C. Roca, on behalf of the ROADSTR Near-Field Working Group:

T. Akindele, N. Bowden, L. Carman, T. Classen, S. Dazeley, M. Ford, V. Li, M. Mendenhall, F. Sutanto, N. Zaitseva and X. Zhang, S. Durham

presents:

DESIGN, TEST AND PRODUCTION AT LLNL OF:

NOVEL PSD PLASTIC SCINTILLATOR TECHNOLOGIES FOR NEUTRINO DETECTION

Snowmass Summer Meeting 2022 - 25.VII.2022

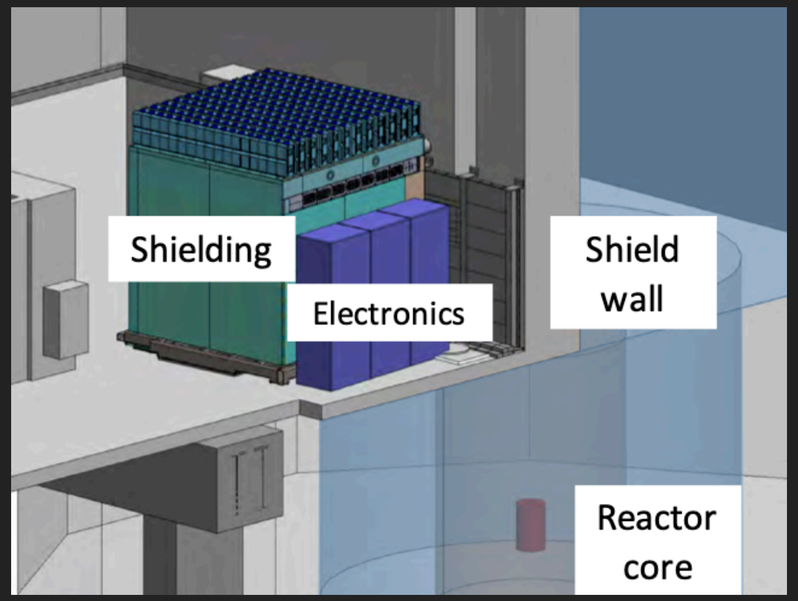
LLNL-PRES-XXXXX
This work has been performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

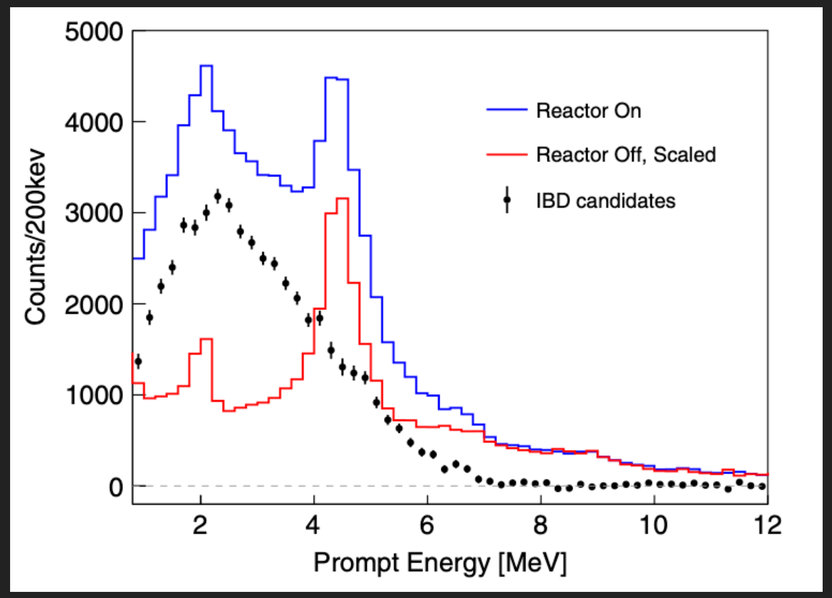
STATE OF THE ART: ABOVEGROUND REACTOR NEUTRINO DETECTION

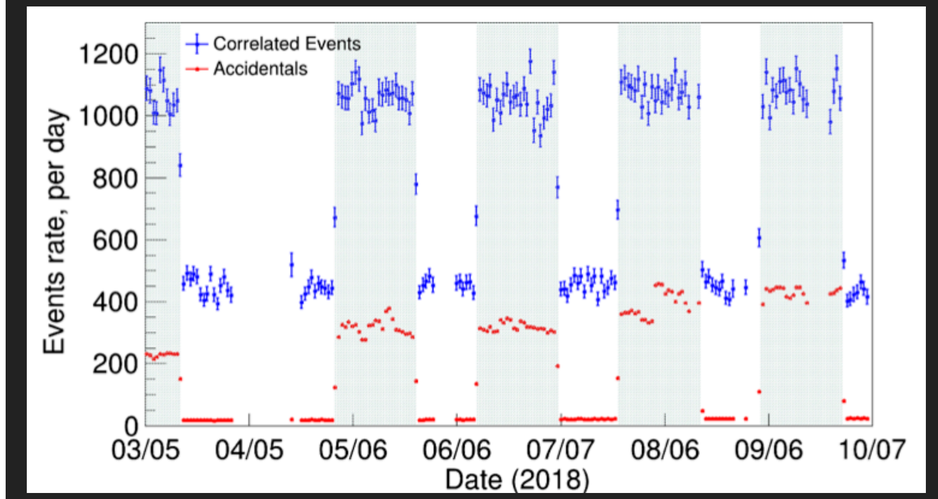
PROSPECT has demonstrated first high sensitivity aboveground detection and identified important capabilities.

PROSPECT

- Segmentation
- Li dopped scintillator
- PSD capabilities

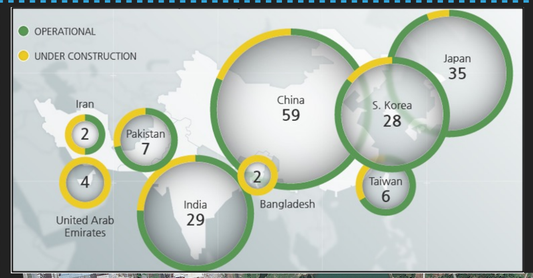




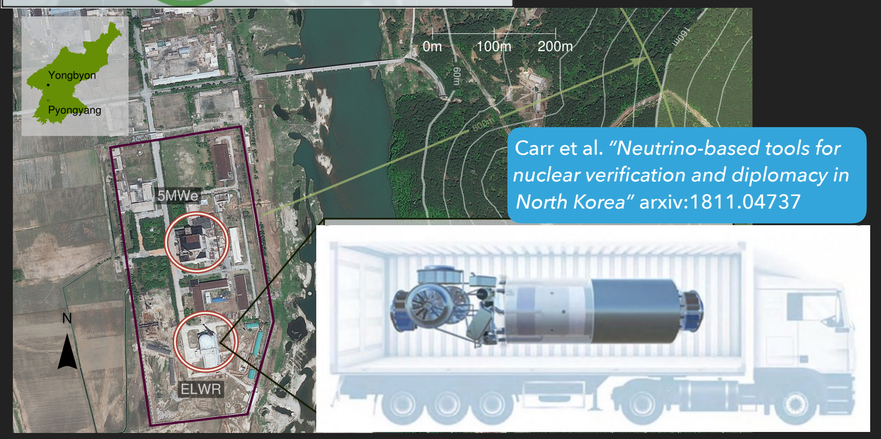


There is a strong interest in readily mobile precision neutrino flux detectors

MOTIVATIONS FOR READILY MOBILE ABOVEGROUND DETECTION SYSTEM



Nuclear safeguards and verification applications



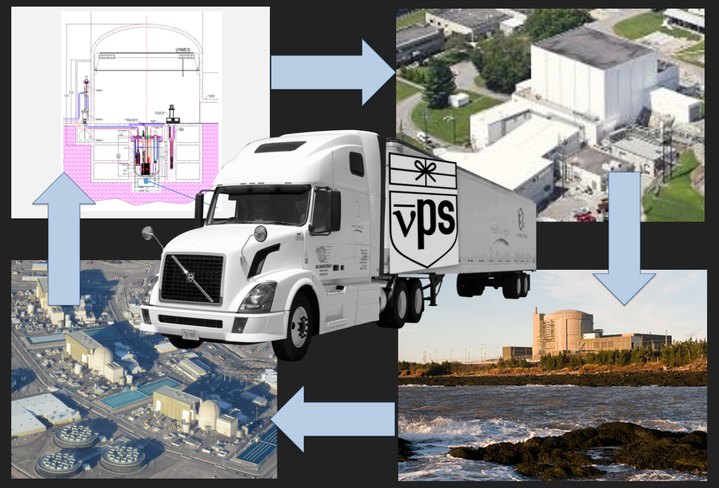
Carr et al. *"Neutrino-based tools for nuclear verification and diplomacy in North Korea"* arxiv:1811.04737

- Potentially useful tool for negotiation and verification of nuclear agreements.
- Advanced reactors may be difficult to safeguard with conventional approaches.

PROSPECT aboveground demonstration has inspired new use cases studies.

Readily mobile systems have several motivations

Multi-reactor measurement campaign with same mobile detector design



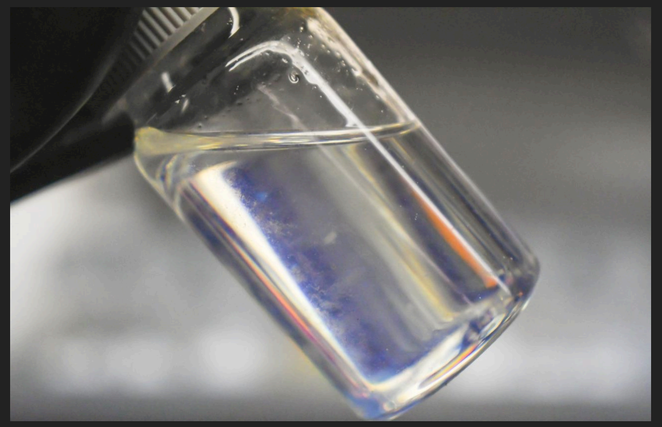
- Benchmarks for applications
- Validating flux & spectrum predictions against diverse fuel types.

There is a strong interest in readily mobile precision neutrino flux detectors

PSD PLASTIC MATERIALS: HOMOGENOUS ^{6}LI-DOPING

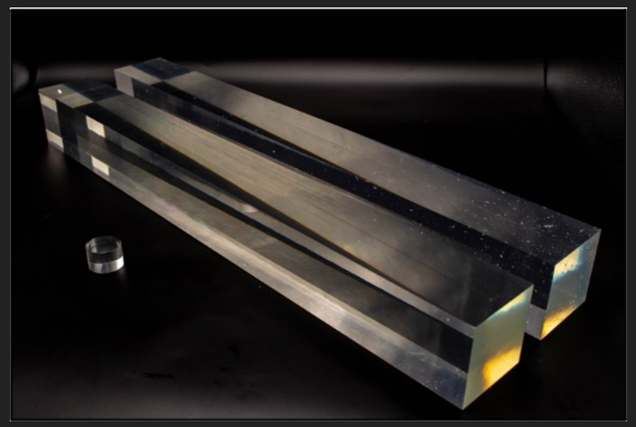
- Building on more than a decade of effort at LLNL by **N. Zaitseva**, **A. Mabe** & **M. Ford**
- Eljen Technology has started mass-producing PSD plastic bars with lab's formulation.

Developing formulations and production processes

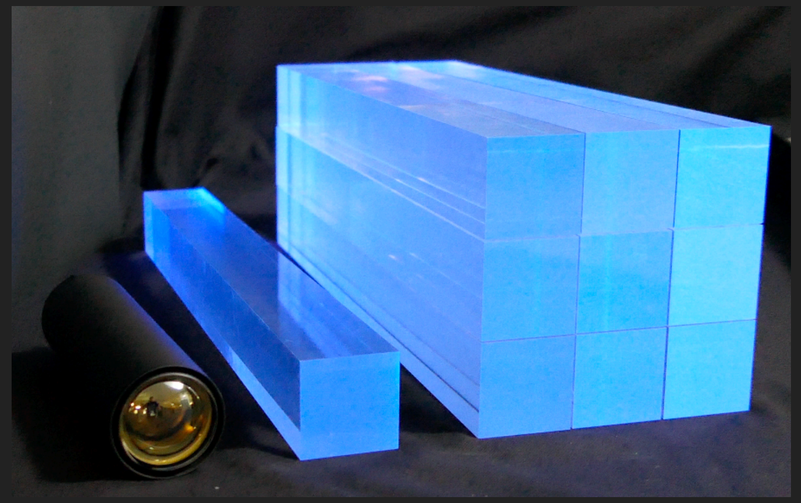


Exploring solubility of multiple Li bearing compounds and their stability

Transferring technology for commercial production



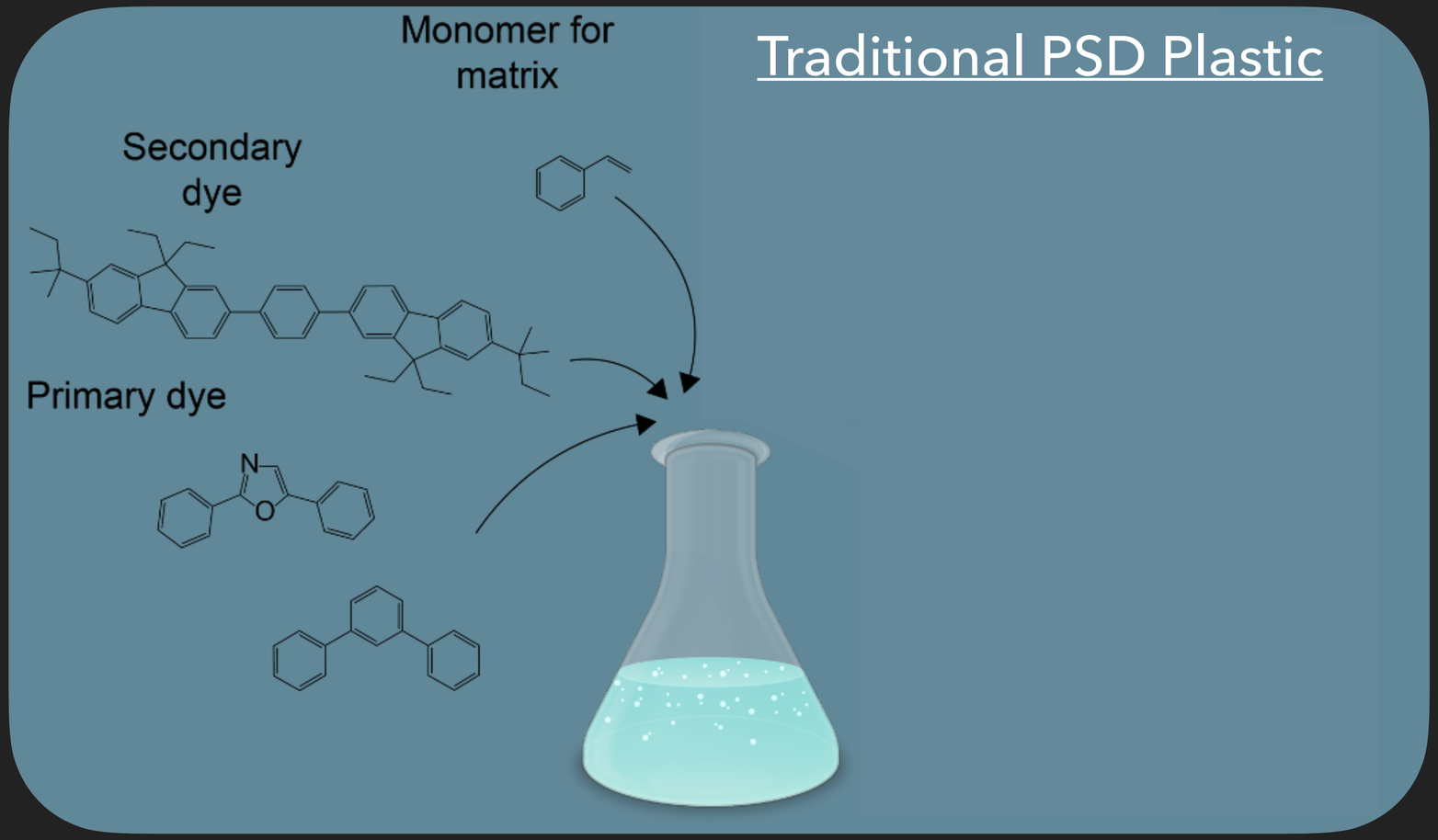
Evaluating light yield, attenuation length, PSD properties

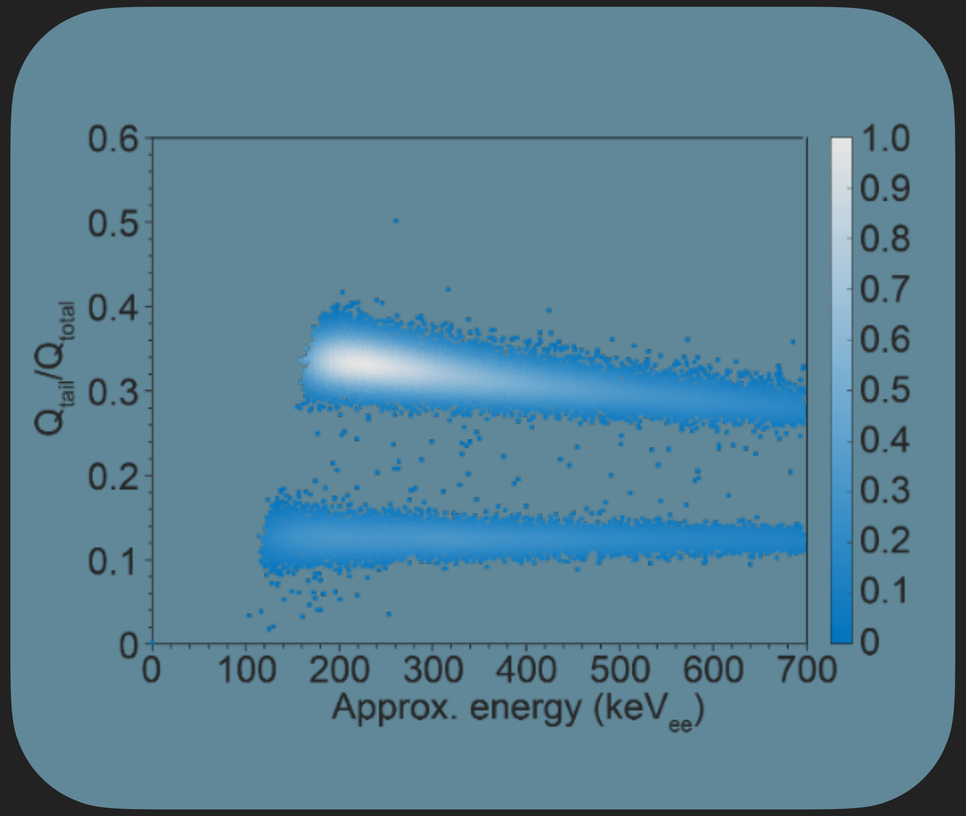


Build up a characterization setup to test bars as they are produced

Advancing PSD plastic materials with the goal of matching demonstrated performance of liquids to enable easily mobile systems

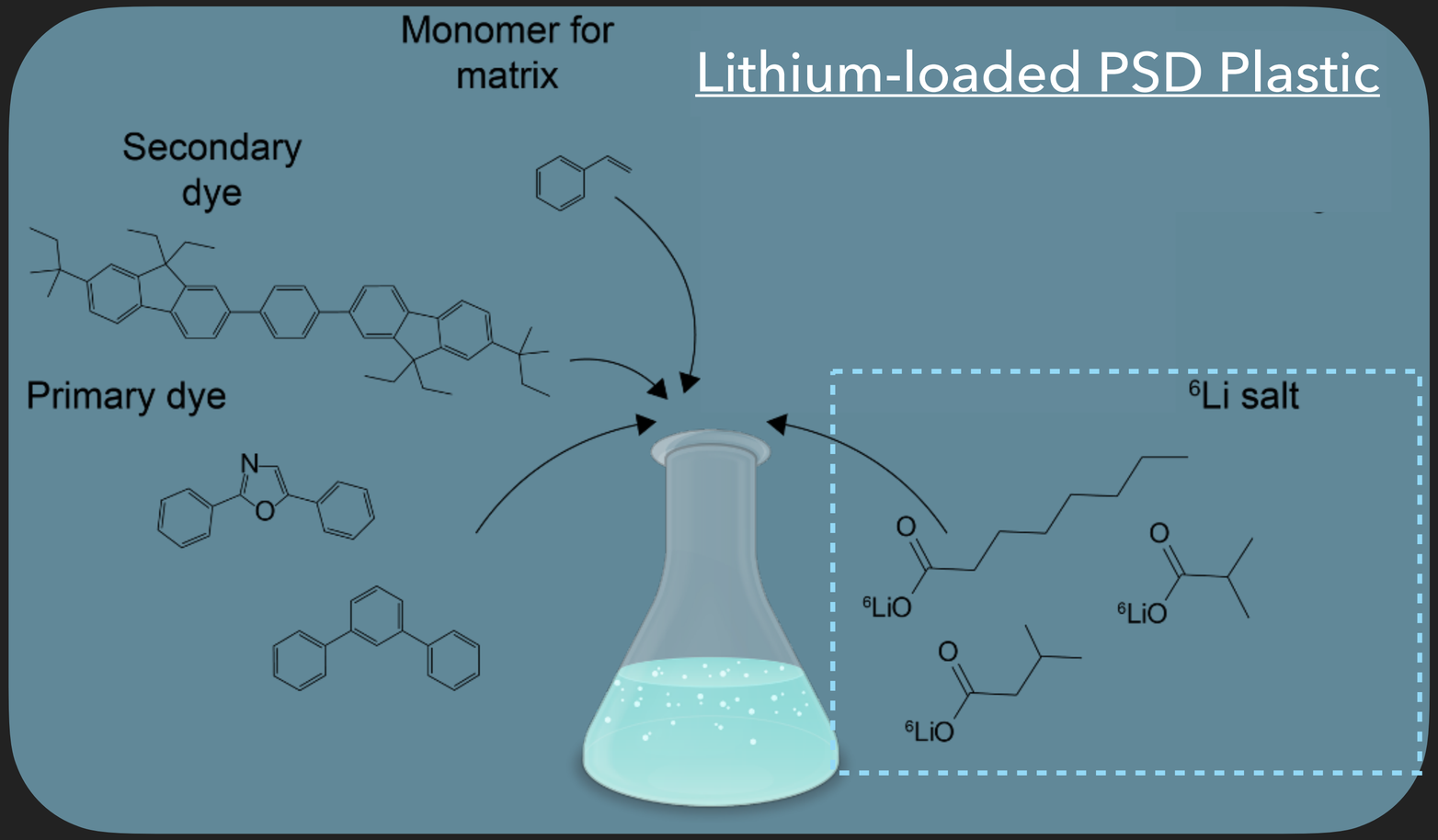
BASICS OF PSD PLASTIC CHEMISTRY

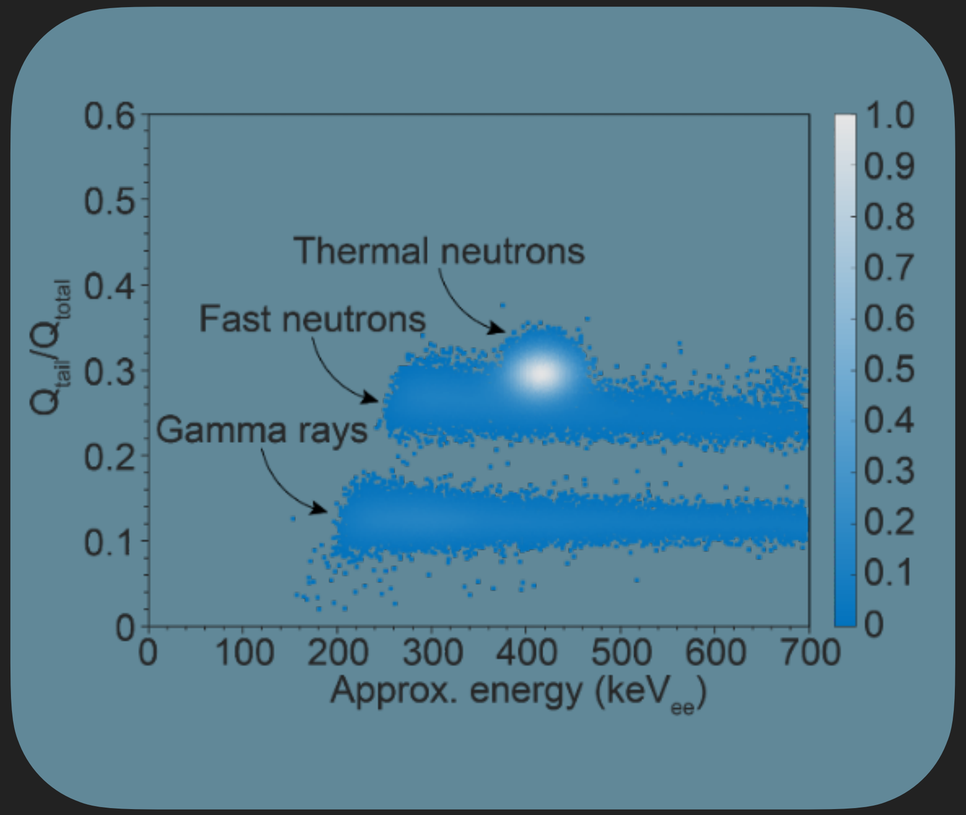




Primary and secondary dyes are responsible for PSD and wavelength shifting

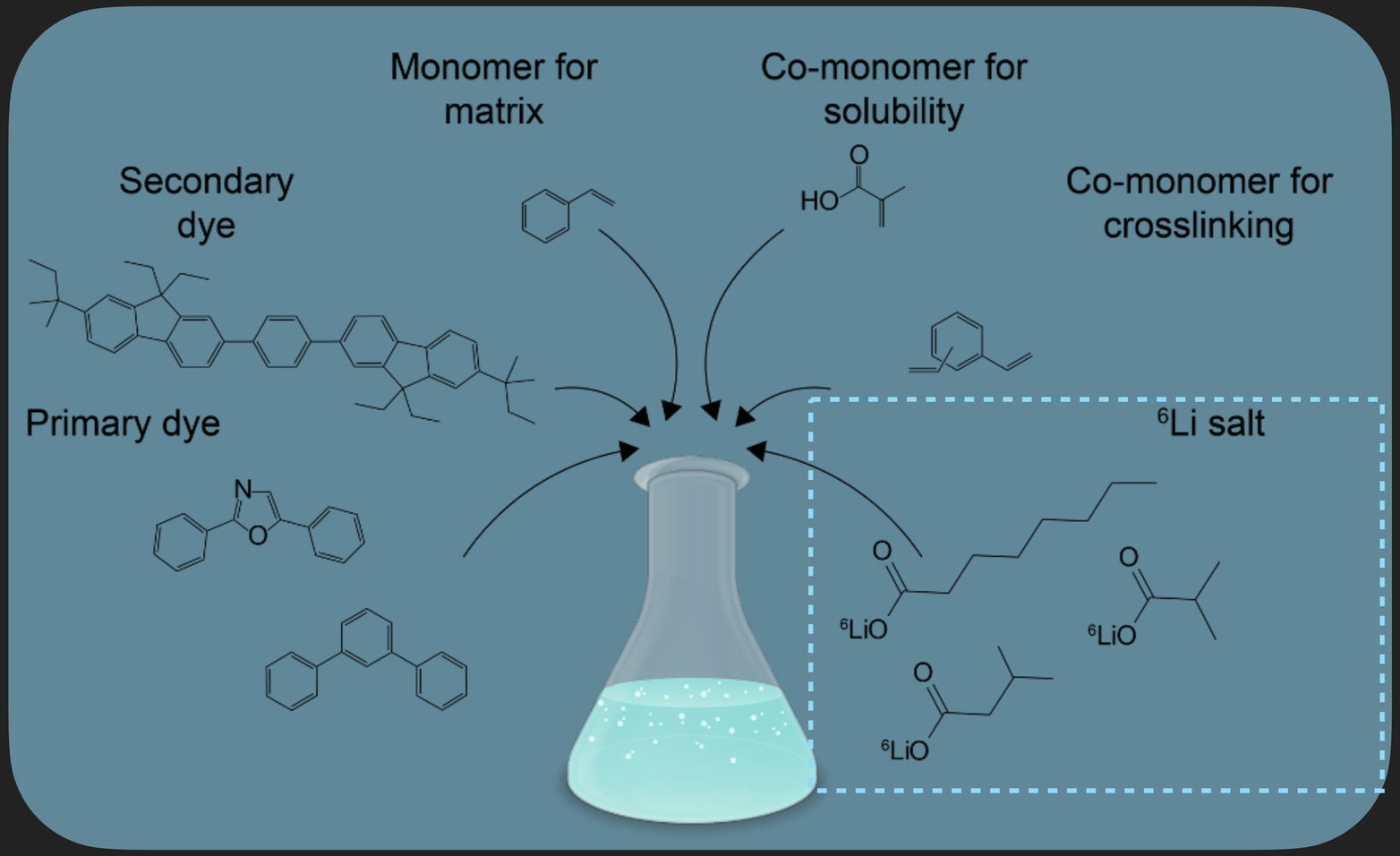
BASICS OF PSD PLASTIC CHEMISTRY

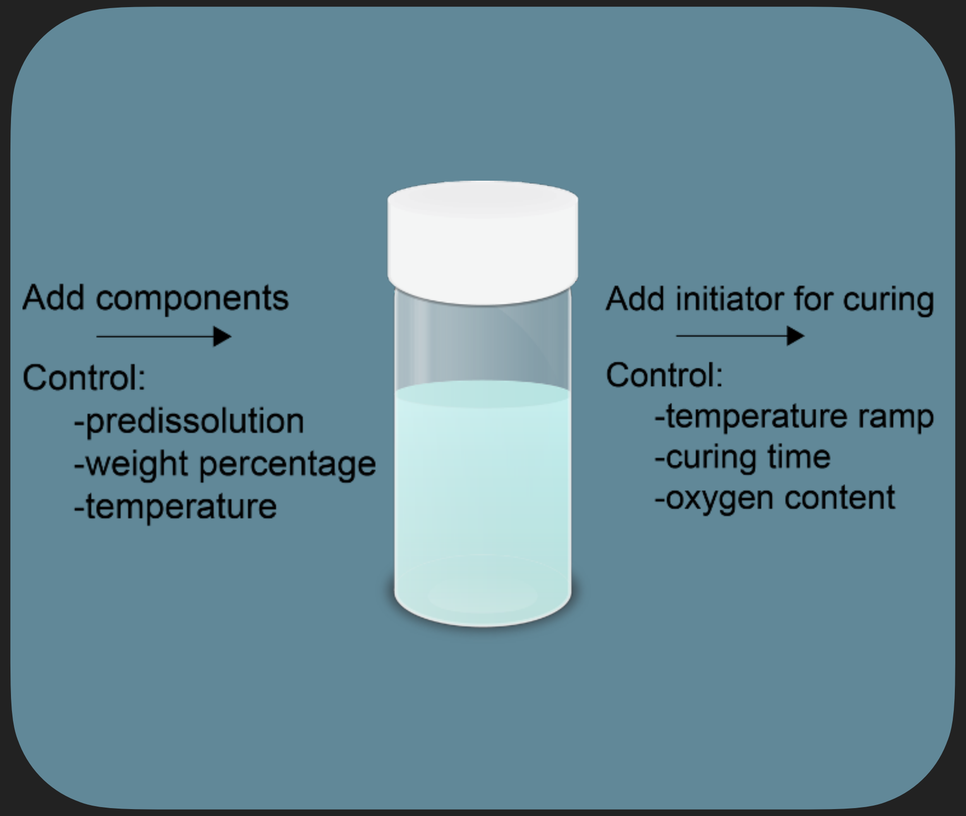




Lithium salts are added to ensure correlated event selection through n-capture process

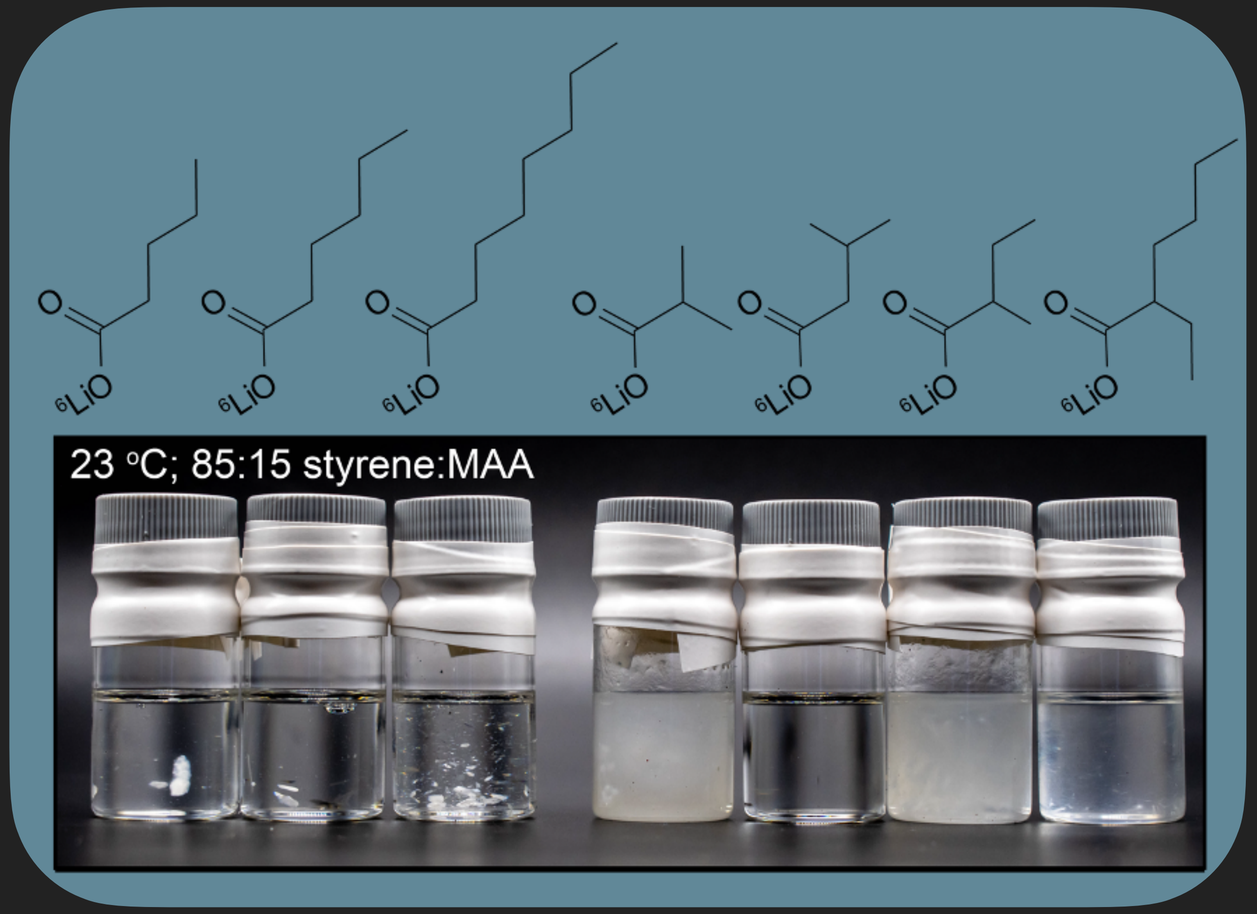
BASICS OF PSD PLASTIC CHEMISTRY

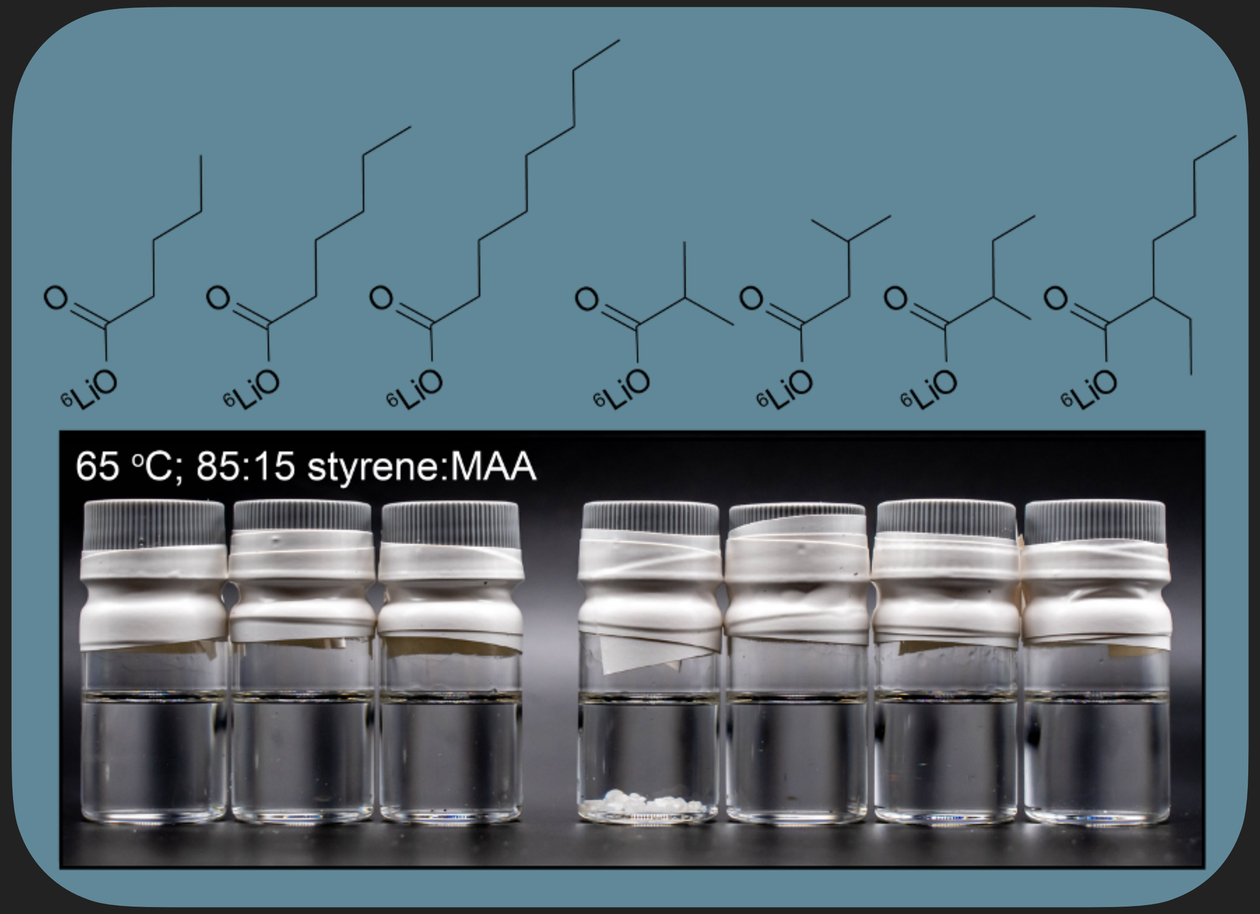




Addition, mixing and curing of components require very strict condition controls

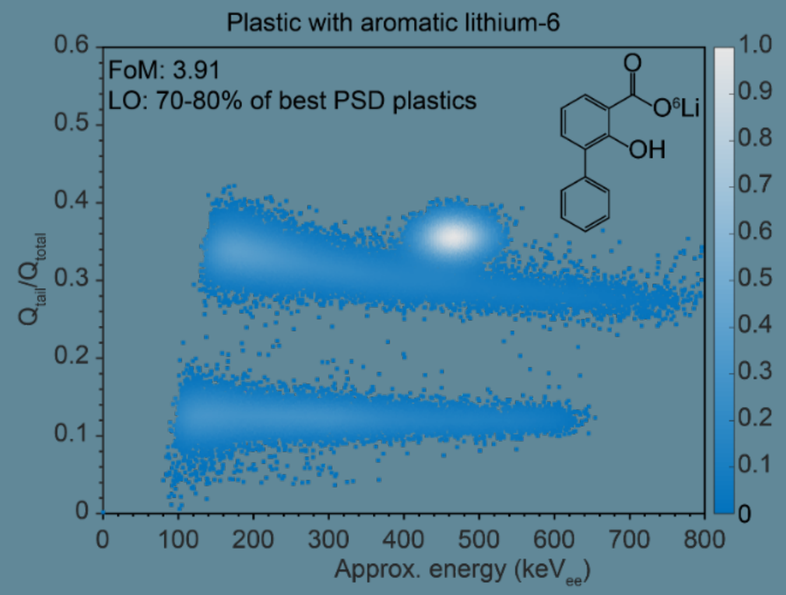
SOLUBILITY OF ^{6}Li SALTS

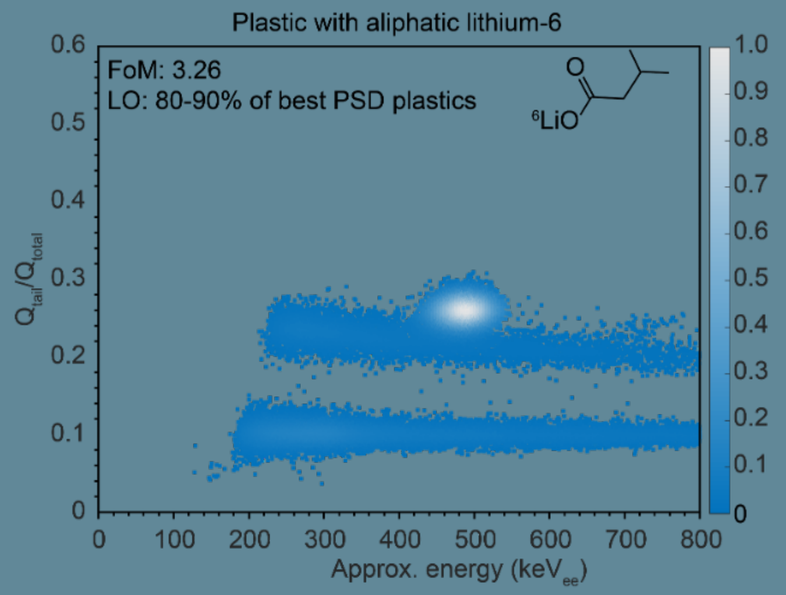


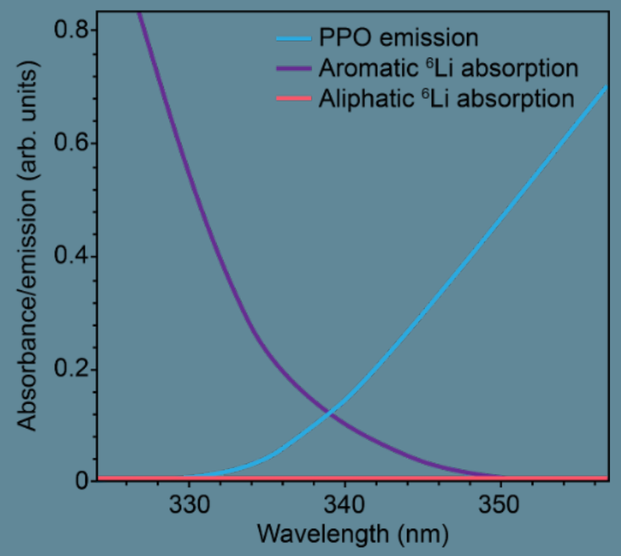


Good 6Li solubility is paramount, so a variety of Li salts are being studied dissolved at different temperatures

PSD FOR DIFFERENT ^{6}Li SALTS







Advantages

- Good solubility of 6Li salt
- Good stability

Disadvantages

- Difficult to produce
- Lower light output

Advantages

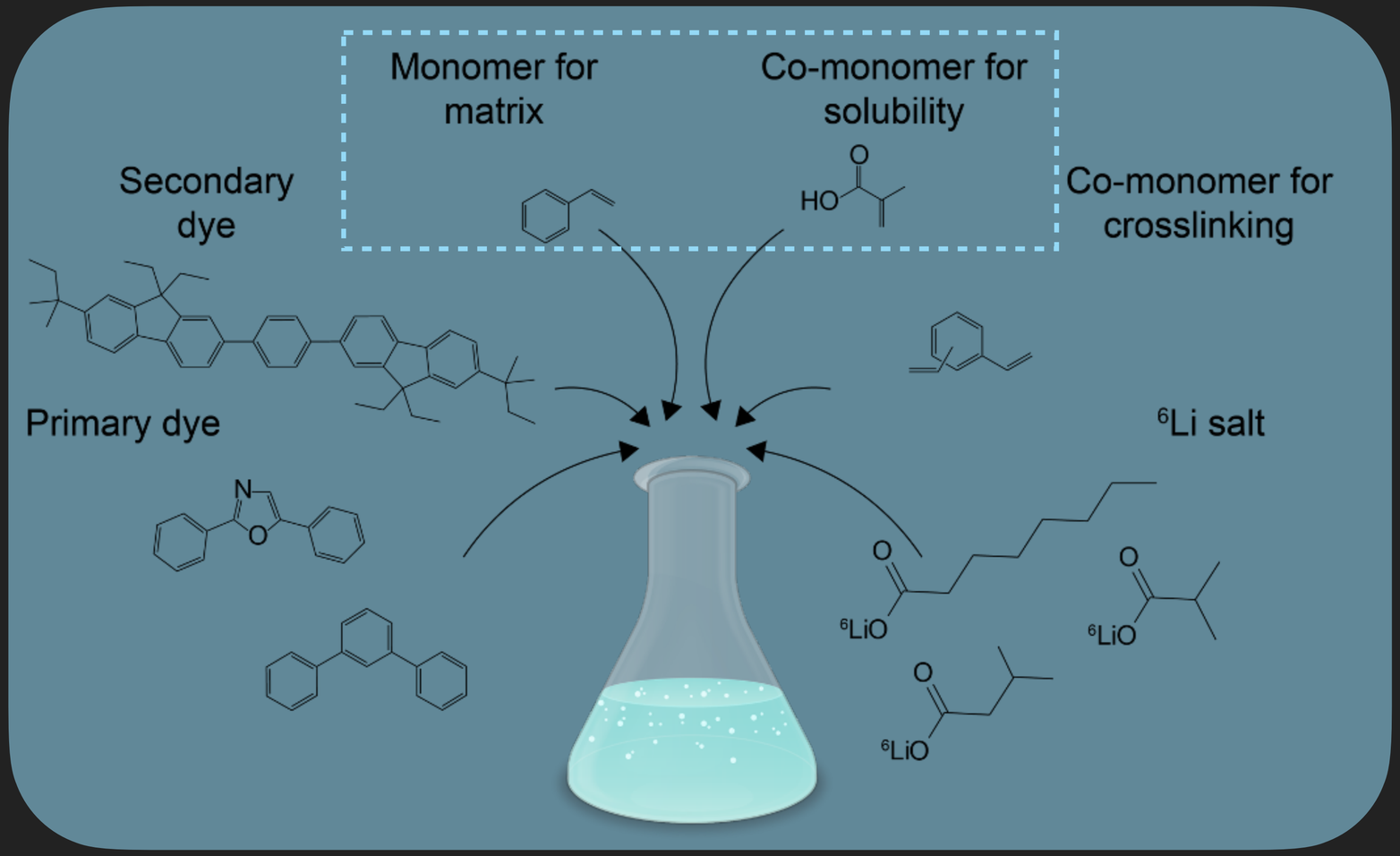
- Simple synthesis of 6Li salt
- Good light output

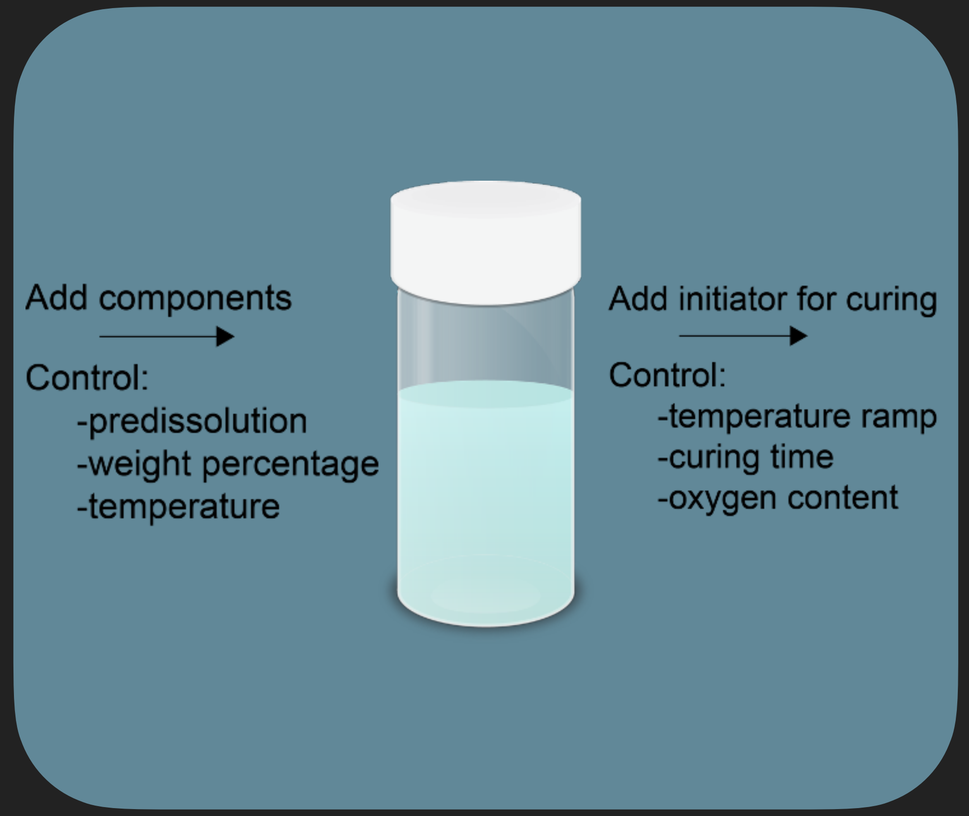
Disadvantages

- mTP required for high LO
- Lower Figure of Merit

For commercial production we have proceeded with an aliphatic ^{6}Li salt

BASICS OF PSD PLASTIC CHEMISTRY



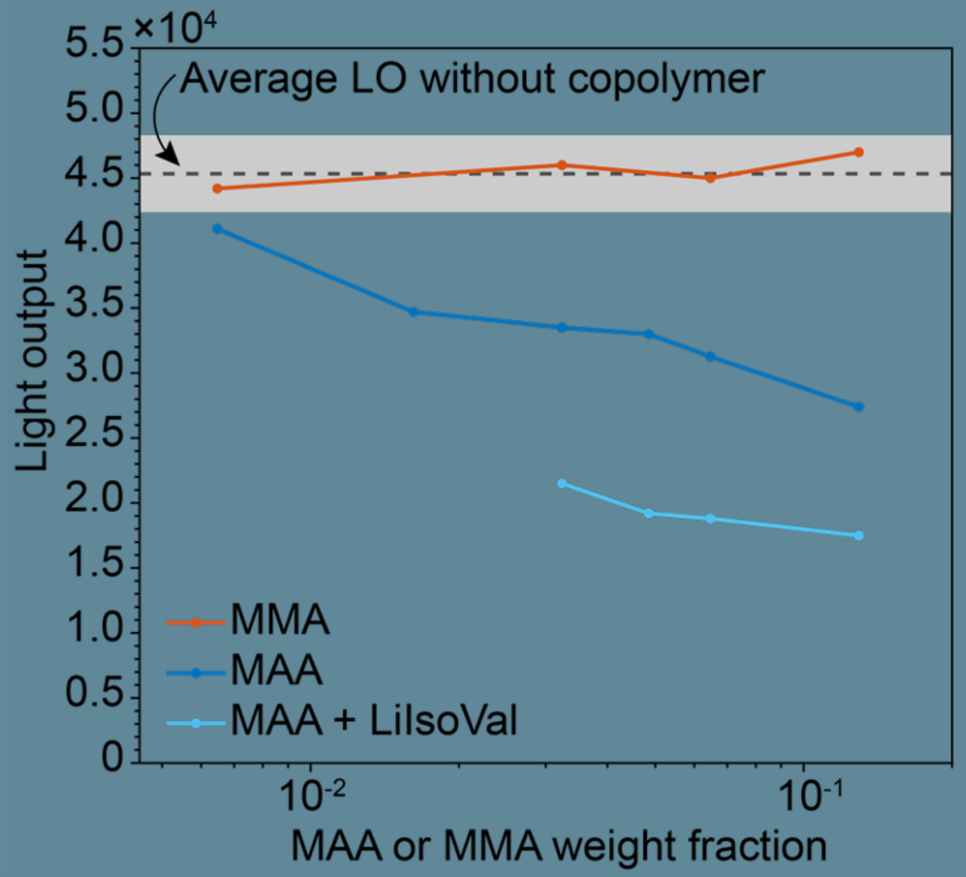


Co-monomer addition to main matrix element in order to dissolve 6Li salt

SOLUBILITY OF ^{6}Li SALTS

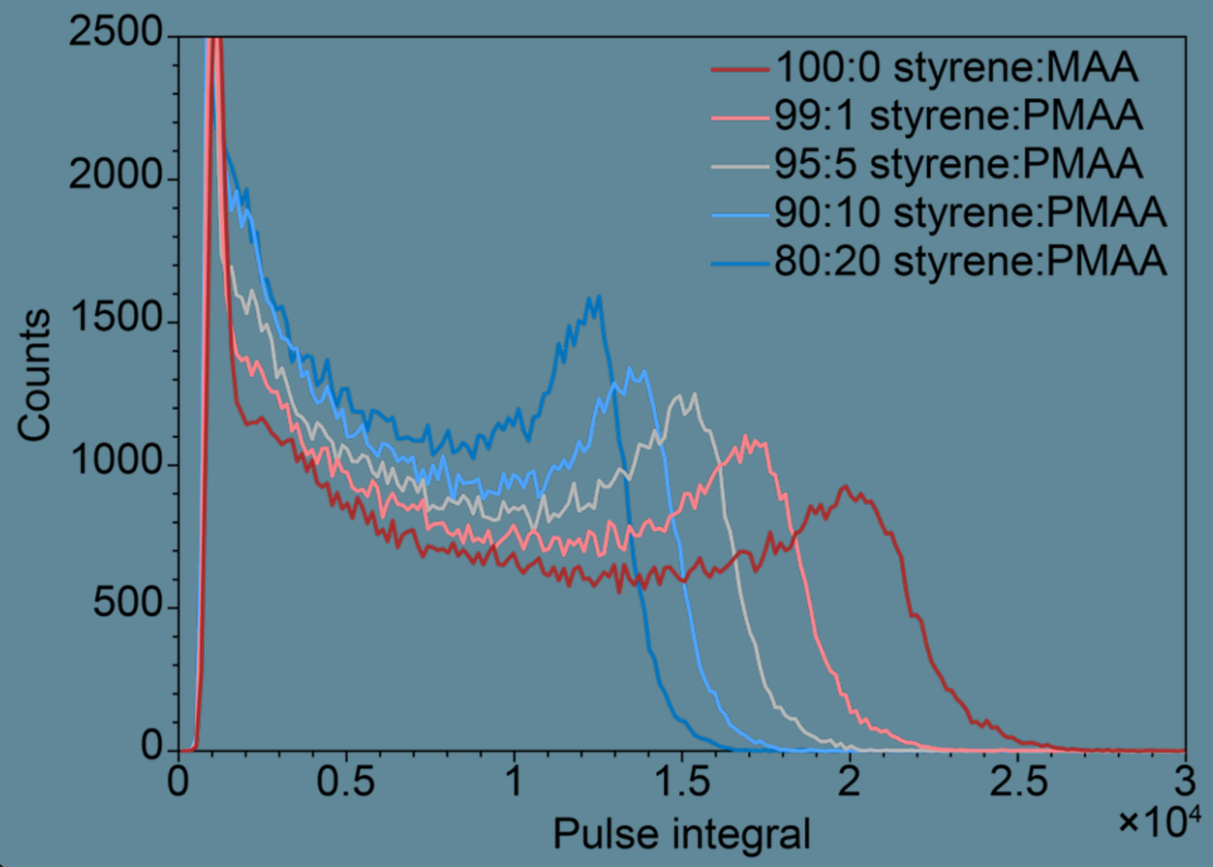
High MAA content reduces light output - but lower MAA requires higher processing temperatures

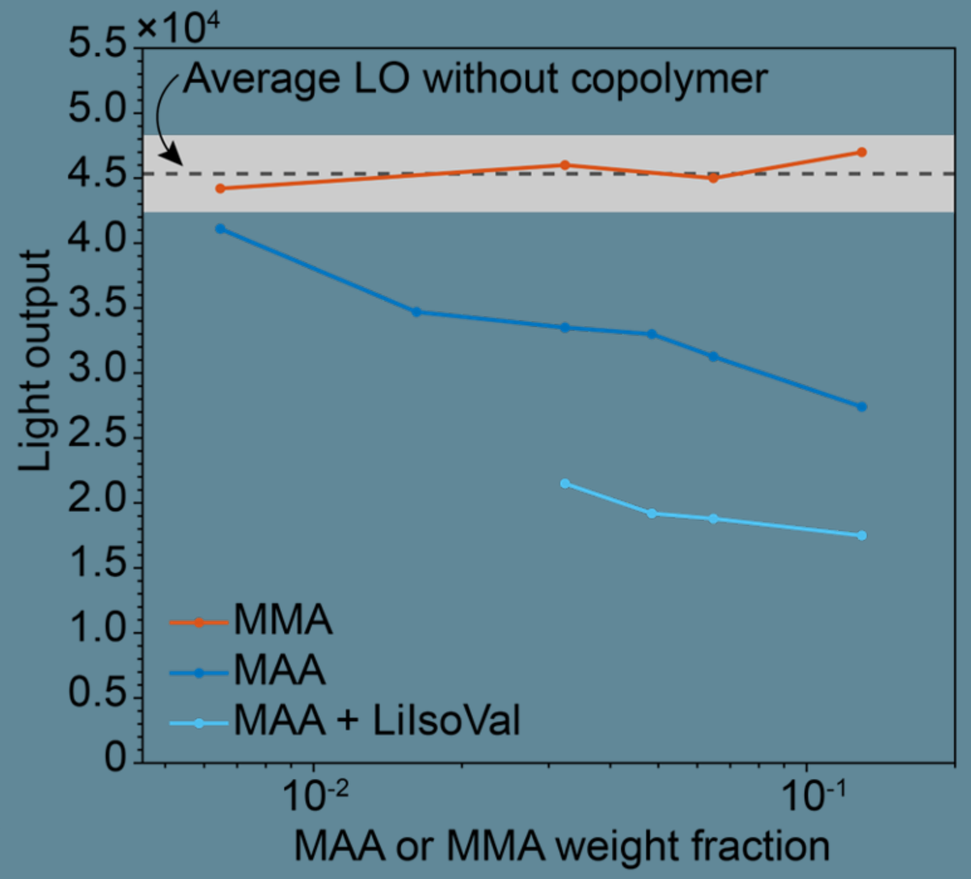
LIGHT OUTPUT VS CO-MONOMER FRACTION



There is a critical mass fraction from which light output declines rapidly. This point has not been reached using MMA.

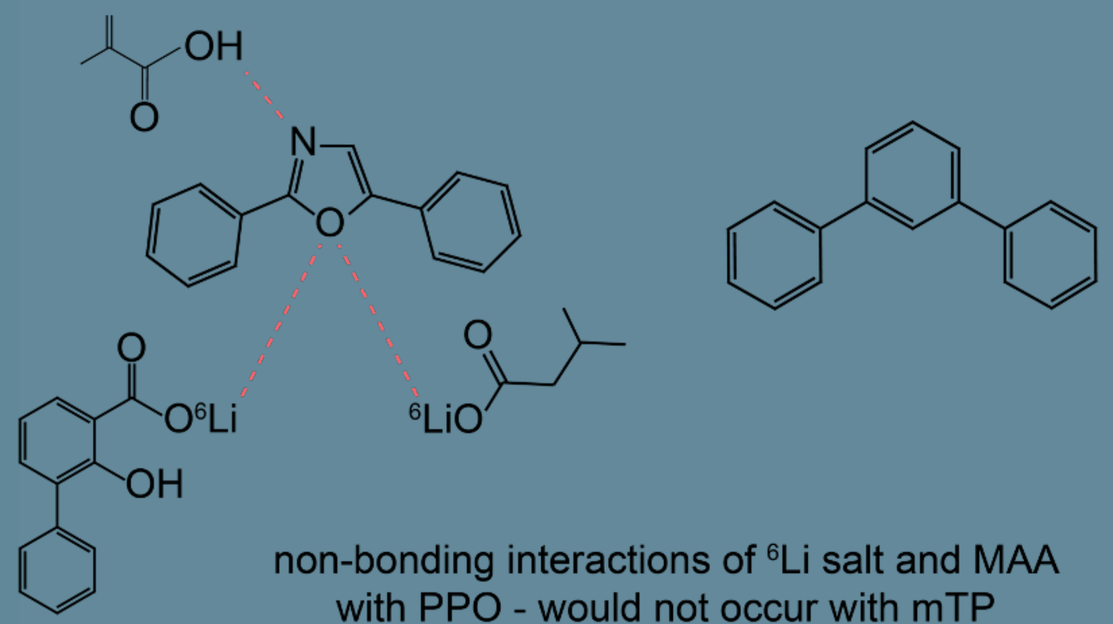
LIGHT OUTPUT VS CO-MONOMER FRACTION



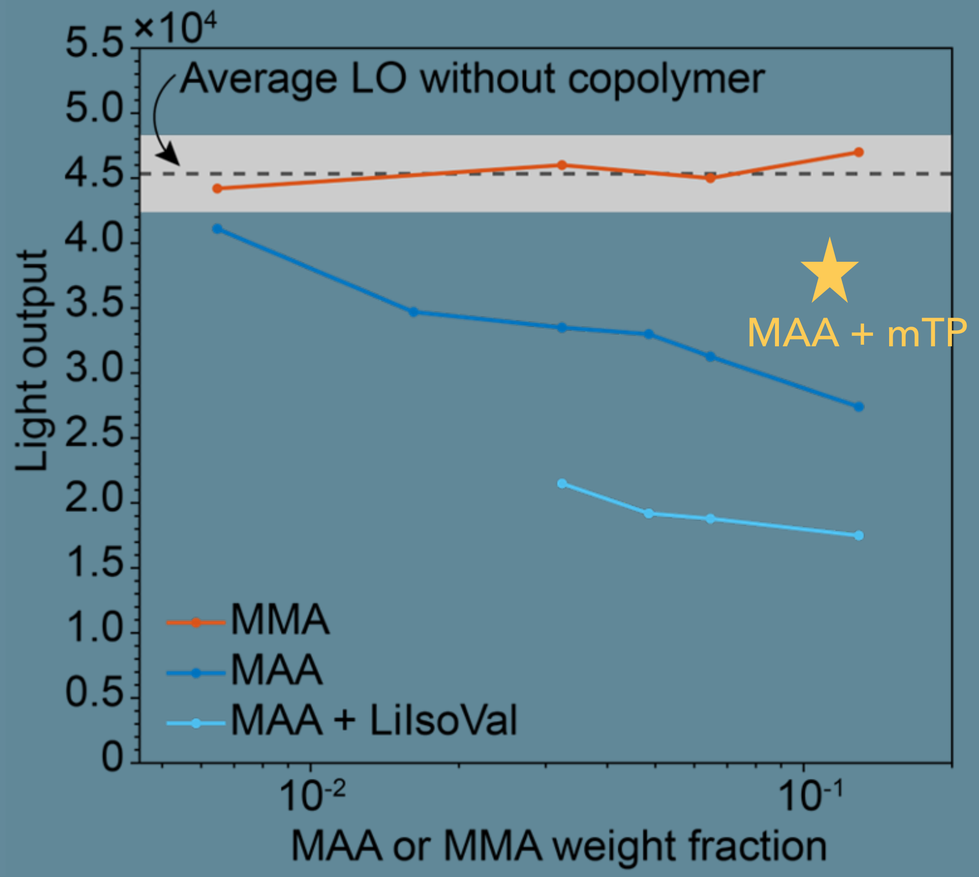


There is a critical mass fraction from which light output declines rapidly. This point has not been reached using MMA.

PRIMARY DYE AS LIGHT ATTENUATOR WITH MAA

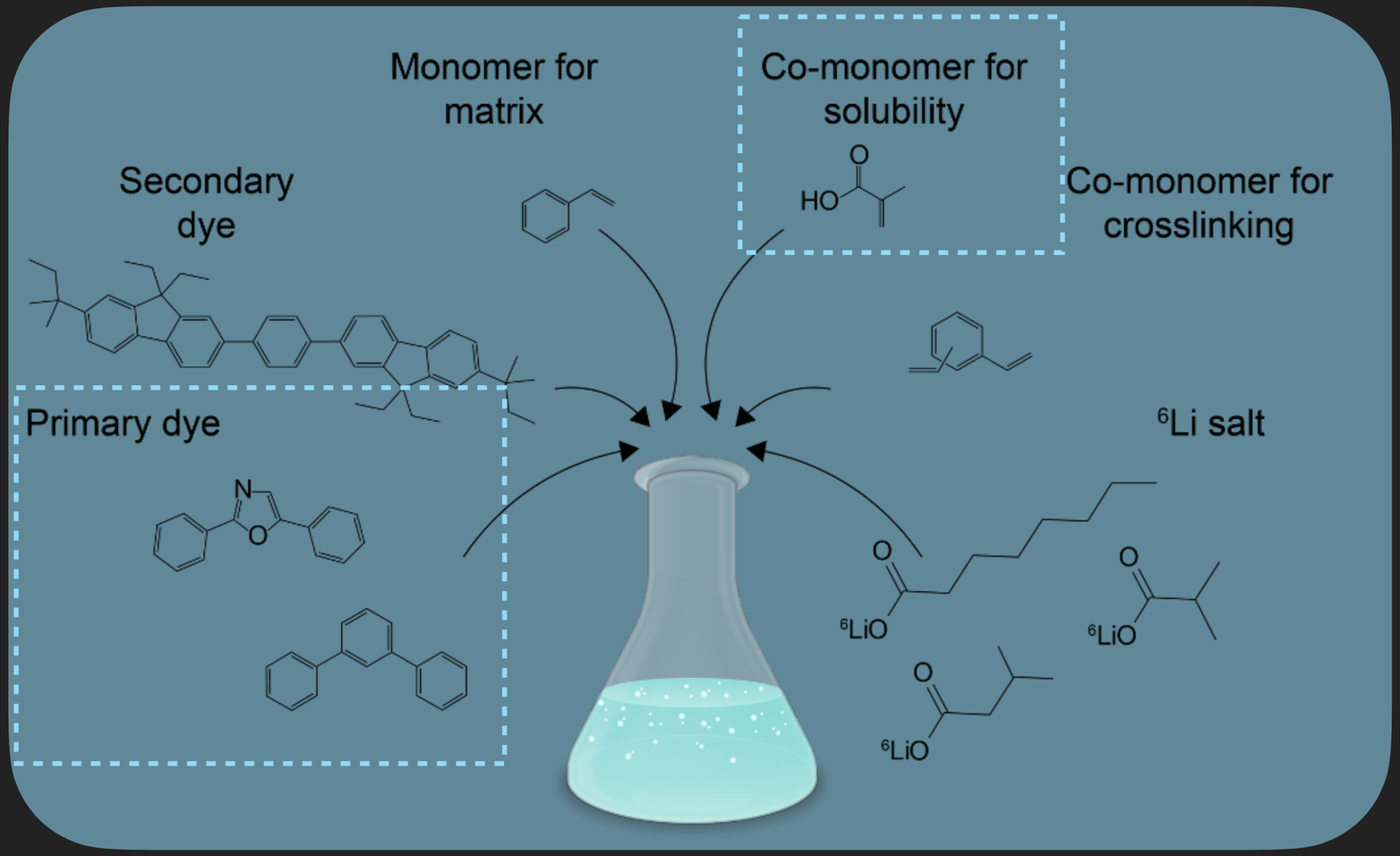


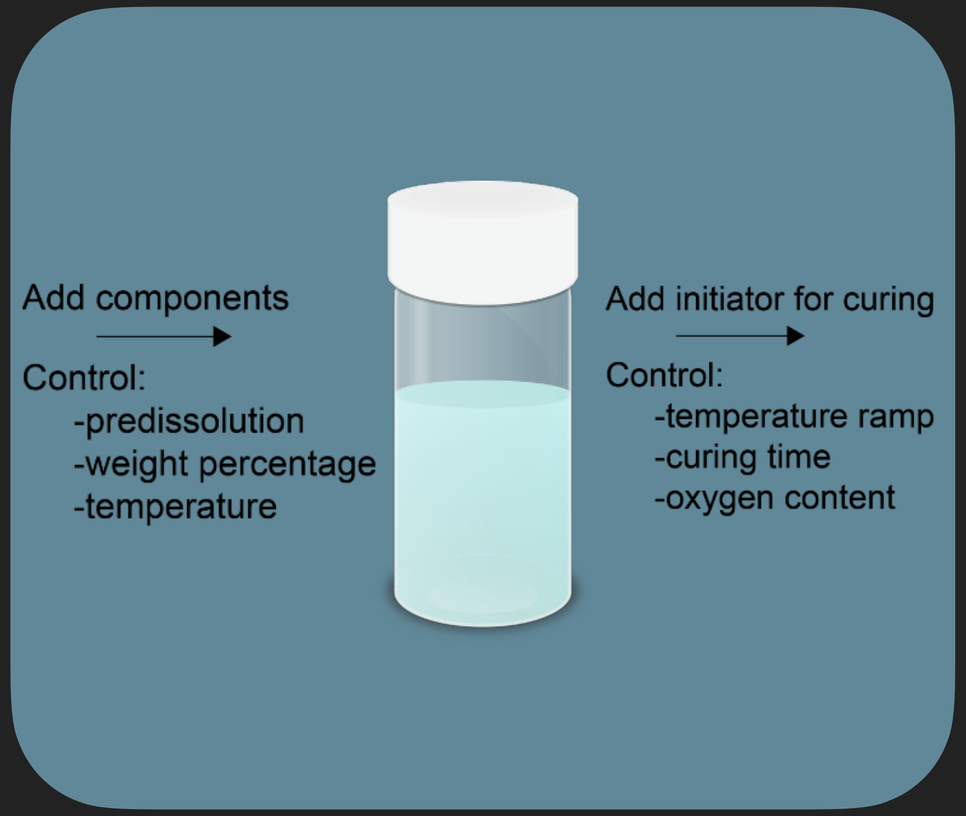
non-bonding interactions of ^{6}Li salt and MAA with PPO - would not occur with mTP



When using mTP as primary dye instead of PPO, critical point is for declining LO is not reached

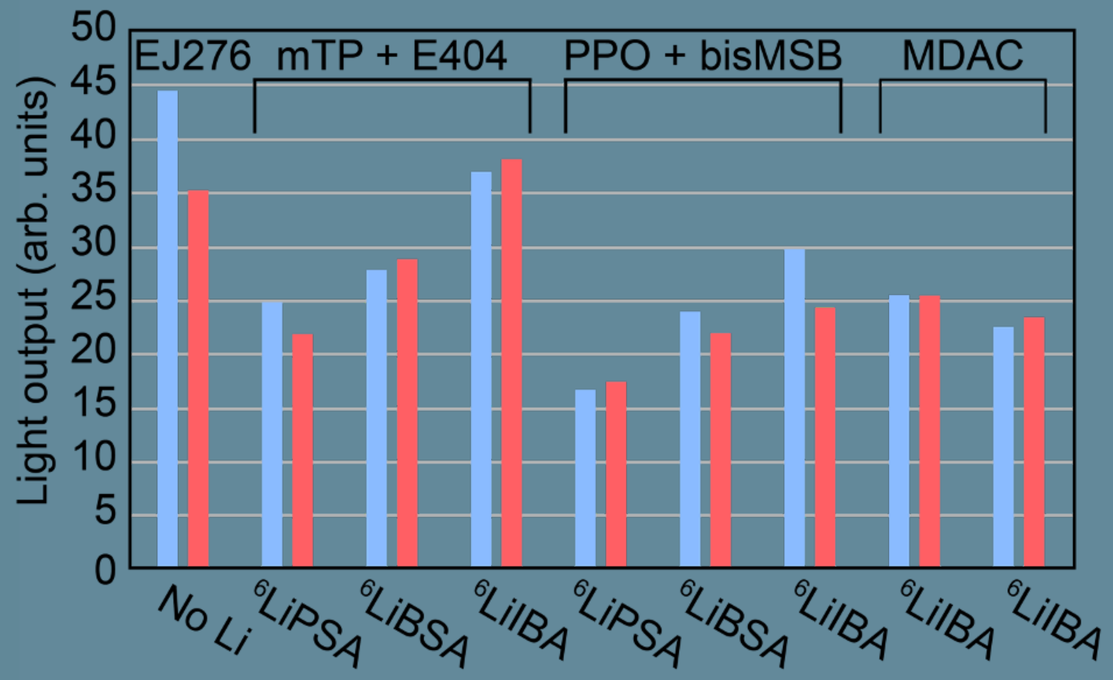
BASICS OF PSD PLASTIC CHEMISTRY

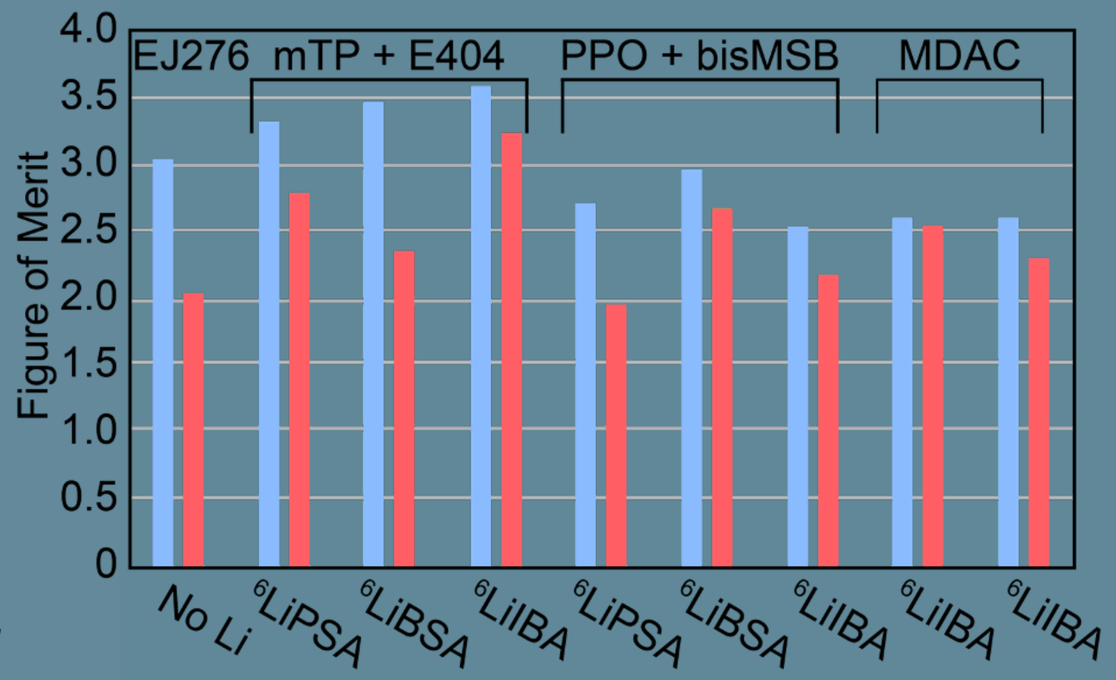




Dyes used during the production may impact the long way stability of the plastics

STABILITY OF PLASTICS



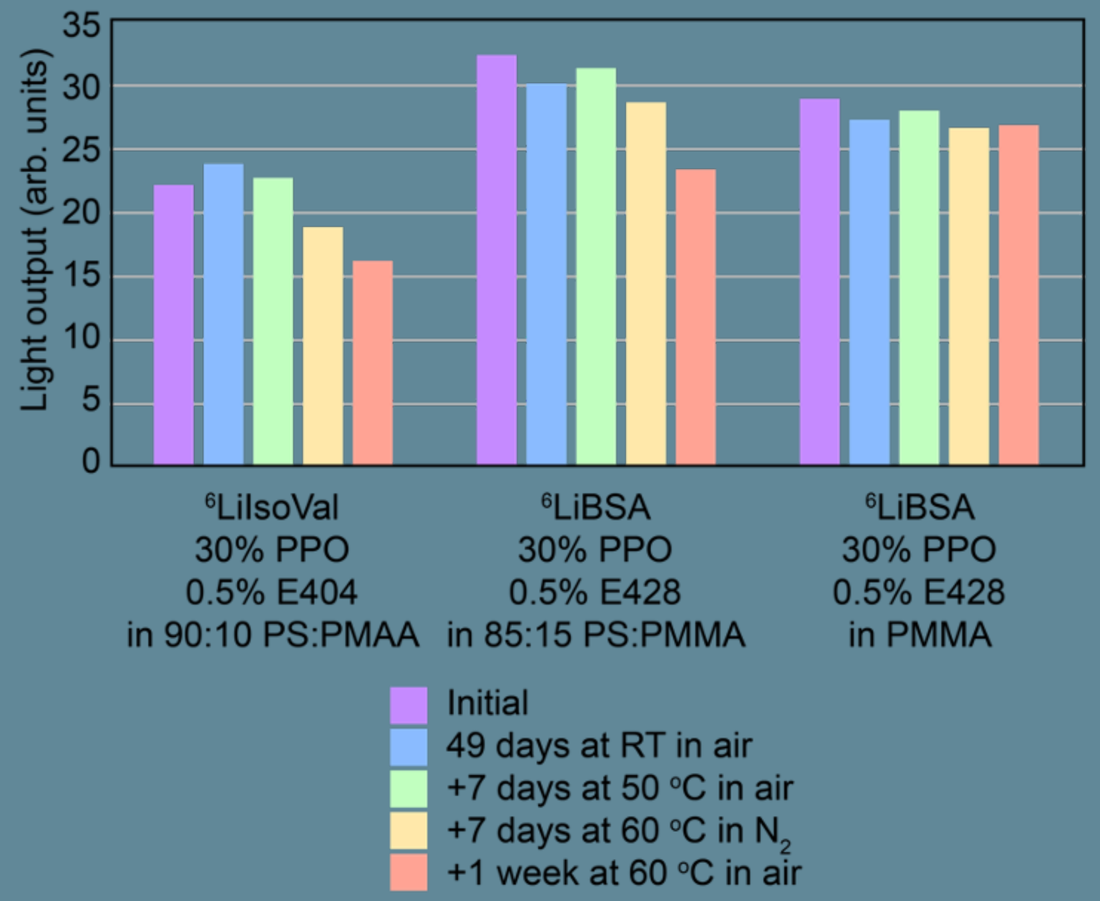


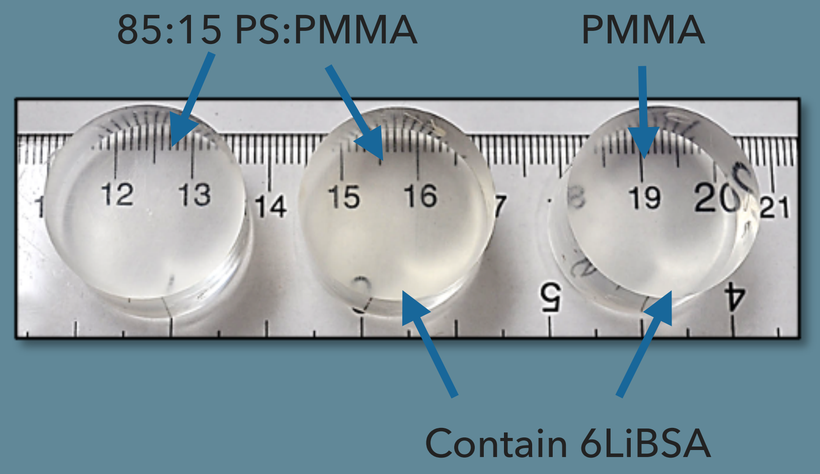
initial
2 years later

Plastics with ^{6}LiPSA, ^{6}LiBSA contain 85:15 PS:PMMA
Plastics with ^{6}LiIBA contain 90:10 PS:PMAA

mTP and MDAC (actual antioxidant) show promising results regarding long term stability

STABILITY OF PLASTICS





Higher temperatures and air are clear reasons for early degradation.

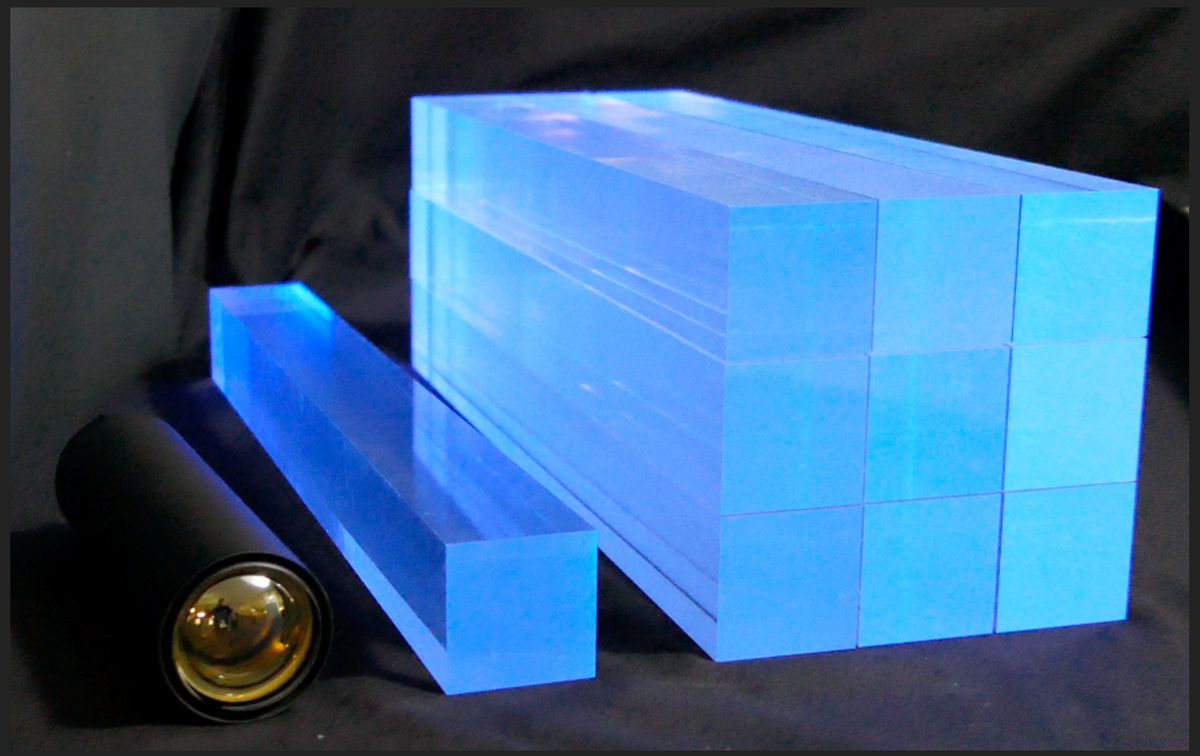
HOME PRODUCTION OF PLASTIC AT LARGE SCALE PROVED CHALLENGING (TEMPERATURE, CONTROL ENVIRONMENT…)

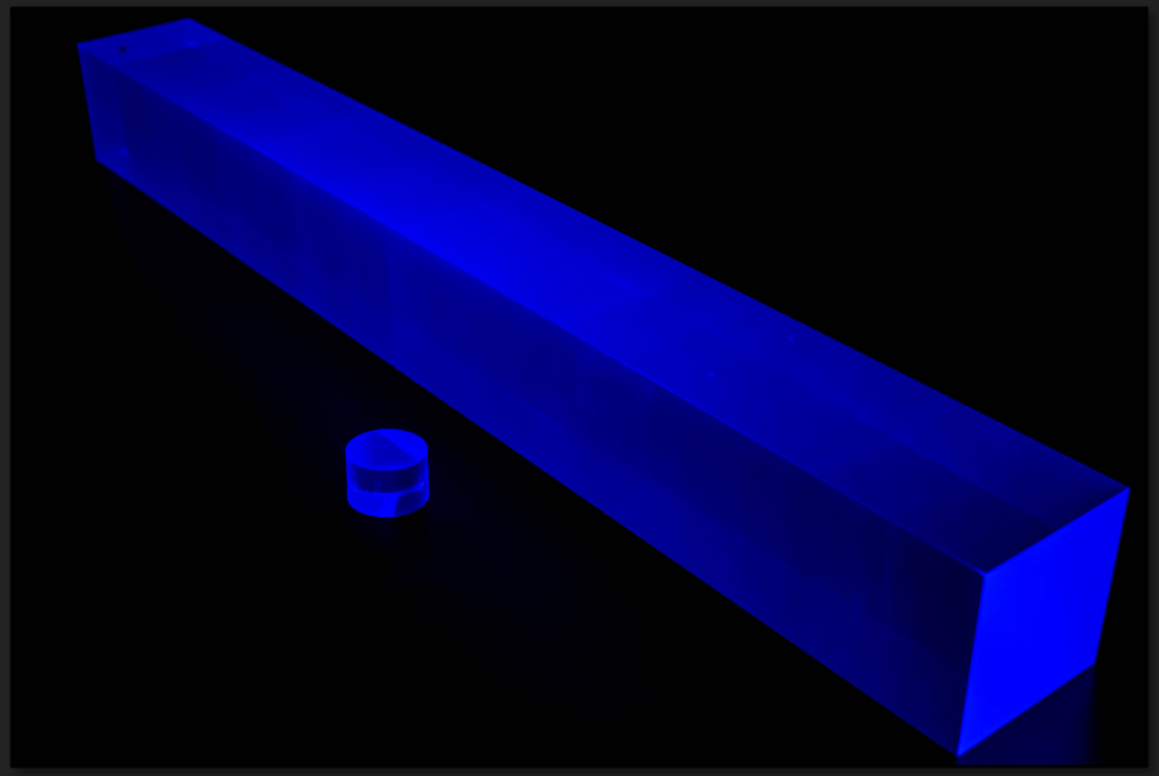
Initial attempts to fabricate plastics at larger scale had defects, discoloration and opacity

FROM LAB TO COMMERCIAL PRODUCTION

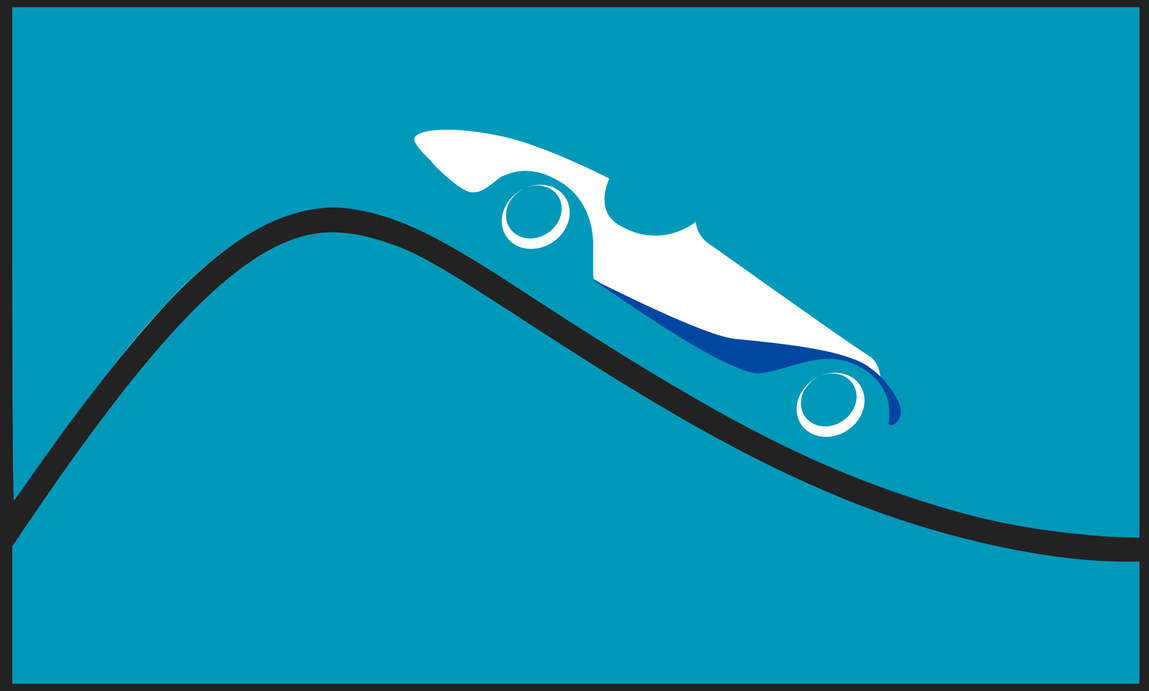
External collaborator is consistently producing batches of 5.5x5.5x50 cm bars for testing

FINAL PRODUCT





External collaborator is consistently producing batches of 5.5x5.5x50 cm bars for testing



ROADSTR

A MOBILE ANTINEUTRINO DETECTOR

TESTING NEW PSD PLASTIC TECHNOLOGY

THE ROADSTR PROGRAM AT LLNL

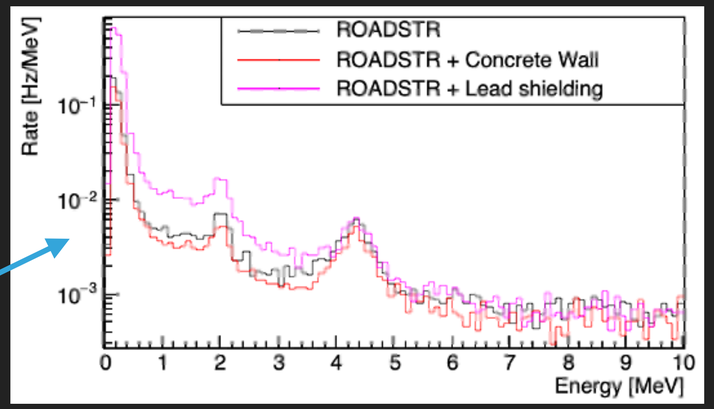
Reactor **O**perations **A**ntineutrino **D**etection **S**urface **T**estbed **R**over

- Building from recent advances, our goals are to develop and demonstrate enabling technologies for mobile antineutrino detectors

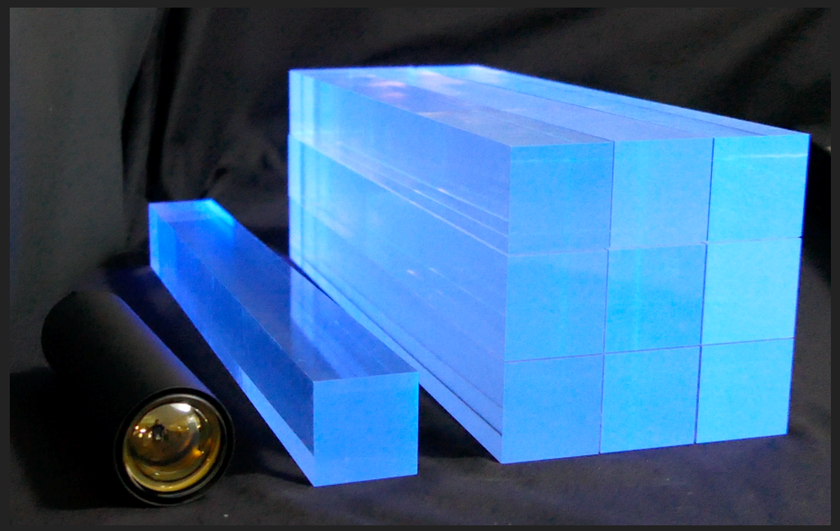
ROADSTR

Areas of development

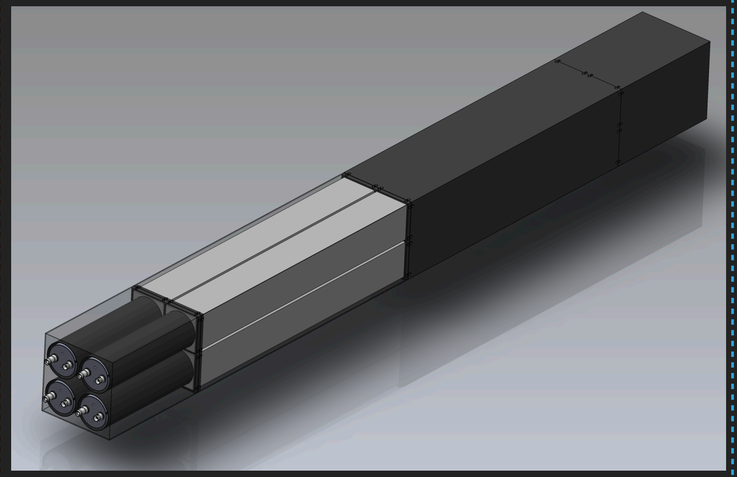
Background prediction



PSD Plastic Scintillators



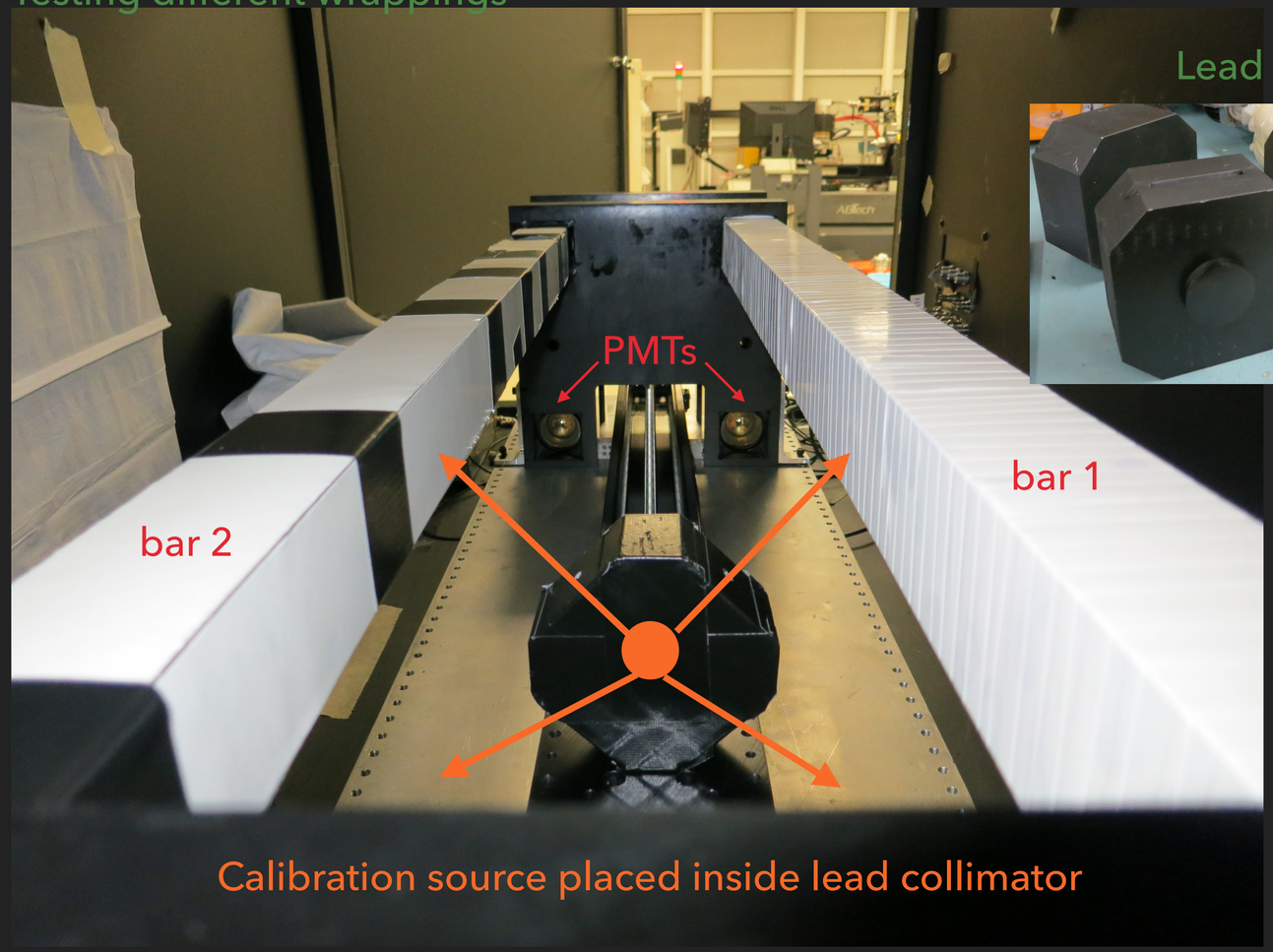
Segmented geometries



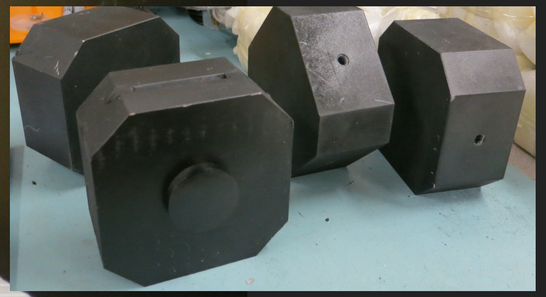
Mobile deployment engineering

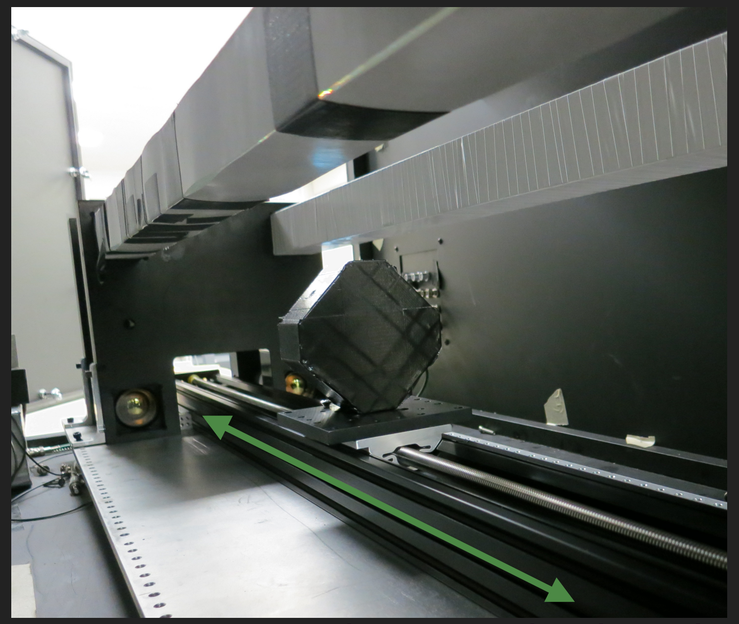
CHARACTERIZATION SETUP FOR COMMERCIALLY PRODUCED BARS

Testing different wrappings



Lead collimators



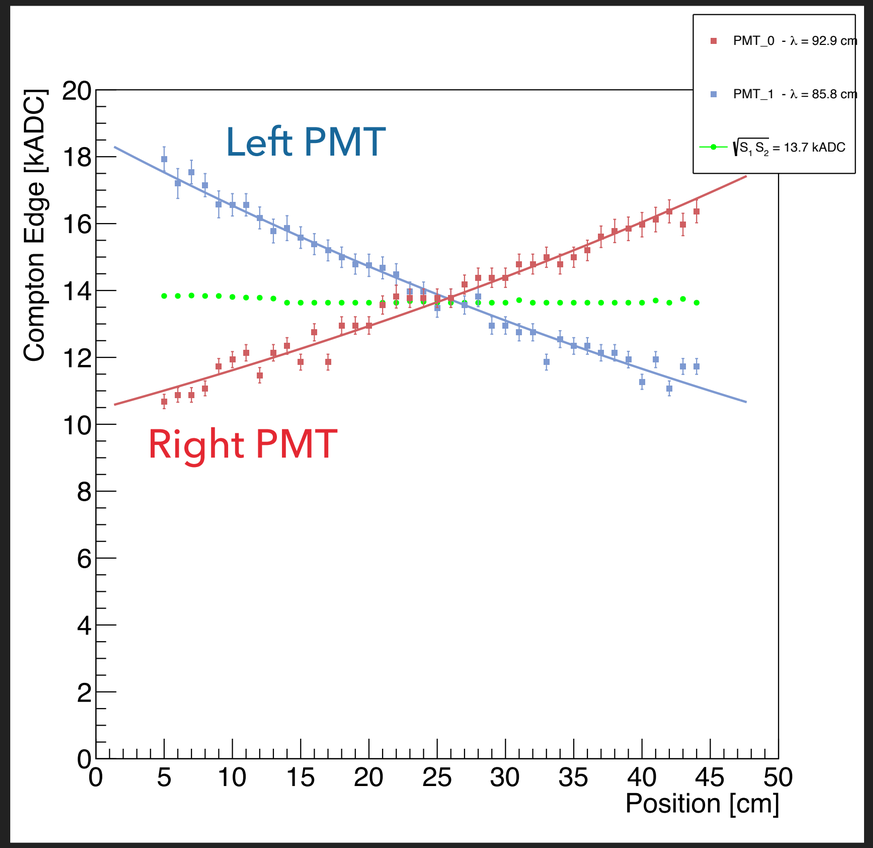


Collimator moves across the setup thanks to linear stage

- Hosts up to 4 segments with **double PMT** readout.
- Linear stage allows precise **position-scan**

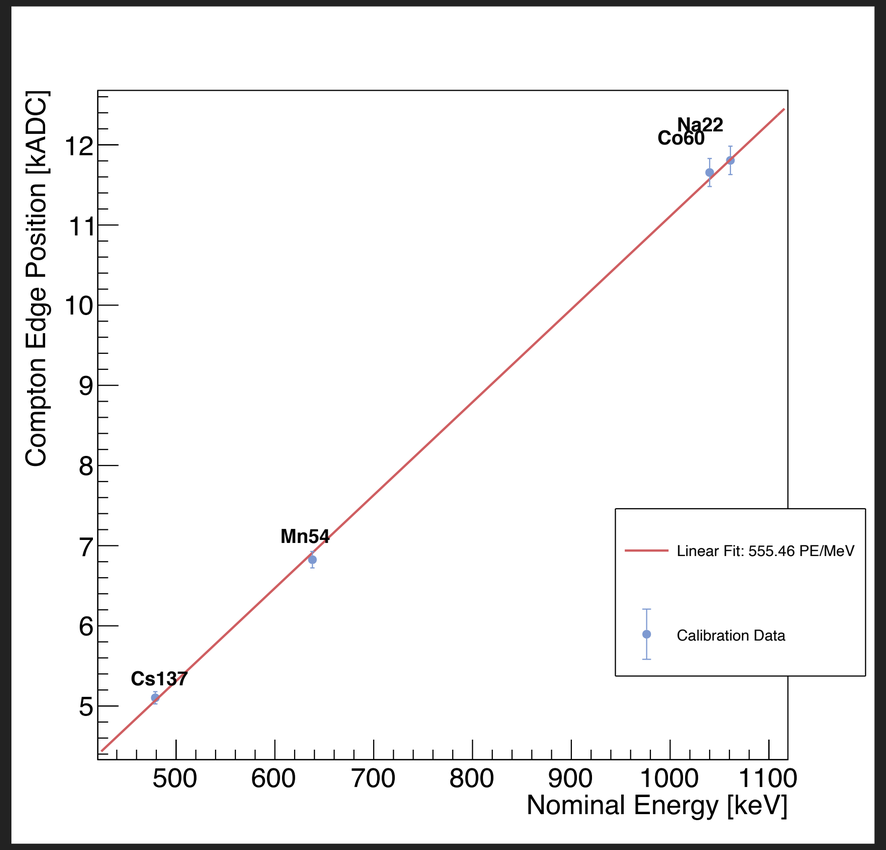
Characterization setup allows for multi-bar testing using different collimated sources placed at varying positions remotely controlled

LINEARITY TEST USING DIFFERENT SOURCES



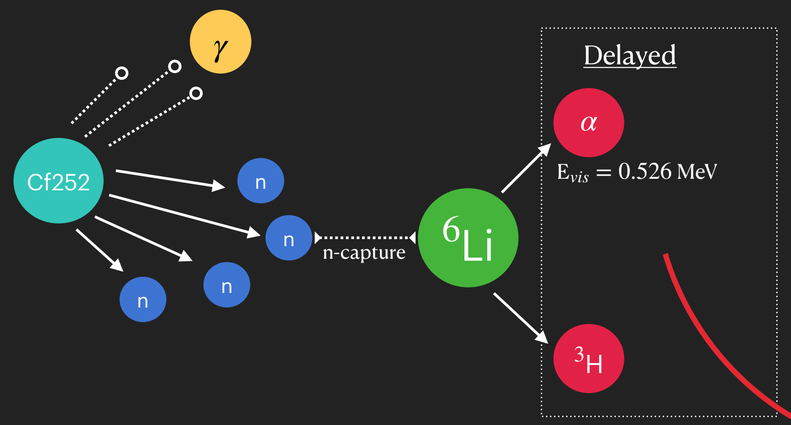
- Position scan displays long attenuation lengths ~80 cm
- Multi-source measurements show good linearity and effective light yield of ~500-600 PE/MeV

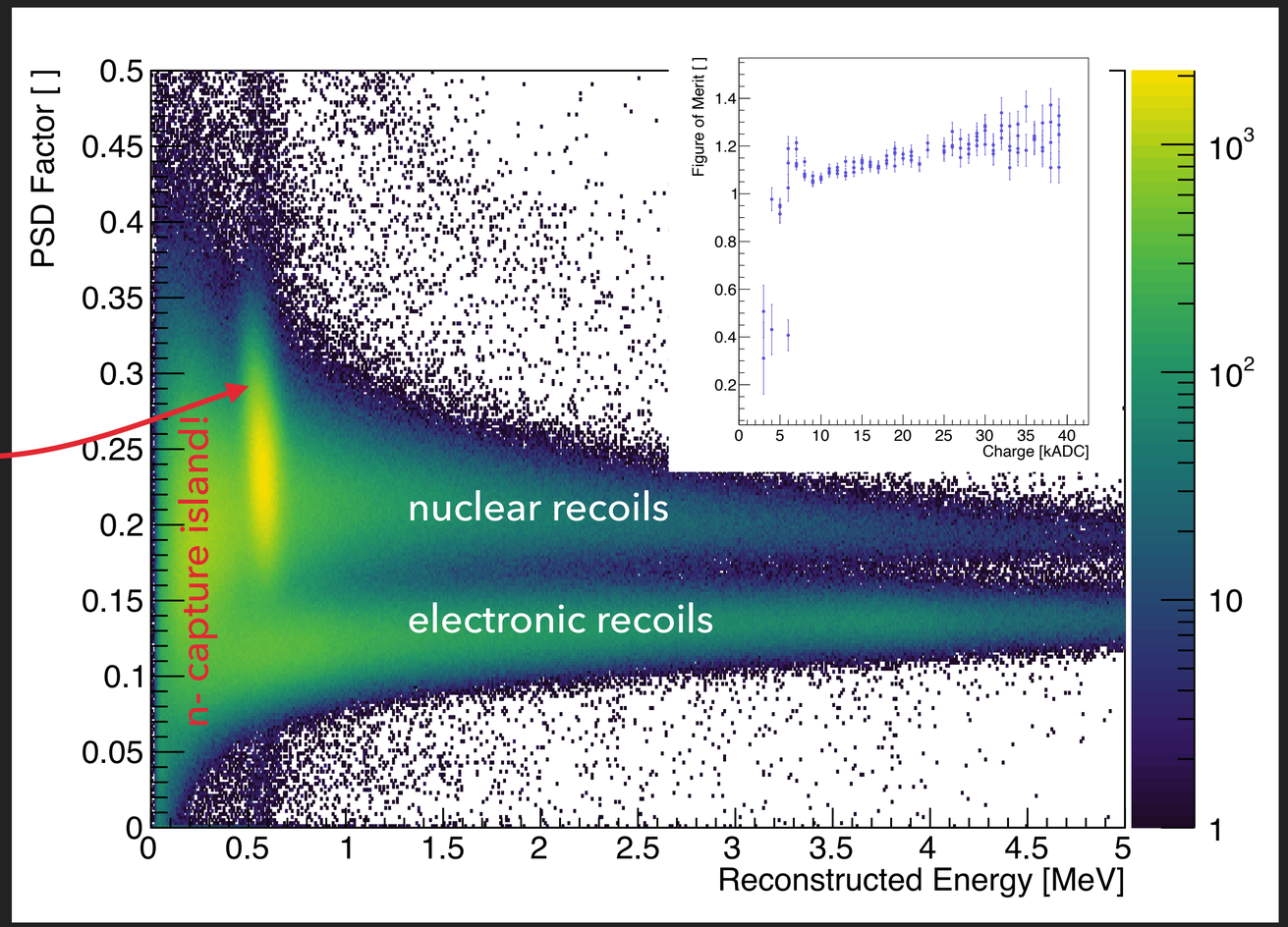
- After characterization, bars are stored in vacuum to avoid deterioration.
- Control bar left in contact with air to test stability of material



All bars tested to this moment have display consistent results in terms of attenuation length and light output

PSD CAPABILITIES USING CF252





- The plastics show excellent PSD capabilities.
- Clear and distinct n-capture island.
- Figure of Merit ~ 1.2 between nuclear and electronic recoils (work in progress)

Being able to

SUMMARY

- The **PROSPECT aboveground** detection is an important capability **demonstration** for reactor **monitoring applications** and other **reactor neutrino** studies
- **Mobile** aboveground systems that maintain **high sensitivity** are a clear **next step** along the technology development path

---

- The **ROADSTR** program at the **LLNL** is **advancing** PSD Plastic Scintillator **technology :**
  - Different 6Li salts (Aliphatic / Aromatic) , solubility monomers (MMA / MAA) and primary dyes (PPO/mTP, MDAC) considered
  - Plastic elaboration approach is extensible to large scale and it's been transferred for external production.
  - Long-term and stability effects on the plastics still under research.


Thanks for your attention!