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Off-gas Xenon Detection and Management in Support of Molten Salt Reactors

Dr. Hunter Andrews and Dr. Praveen Thallapally
Oak Ridge National Laboratory and Pacific Northwest National Laboratory, USA

26 July 2023

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NEA Nuclear Energy Agency
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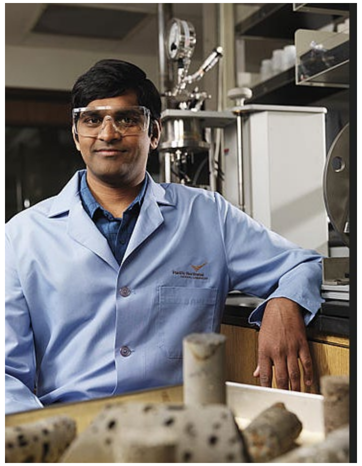
Meet the Presenters

Dr. Hunter Andrews is an early career researcher in the Isotope Applications Research Group within the Radioisotopes Science and Technology Division, Oak Ridge National Laboratory. . Having been at ORNL for the past 3 years, his research focus revolves around the development of in-situ, online monitoring tools for complex environments. His main expertise lies in optical spectroscopy, particularly laser-induced breakdown spectroscopy (LIBS), a rapid form of spectroscopy capable of elemental analysis regardless of sample form. Other research interests include chemometrics, machine learning, mass spectrometry, spectroelectrochemistry, and neutron imaging. He received his PhD in Mechanical and Nuclear Engineering from Virginia Commonwealth University, College of Engineering, USA.

Dr. PraveenThallapally is a chief scientist at PNNL for the past 17 years. He and his team developed a series of novel and transformational applications of porous organic and hybrid (metal organic frameworks, covalent organic frameworks, etc.) nanomaterials and membranes for separation of volatile radionuclides released from nuclear reprocessing and advanced reactors. He published large number of publications (>150) and several patents (>5) focused on materials and membranes for noble gas separation, carbon capture, iodine removal, adsorption chillers/heat pump and sensing. He is tailoring these advanced functional materials as surface acoustic wave sensors to detect and monitor the toxic gases. Other research interests include the development of "porous liquids" for applications in energy storage, catalysis, extraction of critical minerals from unconventional sources. His work was featured on large number of internal and external press. He received his PhD in Chemistry from the University of Hyderabad, India.



Email: andrewshb@ornl.gov; praveen.thallapally@pnnl.gov

Metal Organic Frameworks for Noble Gas Capture

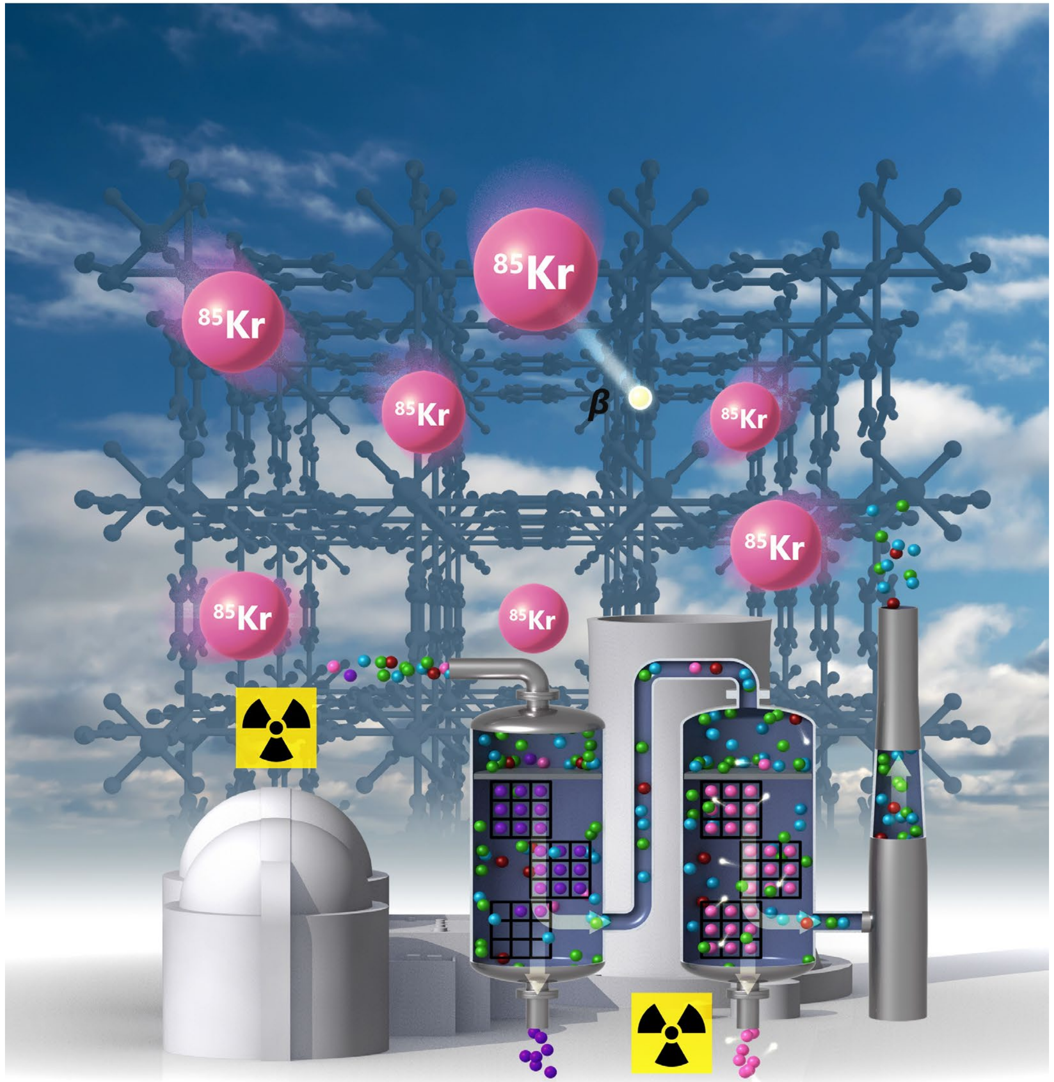
Praveen Thallapally

Pacific Northwest National Laboratory

Driving Factors

- **Why**
  - U.S. EPA 40 CFR 190 and NRC requires volatile radio nuclides (^{14}C, ^{3}H, ^{131}I, ^{133}Xe and ^{85}Kr) must be captured and sequestered to meet the regulation
  - Noble gas capture is the most difficult to capture as they are inert by definition
  - Potential economic incentive if captured

- **Major sources of emissions:**
  - Regular operation of nuclear power plant
  - Advanced reactors
  - Reprocessing of spend nuclear fuel, nuclear accidents, medical isotope facilities



Thallapally and co-workers Nature Communications **volume 11**, Article number: 3103 (2020)

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Applications of Noble Gases

❖ Fortune Business Insights reported ”The noble gases market size stood at **USD 40.34 billion in 2020** and continue to grow

➢ High purity of Xe

❑Space Industry – Propellant

- NASA Xe-ion-thrusters is projected to use approximately 16 metric tones of Xe, for a cost ranging between $81–100 million at today's market price

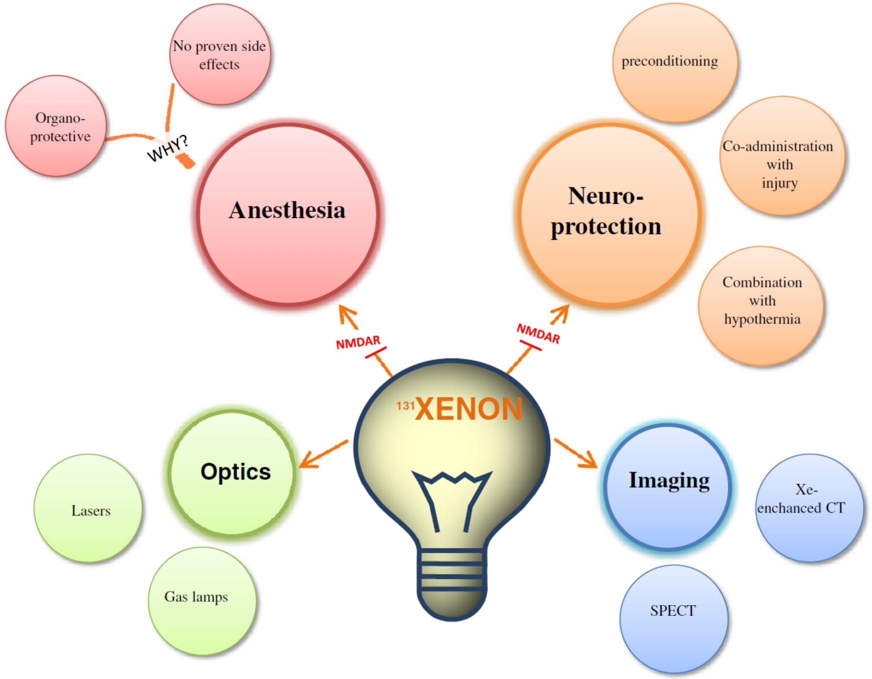
❑ Medical – Anesthesia, Imaging

- Approximately 313.4 million major surgical procedures were performed around the world in each year.
- Due to the supply issues and cost of Xe makes it prohibitive to use. Could open-up huge market

❑ Semiconductor – Plasmas in deposition and etch

- Demand for chips increase so as noble gases (~multi billion-dollar industry)

❑ Building and Automotive – lighting



Esencan et al. Medical Gas Research 2013, 3:4

➢ High purity of Kr

❑ Buildings – Window insulation
❑ Automotive – Head lights, Laser lights
❑ Geoscience – to detect the age of ancient ground water

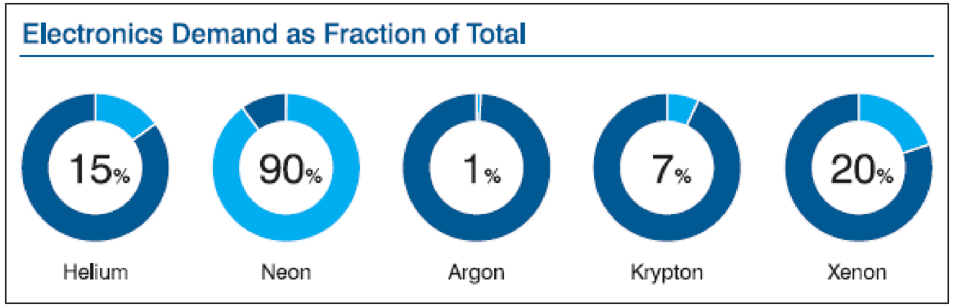


Figure 7. Electronics application demand makes up widely varying fractions of the total market for each of the rare gases.

Source: Linde

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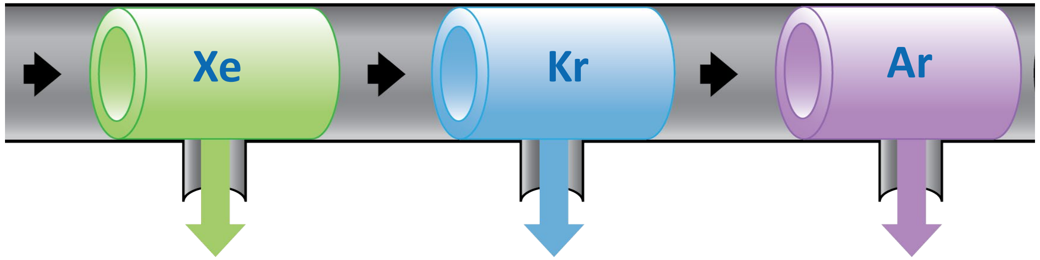
Advanced Reactors

- A gram of actinide material, large MSR produce a kilogram of noble gas per day (~19 L) at reactor operating temperature and atmospheric pressure

Recovery and Better Noble Gas Management

- Provide cleaner gas feed for noble gas recovery
- Enables bulk value-added product
- MSR plant operation enable growing noble gas needs
- Cost of operations and capital reduced with each noble gas recovered
- Sequential removal of volatile gases improves noble gas recovery processes

Sequential Recovery of Noble gases



http://periodictable.com/Elements/054/index.html

to start commissioning SIPF gas centrifuges (GC) to produce enriched Xenon-129. Xenon-129 is the newest isotope to show its effectiveness in polarized lung imaging; there is no U.S. production capability. This isotope has also garnered the interest of the medical community in monitoring lung function and damage from infectious disease such as COVID-19. The FY 2022

Source: DOE isotope production and research

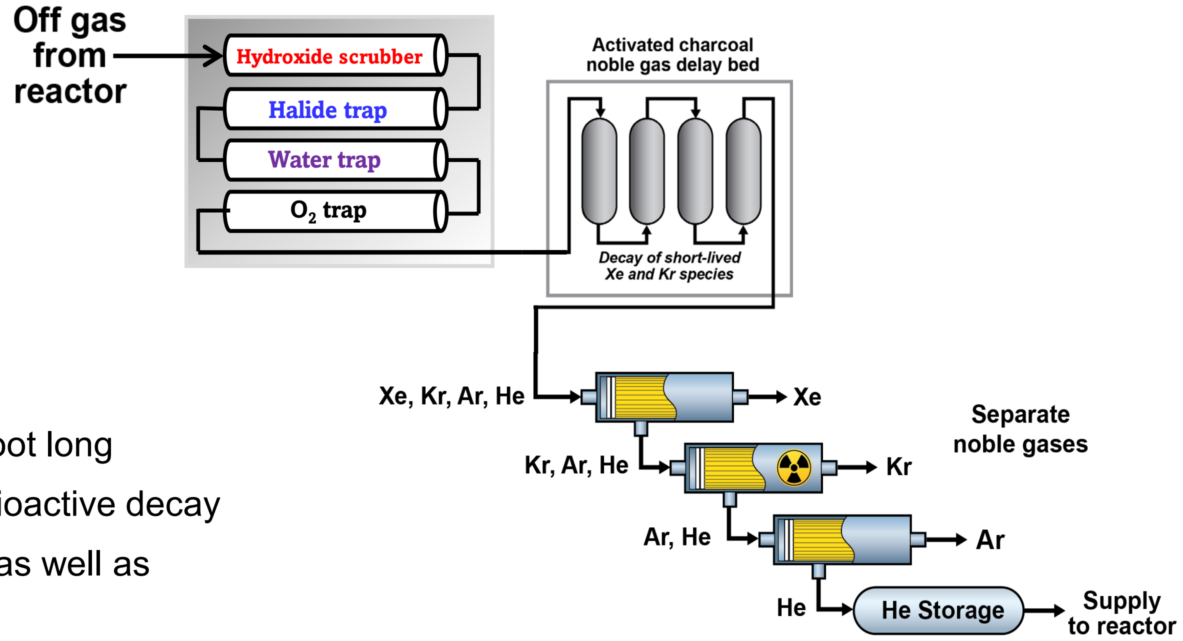
Current Technologies and Alternatives

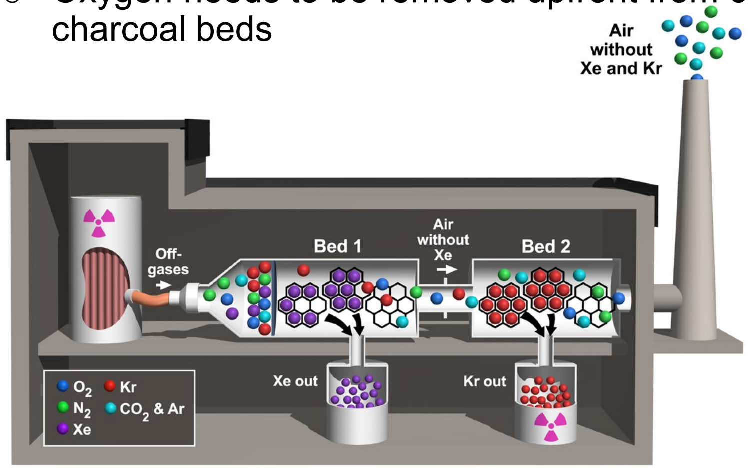
➢ Current Technology

- Cryogenic removal of Xe and Kr
  - Projected to be expensive
  - Potential for O_3 accumulation
  - Hazardous conditions

➢ Charcoal delay beds (MSR)

- Requires 4-5 charcoal tanks with 6 – 9 foot in diameter and 50 foot long
- Fire hazard: Presence of oxygen and heat production due to radioactive decay
- Oxygen needs to be removed upfront from cryogenic distillation as well as charcoal beds





1) Too complex, 2) Large footprint, 3) Costly, 4) Hazardous and safety issues

➢ MOFs as Alternate Technology

- Higher capacity and selectivity represents significant cost reduction compared to cryogenic and charcoal beds
- Smaller size columns, reduced footprint and no fire hazard
- Remove Xe (non-radioactive) and Kr in separate steps at near RT
  - Recover process costs by selling Xe?
- Remove Kr in single step

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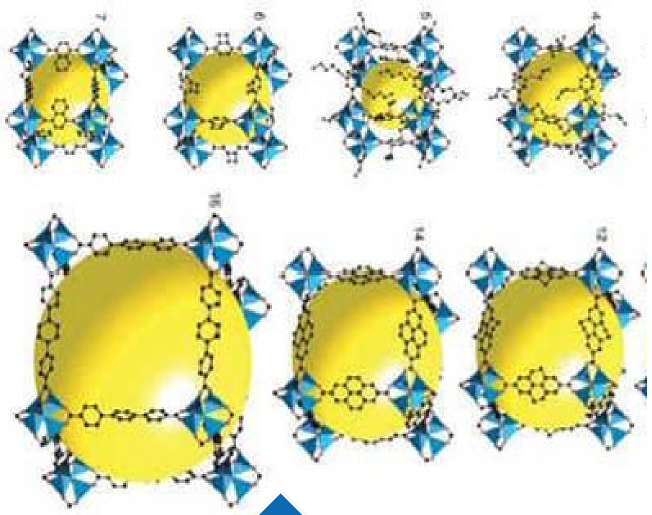
Thallapally and co-workers Compact and Modular Integrated Off-Gas System and Sensors." Invention Disclosure e-IDR 18117

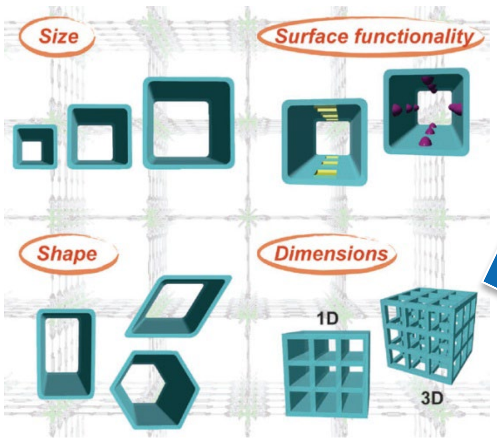
Thallapally, Vienna et. al., USPTOWO/2017/218346A1

Metal Organic Frameworks

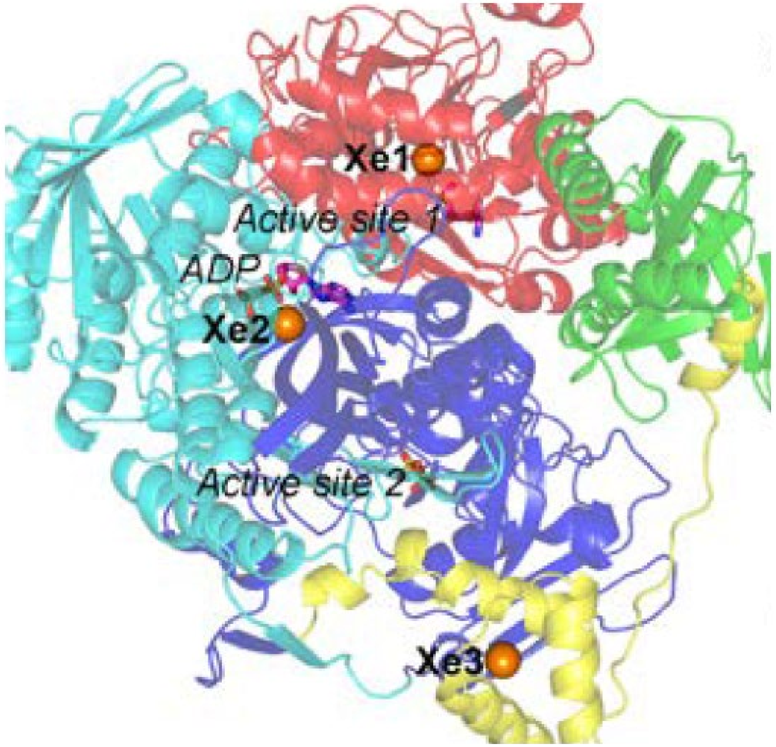
	Zeolites/Charcoal	MOFs
Safety	Potential bed fires (charcoal)	NA
Type	Inorganic/Organic	Hybrid
Diversity	Limited	Infinite
Pore Size	Fixed	Fine-tunable 0.3 to 10 nm
Surface Area	Up to 1000 m^2/g	Up to 8000 m^2/g
Capacity*	Moderate	High
Selectivity	Need to remove CO_2, and Water	Not required (CaSDB) Yes for water (for some MOFs)
Cycle	200	>2000 (PNNL) (water adsorption n desorption)
Stability	Up to 1 x 10^7 RAD	1.75MGy PNNL and SNL Study Recent literature shows even higher stability
Cost	Varies	Varies;

- MOFs with higher adsorption capacity, and selectivity represents significant cost reduction compared to existing technology
- Smaller-size columns and reduced footprint





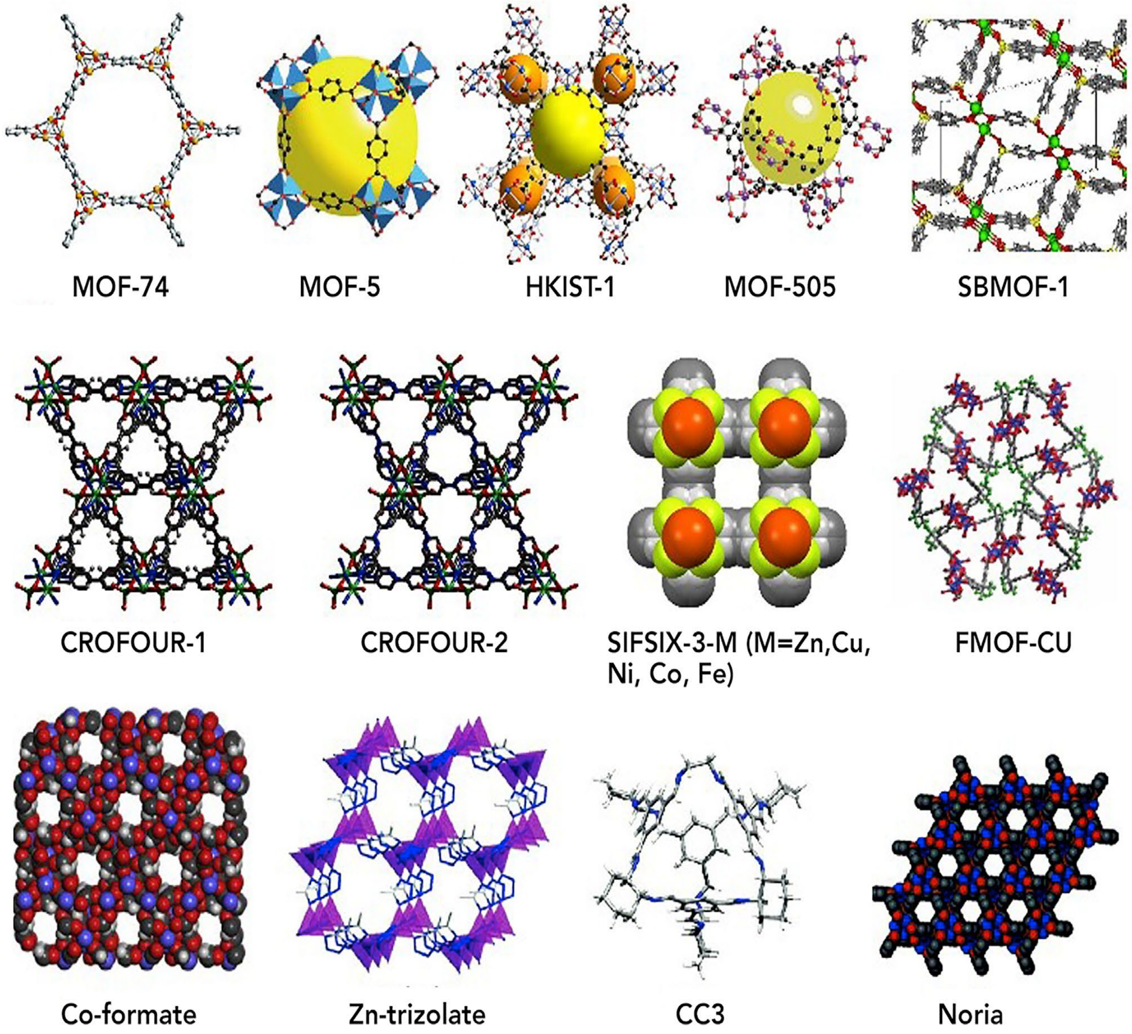
Inspiration from Proteins and Biological Molecules



- Structural biology can provide some insight into how and where noble gases bind to proteins.
- In 1965, Shoenborn et. al., reported the x-ray structure of the complex formed between myoglobin and xenon.
- Crystallographic studies under Xe and Kr pressure provided valuable experimental insight on the importance of hydrophobic cavities, channels, and other structural voids.
- Among many adsorption sites, the prominent cites for Xe and Kr are hydrophobic cavities with pore size ranging from 0.4 to 0.6 nm in size

Design and develop synthetic hosts

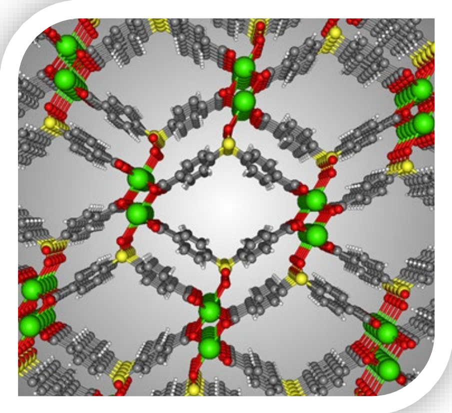
Adsorbents Studied



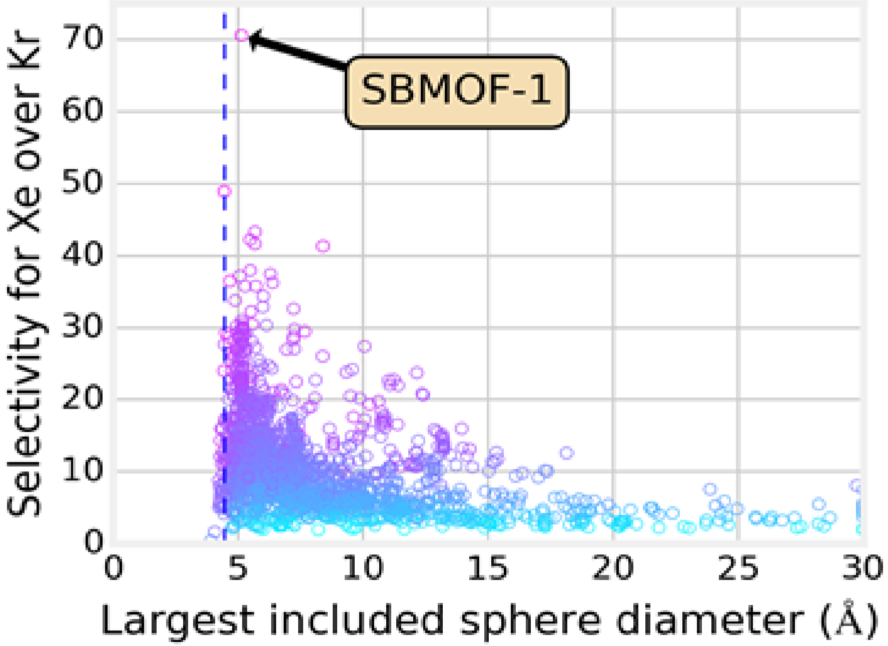
Debasis *et. al., CHEM.*, 4, 466-494, 2018

- **Pore diameter close to the KD of Xe/Kr**
  - Chen et. al., *Nat. Mat.,* 2014
  - Debasis et. al., *Nat. Comm.*, 2016
  - Elsaidi et. al., *Chem. Eur J.*, 2017
  - Elsaidi et. al., Nat. Comm., 2020
- **High density of open metal sites**
  - Thallapally et. al., *Chem. Commun,* 2012
  - Liu et. al., *Chem. Commun*, 2014
  - Ghose et. al., *J. Phys. Chem C.*, 2016
- **Polar functional groups within pore surface**
  - Chen et. al., *J. Am. Chem. Soc.*, 2015
  - Elsaidi et. al., *Angew Chem. Int. Ed.*, 2016
- **Temperature switching selectivity**
  - Fernandez et al., *J. Am. Chem. Soc.*, 2012
- **High surface area and Impregnation with silver Nanoparticles**
  - Liu et. al., *Chem. Commun.*, 2013
  - Feng et. al., *J. Am. Chem. Soc.* 2016
  - Elsaidi et. al., *Chem. Sci.,* 2017

Rare example of computationally inspired material discovery



- ❑ Modelling predicts the CaSDB (SBMOF-1) is the best among 5000 experimental and 125,000 hypothetical MOFs.
- ❑ 3D network structure connected with CaO units
- ❑ Small pore diameter (4.1 Å) with surface area of 120 m^2/g
- ❑ Very stable in air

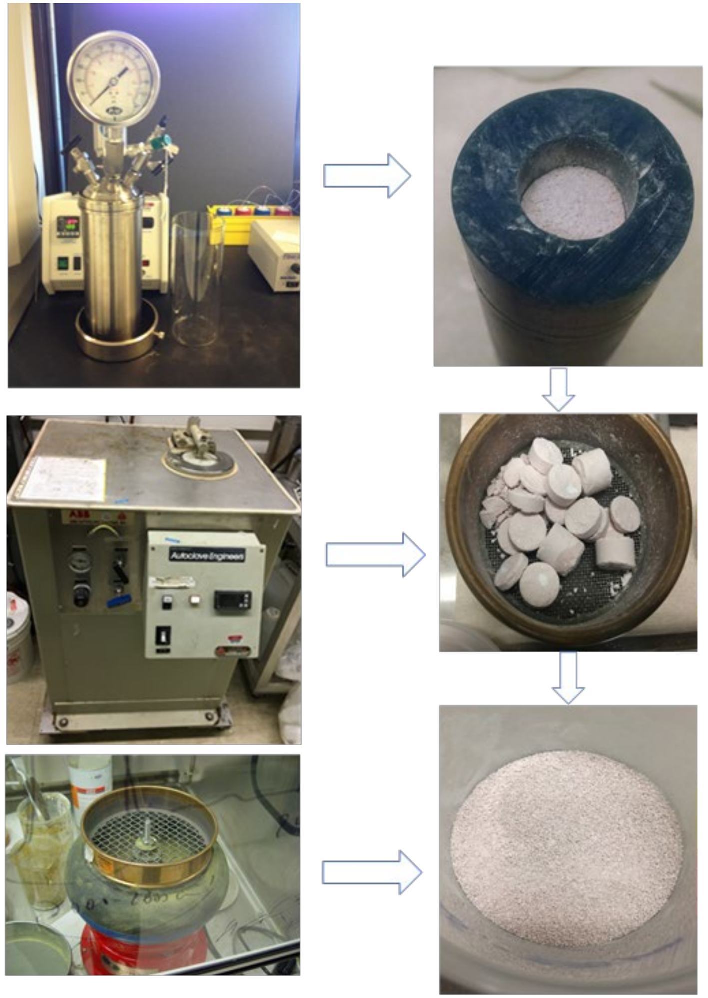


- ❑ A rare example of computationally inspired material discovery

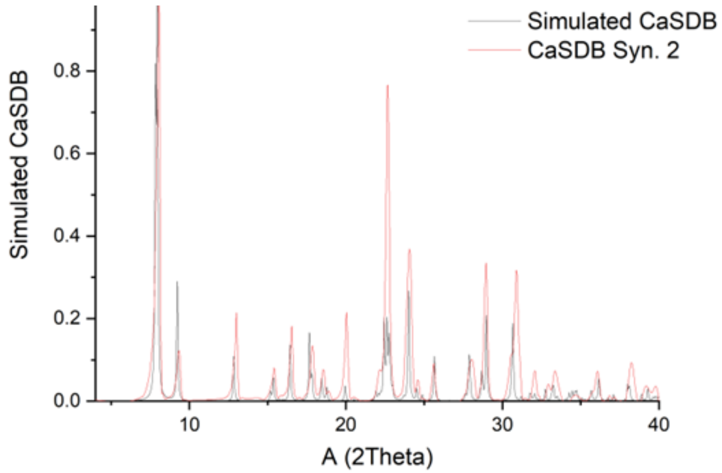
Thallapally, PK., Vienna et. al., USPTO WO/2017/218346A1

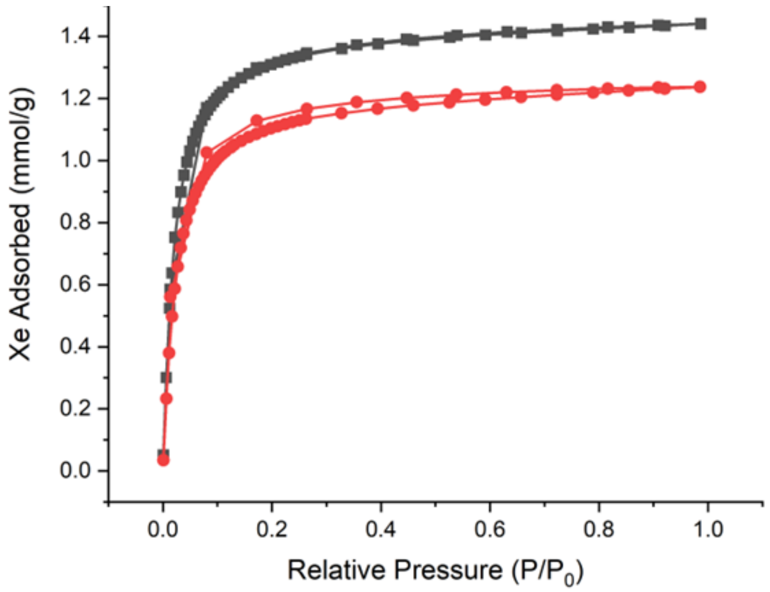
Thallapally, Ali Z. Riley, BJ., Paviet, P., Matyas, J., Vienna, J., Compact and Modular Integrated Off-Gas System and Sensors." Invention Disclosure e-IDR 18117
Banerjee, D, Thallapally, PK, Kunapuli R., McGrail, BP, Liu J et al., Surface acoustic wave sensors for refrigerant leak detection., *USPTO WO2021/041359 A1*

MOF Synthesized at PNNL



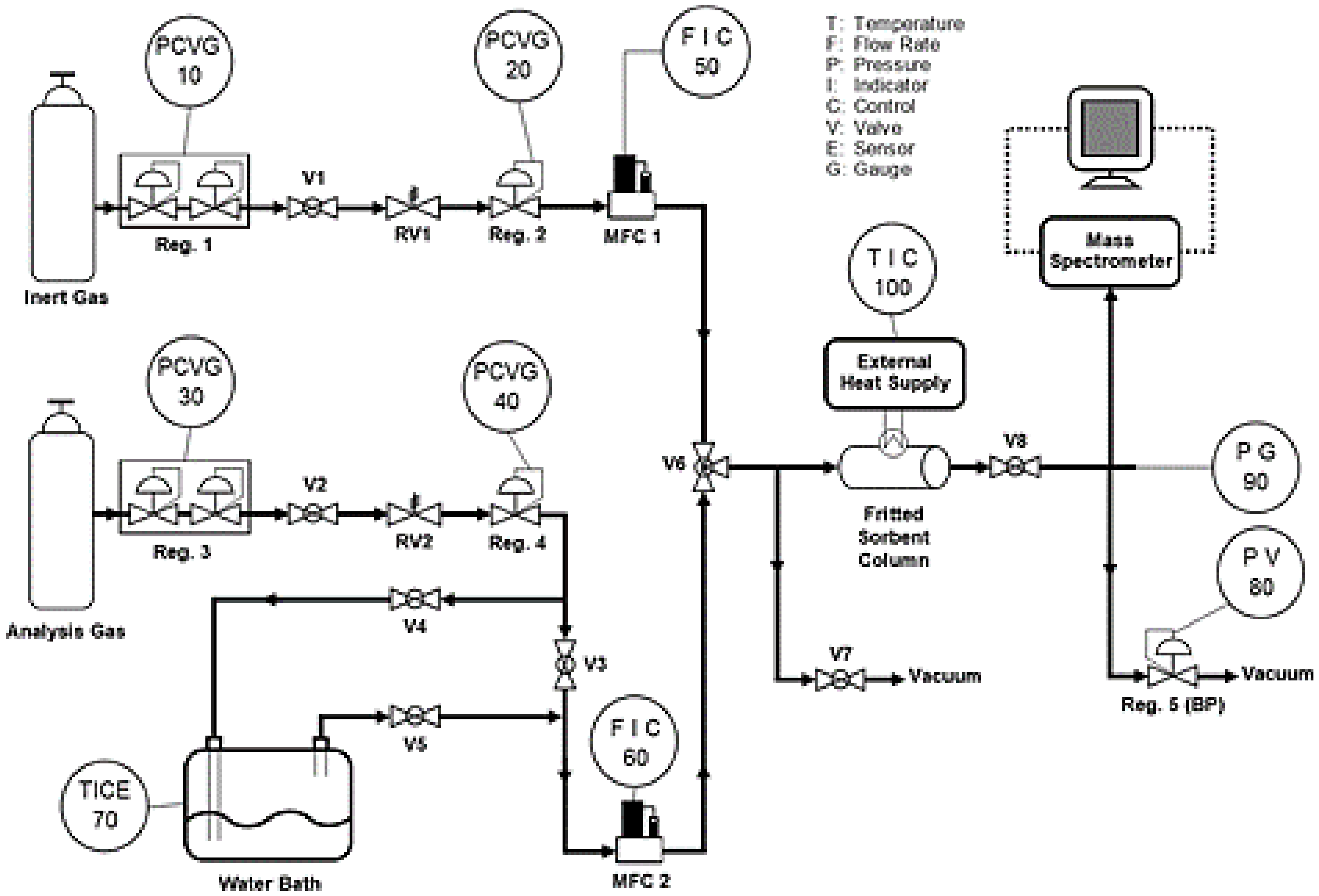
- Identical PXRD confirmed (powder to pellet)
- No amorphous phase
- Reduced BET surface area





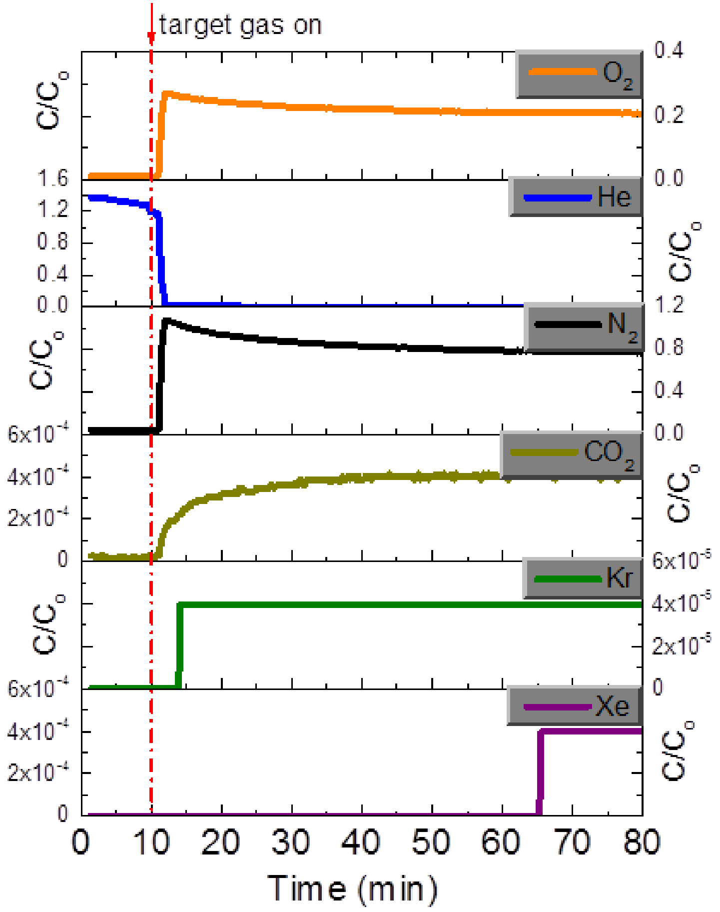
Property	Value
Pressed Pressure	2000 psi for 3 min
Size	600 – 850
BET Surface area	15 m^2/g
BET Surface area, Po	120 m^2/g

Breakthrough Measurements Apparatus



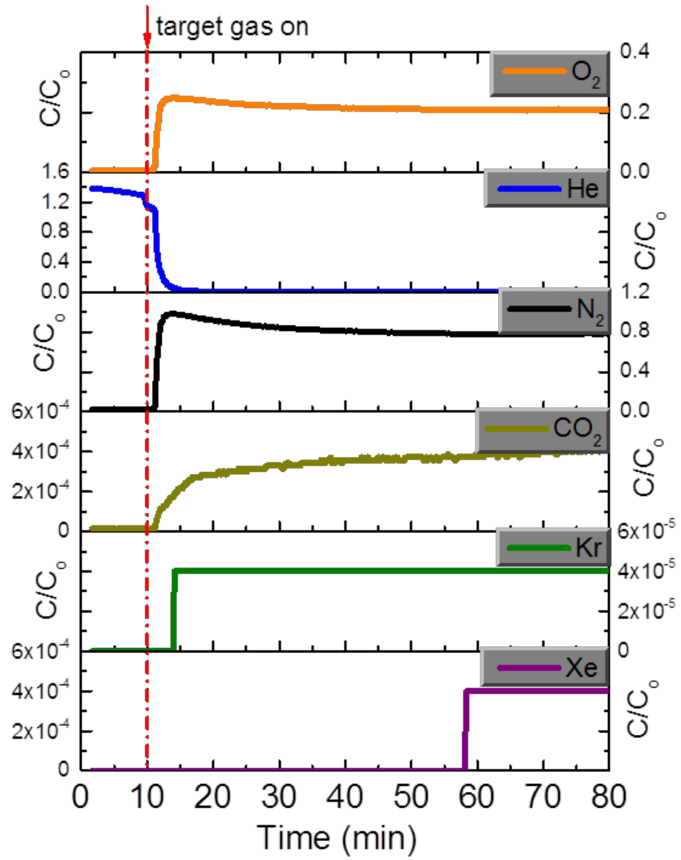
Single Column Breakthrough Experiments

dry gas



> **Conditions**
> - Air = 78% N_2, 21% O_2, 0.9% Ar, 0.03% CO_2, 1300 ppm Xe, 130 ppm Kr
> - Flow rate = 20 cm^3/min
> - T = 25 ^{o}C (298K)
> - MOF = CaSDB
>
> **Results**
> - Xe capacity = 30 mmol/kg *vs* 8 mmol/kg (NiMOF) and 22 mmol/kg (CC3)
> - >95% of the Xe captured from air
> - Xe/Kr (selectivity) = 15

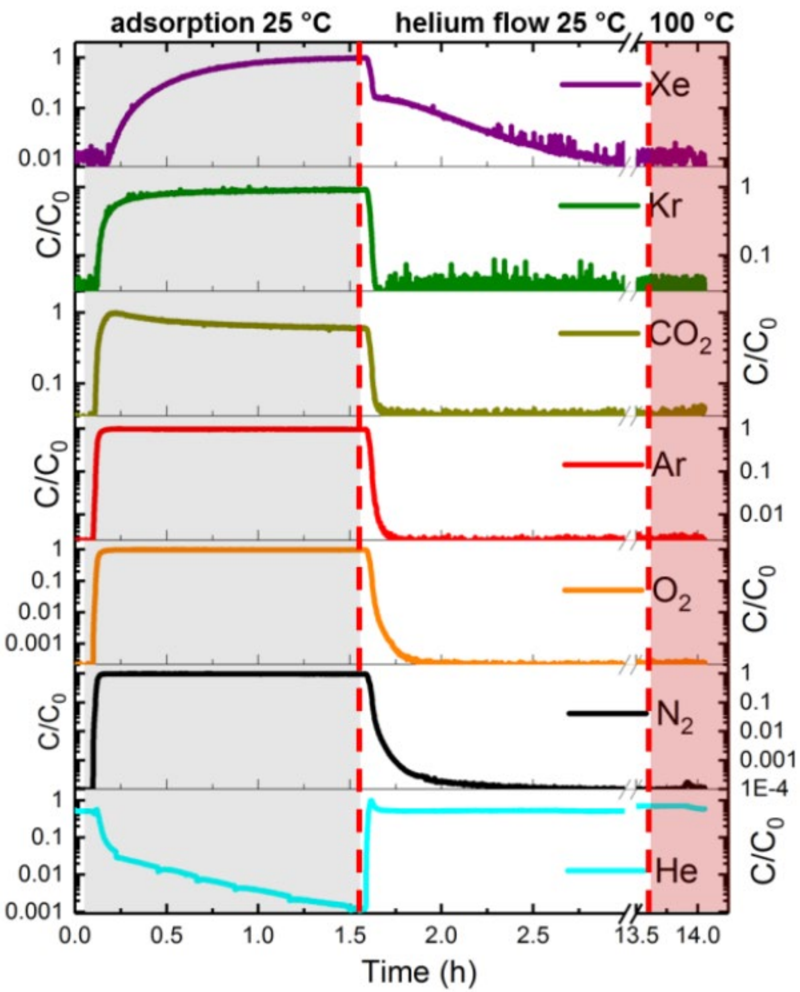
Wet gas (RH 48%)



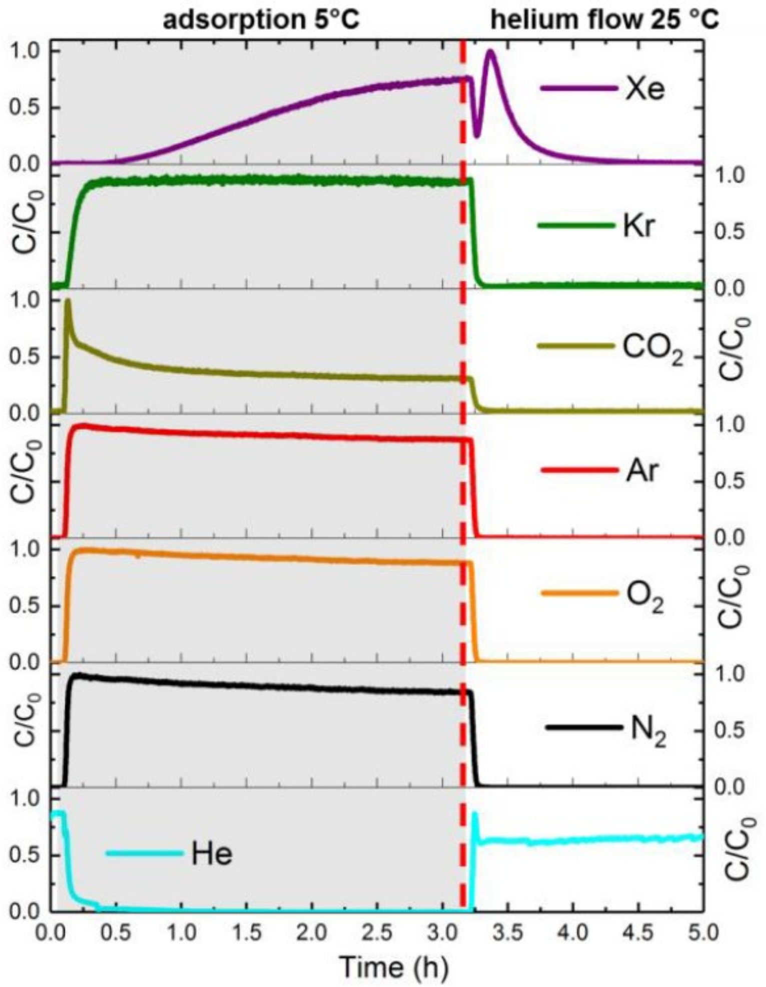
- CaSDB falls in the optimal pore size and shape, making it stand out among other MOFs

Thallapally, Vienna et. al., USPTO WO/2017/218346A1
Banerjee *et. al., Nature Communications,* 2016

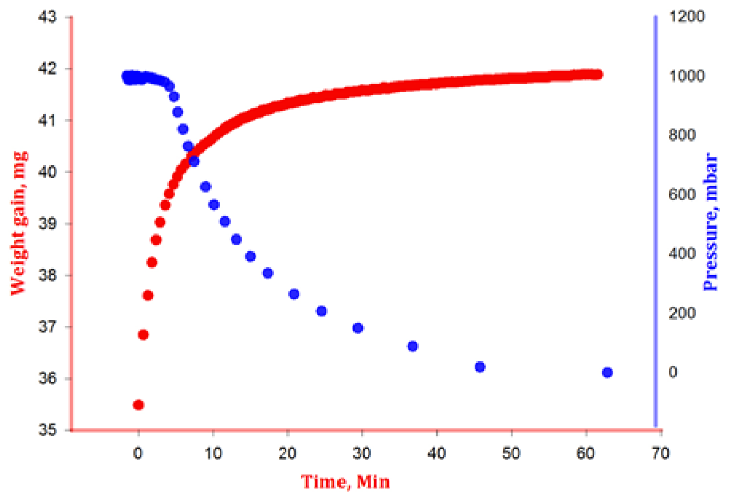
Optimization and Desorption



- Adsorption at 5 C
- 220 mmol/kg of Xe at 5 C, 8 times higher than at RT.
- Desorption at 25 C by He purge
- Desorb within 2 hr with He purge

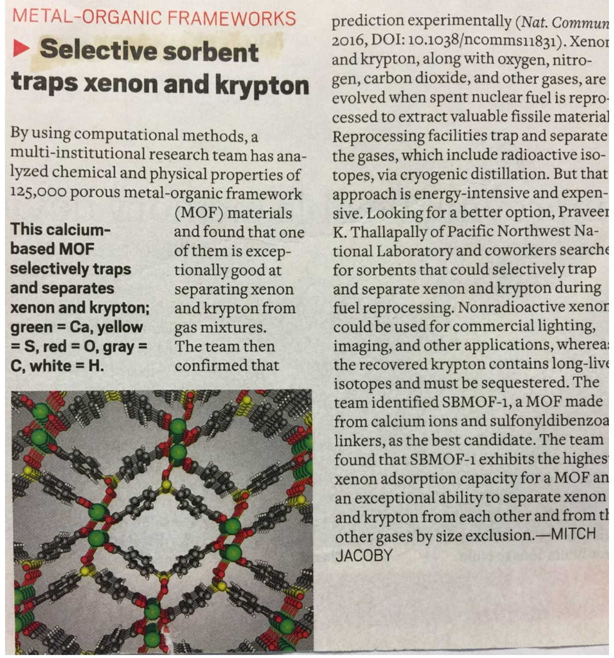


Kinetics and Cycle Experiments at Room Temperature



- Faster kinetics, 80% of Xe adsorbed within 10 minutes.
- Cycling study indicate no loss of capacity even after 20 cycles.

Chemical & Engineering News., 94, 26, June 27, 2016

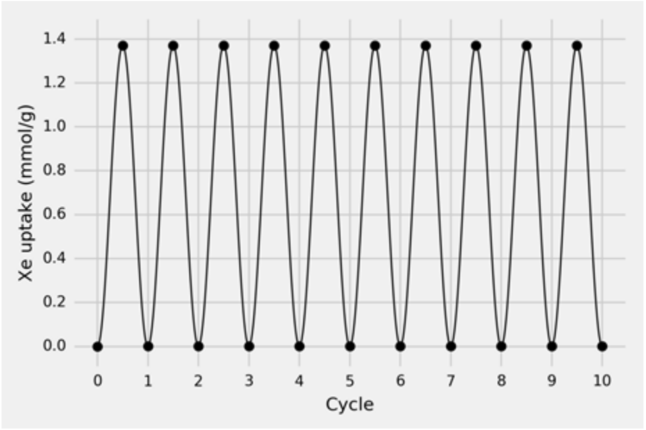


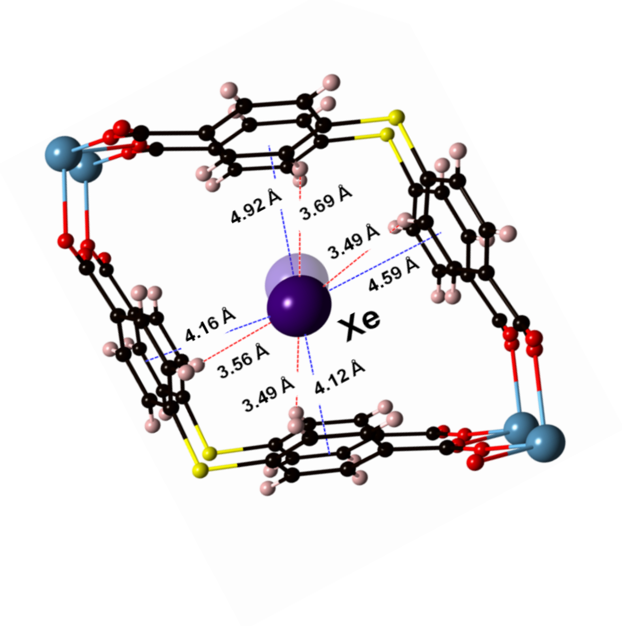
METAL-ORGANIC FRAMEWORKS

▶ **Selective sorbent traps xenon and krypton**

By using computational methods, a multi-institutional research team has analyzed chemical and physical properties of 125,000 porous metal-organic framework (MOF) materials and found that one of them is exceptionally good at separating xenon and krypton from gas mixtures. The team then confirmed that prediction experimentally (*Nat. Commun* 2016, DOI: 10.1038/ncomms11831). Xenon and krypton, along with oxygen, nitrogen, carbon dioxide, and other gases, are evolved when spent nuclear fuel is reprocessed to extract valuable fissile material. Reprocessing facilities trap and separate the gases, which include radioactive isotopes, via cryogenic distillation. But that approach is energy-intensive and expensive. Looking for a better option, Praveen K. Thallapally of Pacific Northwest National Laboratory and coworkers searched for sorbents that could selectively trap and separate xenon and krypton during fuel reprocessing. Nonradioactive xenon could be used for commercial lighting, imaging, and other applications, whereas the recovered krypton contains long-lived isotopes and must be sequestered. The team identified SBMOF-1, a MOF made from calcium ions and sulfonyldibenzoa[te] linkers, as the best candidate. The team found that SBMOF-1 exhibits the highest xenon adsorption capacity for a MOF an[d] an exceptional ability to separate xenon and krypton from each other and from th[e] other gases by size exclusion.—MITCH JACOBY

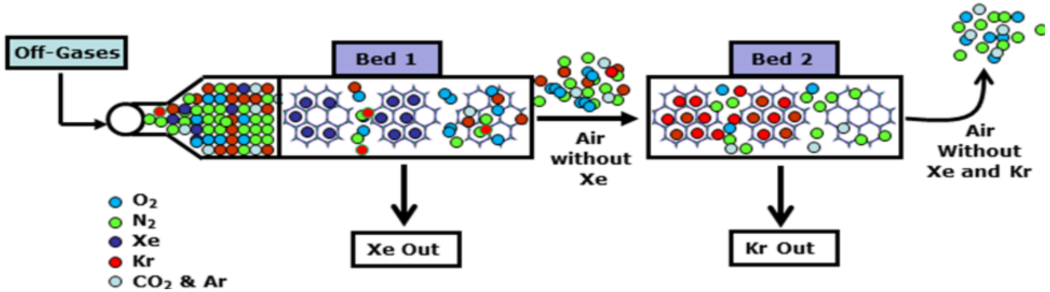
This calcium-based MOF selectively traps and separates xenon and krypton; green = Ca, yellow = S, red = O, gray = C, white = H.





Two-Column Breakthrough and Co-Adsorption at RT

- **A two-bed technique to remove and separate**
  - Bed 1 remove Xe from air
  - Bed 2 remove Kr
    - Yields air without Xe and Kr
    - Off-gas can be released



Results:

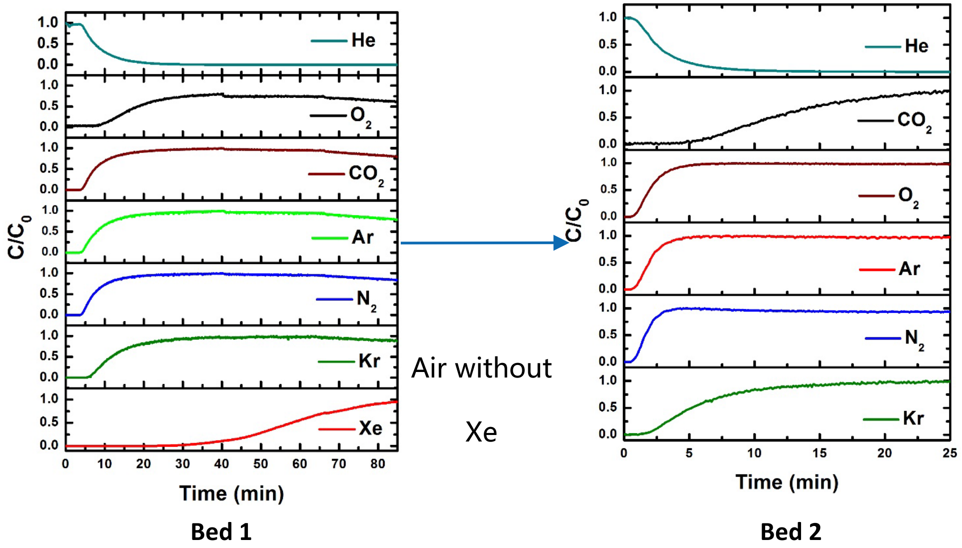
- **Bed - 1**

Gas	Breakthrough Time (min)	Capacity (mmol/kg)	Selectivity of Xe
Xe	18	16 (33.8)[a]	
Kr	1	0.11 (0.75)[a]	14
CO_2	5	1.2	3
N_2	0.08	47	209
Ar	0.08	5.28	210
O_2	0.08	12	206

[a] Capacity at equilibrium

- **Bed - 2**

Gas	Breakthrough Time (min)	Capacity (mmol/kg)	Selectivity of Kr
Kr	2.5	0.13	
CO_2	7.5	0.90	0.3
N_2	0.25	80.8	9.9
Ar	0.25	9.09	9.3
O_2	0.25	21.2	9.3



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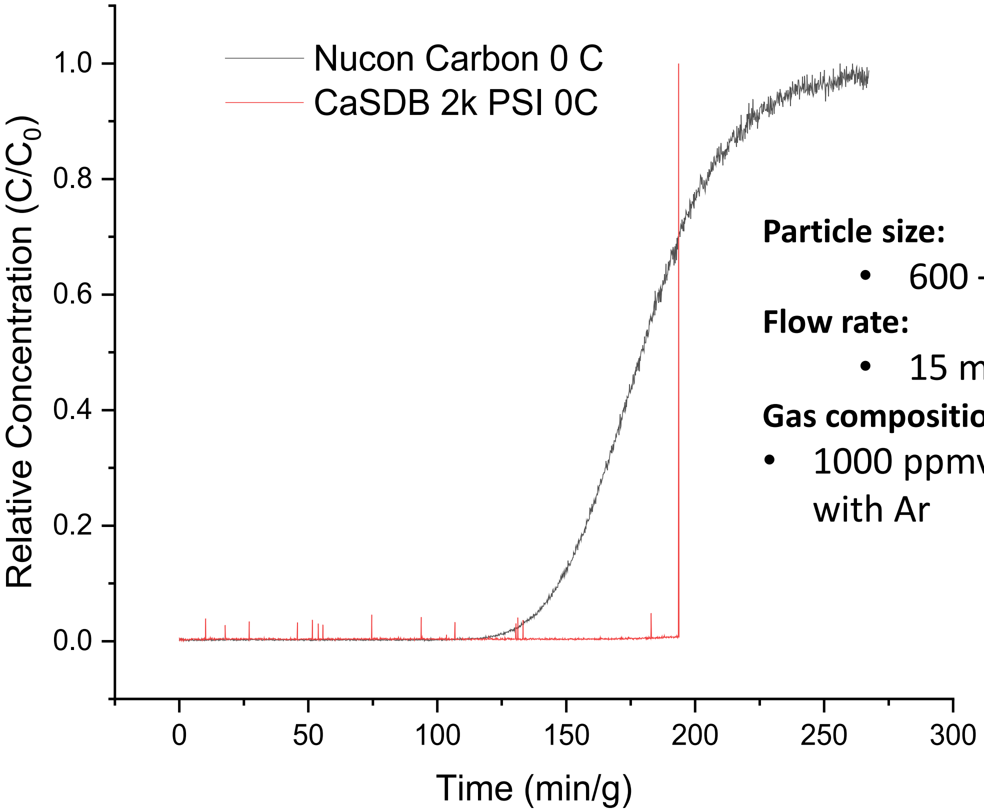
Comparison of MOF vs Carbon



Particle size:

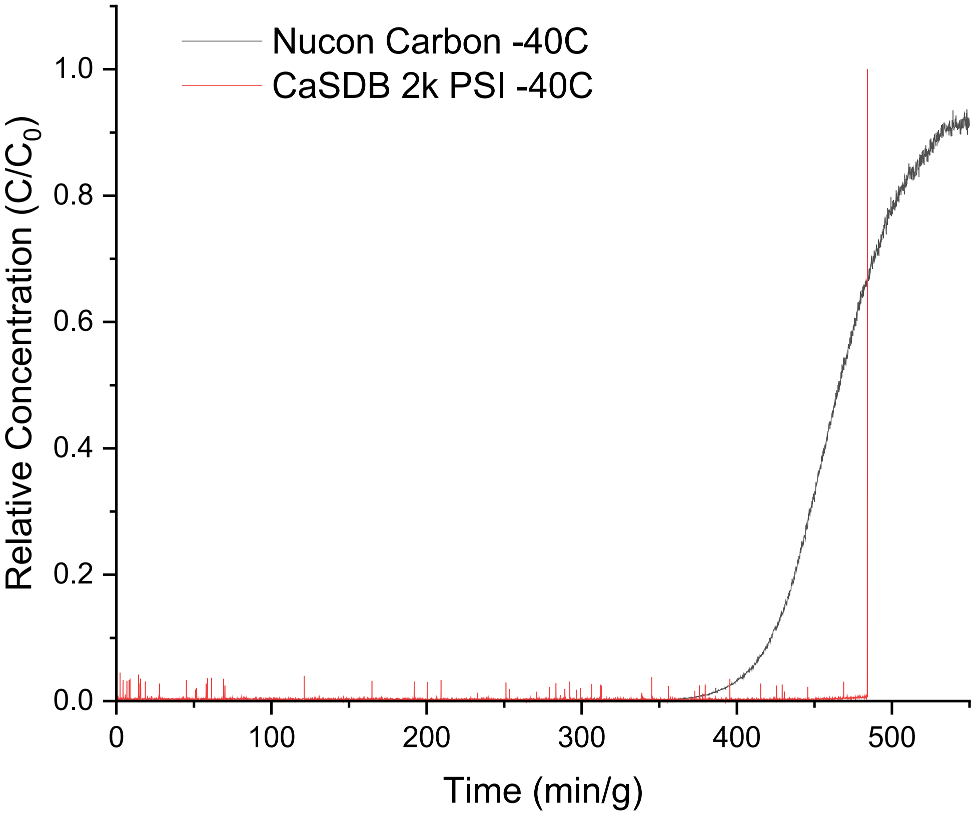
- 600 – 850 micron

Flow rate:

- 15 mL/min

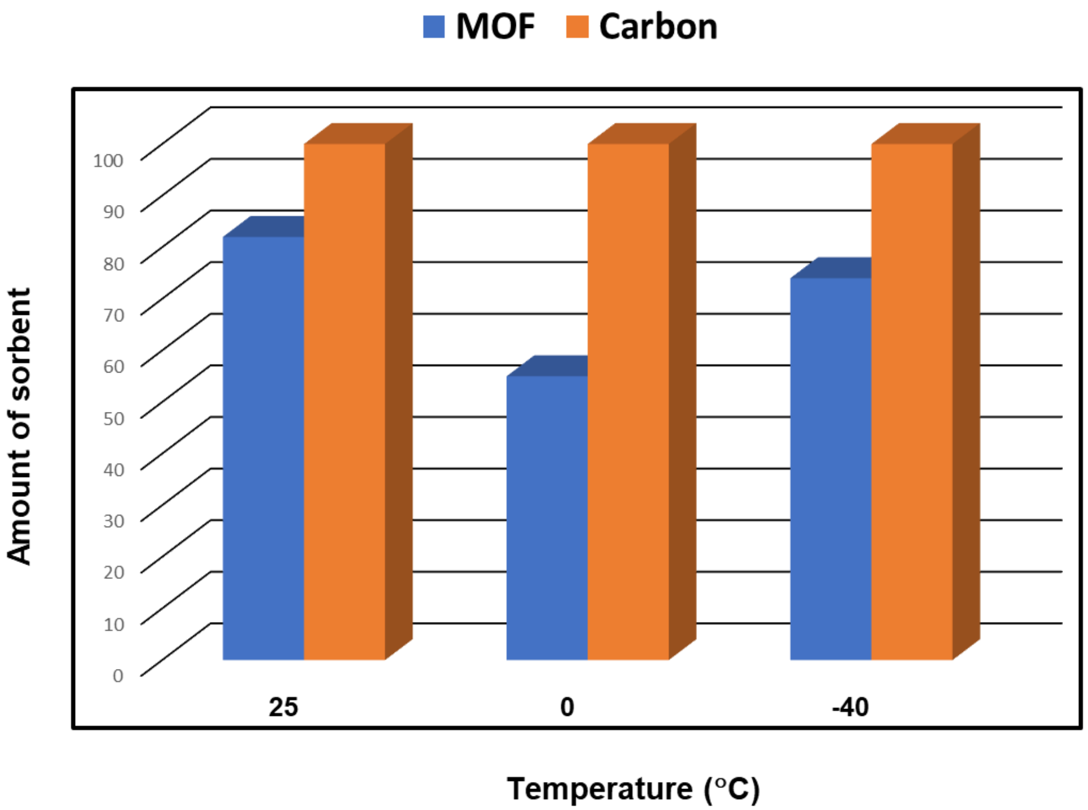
Gas composition:

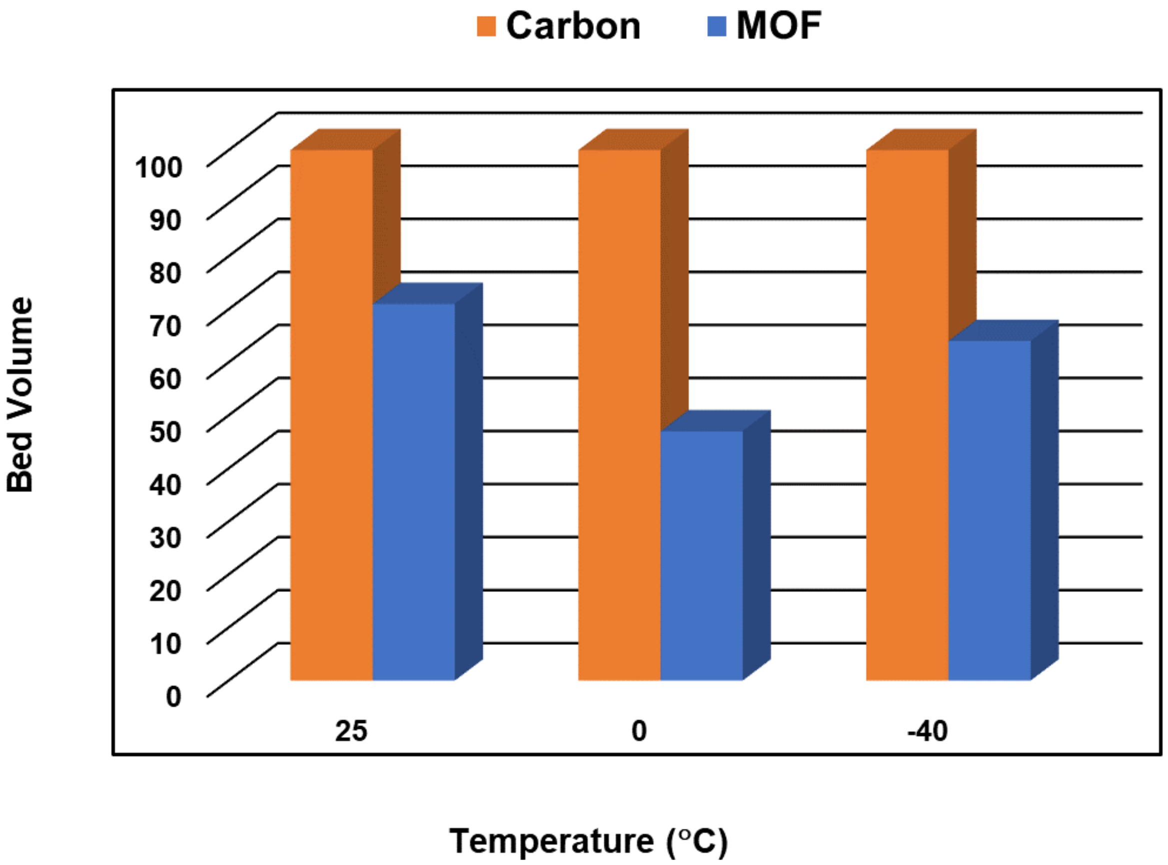
- 1000 ppmv Xe, 100 ppmv Kr balanced with Ar



Thallapally, P. K., Robinson, A. J., Zbib, A., Riley, B. J., Chong, S., Liu, J., Murphy, M. K., Okabe, P., Sherrod, R. *Noble Gas Management: SBMOF 1 vs. NUCON Carbon*; PNNL-33314: The U.S. Department of Energy - Office of Nuclear Energy: GAIN VOUCHER, 2022

Relative Bed Size: MOF Vs Carbon





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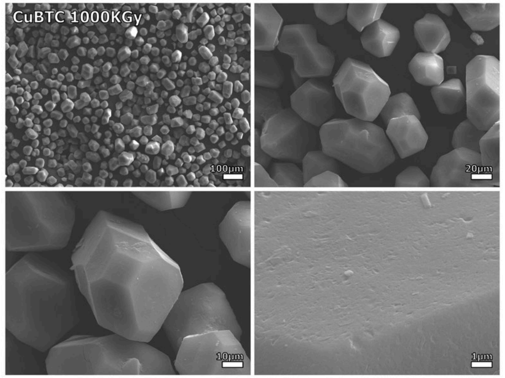
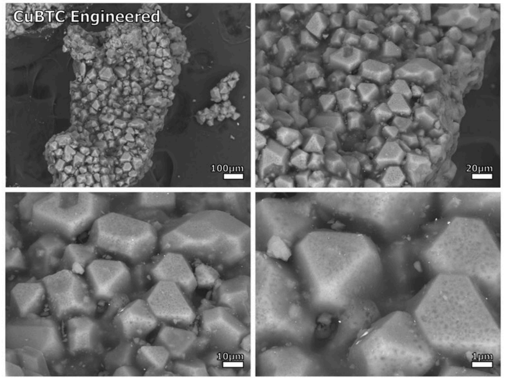
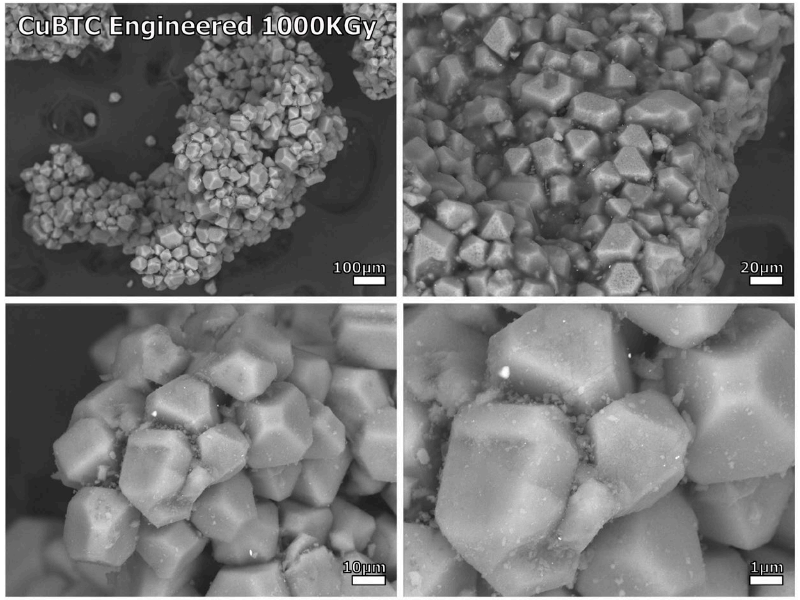
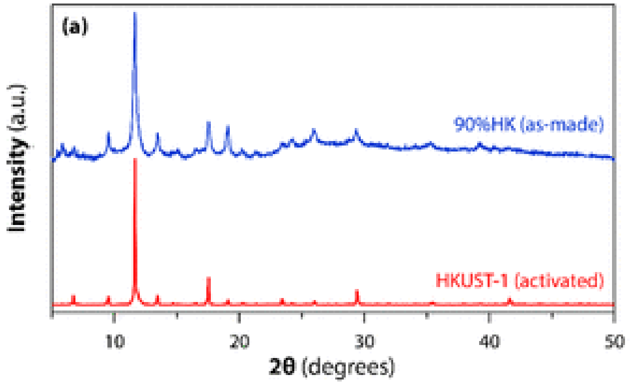
- Thallapally, P. K., Robinson, A. J., Zbib, A., Riley, B. J., Chong, S., Liu, J., Murphy, M. K., Okabe, P., Sherrod, R. *Noble Gas Management: SBMOF 1 vs. NUCON Carbon;* PNNL-33314: The U.S. Department of Energy - Office of Nuclear Energy: GAIN VOUCHER, 2022

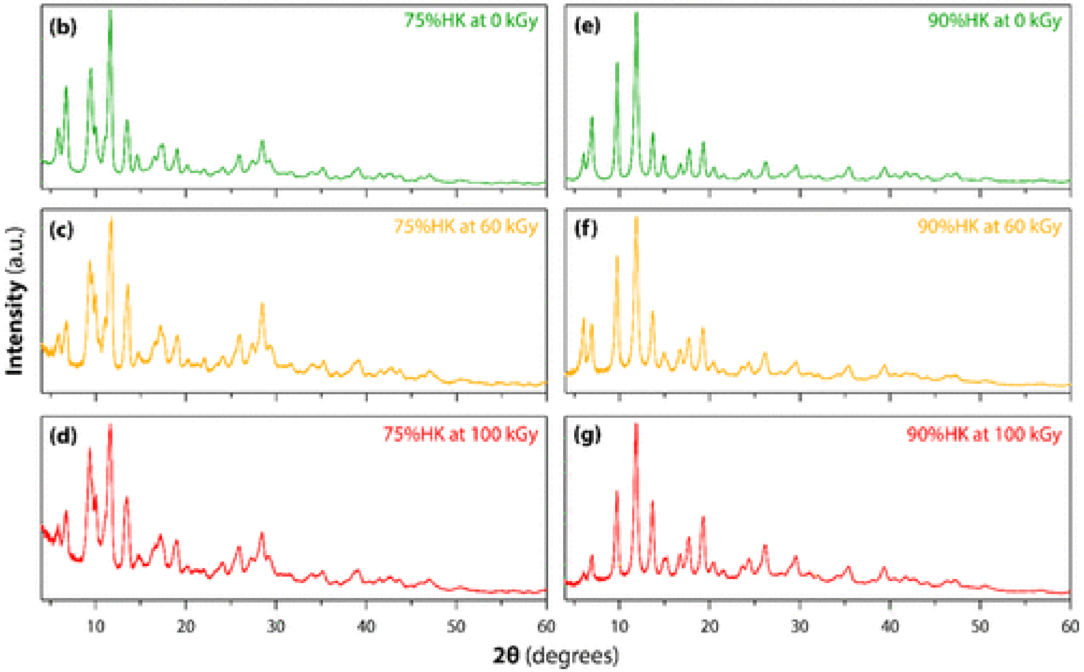
Radiation Stability











Preliminary radiation stability

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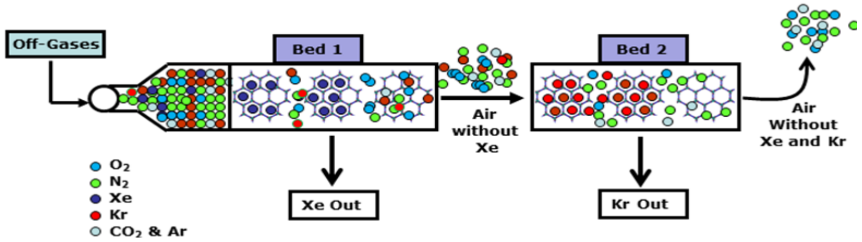
Thallapally and co-workers *ACS Appl. Mater. Interfaces* 2020, 12, 40, 45342–45350
Thallapally and co-workers *Nature Communications*, 2020

Economic Analysis of Noble Gas Separation



- Techno-economic considerations for noble gas capture from nuclear fuel processing
- Extrapolated the data from two column approach to 400 m^3/h flow rate

Process	Decontamination Factor	Total Project Capital ($\$10^6$)	Proposed Annual Consumables[A] ($)
Cryogenic Distillation	67	8.77	267,000[A]
Porous material	100[B]	8.42	78,000

A: Includes compressor/pump utility loads adjusted to capacity factor and $0.10/kWh, and annual consumables (hydrogen for cryogenic and MOF for the adsorbent process).
B: The MOF DF is theoretical and neither measured nor calculated. The model assumed complete adsorption based on experimental data and performance criteria established in bench scale testing.

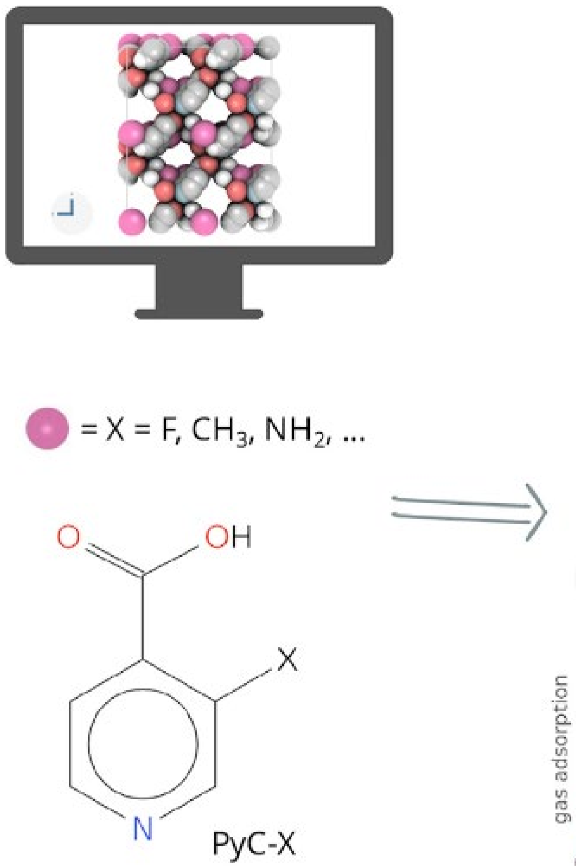
- The economic assessment indicate that improvements in capital outlay, annual operating costs, and improved environmental release profiles with potentially high decontamination factors.
- Improving the noble gas capacity and selectivity will further improve the economics
- **Assumptions include:**
  - Xe is not recovered for sell
  - Recovery of Xe can further improve the economics

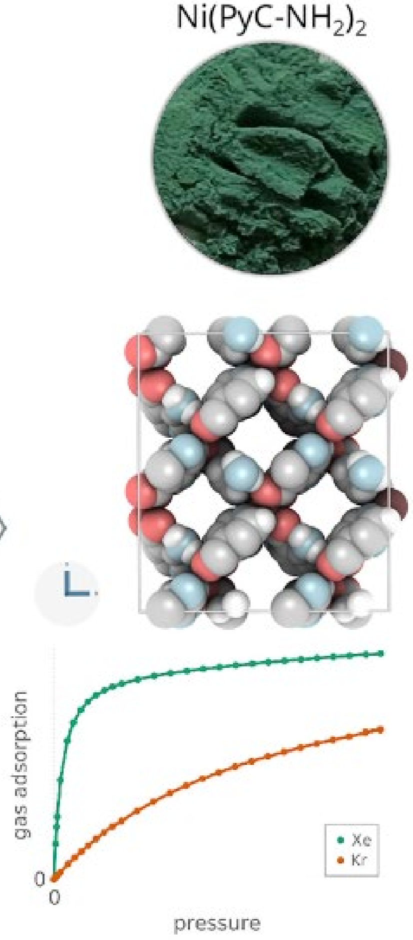
Improved the Xe loading 10X since this report

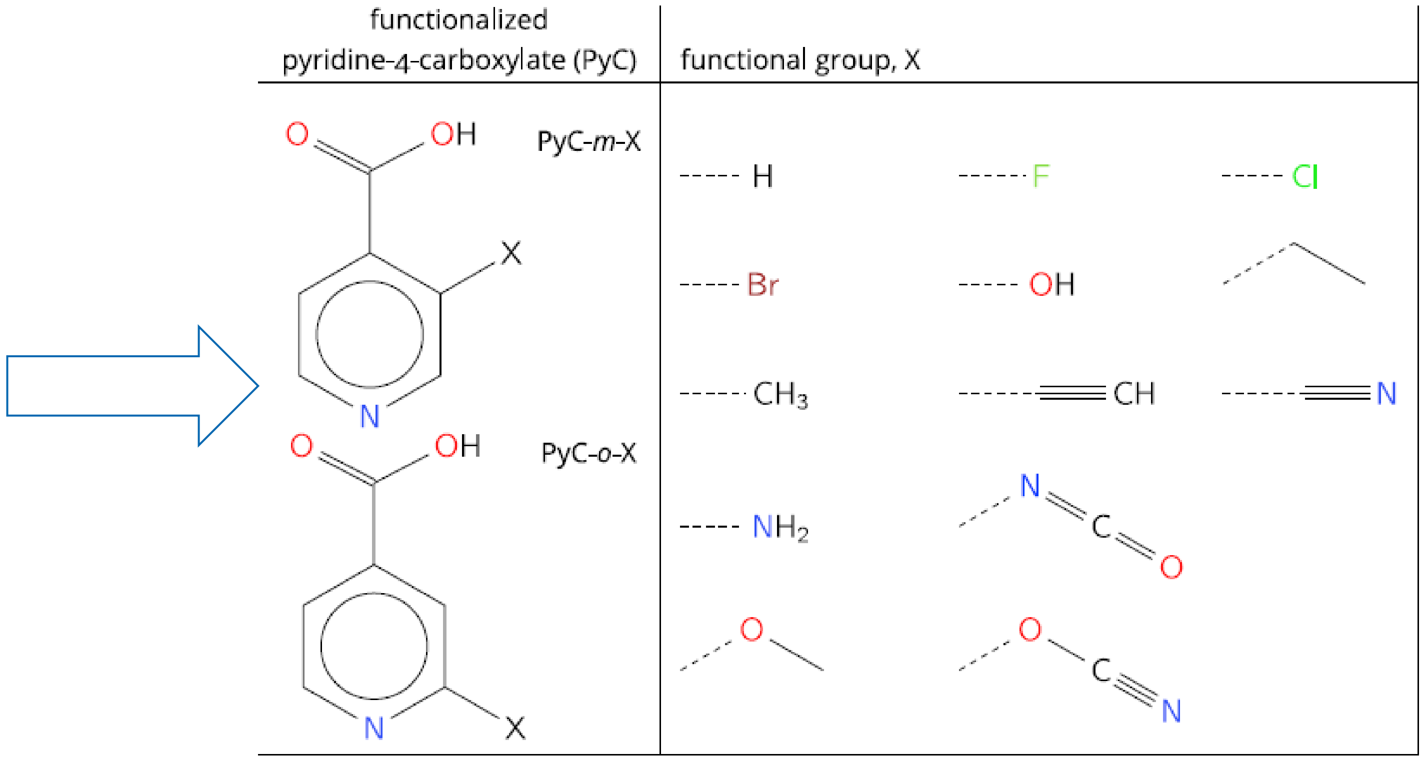
DOI: 10.13140/RG.2.1.3431.2725

Thallapally, Ali Z. Riley, BJ., Paviet, P., Matyas, J., Vienna, J., Compact and Modular Integrated Off-Gas System and Sensors." Invention Disclosure e-IDR 18117
Thallapally, PK., Vienna et. al., USPTO WO/2017/218346A1

Computation Informed Optimization

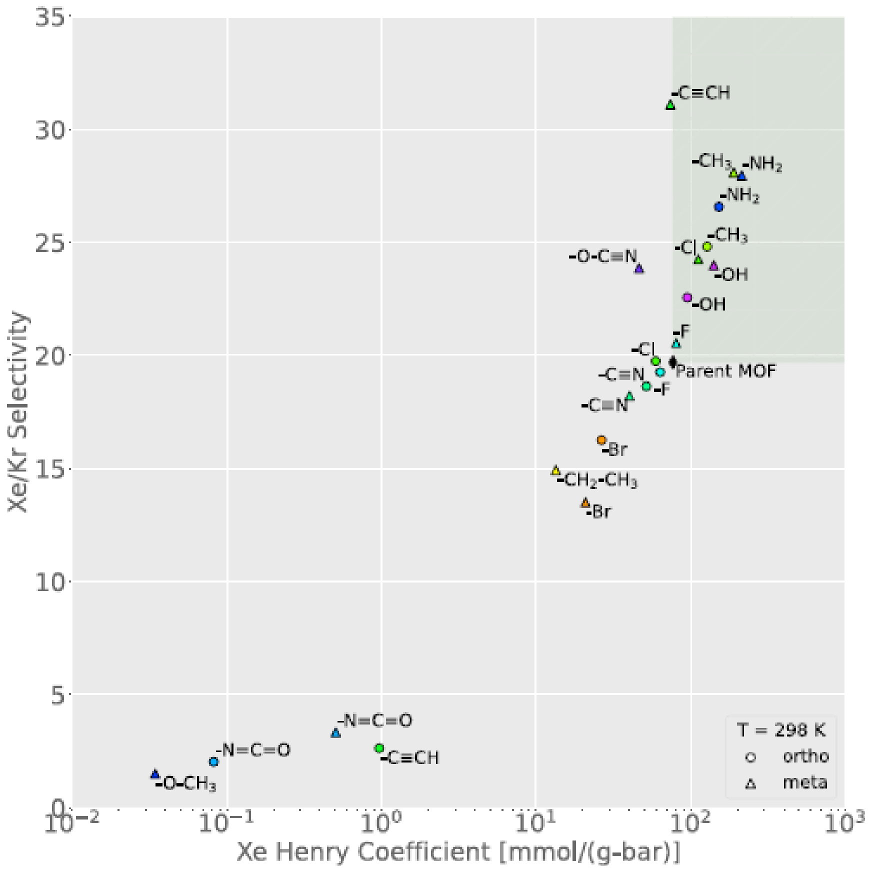


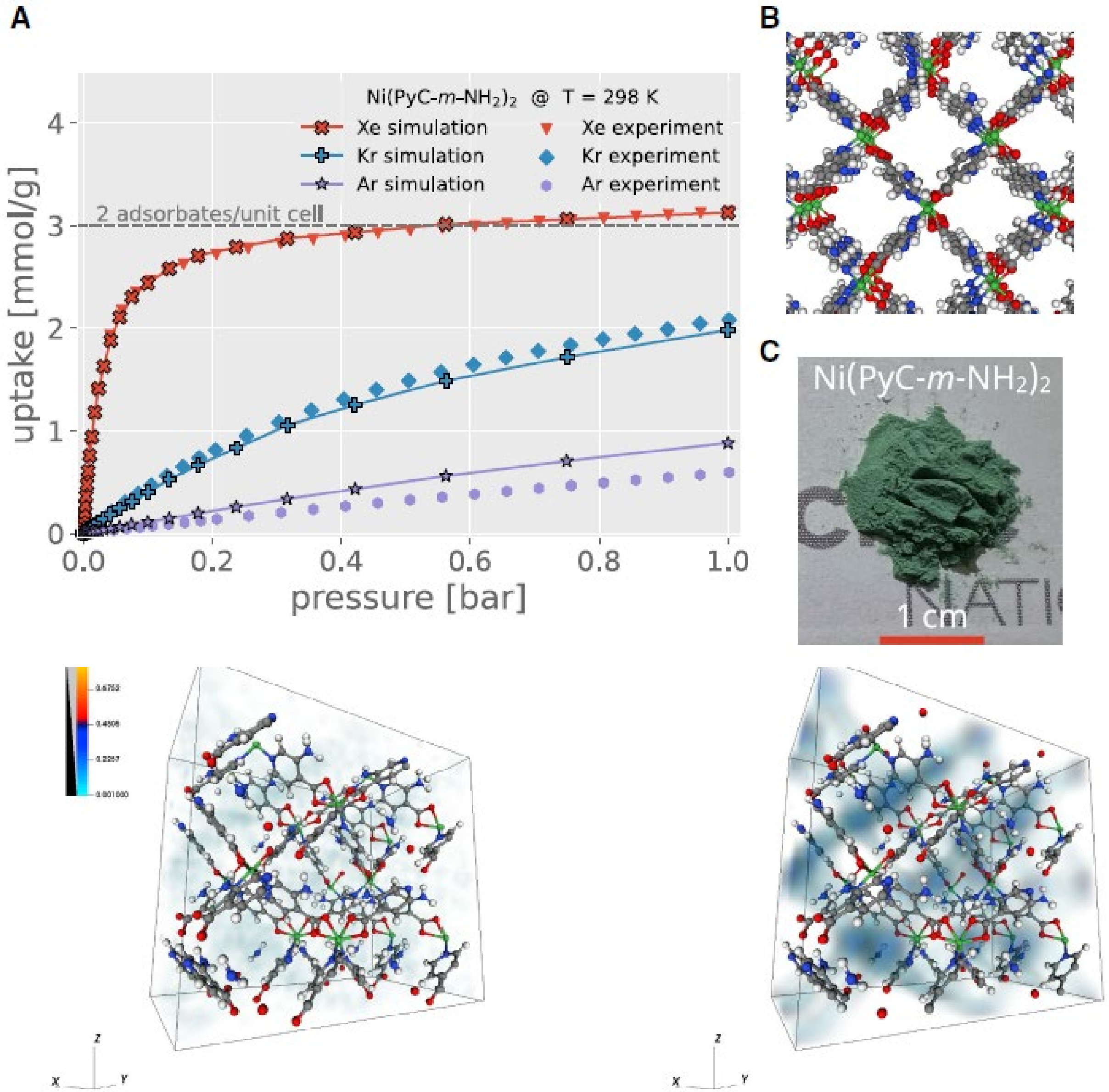




Gantzler, et. al., Cell Reports Physical Science, 3, 101025, 2022

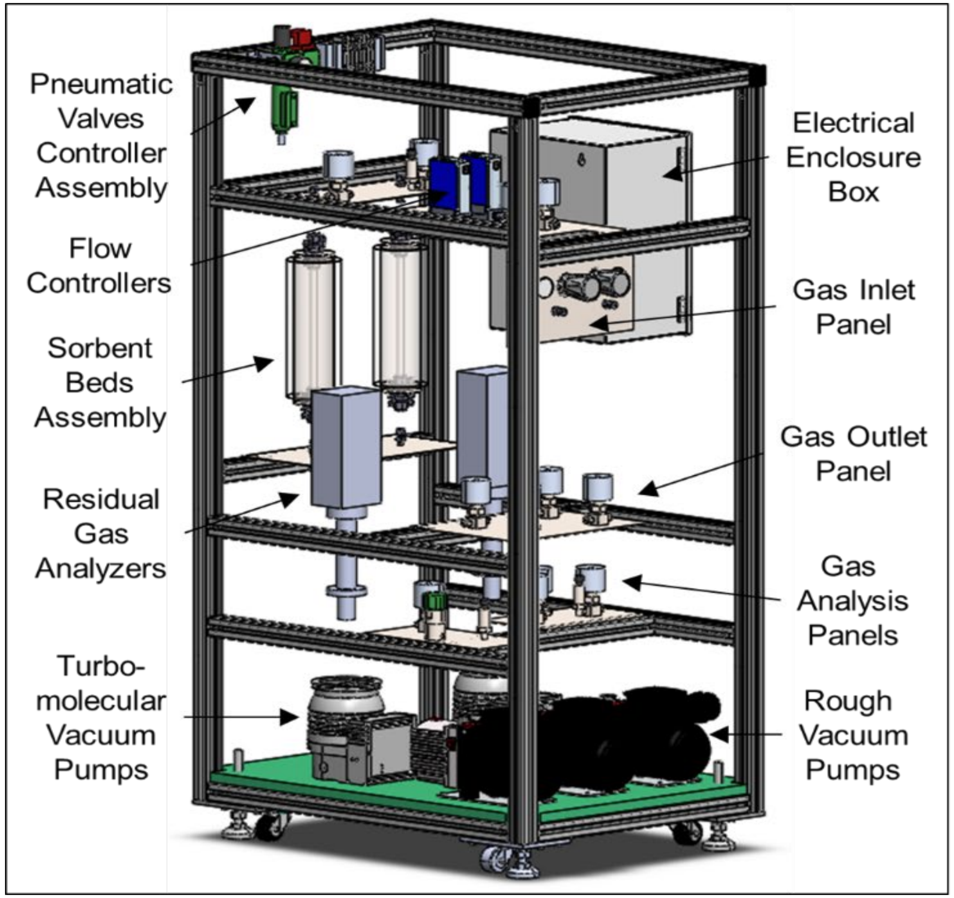
Computation Informed Optimization

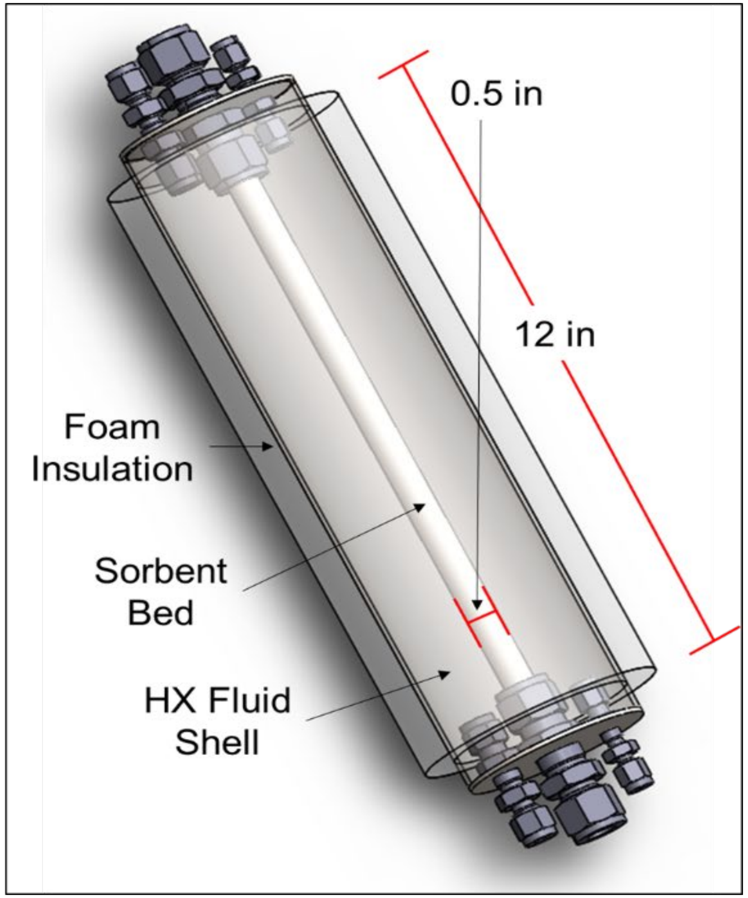




Gantzler, et. al., Cell Reports Physical Science, 3, 101025, 2022

Modular Off-Gas System





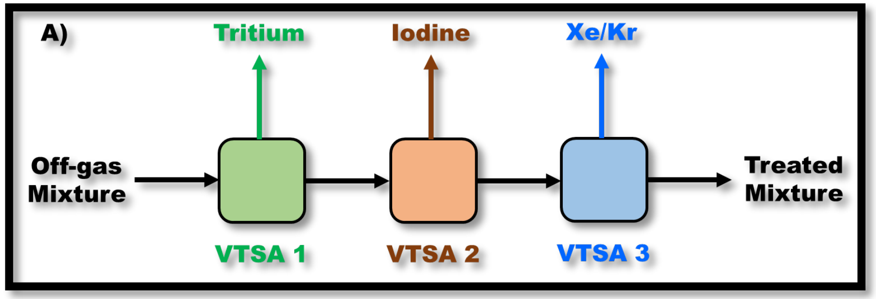
Under development as part of ARPA-E program

(Additional beds in sequence to design an integrated off-gas system)

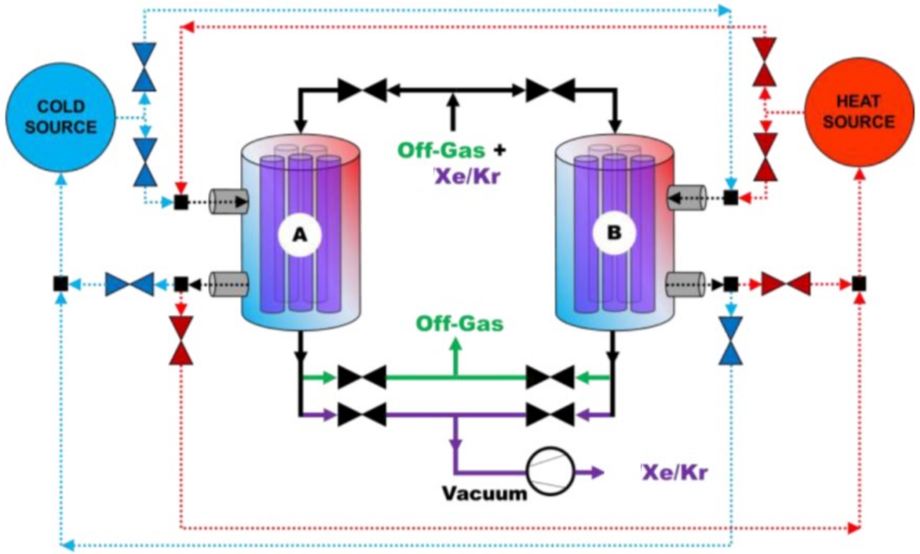
Thallapally, Ali Z. Riley, BJ., Paviet, P., Matyas, J., Vienna, J., Compact and Modular Integrated Off-Gas System and Sensors." Invention Disclosure e-IDR 18117
Thallapally, PK., Vienna et. al., USPTO WO/2017/218346A1
Banerjee, D, Thallapally, PK, Kunapuli R., Mcgrail, BP, Liu J et al., Surface acoustic wave sensors for refrigerant leak detection., *USPTO WO2021/041359 A1*

What next?

- ❑ MOFs are being developed and tested for noble gas management with success
- ❑ Further research is needed to evaluate if MOFs are beneficial to collection of Xe from molten salt reactors
  - ❑ Impact of acid gases on Xe/Kr
  - ❑ Impact of Radiation
  - ❑ Build a small-scale integrated system
- ❑ Integrate MOF capture technology with molten salt test loop at ORNL
  - ❑ MOF scale up and fabrication
- ❑ Build a lab and bench scale system coupled with selective gas sensors



Integrated off-gas system



Integrated off-gas system

Laser-Induced Breakdown Spectroscopy for off-gas monitoring

Hunter Andrews

Oak Ridge National Laboratory

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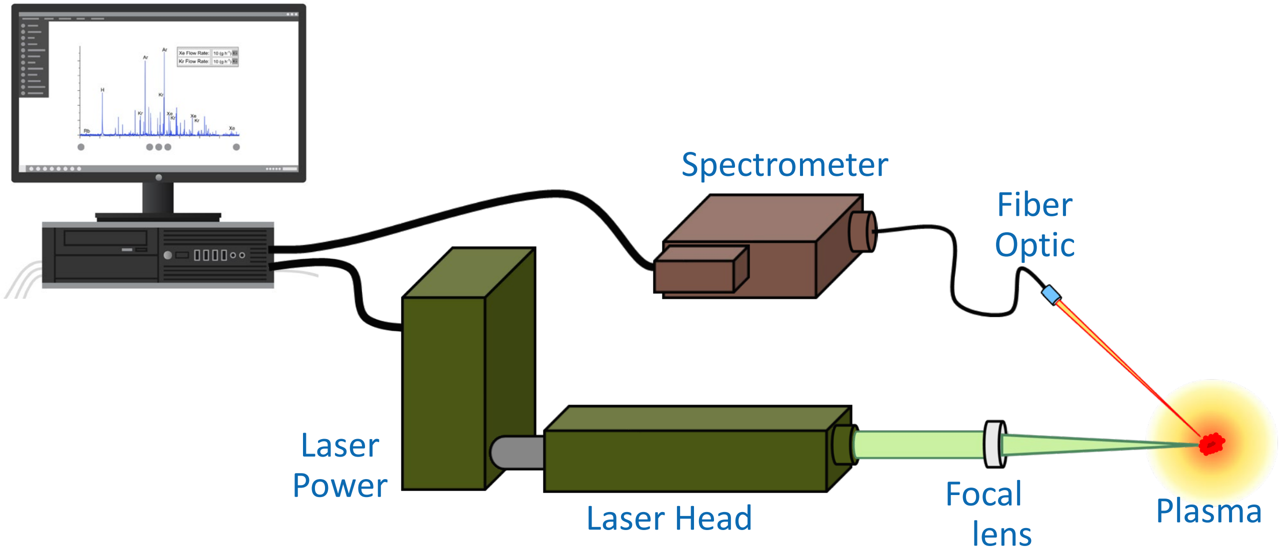
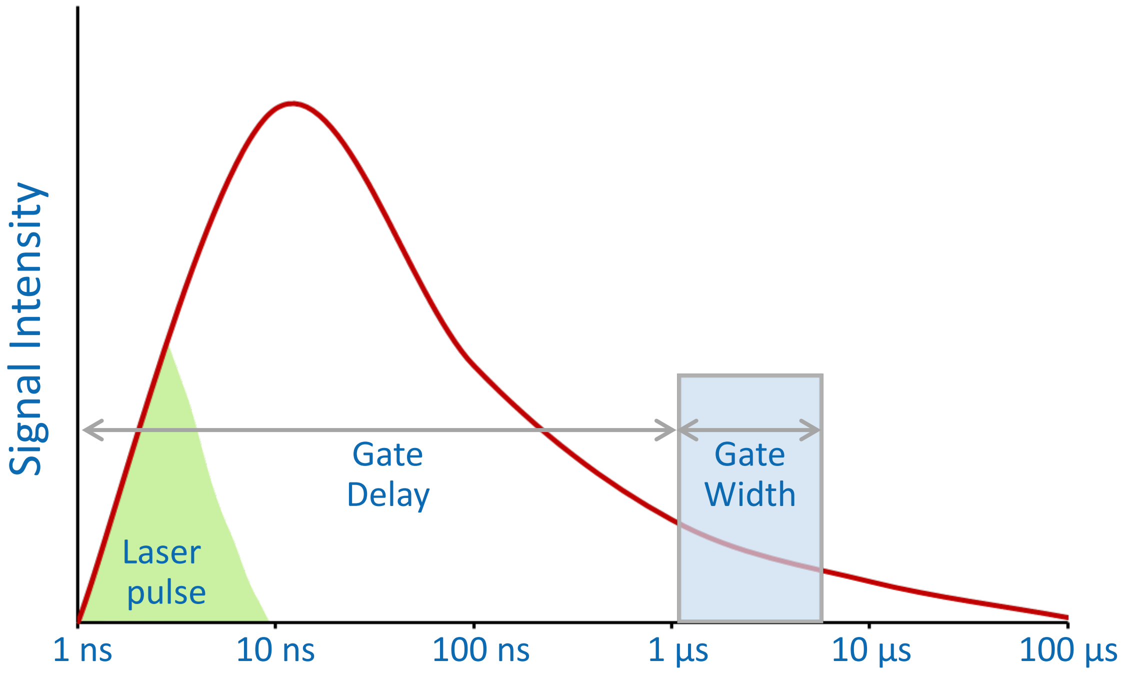
Laser-induced breakdown spectroscopy (LIBS) can provide an elemental fingerprint in real-time

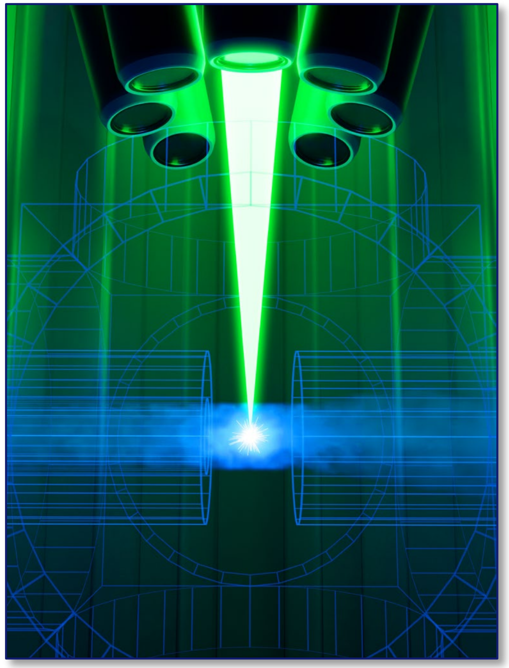
A high energy density laser pulse ablates a sample to form a micro plasma at T~10,000 K

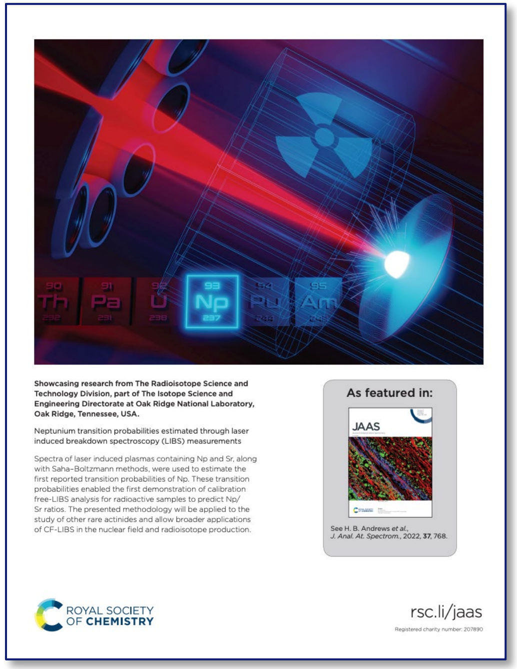


The plasma light is collected with a gated spectrometer to measure an elemental signature



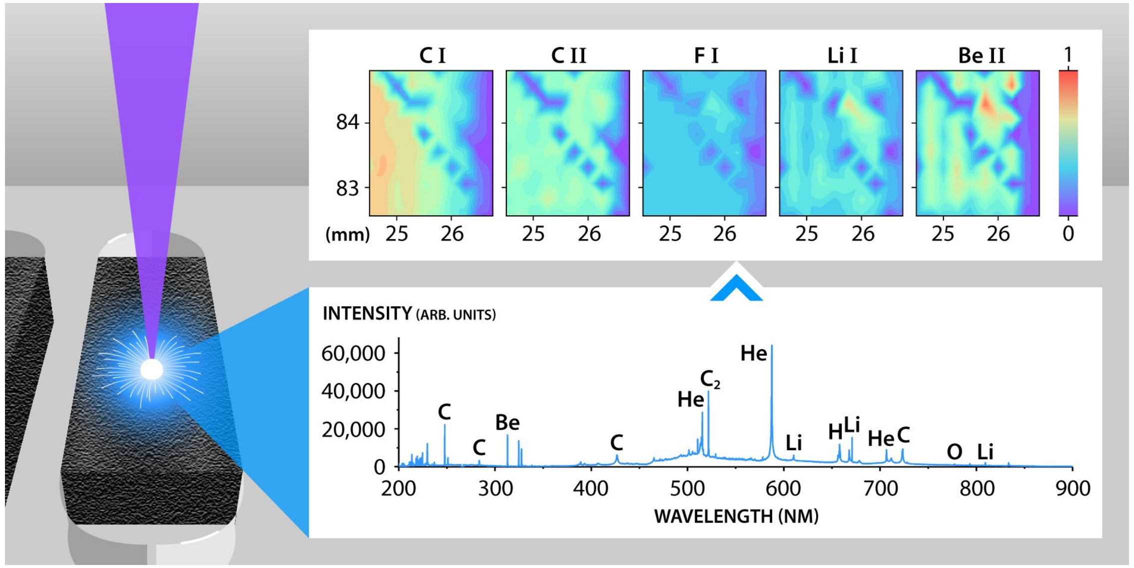
LIBS is being used at ORNL to aid in several areas of nuclear science





LIBS in advanced reactors

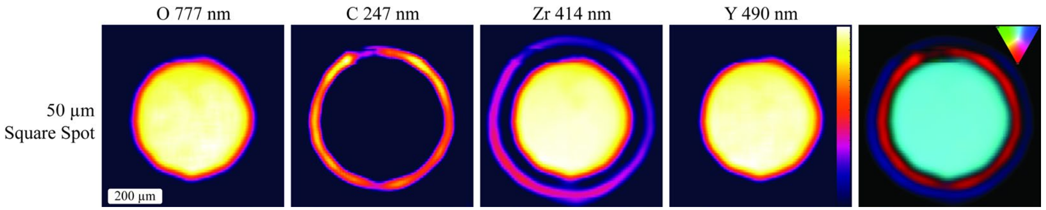
- LIBS being used to evaluate nuclear reactor materials
  - Penetration of salts (FLiBe, FLiNaK) into graphite passively and with positive pressure
  - LIBS can monitor all relevant species (H, Li, Be, C, O, F, Na) in 3D through continued ablation

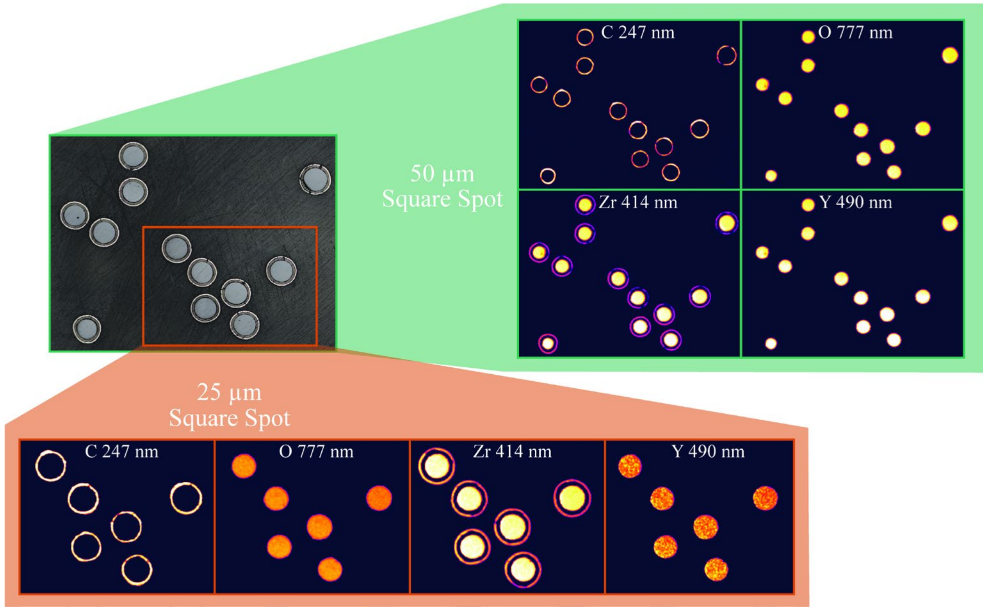


Myhre, Andrews, Gallego et al. *Journal of Analytical Atomic Spectrometry* 37 (2022): 1629-1641.

LIBS in advanced reactors

- LIBS being used to evaluate nuclear reactor materials
  - Elemental mapping of surrogate TRISO particles
  - Elemental depth profiling to investigate layer thicknesses and homogeneity





Manard and Andrews et al. *Journal of Analytical Atomic Spectrometry* 38 (2023): 1412-1420.

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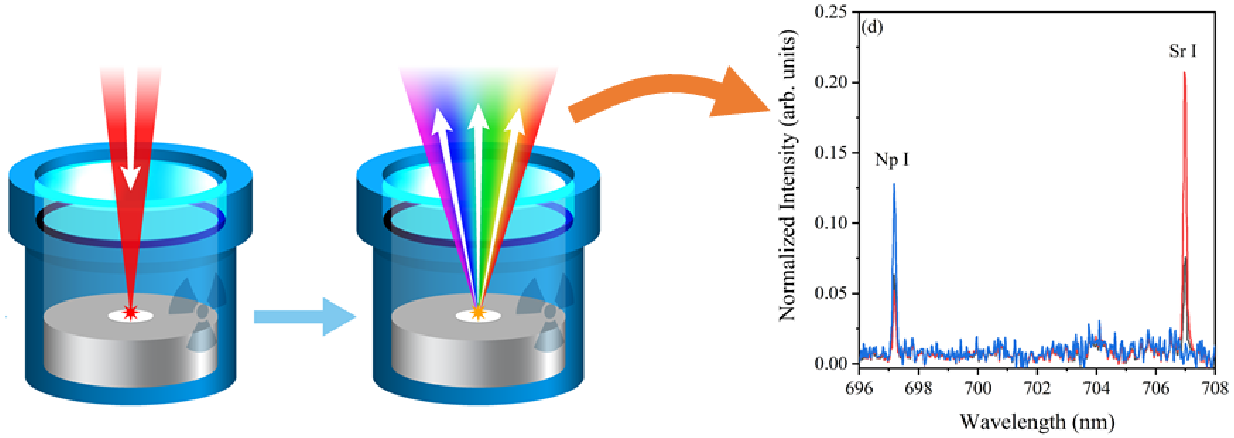
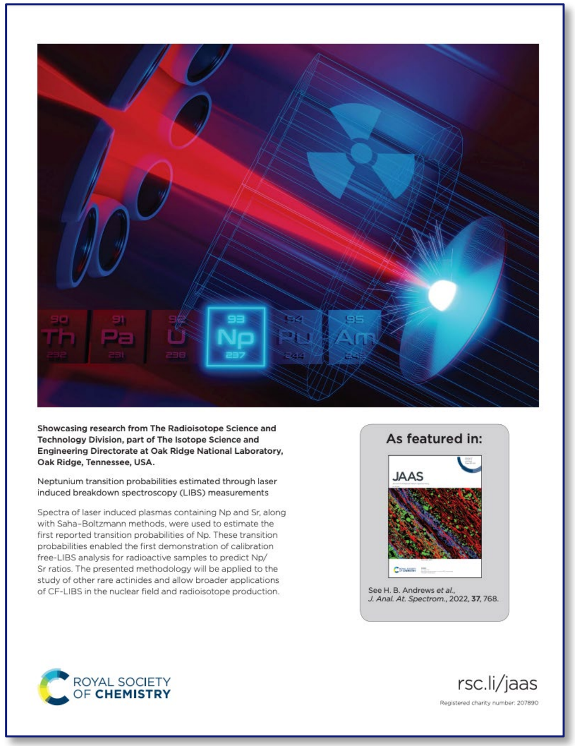
LIBS for monitoring reprocessing/chemical separations

- LIBS is being used for impurity analysis in radioactive samples
- First calibration free – LIBS measurements of actinides




Showcasing research from The Radioisotope Science and Technology Division, part of The Isotope Science and Engineering Directorate at Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

Neptunium transition probabilities estimated through laser induced breakdown spectroscopy (LIBS) measurements

Spectra of laser induced plasmas containing Np and Sr, along with Saha–Boltzmann methods, were used to estimate the first reported transition probabilities of Np. These transition probabilities enabled the first demonstration of calibration free-LIBS analysis for radioactive samples to predict Np/Sr ratios. The presented methodology will be applied to the study of other rare actinides and allow broader applications of CF-LIBS in the nuclear field and radioisotope production.

As featured in:

JAAS

See H. B. Andrews *et al.*, *J. Anal. At. Spectrom.*, 2022, **37**, 768.

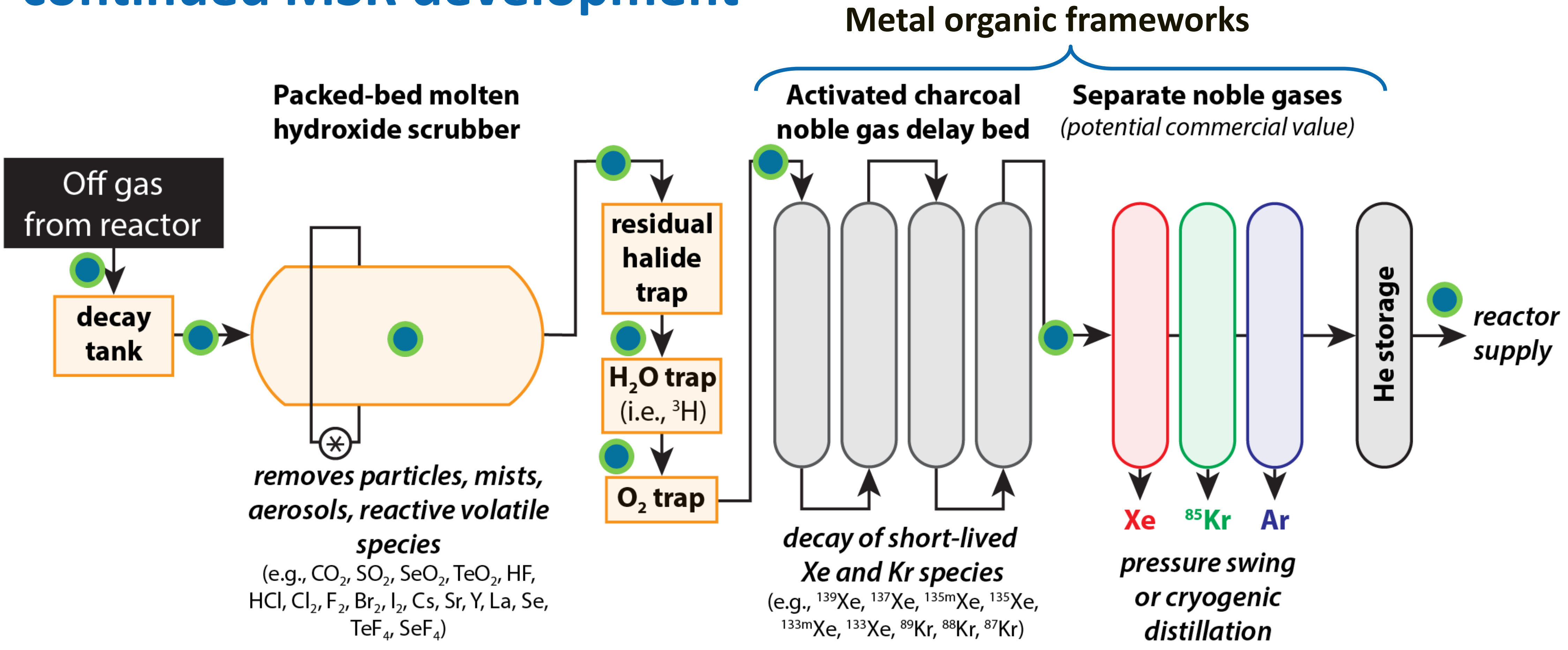
ROYAL SOCIETY OF CHEMISTRY

rsc.li/jaas

Registered charity number: 207890

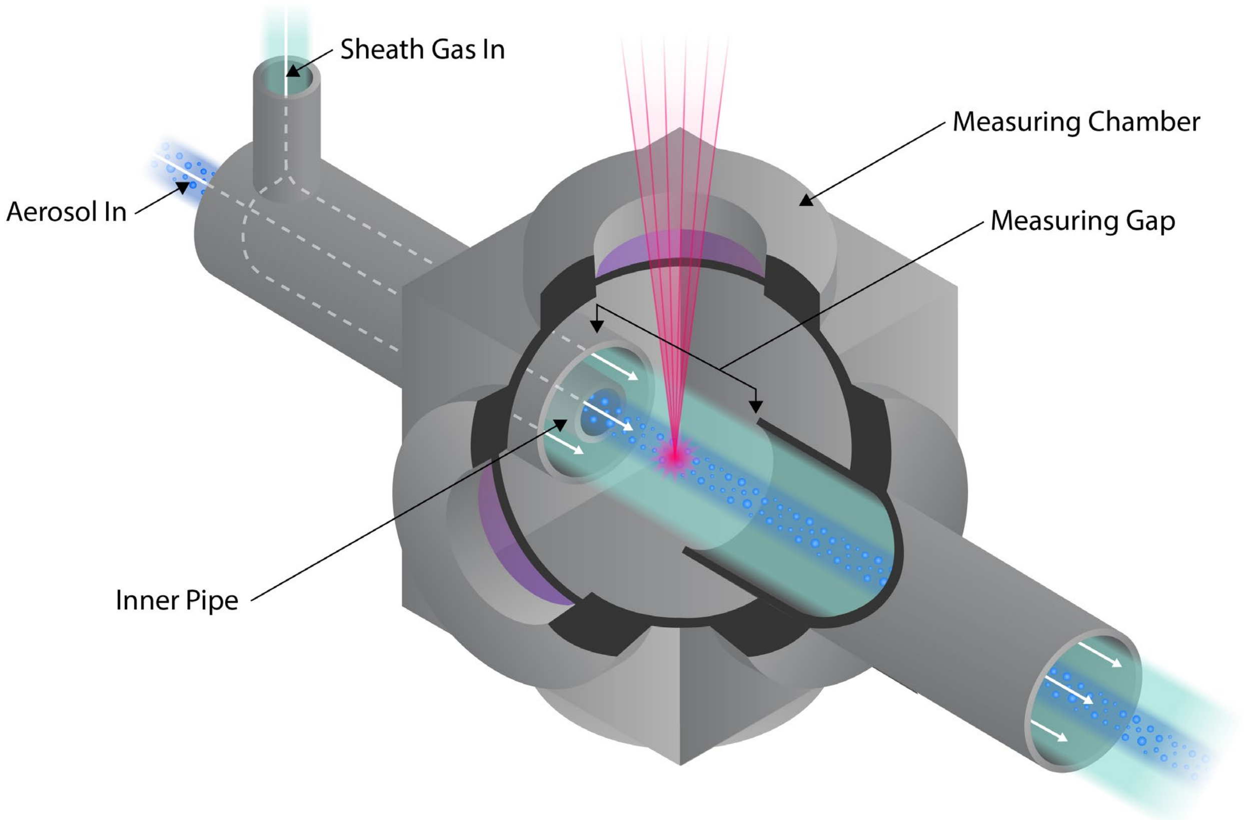
Andrews et al. *Journal of Analytical Atomic Spectrometry* 37 (2022): 768-774.

The off-gas treatment system development is critical for continued MSR development



Andrews et. al., Nuclear Engineering and Design., 2021, 385, 111529.

Initial feasibility has been shown on surrogate off-gas streams

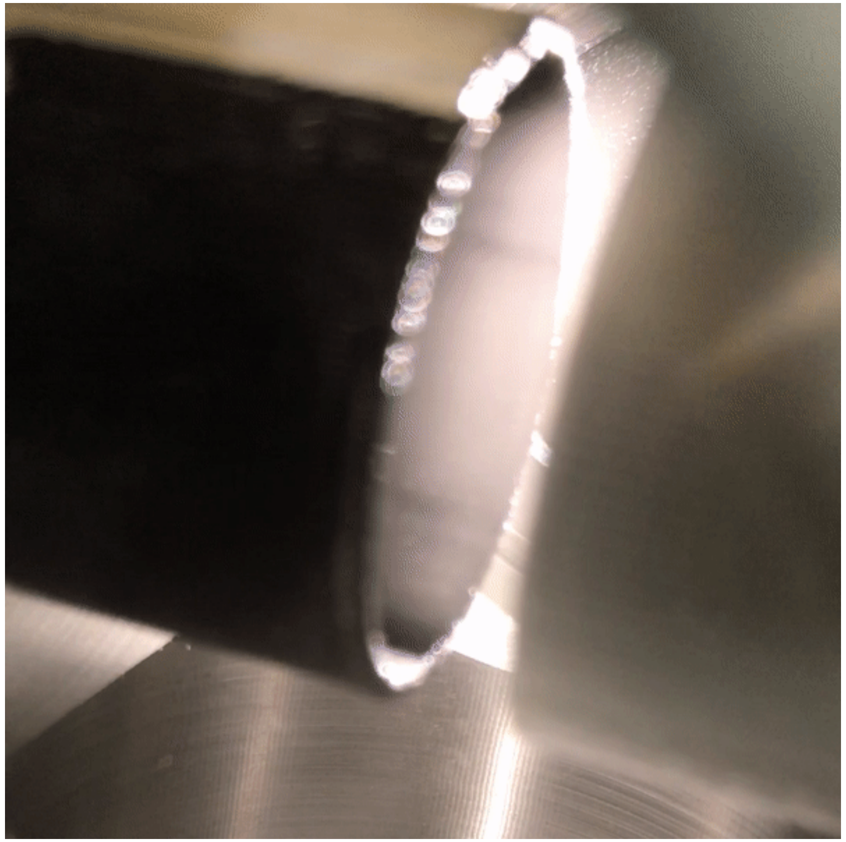


Special Issue
Applied Spectroscopy
www.s-a-s.org
Applied Spectroscopy
2022, Vol. 0(0) 1–10

DOI: 10.1177/00037028211070323
journals.sagepub.com/home/asp
SAGE

Quantification of Lanthanides in a Molten Salt Reactor Surrogate Off-Gas Stream Using Laser-Induced Breakdown Spectroscopy

Hunter B. Andrews and Kristian G. Myhre



Sheath gas is turned on and off repeatedly

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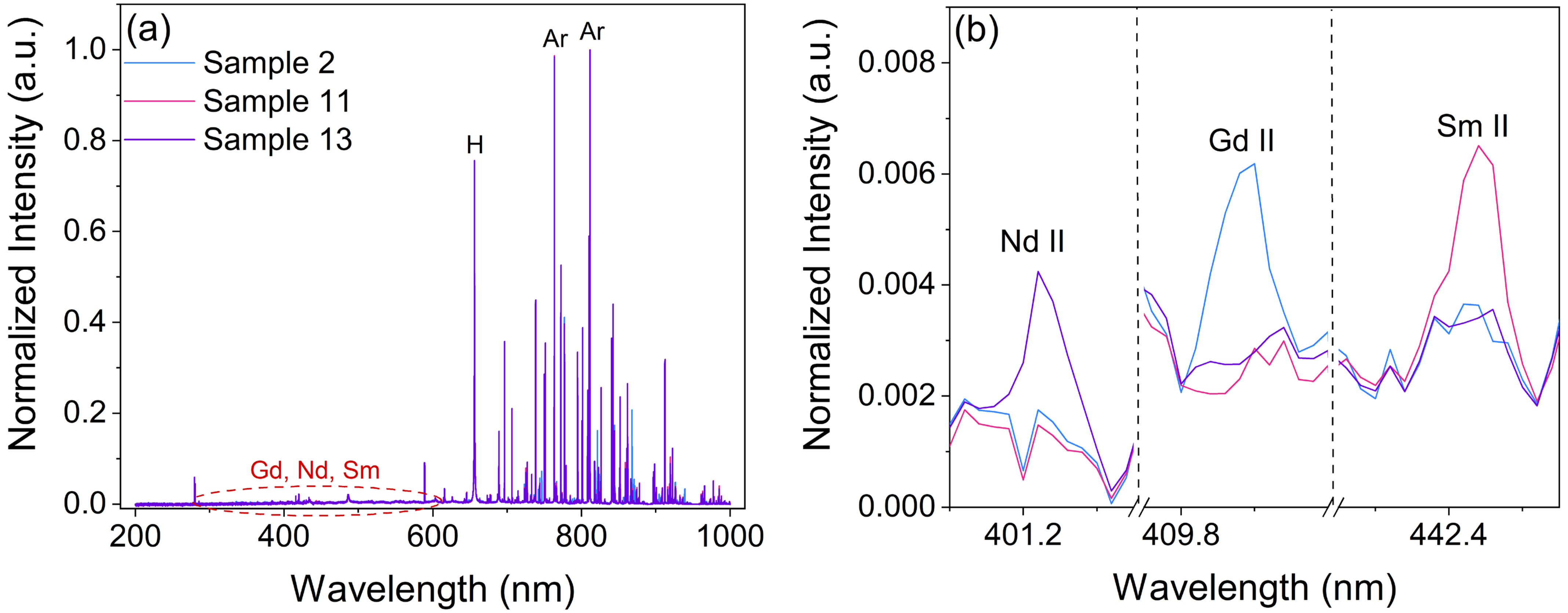
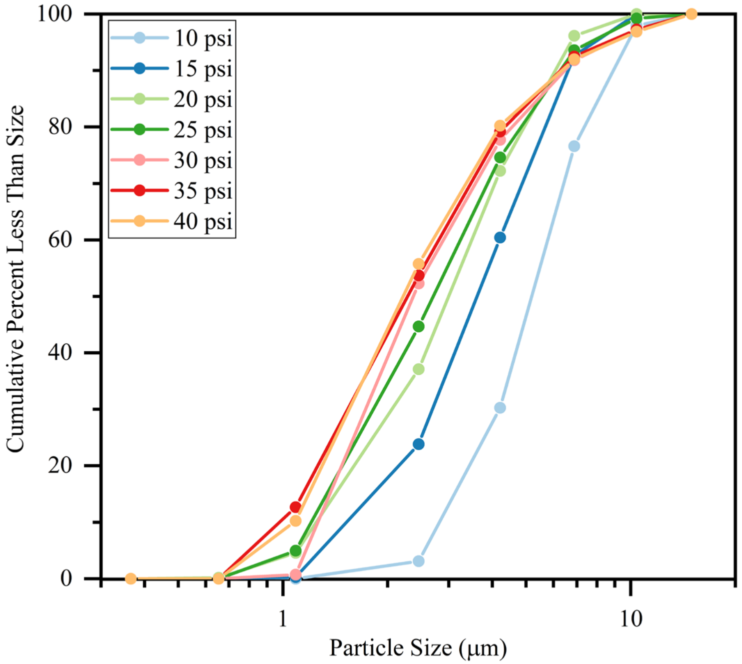
First step: demonstrate quantitative monitoring of lanthanides in aerosol stream



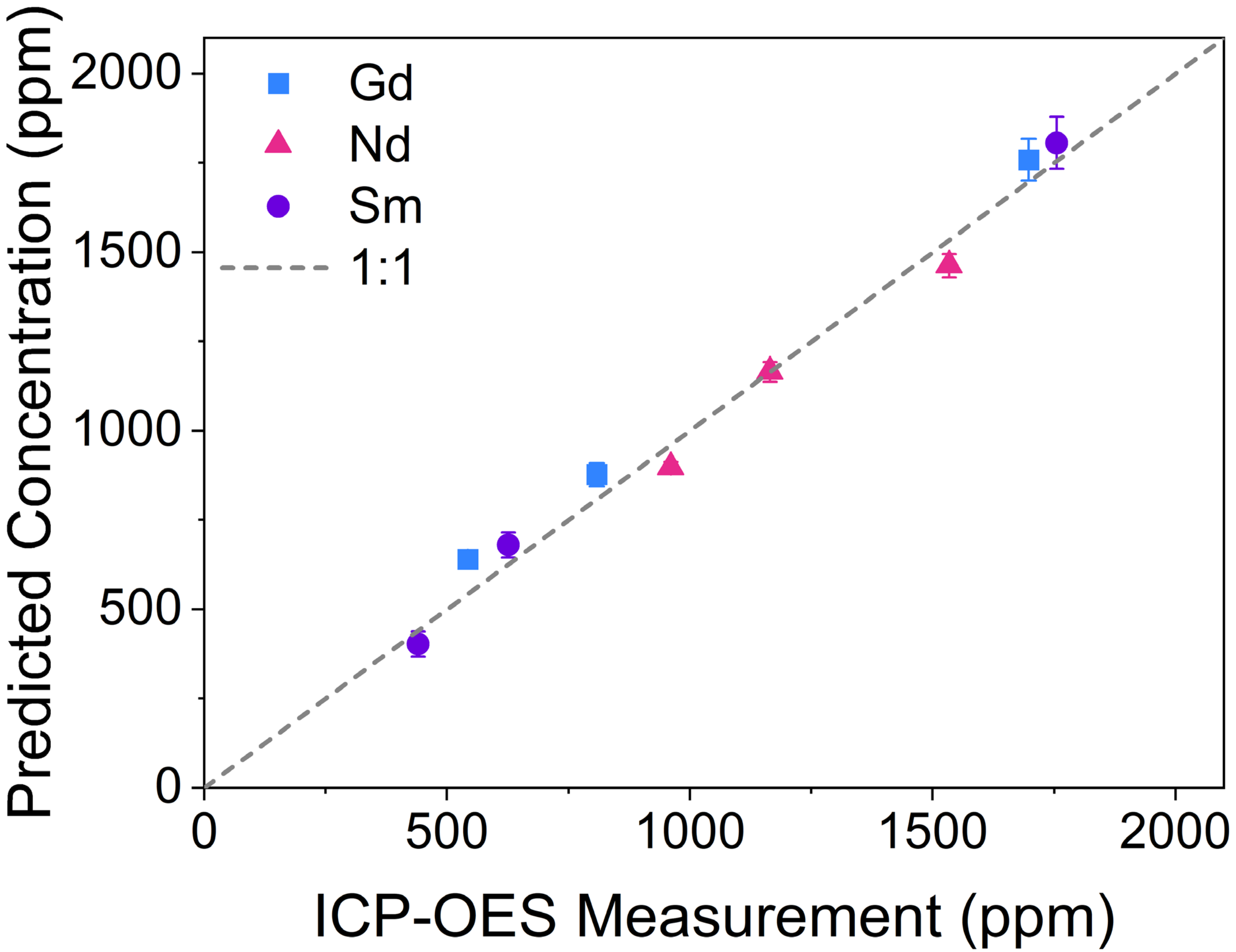
The dilution factor between the lanthanide concentration at the reservoir and measurement point was determined to be 2×10^{-6}, i.e. 2000 ppm in the reservoir ~ 0.0048 ppm in the aerosol stream.

The lanthanide validation samples were predicted with high accuracy

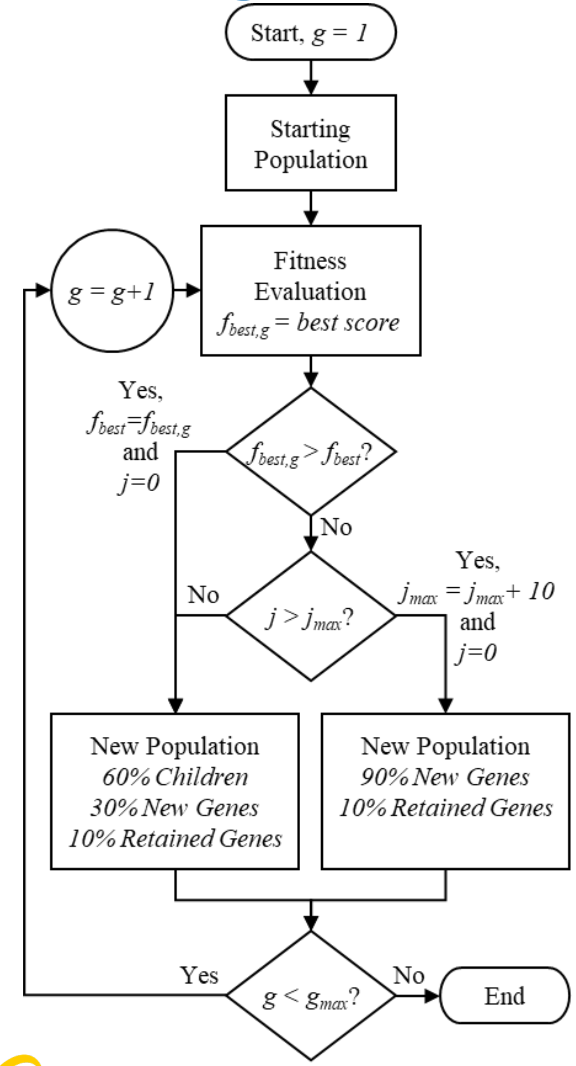


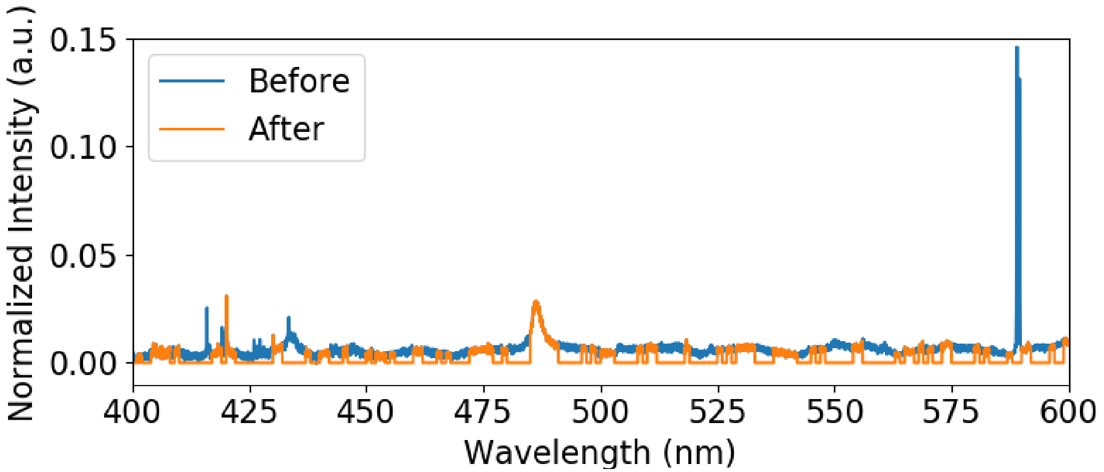
<u>Design of experiments</u>

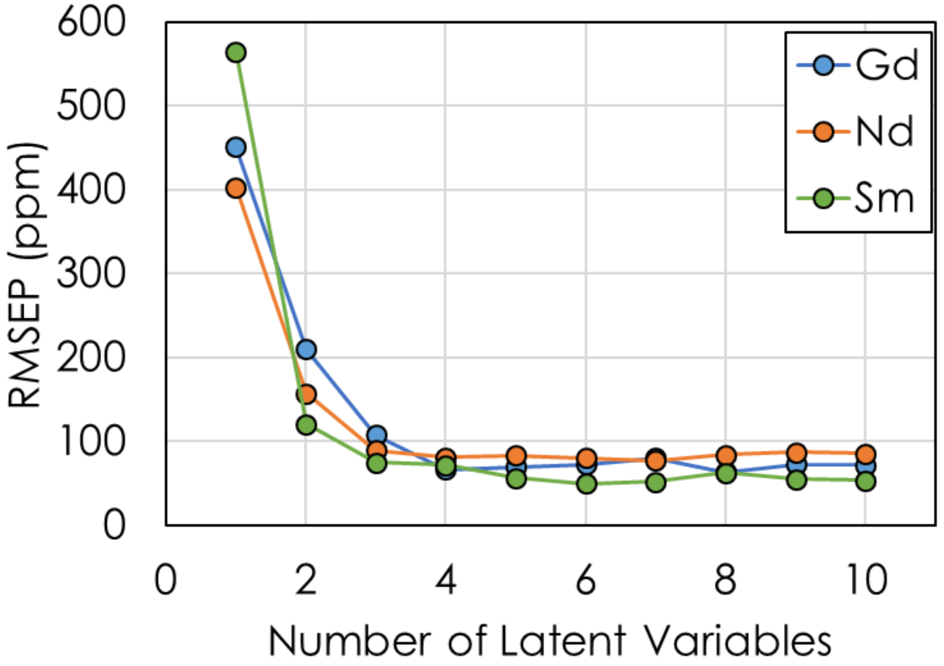
- Only 15 calibration samples
- 125 needed for full factorial design
- Validated with separate samples



Genetic algorithm used to refine PLS feature selection







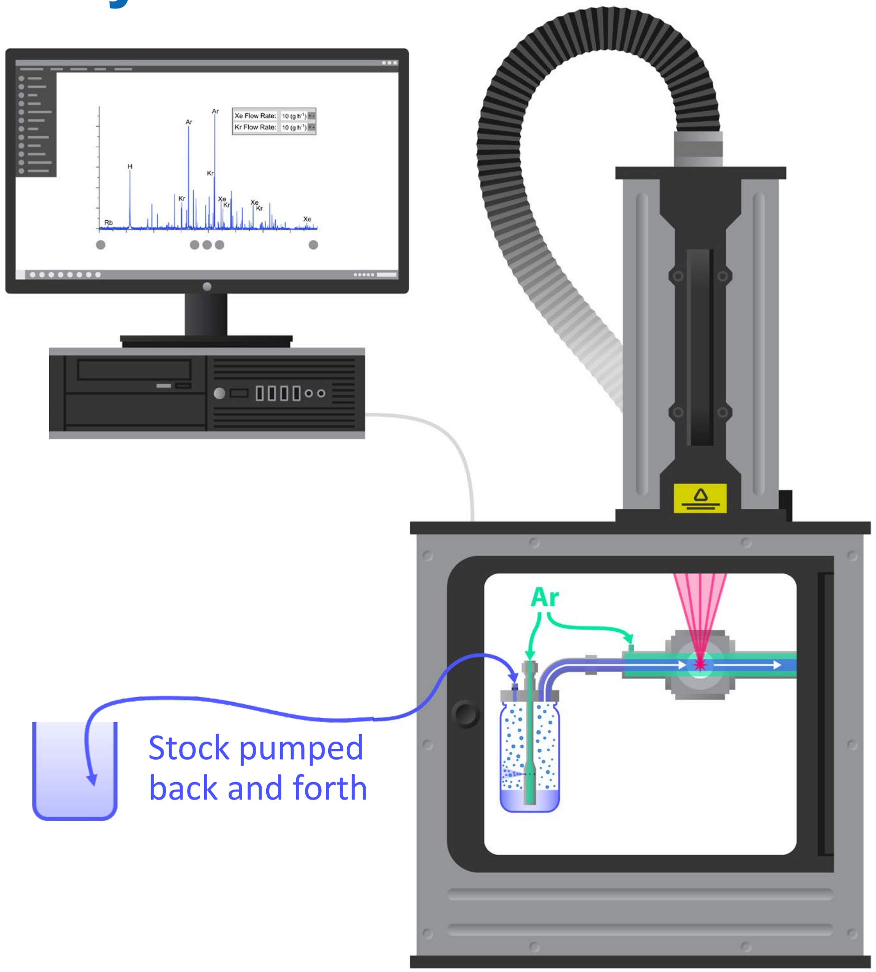
Number of LVs

Gd: 5 → 4

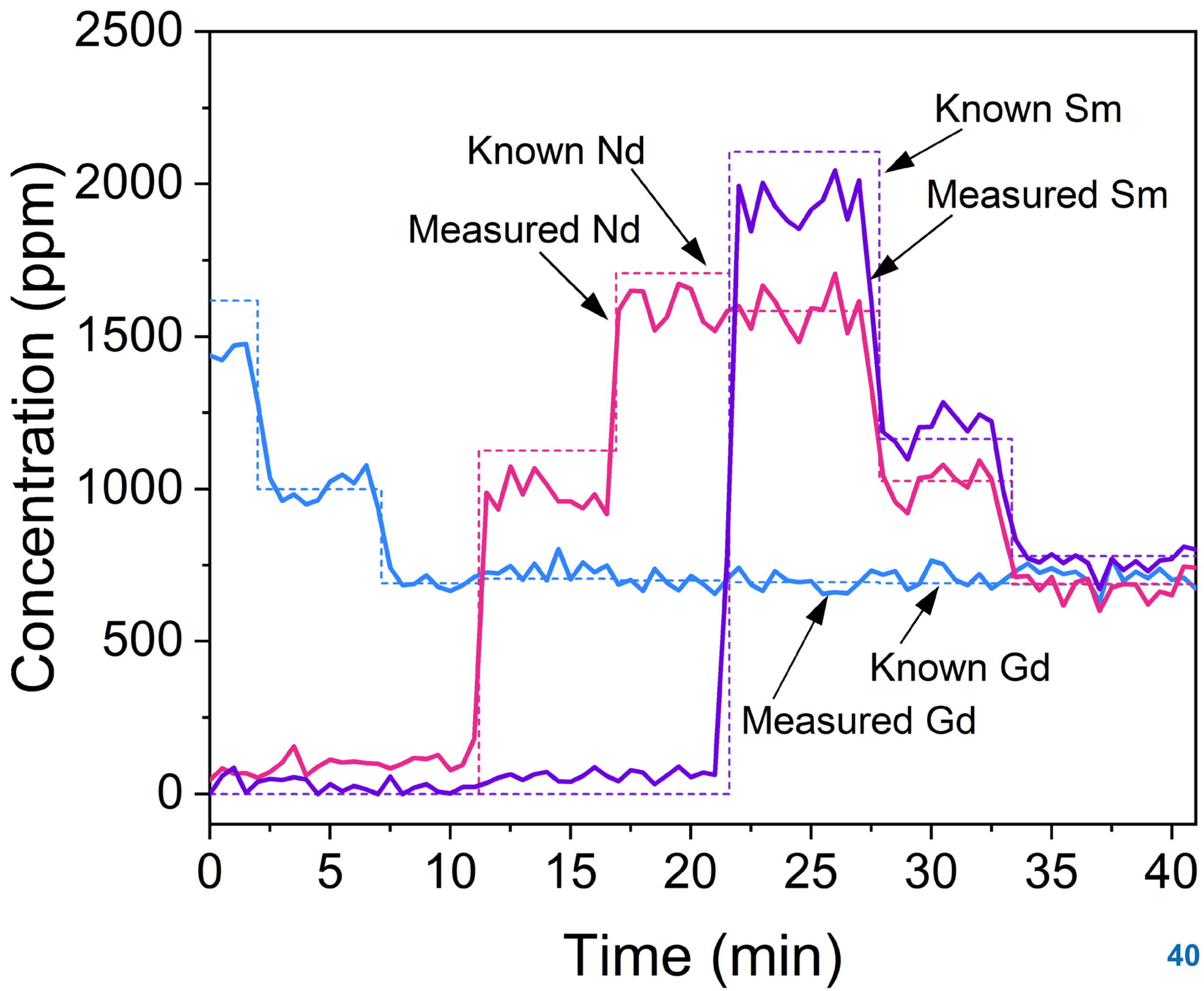
Nd: 6 → 3

Sm: 9 → 3

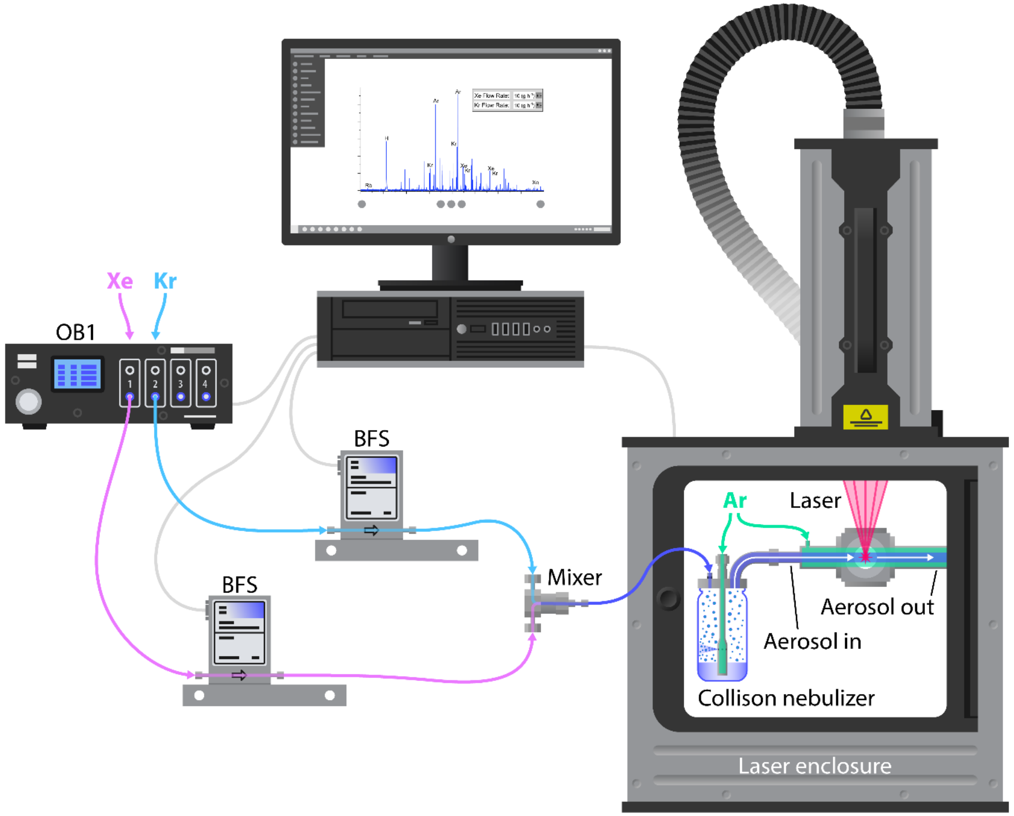
Real-time monitoring demonstrates how LIBS can be deployed in a live system

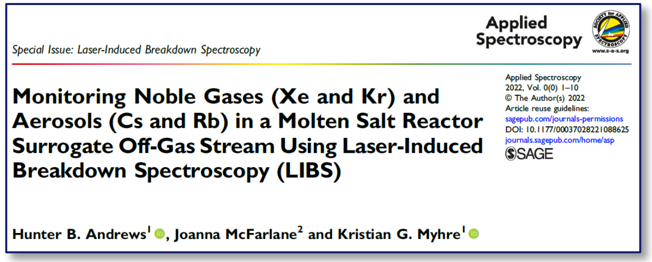


Genetic algorithm feature selection improved fit up to 73%



Second step: demonstrate the utility of monitoring noble gases via LIBS



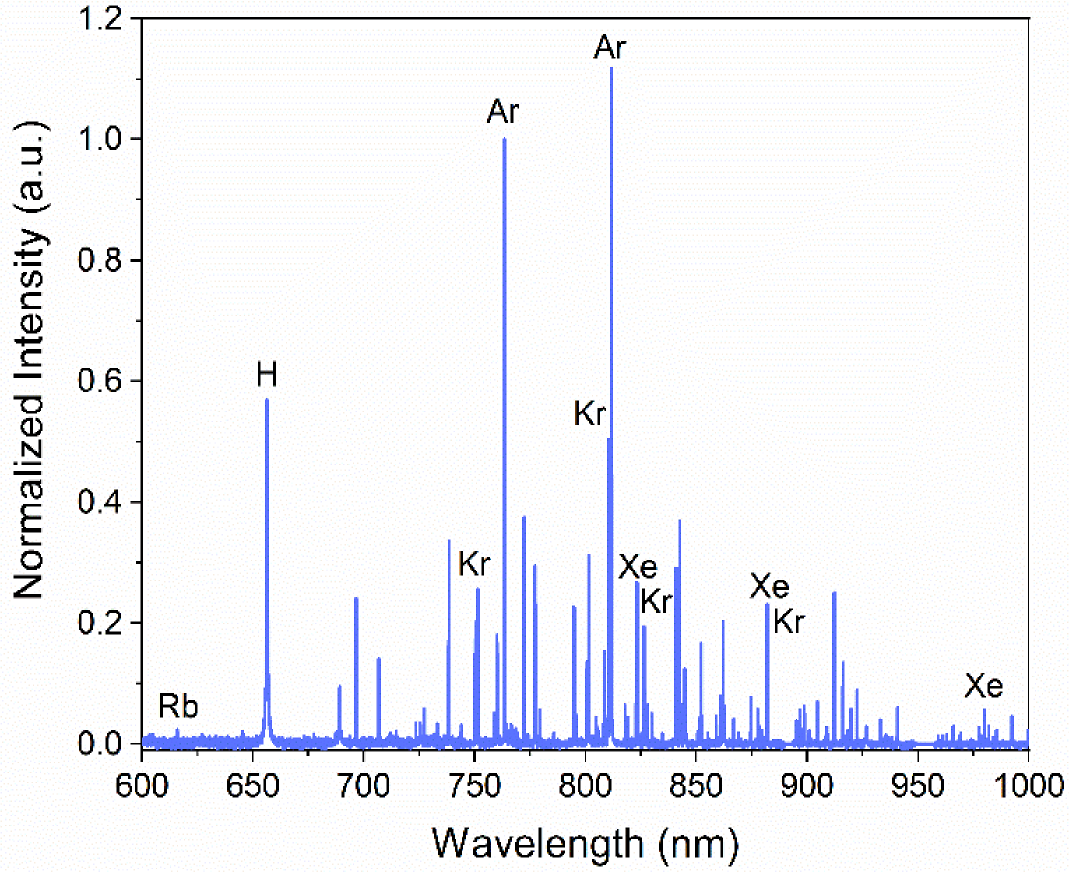

Special Issue: Laser-Induced Breakdown Spectroscopy
Applied Spectroscopy

Monitoring Noble Gases (Xe and Kr) and Aerosols (Cs and Rb) in a Molten Salt Reactor Surrogate Off-Gas Stream Using Laser-Induced Breakdown Spectroscopy (LIBS)

Applied Spectroscopy
2022, Vol. 0(0) 1–10

DOI: 10.1177/00037028221088625
journals.sagepub.com/home/asp
SAGE

Hunter B. Andrews[1], Joanna McFarlane[2] and Kristian G. Myhre[1]



Collected LIBS spectrum containing:
1.21 mol% Xe
1.90 mol% Kr
2000 ppm Rb.

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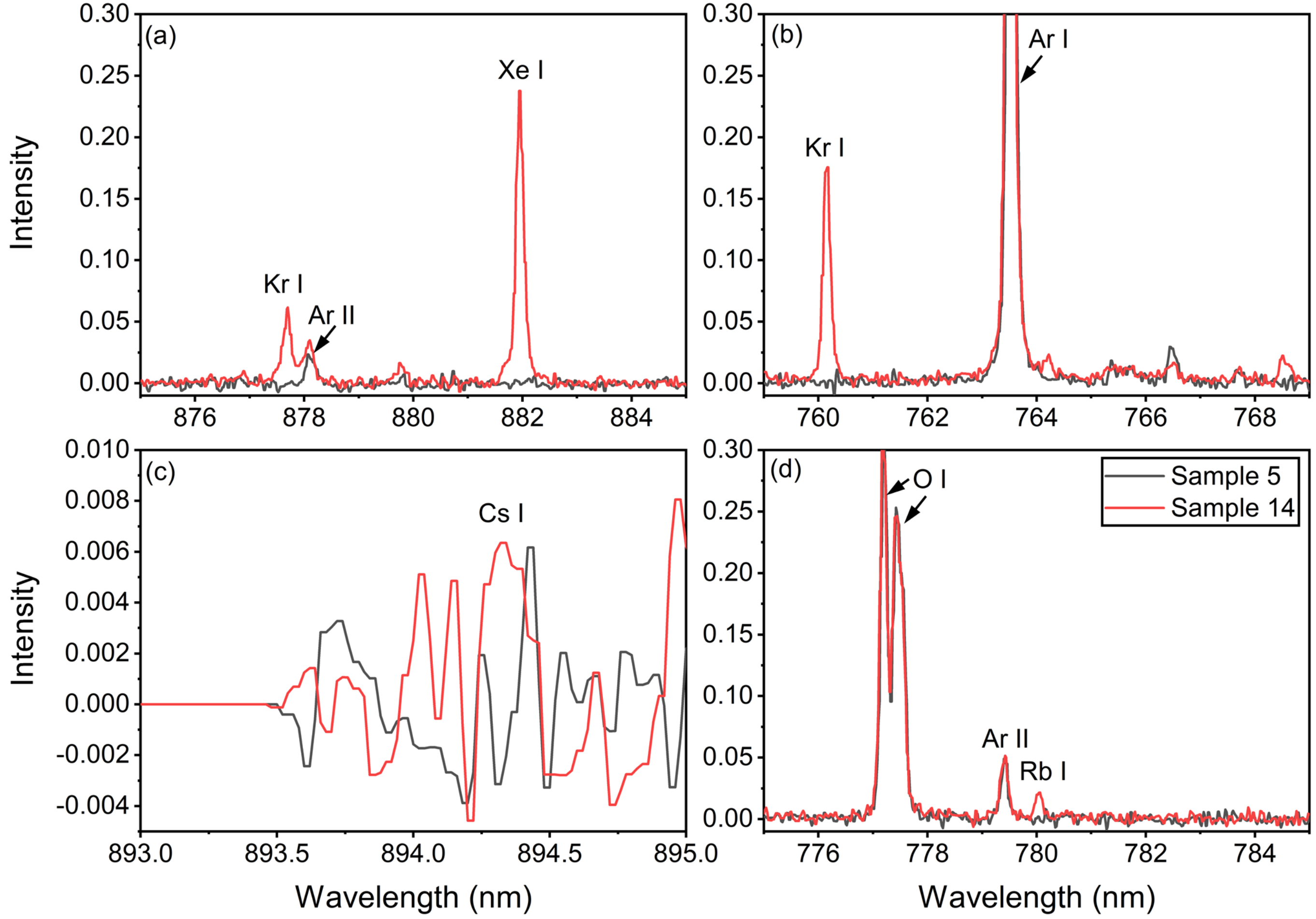
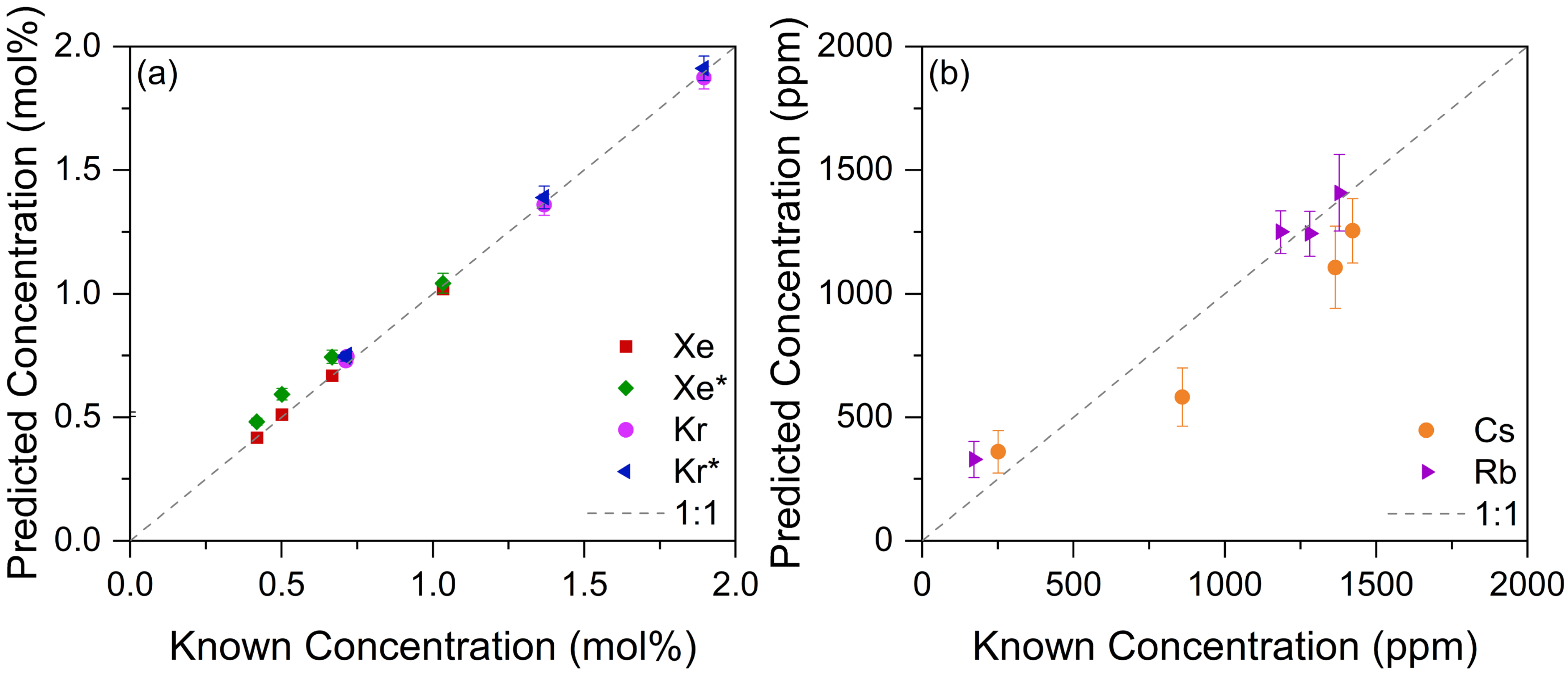
A closer look at collected spectra reveal strong gas peaks in the NIR region



Collected LIBS spectrum of a blank sample (sample 5) and sample 14 containing 1.21 and 1.90 mol% of Xe and Kr and 2000 and 1800.9 ppm of Cs and Rb.

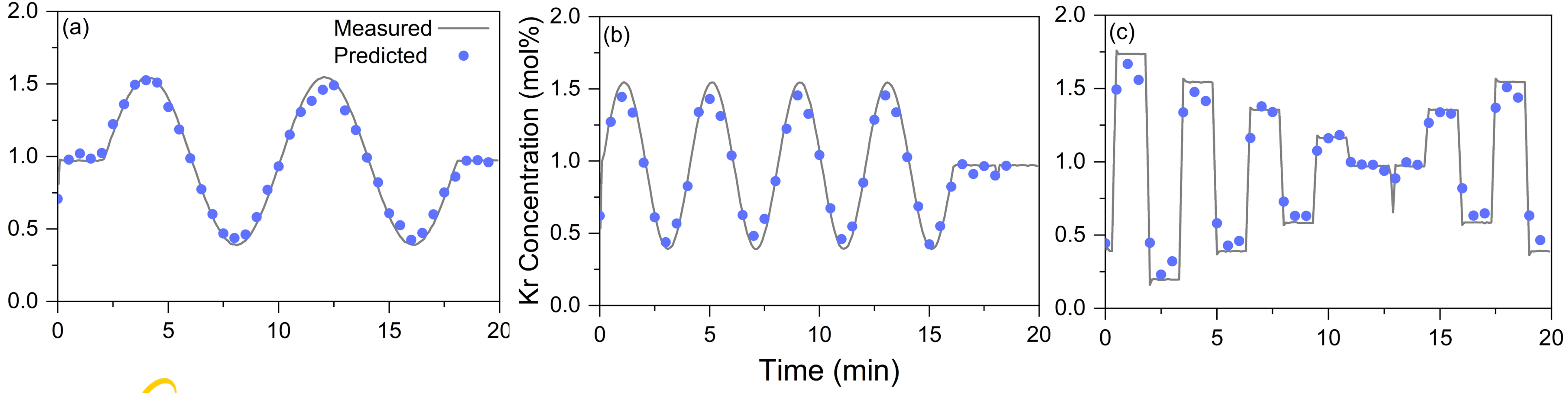
The noble gas validation samples were predicted with high accuracy



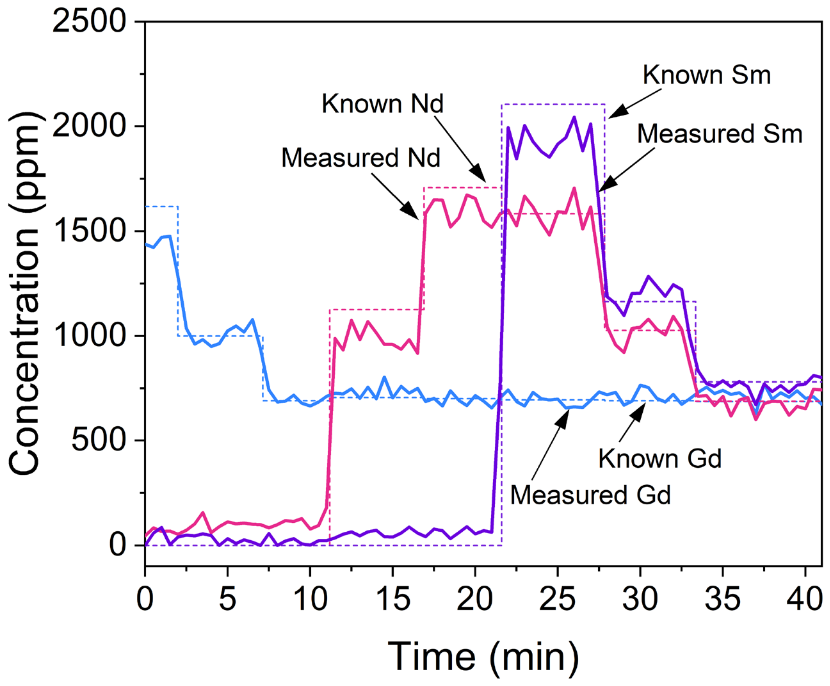
*signifies a univariate regression model

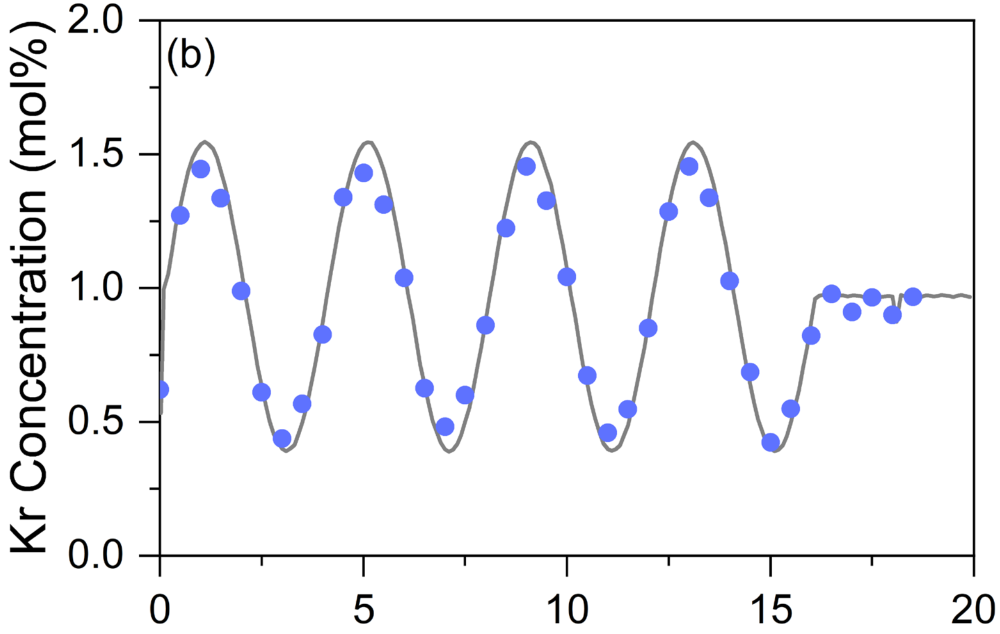
The Kr concentration was successfully predicted in real time

- Real time model successfully estimates the concentration of Kr gas when the gas flow rate is changed.
- Kr signal was collected from a plasma form within aerosol stream.
- Model can cope with entire concentration range and dynamic changes to sample being interrogated.



We have successfully used LIBS to monitor aerosolized lanthanides and Kr in real-time





Coupling LIBS with MOF for Xe breakthrough tests

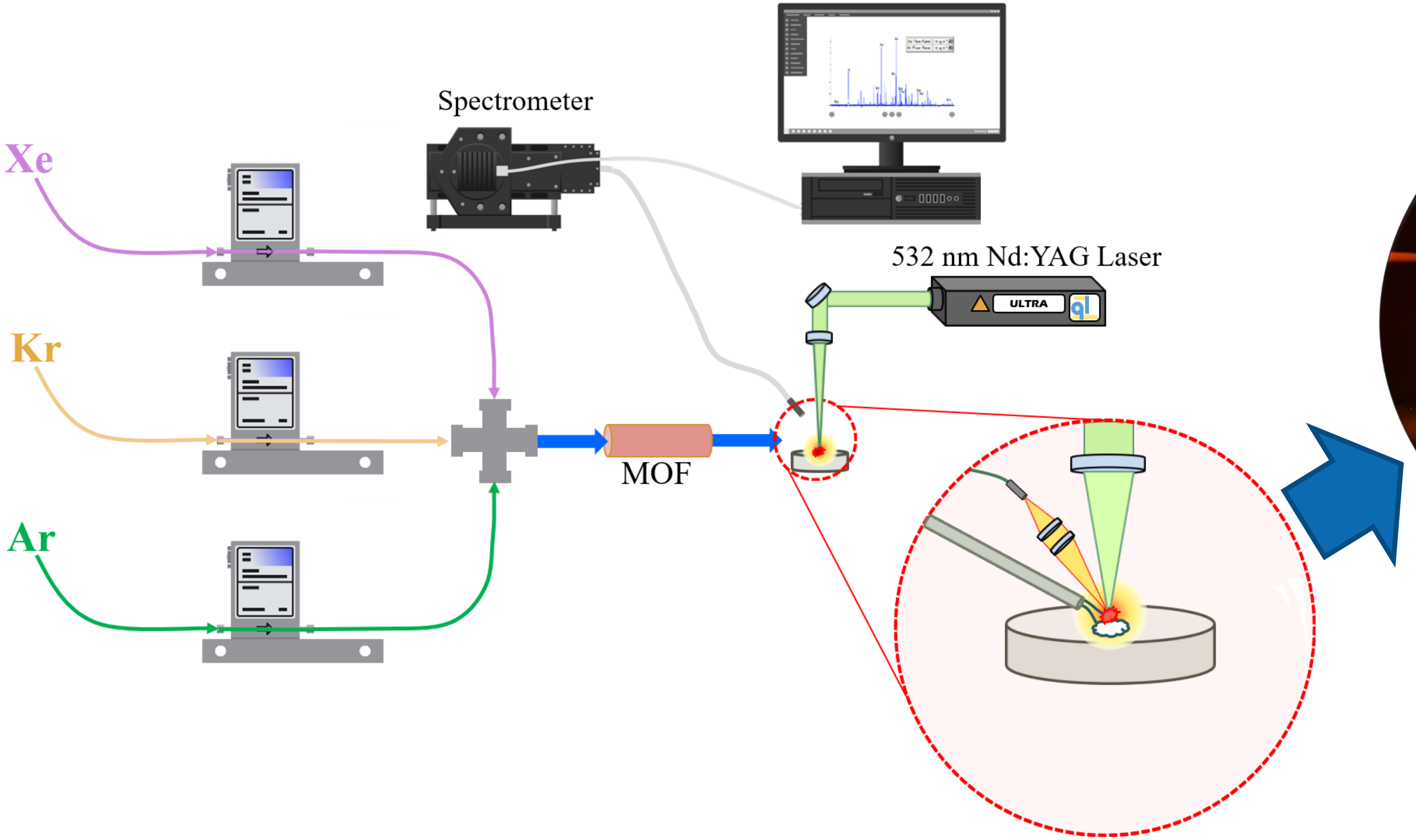
Open Access | Feature Paper | Editor's Choice | Article

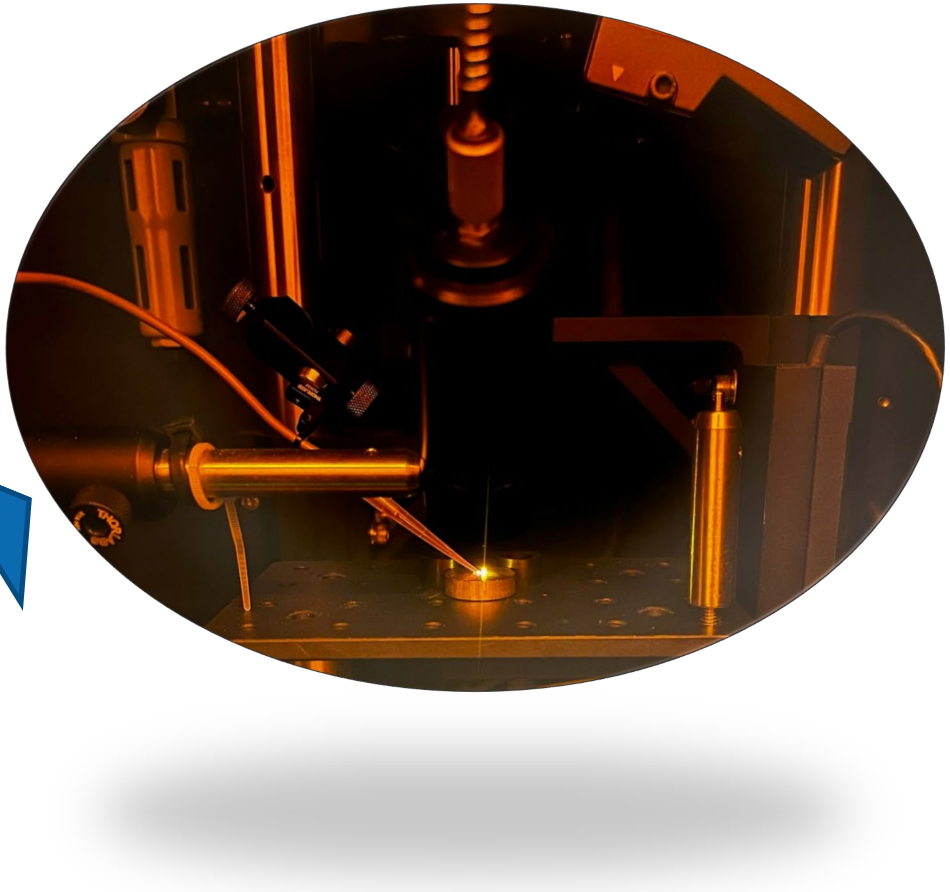
Monitoring Xenon Capture in a Metal Organic Framework Using Laser-Induced Breakdown Spectroscopy

by Hunter B. Andrews [1,*], Praveen K. Thallapally [2] and Alexander J. Robinson [2]

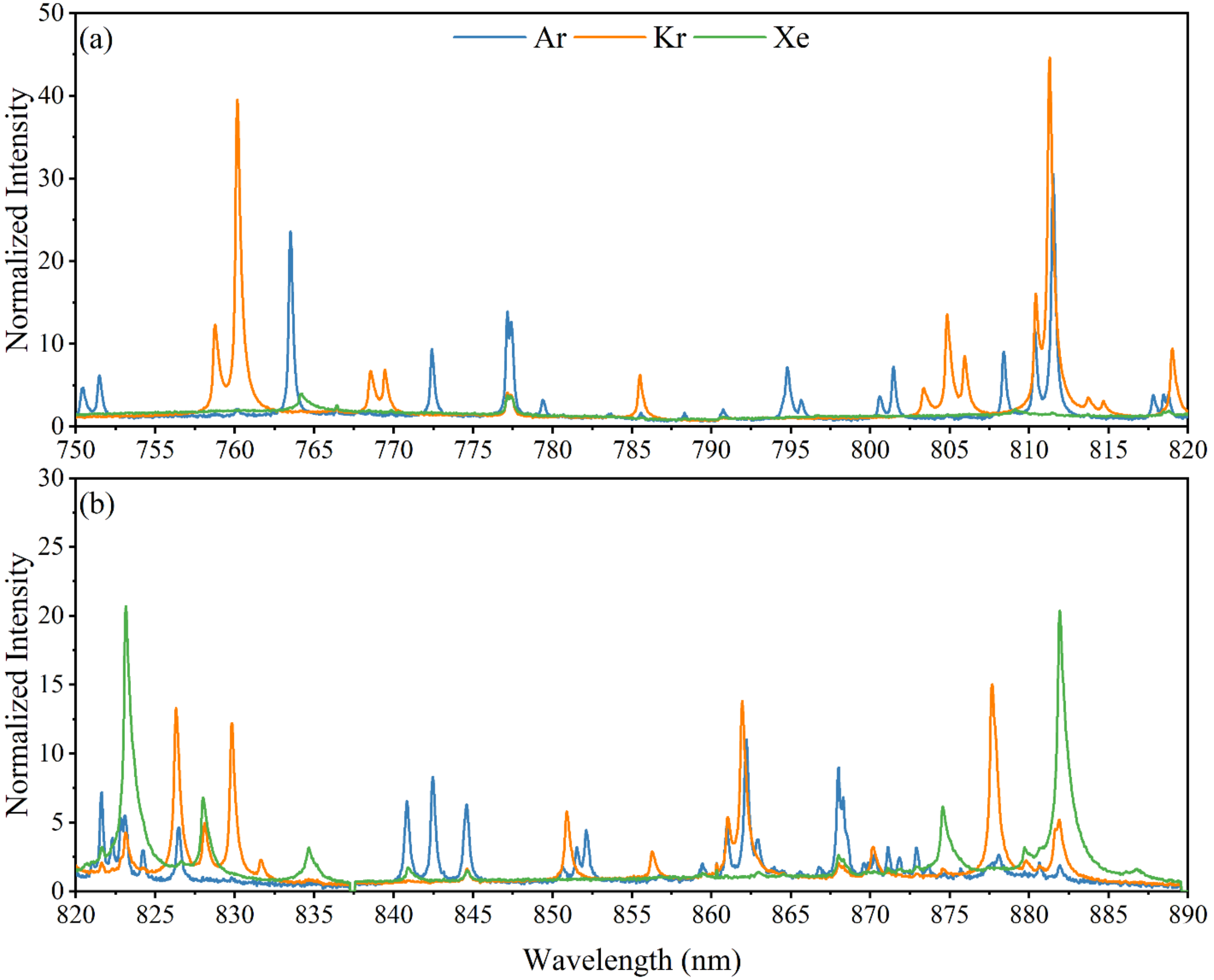
[1] Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA
[2] Pacific Northwest National Laboratory, Richland, WA 99352, USA

New LIBS setup was needed to facilitate MOF size and flowrates

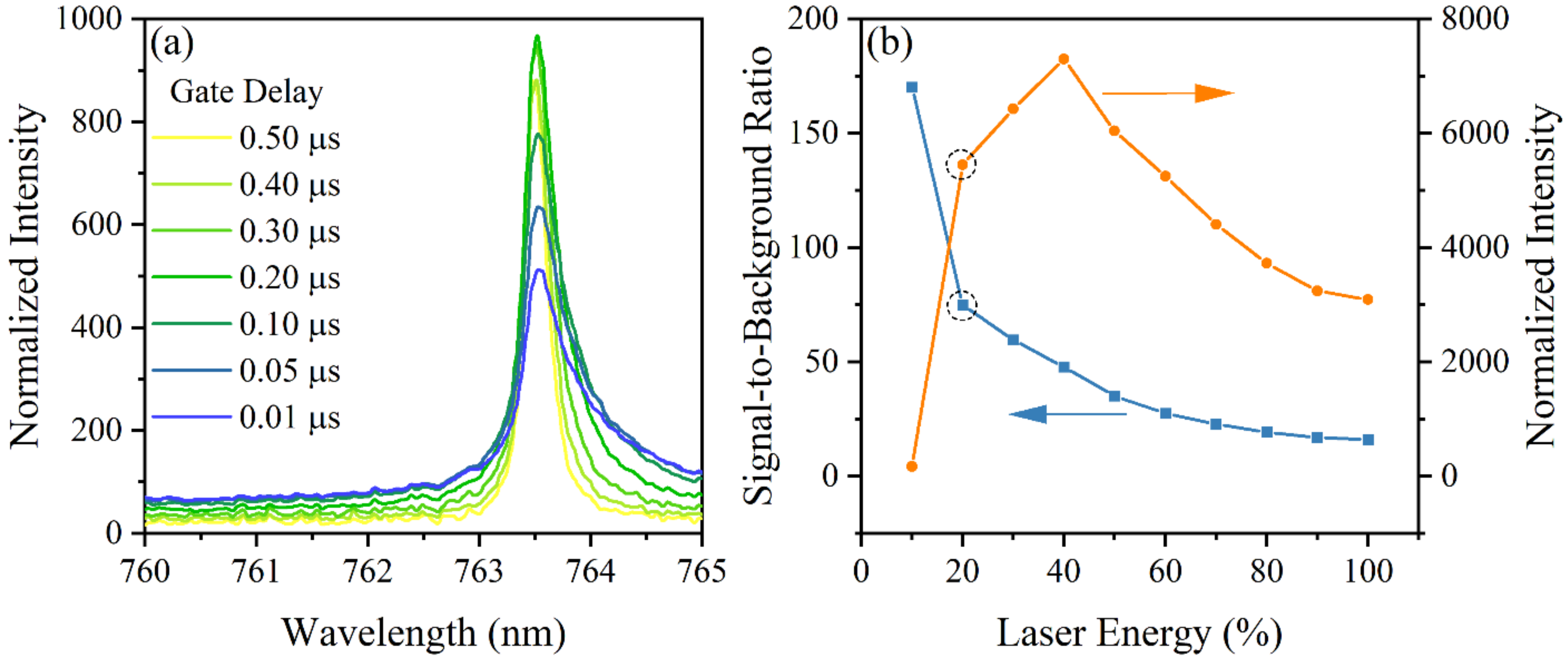




Pure gases were run to facilitate peak identification

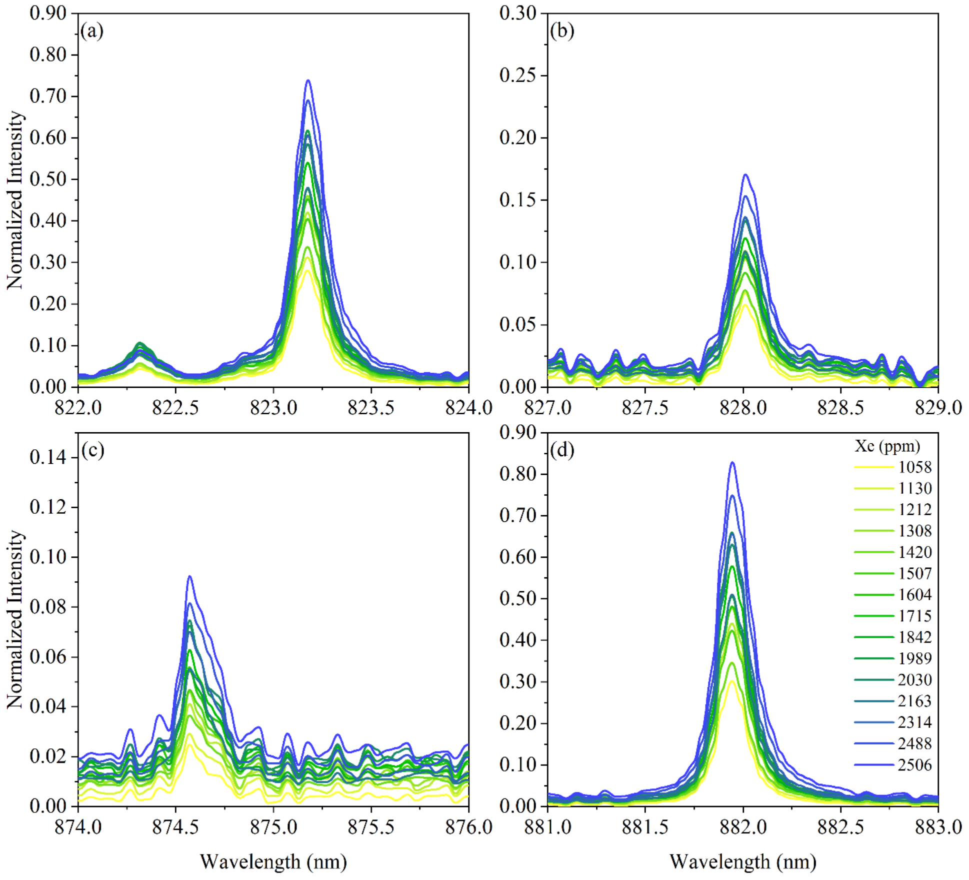


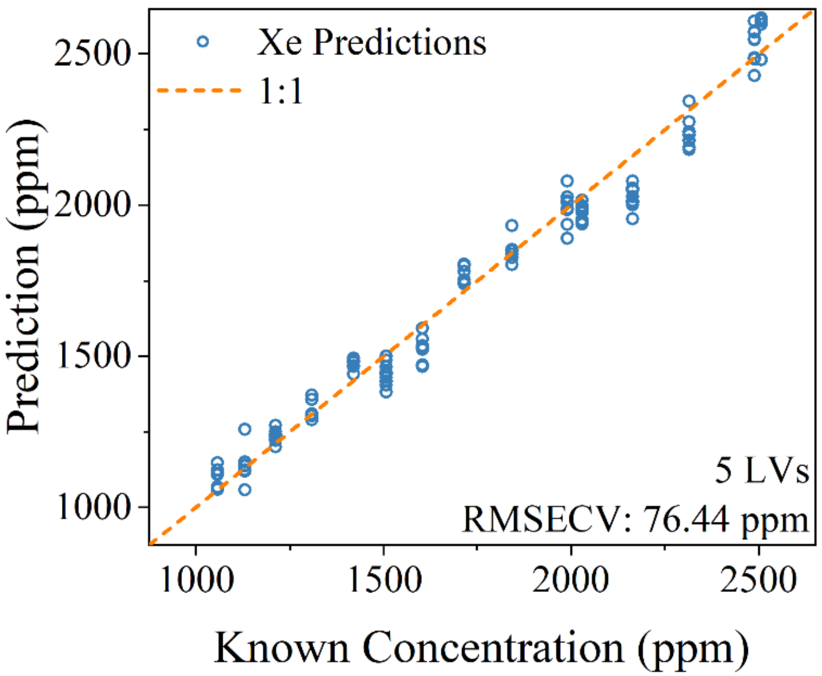
Spectrometer gating and laser energy were optimized prior to data collection



$$SBR = \frac{Peak\ Intensity\ - Background\ Intensity}{Background\ Intensity}$$

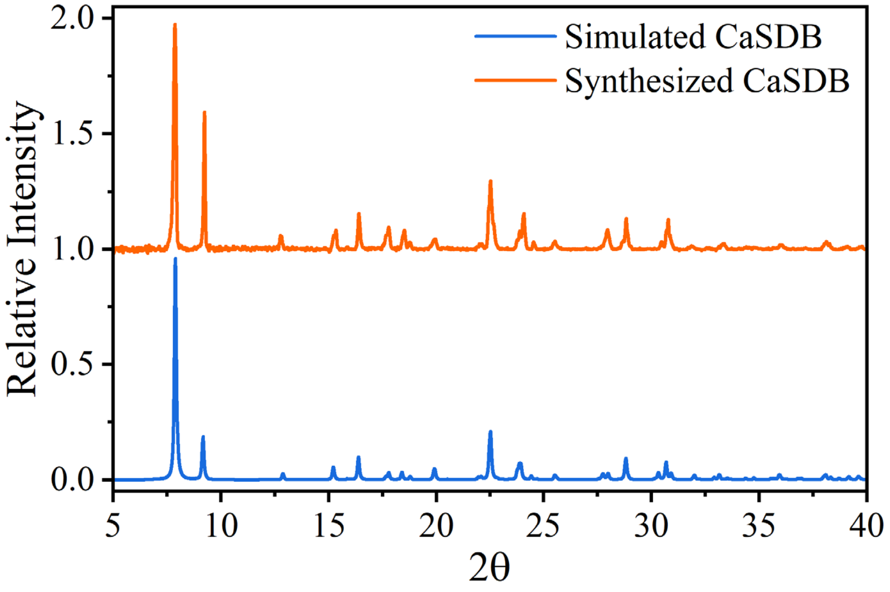
A multivariate model was built for Xe ranging from 1000 – 2500 ppm to estimate limits of detection for the given setup

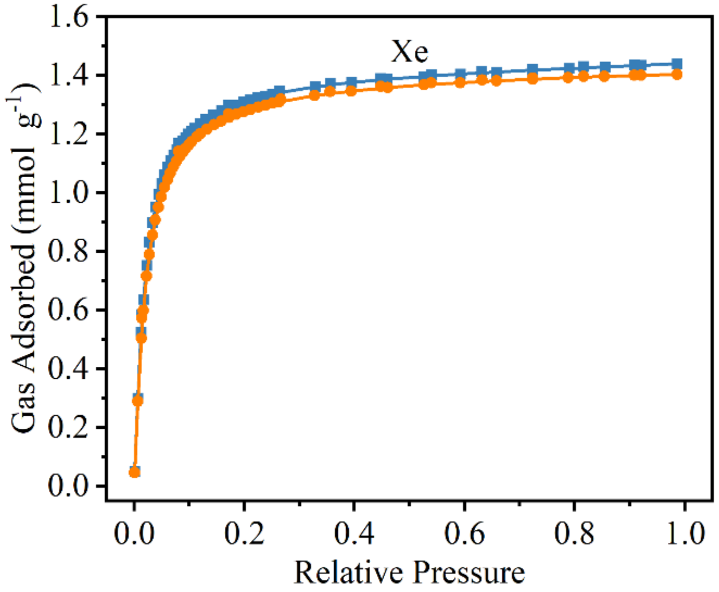


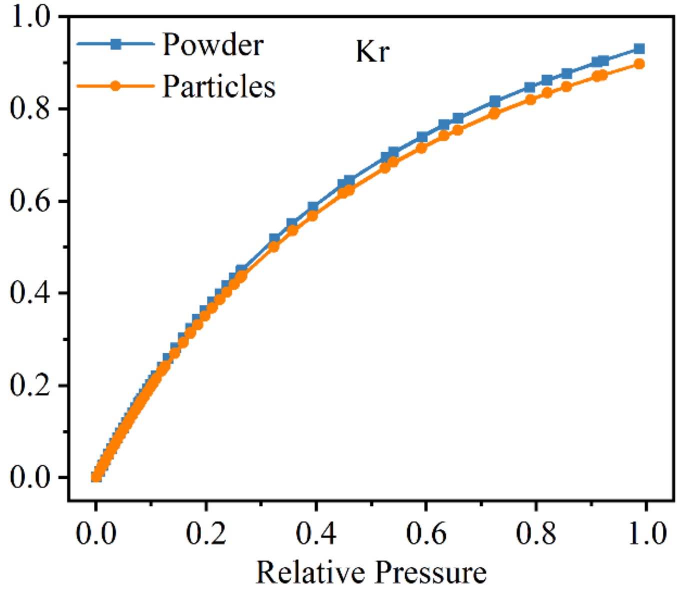


LOD_{Xe}= 167 ppm

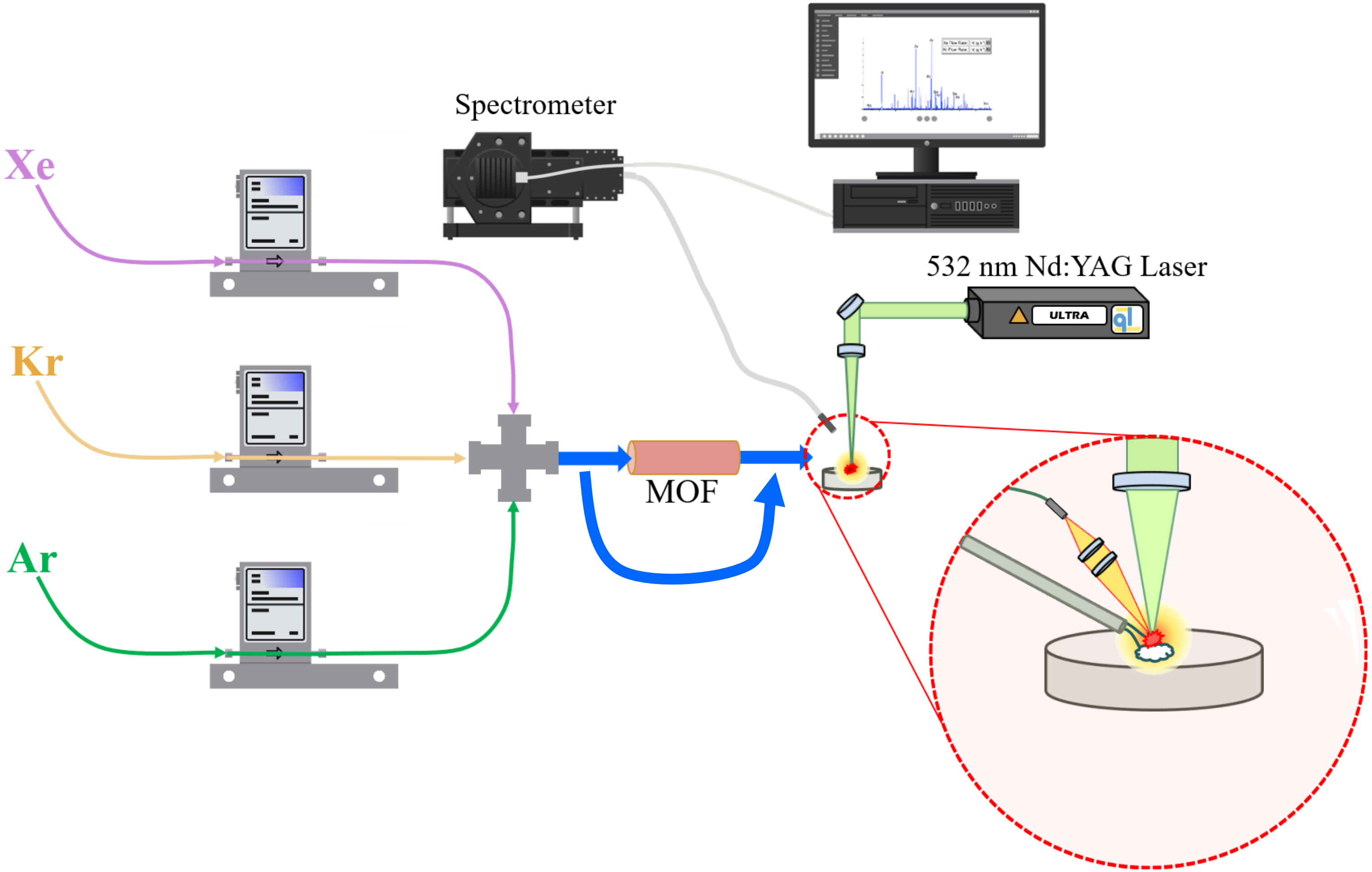
MOF column was synthesized at PNNL and shipped to ORNL for testing







MOF column was activated and loaded into testing system

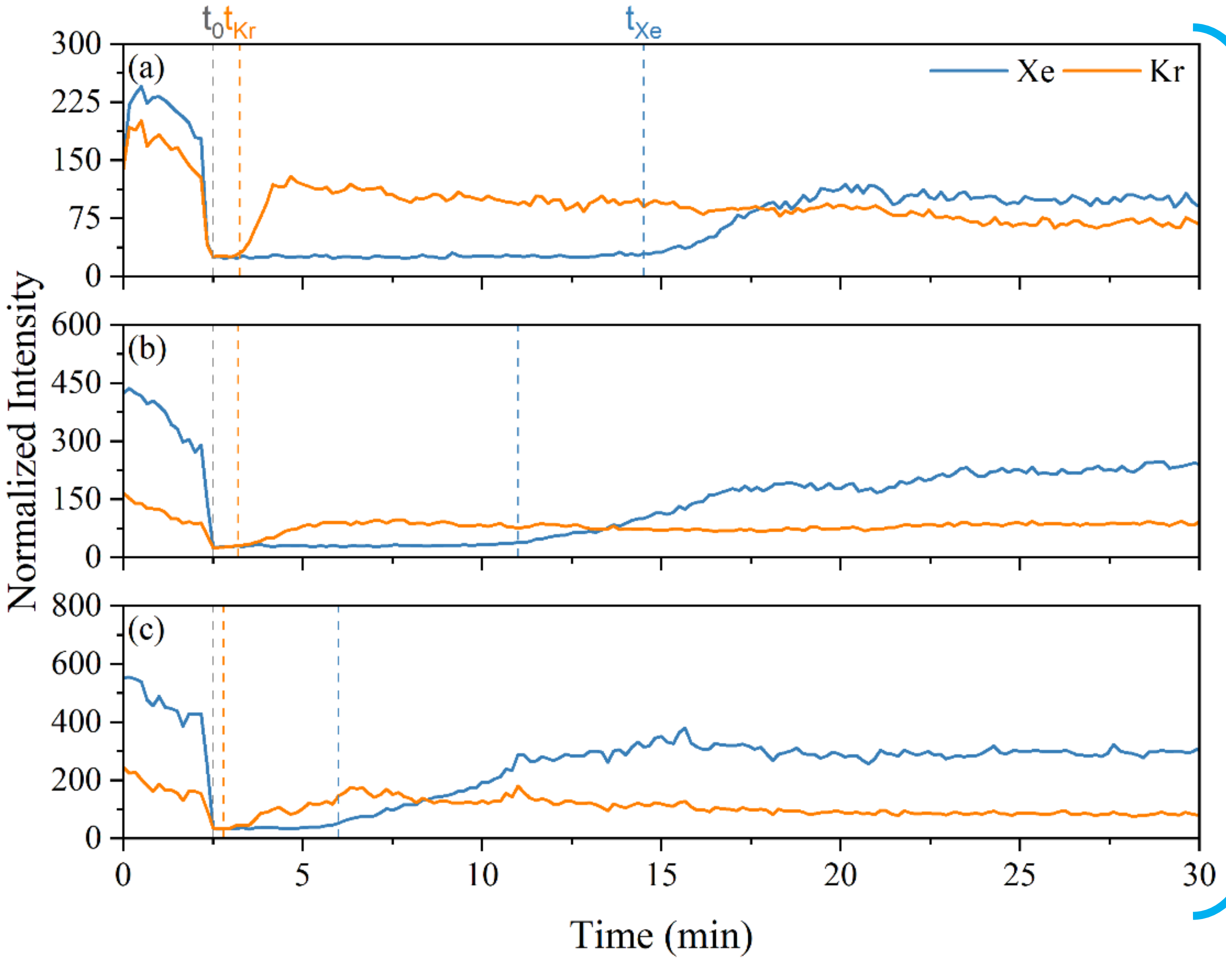


Breakthrough tests were completed on the activated MOF with the LIBS inline for noble gas tracking

(a) 1000 ppm Xe, 1000 ppm Kr

(b) 2000 ppm Xe, 1000 ppm Kr

(c) 3000 ppm Xe, 1000 ppm Kr



$$S_{Xe/Kr} = \frac{x_{Xe}/y_{Xe}}{x_{Kr}/y_{Kr}} = \sim 12\text{-}16$$

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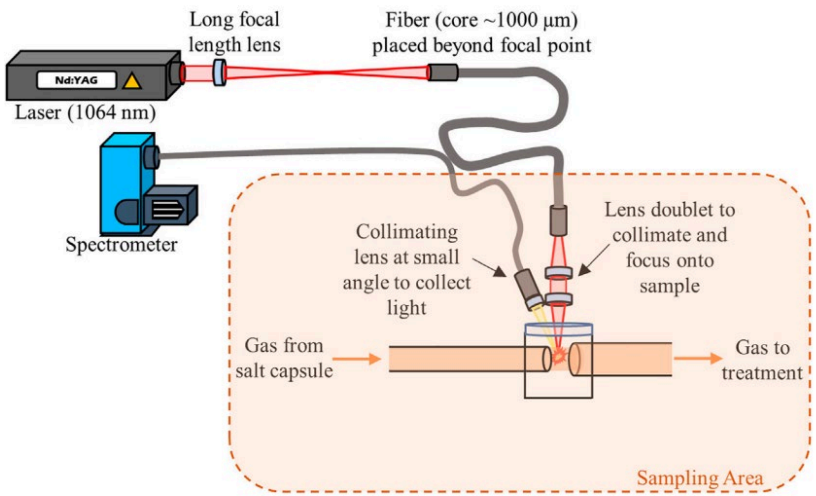
Future work will focus on enhancing the LIBS noble gas sensitivity

- Designing new gas cell for in-line LIBS measurements
  - Driving down detection limits will increase the usefulness for such a technique
  - Removal of a sampling substrate will extend the sampling lifetime

- Conversations for deploying LIBS gas sensor on molten salt loops are ongoing
  - Fiber-launched Nd:YAG lasers allow safe integration of LIBS measurement systems onto engineering scale tests
- Isotopic LIBS measurement capabilities are being established for future experiments

Credit: LTB, Lasertechnik Berlin



Thank you

Hunter Andrews, andrewshb@ornl.gov

Praveen Thallapally, praveen.Thallapally@pnnl.gov

Upcoming Webinars

Date	Title	Presenter
31 August 2023	Corrosion and Cracking of Supercritical Cooled Water Reactor (SCWR) Materials	Prof. Lefu Zhang, Shanghai Jiao Tong University, China
27 September 2023	EPRI Virtual Reality Training	Robert Eller, EPRI, USA
31 October 2023	The Nuclear Workforce of The Future – Opportunities and Needs for The International Nuclear Sector	Callum Thomas, Thomas THOR, United Kingdom

2nd Molten Salt Bootcamp

What to expect

Three days of lectures, discussions and hands-on activities on multi-disciplinary aspects of molten salt science and technology supported by world experts.

Who should apply

Graduate students, postdocs and professionals with interest in molten salts. Previous experience is not necessary, but selected participants will be required to complete an introductory class ahead of the bootcamp.

Agenda

Day 1 – Multiphysics modelling of MSRs
Day 2 – Experimental characterization of molten salts
Day 3 – Large scale experimental facilities

Participants will work on group projects throughout the bootcamp to explore the concepts learnt.

Contact Us

msrbootcamp@icloud.com

University of California, Berkeley

September 6-8, 2023

Application deadline
July 28, 2023

Notifications
August 1, 2023

Submit your application <u>here</u>

Berkeley
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SAM SAFER