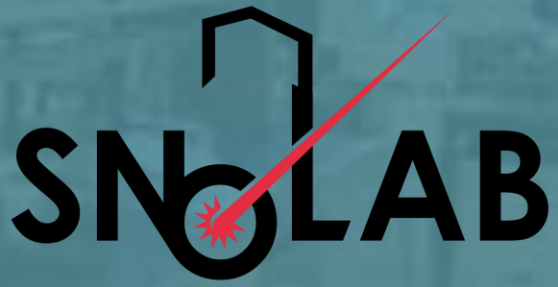
Developing Silver Doped Zinc Sulfide Scintillator for Lucas Cell ^{222}Radon Counting

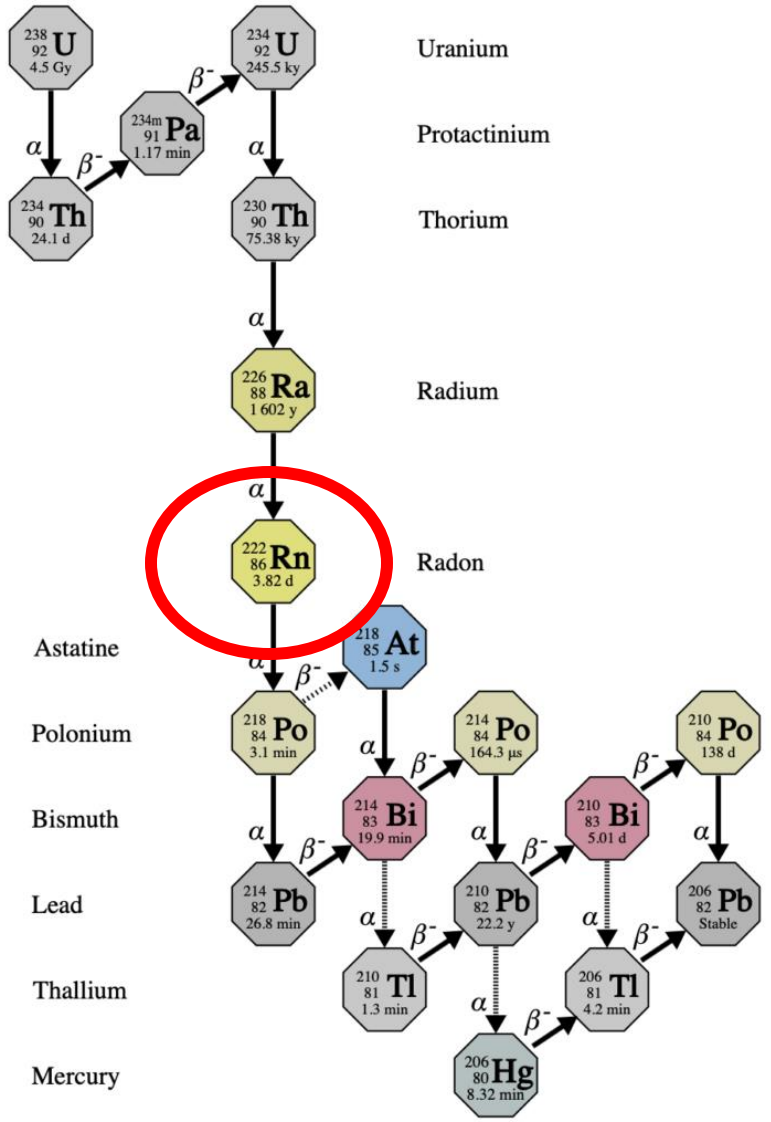
Kacper Rogut (He/Him)
Undergraduate Chemistry Assistant



Background: Radon at SNOLAB

Intro to the project

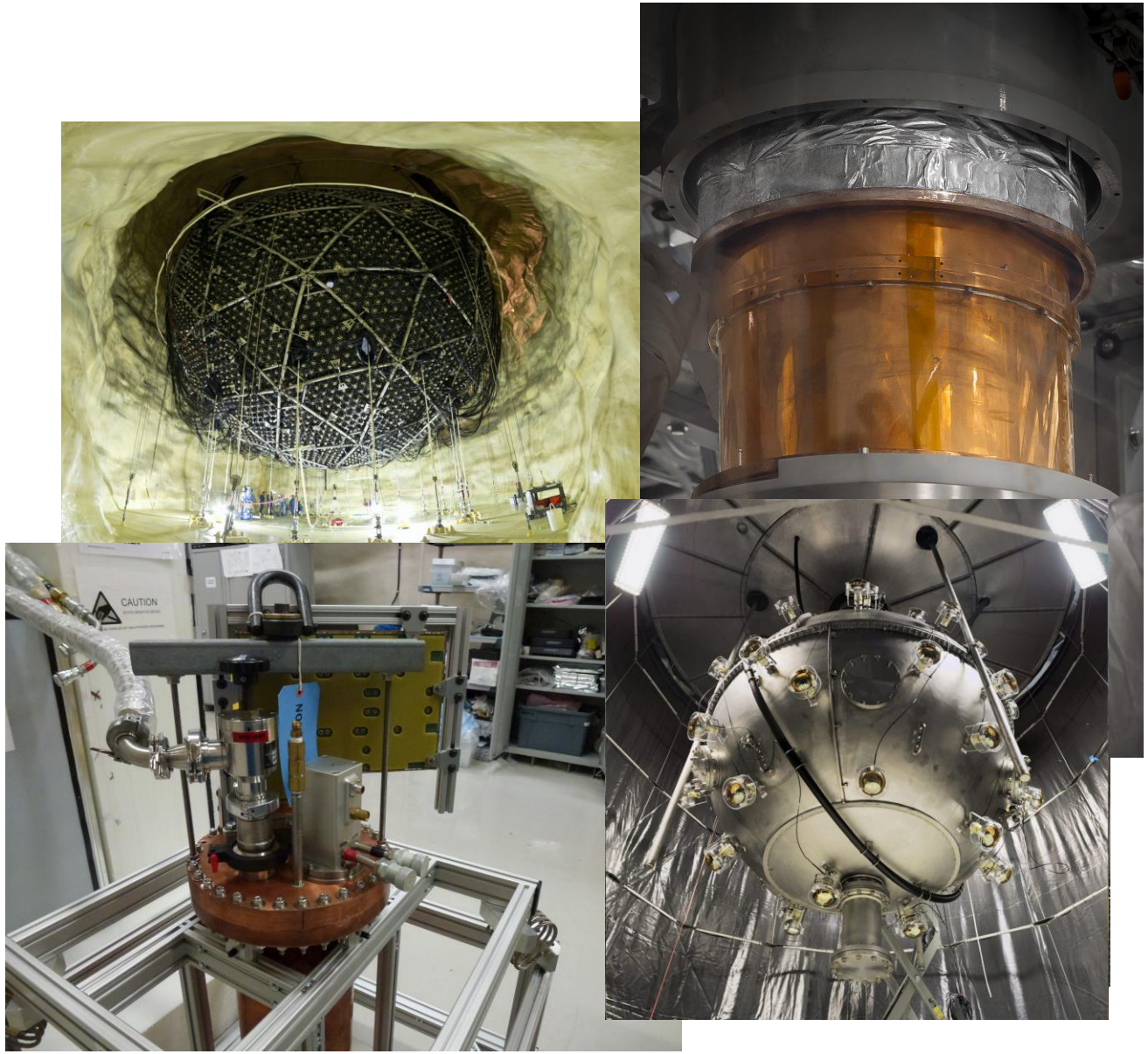
- First thing to understand is Radon
  - Noble Gas
  - α-particle decay
  - ^{222}Rn half-life ~4 days
- Emanates from materials and from underground
- A significant background source in low background experiments



Intro to the project

- Radon assay boards used for
  - High sensitivity radon emanation measurement

- SNOLAB experiments that use Rn measurements
  - SNO+
  - CUTE
  - DAMIC
  - DEAP-3600
  - XLZD

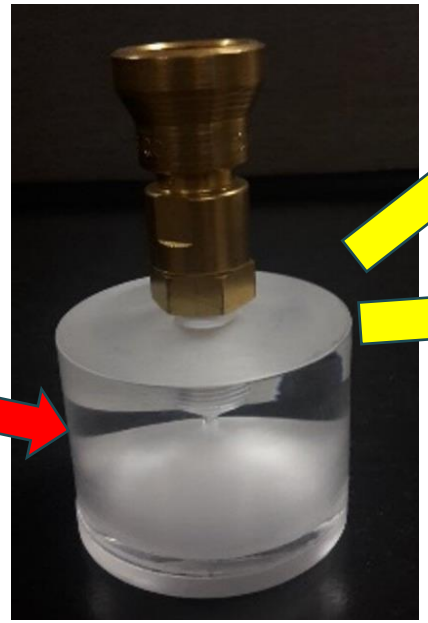


Improving radon assay capabilities is a priority at SNOLAB

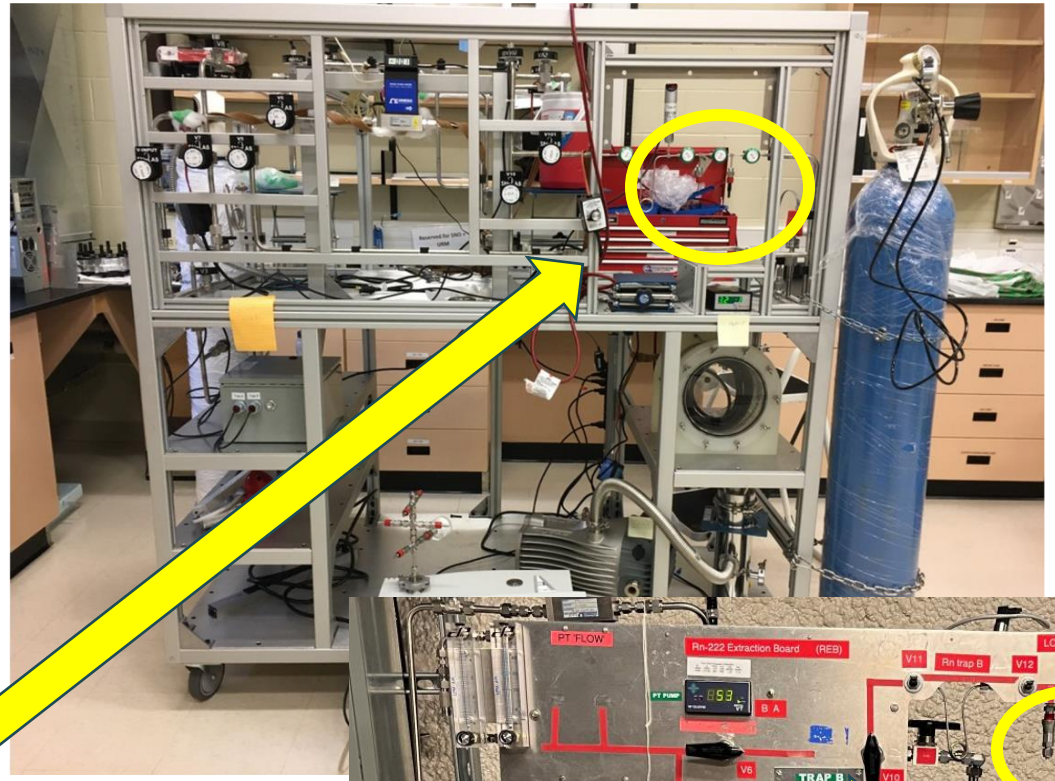
Background

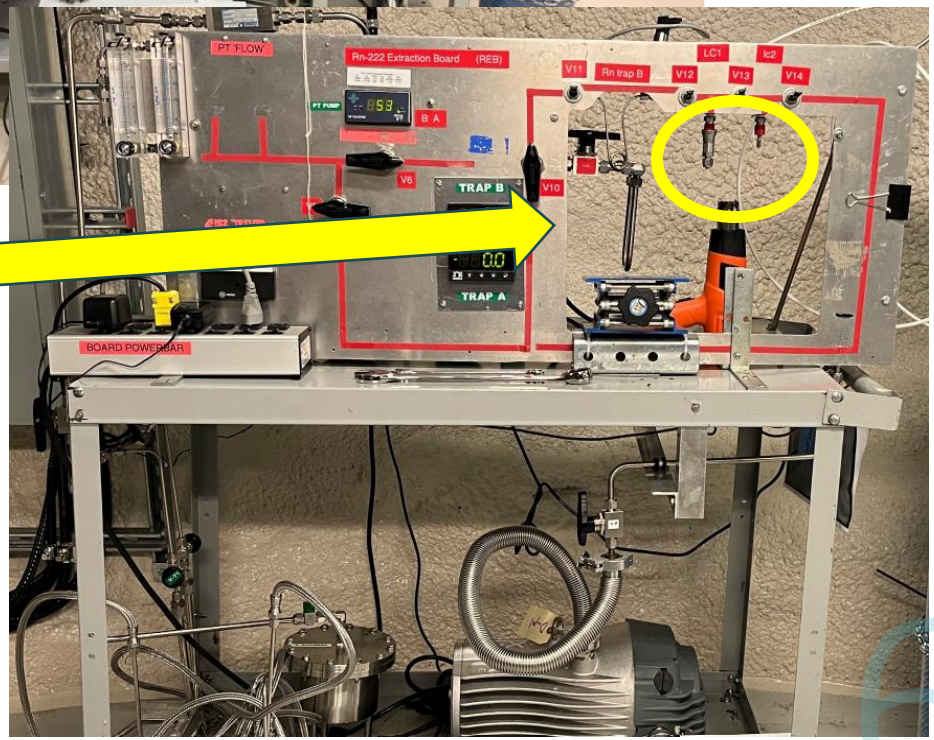
- Your new favourite words:
  Lucas Cell and ZnS:Ag

ZnS:Ag



Lucas Cell (LC)





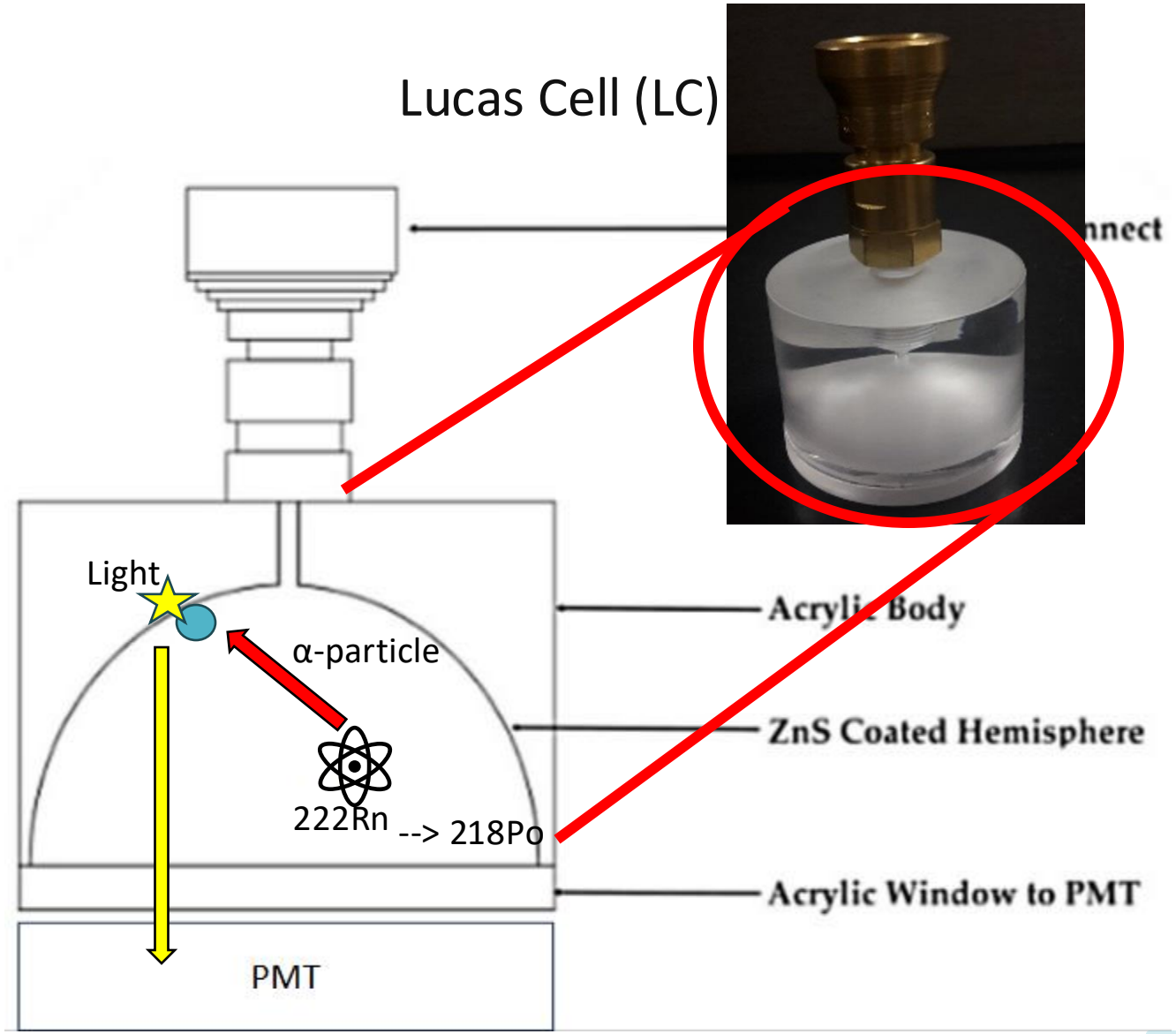
Questions

- Who is Lucas?

- What is a Lucas Cell?

  - Measures Radon decay using α-particle scintillator, ZnS:Ag

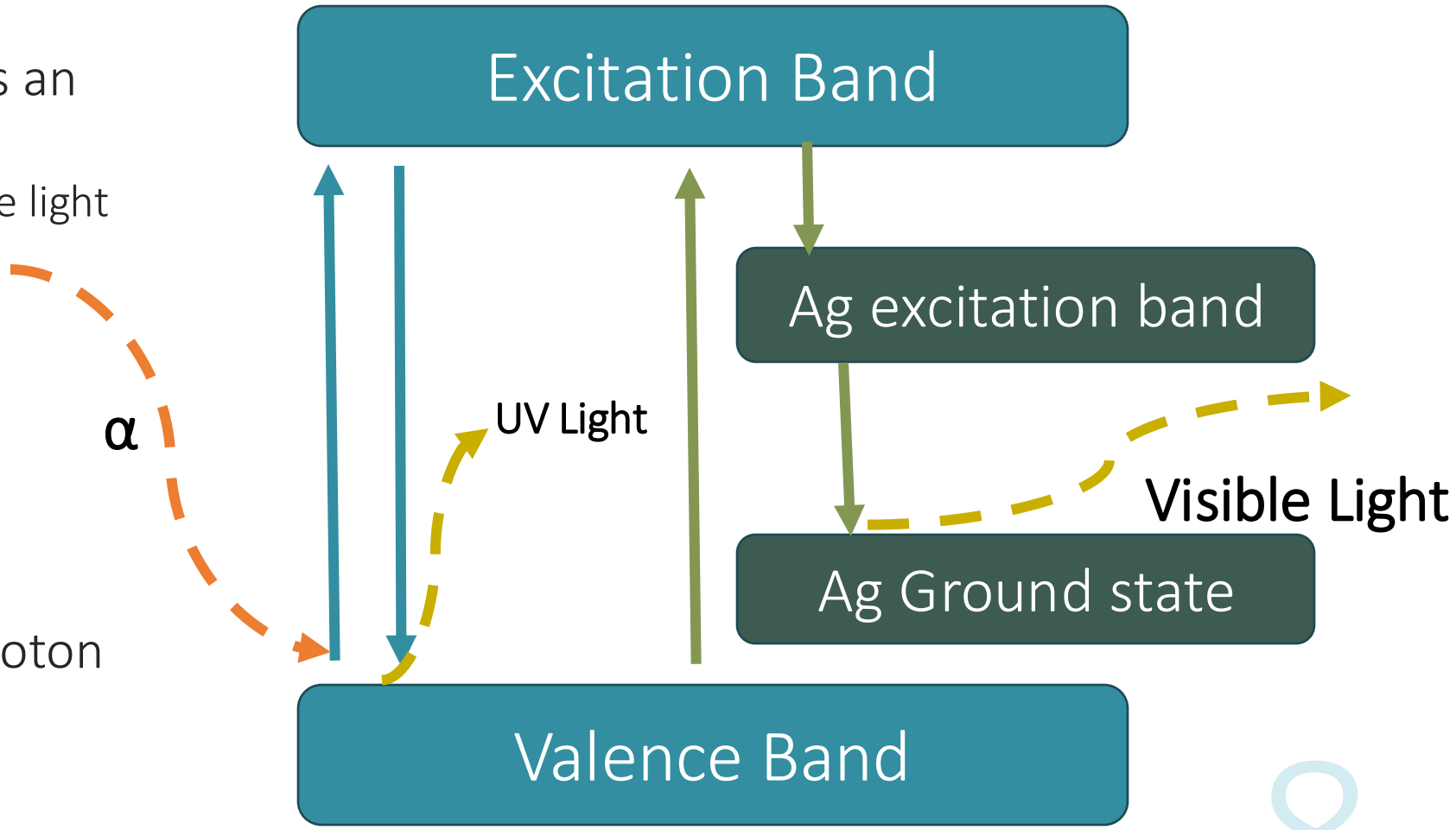
- Photomultiplier tube (PMT) collects and amplifies light so it can be analyzed



Background- Scintillation

- ZnS scintillation requires an activator.
  - Silver provides a bright blue light and is ideal for alpha

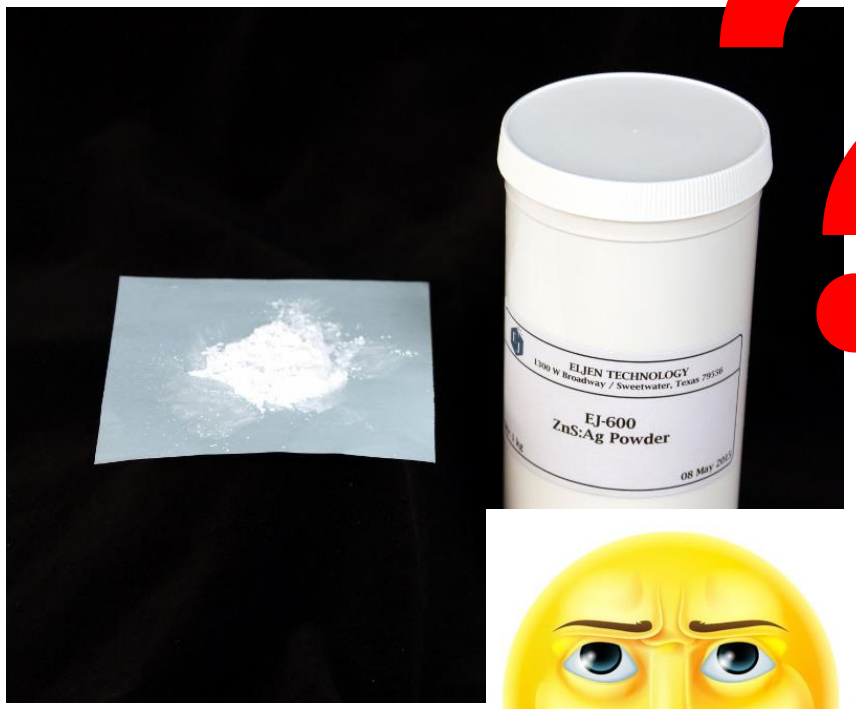
- Band gap is forbidden
- Excitation of electron
- Energy transfer to an activator (Ag)
- De-excites and emits photon



Background

- LC is coated with ZnS:Ag
- Should we buy commercial?

NO



ZnS:Ag

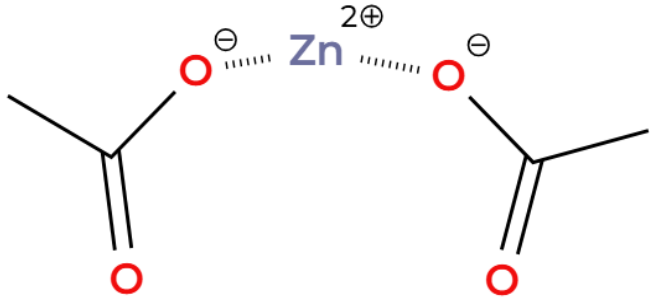
Lucas Cell (LC)

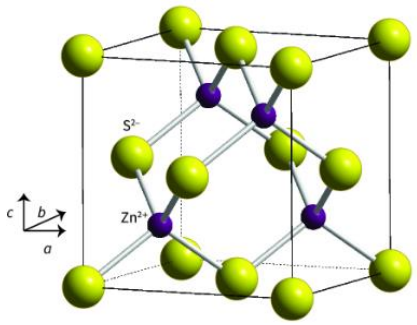
- Too much background for our low-background experiments!
- This is my role... synthesizing low-background ZnS:Ag

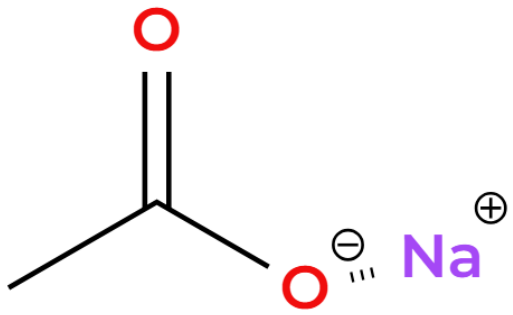
Experiment - Synthesis

1. Synthesize zinc sulfide
2. Silver doping

- Zinc Acetate and Sodium sulfide as initial reagents

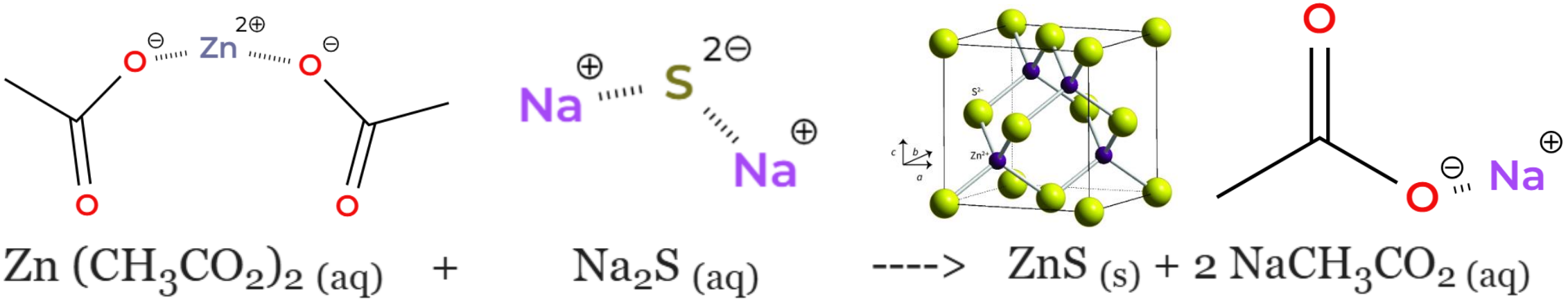






$$Zn\,(CH_3CO_2)_{2\,(aq)} + Na_2S_{\,(aq)} \longrightarrow ZnS_{\,(s)} + 2\,NaCH_3CO_{2\,(aq)}$$

Experiment - Synthesis



$$Zn(CH_3CO_2)_{2\,(aq)} + Na_2S_{(aq)} \longrightarrow ZnS_{(s)} + 2\,NaCH_3CO_{2\,(aq)}$$

- Zinc Sulfide is formed as a precipitate.
  - Everything else stays in solution.
- Product is filtered and collected as a wet solid

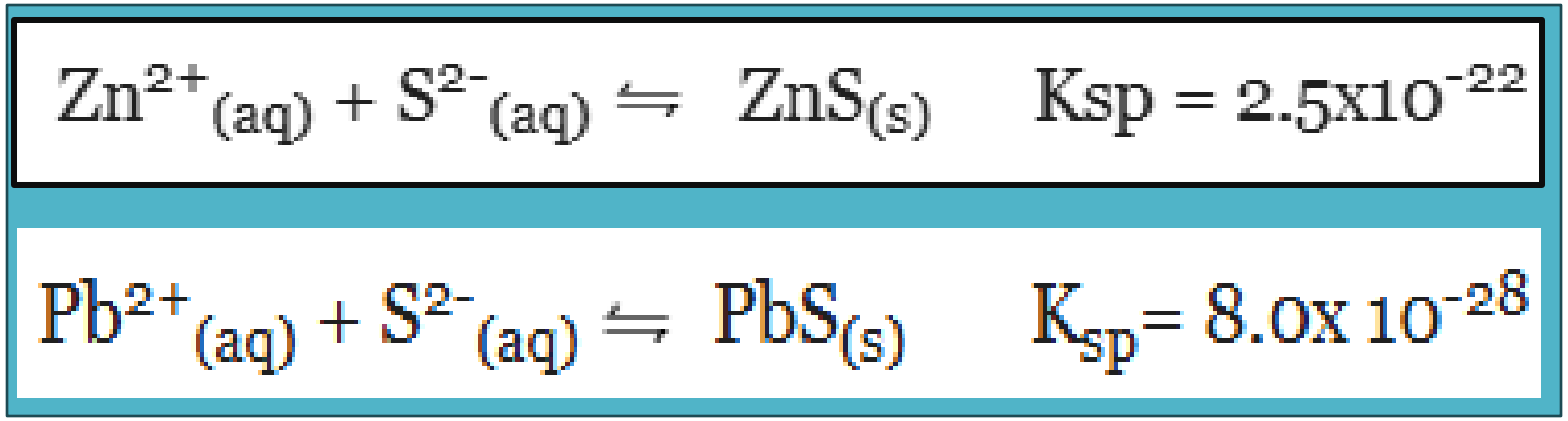
  => Bulk ZnS

How do you remove background?

Selective Precipitate

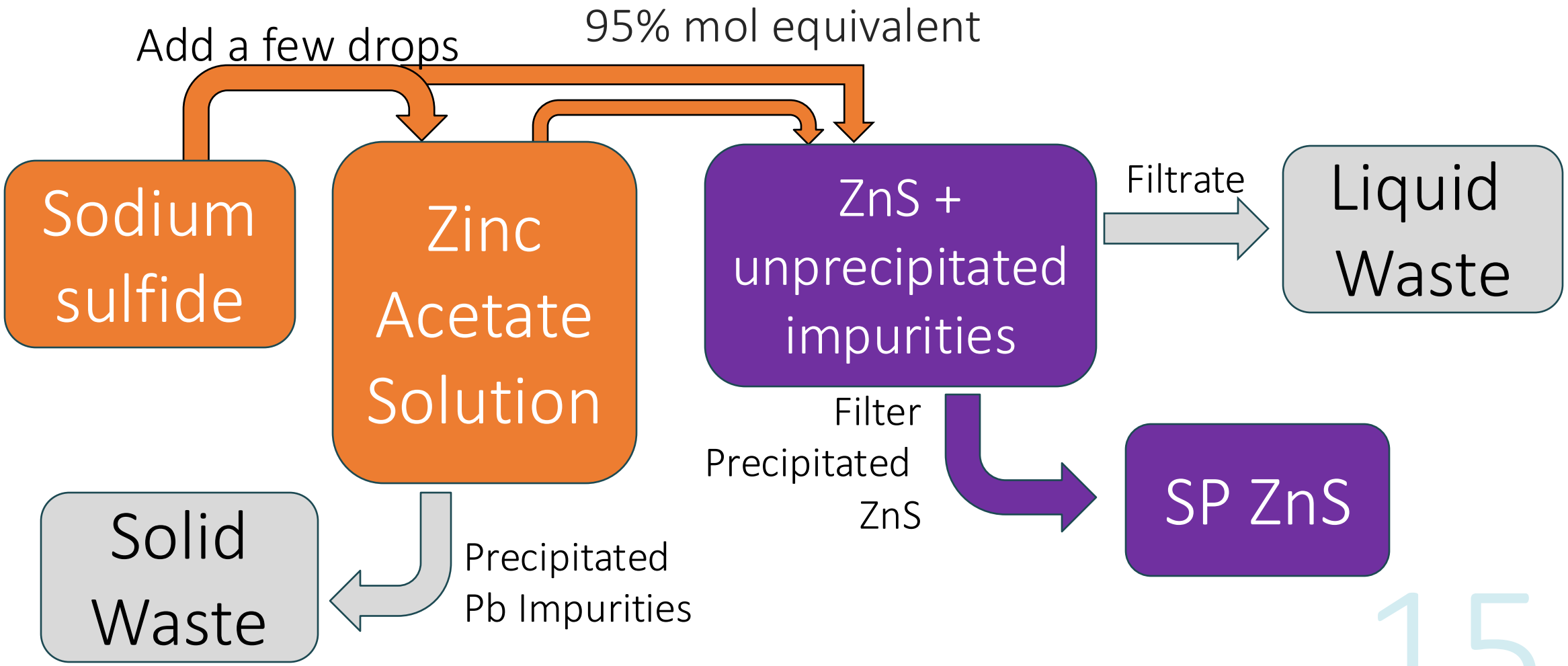
Experiment - Selective Precipitate

- This method takes advantage of Ksp, product solubility
    - Smaller Ksp = first to precipitate



- The impurities uranium, thorium, and lead have extremally small Ksp in this reaction

Experiment - Selective Precipitate

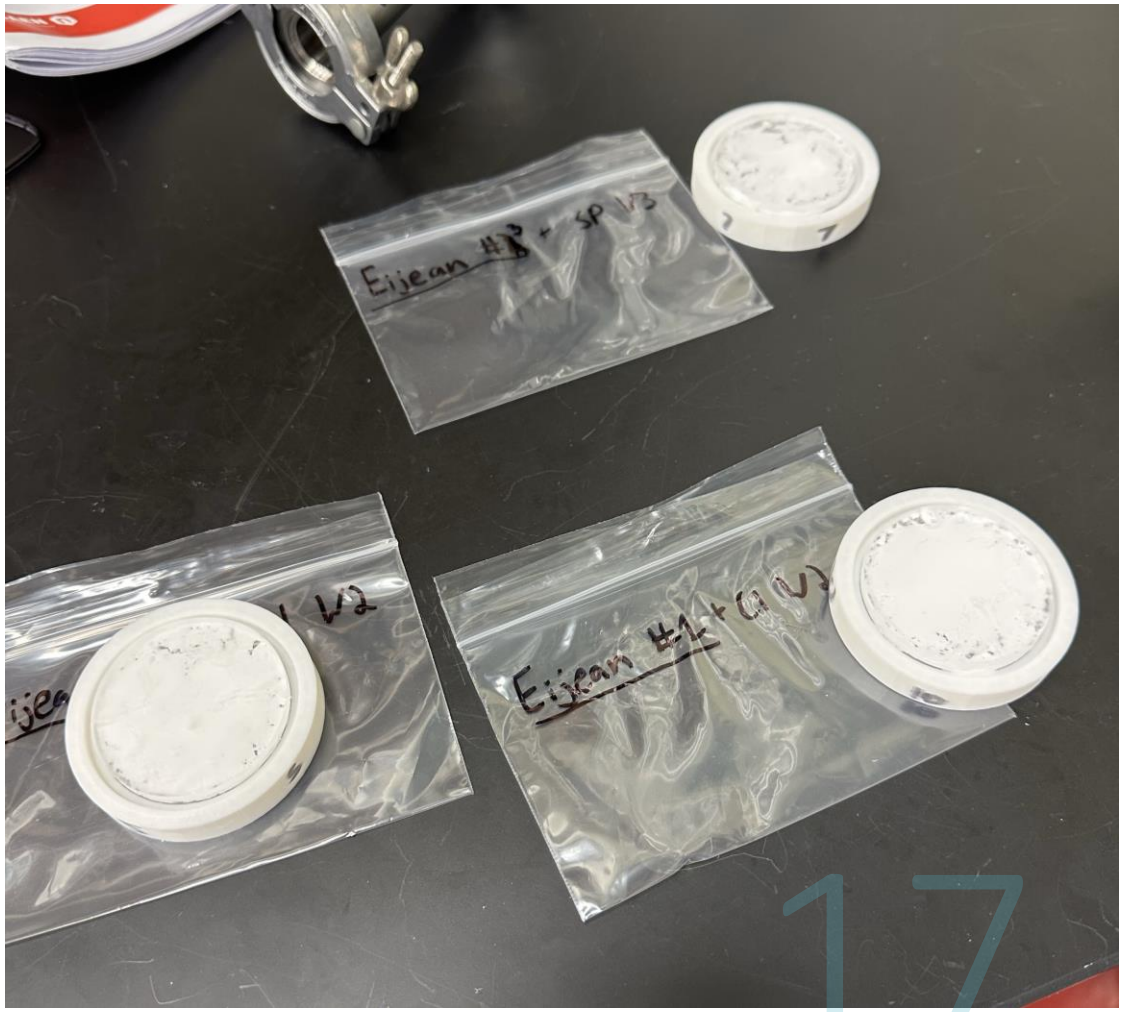


ZnS Background Testing

Experiment - Radon Counting

- Initial background testing:

- Three samples we tested:
  - In-house SP ZnS
  - In-house bulk ZnS
  - Commercial ZnS:Ag

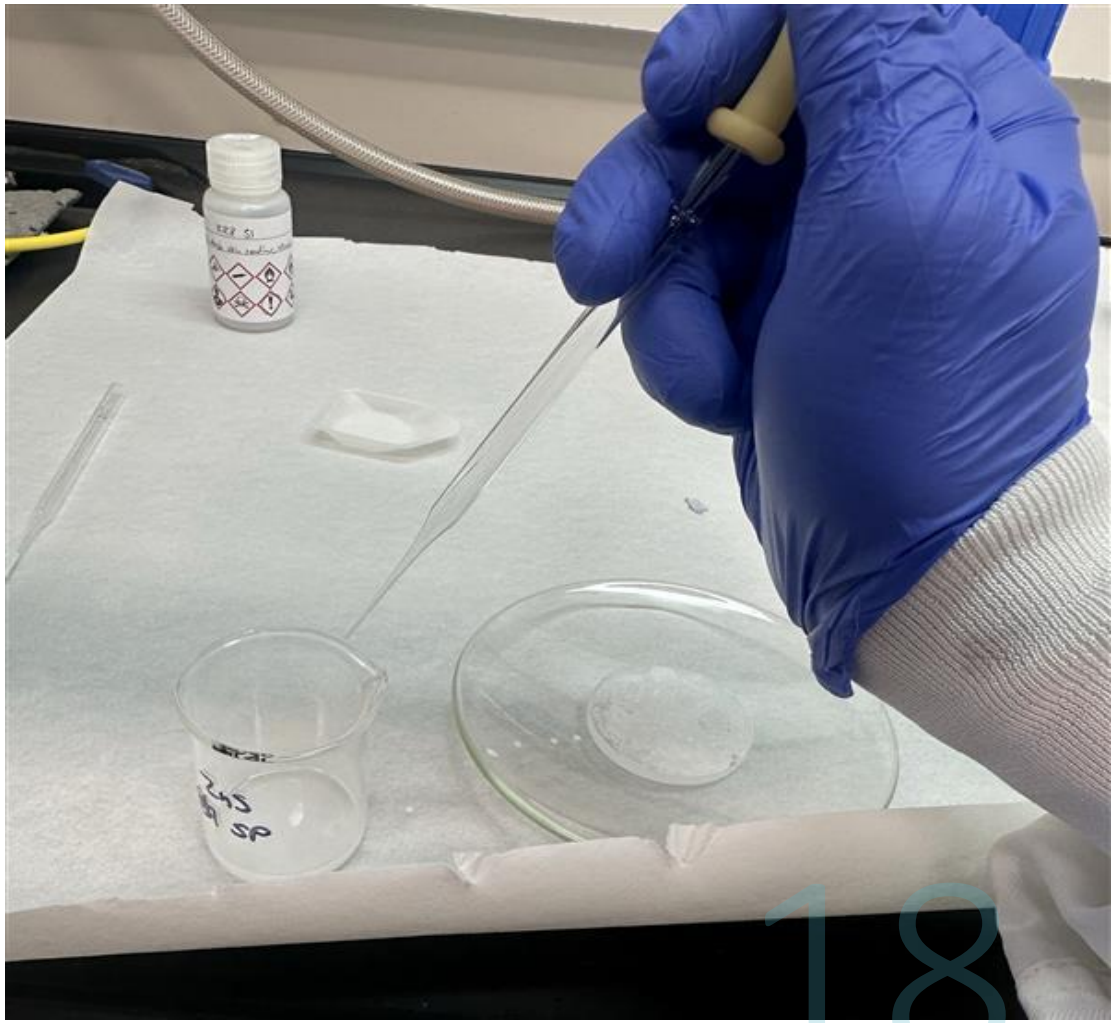


Experiment - Radon Counting

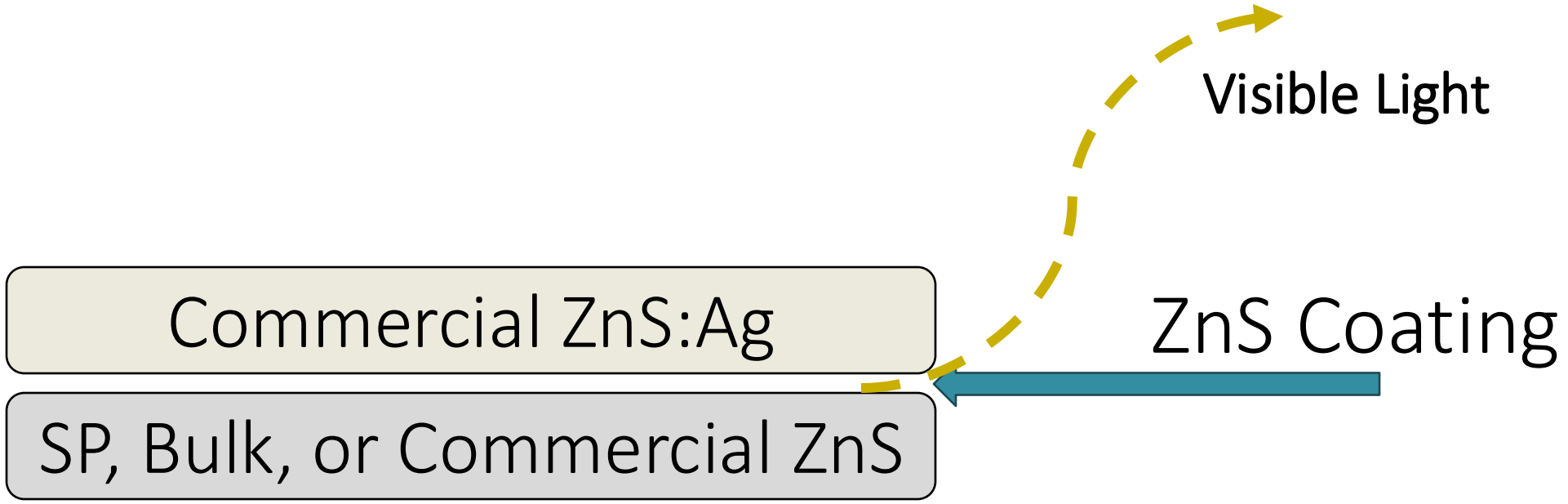
- Developed new procedure for Radon counting

  - Acrylic windows, same material as LC

  - Sandwich with a scintillating commercial ZnS:Ag



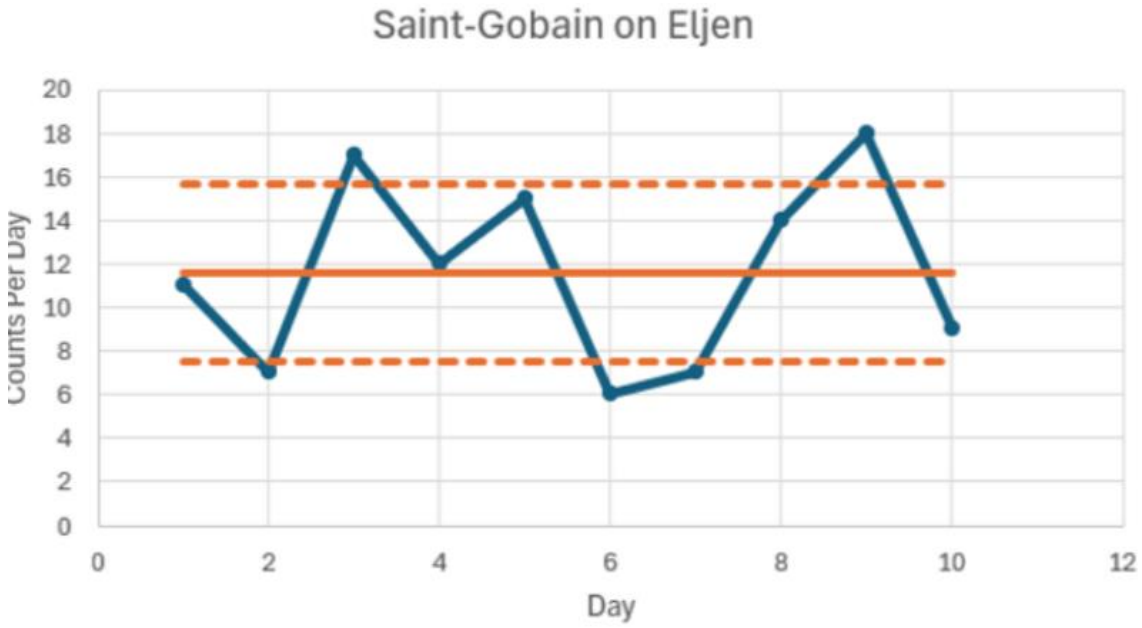
Experiment - Radon Counting

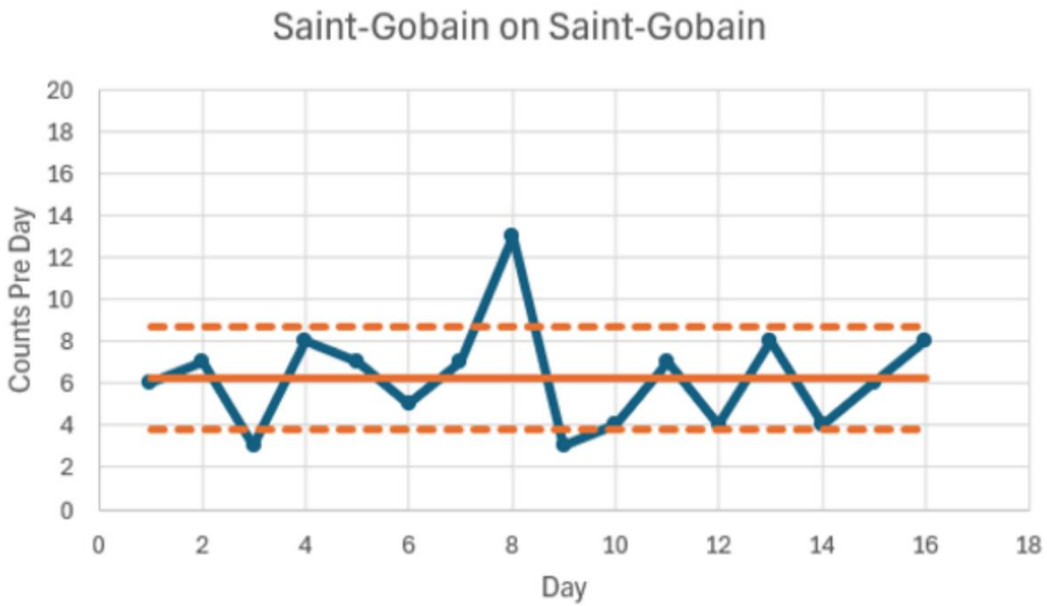


Experiment - Window Radon Counting

Sandwich:

Commercial on commercial ZnS:Ag





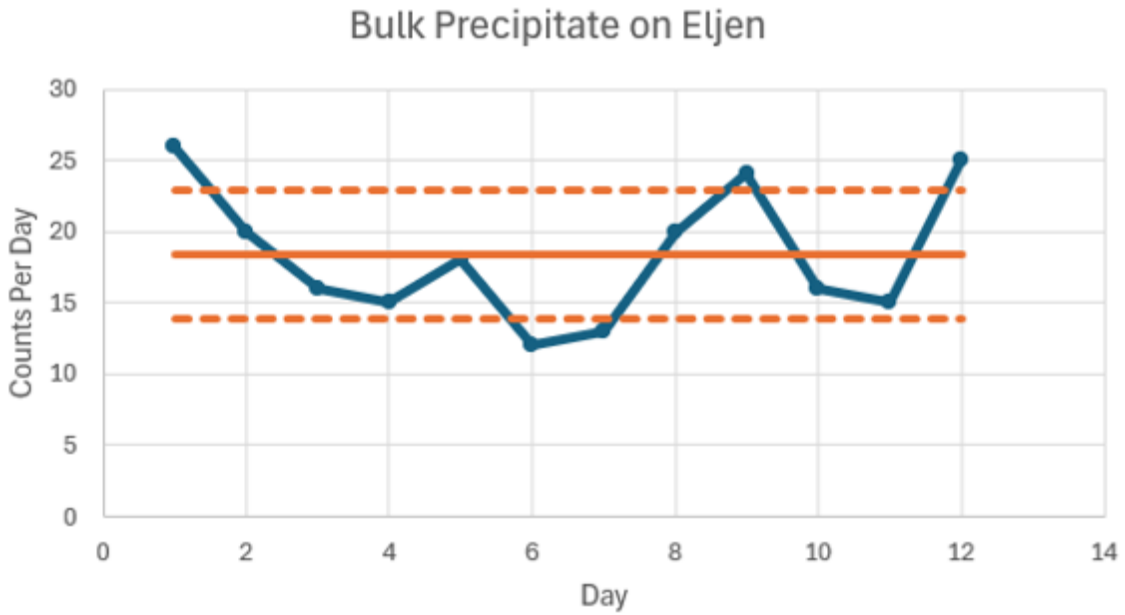
~12 Radon counts/day

~6 Radon counts/day

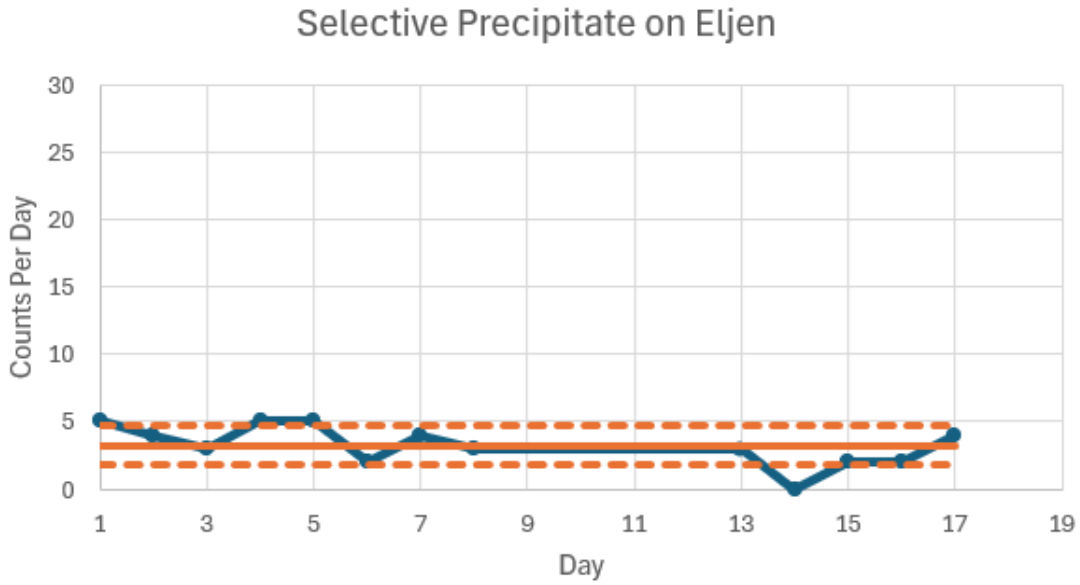
Experiment - Window Radon Counting

Sandwich:

In-House ZnS on commercial ZnS:Ag



~18 Radon counts/day



~3 Radon counts/day

Experiment - Window Radon Counting

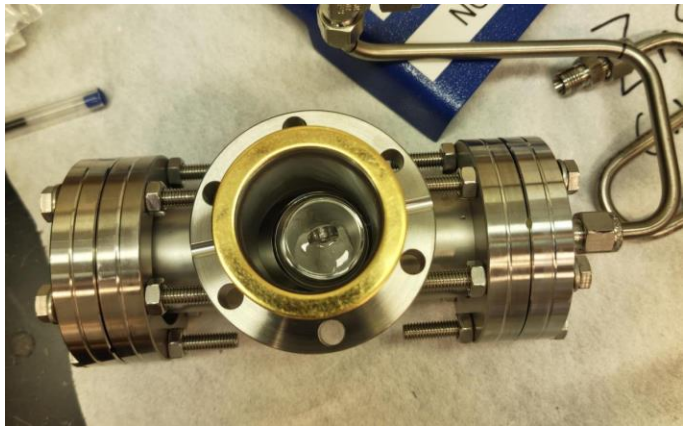
Bottom Window	Top Window	Radon Count / Day
In-house ZnS SP	Commercial Eljean	3
Commercial St.G	Commercial St.G	6
Commercial St.G	Commercial Eljean	12
In-house ZnS Bulk	Commercial Eljean	18

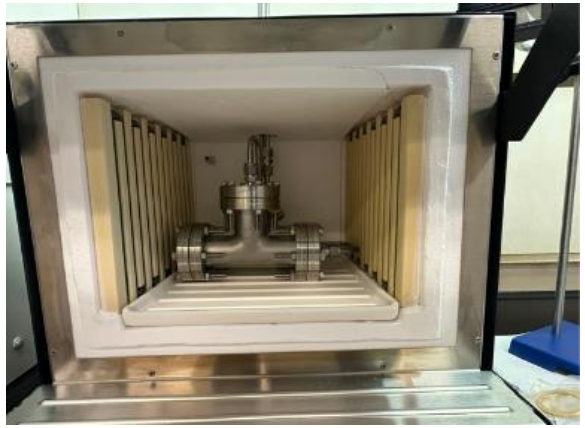
- Two coatings, therefore SP may be as low as 0 counts / day
- This demonstrates our new Rn assay system is working and lowering ZnS:Ag background

Silver Doping

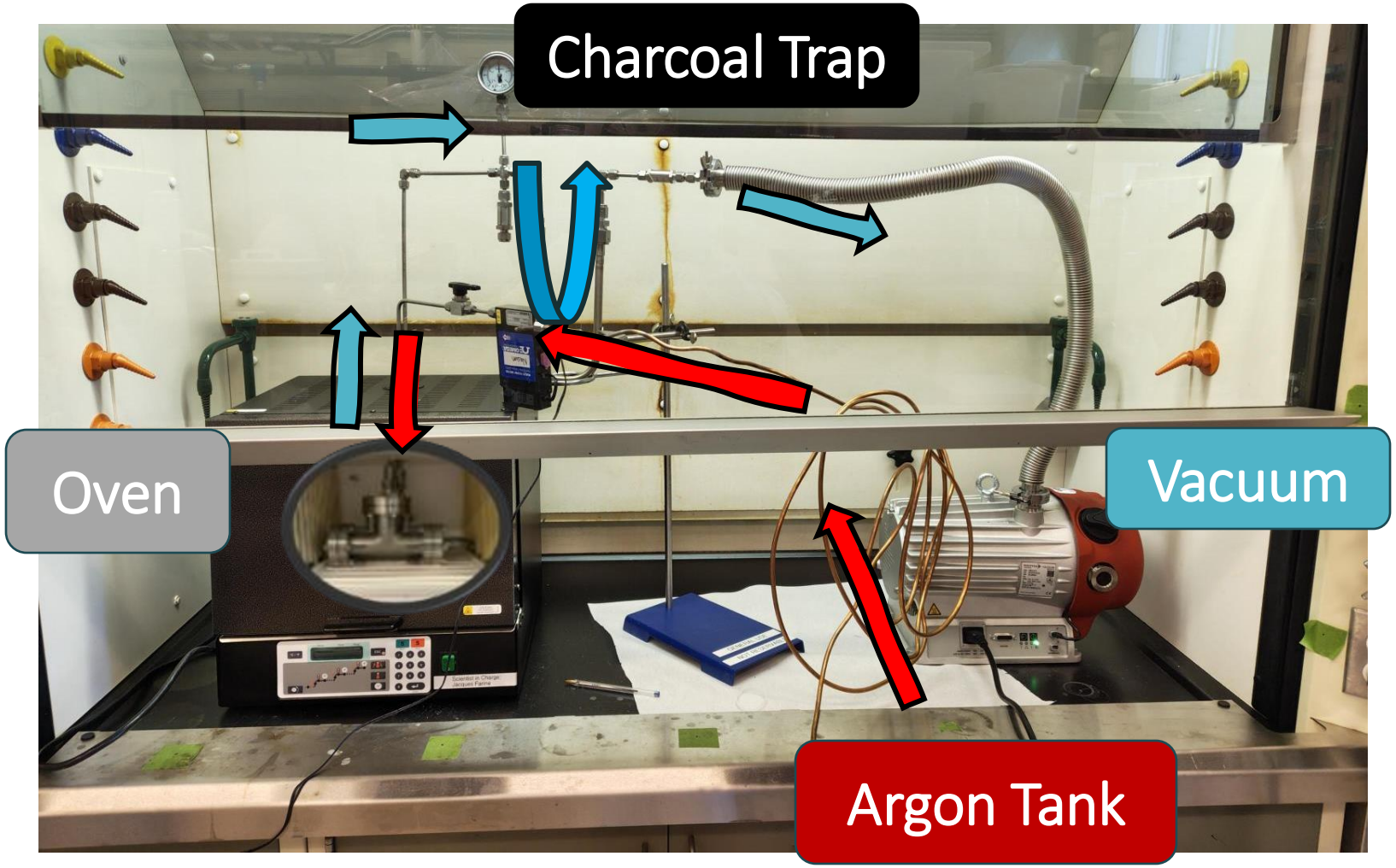
Experiment - Silver Doping Oven

- Silver is baked into the ZnS
- Air causes oxidation
  => ZnO
- Makeshift inert oven





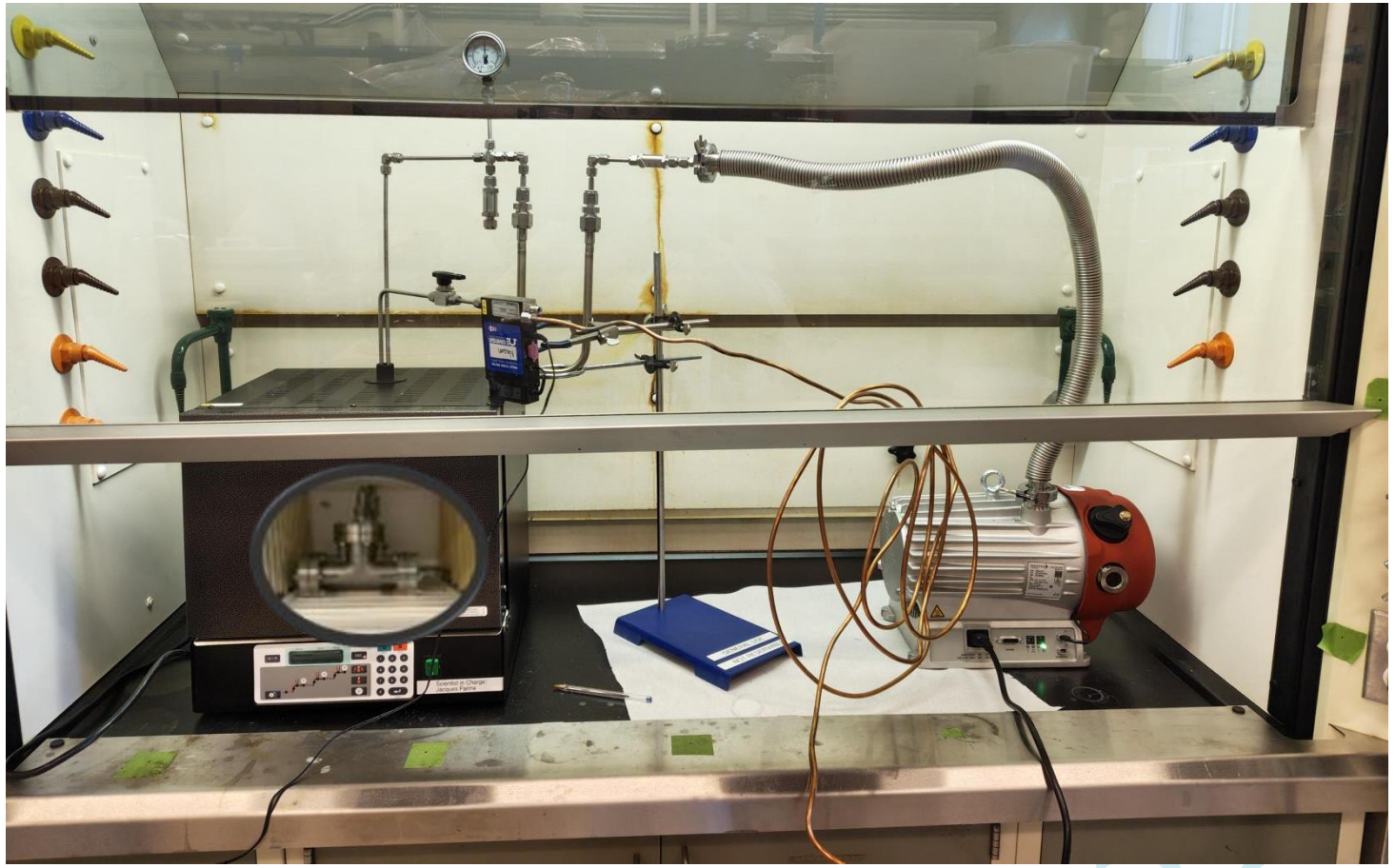
Experiment - Silver Doping Oven Set Up



Experiment - Silver Doping Procedure

The sample mixture:

- ZnS
- Silver acetate
- Salt (flux)
- Elemental sulfur (O_2 scavenger)

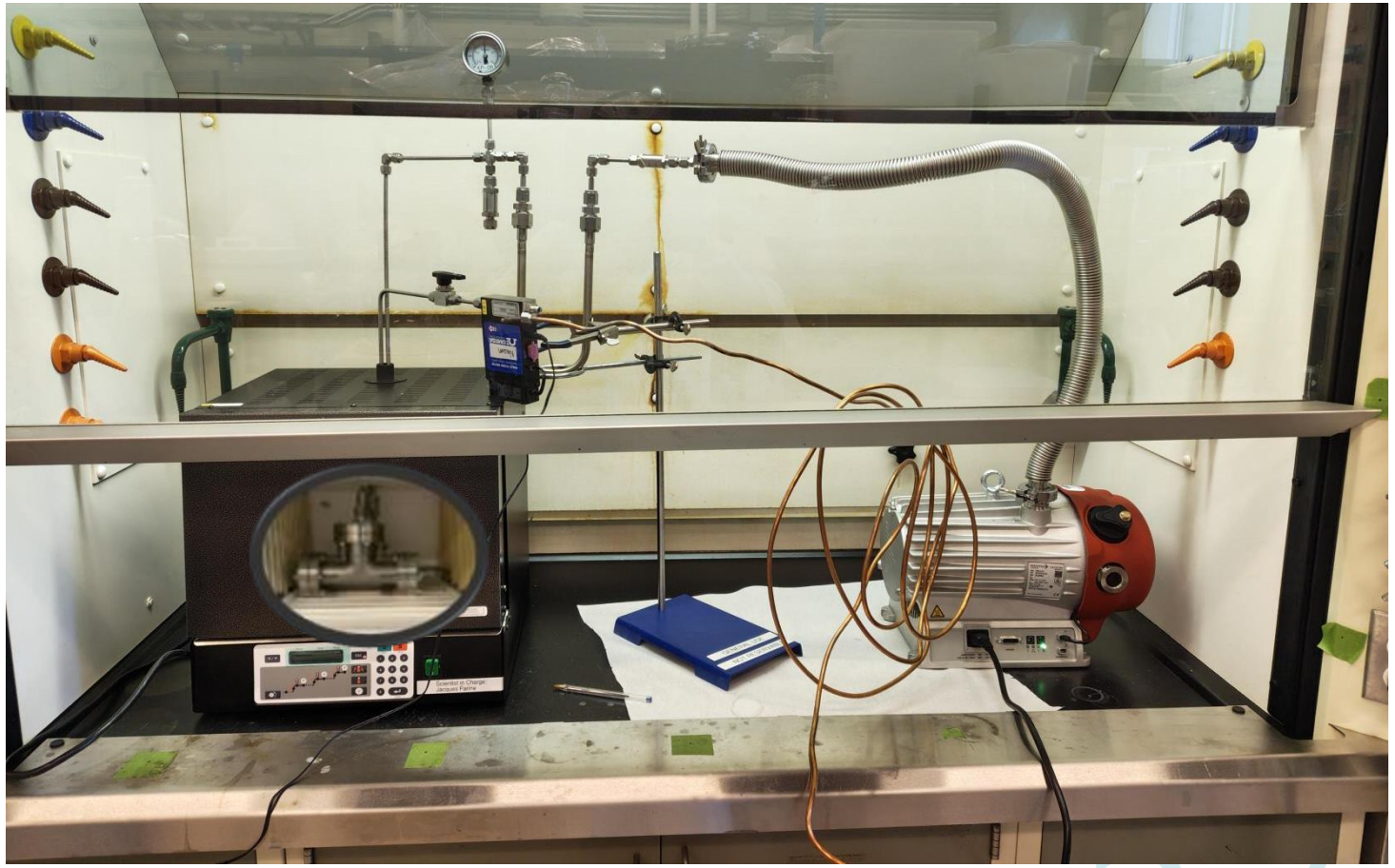


Synthesis of Silver-Activated Zinc Sulfide (Zns:Ag) Powder by Thermal Diffusion Method for Production of Thin Film Alpha Scintillators by Mehdi Sohrabi, Fereshteh Saheli and Kheirollah Mohammadi

Experiment - Silver Doping Procedure

1. Create vacuum, fill with Ar x5

2. Bake moisture off at 120°C



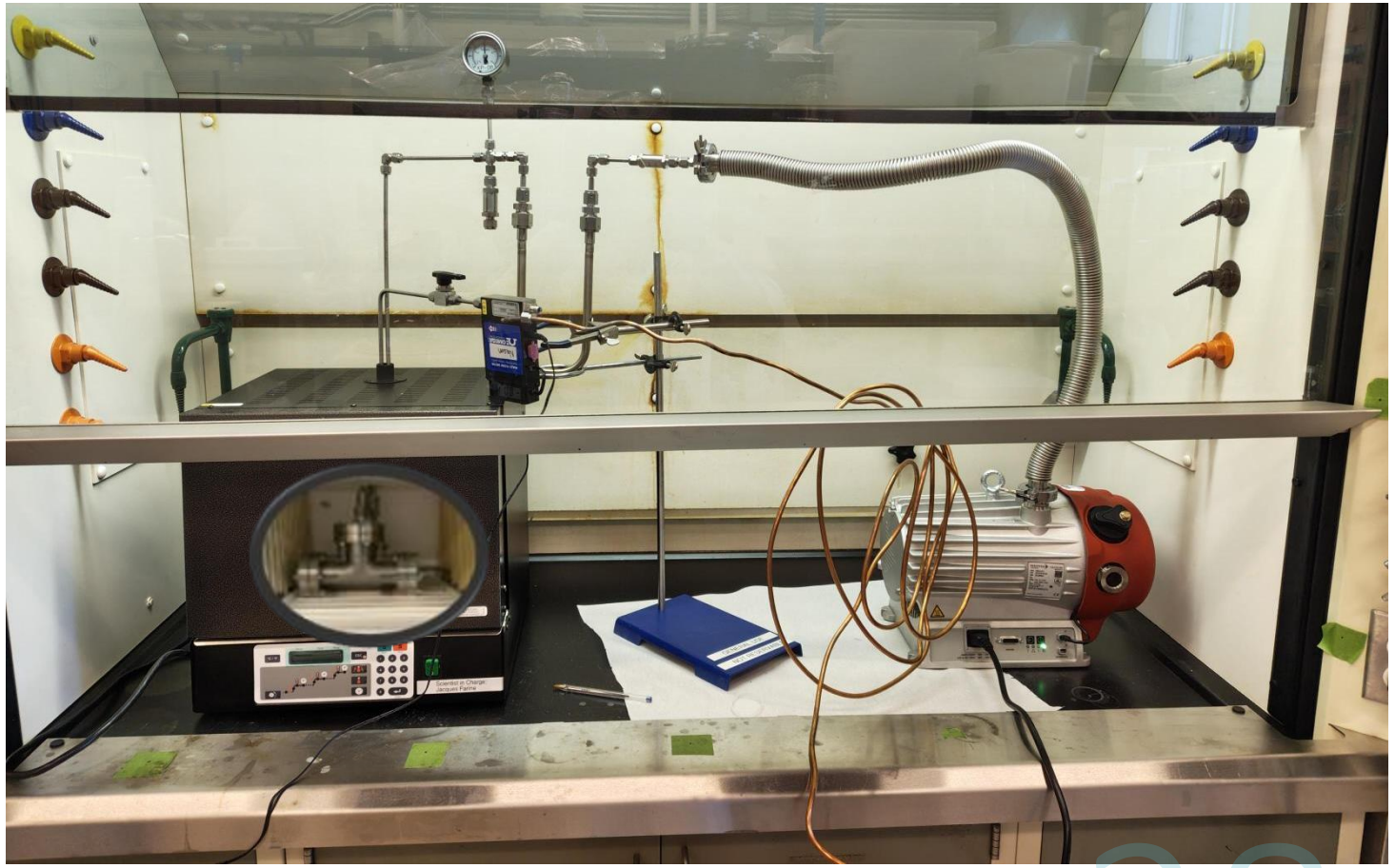
Synthesis of Silver-Activated Zinc Sulfide (Zns:Ag) Powder by Thermal Diffusion Method for Production of Thin Film Alpha Scintillators by Mehdi Sohrabi, Fereshteh Saheli and Kheirollah Mohammadi

Experiment - Silver Doping Procedure

3. Heat to 350°C
- Sulfur melts
- Displaces air in pores

4. Heat slowly to 950°C
- Sulfur boils, reacts with O_2 and leaves as gas
- ZnS and Ag melts at 900°C

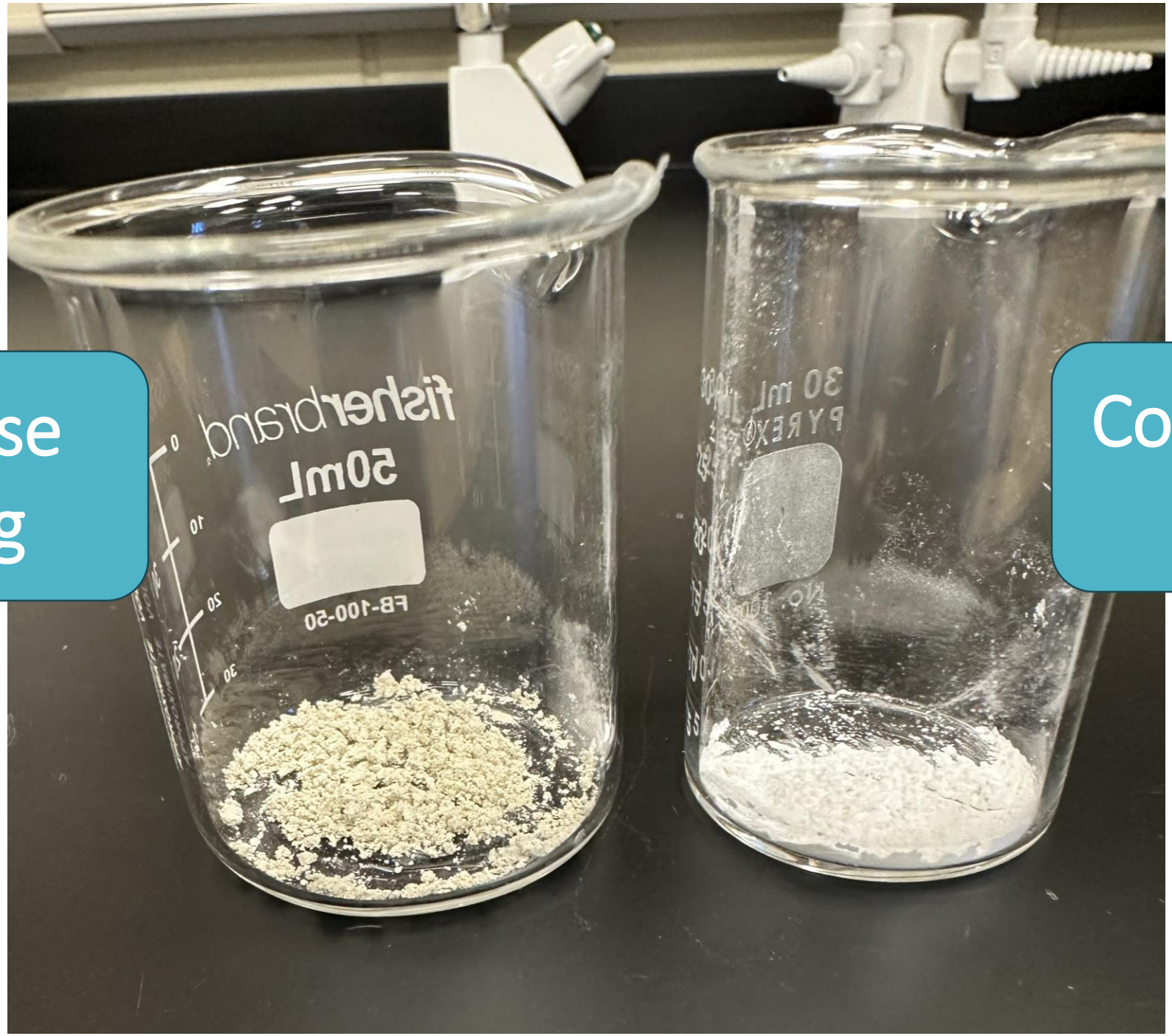
5. Cool to room temp
- Wash with UPW to remove salt



Synthesis of Silver-Activated Zinc Sulfide (Zns:Ag) Powder by Thermal Diffusion Method for Production of Thin Film Alpha Scintillators by Mehdi Sohrabi, Fereshteh Saheli and Kheirollah Mohammadi

Silver Doping Results

In-House
Zns:Ag

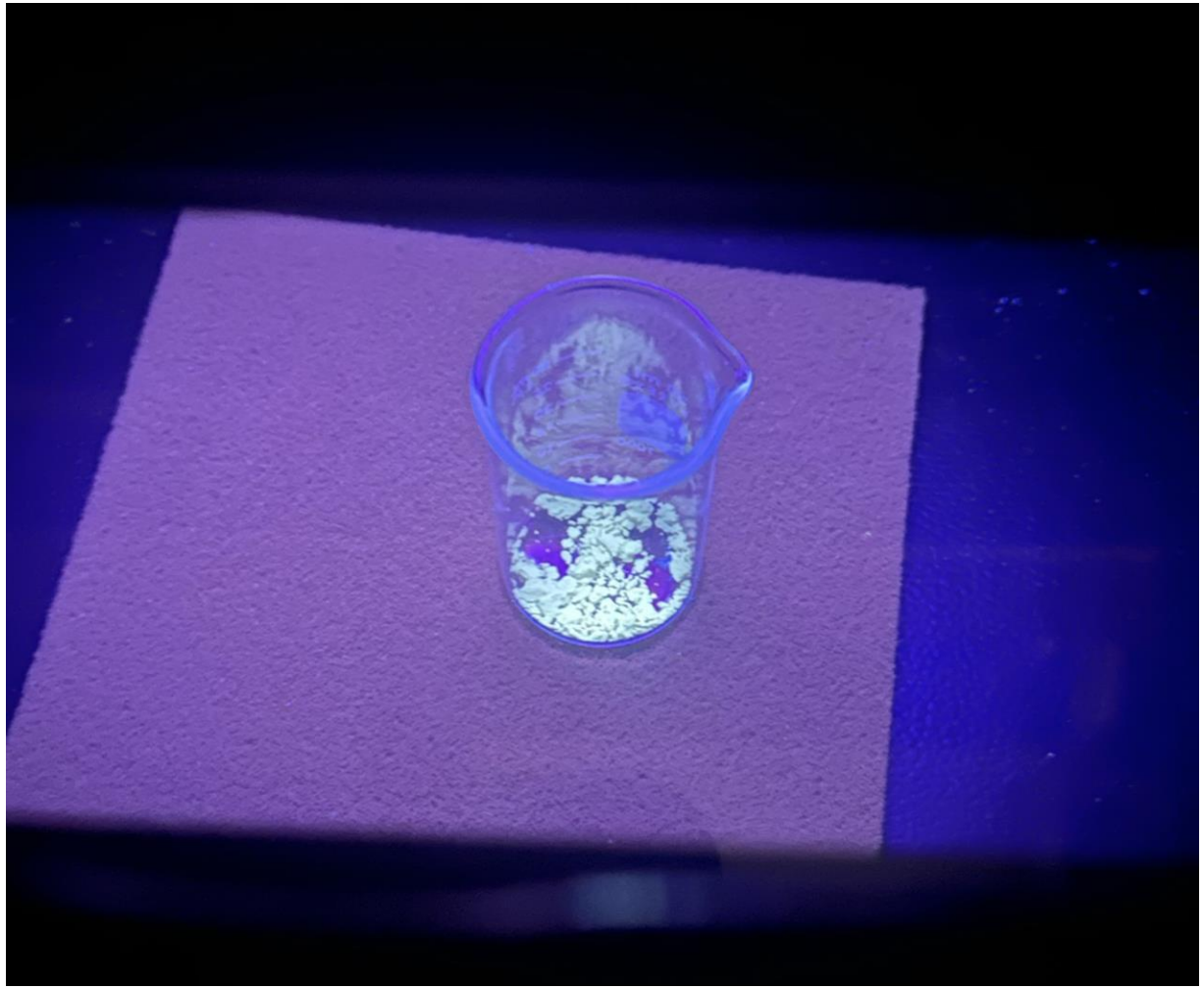


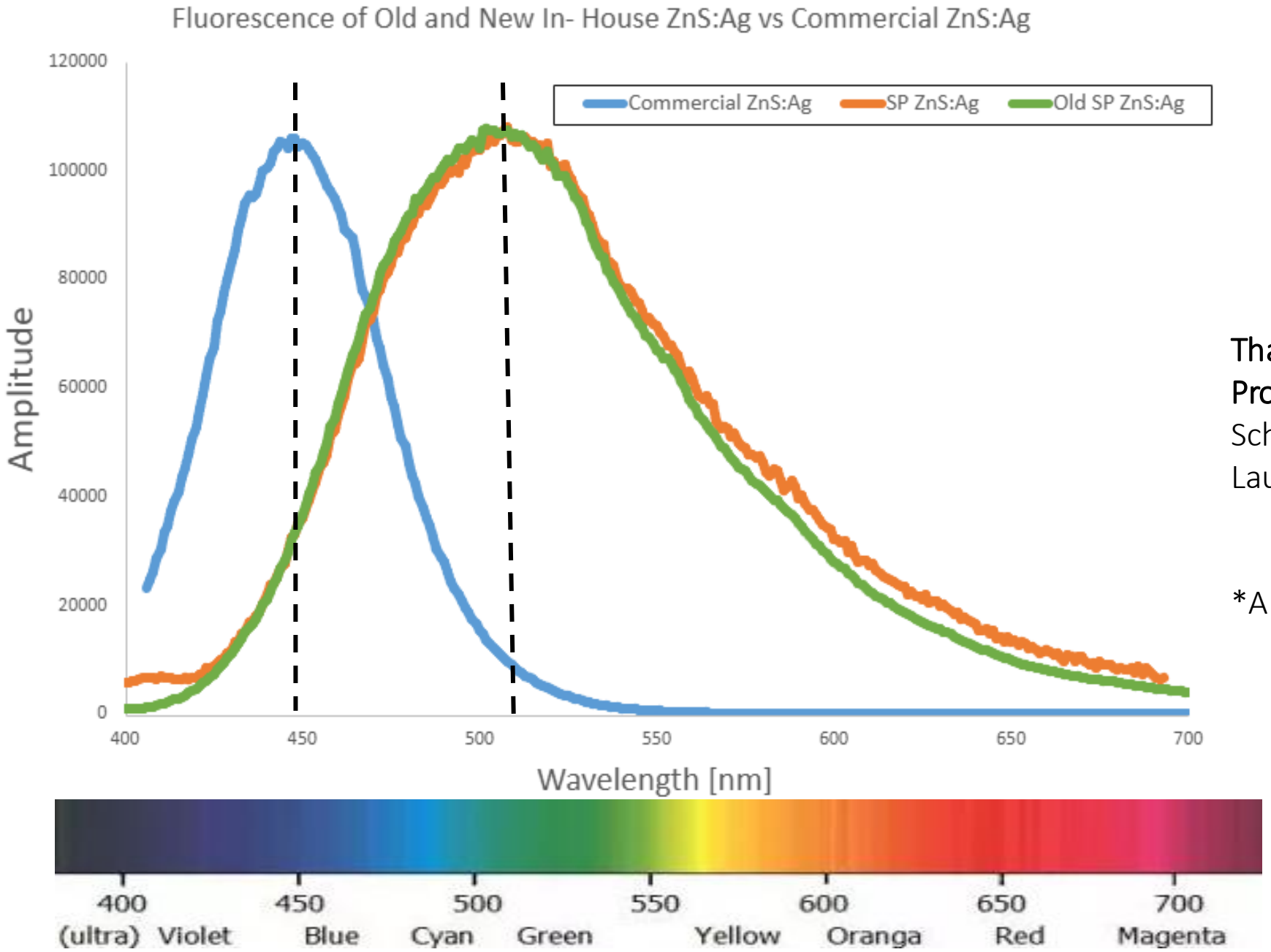
Commercial
Zns:Ag

Experiment - Silver Doping Results

- Doping worked

- There is light
  - Green / Blue

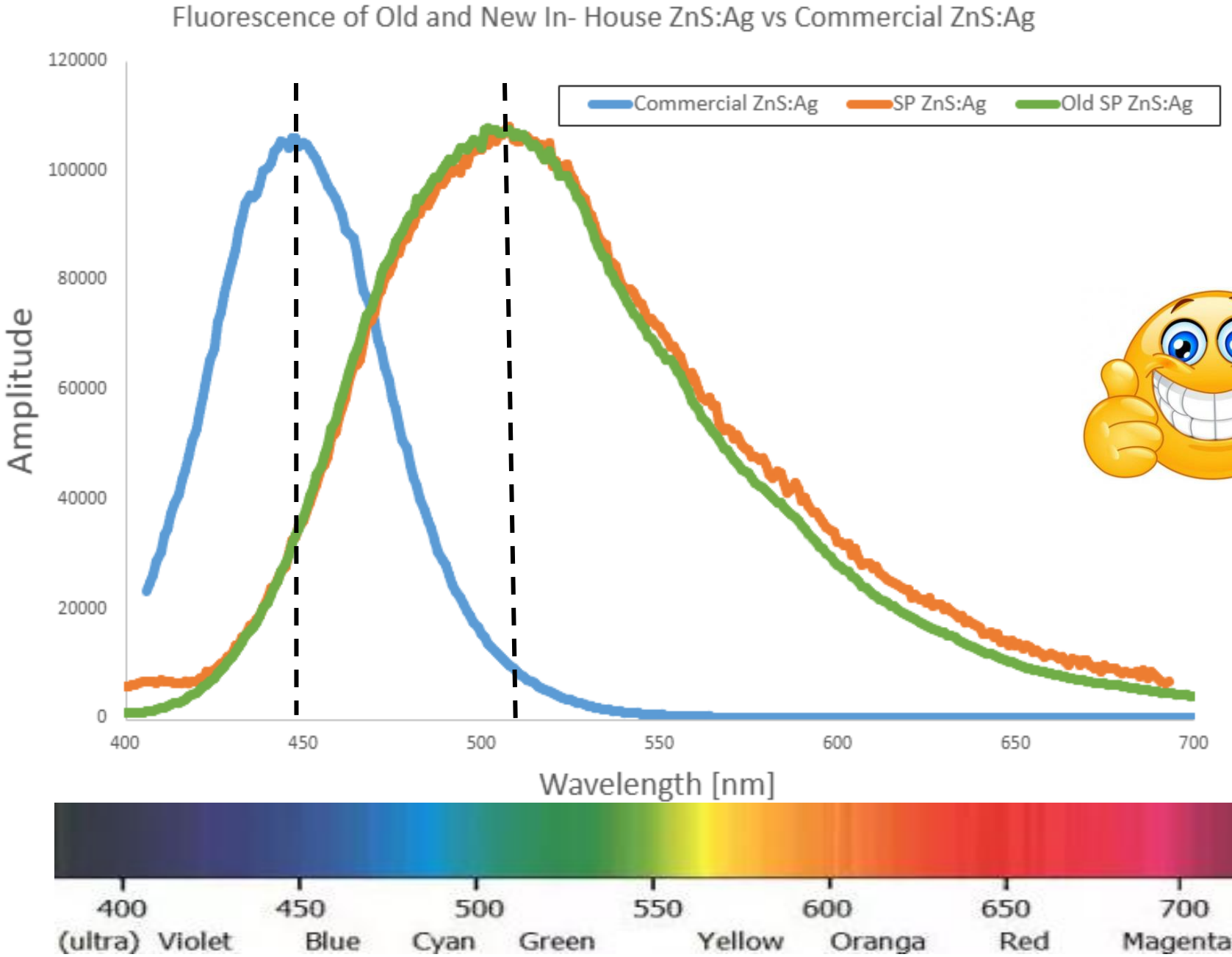


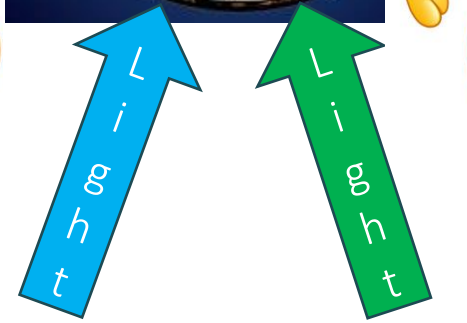


https://www.gigahertz-optik.com/en-us/service-and-support/knowledge-base/basics-light-measurement/light-color/

Thank you to
Prof. Stefan Siemann
School of Natural Sciences
Laurentian University

*Amplitudes are normalized





Thank you to
Prof. Stefan Siemann
School of Natural Sciences
Laurentian University

https://www.gigahertz-optik.com/en-us/service-and-support/knowledge-base/basics-light-measurement/light-color/


In-House
Zns:Ag
Commercial
Zns:Ag
Old In-House
Zns:Ag

What Went Wrong?

- Paper's procedure found ~80% efficiency compared to commercial

- Too much silver
  - Measured ~1500ppm compared to ~600ppm Ag
  - This quenches light efficiency

OR

- Too little silver
  - Acetate group calcined off
  - Silver couldn't be doped in easily

Next Steps

- PXRD (Powered X-ray diffraction)
  - to analyze chemical structure
- XIA α-particle counter tests in progress

- Future procedure must adjust to match commercial results
  - Different Ag concentrations and reagents
  - Different O_2 scavenging methods

Selective precipitate has promising results for lowering background

Acknowledgements

Steve Maguire

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Scientific Support Team

Peter Qin

Connor Stubbs

Martin Blanco

Thank You for Listening

Extra Slides

WHO IS LUCAS??

Henry F. Lucas

May 3, 1926 — Nov 12, 2020

September 1957

Improved Low-Level Alpha-Scintillation Counter for Radon https://pubs.aip.org/aip/rsi/article-abstract/28/9/680/299355/Improved-Low-Level-Alpha-Scintillation-Counter-for?redirectedFrom=fulltext

"he focused his research on the health effects of Radon Gas and went on to invent the Lucas Cell, which is recognized as a sensitive, reliable method for measuring Radon"

https://www.trimblefuneralhomes.com/obituaries/henry-f-lucas

Experiment - Selective Precipitate

- Wet solid
- Baked at 40-45C
- 46g: ~97% yield

https://www.sciencing.com/chemical-reactions-involved-baking-cake-7173041/