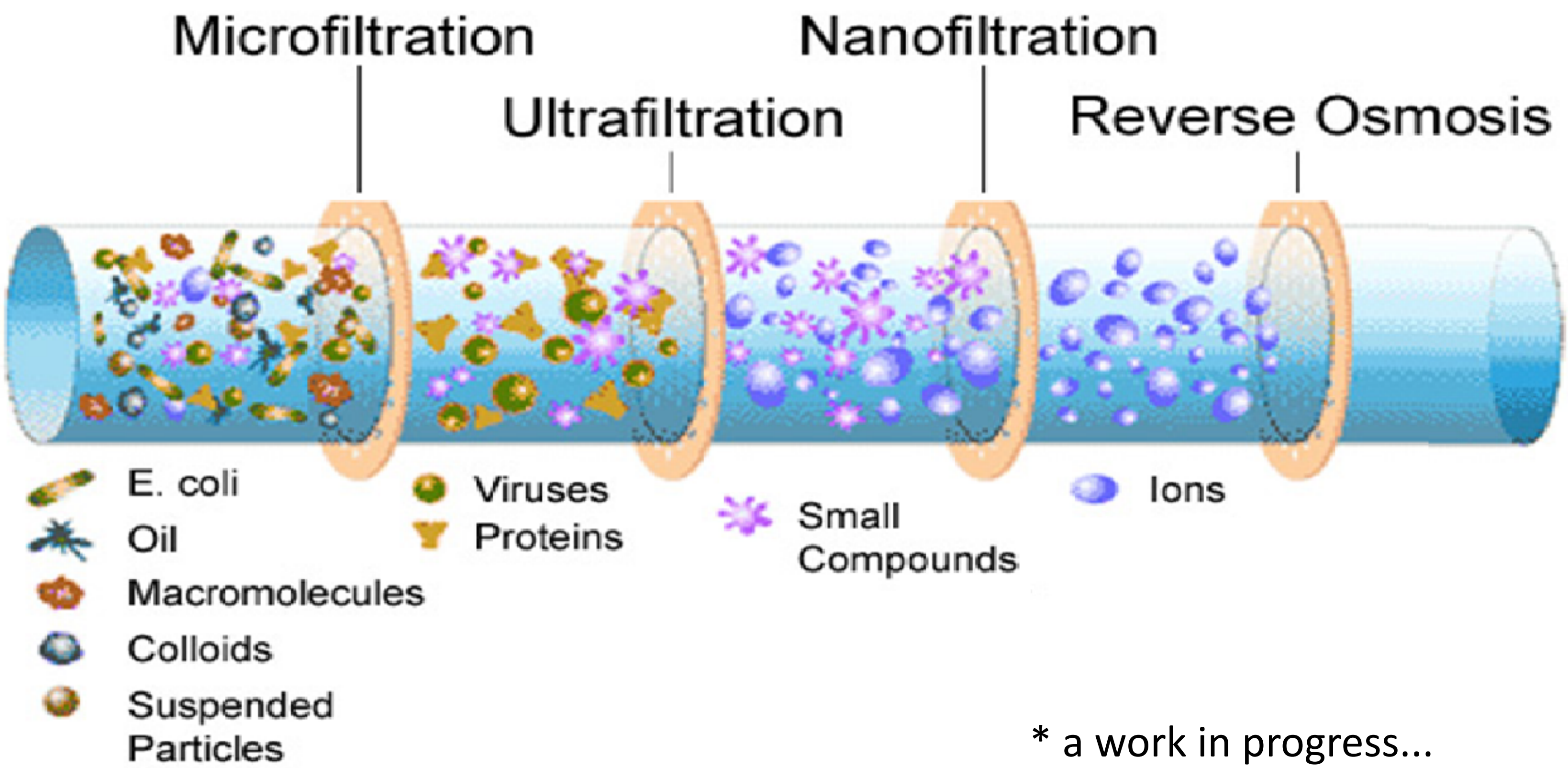
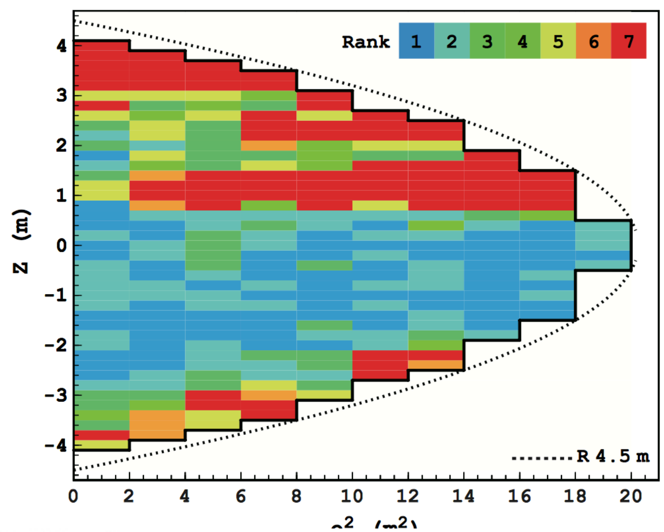
Getting Rid of Radiological Contaminants in Scintillator via Nanofiltration*

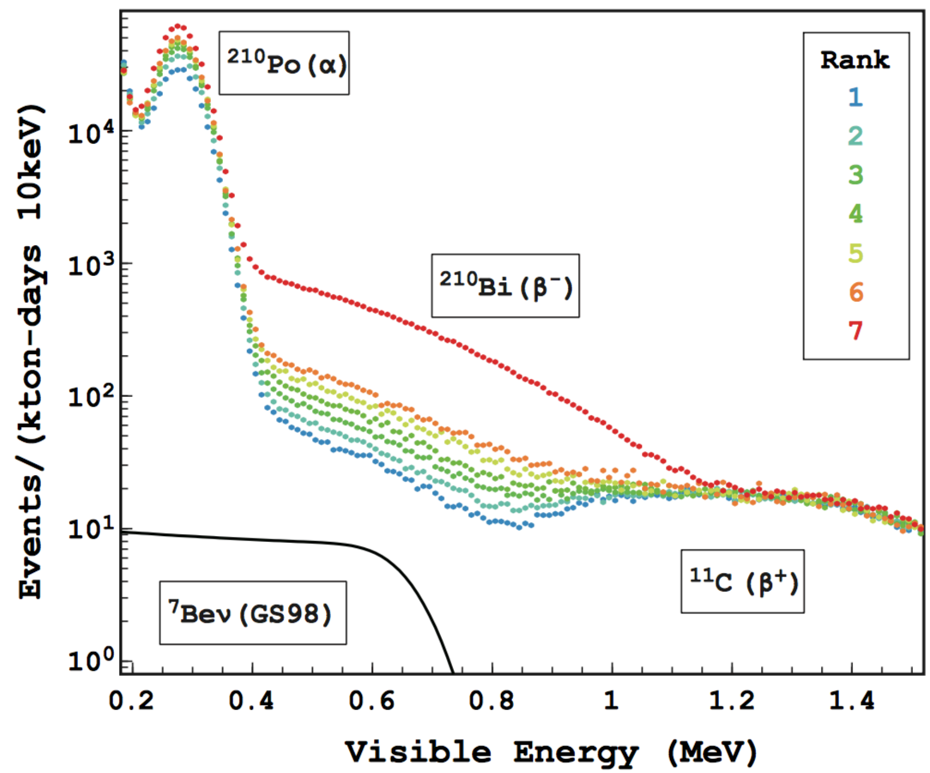


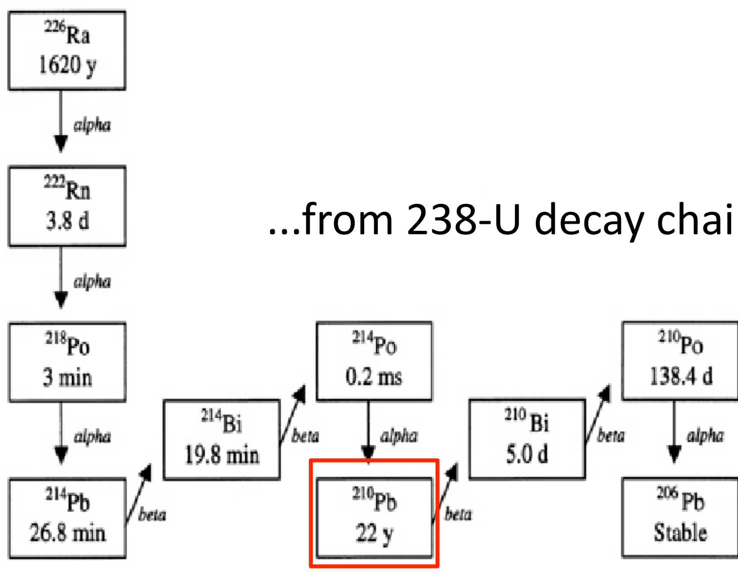
* a work in progress...

Background in KamLAND 7-Be Measurement

location of background in detector







...from 238-U decay chain

radon exposure leads to plating of 210-Pb on surfaces and near-surface

(11-C is cosmogenic and depends on muon rate)

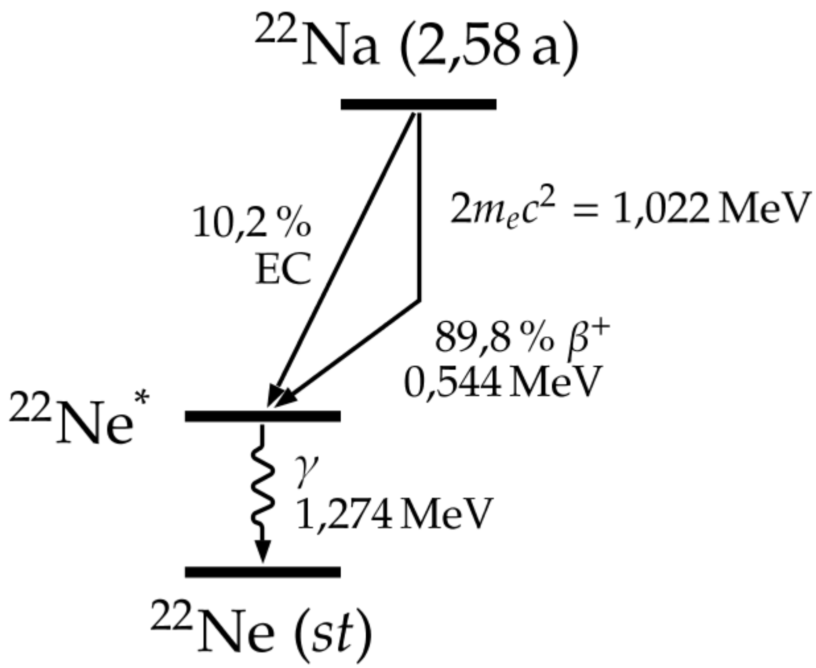
Radioactive Contamination of Liquid Targets is a real problem

210-Pb from radon exposure limits KamLAND solar neutrino measurements. Will also be a serious problem for SNO+

Alpha's from internal U/Th contamination are a serious background for low rate reactor experiments, relic SN neutrino searches, and geo-neutrinos (see KamLAND measurements)

$$\alpha + {}^{13}\mathrm{C} \rightarrow n + {}^{16}\mathrm{O}$$

Cosmogenic activation of sulfer in some LS components (especially surfactants) can lead to 22-Na contamination.



This can be uncomfortably close to neutrinoless double beta decay endpoints

There is also some evidence that optical transparency in some scintillators is limited by dimerism of basic components during manufacturing.

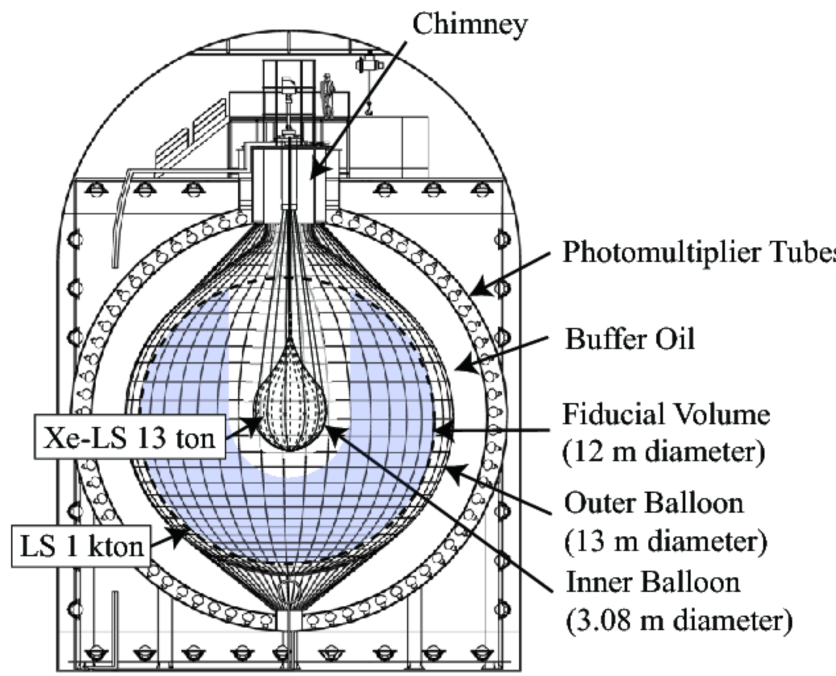
Essentially, two (or more) large organic molecules get joined together to make a larger molecule with adverse optical properties.

Difficult to remove by standard techniques.

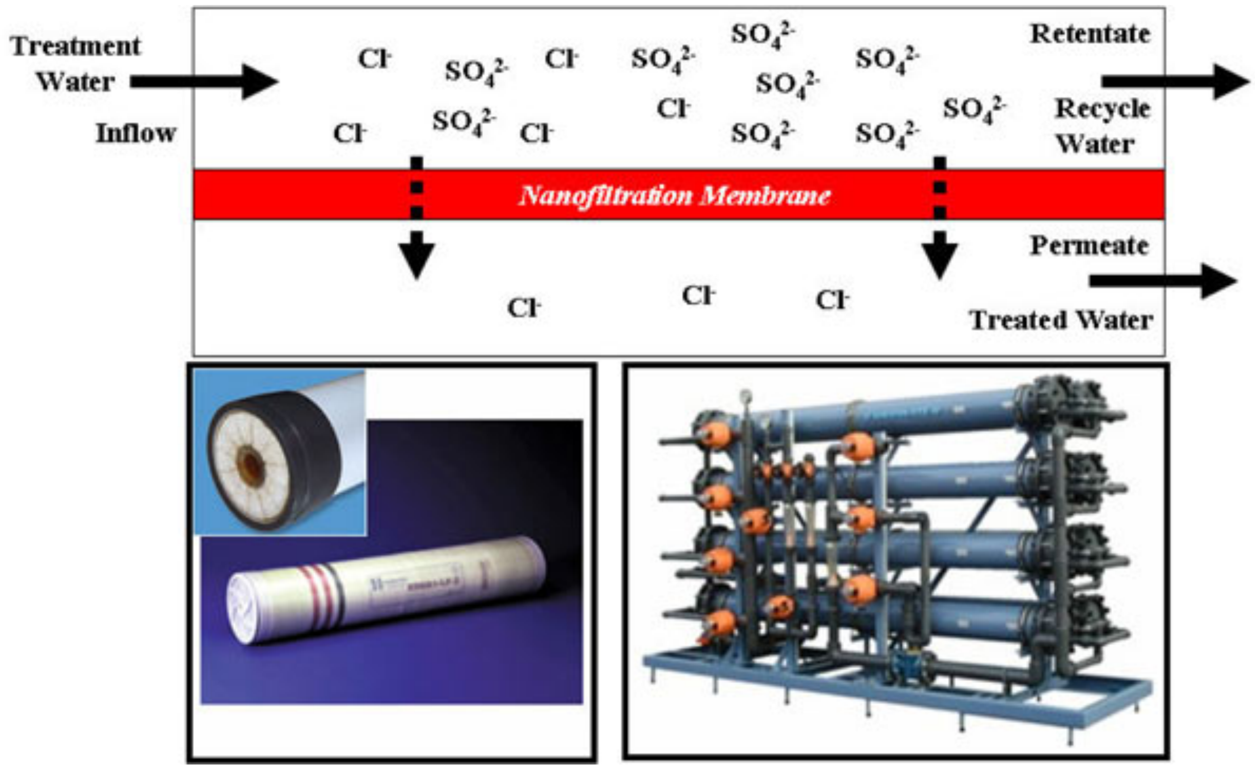
Getting rid of these contaminants has been handled by making expensive and complex distillation/scavenging plants. Problems in boiling combustible liquids underground and in scavenger regeneration.

Can we find a better way?

KamLAND



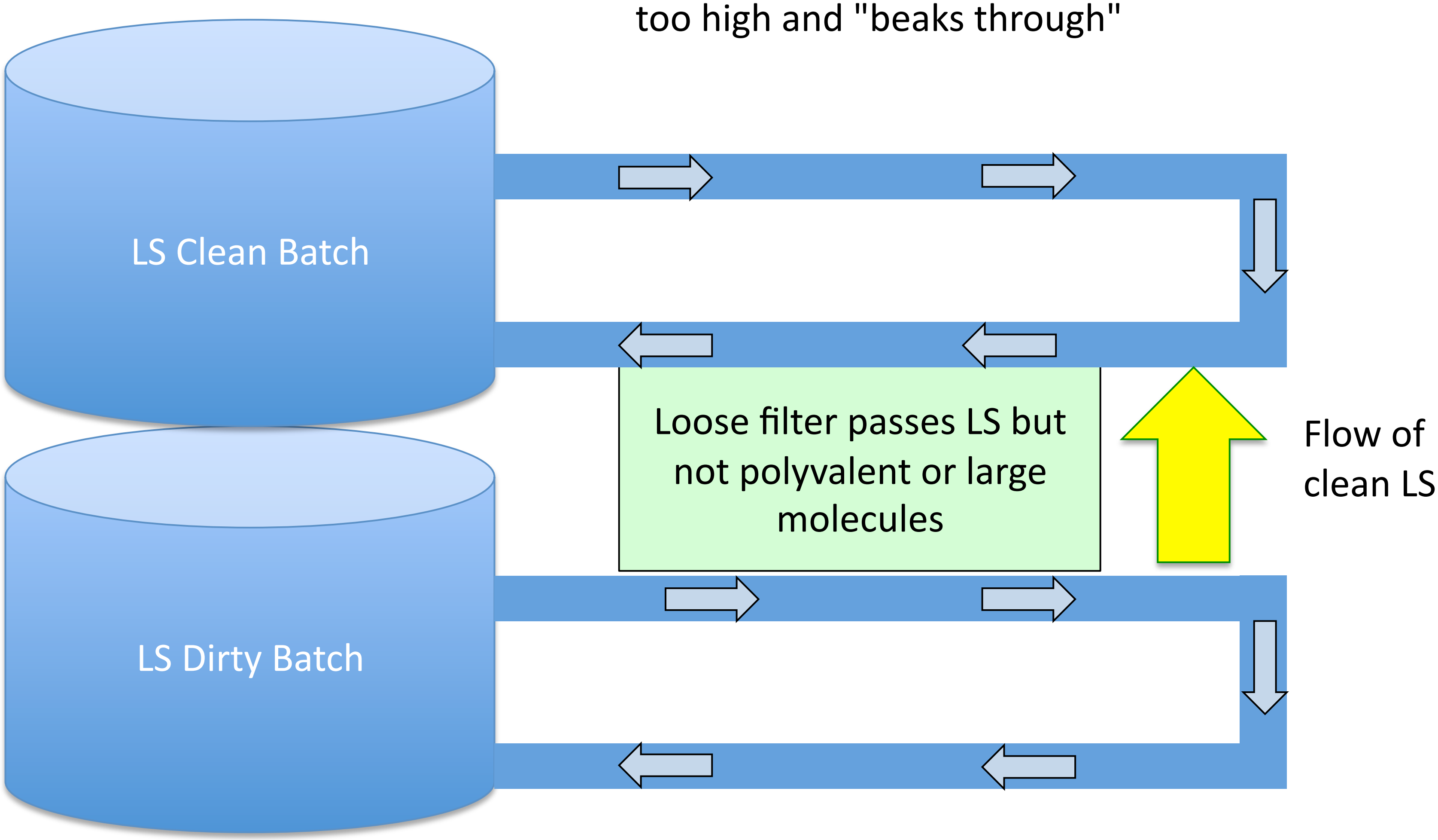
Nanofiltration of water is common, can it be applied to LS?



Two basic approaches...

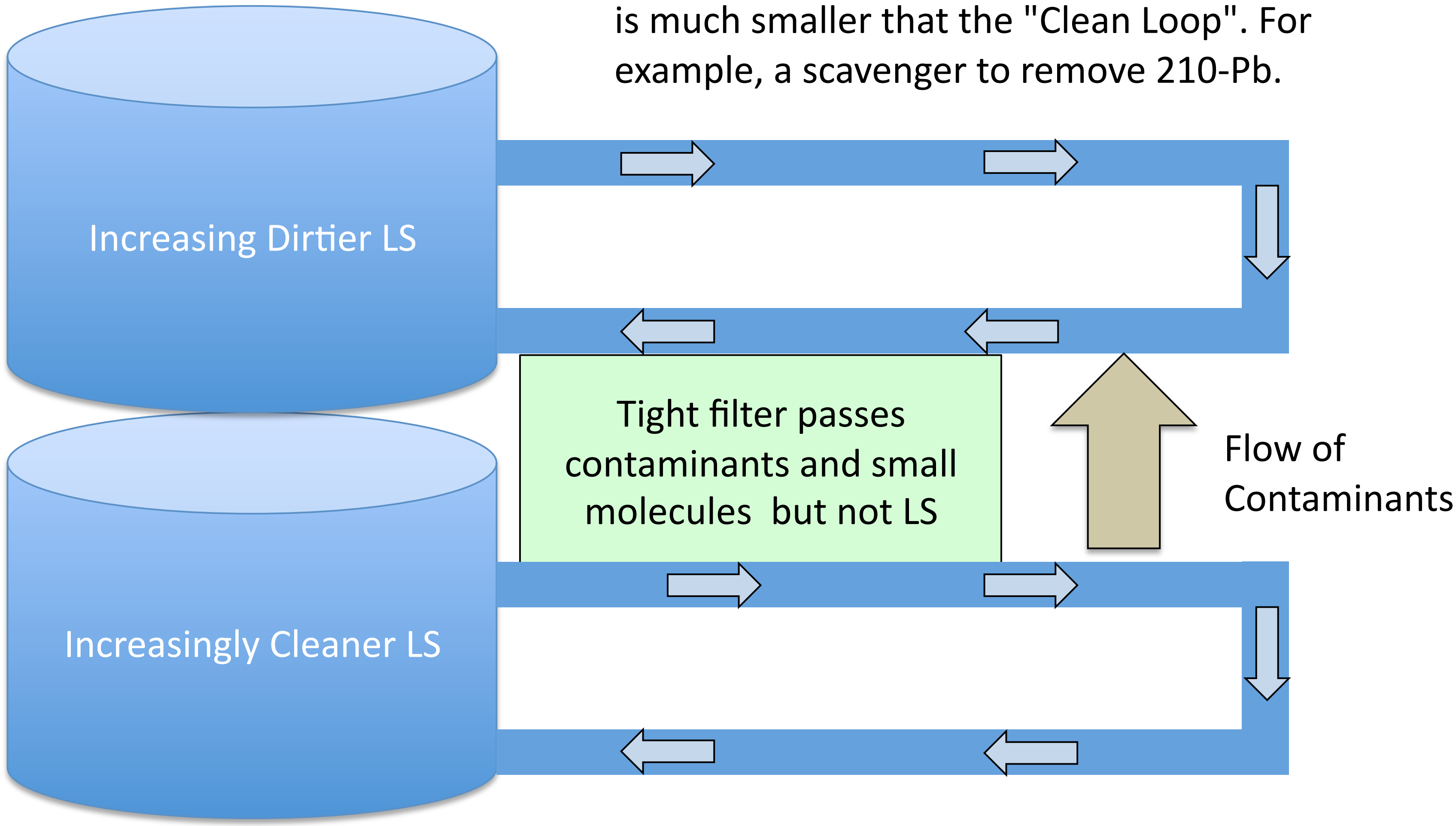
Loose Filter Approach

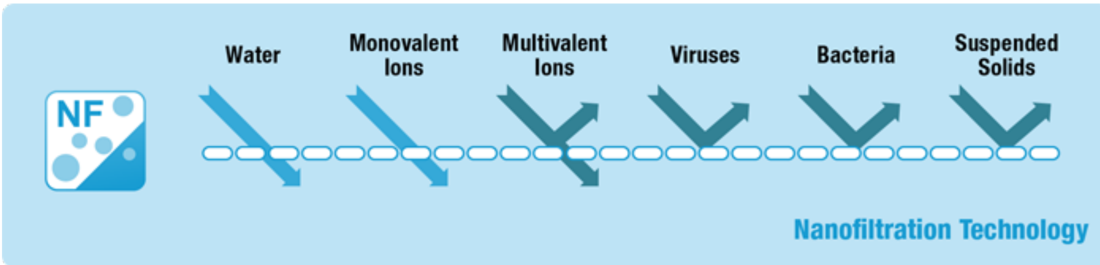
Need to reject Dirty Batch when contaminant concentration becomes too high and "beaks through"



Tight Filter Approach

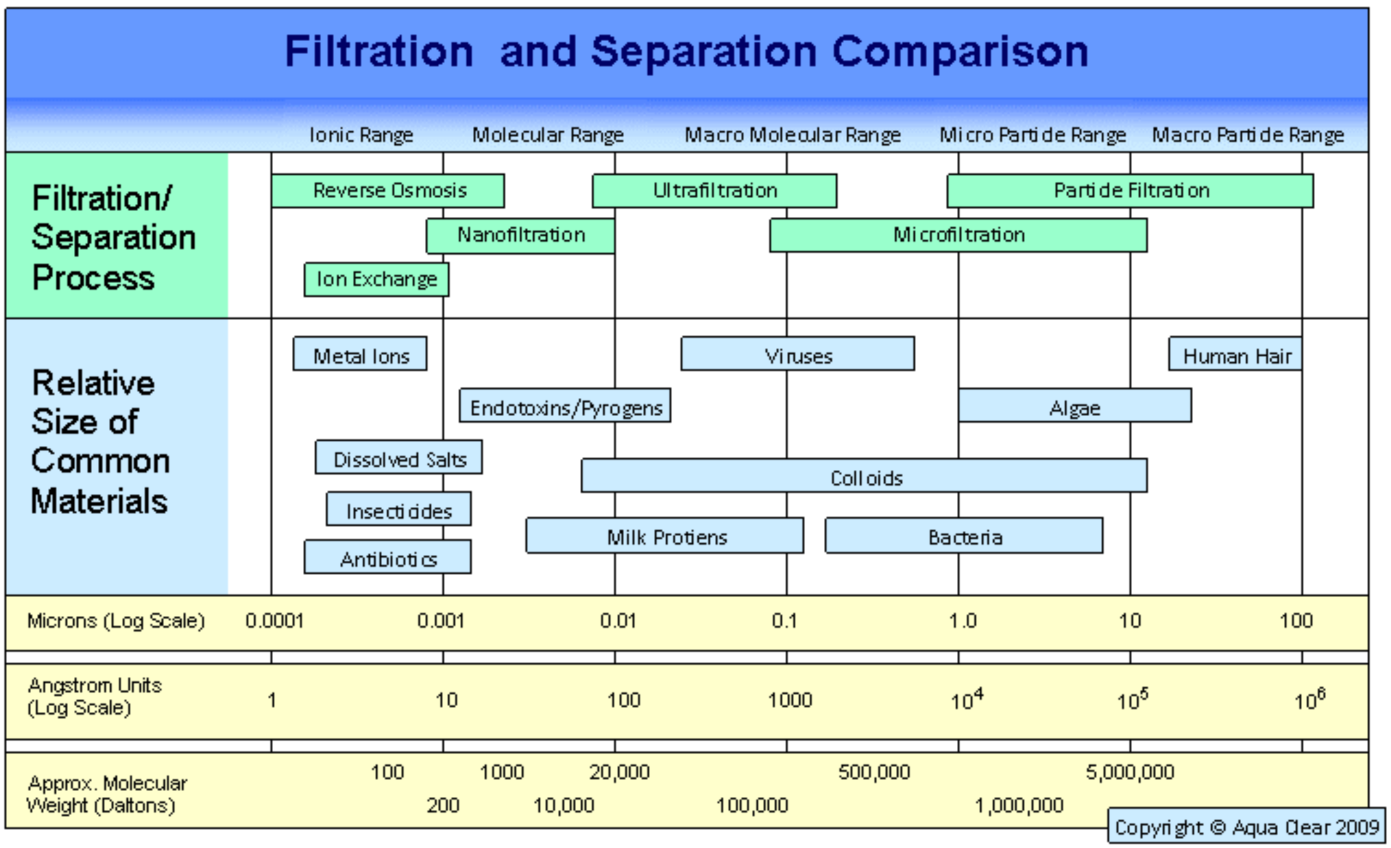
This has the advantage that the "Dirty Loop" could be cleaned continuously if the volume is much smaller that the "Clean Loop". For example, a scavenger to remove 210-Pb.





What filter to use?

Looks easy, just pick appropriate Molecular Weight CutOff (MWCO) for what you want to filter.



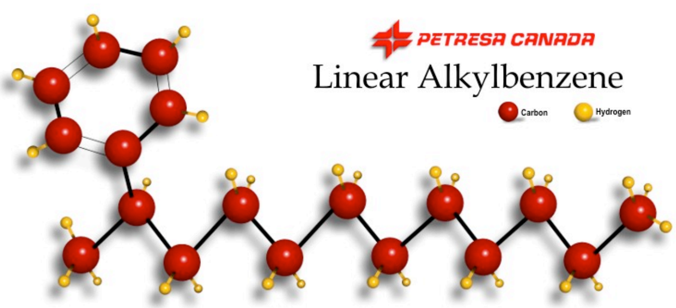
Molecule Lengths

Selected bond lengths

- C-H (single): 109 pm
- C-C (single): 154 pm
- C=C (double): 134 pm
- C≡C (triple): 120 pm
- C-O (single): 142 pm
- C=O (double): 122 pm
- C≡O (triple): 107 pm
- C-N (single): 147 pm
- C=N (double): 122 pm
- C≡N (triple): 111 pm
- C-F (single): 136 pm
- C-Cl (single): 176 pm
- C-Br (single): 191 pm
- C-S (single): 181 pm
- O-H (single): 96 pm
- N-H (single): 101 pm
- N-O (single): 145 pm
- N=O (double): 117 pm
- Benzene hexagon width from point to point: 280 pm

Selected Van der Waal's radii

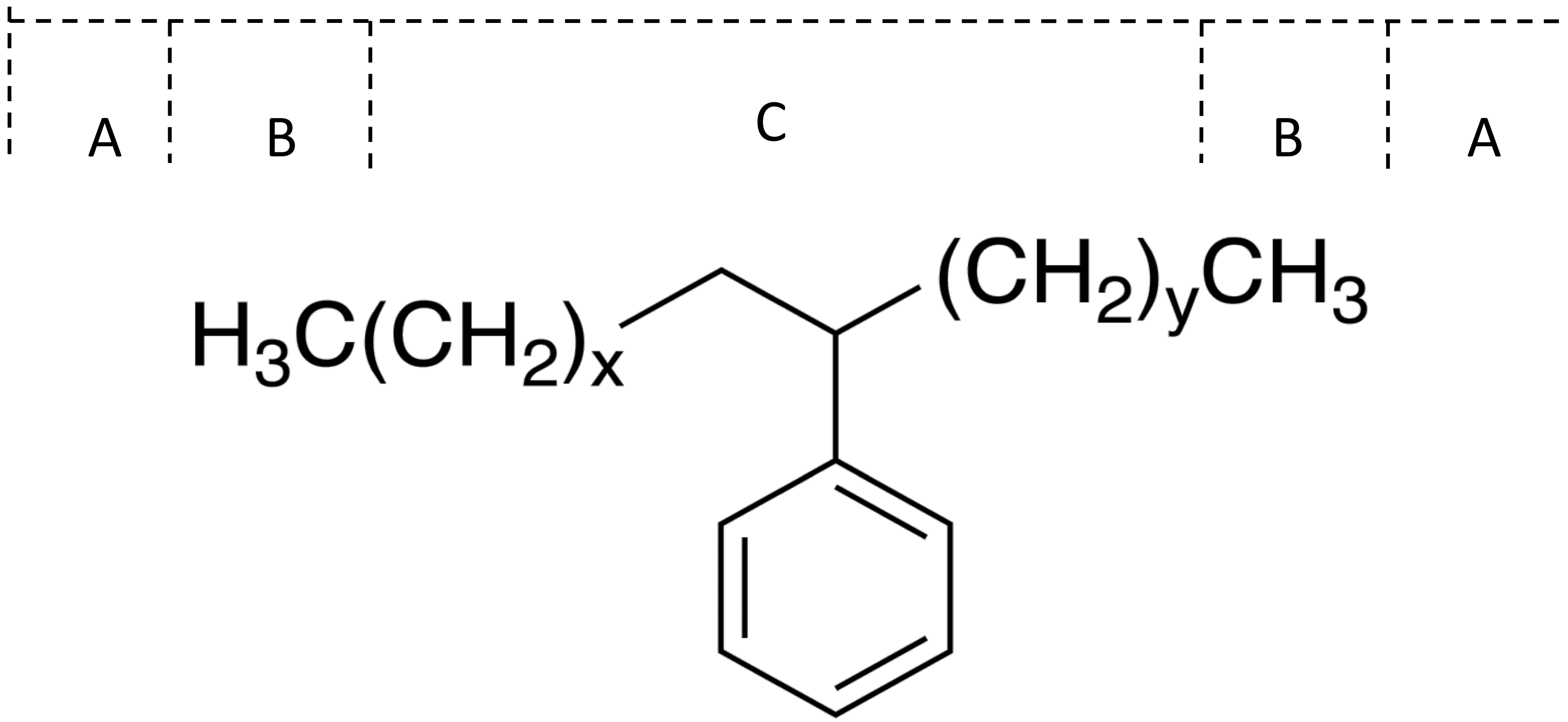
- H:120 pm
- CH_3:200 pm
- N: 155 pm
- O: 152 pm
- S: 180 pm
- F: 147 pm
- Cl: 175 pm
- Br: 185 pm



http://h2g2.com/edited_entry/A791246

LAB Carbon Chain Length

A=200 pm B=(0.82)(109)=89 pm C=(x+y)(109)=872 to 1526

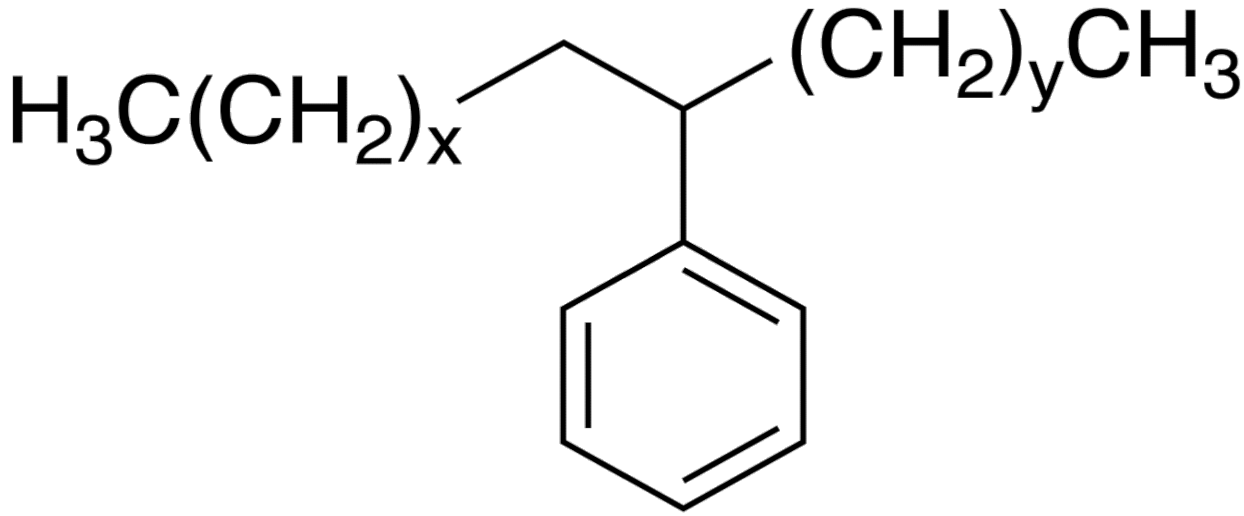


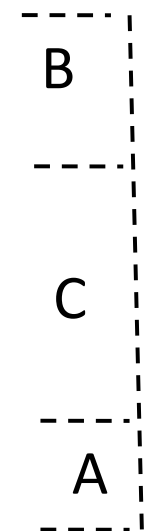
Length = 2(200)+2(89)+(872 to 1526) = 1.45 to 2.10 nm

LAB Benzine Ring Length

A=120 pm   B=109 pm   C=280 pm

Length = 120+109+280 = 0.51 nm



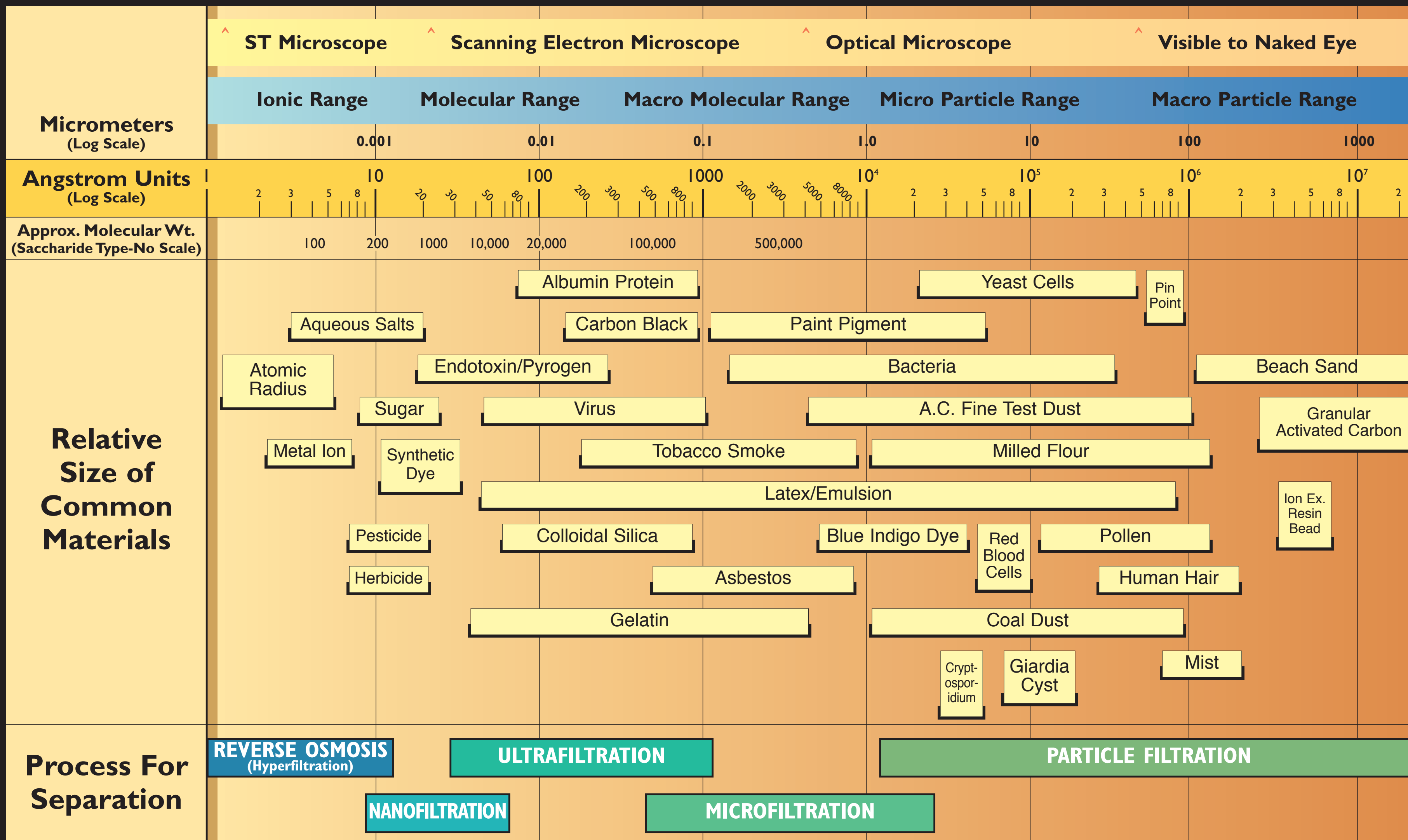


Total Length (estimate): 1.4 to 2.1 + 0.5 = 1.9 to 2.6 nm

Width estimate: 280 + 2(120) = 0.5 nm

OSMONICS

The Filtration Spectrum



Note: 1 Micron (1×10^{-6} Meters) ≈ 4×10^{-5} Inches (0.00004 Inches)
1 Angstrom Unit = 10^{-10} Meters = 10^{-4} Micrometers (Microns)

10 Angstrom Unit = 1 Nanometer

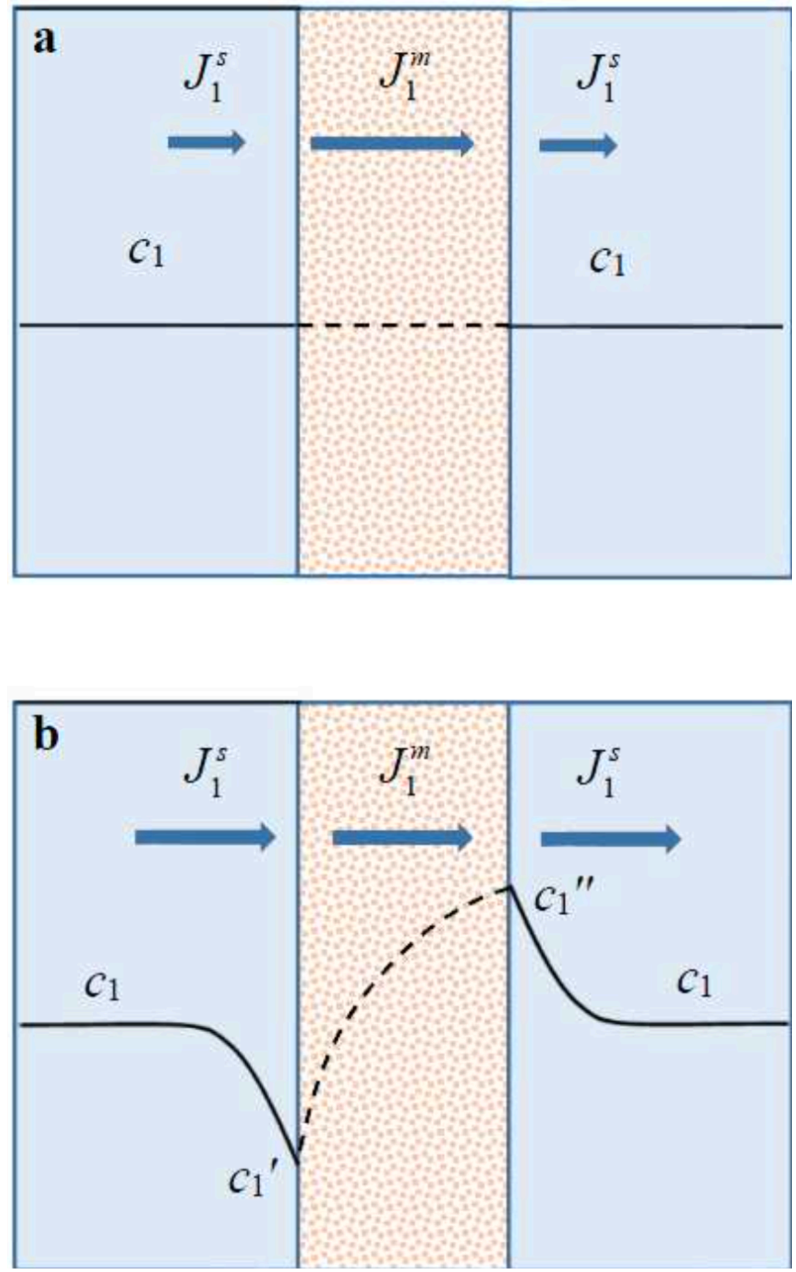
...but there are many considerations

- Molecular Weight CutOff (MWCO) is just the start. There are some serious issues.
- CP saturation effects (next slide)
- Surface charge effects (polar molecules can
- be attached to filters and create an electric field that opposes flow
- Fouling of surfaces by building of molecules that do not pass through

CP* and Nanofiltration

Well known phenomenon in chemistry.

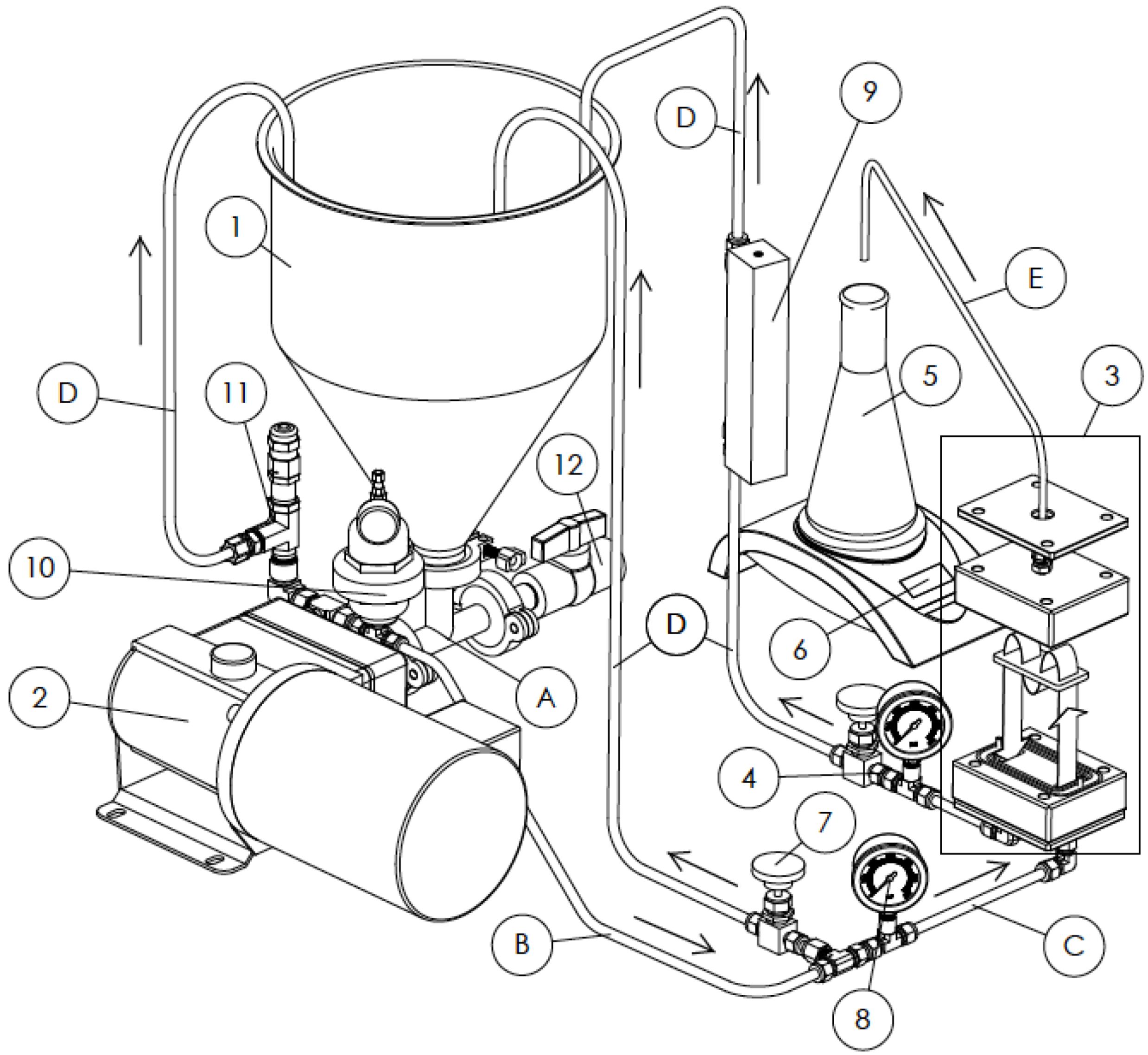
Need to continually remove permeate contaminants
to avoid building up a back diffusion potential that saturates the flow (and
can foul the system eventually)



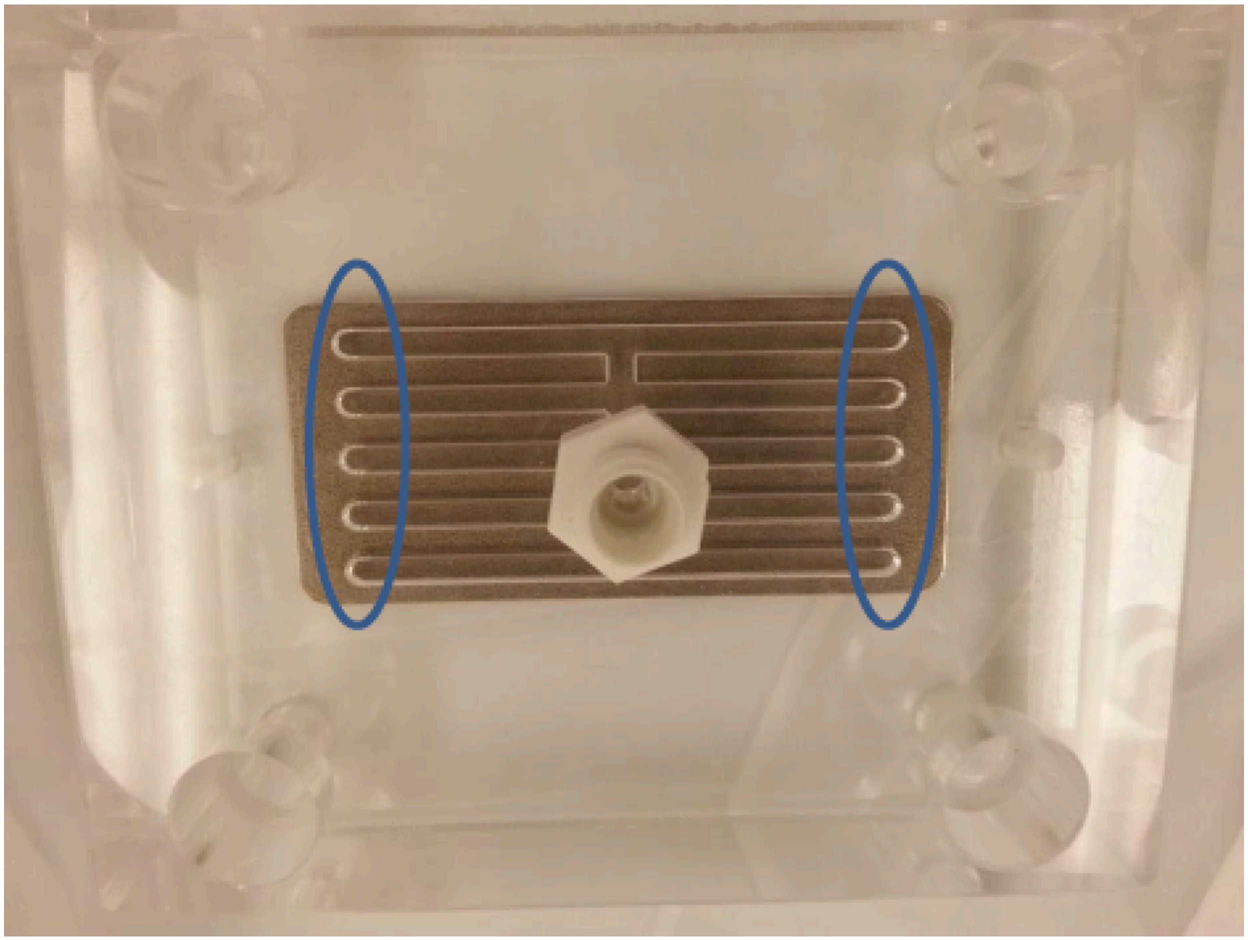
* **C**oncentration **P**olarization

Sterlitech CF042
Nanofiltration Unit

Modified at
UC Davis for a permeate loop to overcome CP and for handling viscous LS compared to water



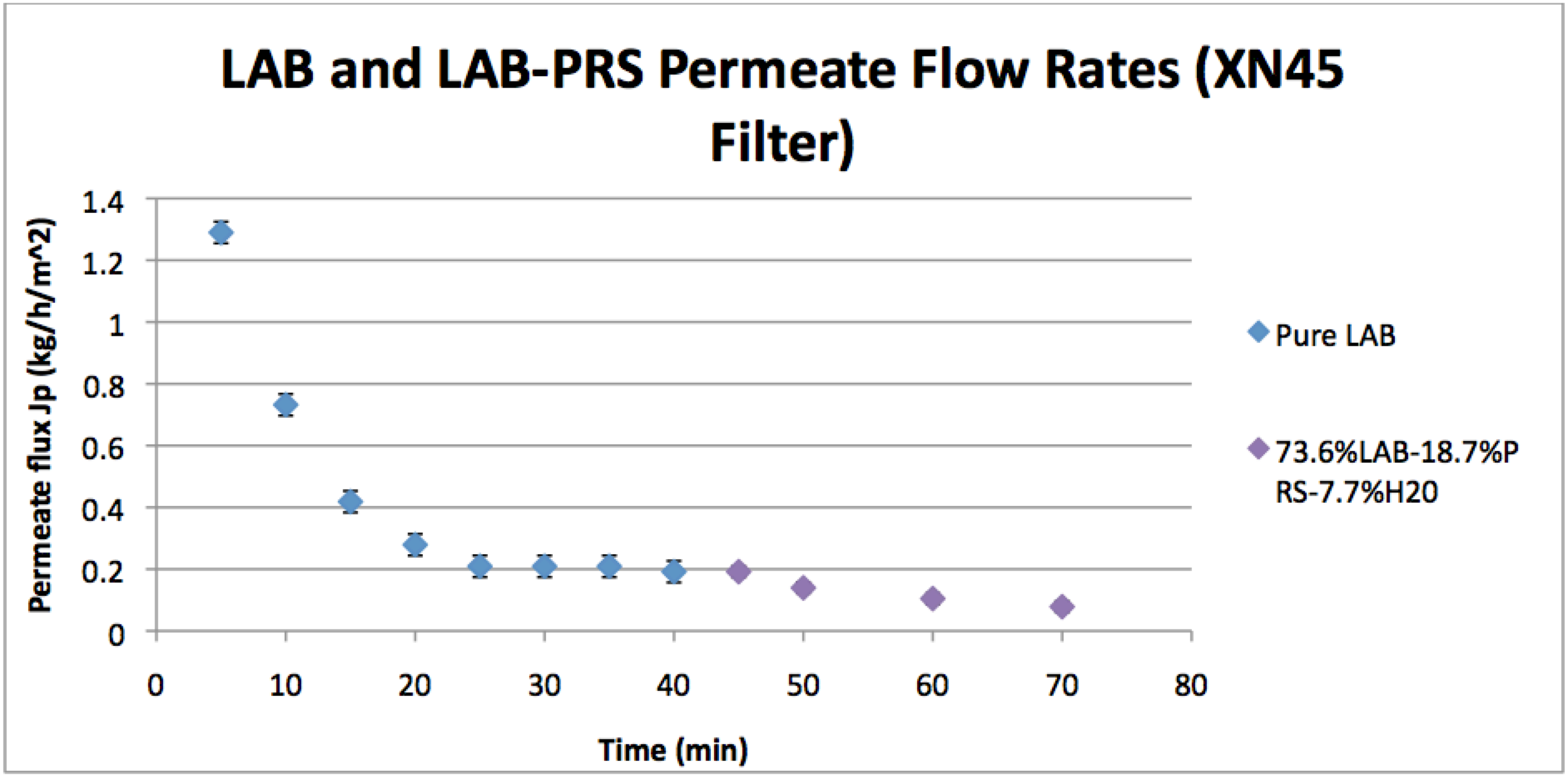
Custom NF cell with permeate loop to avoid CP issues



Systematic testing of commercial filters as a function of temperature, flow, pressure has been completed. We also learned a lot

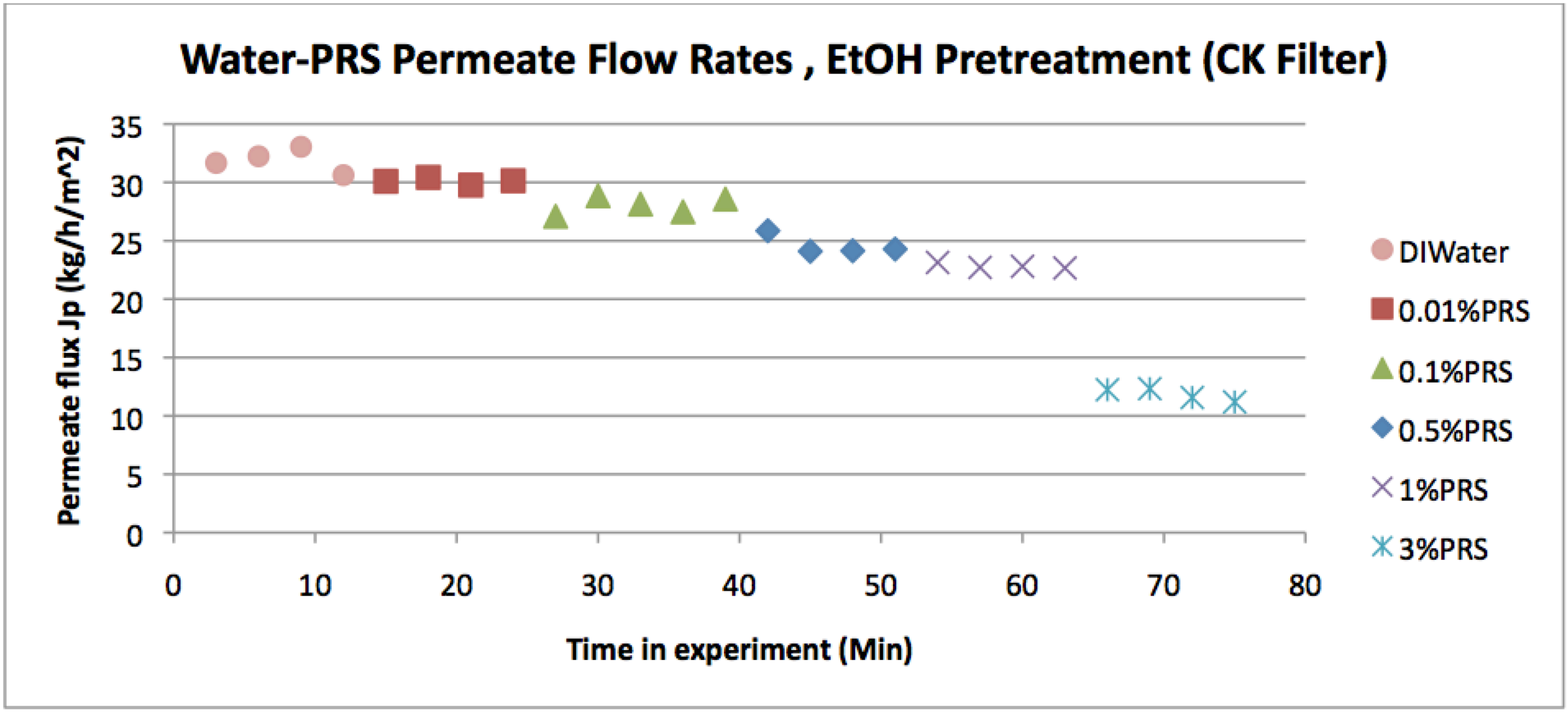
Nanofilter name	Manufacturer	Filter material	Quoted MWCO (Daltons)	pH Range	Max. Feed Temp. (°C)
NFG	Snyder	Polyamide TFC	600-800	4-10	45
CK	GE Osmonics	Cellulose Acetate	2,000	4-10	35
NFW	Snyder	Polyamide TFC	300-500	4-10	45
XN45	TriCep	Polyamide	500	2-11	45
V3	Snyder	PVDF	30,000	2-11	~100 (PVDF melting point)

We have identified a set of filters that has reasonable flow rate for LAB



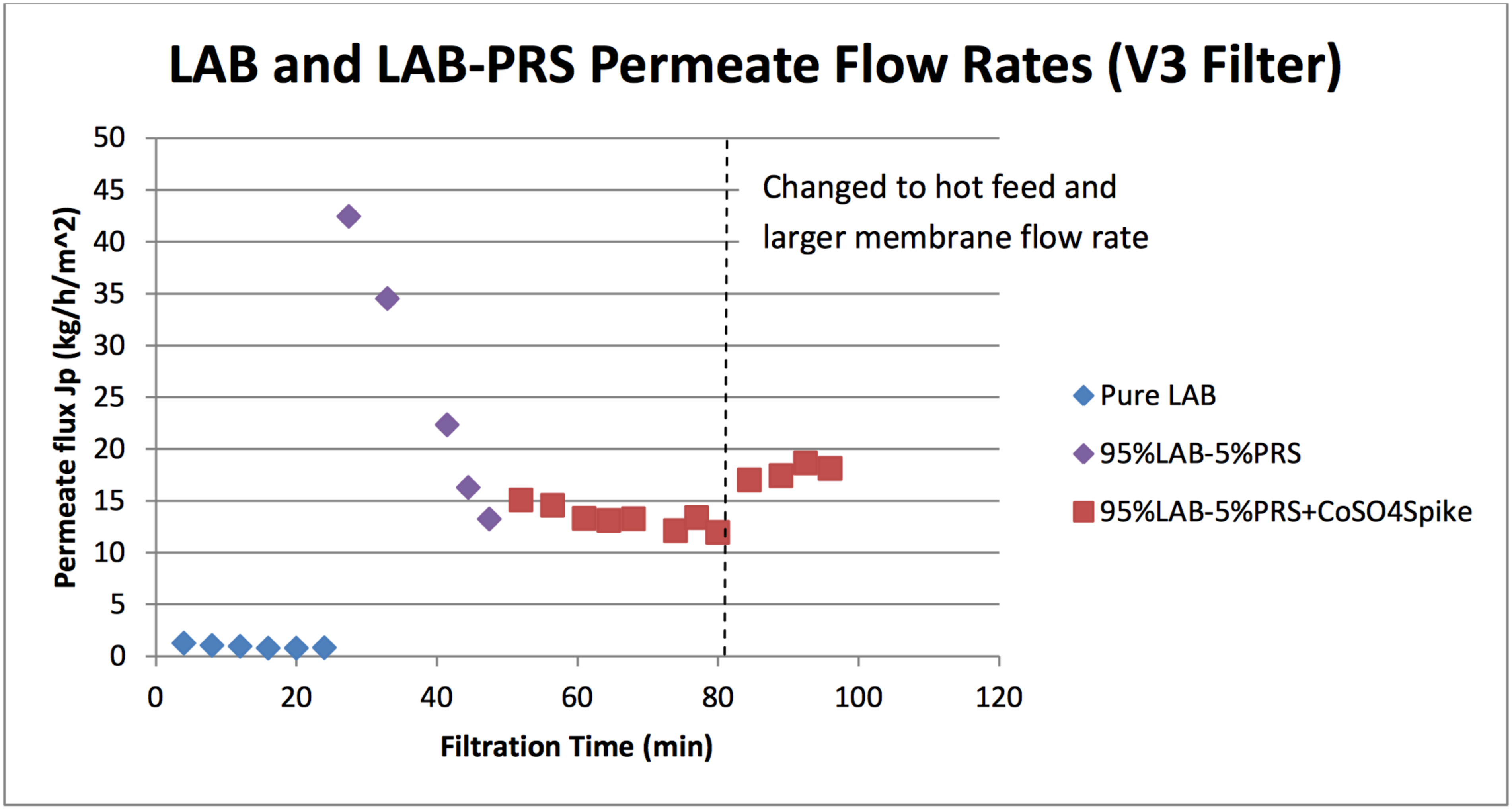
But addition of PRS decreases this flow

PRS has a significant affect on filters with negative surface charge



Test with water shows that PRS has a significant effect

We have also identified some *positive* filters where PRS IMPROVES flow over pure LAB



Where we are now...

- Pursuing positive filters and the idea of large chelating molecules for latching onto polyvalent metals such as 210-Pb, 238-U, 232-Th
- Getting some help from FOOD INDUSTRY
- Just started looking into filtering of monovalent atoms such as sodium. Some interesting first results...

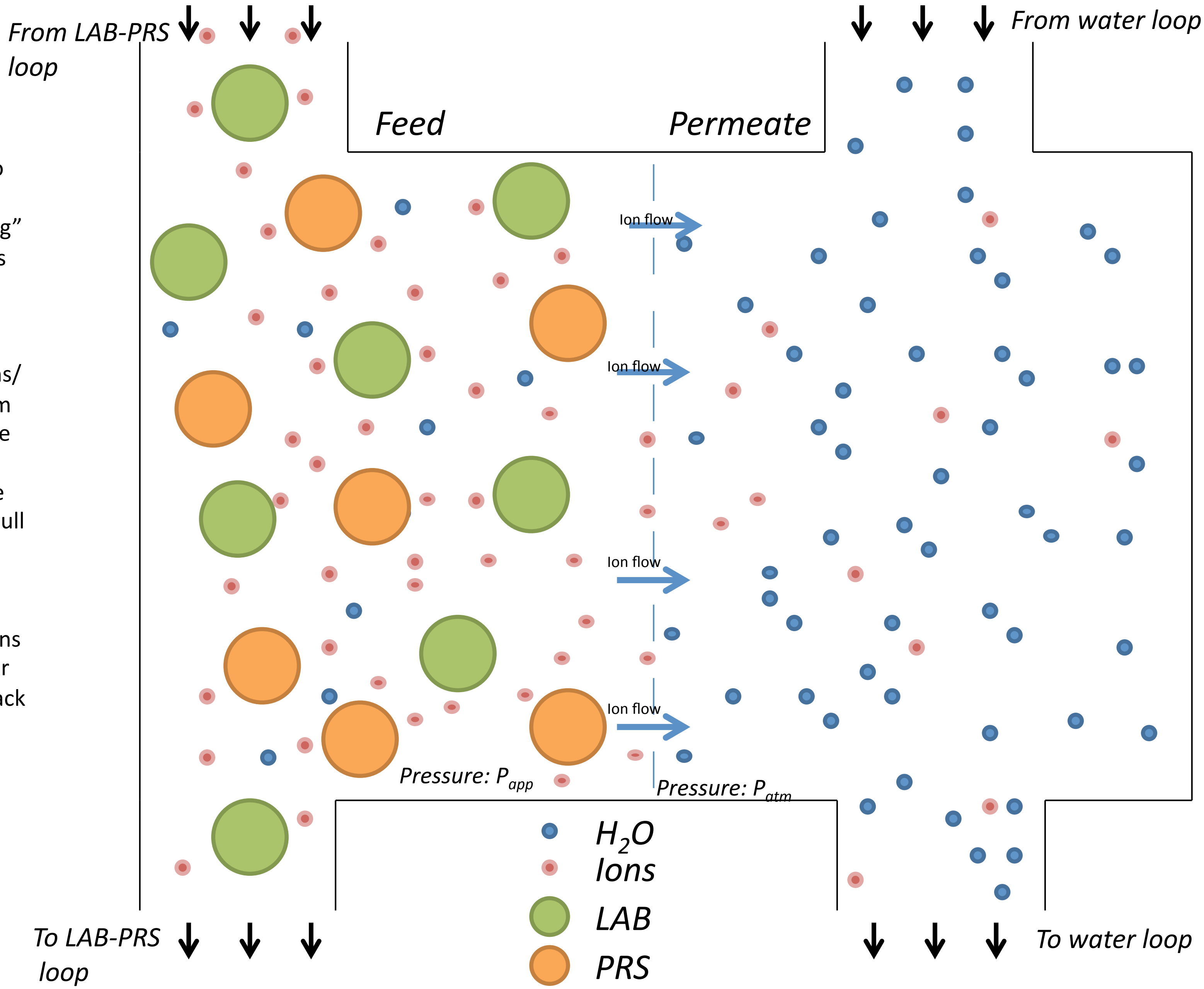
Pushing Ions from LAB-PRS to H_2O Permeate

Idea: Make ions always want to go to permeate by constantly "sweeping" away the permeate's ions

Step 1. Use applied pressure to push ions/ small impurities from LAB-PRS to permeate

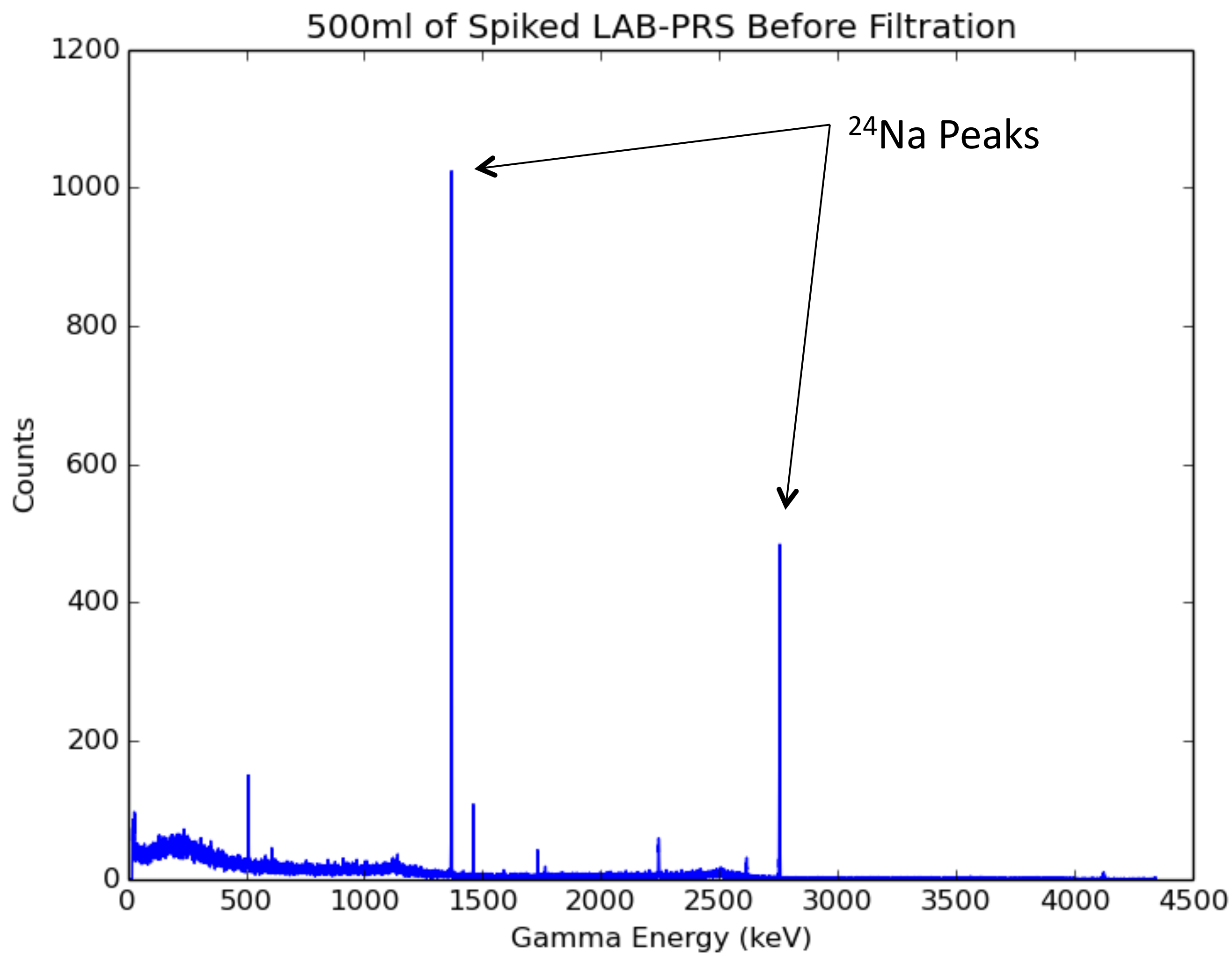
Step 2: Fill permeate with water to help pull ions from LAB-PRS

Step 3: Circulate permeate loop so ions concentrated at filter back will not flow back through the filter to the feed



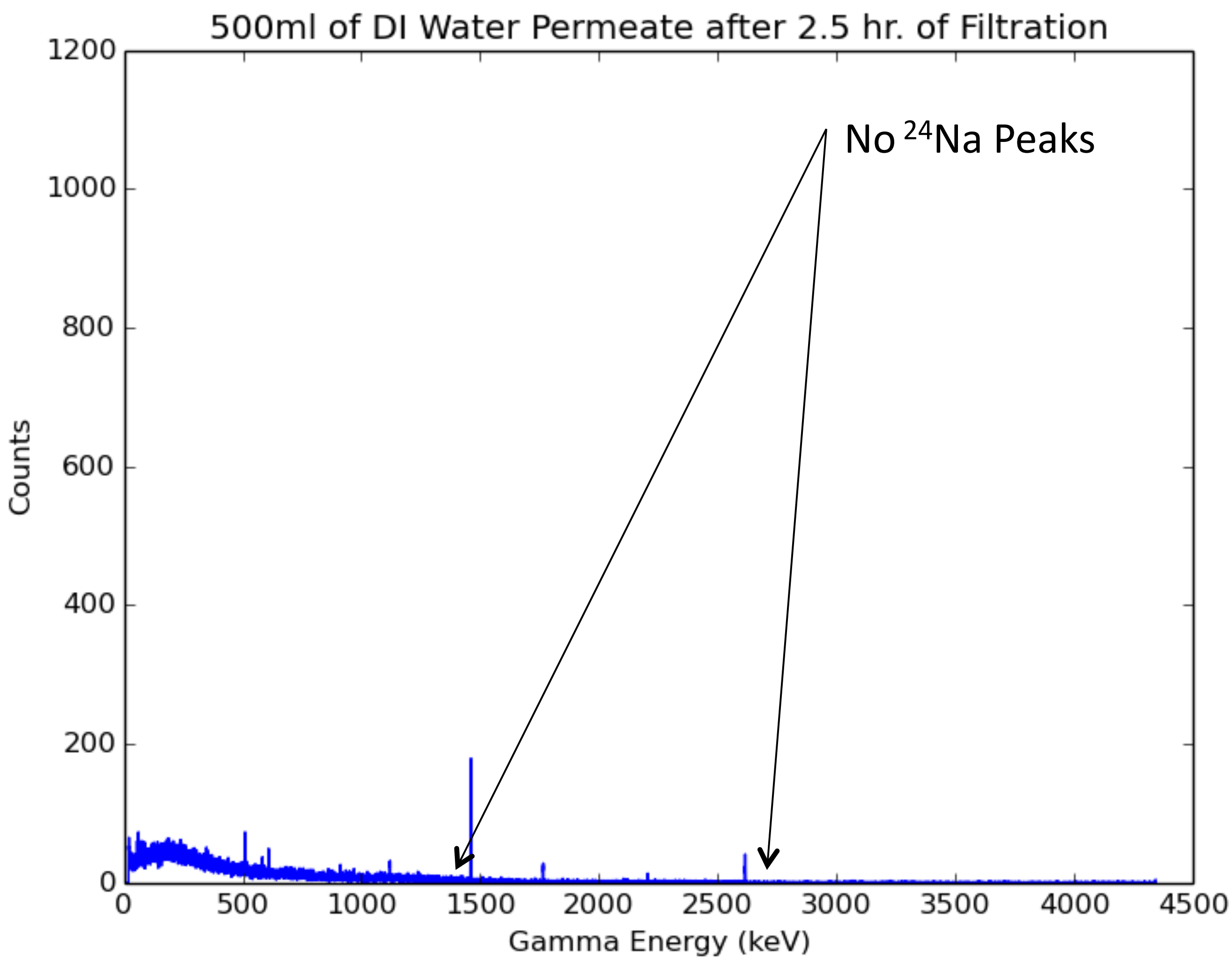
Spectrum of Sodium-Spiked LAB-PRS Feed before Filtration

- Live time counting: 4000 sec.



Spectrum of Permeate Water after 2.5 hours of filtration

- Live time counting: 7200 sec.



Conclusions

After 2.5 hours of filtration, no ^{24}Na appears to have passed from LAB-PRS to permeate water. However, **XRF showed that the few percent of water in the LS actually DID preferentially go through the filter.**

Conclusion: LAB/PRS has a higher affinity for Na than does water

Next – we will try improving sodium mobility off LAB/PRS using chelating compounds

Conclusions

- Nanofiltration is a technique well known in industry for purifying water
- Work is ongoing to try and apply this method to liquid scintillator
- Work on Water-based Liquid Scintillator will also start – this is actually an easier problem

Experimental Process

- Prepare ~30nCi of ^{24}Na by putting 100 μg of $NaHCO_3$ in the McClellan reactor for 30 sec.
- Transfer sodium tracer into 49.2% PRS, 50.8% LAB (w/w) with ~4ml of DI water
- Count 500 ml of LAB-PRS with tracer in HPGe counter for 1 hour as a control
- Put LAB-PRS into feed, put DI water into permeate
- Condition filter at 100 PSI for 30 min, filtrate at 200 PSI for 30 min (flow on filter: 0.7 LPM)
- Collect 500 ml DI water permeate and count in counter to check for sodium
- Return DI water to permeate, filtrate another 1.5 hours at 200 PSI (flow on filter: 0.7 LPM)
- Collect 500 ml LAB-PRS feed, count to check sodium levels
- Collect 500 ml DI water permeate and count again in HPGe

Experimental conditions/Important information

- NF filter: NFG from Snyder
  - Quoted MWCO: 600-800 daltons
  - Quoted sodium rejection: ~10% (so, should let sodium through filter well)
- Soaked filter in DI water for 24 hours
- LAB-PRS volume in feed: 842 ml, DI water volume in permeate: 842 ml
- ^{24}Na half-life: 14.96 hours
- Molar mass of Sodium bicarbonate: 84 g/mol