Membranes for Pure Water Systems

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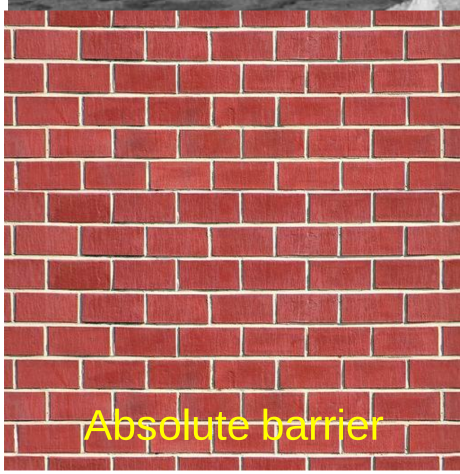
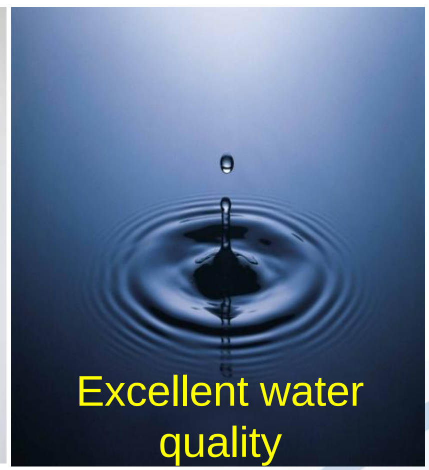
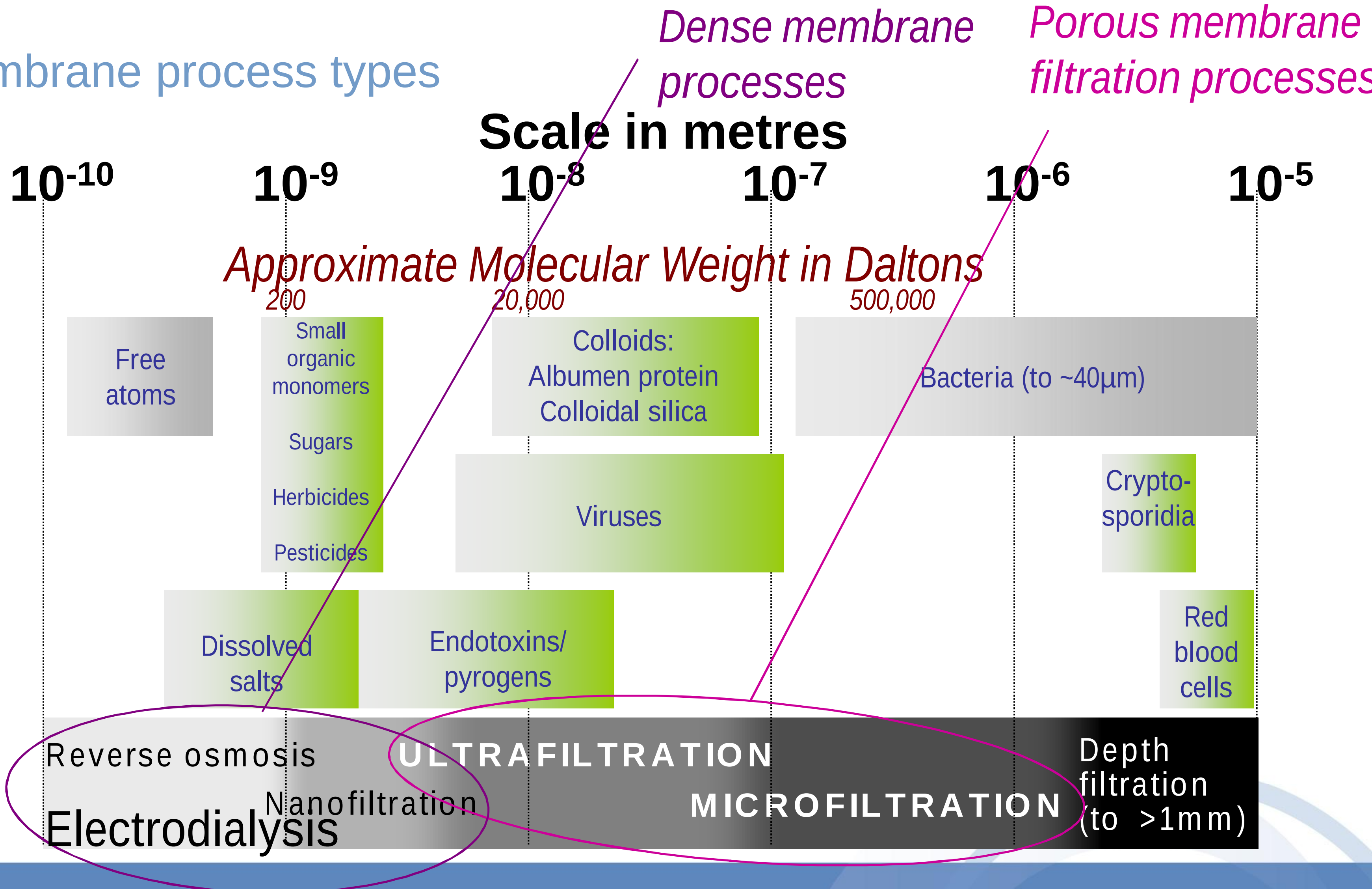
Membrane processes: Pros and cons

High
maintenance





Membrane process types



Pure water systems

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Basic design

Pretreatment

Media of membrane filtration (ultrafiltration, microfiltration)

RO

Reverse Osmosis

CDI

Continuous deionisation (supersedes twin bed IEX)

Storage (optional)

POU filters

- MF, Cartridge microfilters
- UF, Ultrafiltration skid

Reverse osmosis

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Key RO process parameters

- **Water flux**
  - determines production rate
    - high is better
- **Salt flux or passage**
  - combined with water flux, determines permeate product water quality
    - low is better
- **TMP**
  - Determines energy demand
    - low is better; stable is essential
- **Conversion**
  - Proportion of feedwater recovered as permeate
    - high is better: determined to a large extent by the flux
- **Rejection**
  - Proportion of ions rejected: relates to inverse salt passage
    - high is better: determined to a large extent by the ratio of the flux to salt passage

RO fluxes

Water flux:

Transmembrane pressure (TMP)

Transmembrane osmotic pressure)

$$J_w = k_1(\Delta P - \Delta \Pi)$$

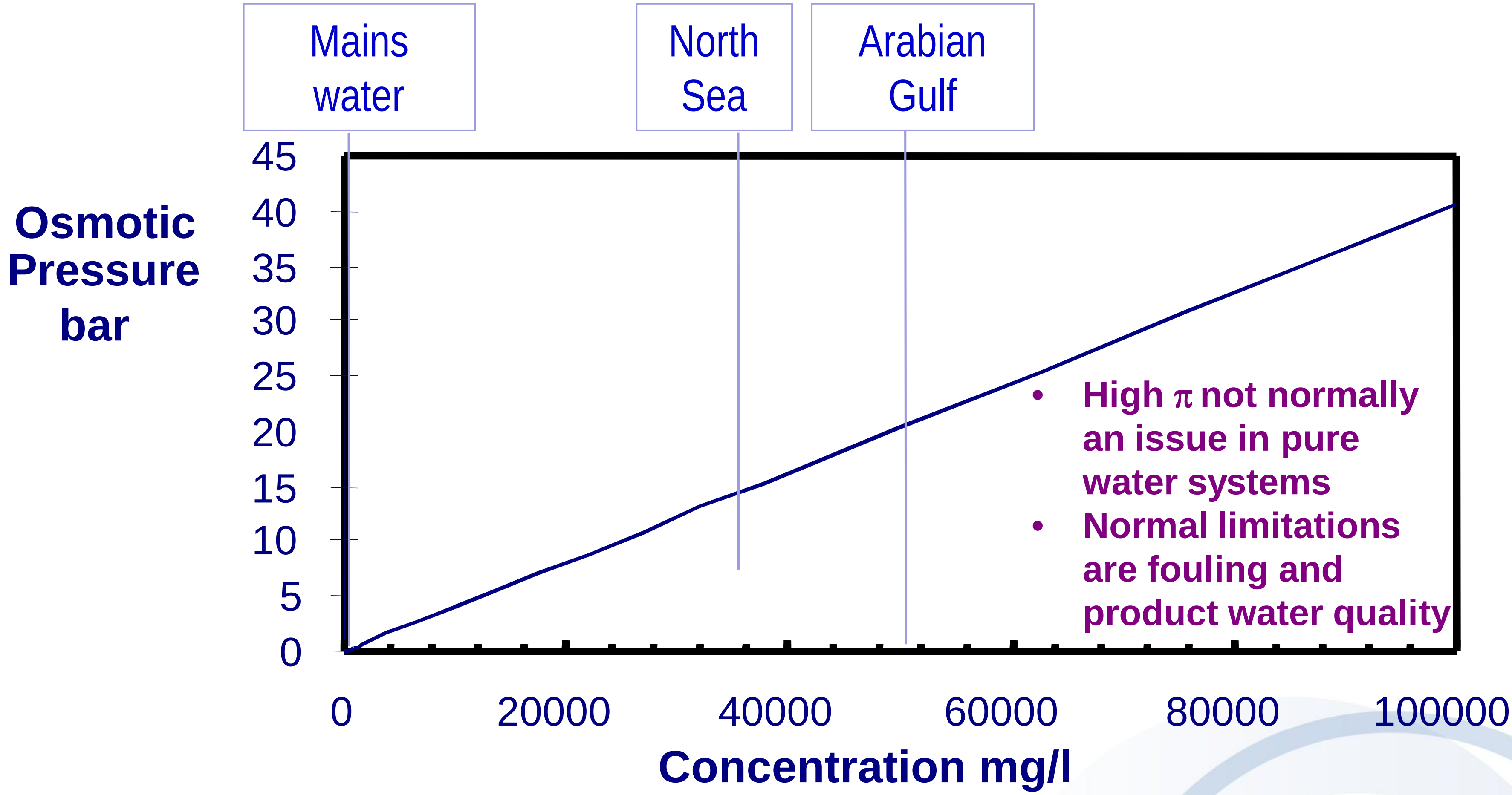
Salt flux:

Transmembrane concentration difference

$$J_s = k_2 \Delta C$$

- **Permeate salt concentration given by ratio of J_W to J_S**
- **Dependent on $k_1$and k_2, which are membrane material-dependent**

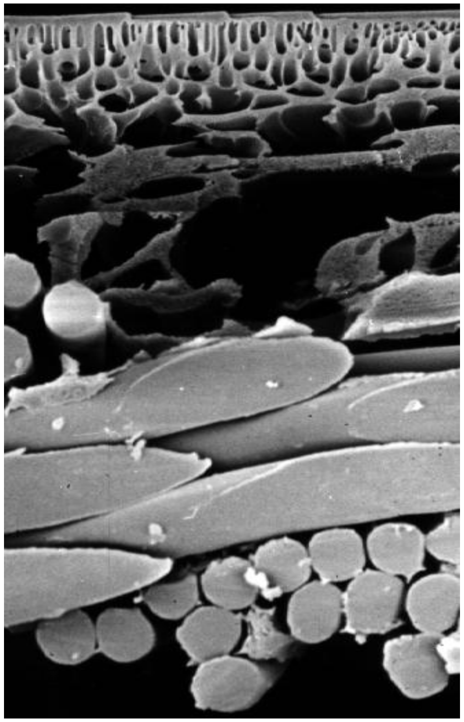
Osmotic pressure, NaCl, 25ºC



- High π not normally an issue in pure water systems
- Normal limitations are fouling and product water quality

RO membranes

RO membranes have additional ultrathin “active” layer for added perm-selectivity to form a composite material



RO Layer
50 - 200 nm

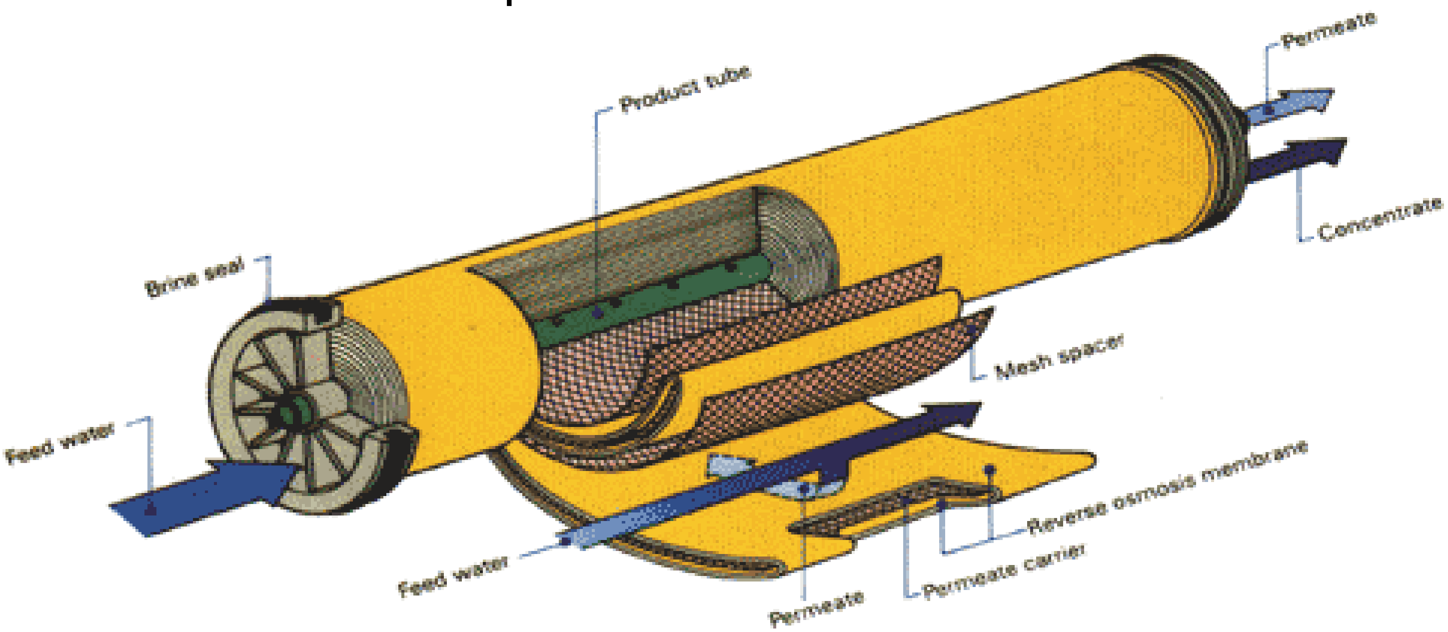
Ultrafiltration Layer - 50 µm

Backing Cloth

80 - 100 µm

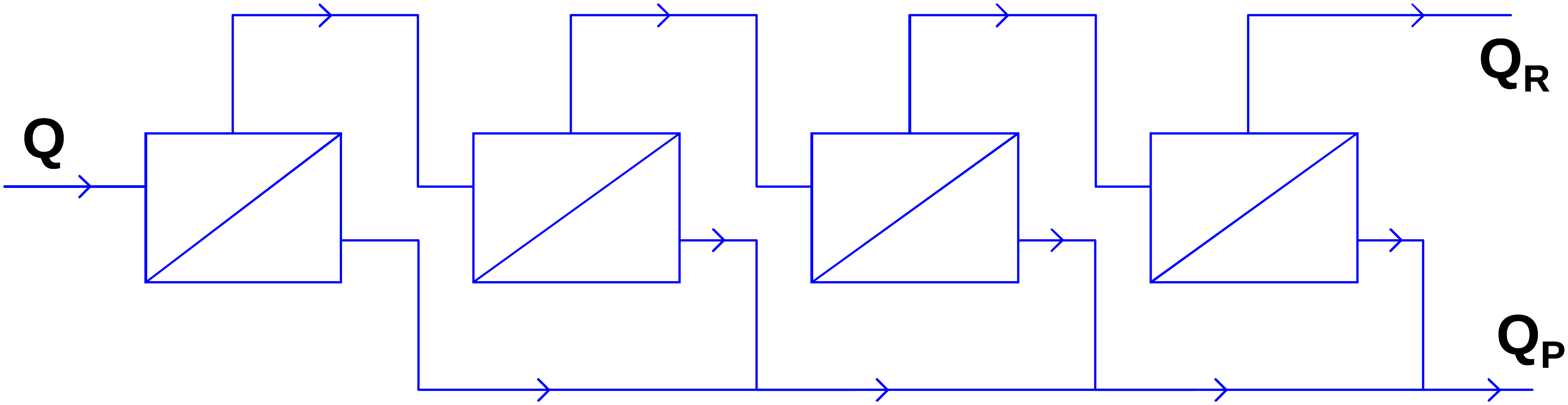
RO element

RO membranes are made as flat sheets and formed into spiral wound elements:



RO elements and modules

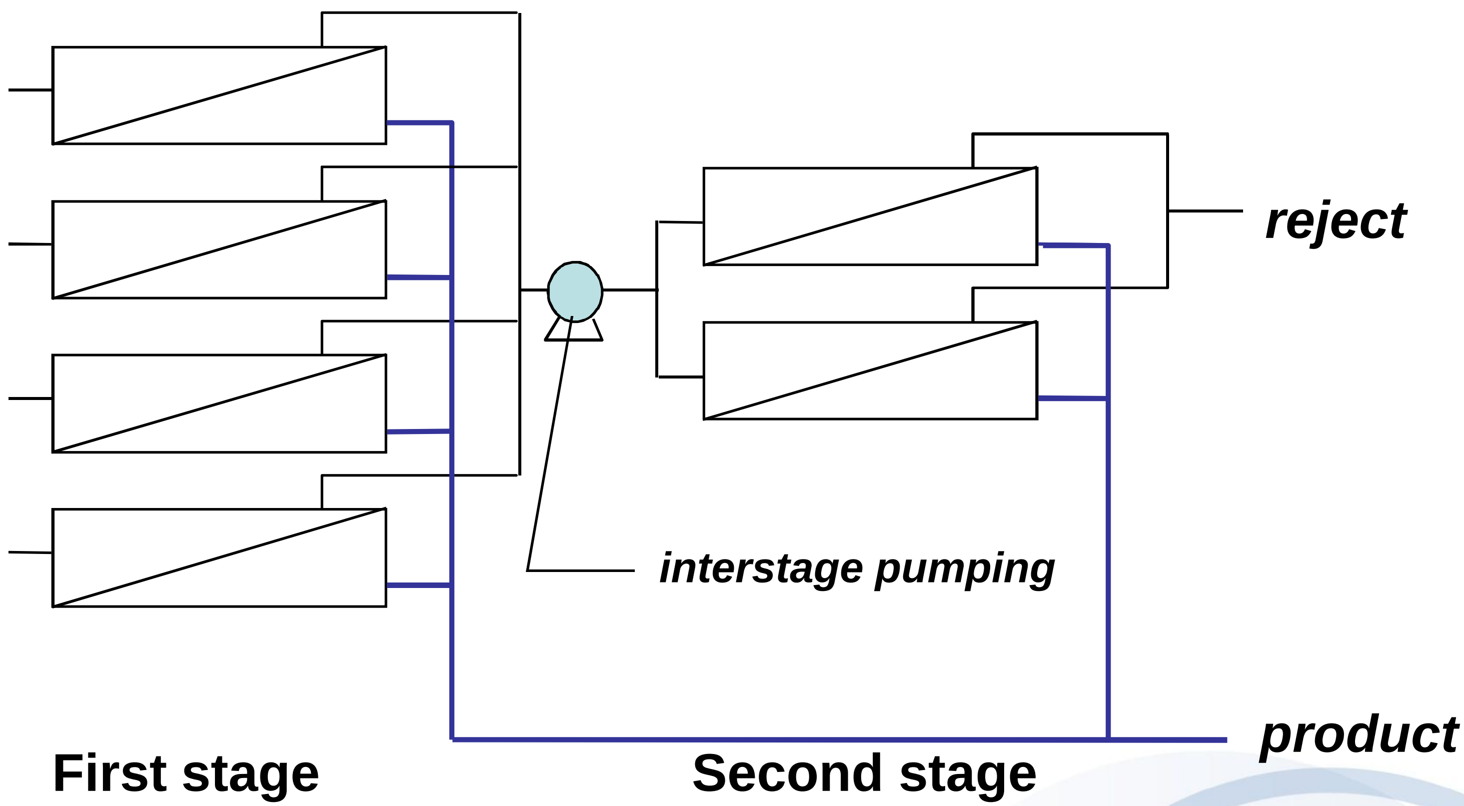
- Individual RO element can only achieve limited conversion
- Elements are linked to form a chain of 2-6 elements in an individual *module* (or *pressure vessel*):



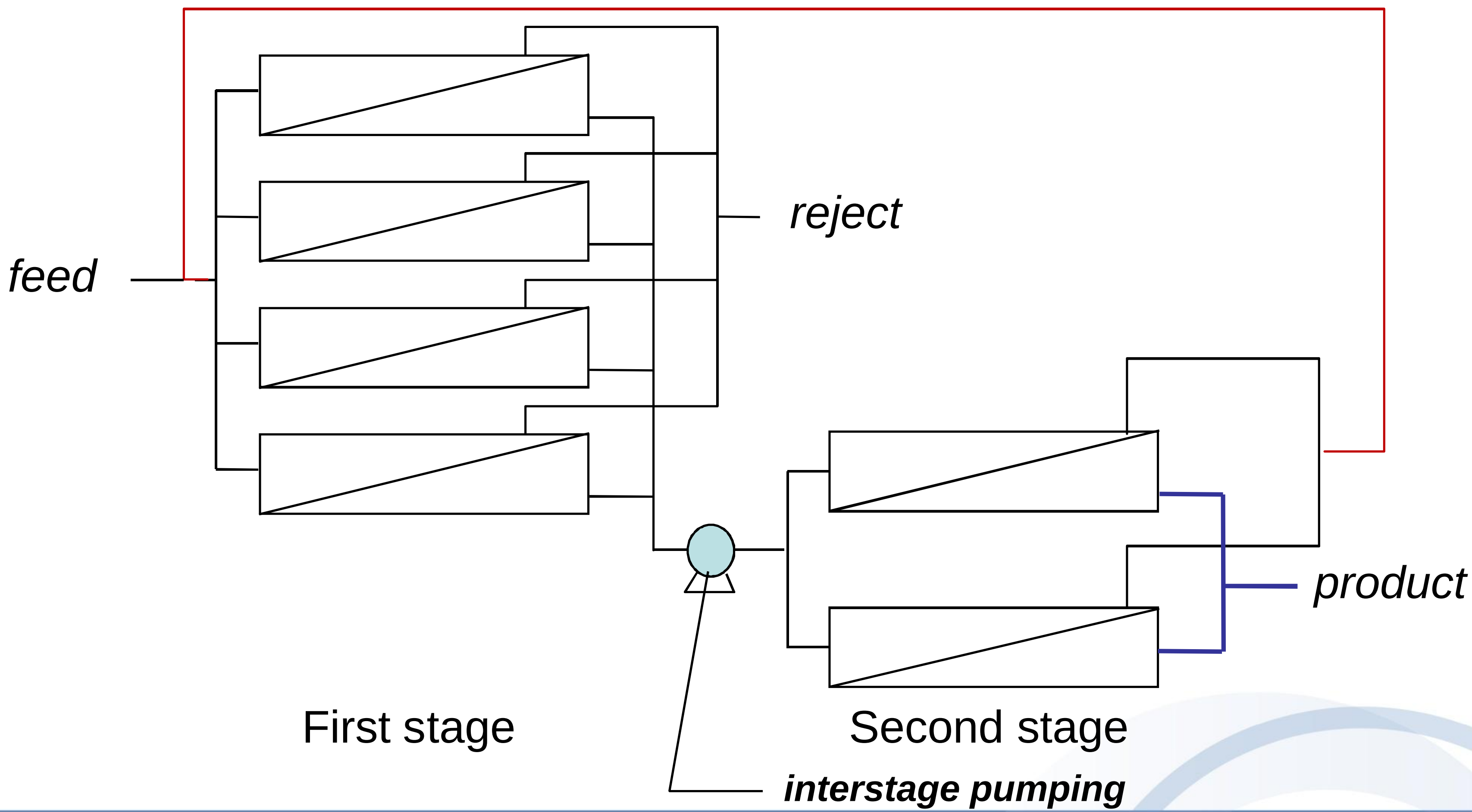
$Q_R = Q\ (1-\theta)^n$, where θ = conversion per element and n = no. elements

- As water travels along the module:
  - retentate flow rate decreases
  - retentate concentration increases
  - total pressure losses on retentate side increase
- This means that:
  - scaling propensity is highest at module outlet
  - hydraulic loading is highest at module inlet
    - retentate pressure gradient is thus also greatest at inlet
  - permeate flux is lowest at the outlet
- When outlet flux gets too low, *staging* is employed

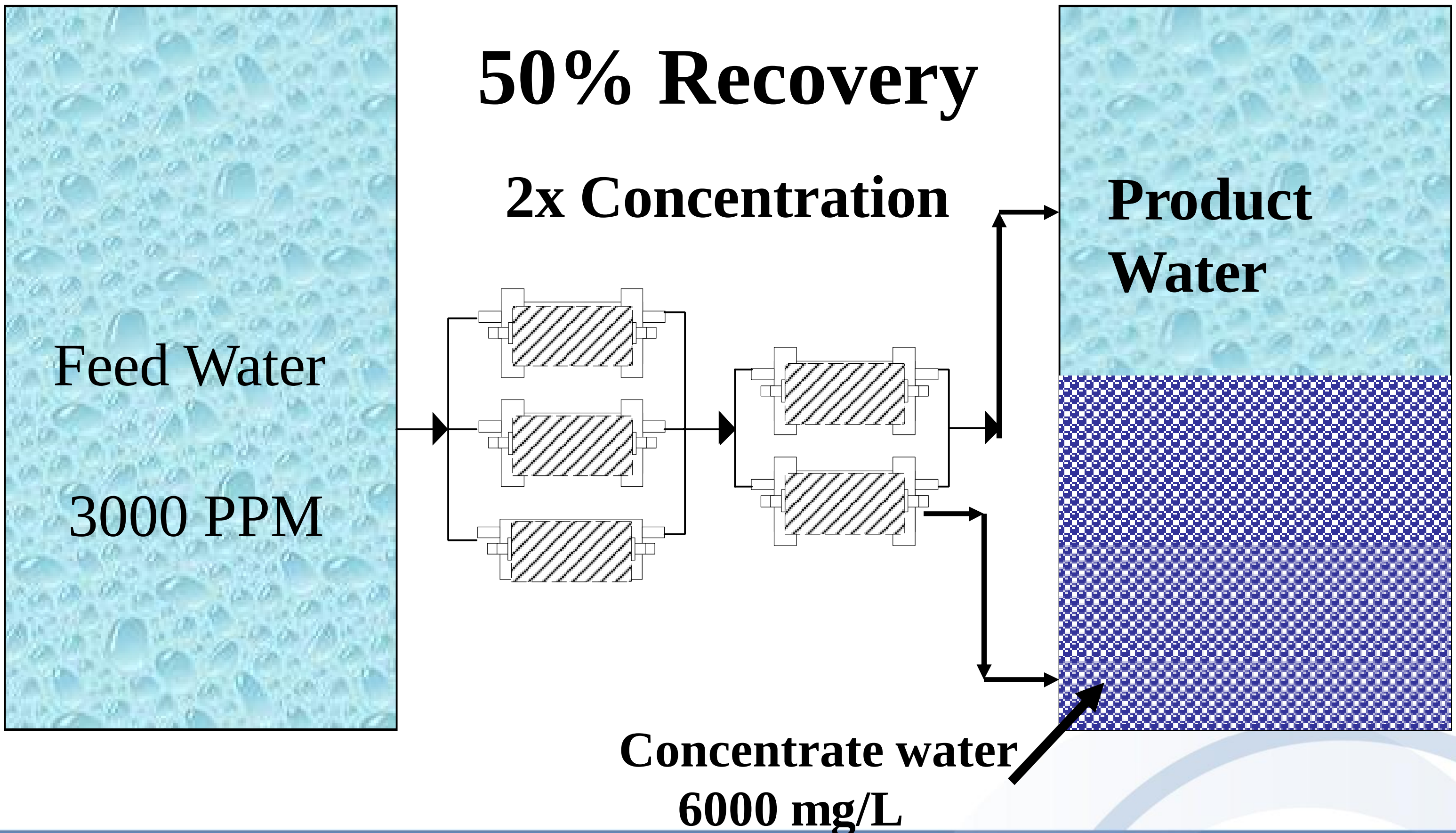
RO design: retentate staging



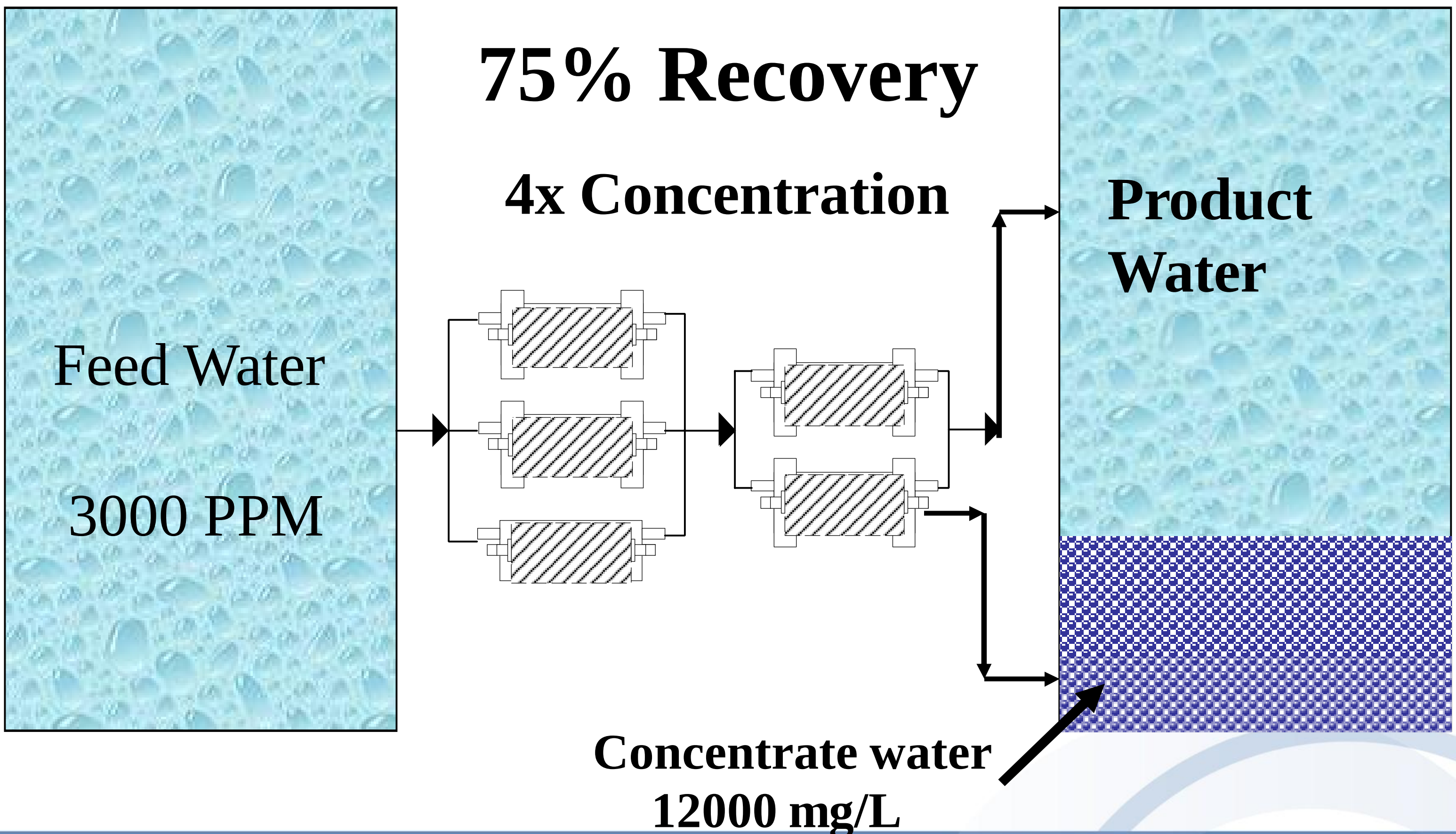
Twin pass system



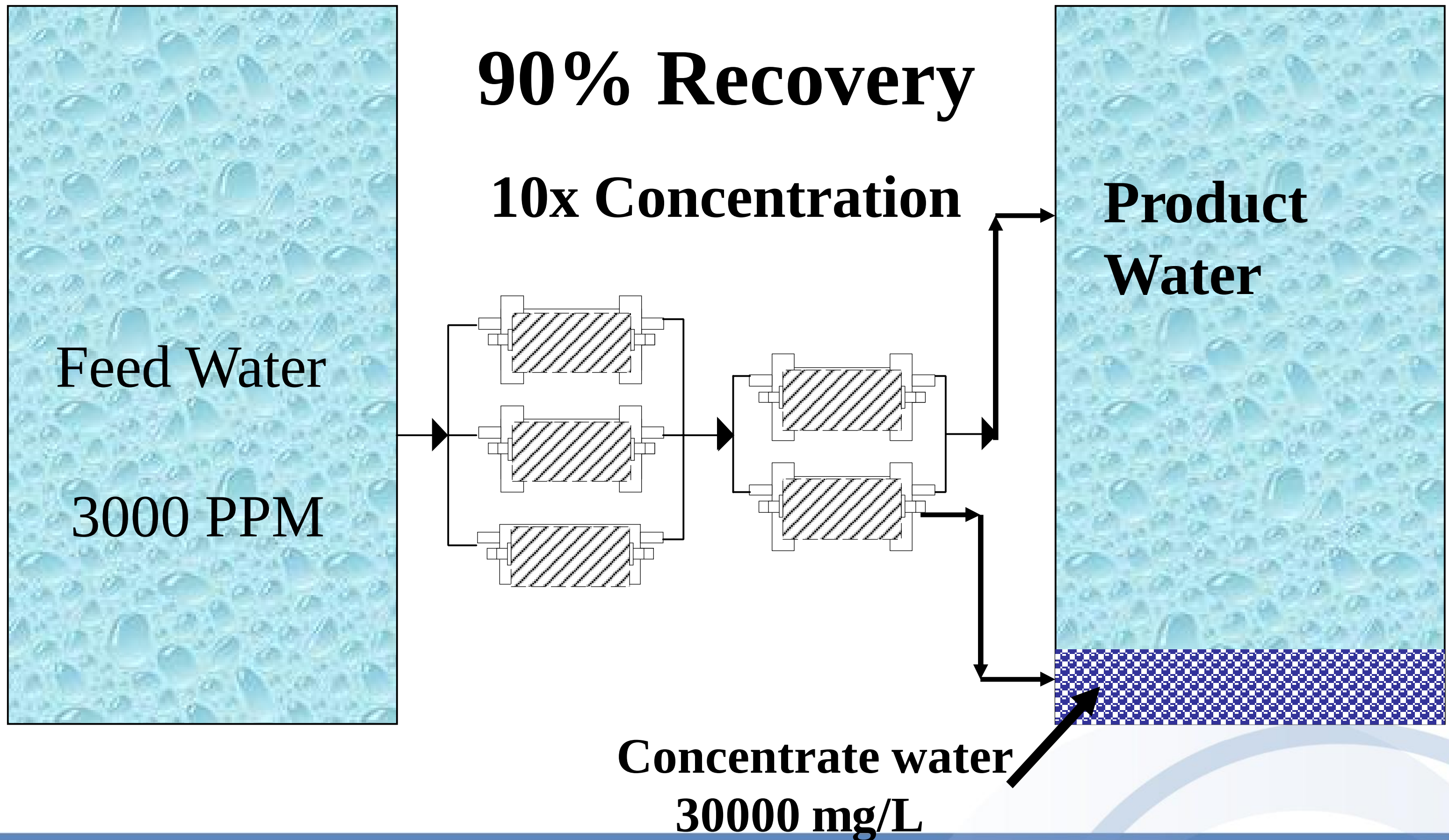
Concentration Factor



Concentration Factor



Concentration Factor



Flux, conversion and pressure: summary

- High fluxes tend to:
  - increase conversion, which
  - increases concentration factor (CF)
  - increases concentration of species at membrane solution interface (i.e. concentration polarisation), which
  - increases osmotic pressure, and also
  - promotes precipitation of sparingly soluble species, both of which
  - increase the hydraulic resistance
- Also, high flows can:
  - Hydraulic overloading takes place at the front of the module, which
  - causes pore plugging.

All of which means that

.. you can only go so far:

Fouling and cleaning

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Membrane fouling

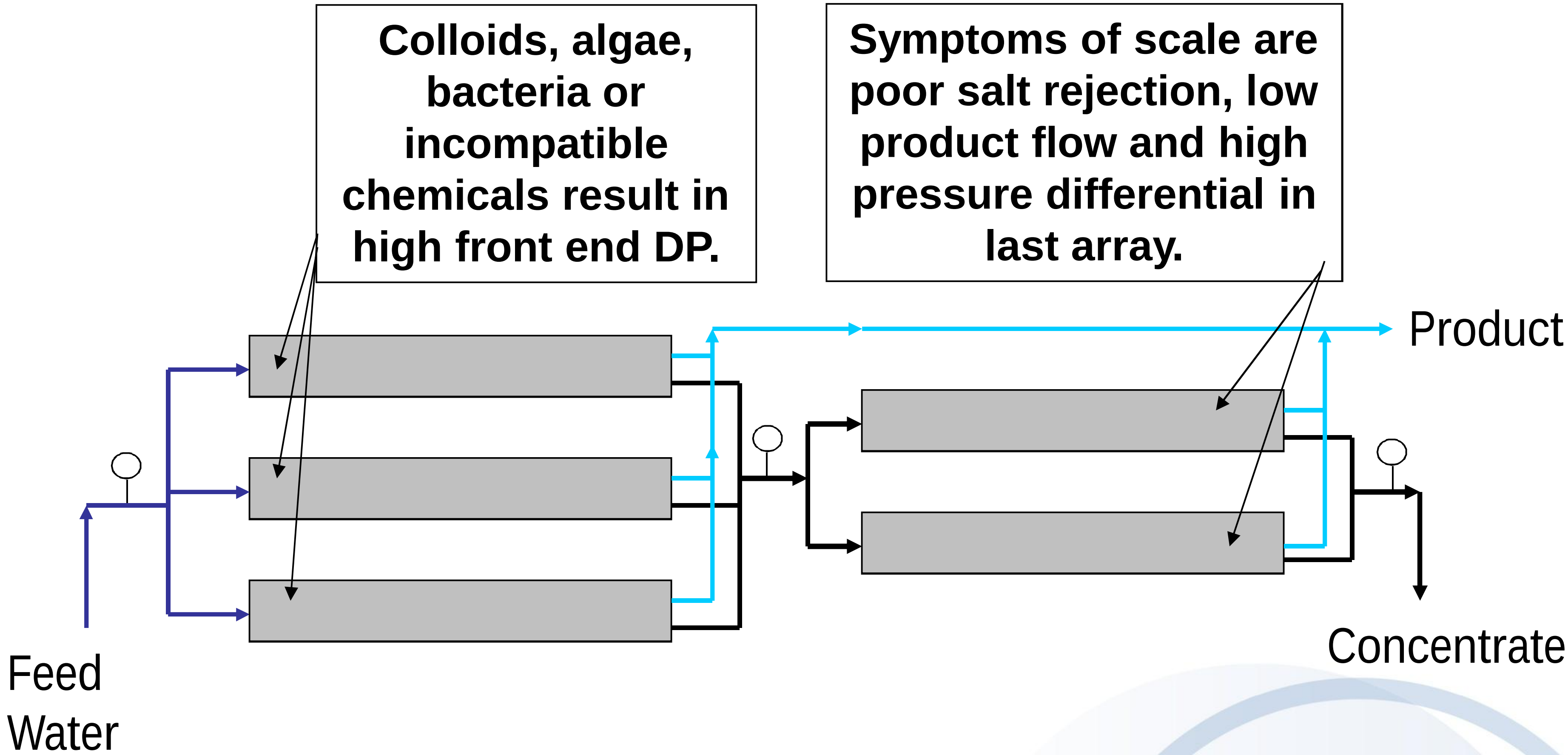
- Suspended solids
- Colloids (turbidity)
- Organics
- Precipitation - scaling
- Biological - bacteria




Scale

- Sparingly soluble inorganic salts, e.g.
  - calcium carbonate
  - calcium fluoride and phosphate
  - sulphate salts of barium, strontium and caesium
  - magnesium hydroxide
  - active silica
- Normally builds up in the last element
- Can be identified in the last stage by:
  - increase in TMP
  - increase in salt passage
- Normally be seen in the vessels and concentrate pipework.
- Demands care when cleaning

Localised fouling

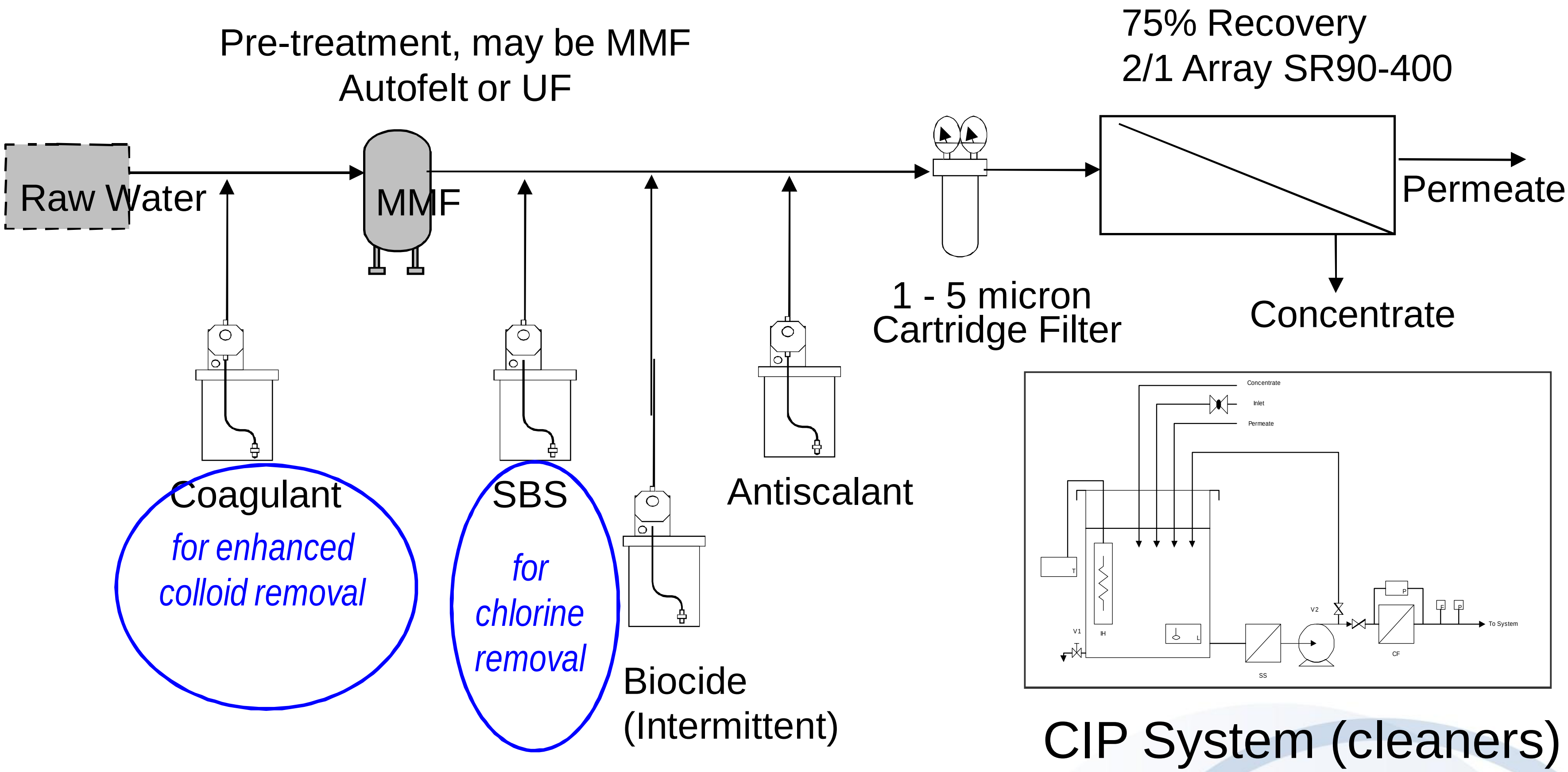


Fouling amelioration

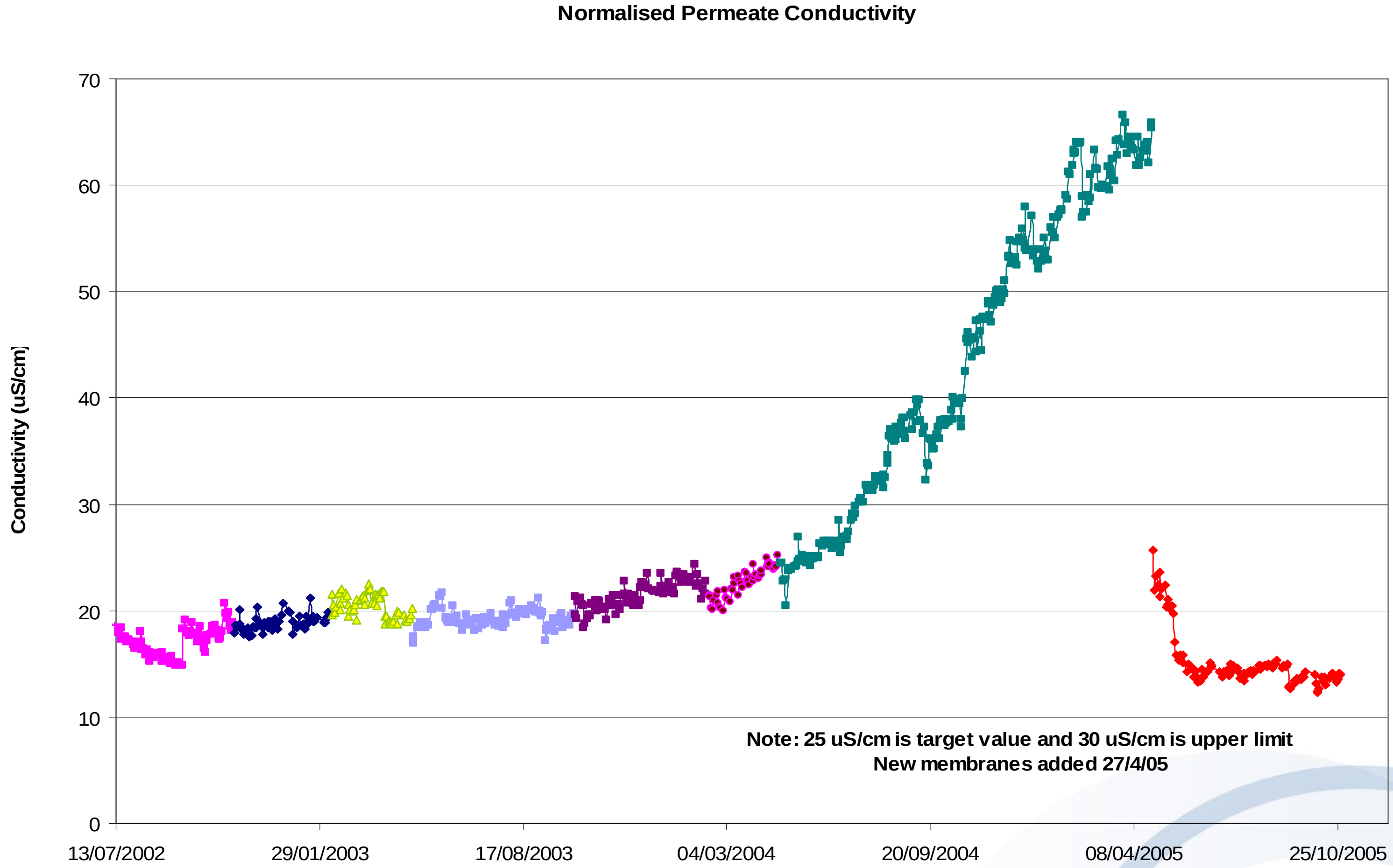
- Suspended solids (e.g. sand) and colloids
  - Pretreat: remove by filtration
  - Colloids most effectively removed by UF
- Organics
  - Pretreat using UF or media filtration if colloidal
  - Pretreat using GAC if dissolved
- Inorganic scalants
  - Chemical dosing:
    - mineral acids
    - antiscalants
- Biological
  - Periodic/seasonal dosing with bespoke chemicals

Pretreatment

Classical RO/NF flowsheet



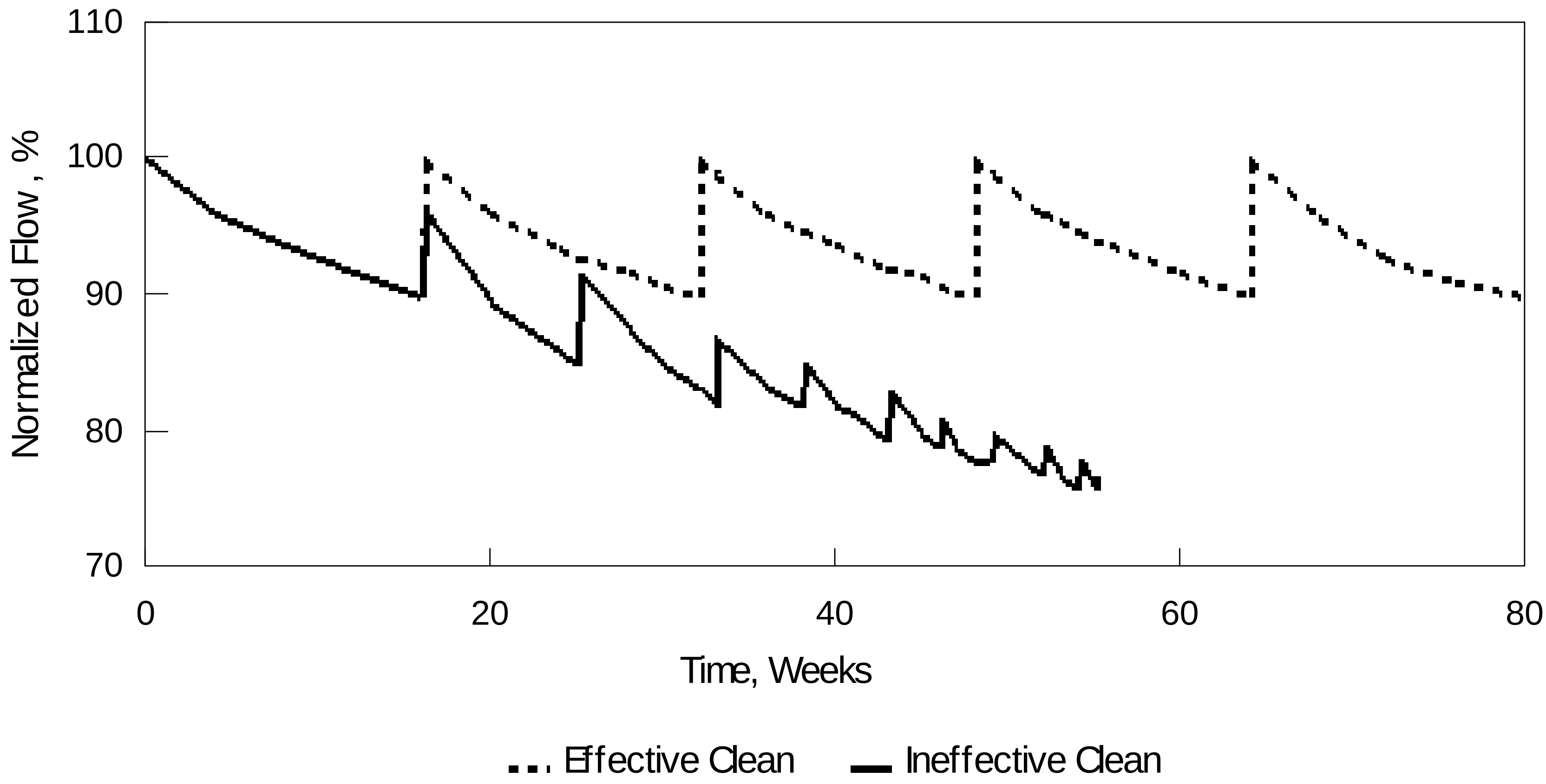
Membrane integrity: oxidative damage



Membrane cleaning

- Fouling eventually leads to membrane damage and replacement without cleaning
- Simple replacement is not cost effective

Membrane cleaning



Guidelines for cleaning initiation, Dow

- 10-15% reduction in normalised flow
- 15% increase in normalised feed pressure
- 15% increase in pressure differential (“DP”)
- 10% increase in salt passage

When/why to choose RO vs. IEX?

When/why to choose RO vs. IEX?

Comparison of (i) IEX vs. (ii) RO with IEX mixed bed polish
Surface water: 50-200 m3/h; outlet quality <1 µS cm^{-1}

- 70-80 % of cost is operational
- For IEX cost to produce water increases with TDS – due to regen. chemical costs
- RO system costs (capex and opex) less sensitive to salinity increase
- At higher IEX scales, whilst chem demand increases, EOS reduce
- BEP for favourable RO/IEX is 7-8 eq m^{-3} (~400 ppm $CaCO_3$)
- Decision sensitivity to local chemical cost for IEX, power consumption for RO
- Selection of source water impacts economics as does reject disposal (greater impact on RO)

Summary of DOW Chemicals study, fur further information, see:
http://www.dowwaterandprocess.com/support_training/literature_manuals/ix_techinfo/ix_ro.htm

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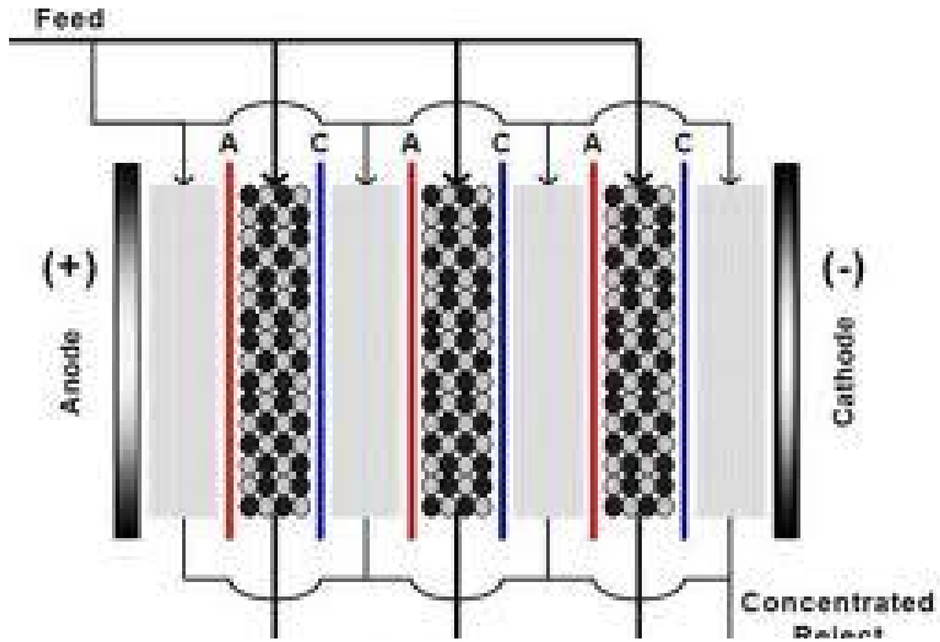
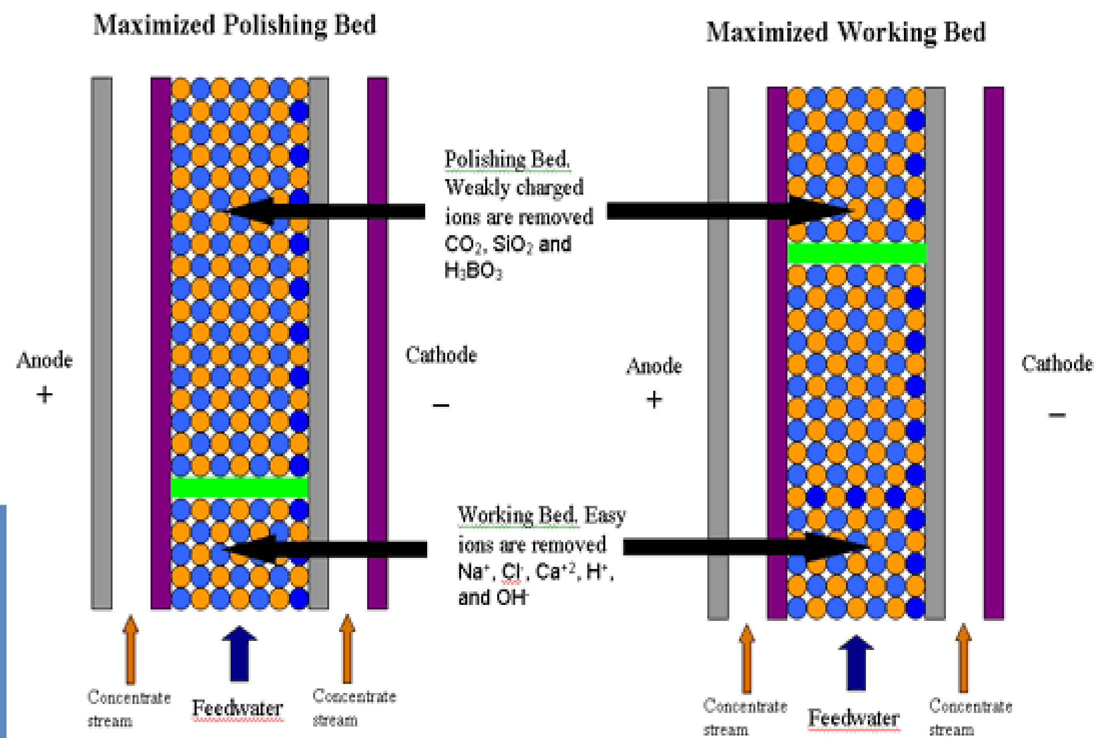
- Continuous deionisation
- Combines electrodialysis with ion exchange
- Displaces classical twin bed deionisation
- Can include polishing section





Units and skids

SW configured EDI (Dow)

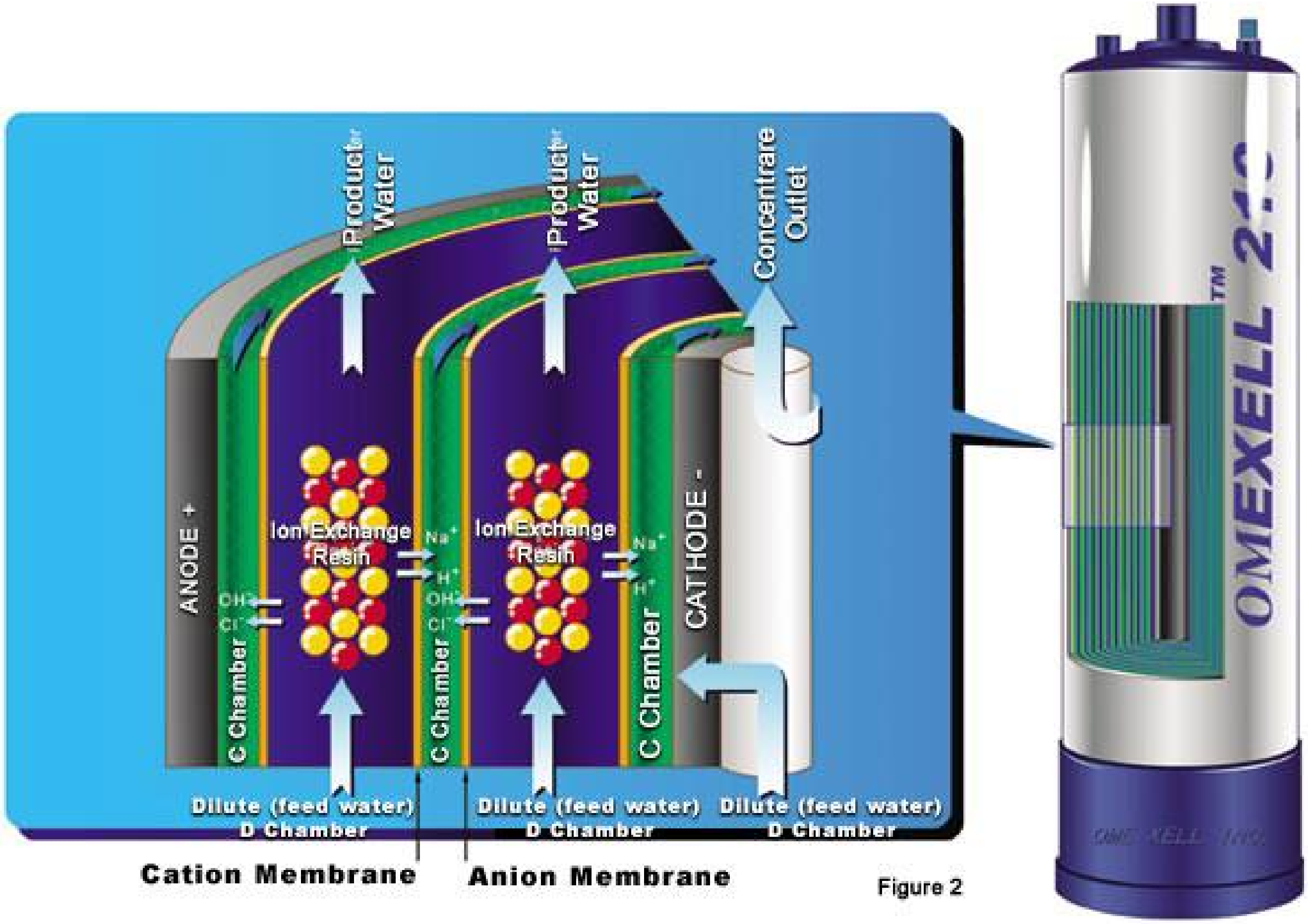


Figure 2

CDI vs twin-bed DI

Advantages

- Continuous
- Compact
- No risk of breakthrough:
  - Continuous regeneration
- Reduced ionic load in waste stream

Disadvantages

- More expensive

One more membrane...

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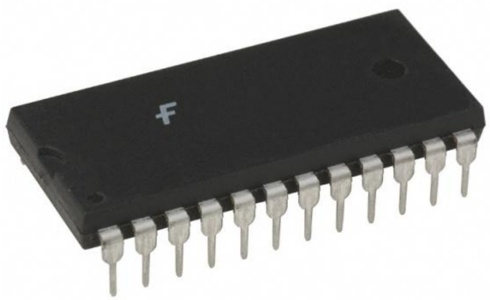
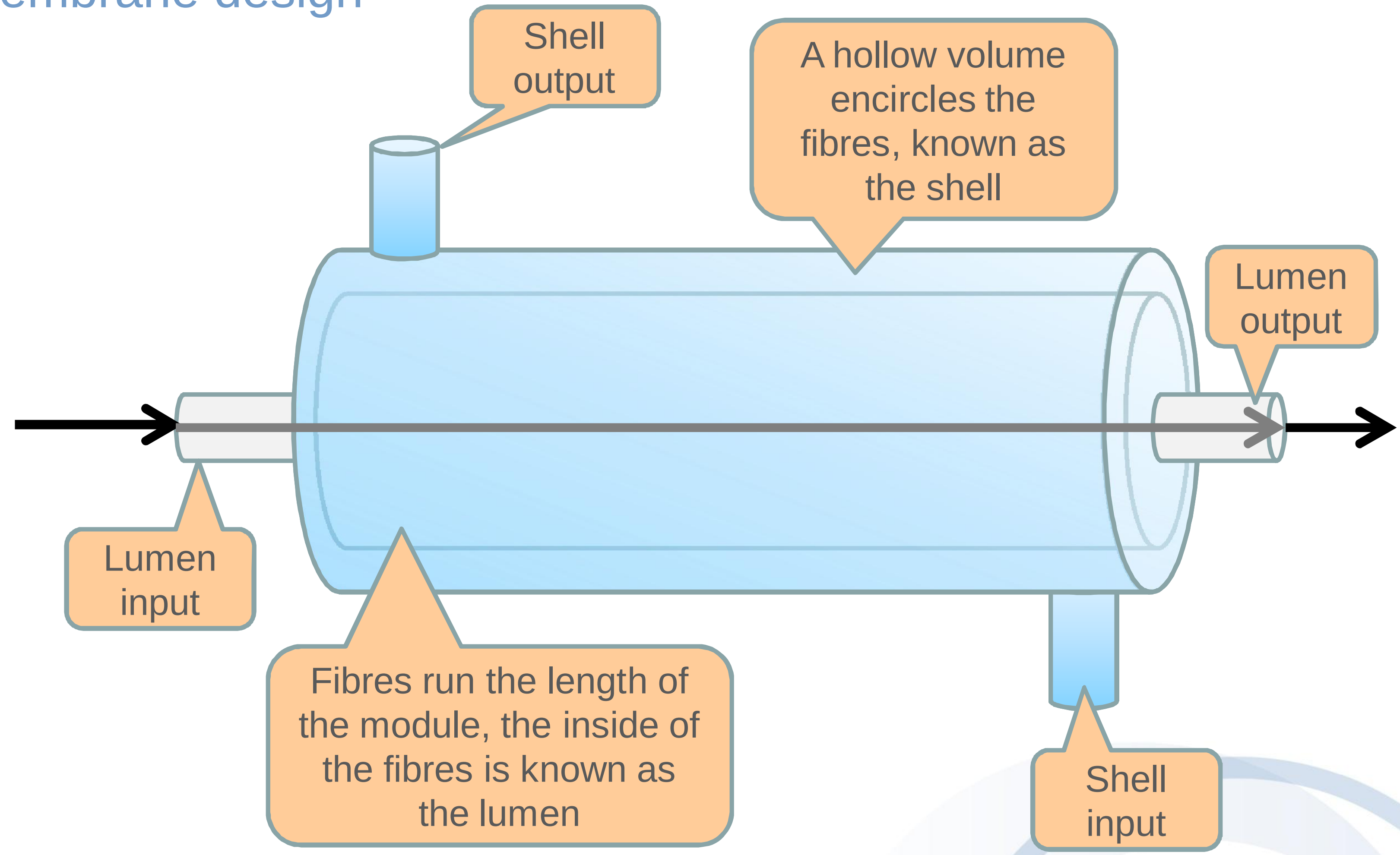
Development of membrane contactors

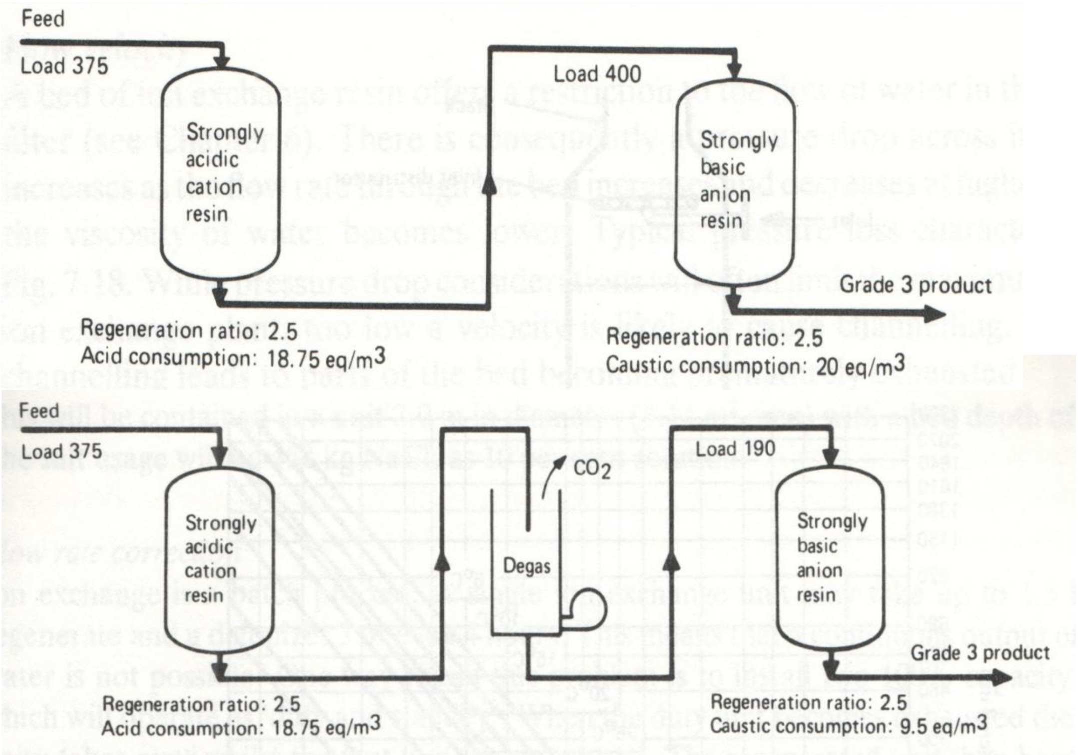



Membrane design



Membrane contactors for pure water IEX



$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^- \longleftrightarrow H^+ + CO_3^{2-}$

Low pH waters produce >free CO_2

Cation IEX exchanges H^+

Contactors vs. FDA for pure water IEX

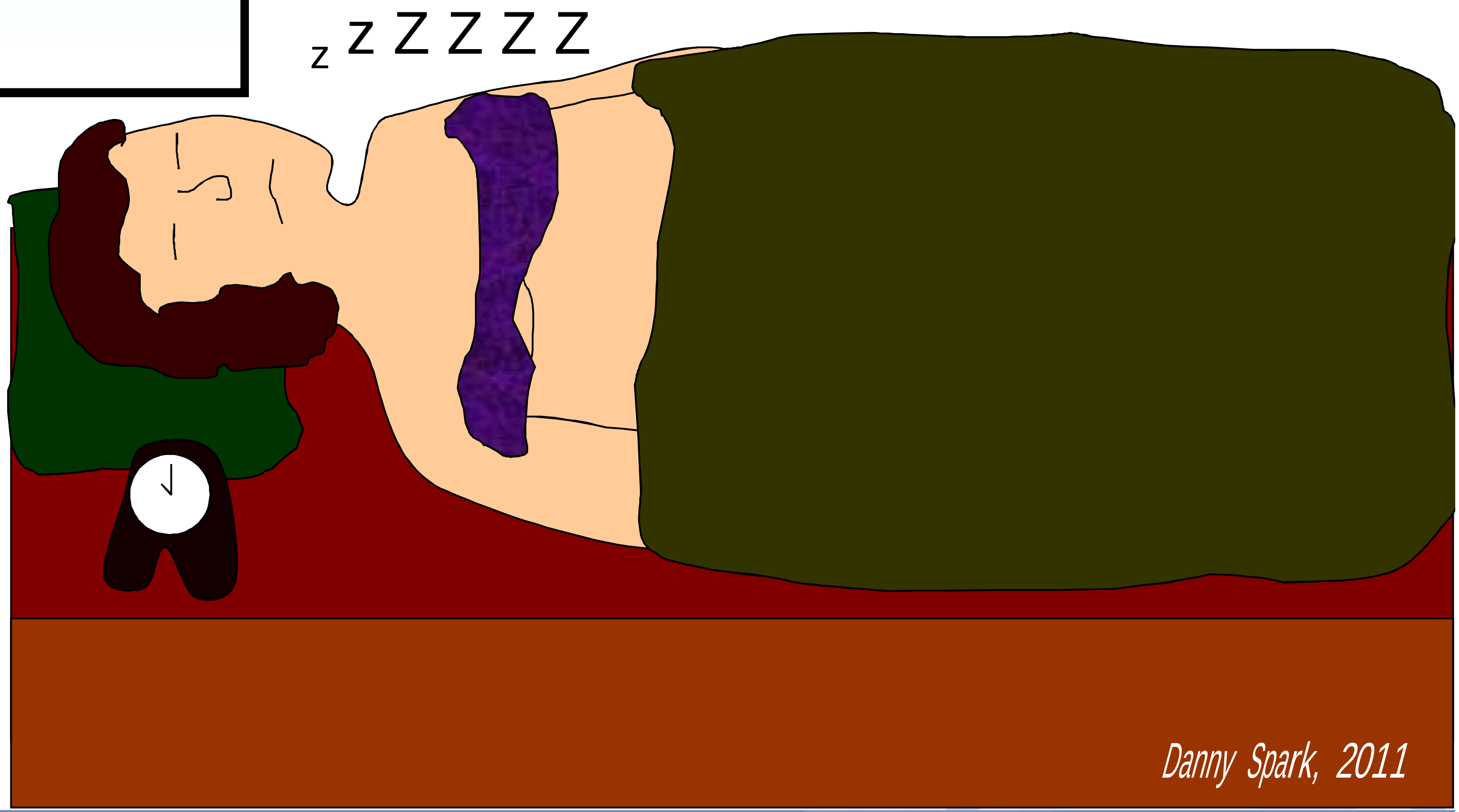
System Configuration	30% HCl Cons. (metric ton)	NaOH Cons. (metric ton)	Total yearly regen. (approx.)
Without CO_2 removal	1.416	0.516	£63,240
With CO_2 removal (FDA)	1.070	0.372	£46,649
With CO_2 Removal (MC)	0.842	0.278	£35,740

Q = 110 m3/h flow

- 180 ppm free CO_2
- 70% removal = 50% anion load reduction
- Footprint (FDA commonly 10 m height also)
- Mechanical energy

Summary of Liqui-Cel study, for further information, see: http://www.liqui-cel.com

THANK YOU FOR YOUR ATTENTION



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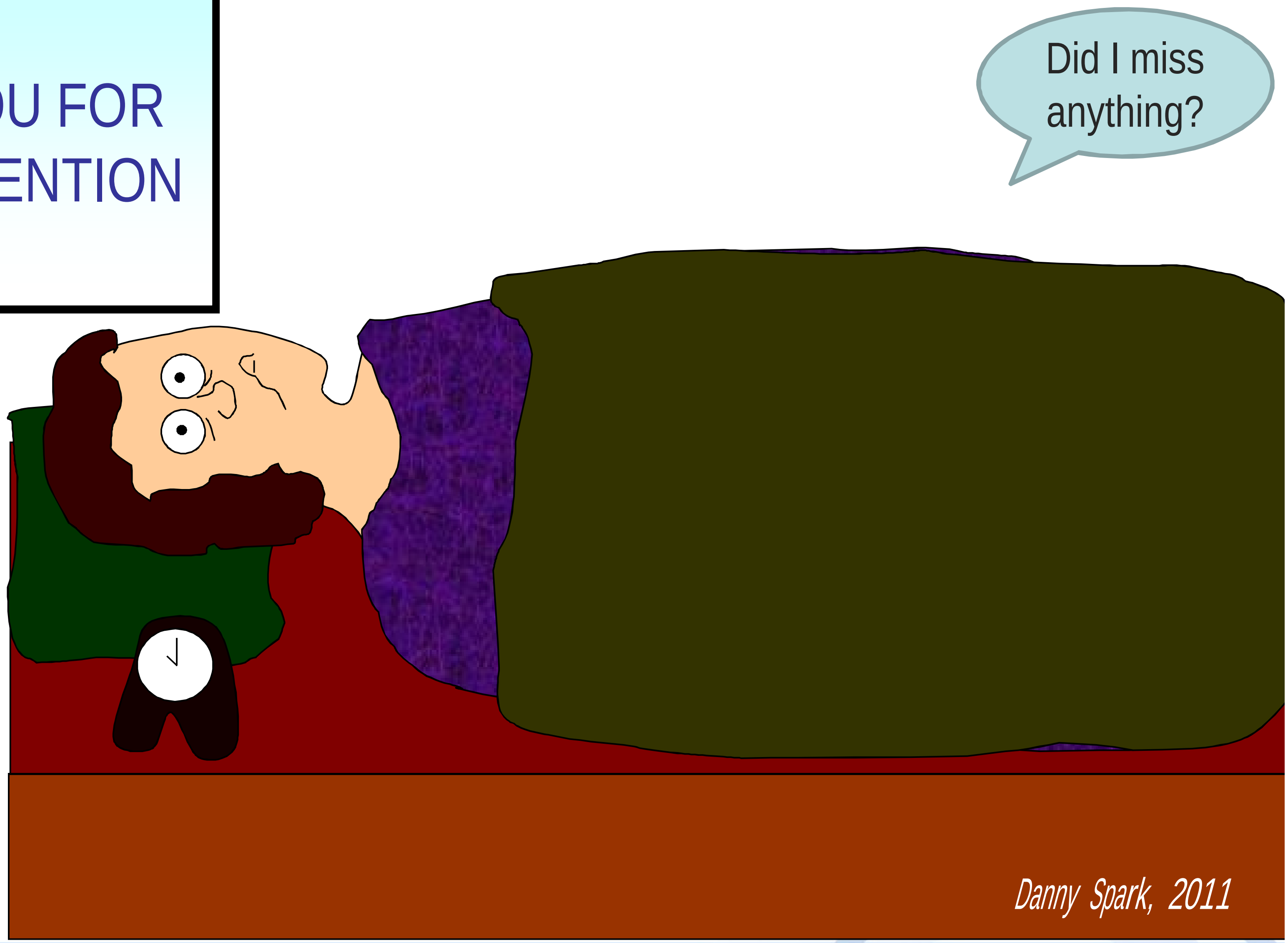

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