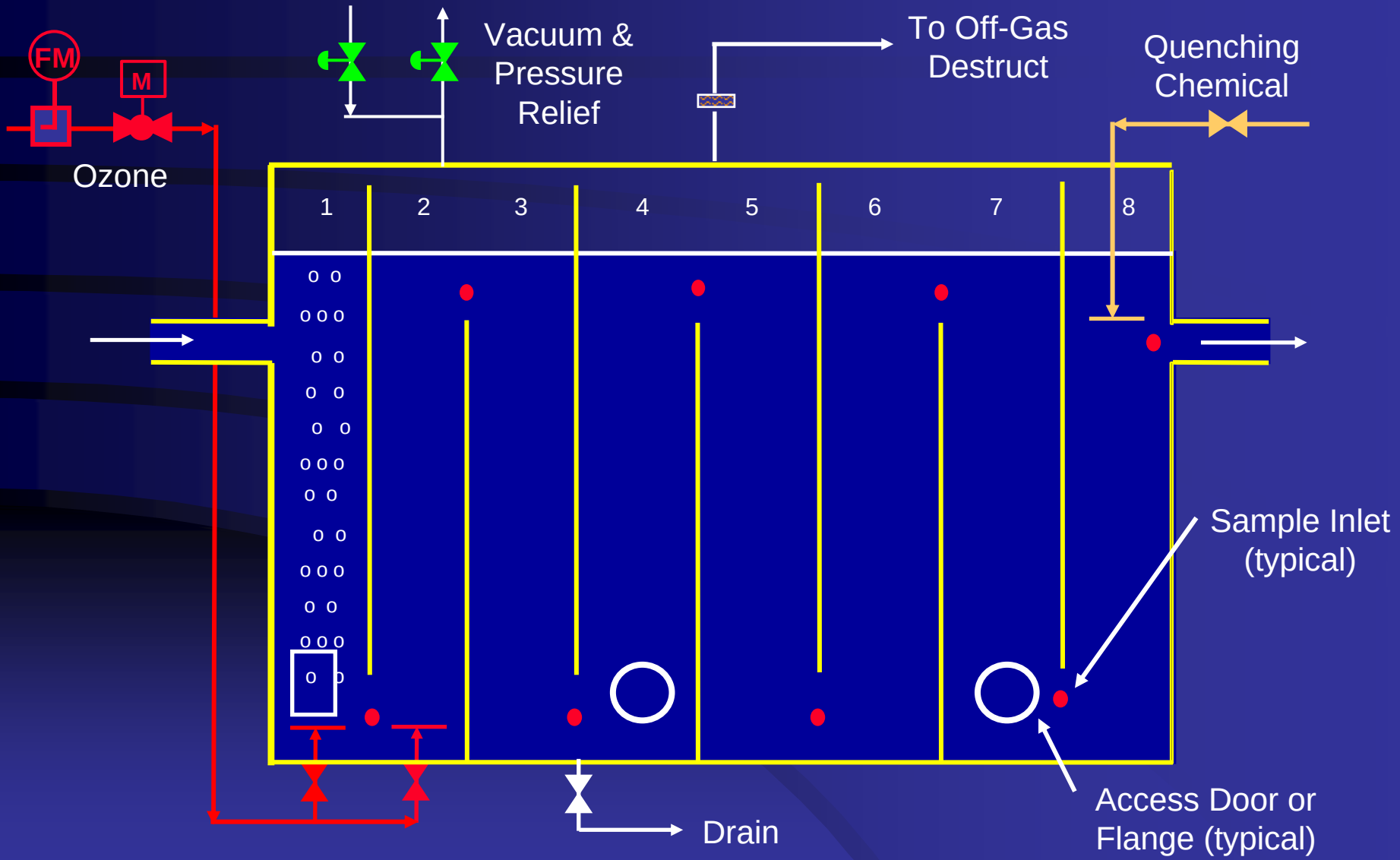
Vertically baffled contactors

Residual measurement & grab sampling

Fine bubble diffusers



Bubble Diffuser Contactor



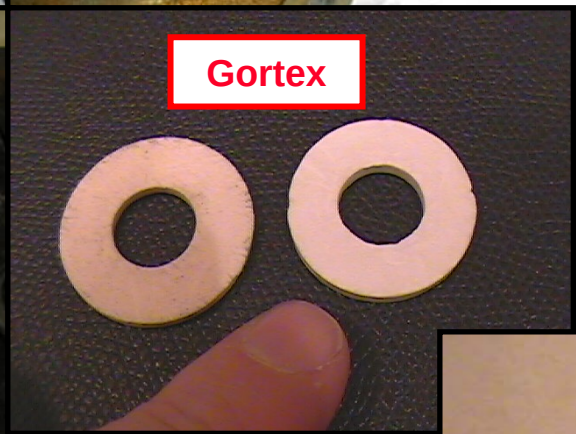
Diffusers


ROD DIFFUSER
DOME DIFFUSER
Rod
Dome


Gaskets


Checking bubble pattern

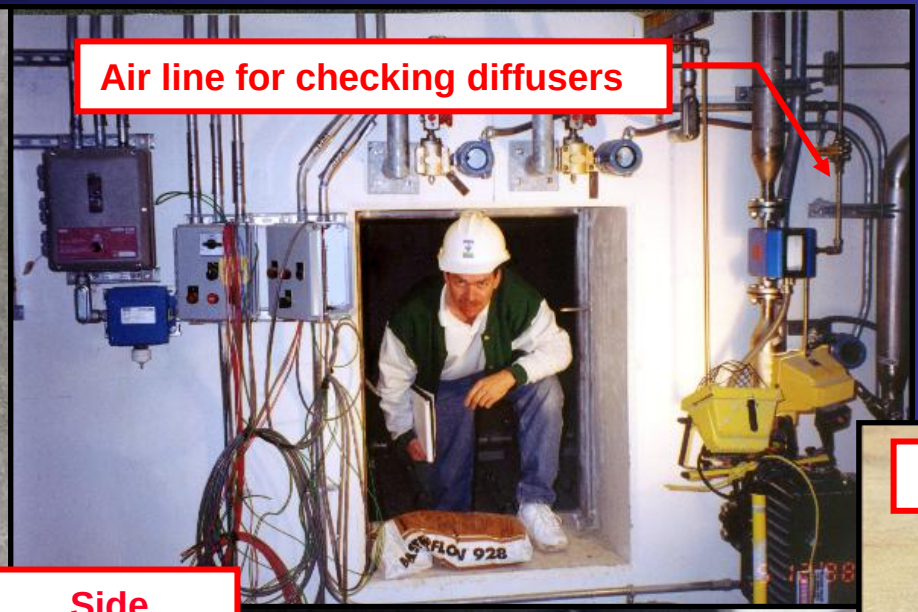
Gasket Materials

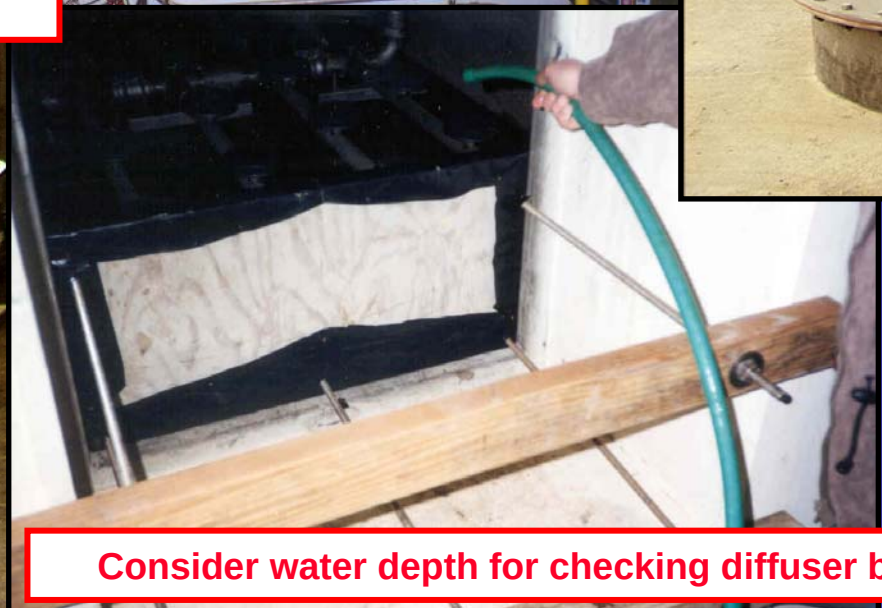


Diffuser Issues

- Hypalon deteriorates quickly
- Viton is reported as better
- Gortex is reported best, but expensive
- If diffuser clogs quickly, consider less expensive gaskets and more frequent cleaning
- Reduced maintenance might justify more expensive Gortex gaskets

Contactor Access





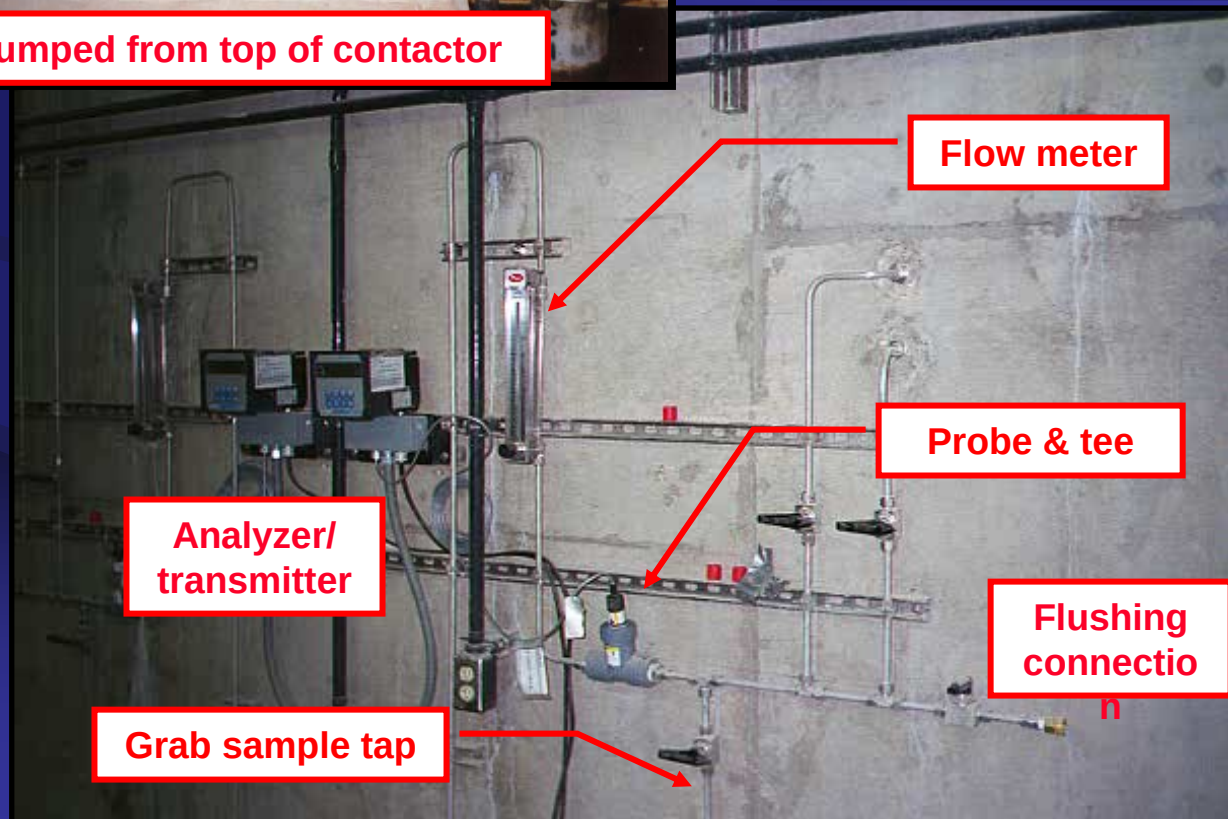
Consider water depth for checking diffuser bubble pattern

Ozone Residual Sampling

"Texas" tee

Pumped from top of contactor

Sample inlet inside contactor



Flow meter

Probe & tee

Analyzer/ transmitter

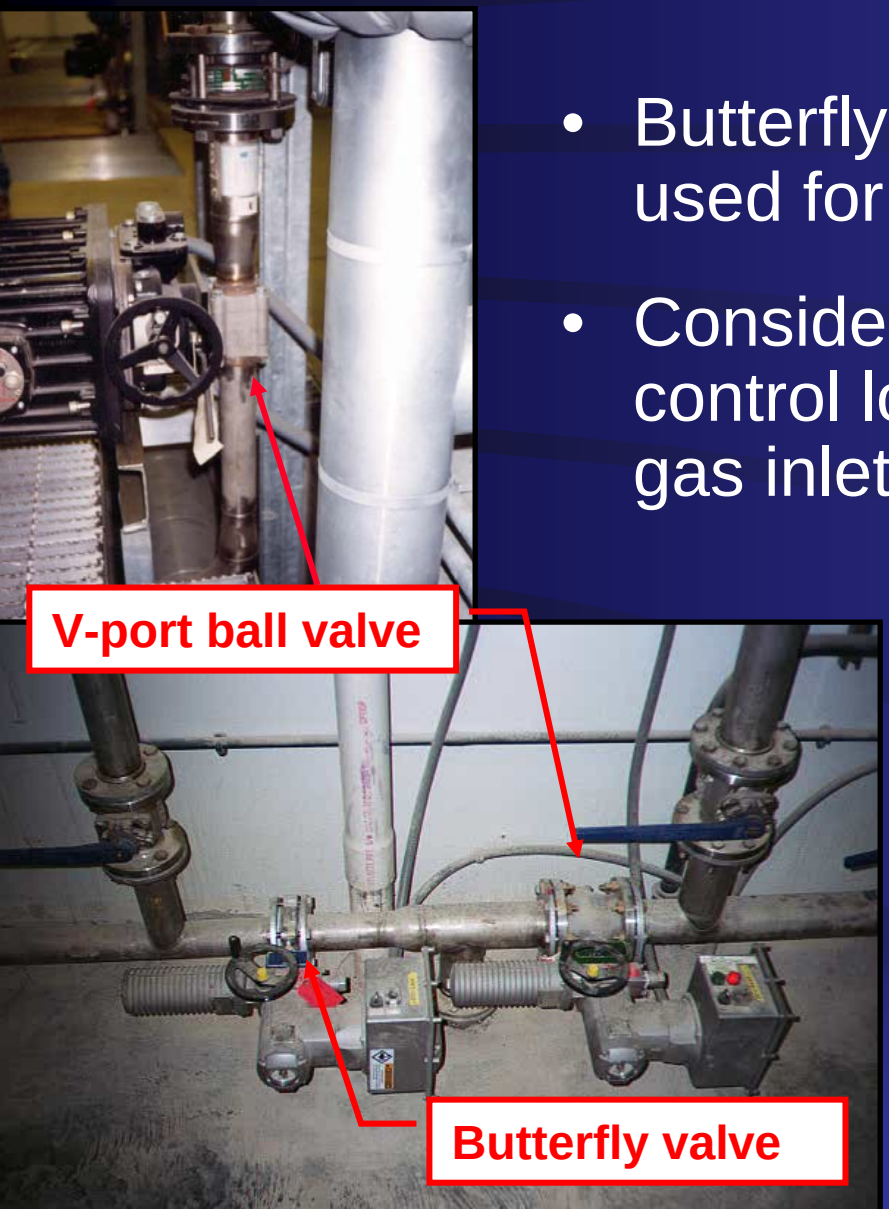
Flushing connection

Grab sample tap

Sampling Issues

- Minimize decay
  - Gravity or pumped sample flow
  - Length/diameter of sample line
  - Sample flow rate
- Flexibility for adjusting sample locations within the contactor
- Provisions for grab sampling
  - Close to probe, preferably downstream
  - Use small (~1/8”) dia. tubing and valve
- Number of analyzers

Valves for Ozone Gas Service

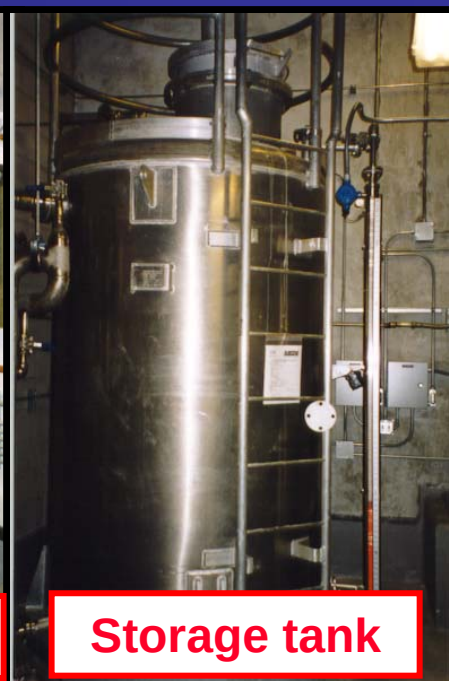


- Butterfly, ball, or plug valves may be used for on/off service or isolation
- Considerations for critical gas flow control locations such as the contactor gas inlet, include:
  - Precision actuator
  - Precision control valve such as V-port ball valve
  - Function of control valves and flow meters under minimum gas flow conditions

Quenching Ozone Residual

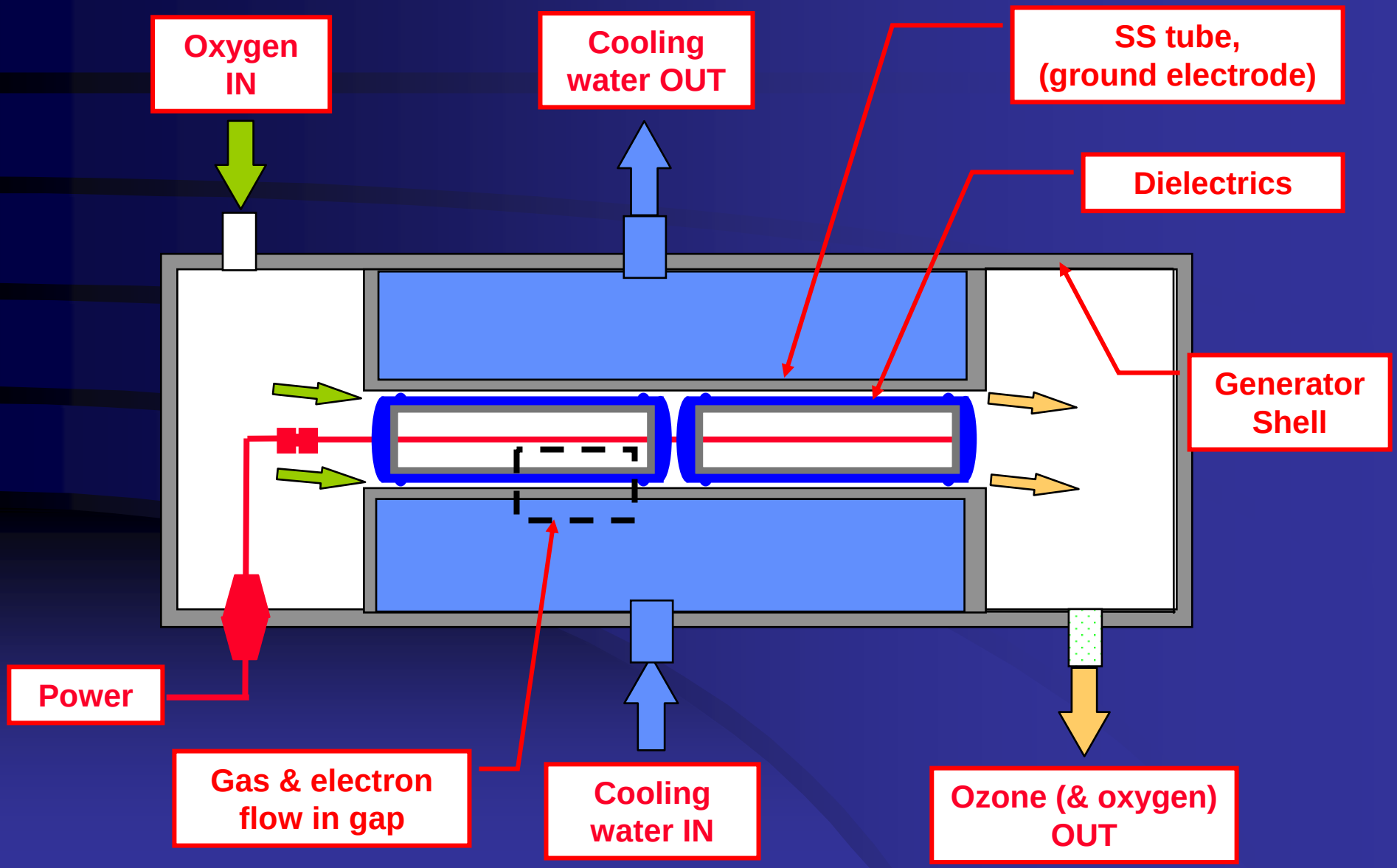
- Eliminate ozone residual remaining at contactor outlet (safety consideration)
- Might be necessary for *crypto* disinfection
- Might not be necessary for *Giardia* or virus disinfection
- Calcium thiosulfate
- Sodium bisulfite
- Hydrogen peroxide

Metering pumps

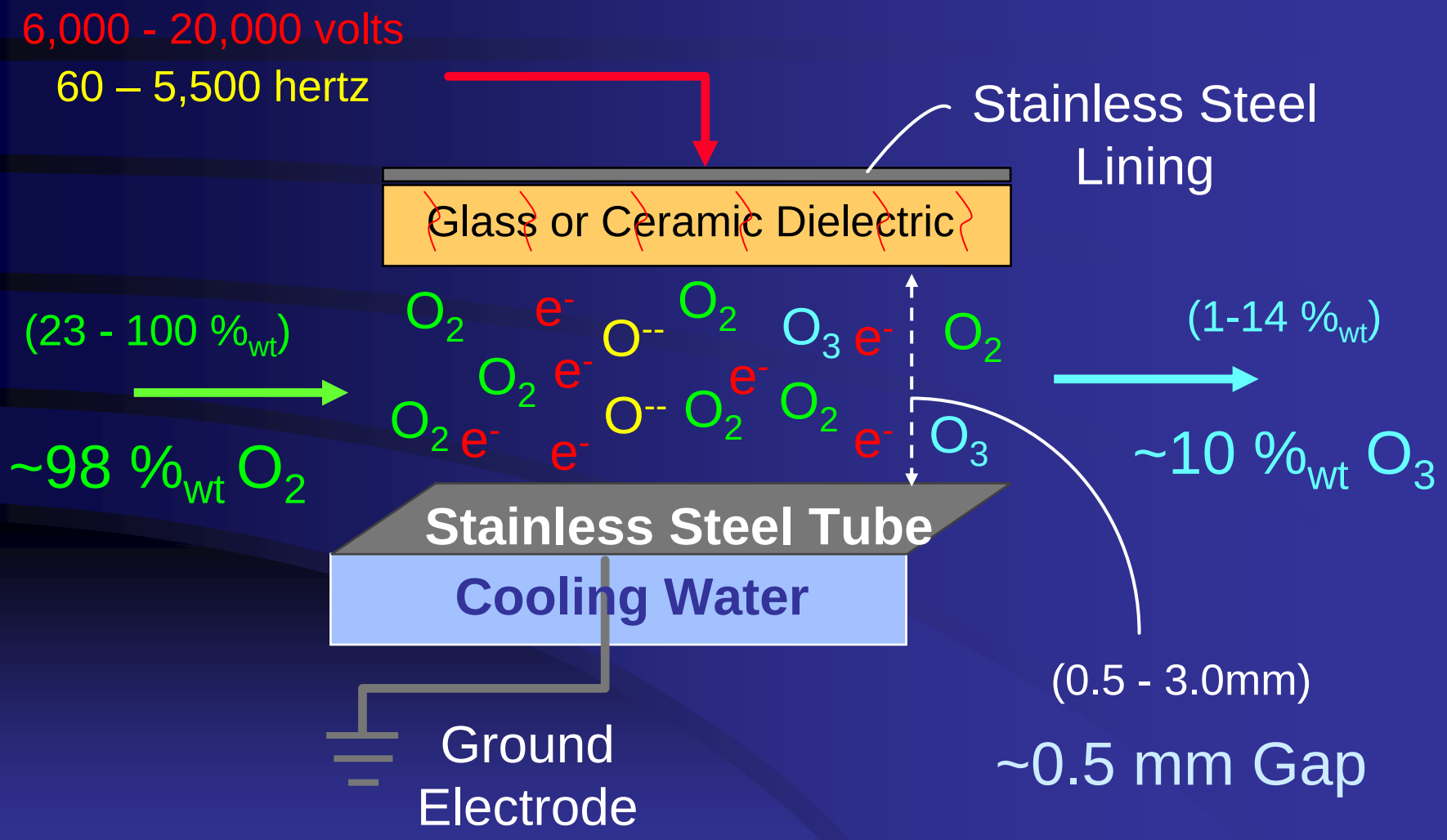


Storage tank

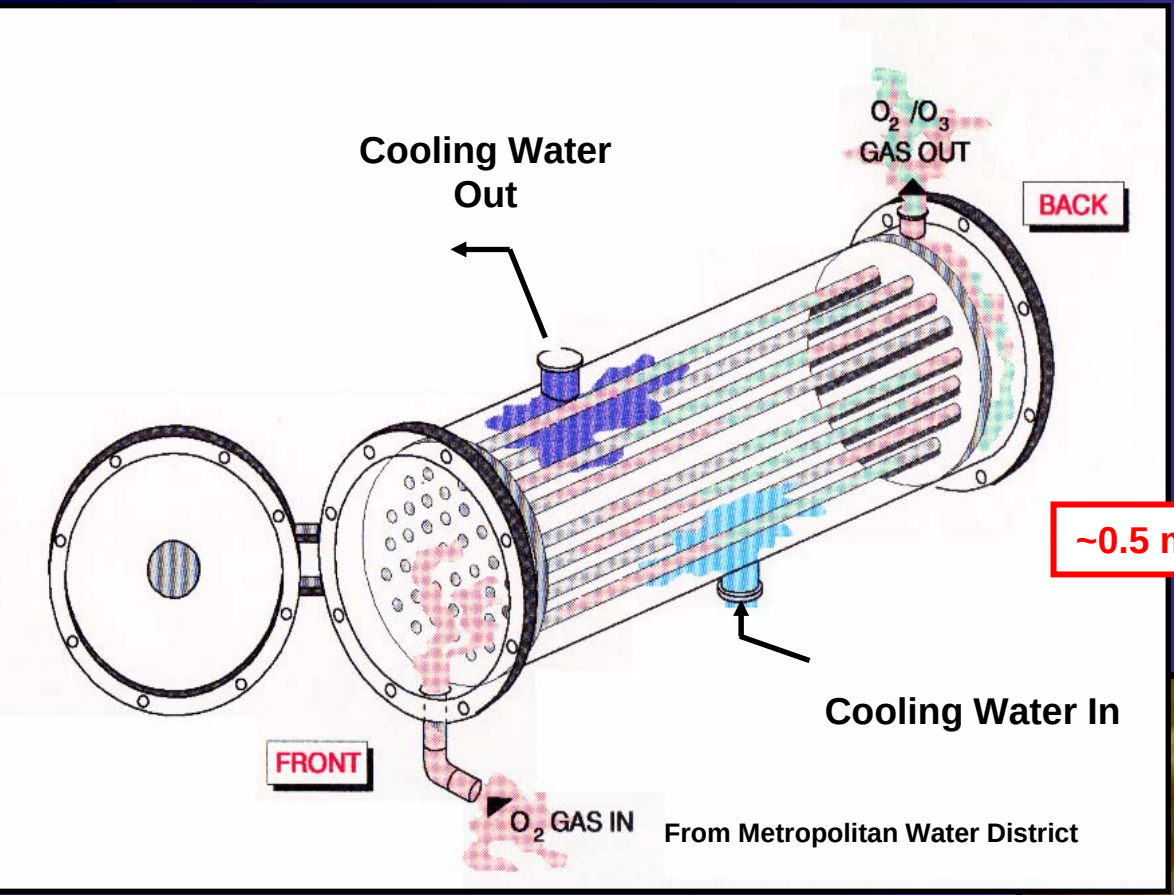
Ozone Generator Components



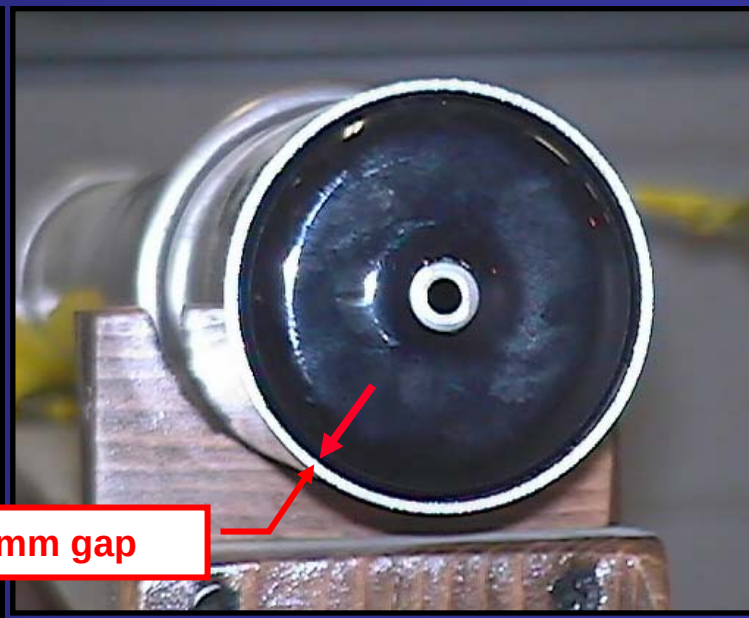
The Ozone Generator Controls the Electric Discharge

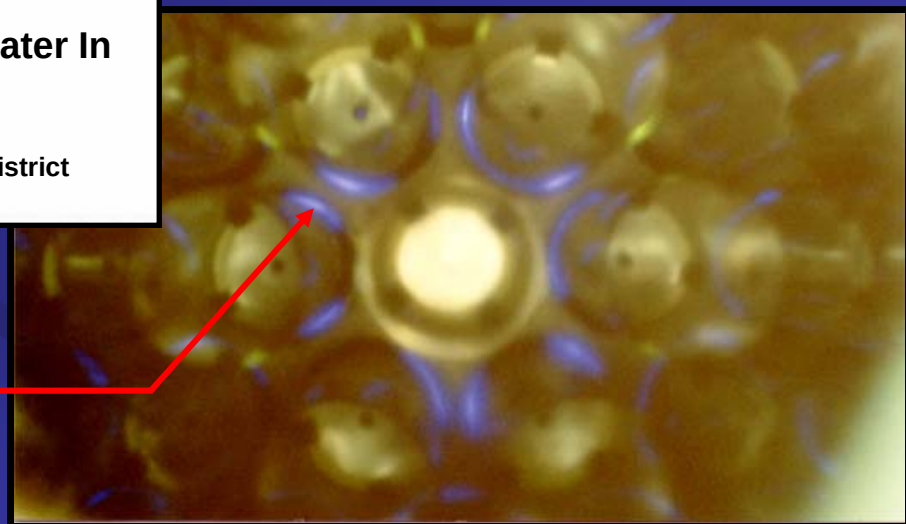


Multiple-Tube Ozone Generator

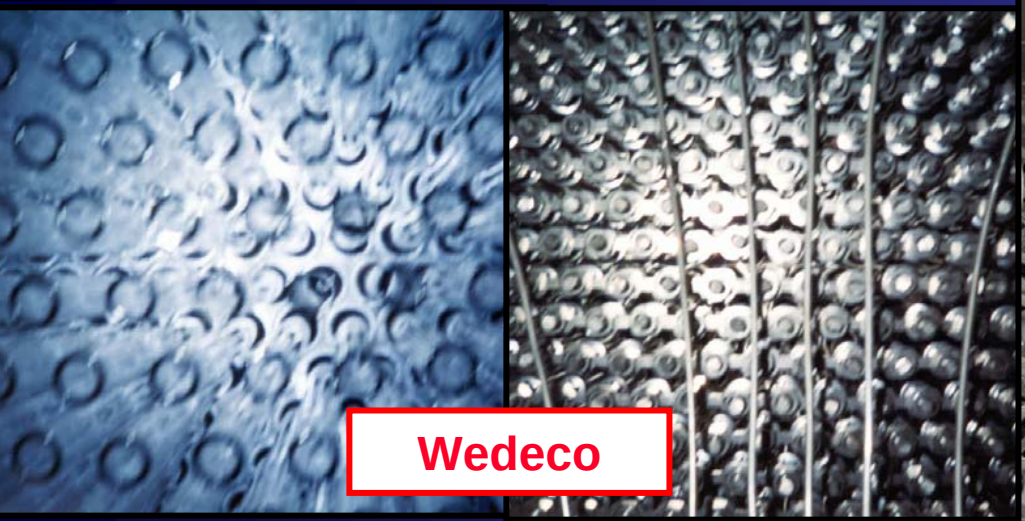


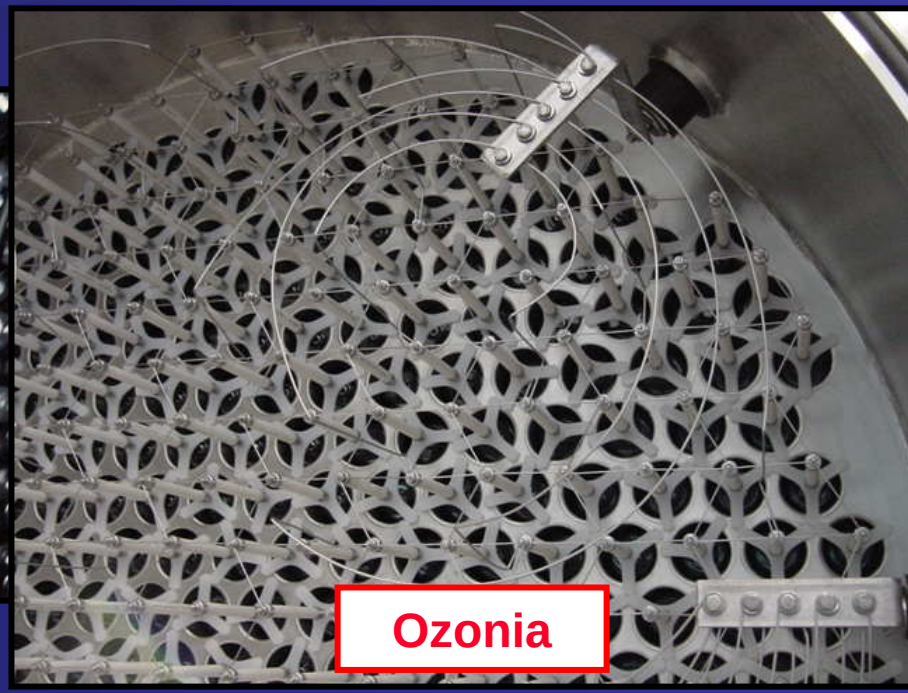
From Metropolitan Water District

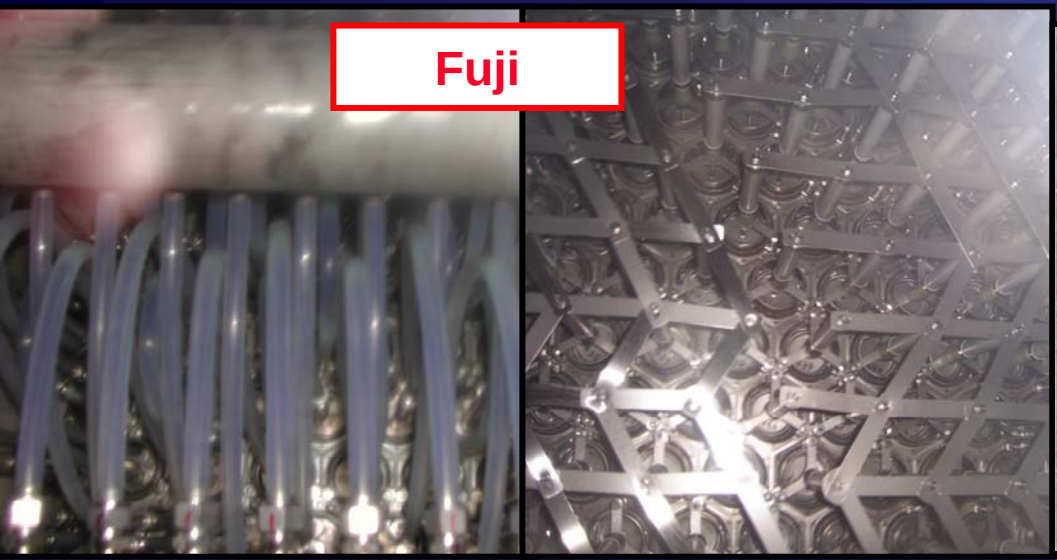




Dielectrics



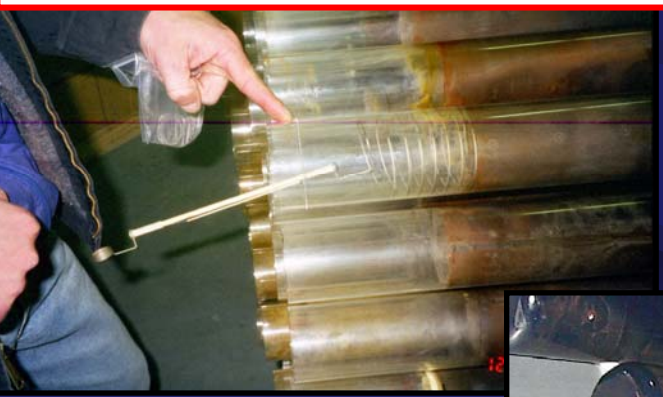




Ozone Generator Cleaning

Cleaning is more frequent when dried air is used for feed-gas

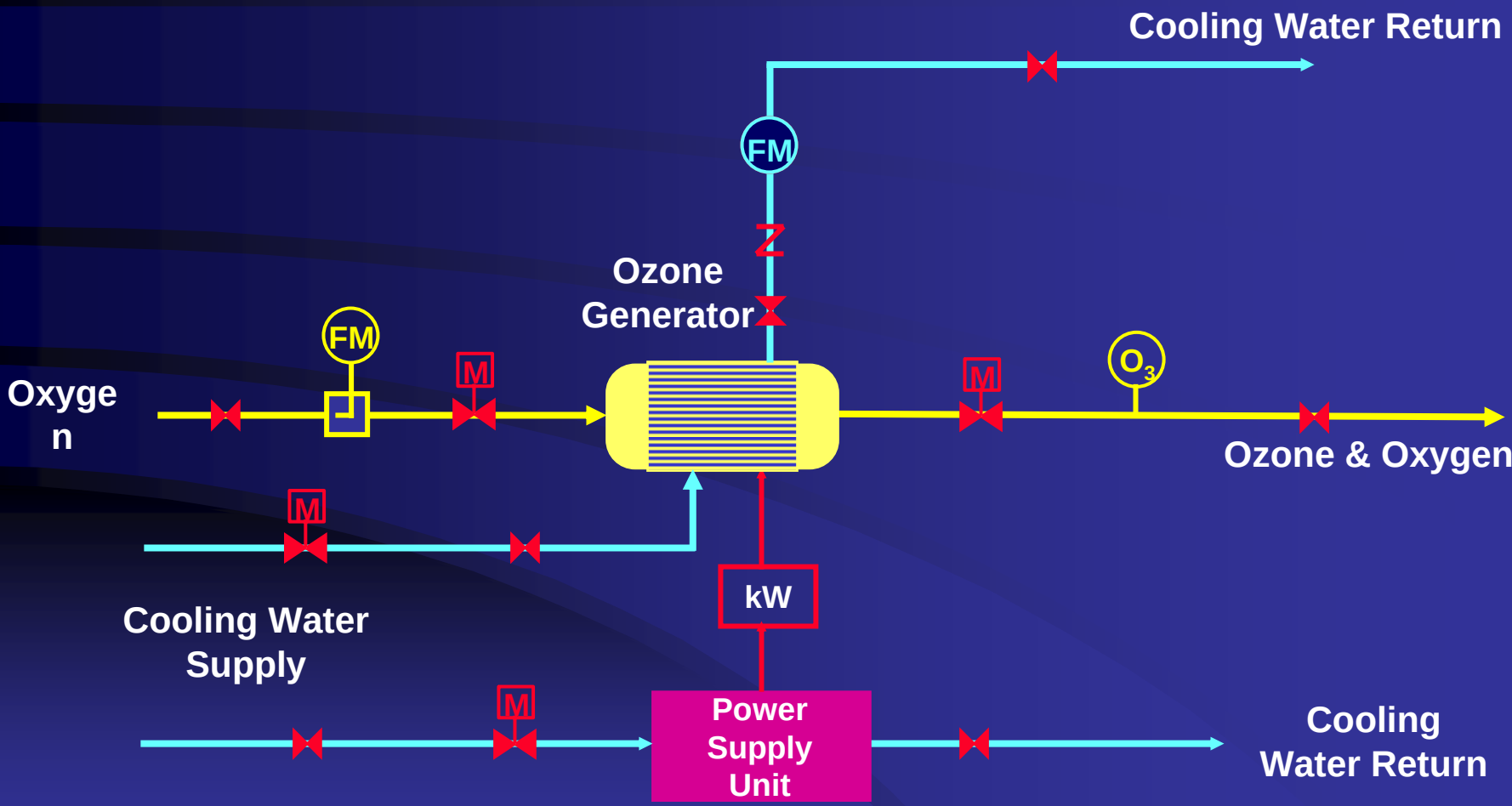
Nitric acid forms when moisture is present in operating generator



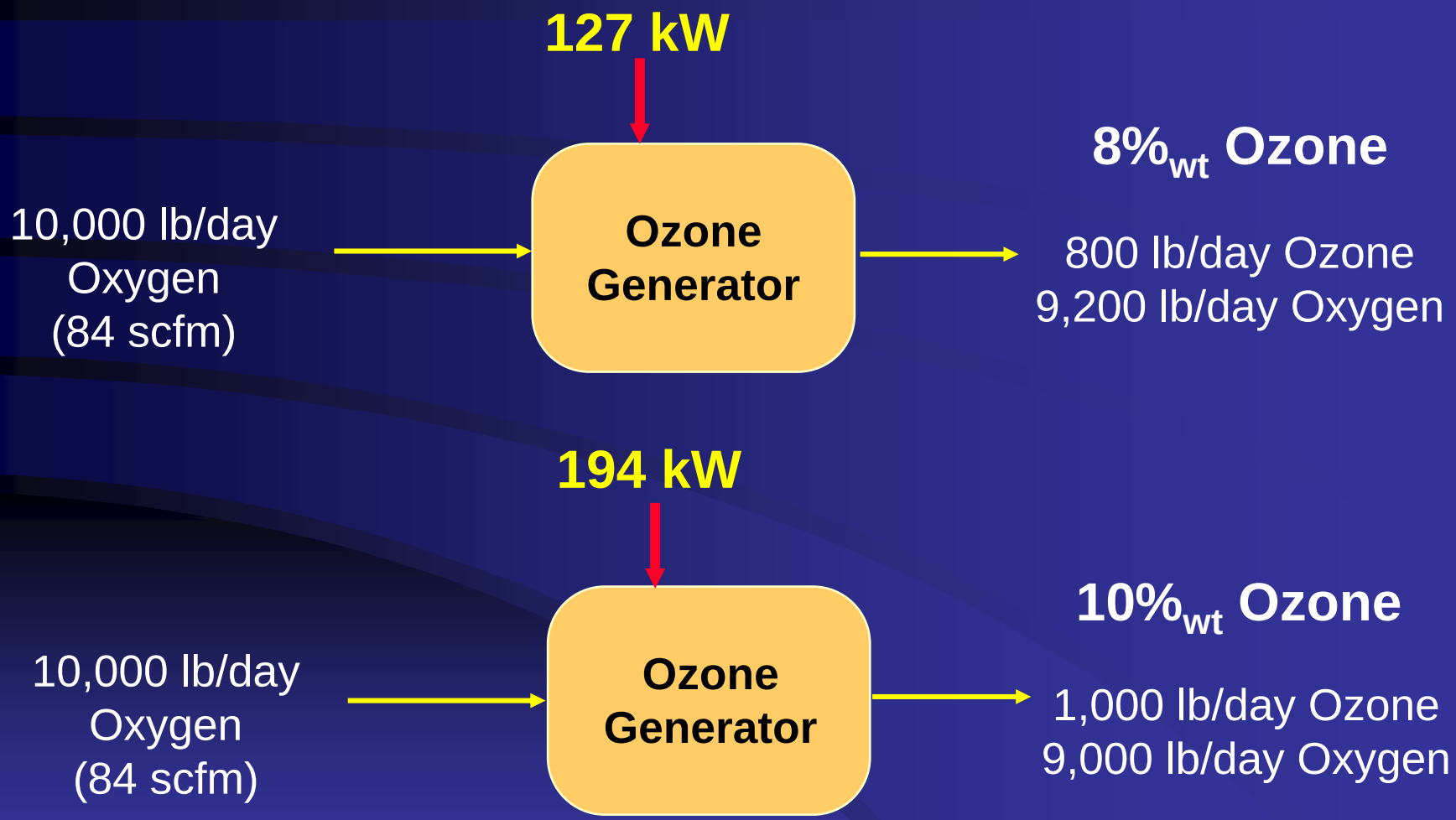
Power Supply Unit

- Transformers
- Rectifier
- Inverter
- Cooling system

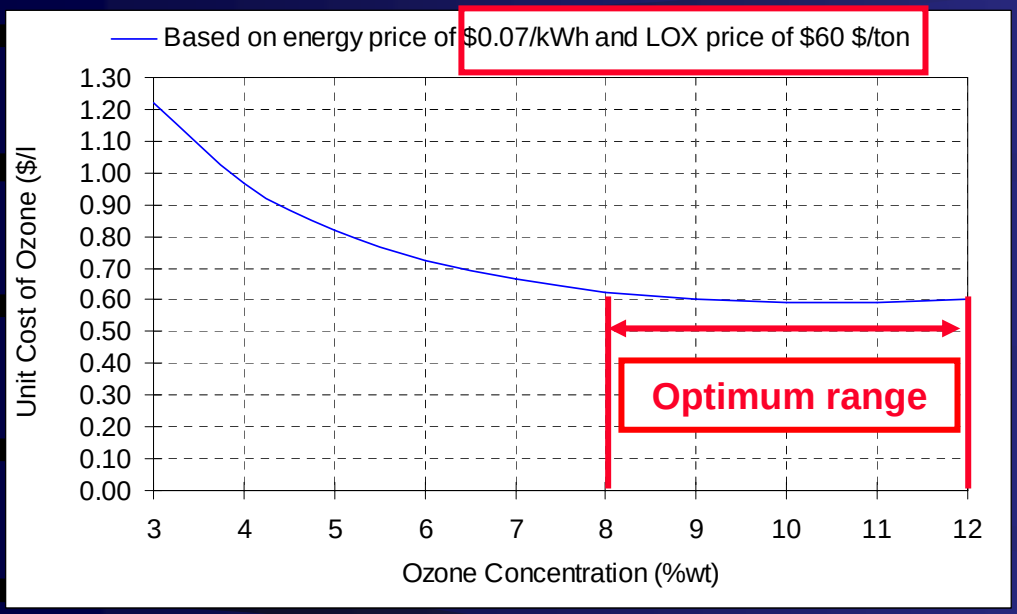
Generator Process Diagram

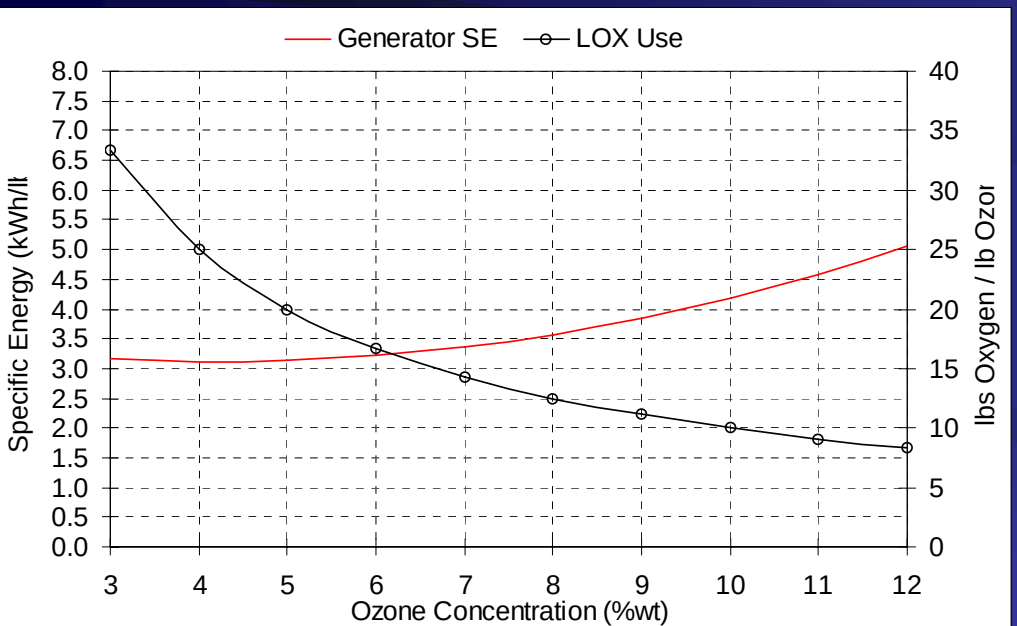


Ozone Generator
Increase Power to Increase Production



Ozone Generator Efficiency Example

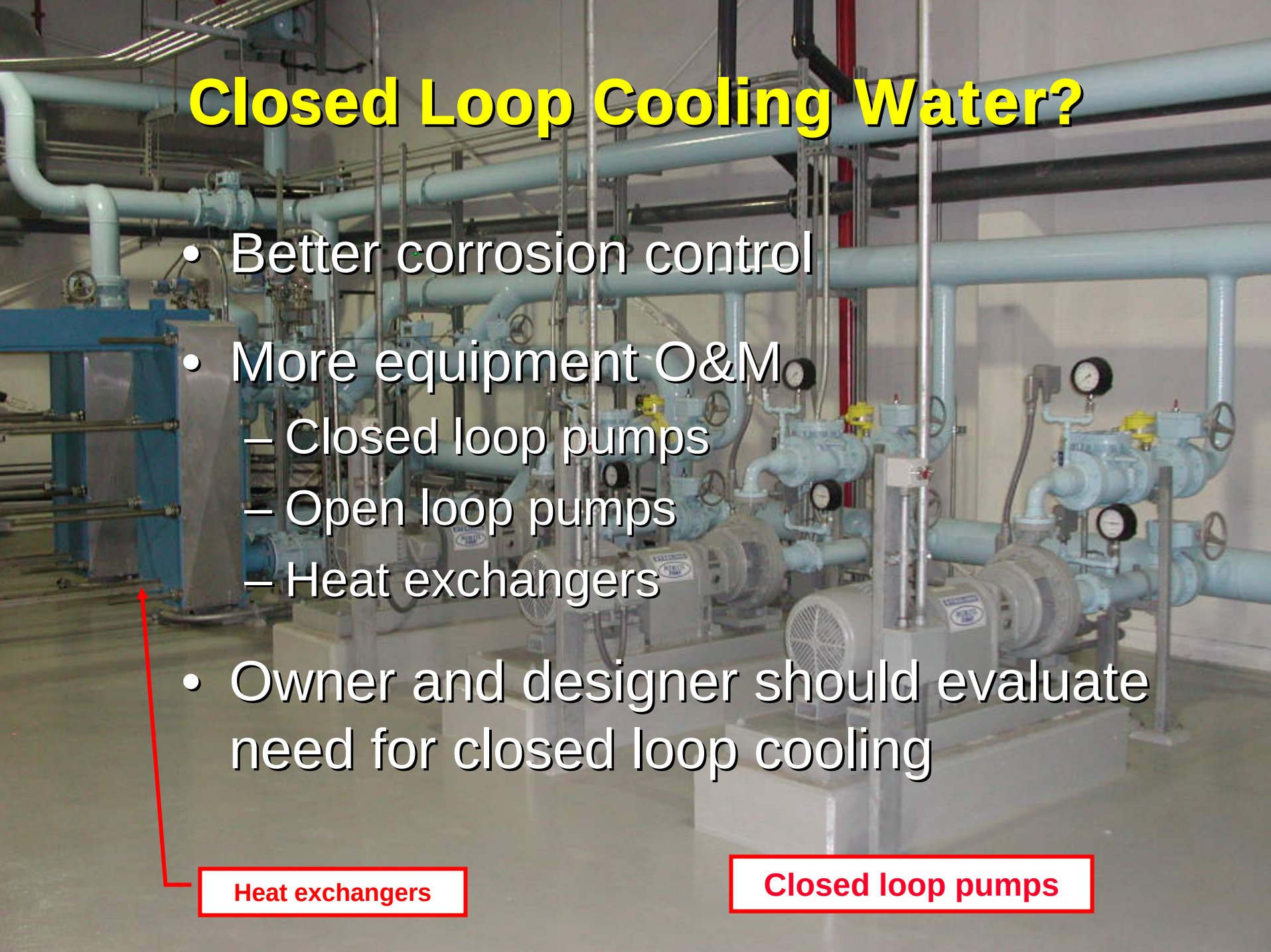




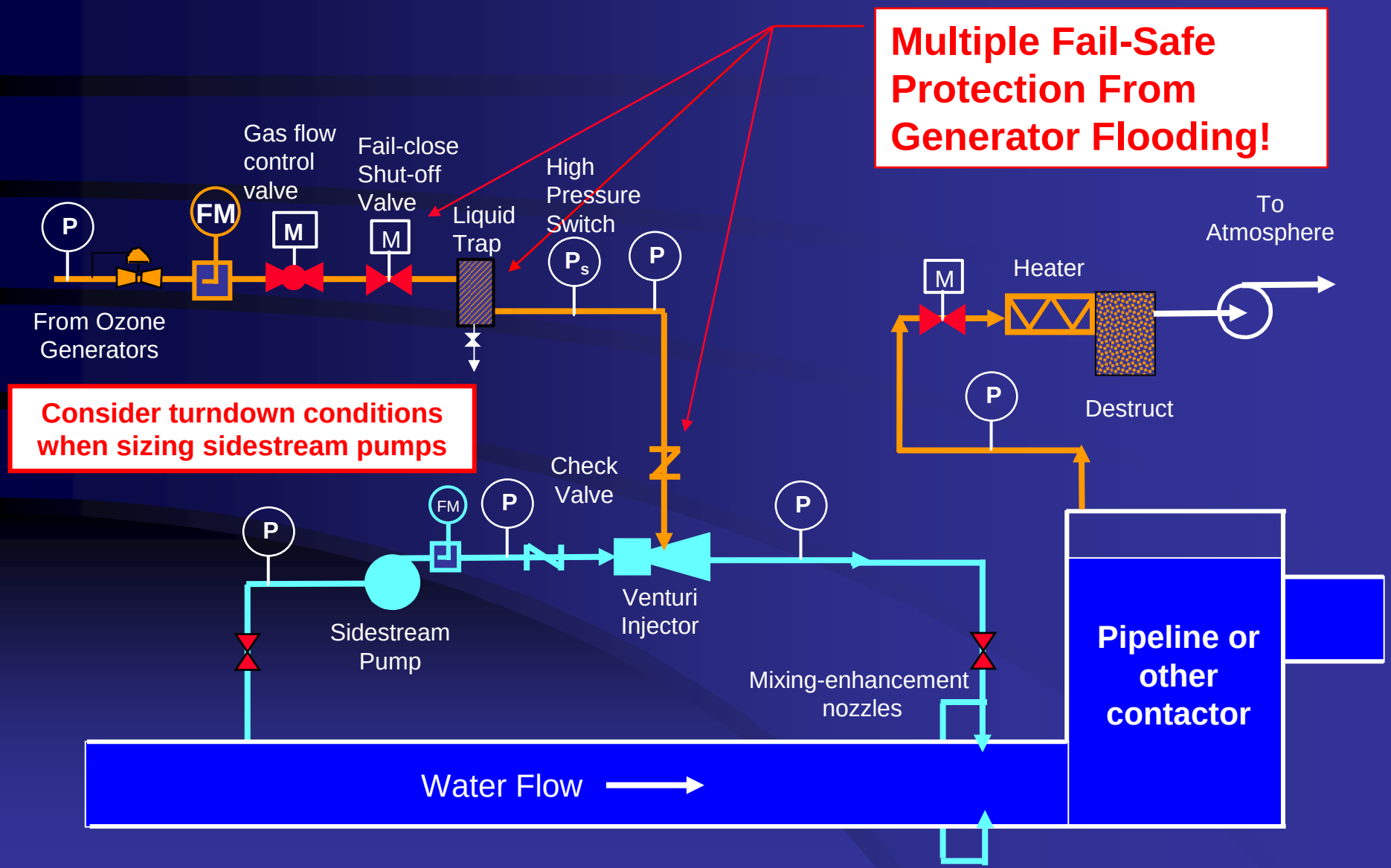
- Design Condition: $10\%_{wt}$, 1000 lb/day, 4.2 kWh/lb, 175 kW
- $12\%_{wt}$, 800 lb/day, 5.2 kWh/lb, 175 kW
- $8\%_{wt}$, 1200 lb/day, 3.5 kWh/lb, 175 kW
- $5\%_{wt}$, 1400 lb/day, 3.0 kWh/lb, 175 kW

Closed Loop Cooling Water?

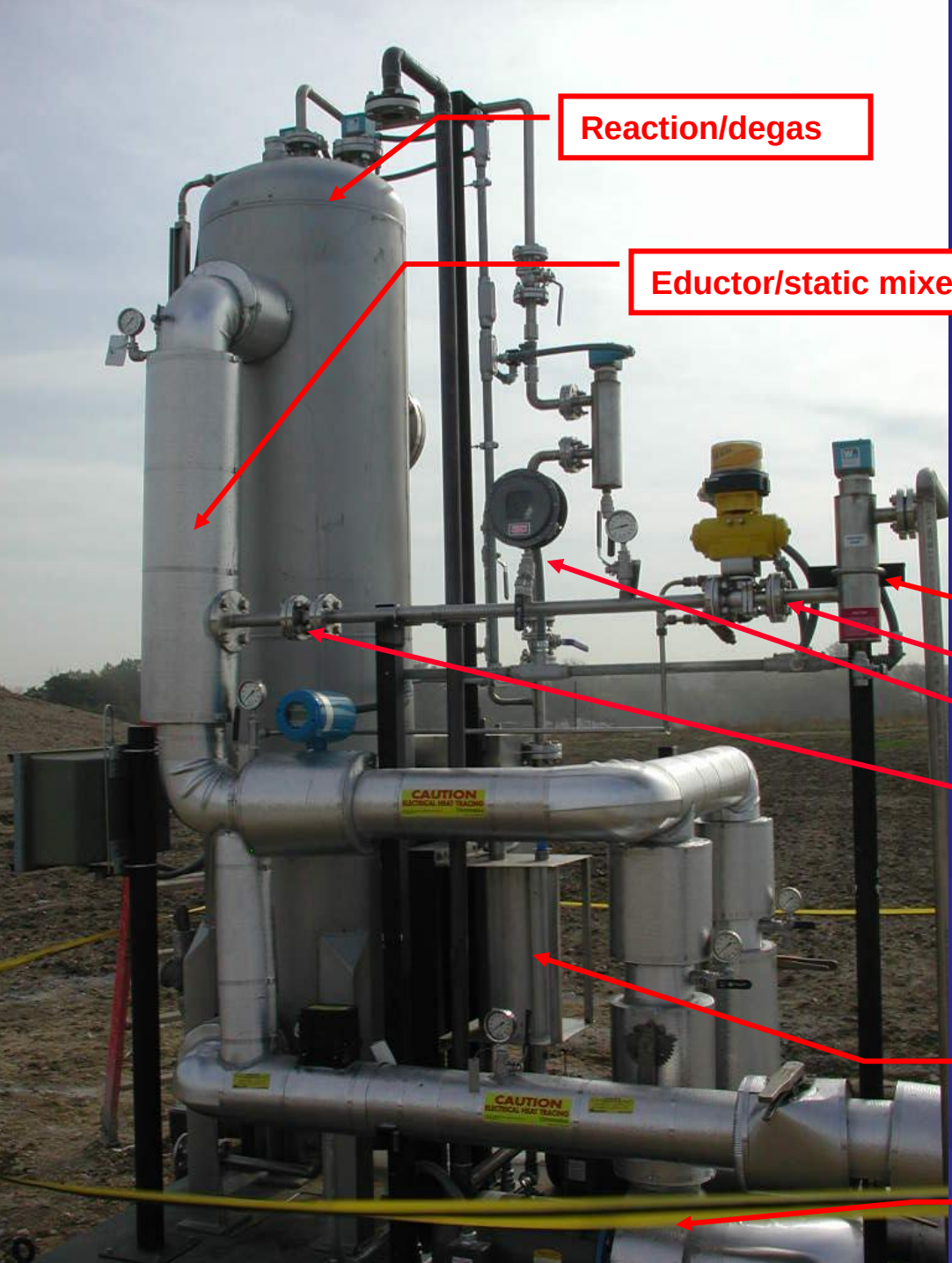
- Better corrosion control
- More equipment O&M
  - Closed loop pumps
  - Open loop pumps
  - Heat exchangers
- Owner and designer should evaluate need for closed loop cooling



Sidestream Ozone Injection



Sidestream Ozone Injection



Reaction/degas

Eductor/static mixer

Ozone Gas (vacuum)

Liquid trap shutoff

Pneumatic valve

High pressure switch

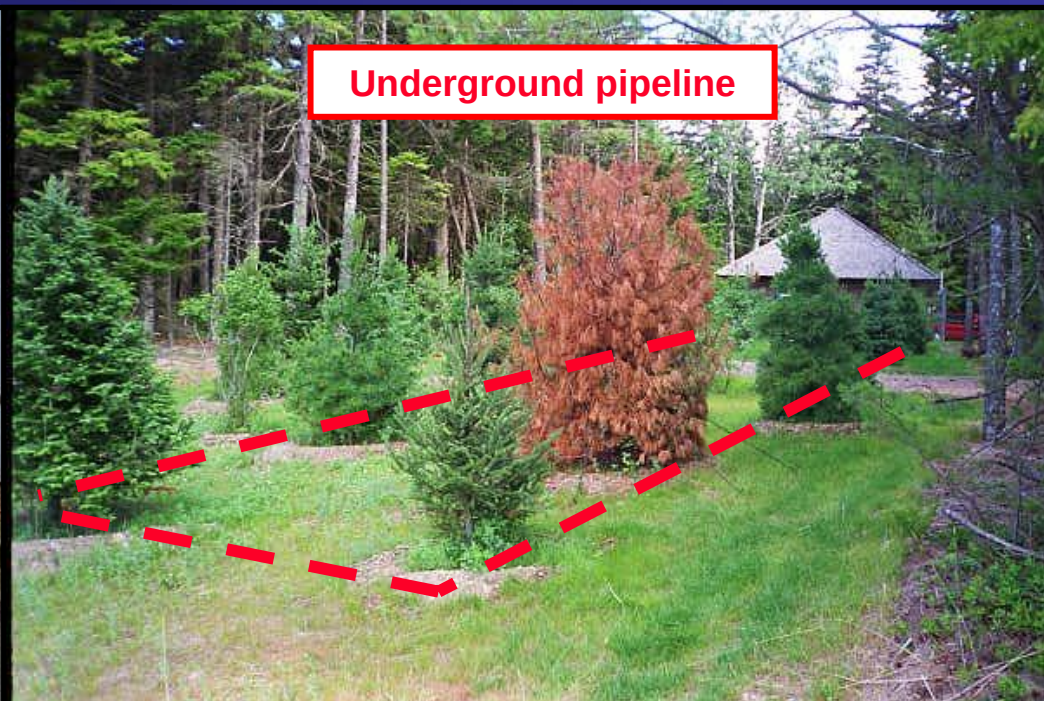
Check valve

Destruct unit

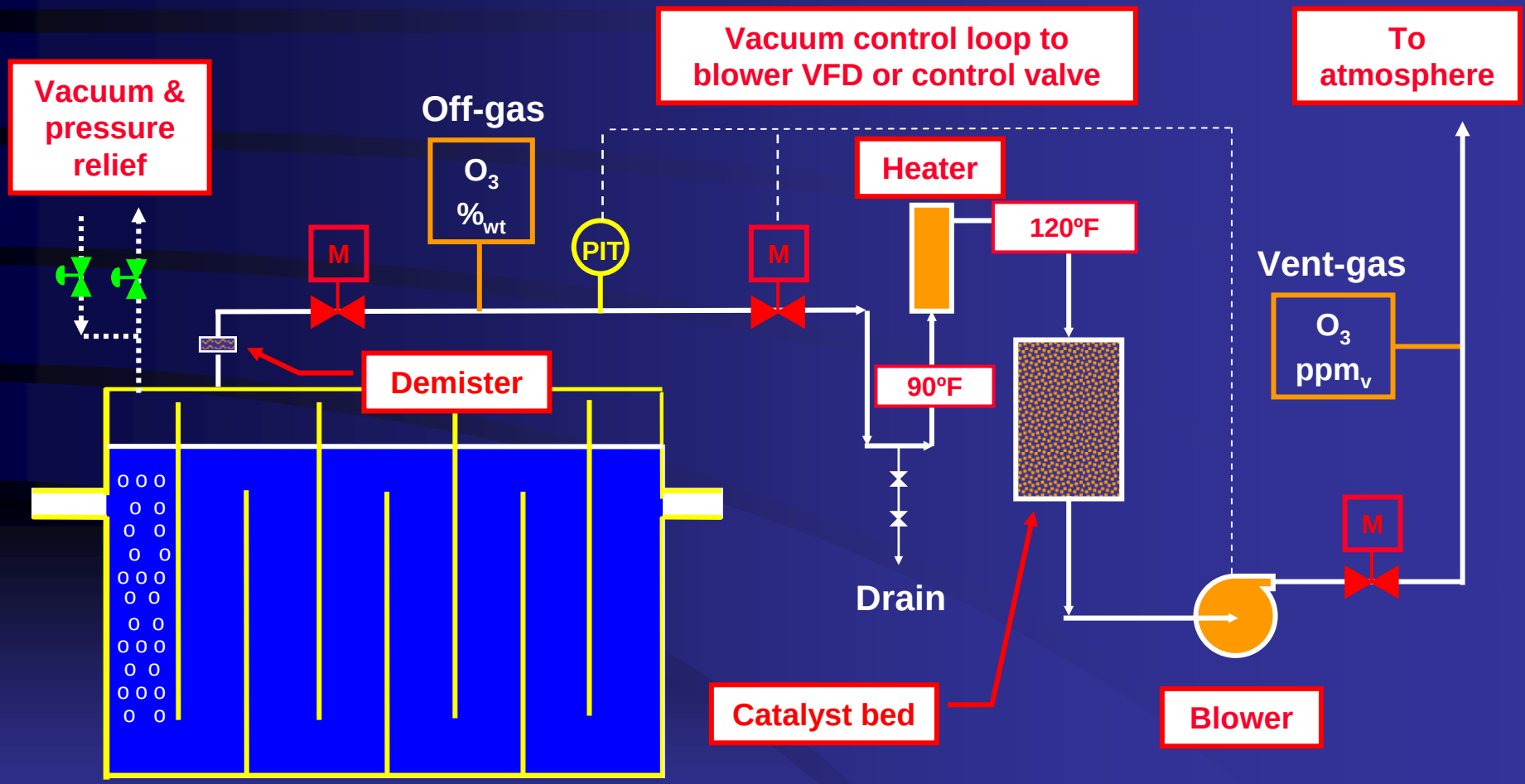
Sidestream pumps

Contactor Options With SSI

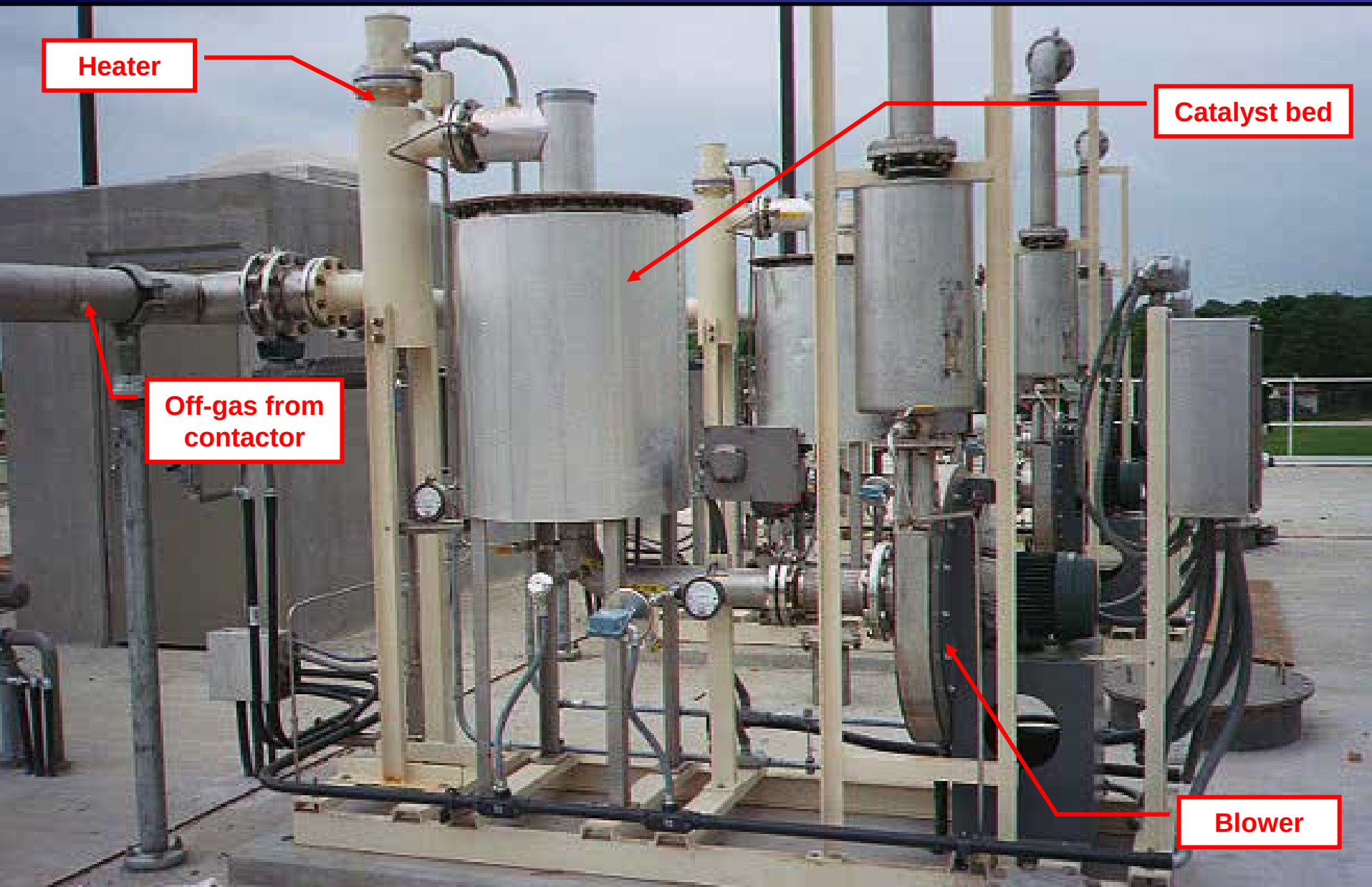
- Vertically baffled deep contactor is not necessary with SSI
- Horizontal baffled shallow contactor
- Pipeline contactor



Off-Gas System



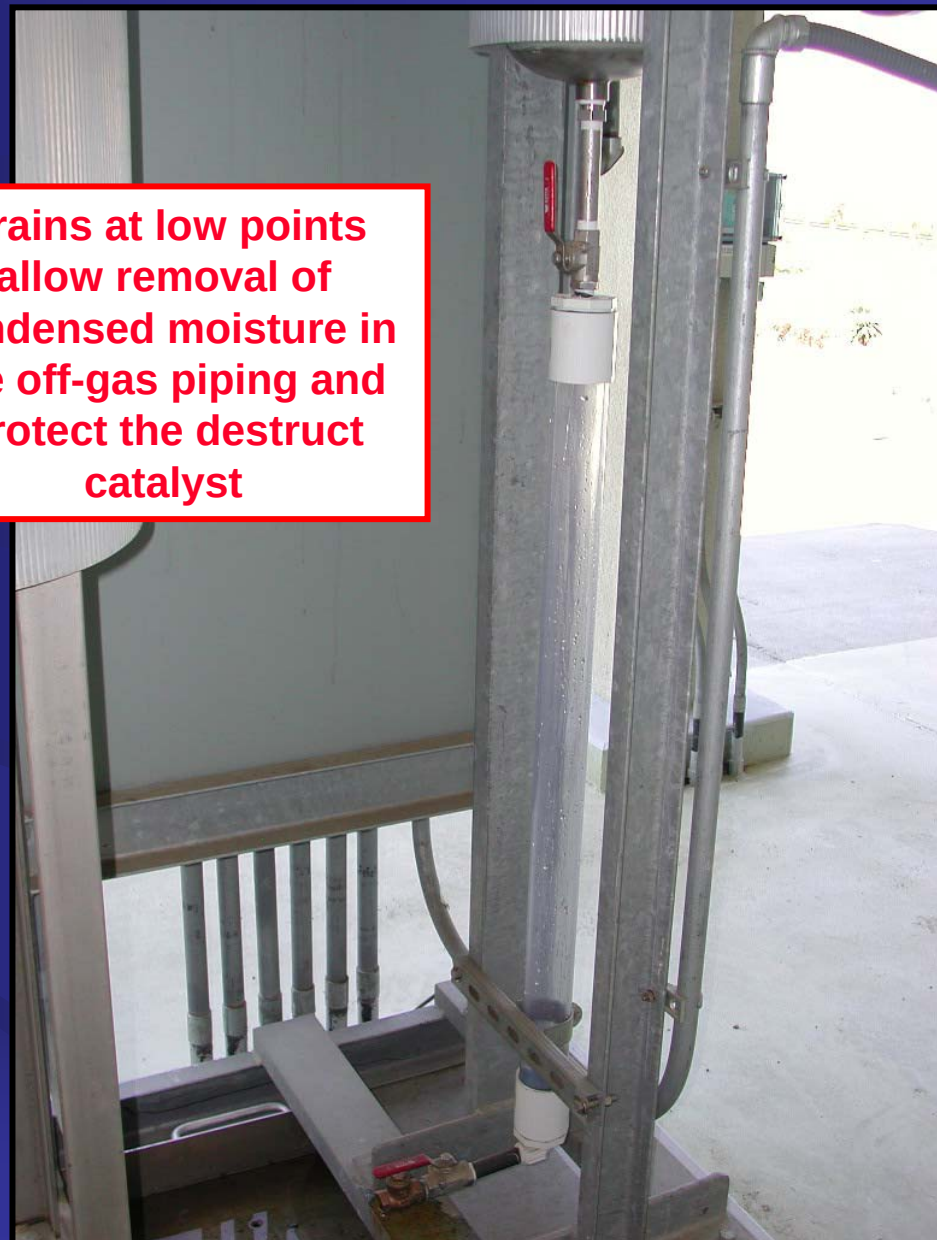
Off-Gas Destruct Unit



Off-Gas Moisture Removal

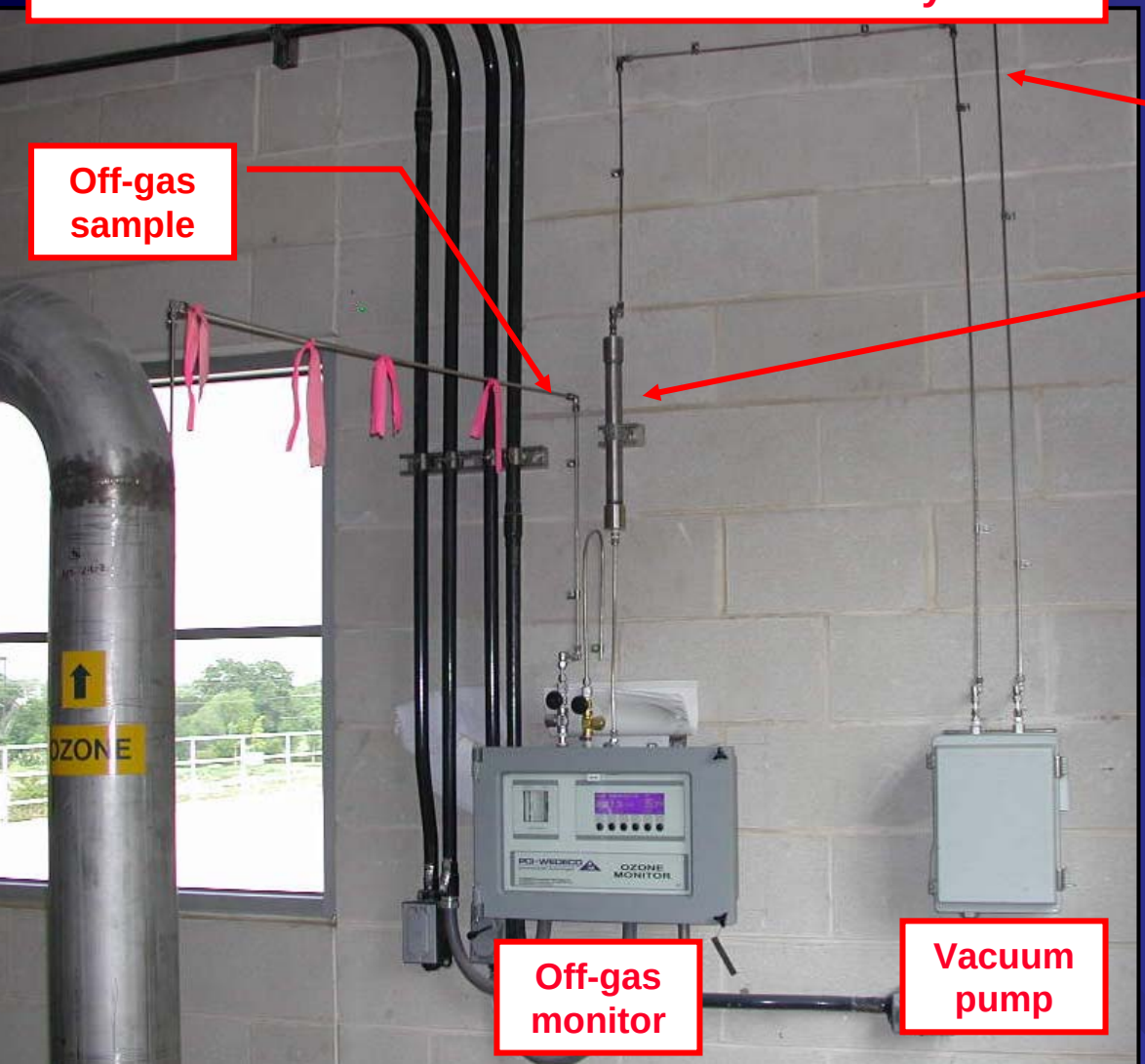
Particulate moisture collects in the demister and drips back into the contactor

Drains at low points allow removal of condensed moisture in the off-gas piping and protect the destruct catalyst



Off-Gas & Vent-Gas Monitors

Off-Gas Ozone Concentration (from contactor, $\%_{wt}$) is used to calculate transfer efficiency



Vent-Gas Ozone Concentration (after destruct, PPM_v)

Vacuum / Pressure Relief Valve

Vacuum/pressure relief valve is for structural protection of contactor

Two sets of weights in the valve set the vacuum and pressure limits at about 2 - 5 inches water column

Ozone Safety Advantages

- Ozone is not stored in bulk on-site
- Catastrophic large-scale release is not likely because generator shutdown eliminates supply of ozone
- Ozone is not explosive or flammable
- No reported fatalities due to ozone exposure

Important Concepts Regarding Ozone Safety

- **Automatic warning - You can smell ozone before it will harm you!**
- Effects of ozone exposure are a function of time and concentration
- First aid
  - Low level exposure - get fresh air
  - High level exposure - seek medical attention
- Fix leaks when they occur

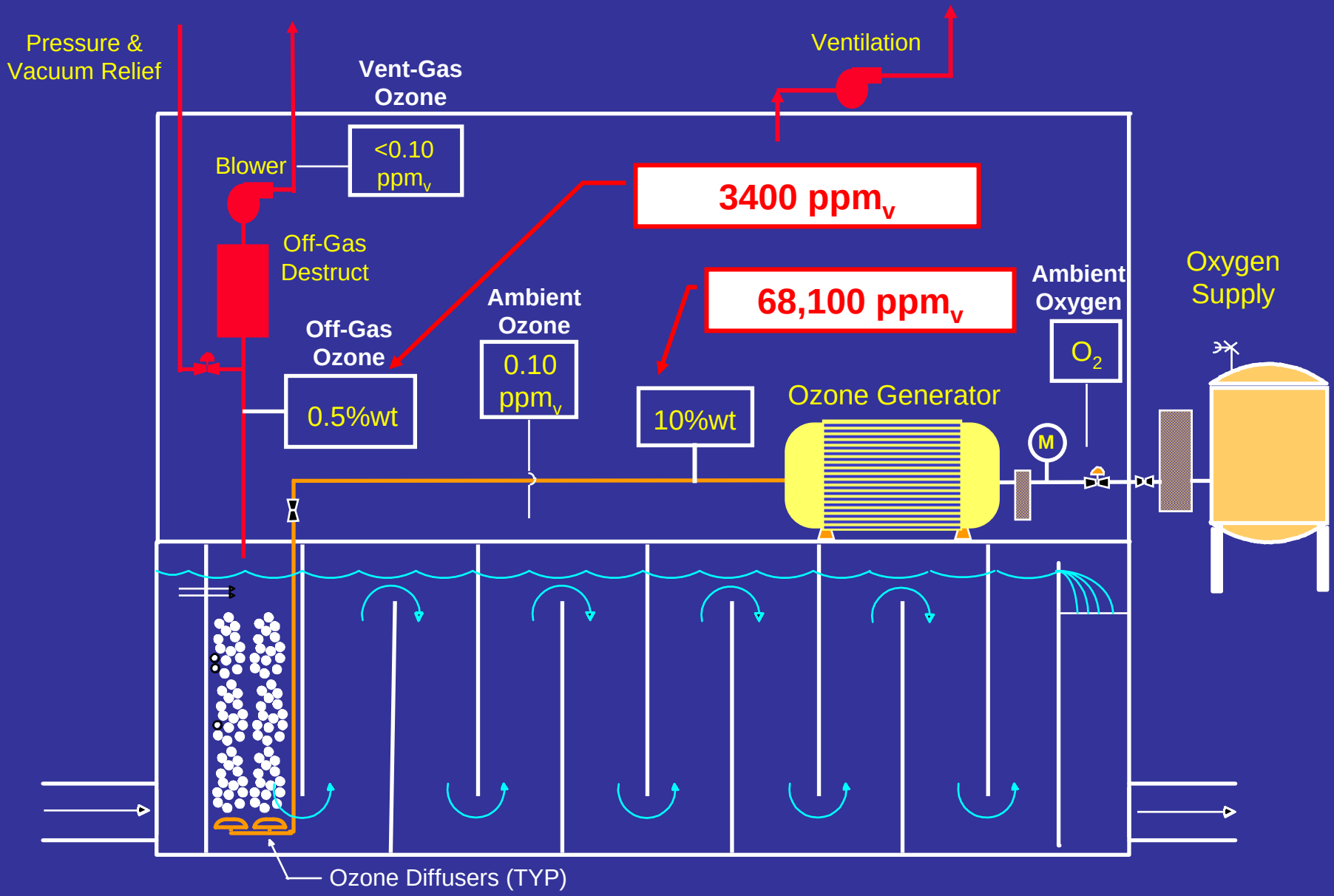
Effects of Ozone Exposure

Condition	Ozone Concentration
Detectable odor	0.01 to 0.04 ppm_v
TLV-TWA 8-hr limit	0.10 ppm_v
Headache, shortness of breath	>0.10 ppm_v
TLV-STEL 15-min limit	**0.30 ppm_v**
Chest pain, dry cough, lung irritation, severe fatigue	0.6 - 1.0 ppm_v (1 - 2 hrs)
Immediately dangerous to life & health	10.0 ppm_v
Expected to be fatal	50 ppm_v (30 min)

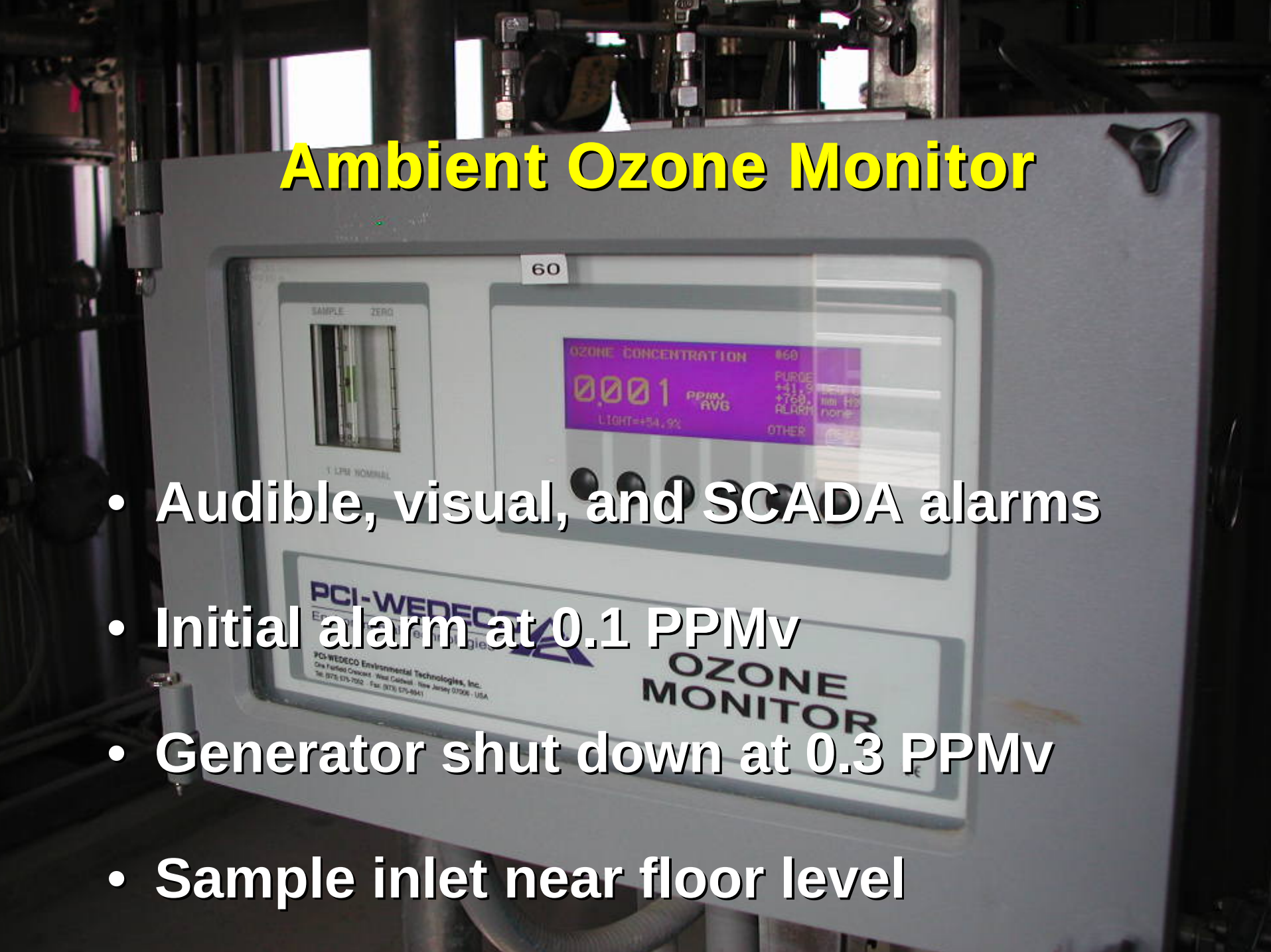
Data from “Ozone Manual of Standard Practice,” Workers Compensation Board of British Columbia, 1992

Reactions to Ozone Exposure

- Irritant to eyes, throat, nose, upper respiratory tract, and lungs
- Headaches, nausea, wheezing, or coughing
- Pulmonary edema (fluid build-up in lungs)
- No evidence that ozone exposure will cause cancer or harm the unborn
- Check with your doctor if you have special respiratory or heart conditions

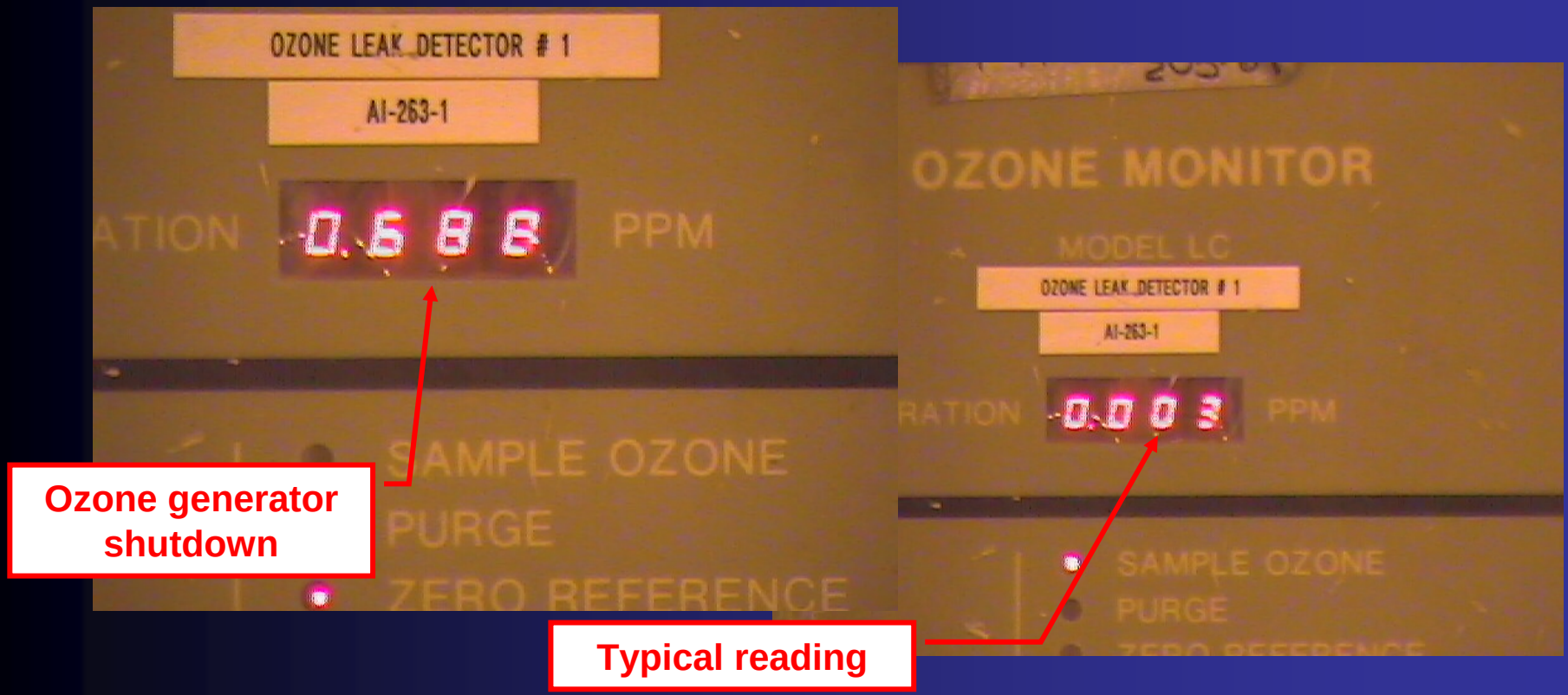

Pressure &
Vacuum Relief
Vent-Gas
Ozone
<0.10
ppmv
Ventilation
Blower
3400 ppmv
Off-Gas
Destruct
Ambient
Ozone
68,100 ppmv
Ambient
Oxygen
Oxygen
Supply
Off-Gas
Ozone
0.10
ppmv
O2
0.5%wt
10%wt
Ozone Generator
M
Ozone Diffusers (TYP)

Ambient Ozone Monitor



- Audible, visual, and SCADA alarms
- Initial alarm at 0.1 PPMv
- Generator shut down at 0.3 PPMv
- Sample inlet near floor level

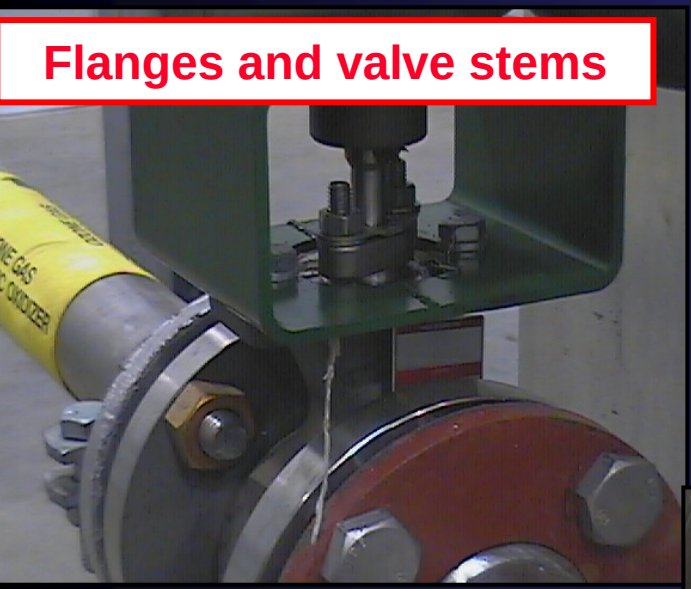
Ambient Ozone Monitor Readings at Plant C



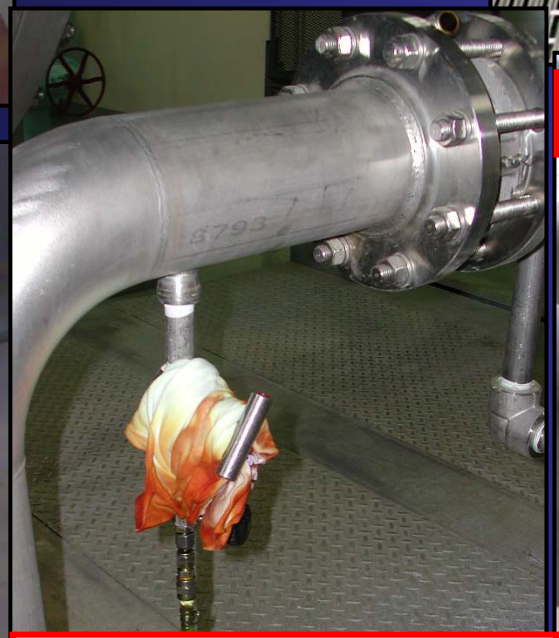
Believe the readings. Your nose may become acclimated!

Leak Sources and Detection

Flanges and valve stems



Another option?



Portable leak detector

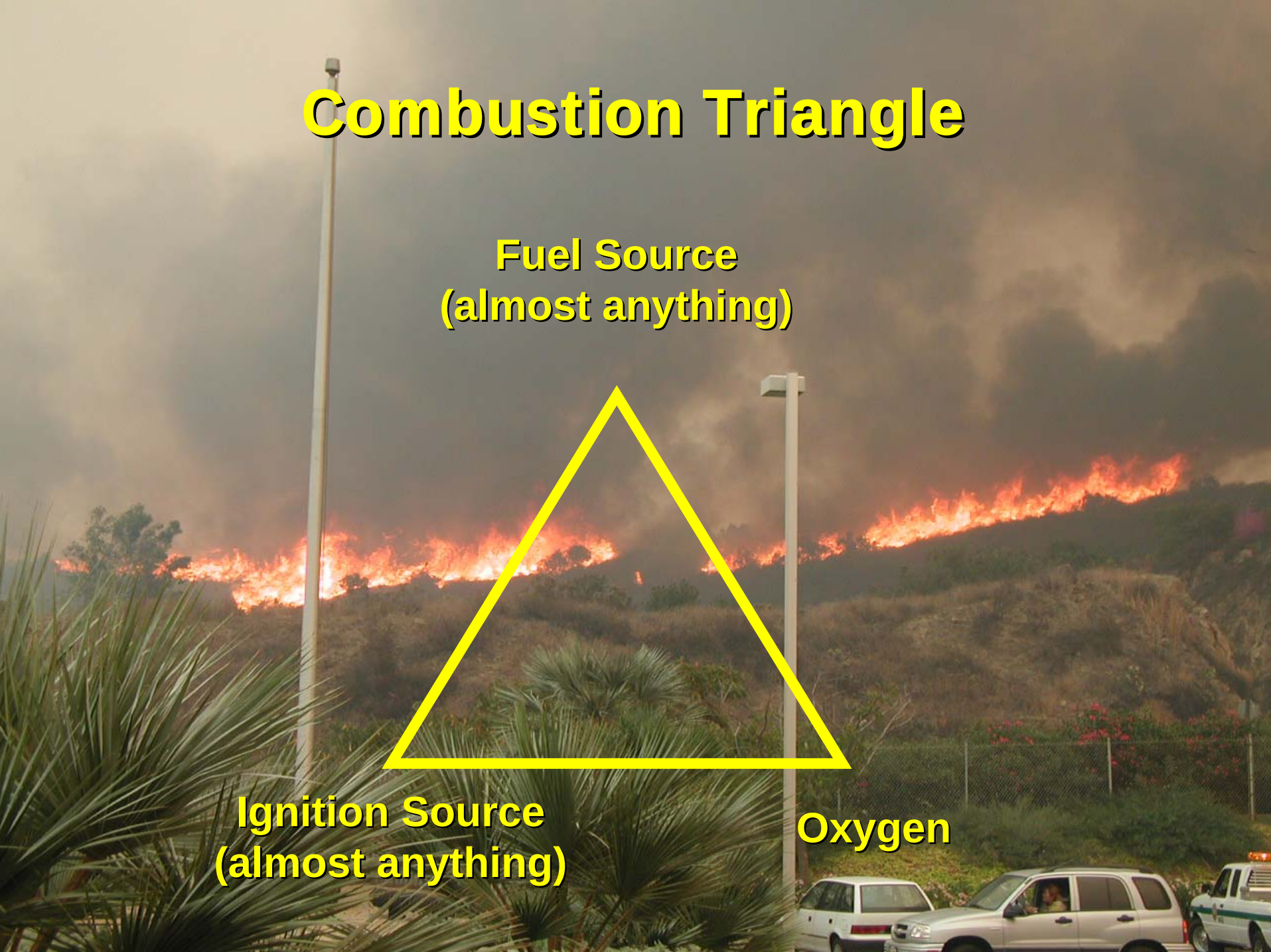
Threaded fittings

Potassium iodide

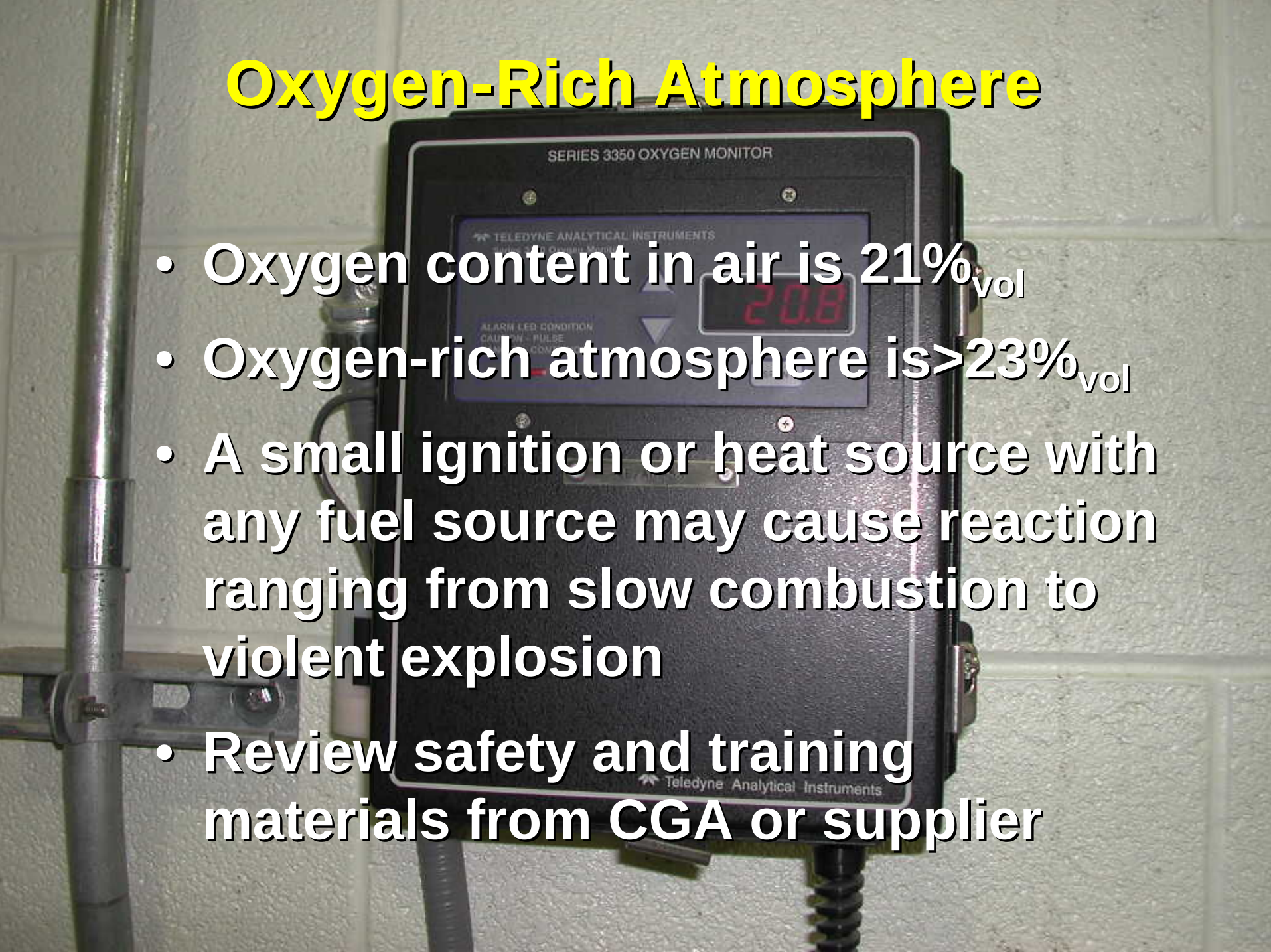
Ozone Safety Information

- Ozone MSDS sheet
- Compressed Gas Association
  703-412-0900, www.cganet.com
  - CGA P-34, Safe Handling of Ozone-Containing Mixtures Including the Installation and Operation of Ozone-Generating Equipment
- Workers Compensation Board of British Columbia
  604-276-3100, www.worksafebc.com
  - BK-47 “Ozone, A Manual of Standard Practice”

Combustion Triangle



Oxygen-Rich Atmosphere



- Oxygen content in air is 21%$_{vol}$
- Oxygen-rich atmosphere is>23%$_{vol}$
- A small ignition or heat source with any fuel source may cause reaction ranging from slow combustion to violent explosion
- Review safety and training materials from CGA or supplier

Oxygen Safety Information

- Oxygen MSDS sheet
- Compressed Gas Association 703-412-0900, www.cganet.com
  - CGA G-4, Oxygen
  - CGA G-4.1 Cleaning Equipment for Oxygen Service
  - CGA P-12, Safe Handling of Cryogenic Liquids
  - CGA P-39, Oxygen-Rich Atmospheres
  - CGA AV-1, AV-8, Videos