Superheated droplet detector response to the source system for zero-knowledge verification

MTV Workshop, 2022

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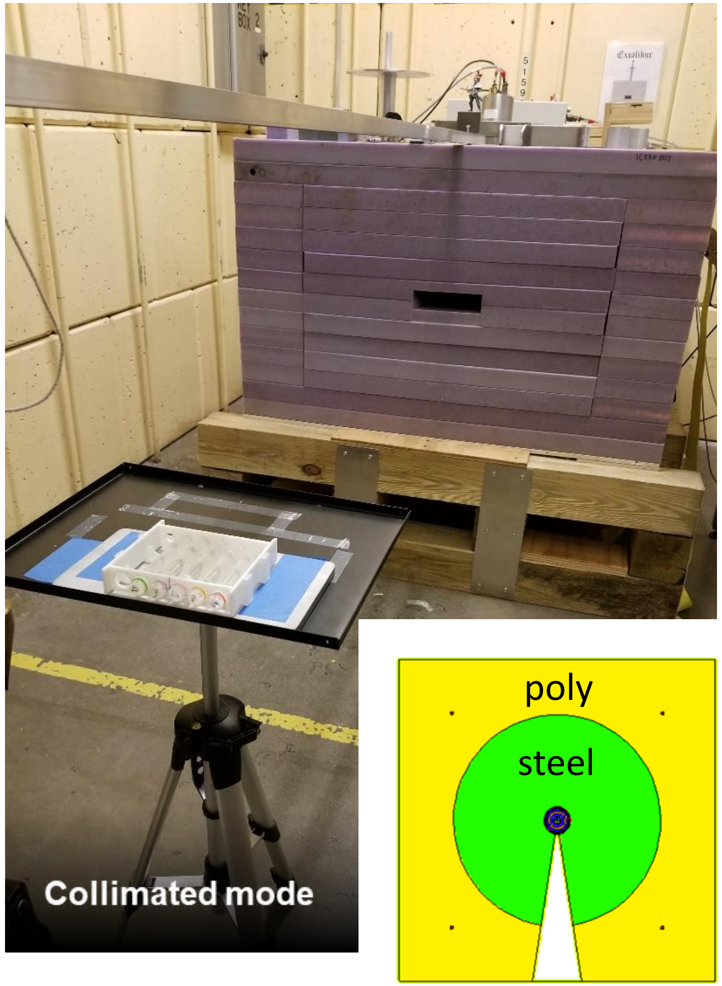
Introduction and Motivation

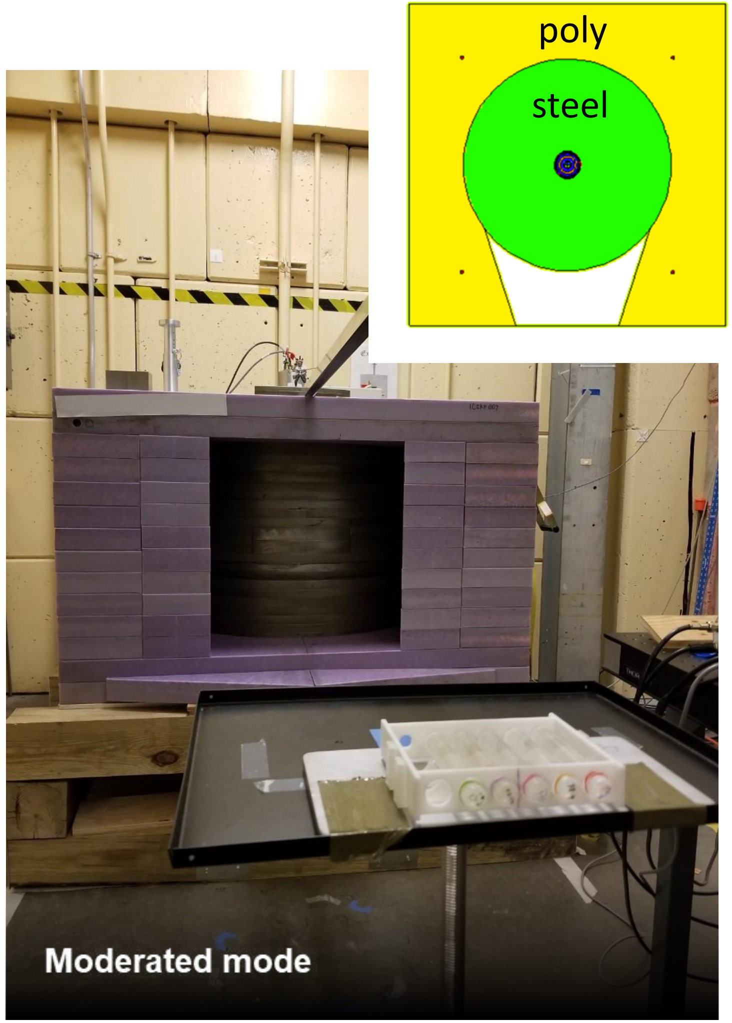
- Verifying the authenticity of nuclear warheads requires gaining confidence on whether or not an object is a nuclear weapon without revealing any sensitive information.
- A zero-knowledge protocol (ZKP) using pre-loadable superheated droplet (bubble) detectors has previously been proposed for this purpose.
- We are both extending this technique for *higher spatial resolution*, and also developing the ZKP technique to *verify fissile material* in presented objects, using the "EXCALIBUR" neutron source available at the Princeton Plasma Physics Laboratory.
  - EXCALIBUR: EXperiment for CALIBration with Uranium

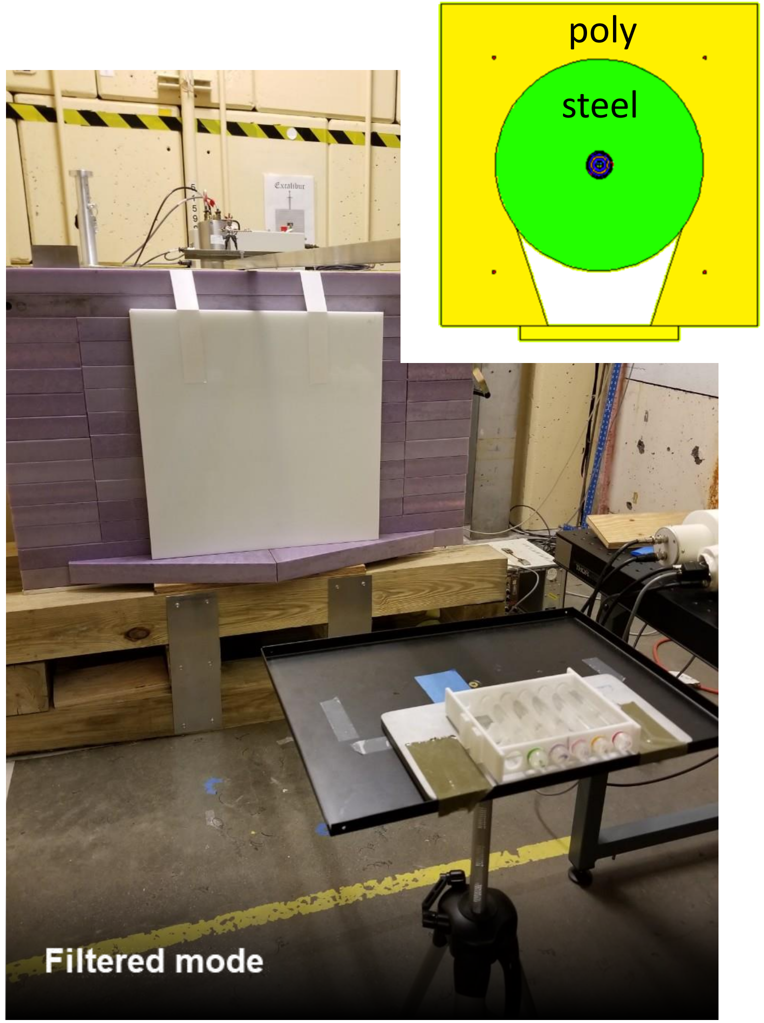
Mission Relevance

- Developing and maintaining the technical means to monitor whether the terms of a nuclear arms control treaty or other international agreement are fulfilled is a critical factor in ensuring that such agreements are successful.
- This study could present another pathway toward a practical and robust system for the development and implementation of arms control treaties.
- ZKP can address one of the challenges in arms control verification, not revealing any sensitive information of nuclear weapons.

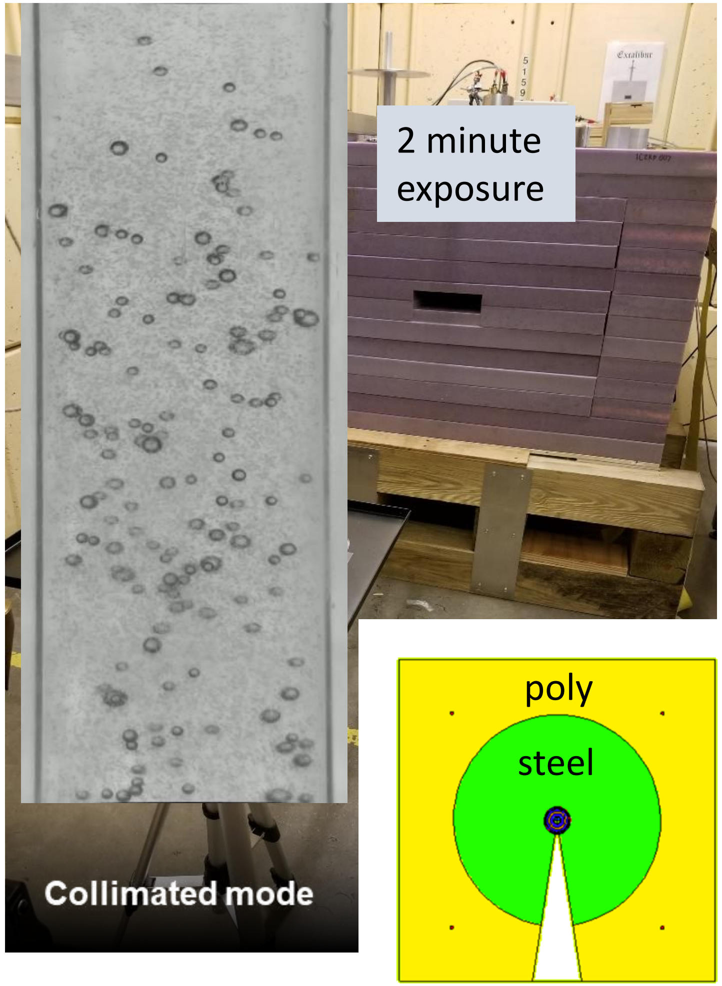
Technical Approach (fission neutron detection)

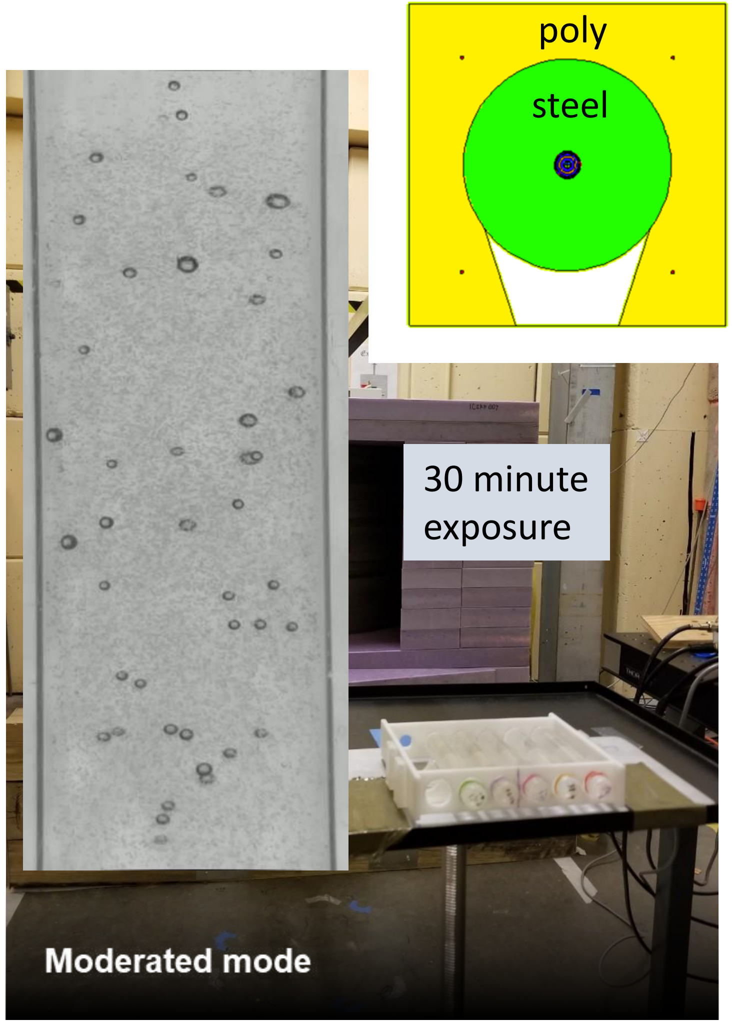


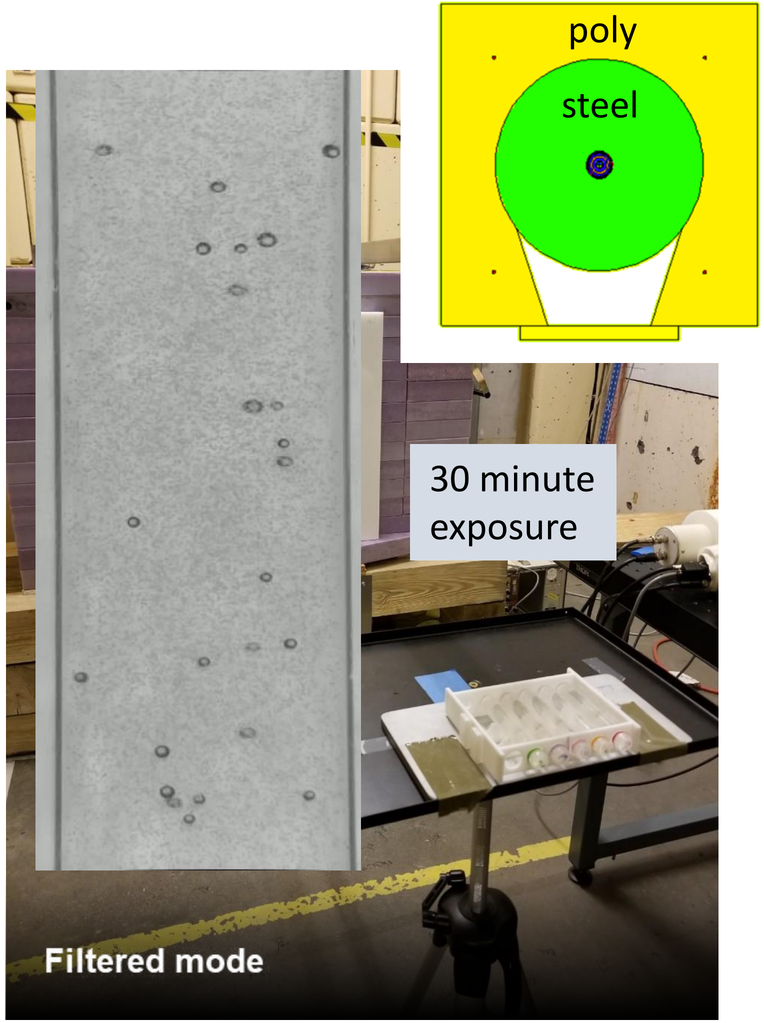




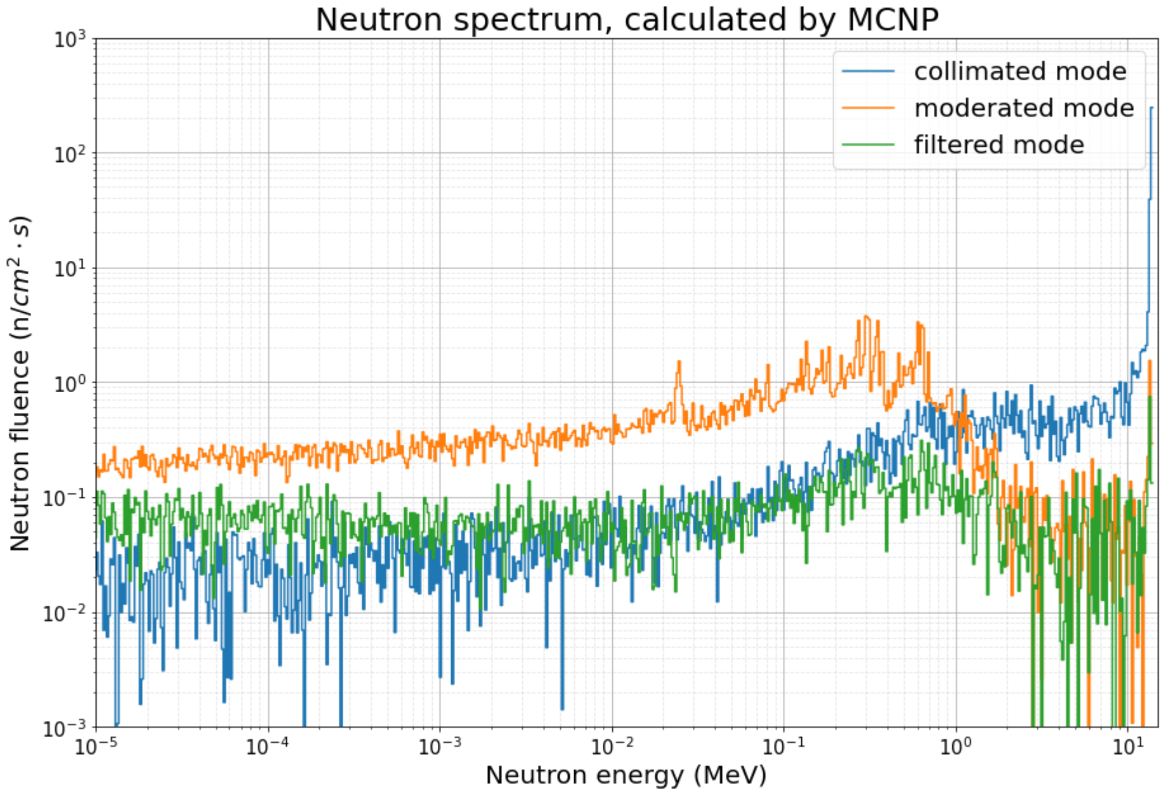
Technical Approach (fission neutron detection)







Results (fission neutron detection)

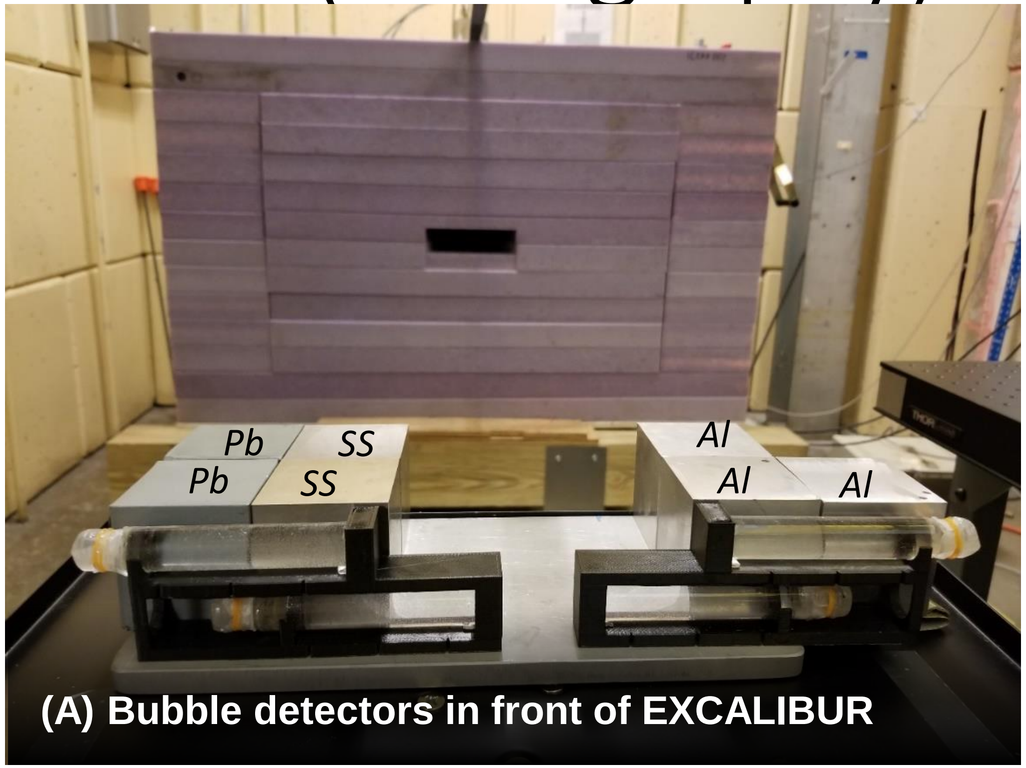


Using proprietary energy dependence for 20 C.

	Ratio of collimated to moderated ($\pm1\sigma$)	Ratio of moderated to filtered ($\pm1\sigma$)
Experiment	46.3 ($\pm$9.82)	1.4 ($\pm$0.46)
MCNP calculation	60.6 ($\pm$2.79)	1.5 ($\pm$0.10)

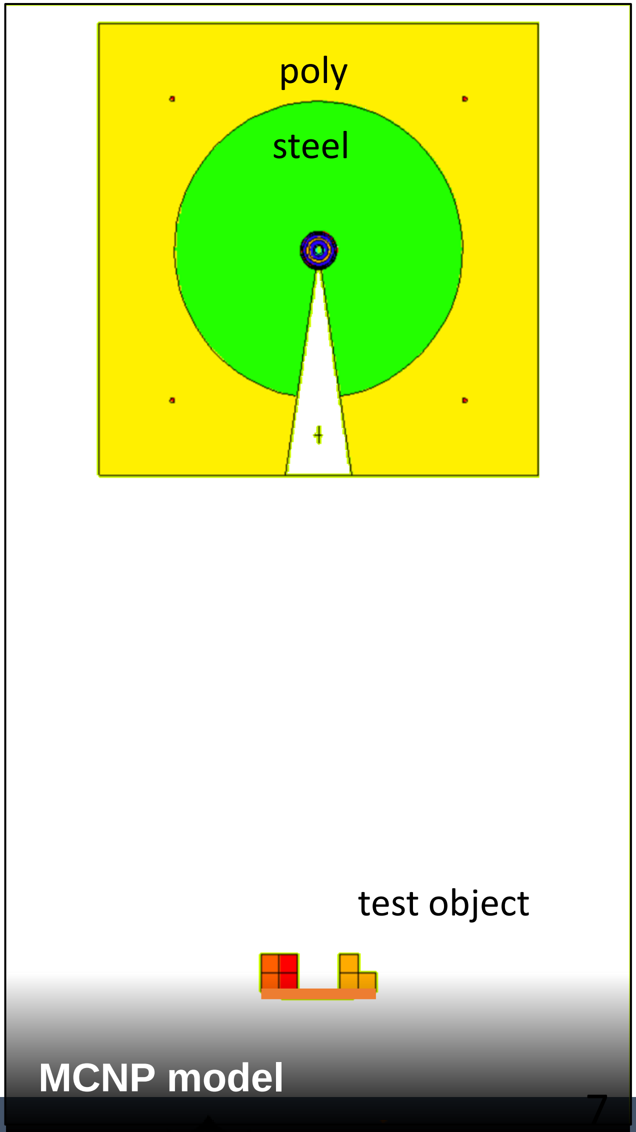
Technical Approach (radiography)

- Exploration of simple preload system
- Detectors are placed in (A) configuration and then measured.
- Same detectors are placed in (B) configuration and then measured.



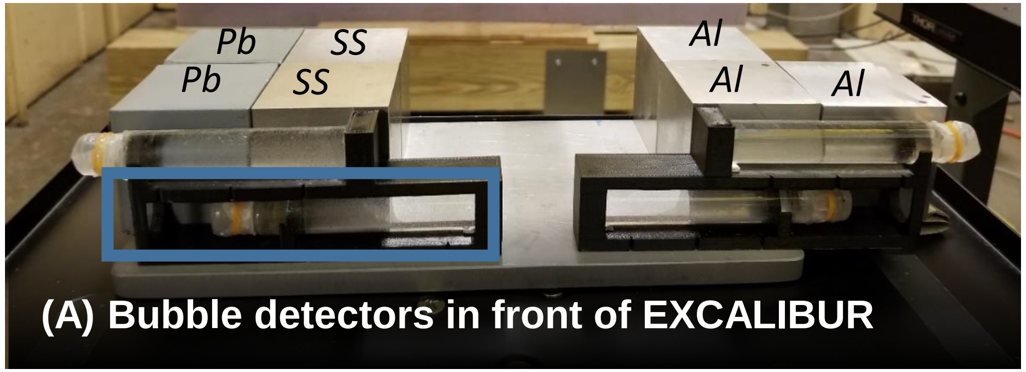
(A) Bubble detectors in front of EXCALIBUR

(B) Detectors are flipped

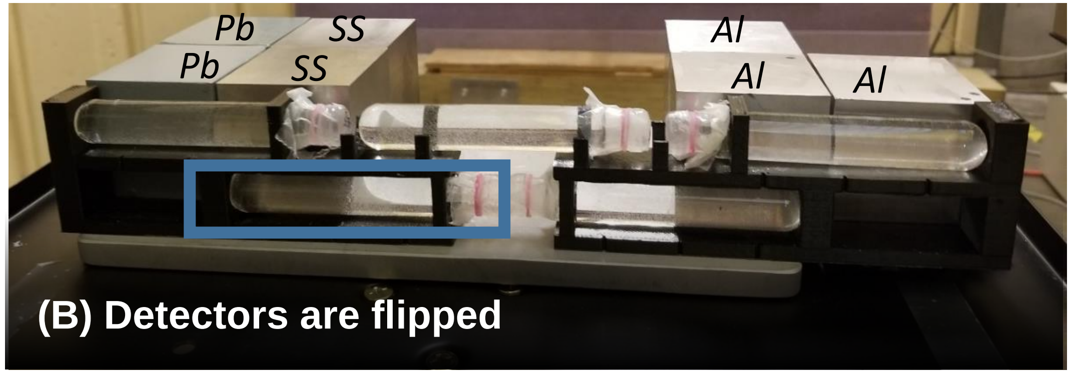


MCNP model

Results (radiography)

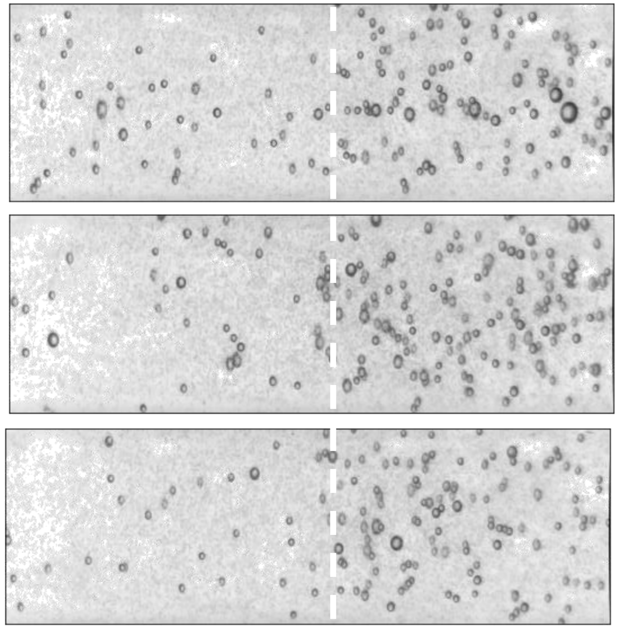


(A) Bubble detectors in front of EXCALIBUR



(B) Detectors are flipped

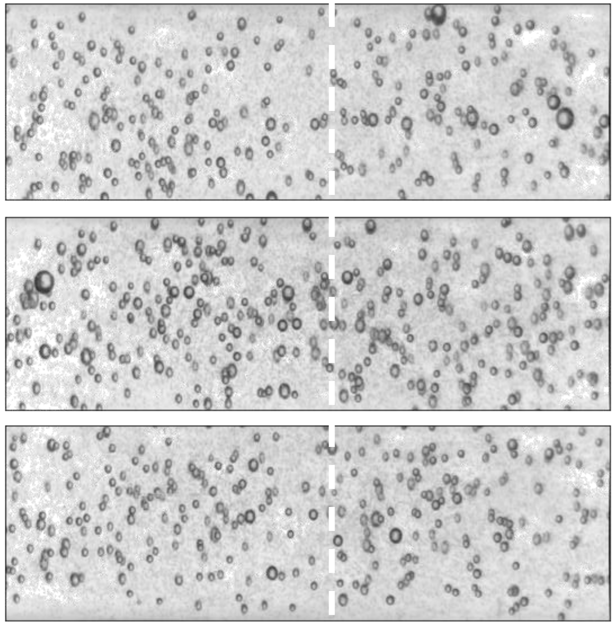
Configuration A SS X 2 Direct view



boundary

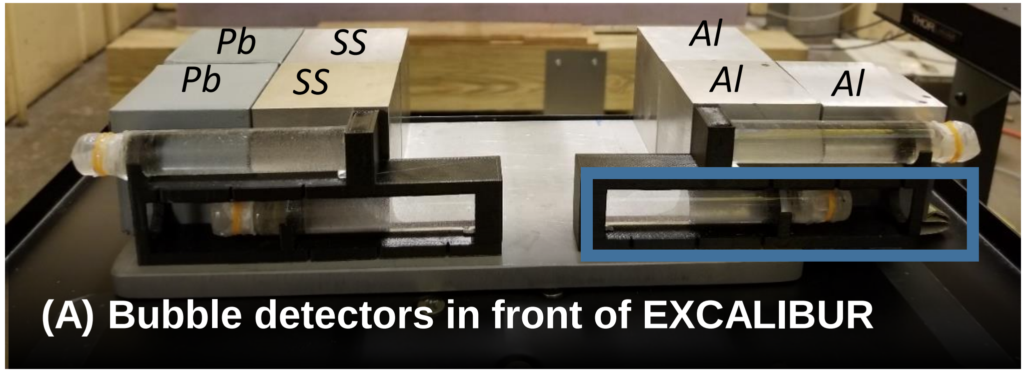
Flip the detector without recompression

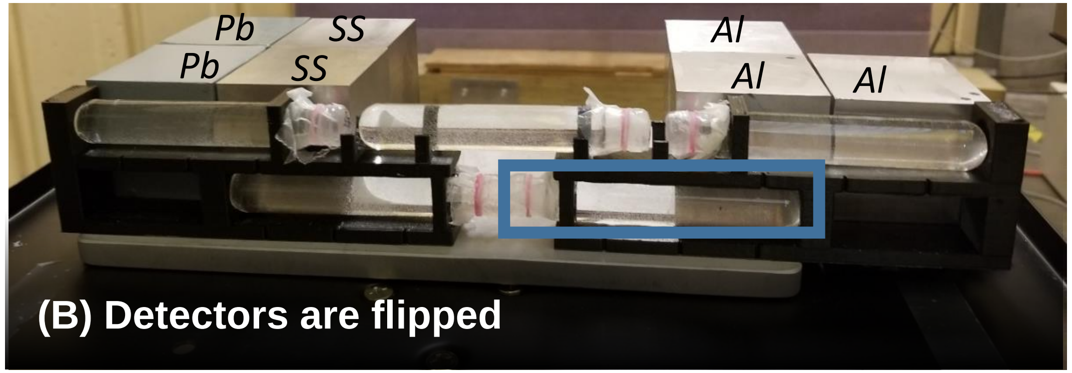
Configuration A + Configuration B



boundary

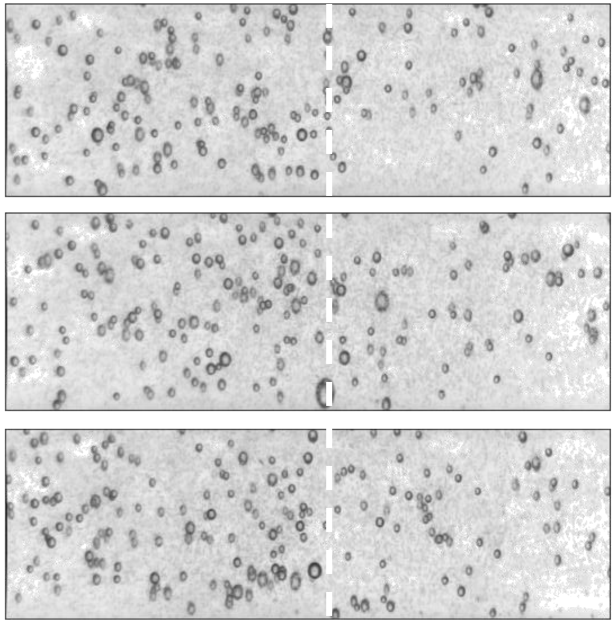
Results (radiography)





Configuration A

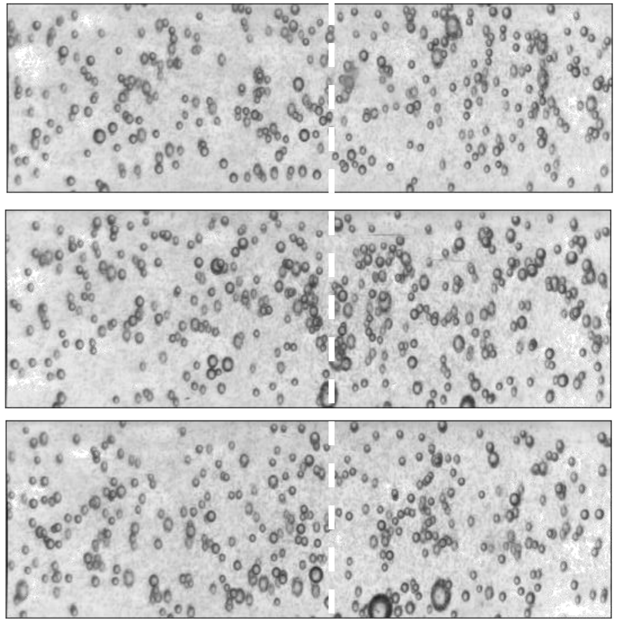
Direct view Al X 2



boundary

Flip the detector without recompression

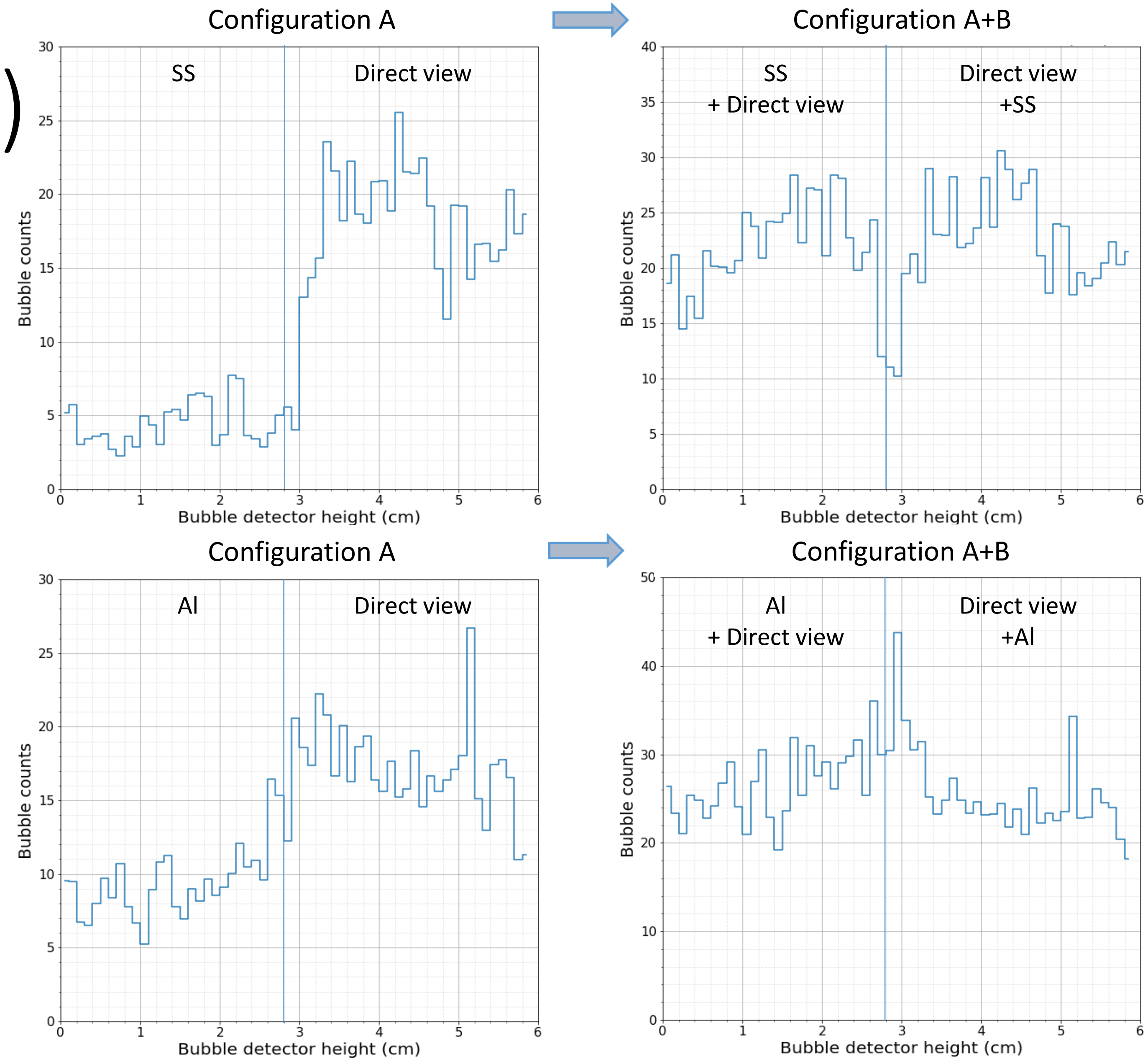
Configuration A + Configuration B



boundary

Results (radiography)

- Experiment results
- Accuracy of alignment in these preliminary experiments was ~3 mm.

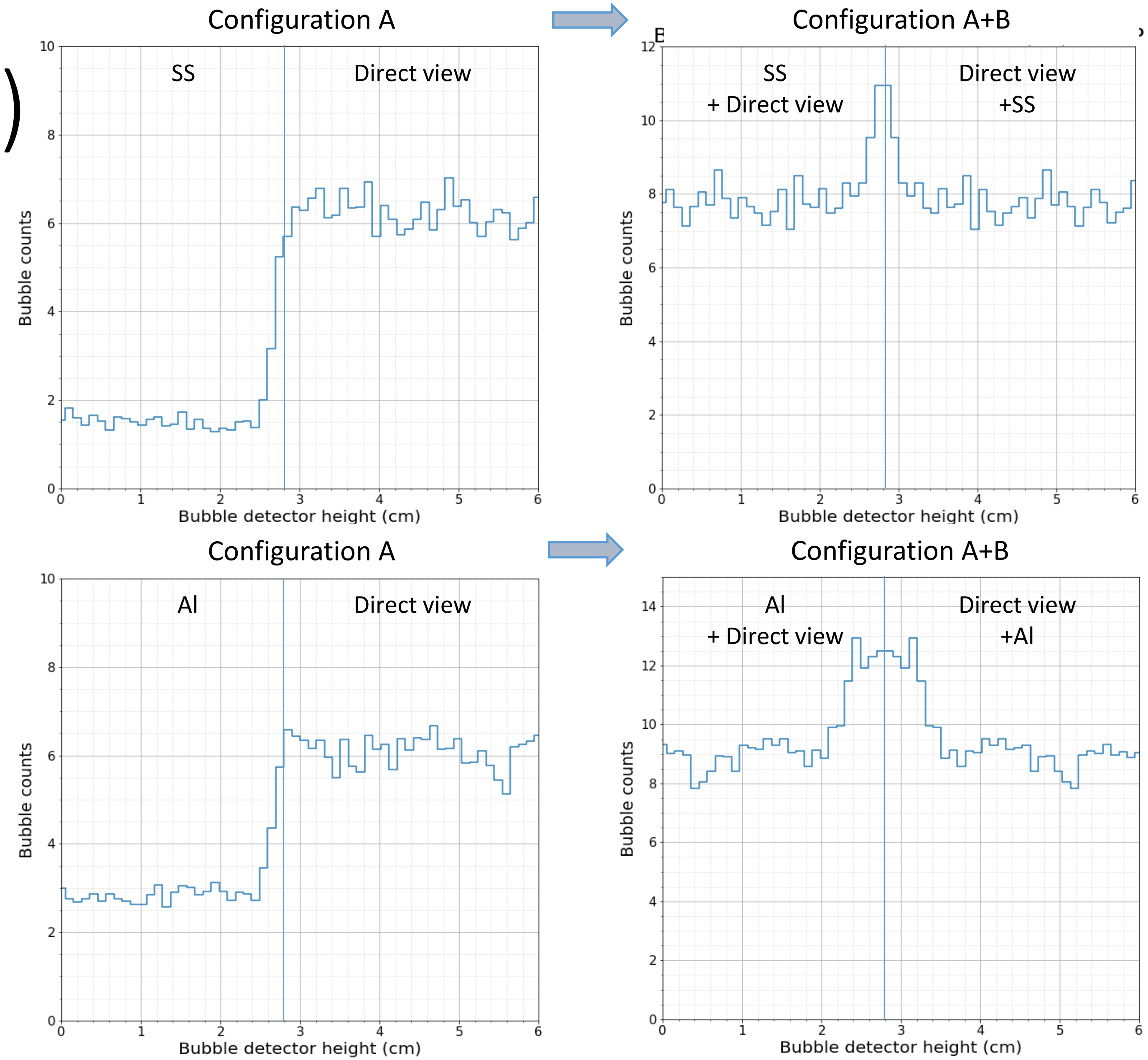


(Bin width: 1 mm)

Results (radiography)

- MCNP6 calculations
- Bulk additions successful.
- Boundaries are not well modelled by simple flip.
- Suggests preload needs to be performed using narrower slices of material near boundaries.

(Bin width: 1 mm)



Conclusion/Next Steps

- The moderator system worked well by giving us 50 times less signal and the detector also did an excellent job being largely insensitive to neutrons below 1 MeV as we expected.
- We made a major step forward in exploring a preload system for ZKP application and we will work toward on refining the system for our template approach.
- We will continue to use these bubble detectors in transverse direction to allow higher spatial resolution.

Expected Impact/MTV Impact

- This study will provide a solid scientific basis for negotiation and a viable option for implementing a zero-knowledge protocol between two parties.
- Close collaboration with Princeton Plasma Physics Laboratory (PPPL) enabled a series of neutron experiments in a safe and seamless manner.
- With Pacific Northwest National Laboratory (PNNL) collaboration, we plan to build additional system together and conduct more runs on fissile neutron detection in spring/summer 2022.

Acknowledgements

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