# Water treatment system and water quality
# Standard, Configuration and Practical Considerations

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# What is Water Treatment System (WTS) ?

- System that Produces Purified Water for Preparation of Dialysate, for Haemodialysis

# ANSI/AAMI RD62 Definition for WTS

- "ANSI" – **A**merican **N**ational **S**tandards **I**nstitute
- "AAMI" – **A**ssociation for the **A**dvancement of **M**edical **I**nstrumentation
- Device used to treat water for:-

1. preparation of concentrates from powder at a dialysis facility;
2. preparation of dialysate; and
3. reprocessing of dialyzers for multiple use.

# Purity – the deliverable

1. Bacterial Content

2. Chemical Species

# Water Bacteriology

- Effect:-
  - Bacteria ➔ pyrogenic (fever-inducing)
  - Bacterial “endotoxins” may cross dialysis membrane
- Limits:-

| Standard | Total viable microbial count | Endotoxin concentration |
|---|---|---|
| AAMI | < 200 CFU/mL | < 2 EU/mL |
| ERA-REDTA | < 100 CFU/mL | < 0.25EU/mL |
| Guideline in HK | < 100 CFU/mL | < 0.25EU/mL |

# Risk of Water Contaminants

| Symptoms | Possible Water Contaminants |
|---|---|
| Anaemia | Aluminium, chloramine, copper, zinc |
| Bone Disease | Aluminium, fluoride |
| Hæmolysis | Copper, nitrates, chloramine |
| Hypertension | Calcium, sodium |
| Hypotension | Bacteria, endotoxin, nitrates |
| Metabolic acidosis | Low pH, sulfates |
| Muscle weakness | Calcium, magnesium |
| Neurological deterioration | Aluminium |
| Nausea and vomiting | Bacteria, calcium, copper, endotoxin, low pH, magnesium, nitrates, sulfates, zinc |
| Death | Aluminium, fluoride, endotoxin, bacteria, chloramine |

(Source: Extracted from Food and Drug Administration (FDA). (1989). *A manual on water treatment for hemodialysis. )*

# Some Recommended Max Allowable Chemical Contaminant Levels

## (Full list and details to be referred to ANSI / AAMI RD62)

Toxicity

Based on U.S. Environmental Protection Agency. Safe Drinking Water Act except with more stringent limits

Physiologically Important for Haemodialysis Application

| Group | Chemical Species | Maximum Concentration (mg/L) |
|---|---|---|
| 1 | Aluminum | 0.01 |
| | Chloramines | 0.1 |
| | Copper | 0.1 |
| | Fluoride | 0.2 |
| | Sulfate | 100 |
| 2 | Arsenic | 0.005 |
| | Barium | 0.1 |
| | Chromium | 0.014 |
| | Mercury | 0.0002 |
| | Lead | 0.005 |
| | Silver | 0.005 |
| 3 | Calcium | 2 |
| | Potassium | 8 |
| | Sodium | 70 |

# System Design

1. Choice of materials
2. Operational Requirement
3. Fluid Path and Individual Components

# Material Compatibility

- Piping, storage, and distribution systems...
- shall not interact **chemically** or **physically w/ Purified water**
  - √ unreactive materials (e.g., plastics) or appropriate stainless steel.
  - X copper, brass, galvanized material, or aluminum

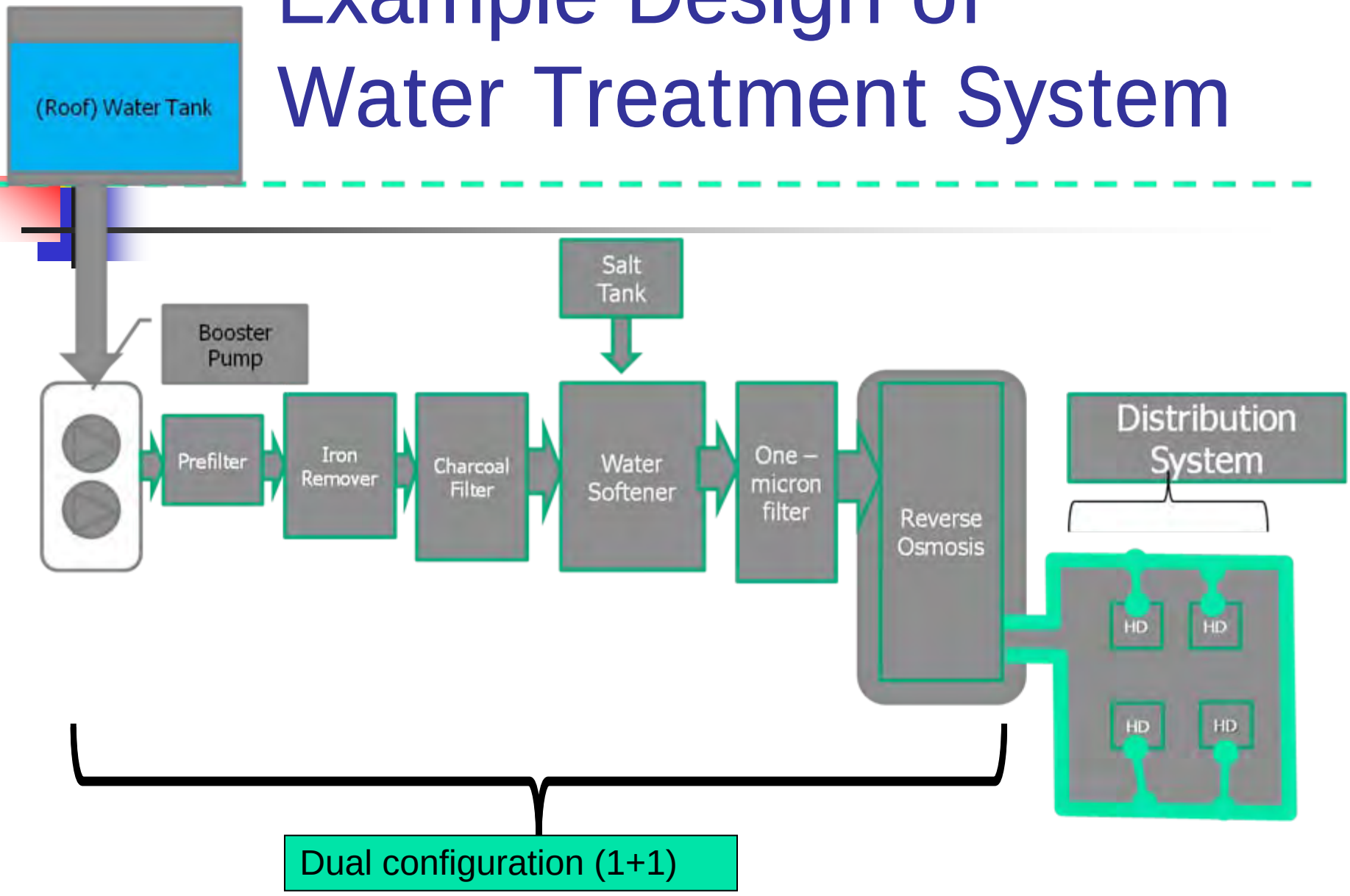
# Operational Safety Requirements

1. Monitors cannot be disabled while a patient is at risk.
2. Audible alarms > 65 dBA at 3 m and non-mutable for > 180 seconds.
3. Resistivity, conductivity, or totally dissolved solids (TDS) monitors shall be temperature compensated (temp ⇑⇒Conductivity⇑).
4. Operating controls shall be designed to prevent inadvertent resetting.
5. Electrical circuits to be separated from hydraulic circuits (against fluid leaks)

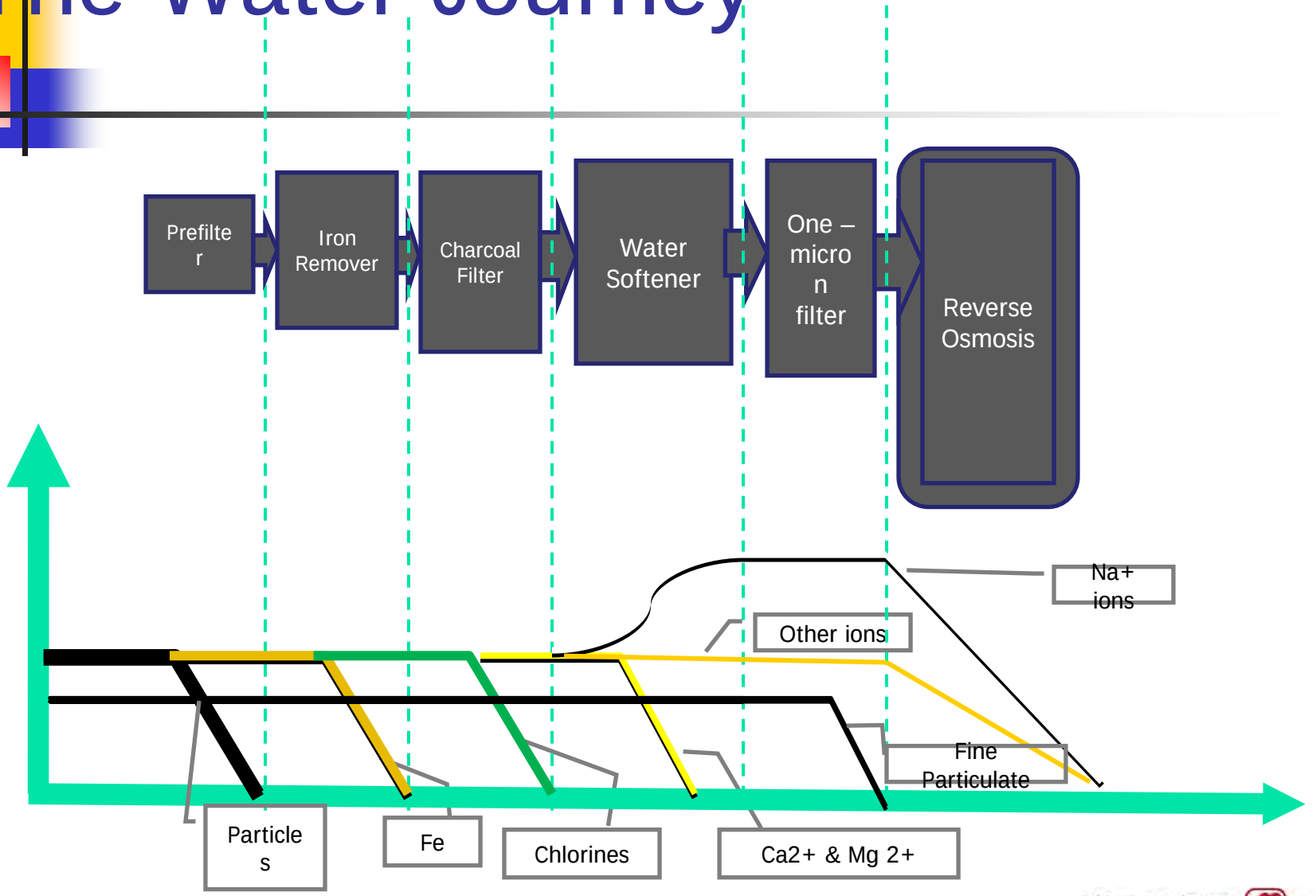
# System Layout

From Water Tank to Haemodialysis Unit ...

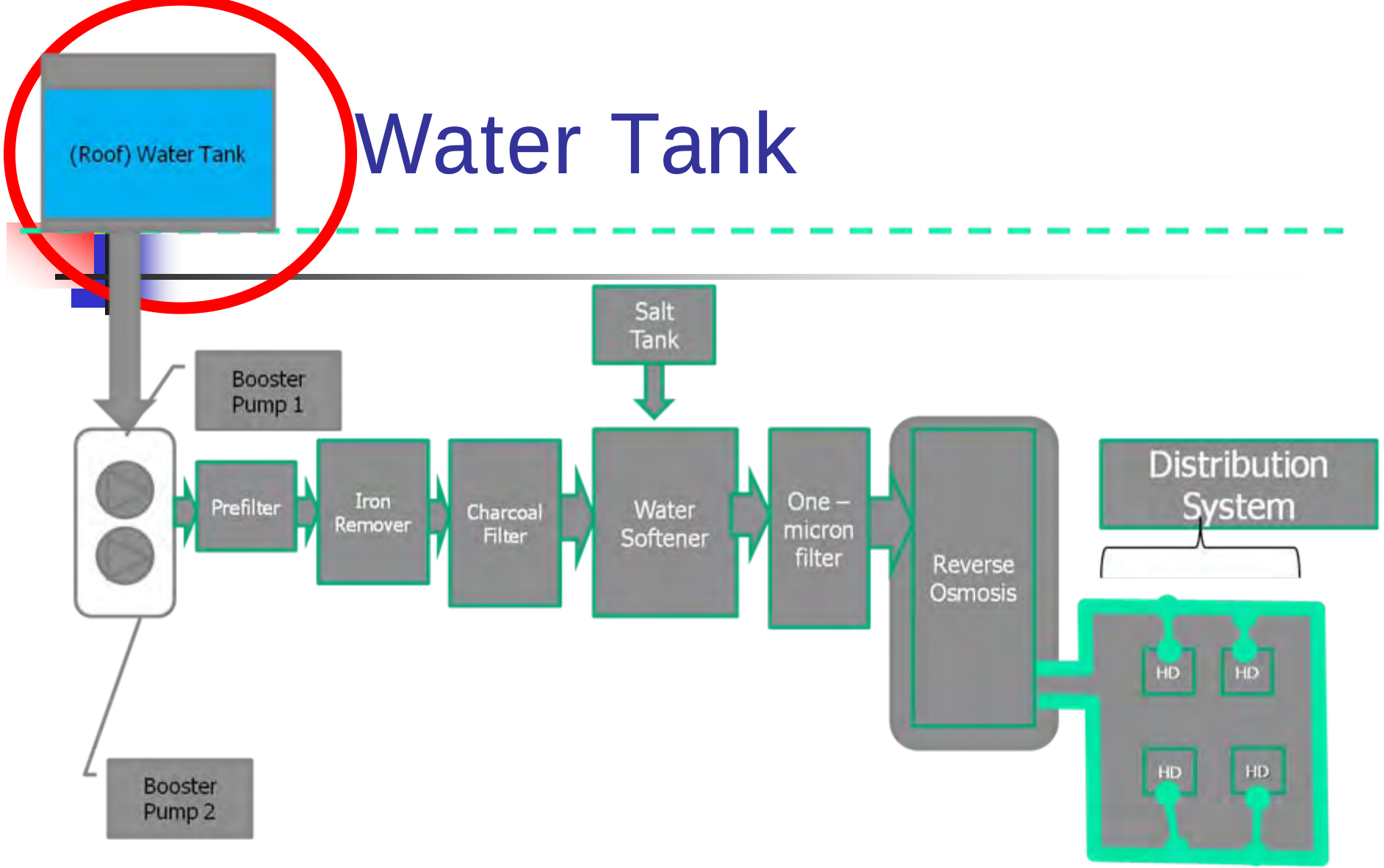
# Example Design of Water Treatment System



# The Water Journey



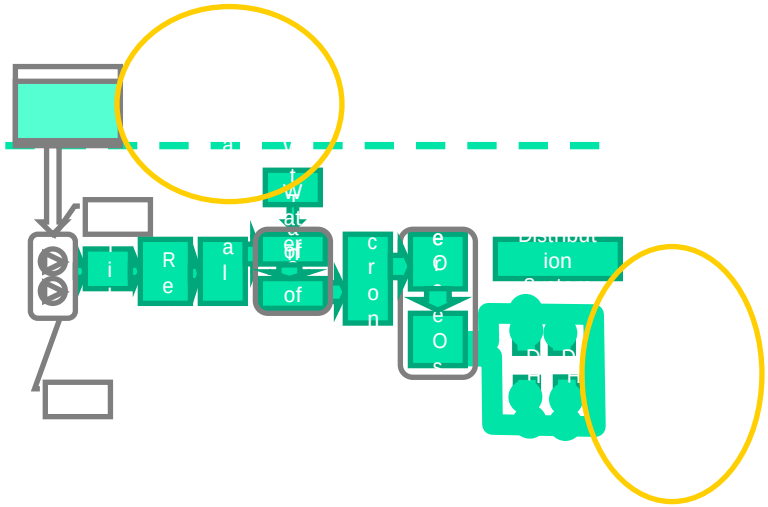
# Water Tank


(Roof) Water Tank
Salt Tank
Booster Pump 1
Prefilter
Iron Remover
Charcoal Filter
Water Softener
One – micron filter
Reverse Osmosis
Distribution System
HD
HD
HD
HD
Booster Pump 2

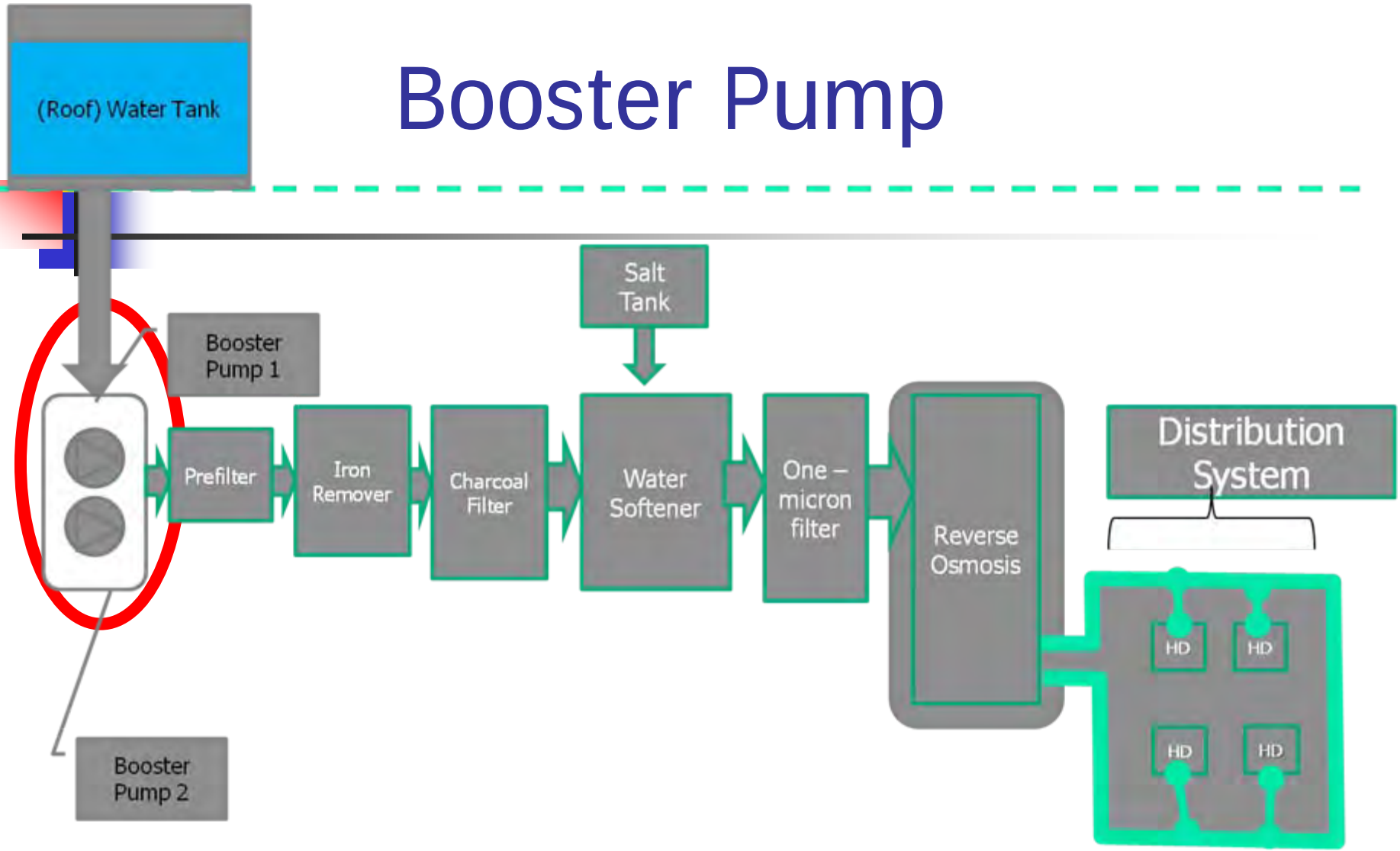
# Water Tank

# Water Tank Sizing

- HD machine Output (e.g. 0.6 L/min)
- Nos. of HDs served (e.g. 20)
- Nos. of Sessions (dependent on operation need)
- Rejection ratio ( say, 50%)
- Contingency ( say, 10%)



# Booster Pump

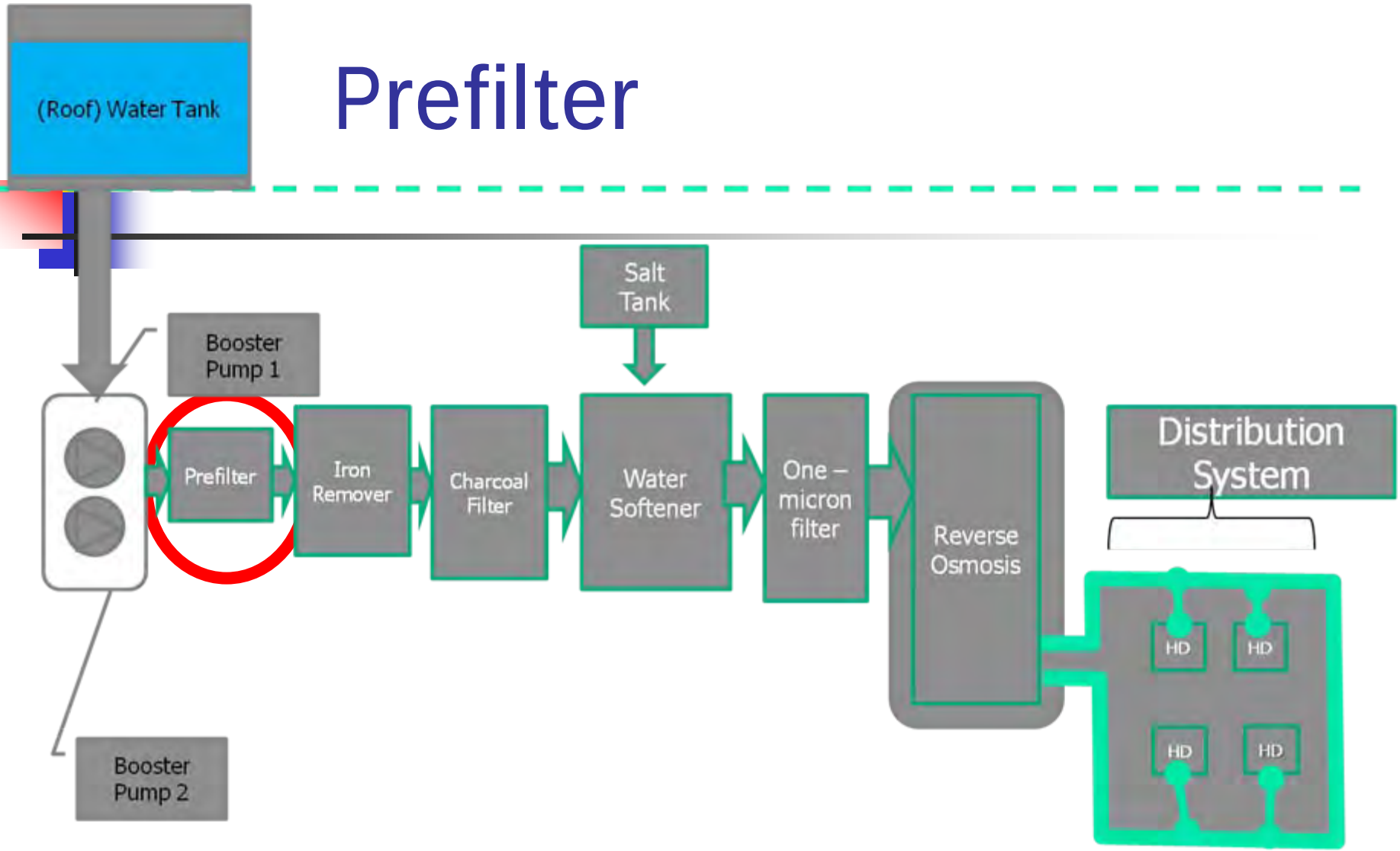


# Booster Pump

- Additional Pressure for Downstream components (incoming at 30 – 45 PSI)
- 3 phase high power pump
- Alarm at control cabinet
  - Low Inlet Pressure
  - Pump Fault
- Operation Lamp
  - Normal

# Booster Pump

# Prefilter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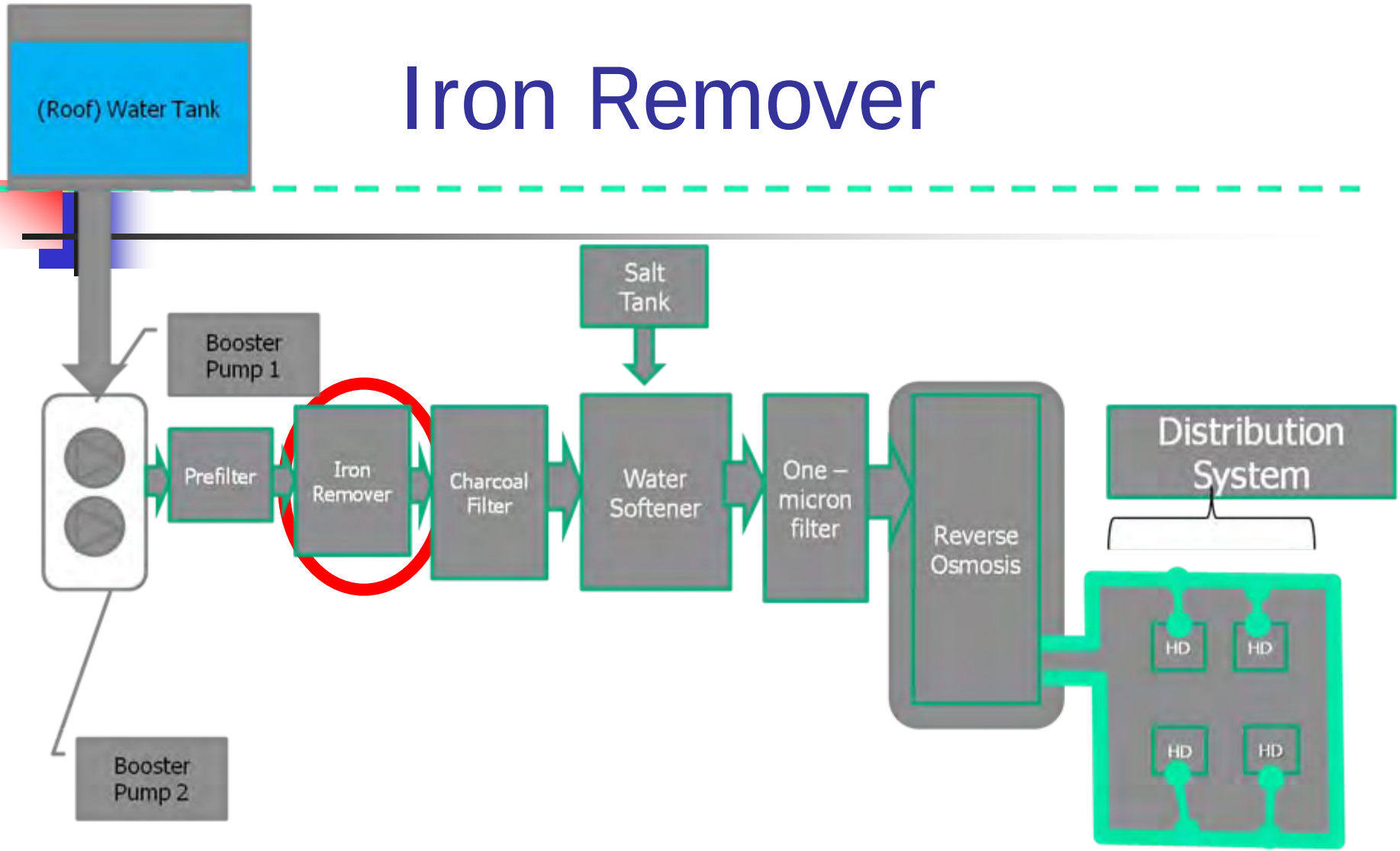
# Prefilter

- First line filtration
- To remove suspended particulates and protect down stream components
- Various size of sand and gravels

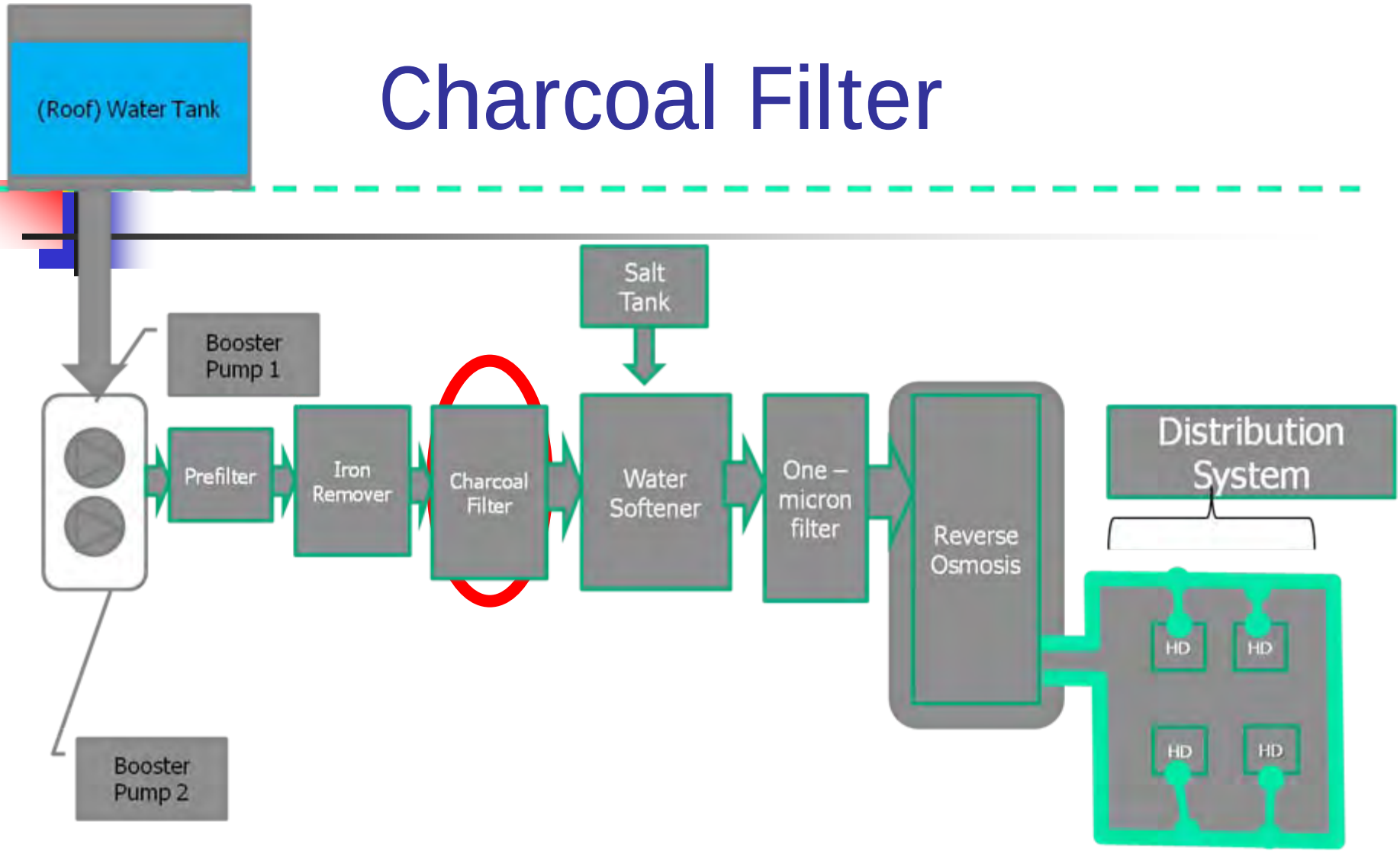
# Iron Remover



# Iron Remover

- Remove Iron
  - No particular limit on Iron level as per AAMI
  - Iron compounds could be detrimental to RO
  - Principle similar to Water softener (Ion exchange)

# Charcoal Filter



# Charcoal / Carbon Filters

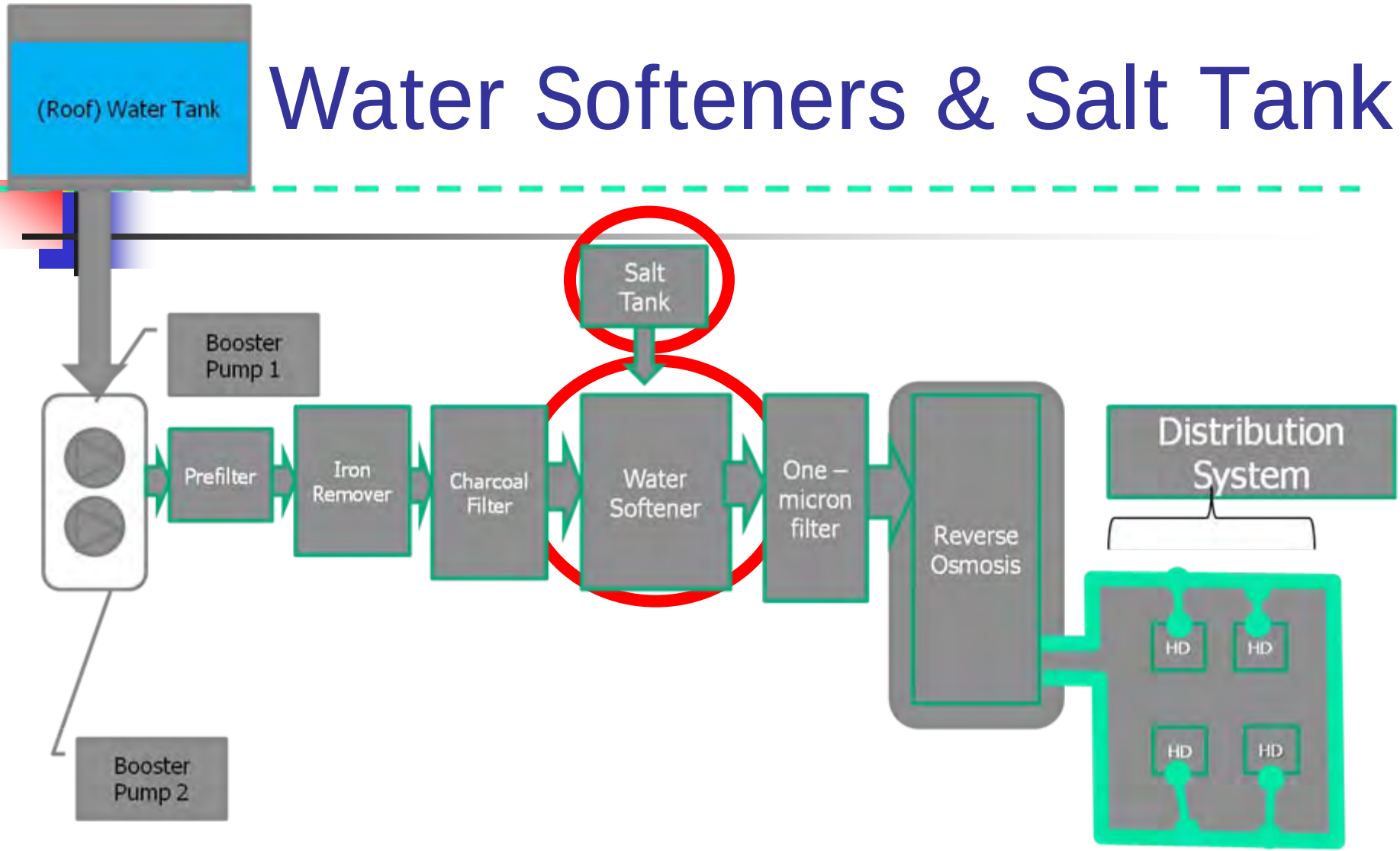
- **Activated Carbon**
- For removal of Chlorine and Chloramines
- to be placed before RO
  - Activated Carbon is a hospitable place for bacterial growth
  - Activated Carbon contains inorganic contaminants
  - Chlorine is detrimental to the thin film composite of RO

# Charcoal / Carbon Filters

- Sized to adapt maximum anticipated water flow rate
- Replacement schedule determined by regular monitoring

# Charcoal / Carbon Filters

# Water Softeners & Salt Tank



# Salt Tank

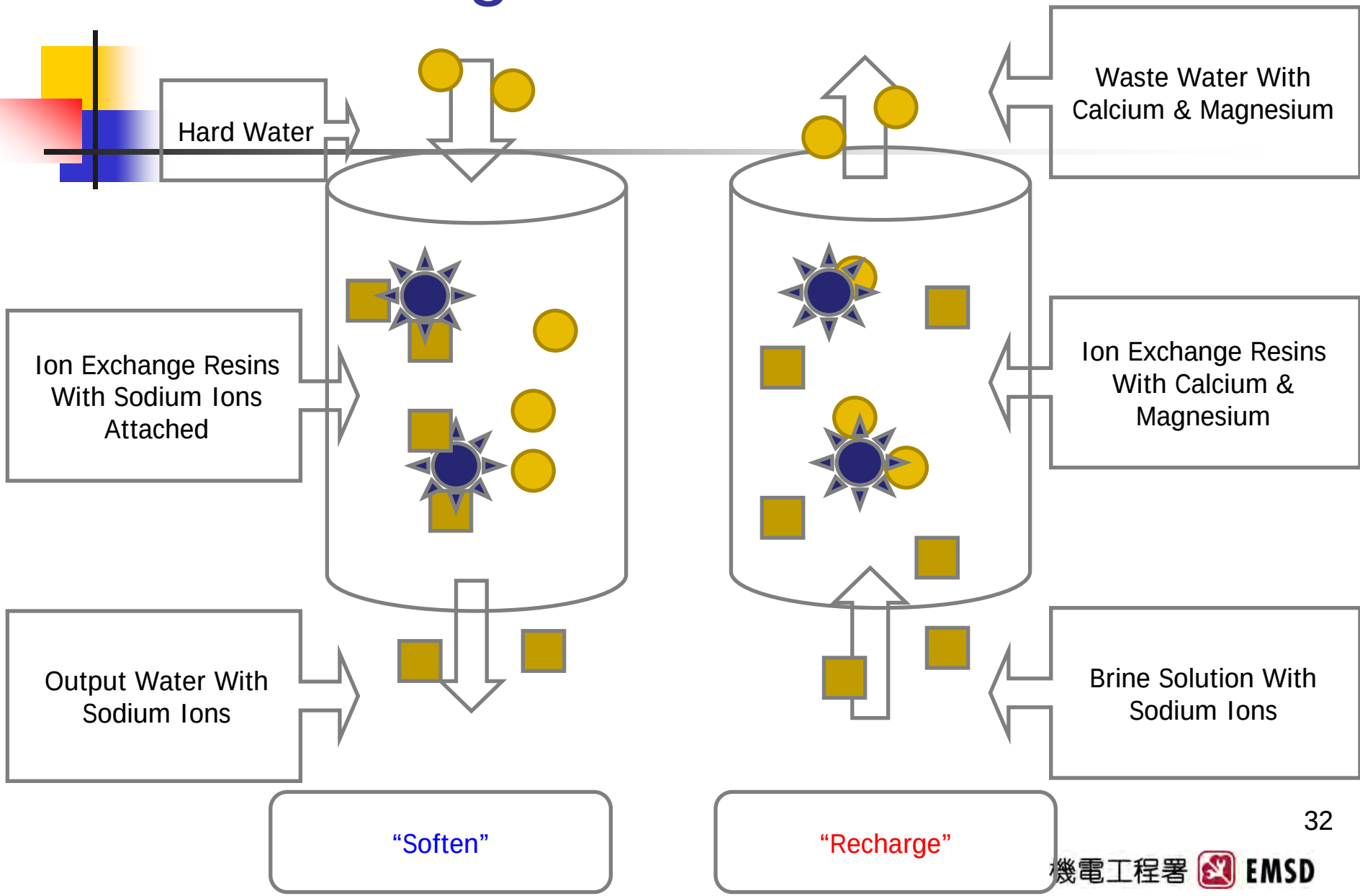
# Water Softeners

- Selectively... ↓ $Ca^{2+}$ and ↓ $Mg^{2+}$ (hardness)
- ⇑ $Na^{+}$
- Pre-conditioning for ROs
  - Calcium precipitate degrade RO membrane's performance)
- Connected with Salt Tanks for replenishment
- Automatic Timer for regeneration

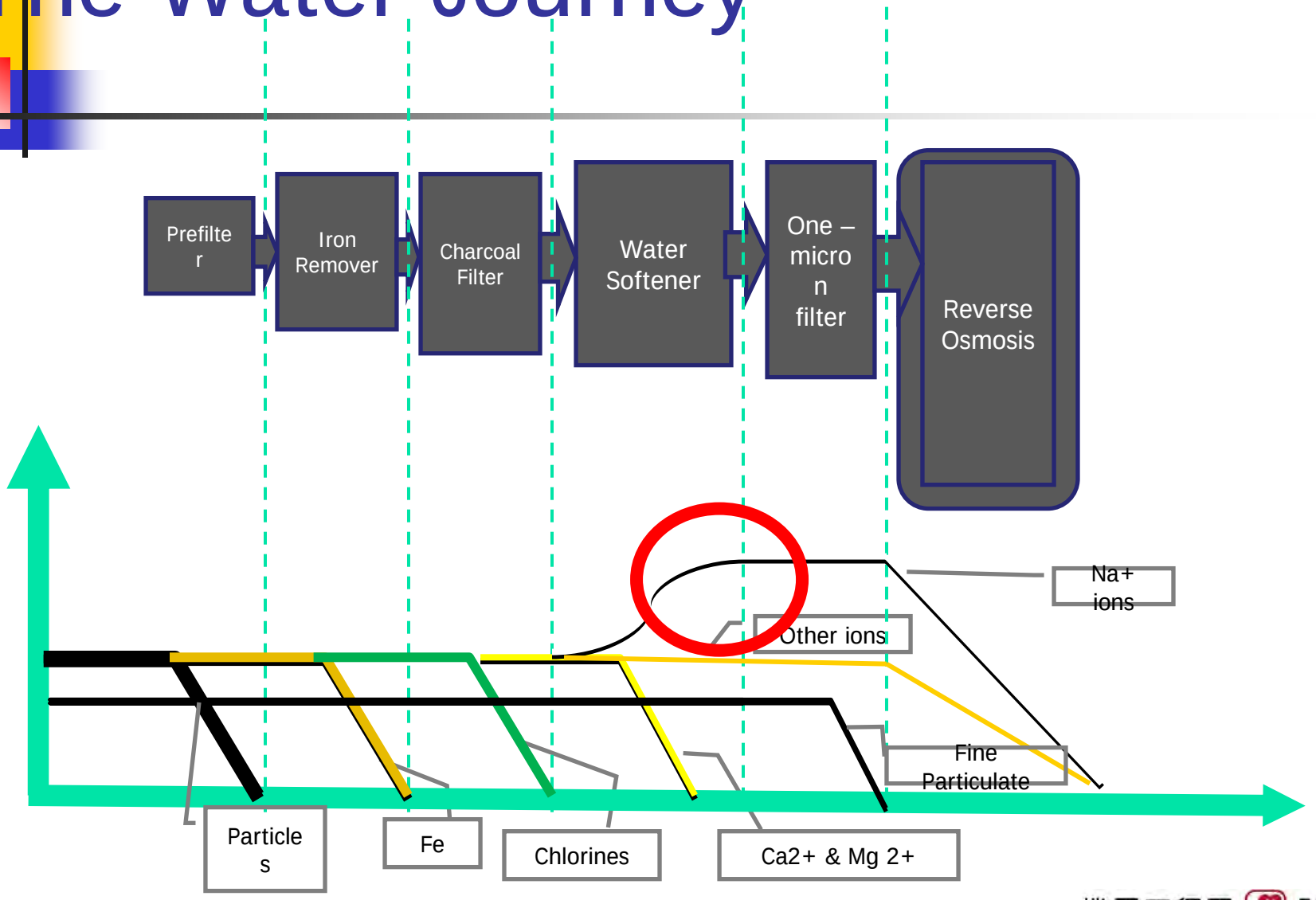
# Chemical Process

- **Softening Proces**
- $NaZeolite + Ca^{2+} \rightarrow CaZeolite + Na^{+}$
  and
  $NaZeolite + Mg^{2+} \rightarrow MgZeolite + Na^{+}$
- **Recharging Process**
- $NaCl + CaZeolite \rightarrow NaZeolite + CaCl$
  and
  $NaCl + MgZeolite \rightarrow NaZeolite + MgCl$

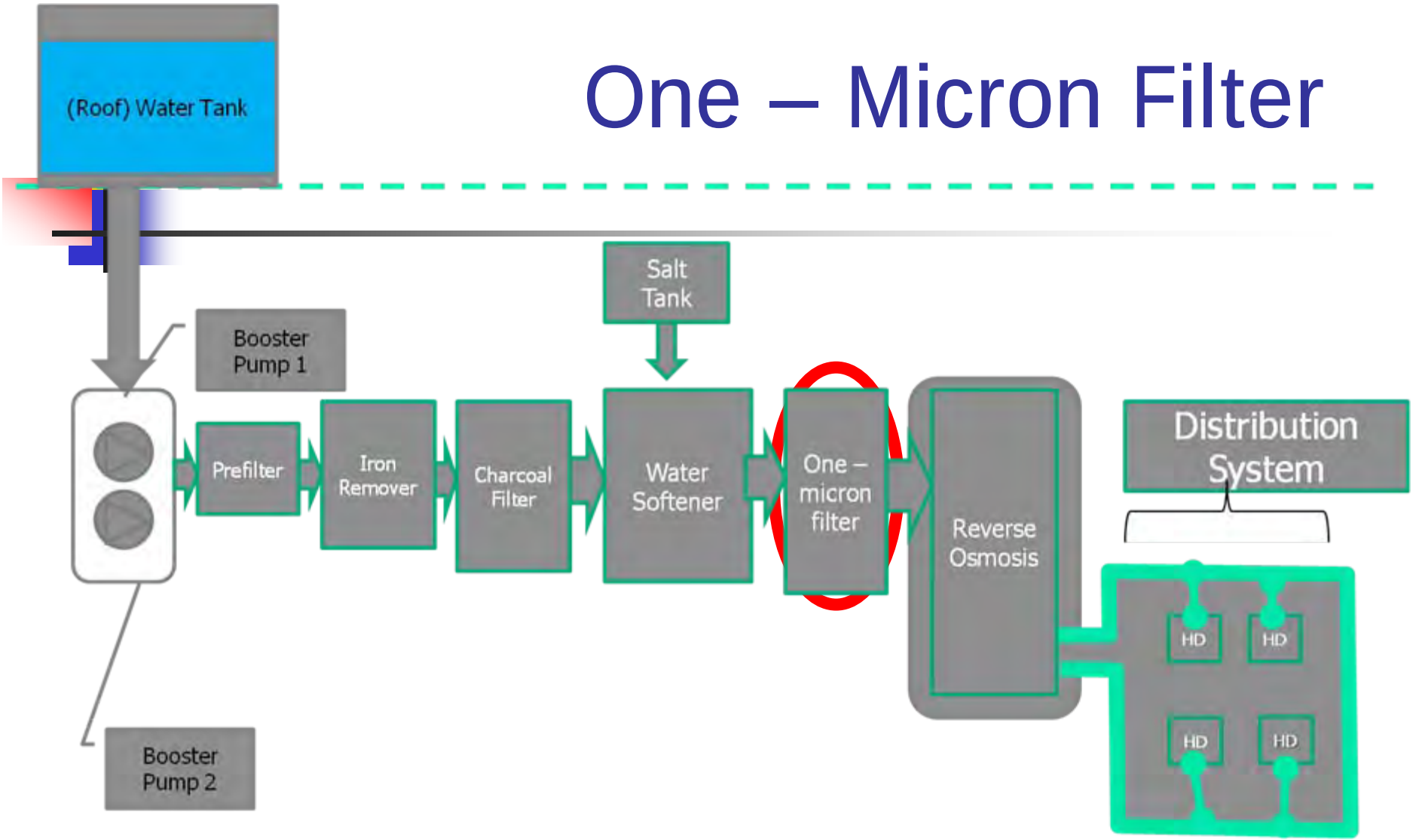
# Ion exchange



# The Water Journey



# One – Micron Filter

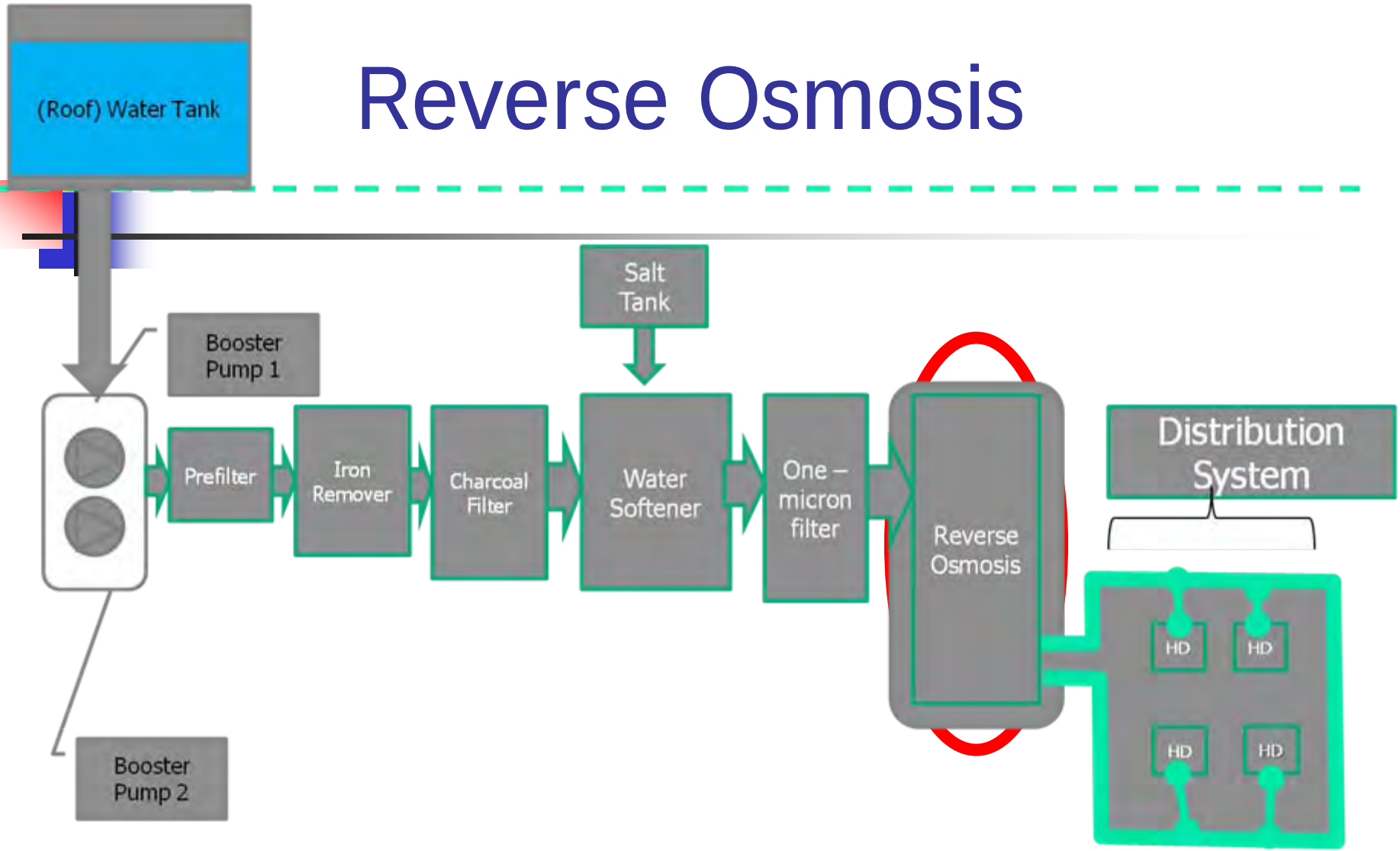


# One Micron Filter

- Remover finer particulates
- Protect RO from incoming / upstream particulate
- Do not remove bacterial nor endotoxin

# One Micron Filter

# Reverse Osmosis

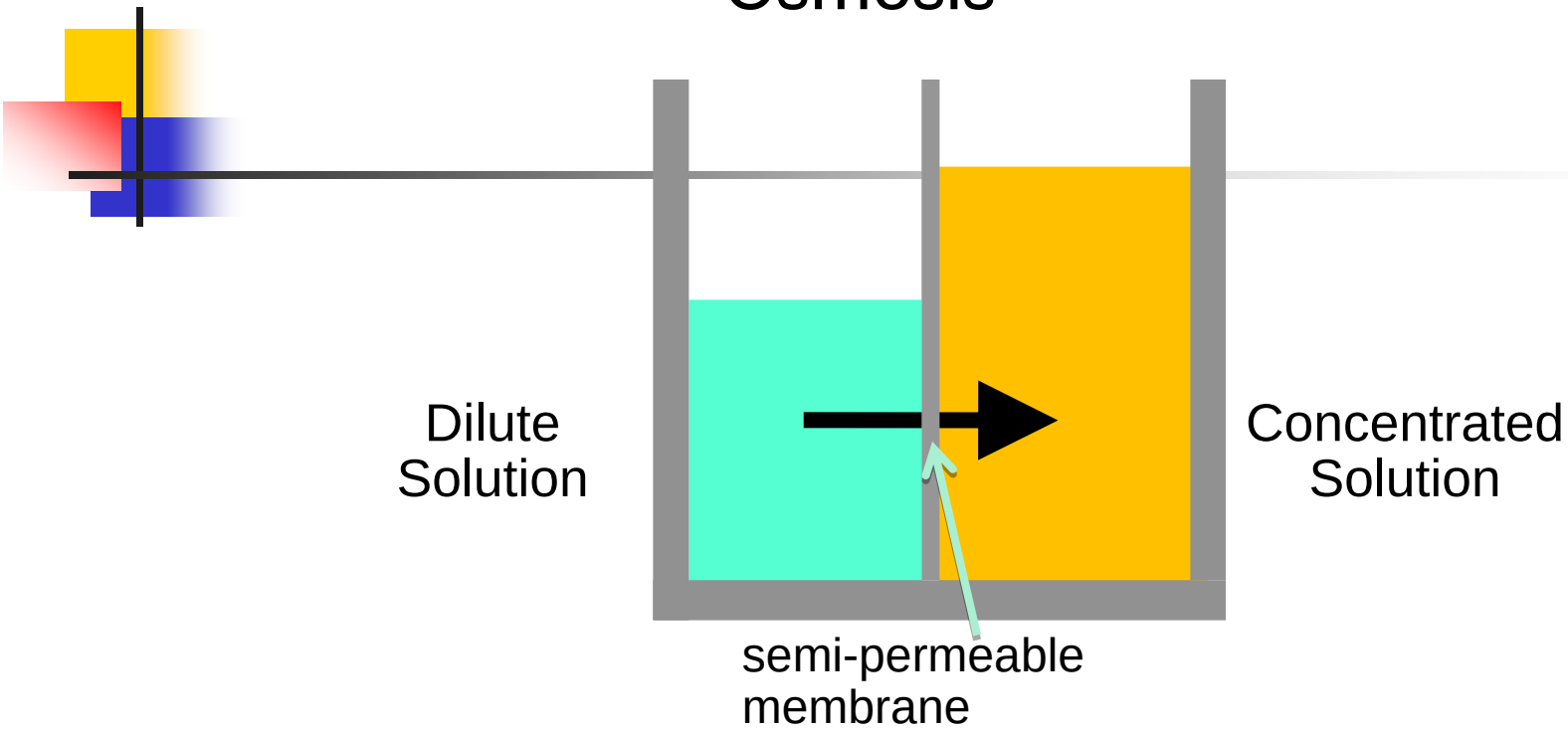


# Reverse Osmosis (RO)

- Must comply with the chemical contaminant conc. (table 1 of AAMI)
- On-line monitors for conductivity
- Alarm shall be audible at patient care area
- If RO is the last chemical purification process
  - Protection be present ➔ diversion to drain

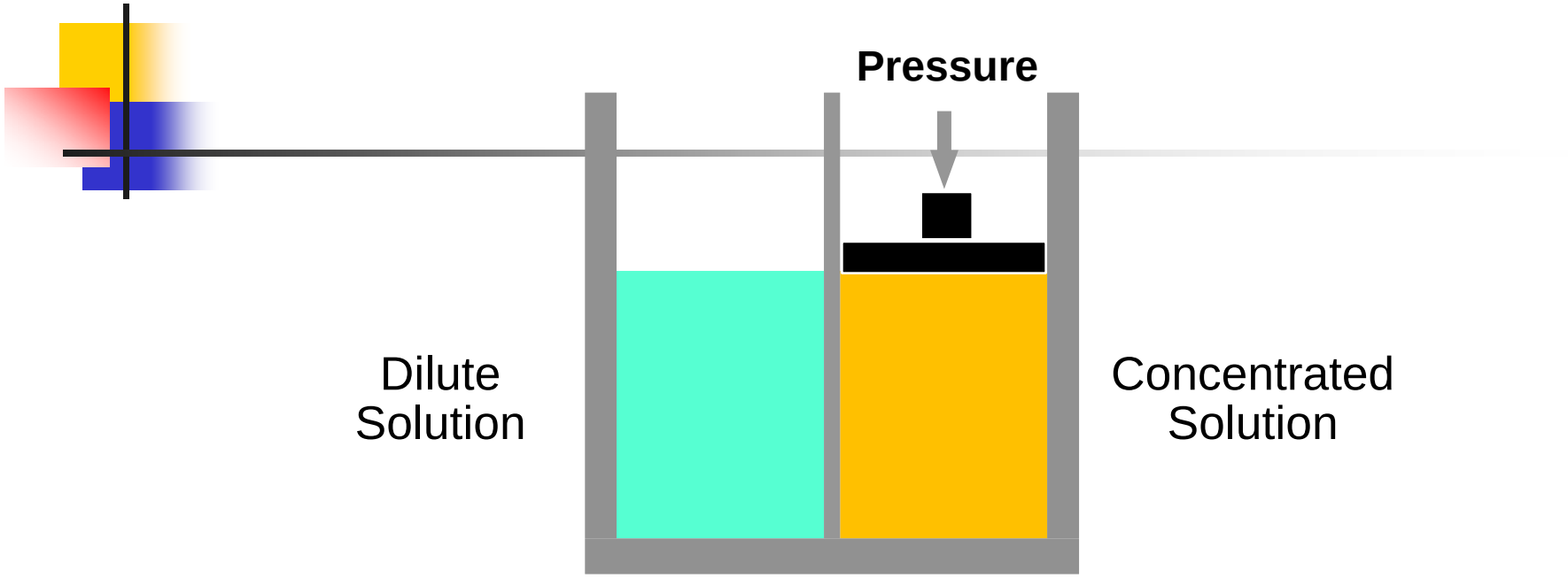
# RO Principle

## Osmosis




Spontaneous flow of water from a dilute solution to a concentrated solution, when the two solutions are separated by a semipermeable membrane.

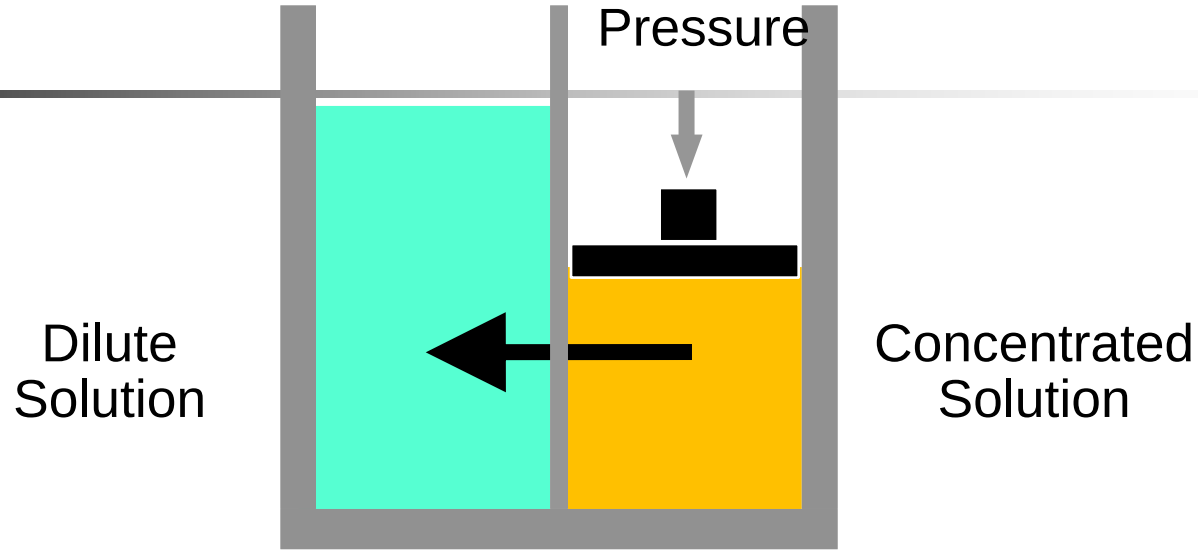
# Osmotic Pressure




**Pressure = $\Delta\pi$**

A pressure that must be applied to a concentrated solution to prevent osmosis. (equilibrium state)

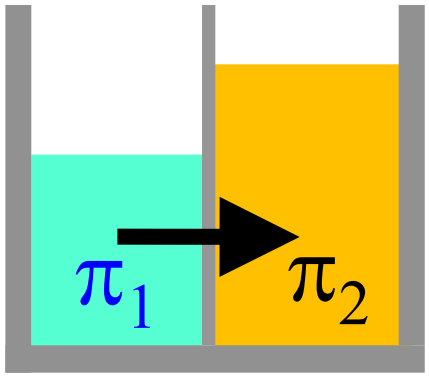
# Reverse Osmosis




**Pressure> $\Delta\pi$** (200 – 250 PSI)

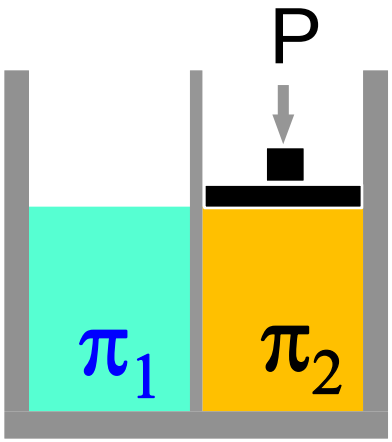
Reversing osmotic flow by applying a pressure in excess of the osmotic pressure

# Summary of the three cases



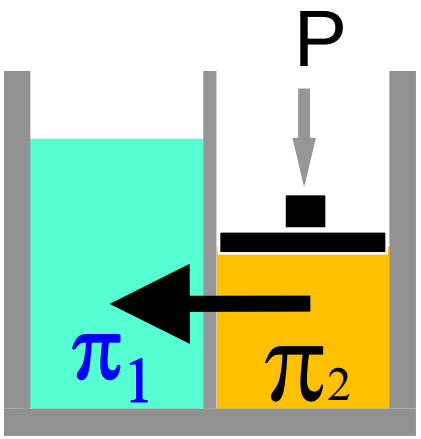

osmosis

$\pi_1 < \pi_2$




equilibrium

$P = \Delta\pi$




reverse osmosis

$P > \Delta\pi$

# RO system

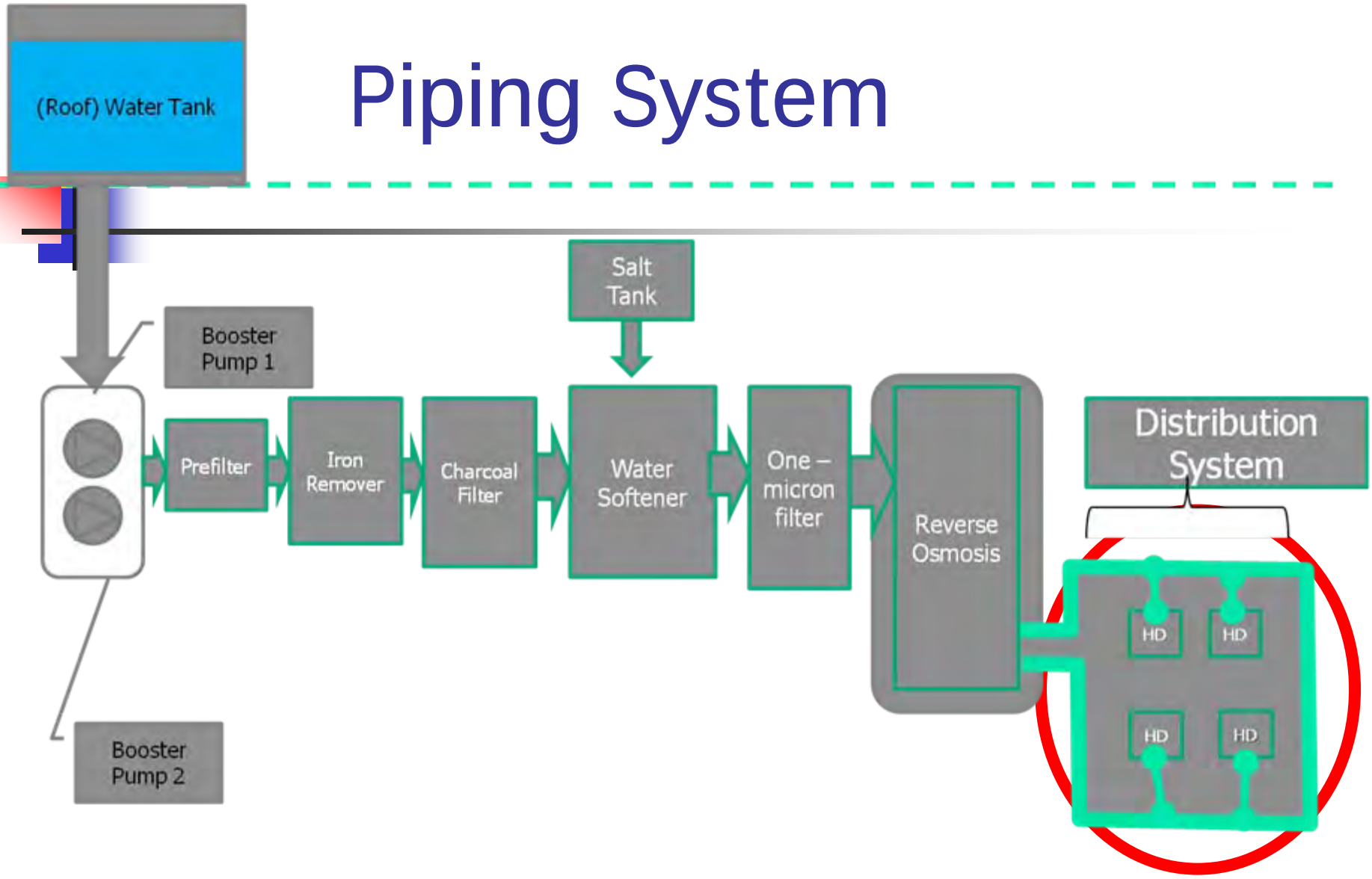
# Capability of Reverse Osmosis

| Reverse Osmosis will remove the following contaminants: | | | |
|---|---|---|---|
| **Contaminant** | **% nominal rejection** | **Contaminant** | **% nominal rejection** |
| Aluminum | 96-98 | Ammonium | 80-90 |
| Arsenic | 98-99% | Borate | 30-50 |
| Bacteria | 99+ | Bromide | 90-95 |
| Boron | 50-70 | Calcium | 93-98 |
| Cadmium | 93-97 | Chromate | 85-95 |
| Chloride | 92-95 | Cyanide | 85-95 |
| Copper | 96-98 | Hardness Ca & Mg | 93-97 |
| Fluoride | 92-95 | Lead | 95-98 |
| Iron | 96-98 | Magnesium | 93-98 |
| Manganese | 96-98 | Nickel | 96-98 |
| Mercury | 94-97 | Orthophosphate | 96-98 |
| Nitrate | 90-95 | Polyphosphate | 96-98 |
| Phosphate | 95-98 | Radioactivity | 93-97 |
| Potassium | 93-97 | Silicate | 92-95 |
| Silica | 80-90 | Sodium | 92-98 |
| Silver | 93-96 | Thoisulfate | 96-98 |
| Sulfate | 96-98 | | |
| Zinc | 96-98 | | |

# UV irradiation

- Facility for killing bacteria
- Irradiance:
  - UV at wavelength of 254 nm
  - Dosage at 30 $mWs/cm^2$

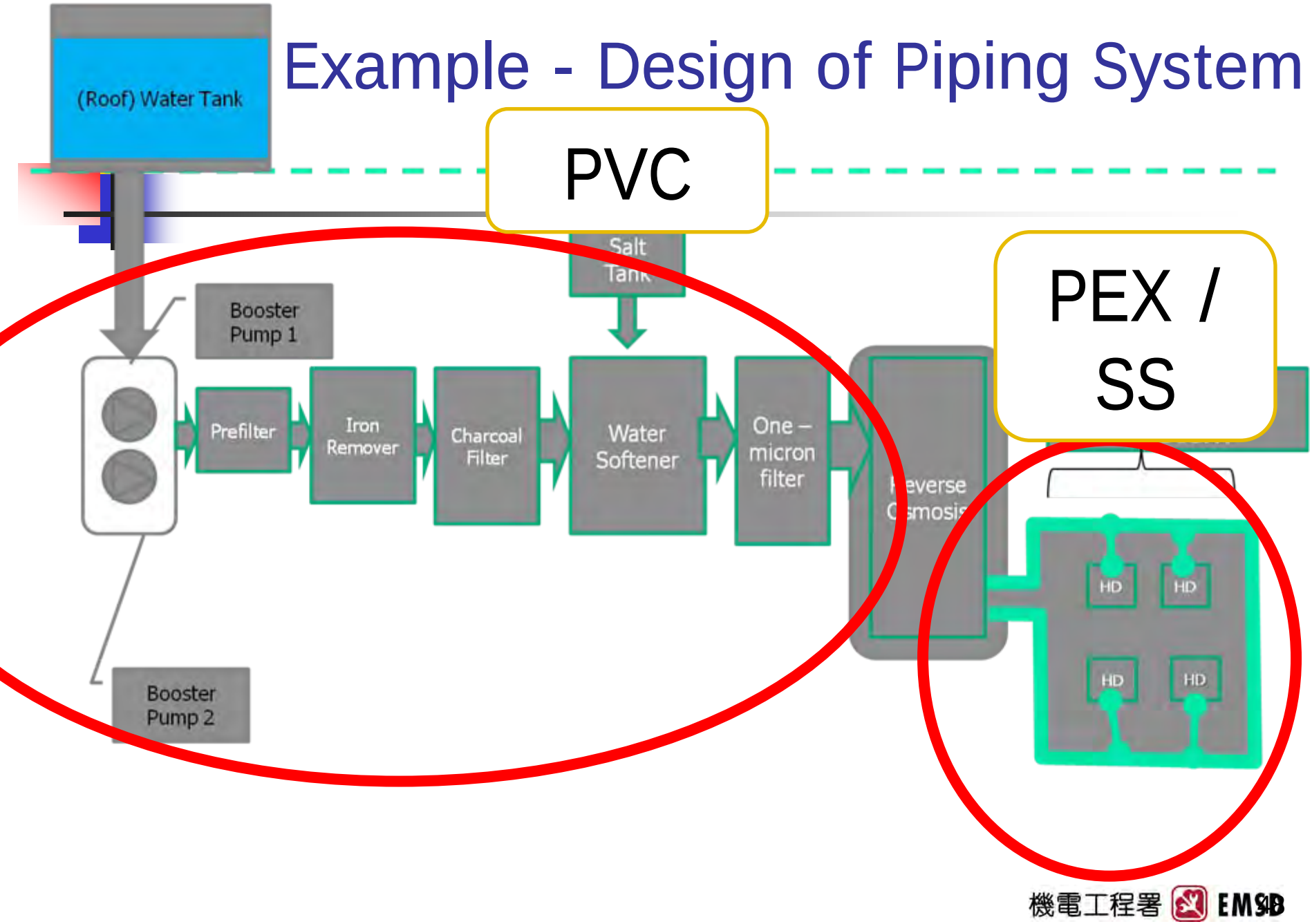
# Piping System



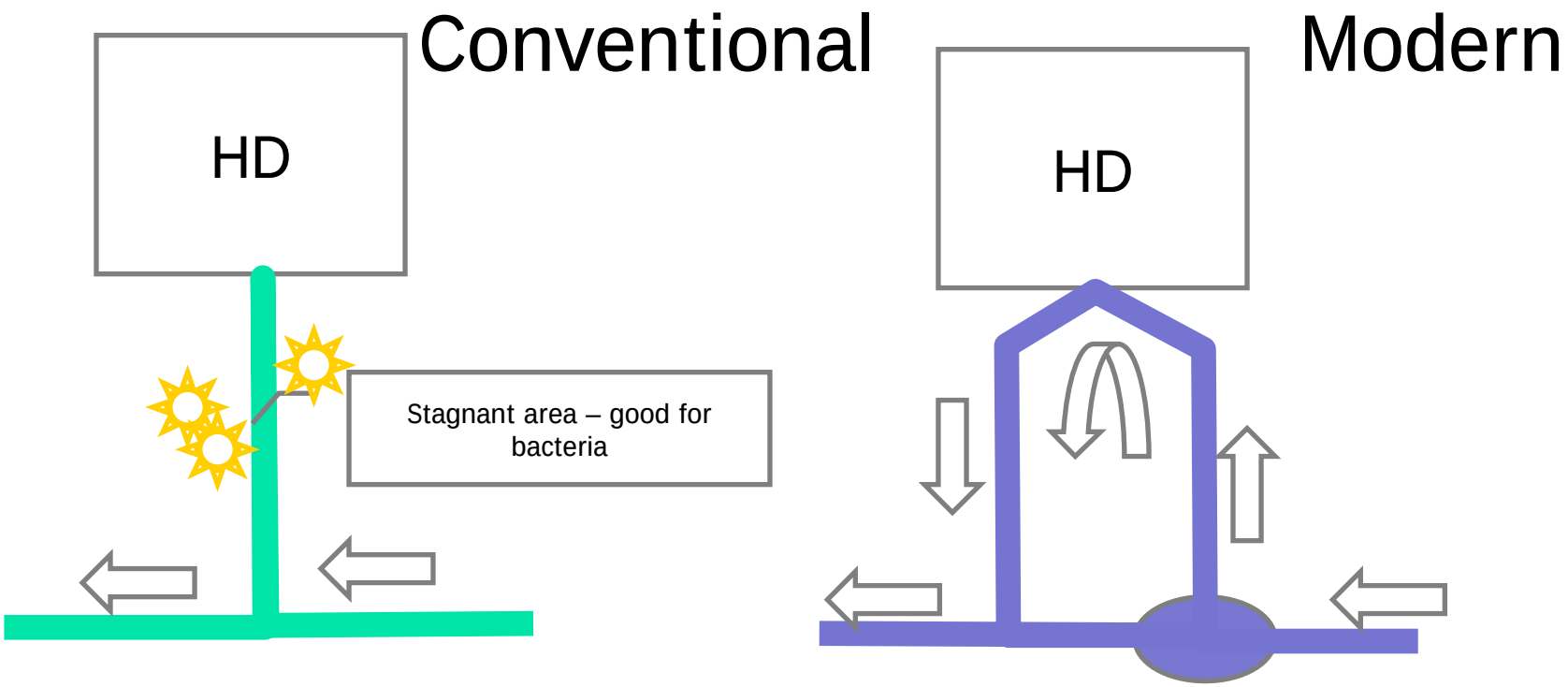
# Piping System

- Material
  - PVC , stainless steel, PP (polypropylene), PEX (crosslinked polyethylene)
- Piping architecture
  1. Continued loop (recommended by AAMI)
  2. non-returning lines (direct to drain)

# Example - Design of Piping System



# Piping System – Permanent Circulation

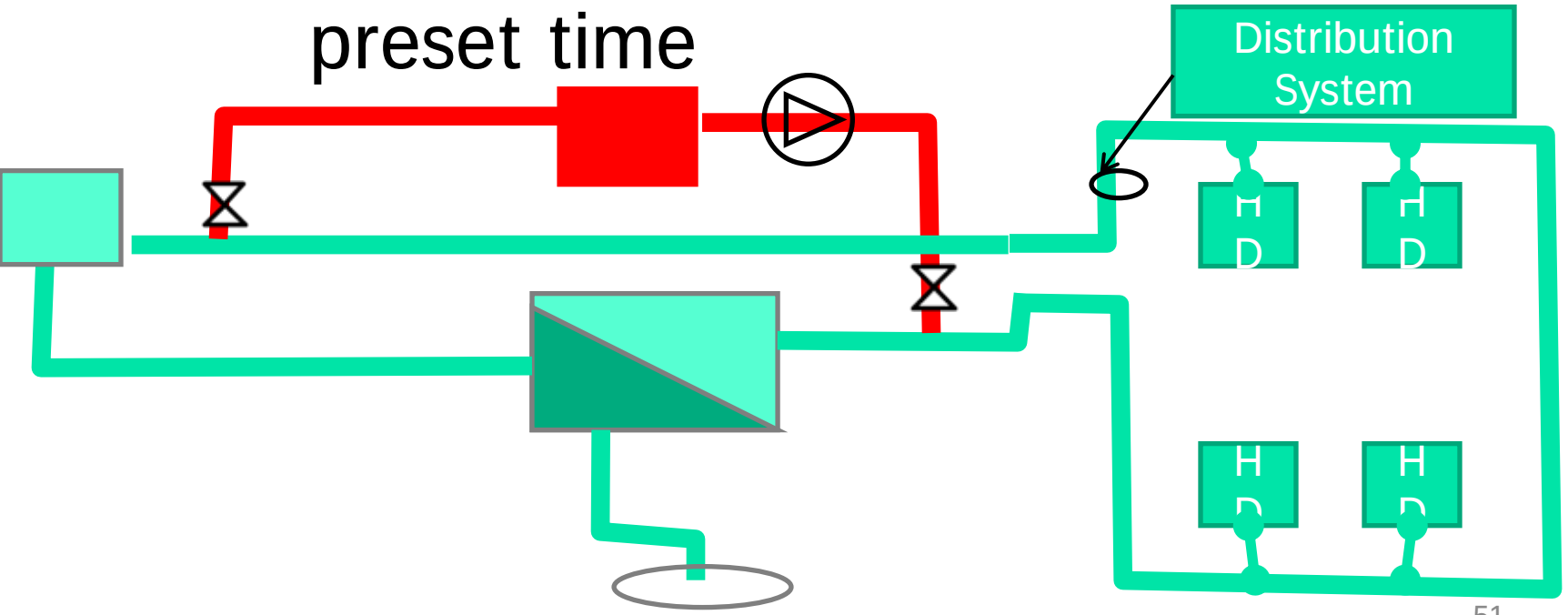


# Disinfection Piping System

- Disinfection of Piping
- Chemical  (Dialox/Peracetic Acid/Sodium Hypochloride)
- Hot water
  - Water heater (min temp 60 deg C at distribution loop)
  - X  PVC
  - √ PP (polypropylene)
  - √ SS
  - √ PEX

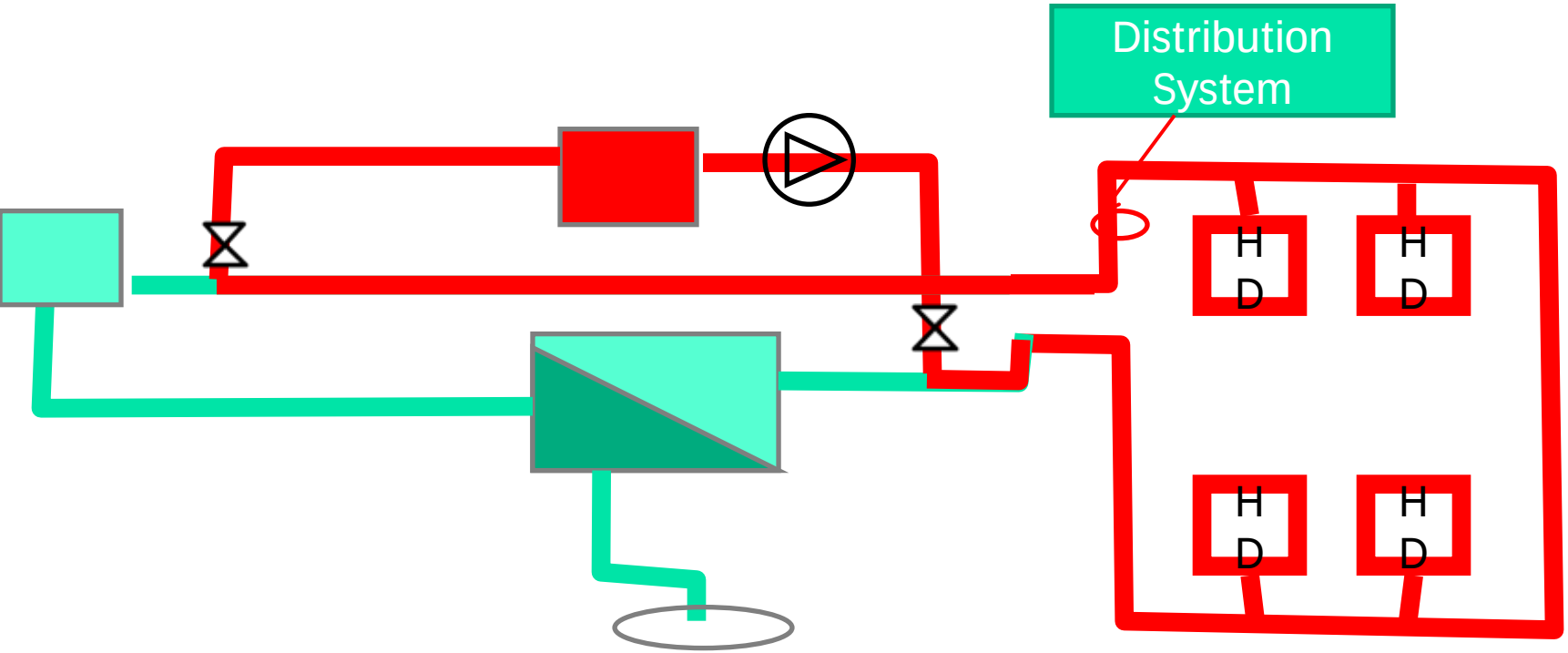
# Hot Water Disinfection

- Daily
- Initiated by Operator ➔ auto start at preset time



# Hot Water Disinfection

## Heating



# Disinfection Protection

- Testing procedures for chemical shall be in place
- Warning be activated immediately after heat/chemical disinfection

# Water Tests

| Test | Frequency |
|---|---|
| Water hardness, pre and post softener | During design and commissioning. Six monthly or after carbon change. |
| Chlorine | During commissioning. At least once per dialysis shift |
| Bacteria | During commissioning. Monthly. |
| Endotoxin | During commissioning. Monthly. |
| Chemical contaminant and heavy metal levels | During commissioning. Six monthly or after carbon or RO change. |

(Source: *CDC recommendation, AAMI and NSW)*

# Quality Control

- Properly written policy with education
- Periodic test schedule
- Proper water sampling
- Trending and Recording
- Maintenance by Designated Personnels

Thank you!