THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

3 rd Workshop on Research and Innovation in Poland

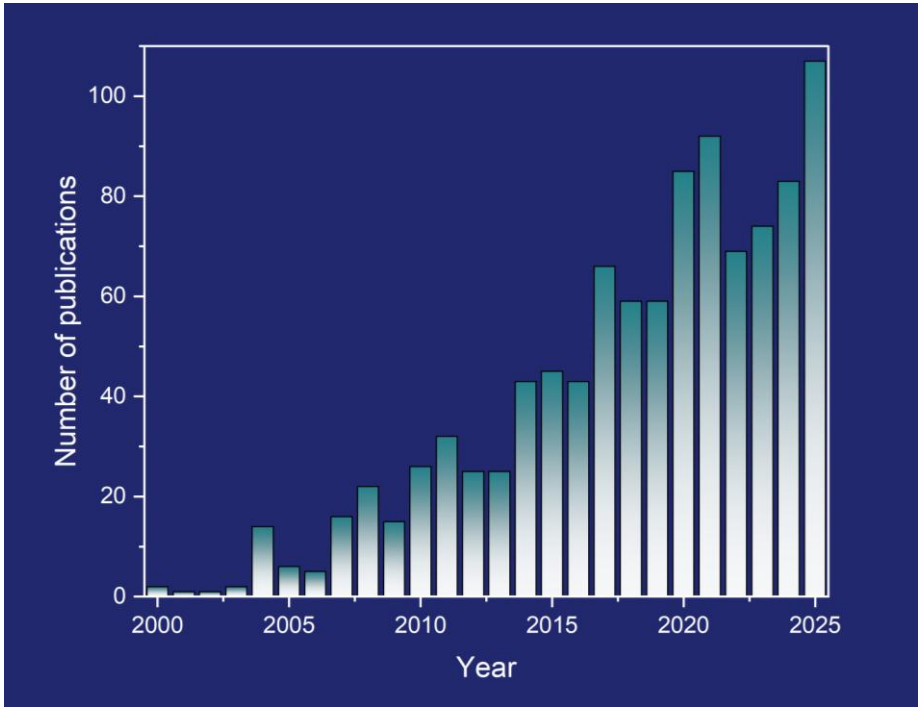
Functionalized mesoporous silica nanoparticles in nuclear medicine: emerging applications and future perspectives

Magdalena Laskowska

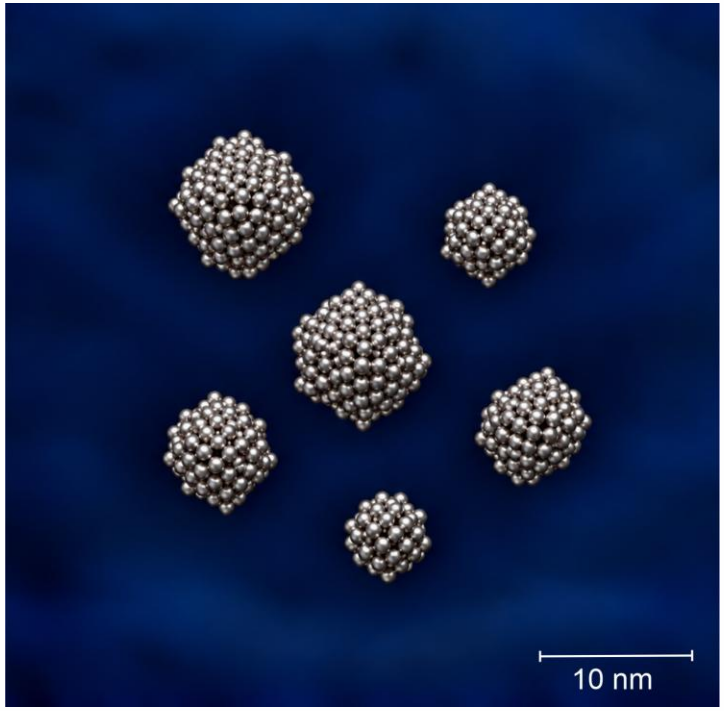
Department of Nuclear Physical Chemistry

Krakow, 23.10.2026

NANOMATERIALS FOR NUCLEAR MEDICINE



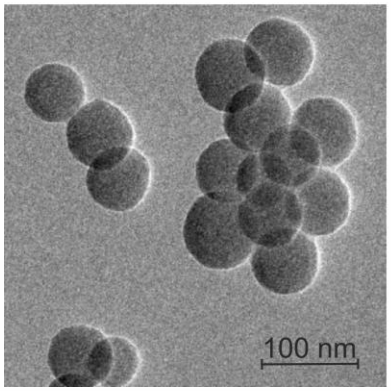
Annual number of publications (2000–2025)
Source: PubMed; search query: nano*[tiab] AND (radioisotop*[tiab] OR radionuclid*[tiab]) AND (therap*[tiab] OR therapeutic*[tiab]) AND 2000:2025[dp]; date of search:10.10.2026



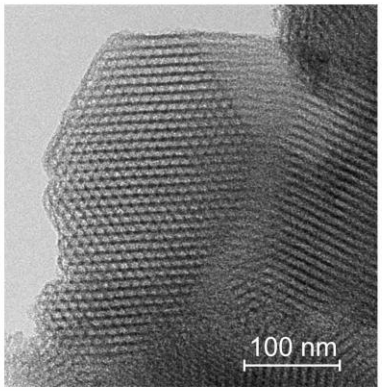
Top-down approach to nanomaterial fabrication

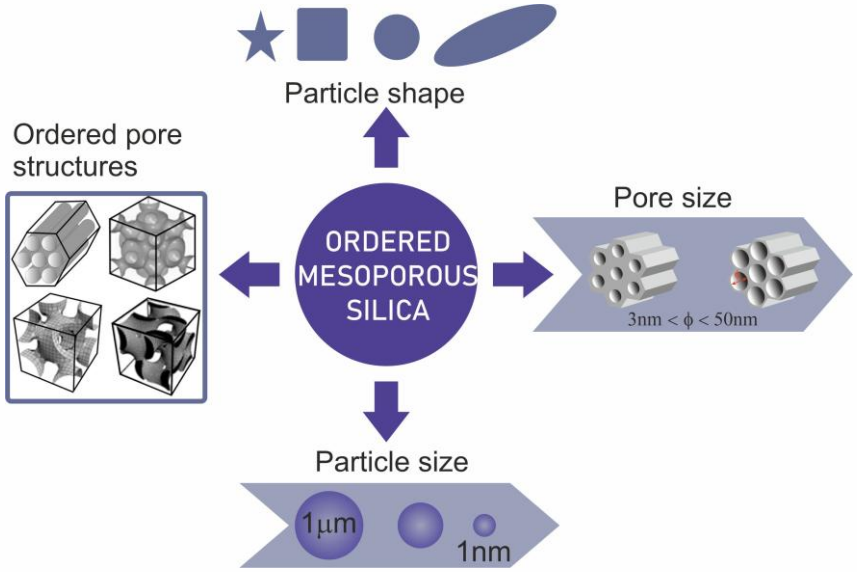
SILICA NANOMATERIALS

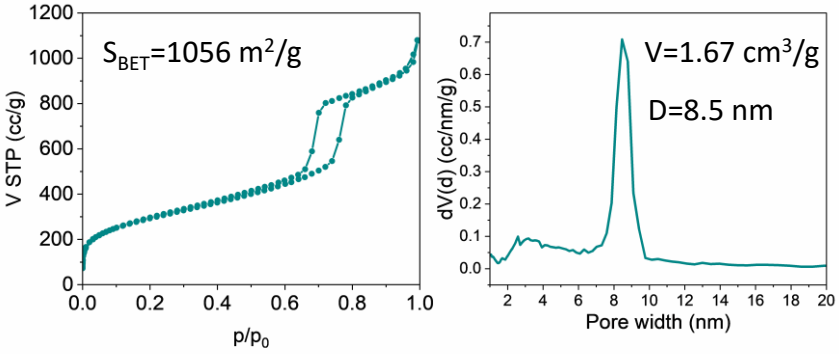
SILICA NANOPARTICLES
size at the nanoscale



SILICA NANOSTRUCTURES
internal structure at the nanoscale

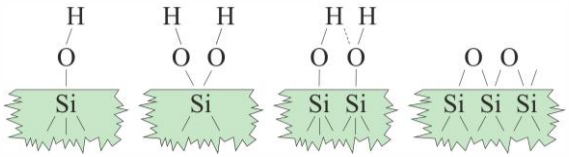




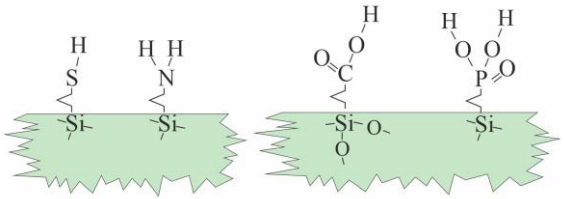


SILICA SURFACE FUNCTIONALIZATION

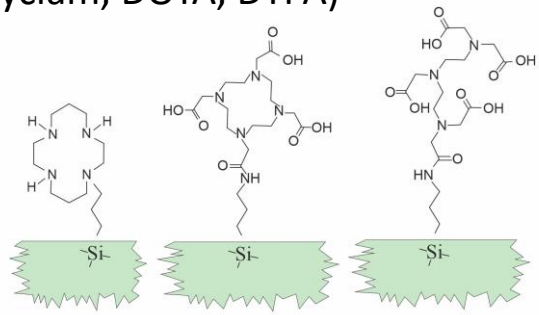
✓Native Silanol Groups (Si–OH)



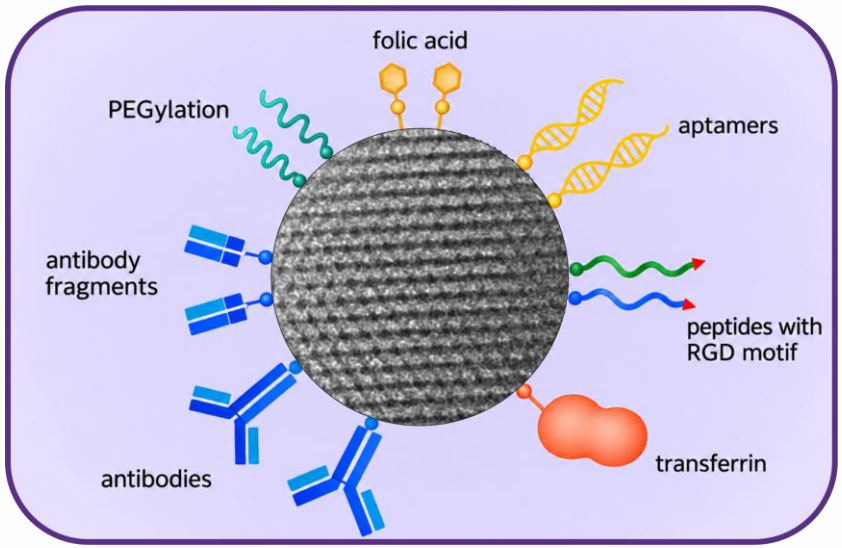
✓Simple Surface Functional Groups
(–COOH, –$PO(OH)_2$, –NH_2, –SH)



✓Multidentate Chelators
(Cyclam, DOTA, DTPA)

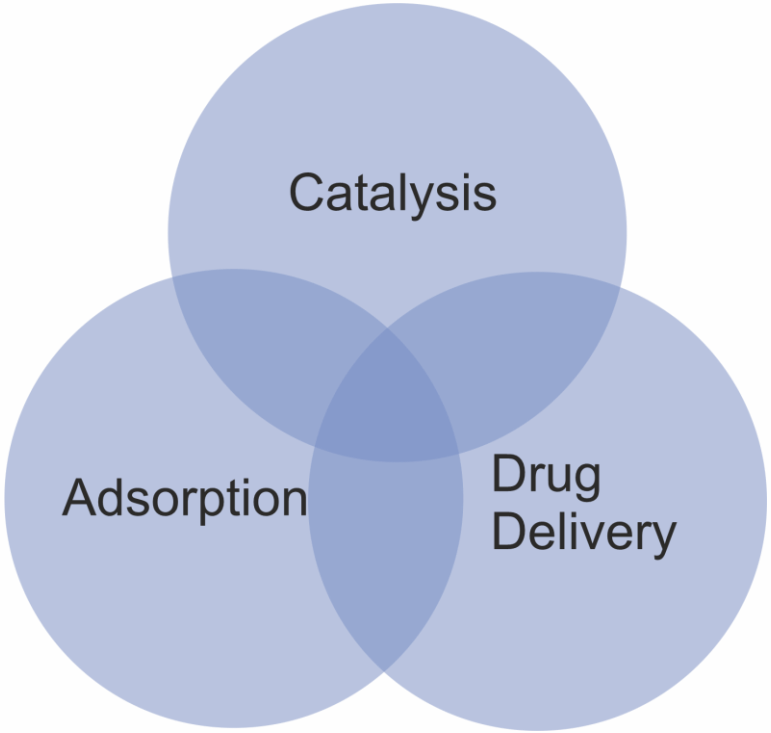






A. Watermann et al., Nanomaterials 2017, 7, 189;

LEADING RESEARCH AND APPLICATION AREAS



ADSORPTION-BASED DETOXIFICATION

Extracorporeal radionuclide and heavy metals removal:

- Blood and plasma purification – selective adsorption of plutonium, americium, uranium, and thorium [1], as well as gadolinium-based contrast agents [2], and lead [3];
- Dialysate regeneration – removal of gadolinium-based contrast agents using functionalized silica sorbents [2].

Intracorporeal detoxification:

- In vivo radionuclide of cesium decorporation in the gastrointestinal tract following oral administration [4] mercury, cadmium, and lead [5];

Current research focuses on optimizing the surface chemistry of silica-based sorbents to achieve:

✓High adsorption selectivity

✓High adsorption capacity

✓Fast adsorption kinetics

✓Strong and stable binding

✓Biocompatibility and safety

✓Stability under varying physiological conditions

[1] W. Yantasee et al., Health Physics (2010) 99 (3) 413-419;
[2] W. Yantasee et al., Nanomedicine: Nanotechnology, Biology and Medicine, 2010, 6.1: 1-8;
[3] Y. Xiang et al., Nanomedicine: Nanotechnology, Biology and Medicine (2017) 13,4,1341-1351;
[4] C. Timchalk et al., Health Phys. (2010) 99(3) 420–429;
[5] T. Sangvanich et al., ACS Appl Mater Interfaces (2014) 6(8) 5483–5493.

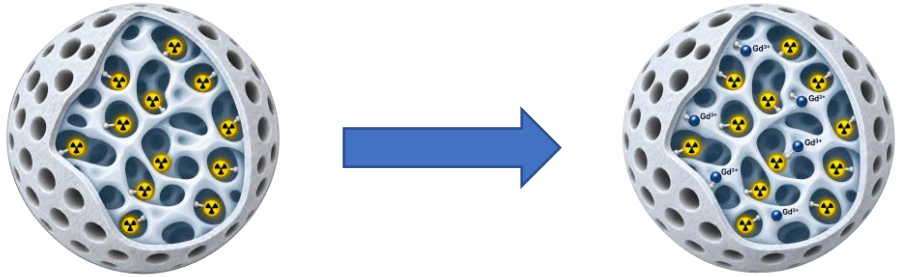
RADIOLABELED MESOPOROUS SILICA FOR IMAGE-GUIDED DRUG DELIVERY

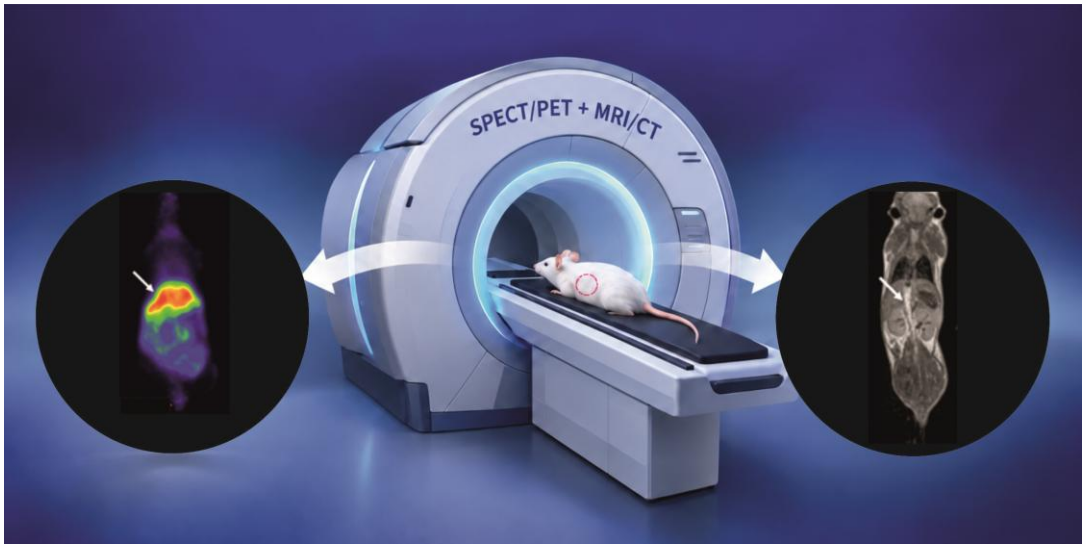
Single-Photon Emission Computed Tomography (SPECT)

- ✓ Technetium-99m [1]
- ✓ Indium-111 [2]

Positron Emission Tomography (PET)

- ✓ Copper-64 [3]
- ✓ Fluorine-18 [4]
- ✓ Gallium-68 [5]
- ✓ Zirconium-89 [6]





[1] H. Gao et al., Nanoscale (2016) 8, 19573–19580;
[2] P. Dogra et al., Nature Communications (2018) 9;
[3] F. Chen et al., ACS Nano (2013) 7 (10): 9027–9039;
[4] S. B. Lee et al., Angew. Chem. Int. Ed. 2013, 52, 1 – 5;
[5] S. Khan et al, Eur J Nucl Med Mol Imaging (2025) 52, 1778–90;
[6]L. Kramer et al, Nanoscale (2017) 9 (27): 9743–9753.

SILICA-BASED NANOMATERIALS FOR THERAPY AND THERANOSTICS

Therapeutic Applications of Radiolabeled Silica Particles:

✓Targeted radionuclide therapy:

- α-Emitter: ^{225}Ac [1]
- β⁻-Emitters: ^{90}Y [2], ^{166}Ho [3], ^{177}Lu [4]

✓Intratumoral radionuclide therapy:

- β⁻-Emitter: ^{177}Lu [5]

Theranostic Applications:

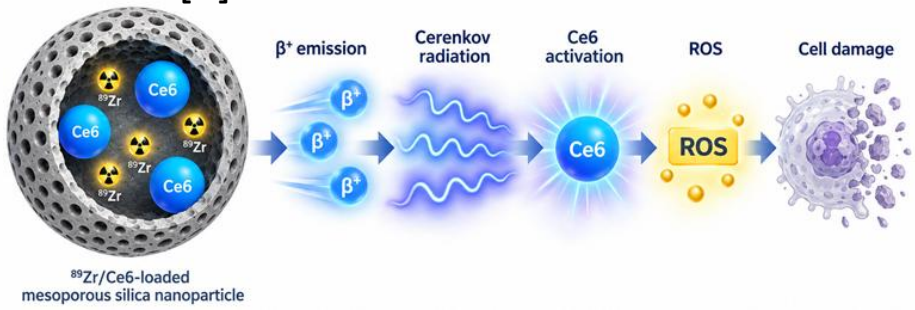
✓ ^{90}Y for radionuclide therapy and ^{86}Y for PET imaging [2]

✓ ^{177}Lu for radionuclide therapy and SPECT imaging [4]

✓ ^{99m}Tc – SPECT imaging and ^{188}Re - potential therapy [6]

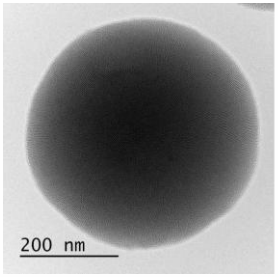
Cerenkov Radiation-Induced Photodynamic Therapy:

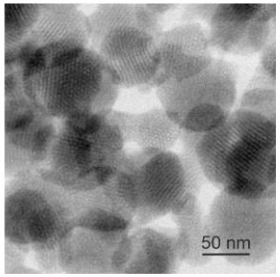
✓ ^{89}Zr [7]

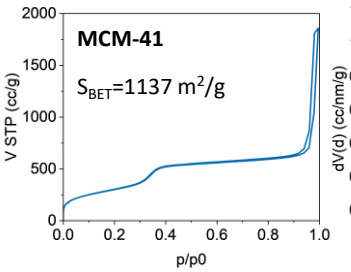


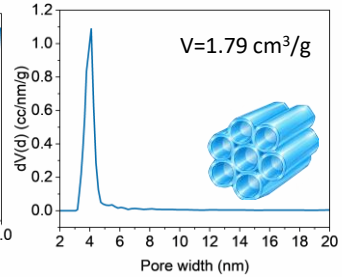
[1] R. M. Pallares et al. ACS Appl. Mater. Interfaces (2020) 12 (36): 40078–84;
[2] C. A. Ferreira et al., Nano Lett. (2021) 21 (11): 4692–4699;
[3] D. Hargrove et al., Int J Pharm. (2025) 669, 125071;
[4] X. Zhang et al., Biomaterials (2020) 241, 119858;
[5] R. da S. Viana et al., ACS Applied Nano Materials (2020) 3 (9) 8691–8701;
[6] M.A. Wuillemin et al., Inorganics (2019) 7 (11), 134;
[7] A. Kamkaew et al., ACS Appl. Mater. Interfaces (2016) 8 (40) 26630–26637.

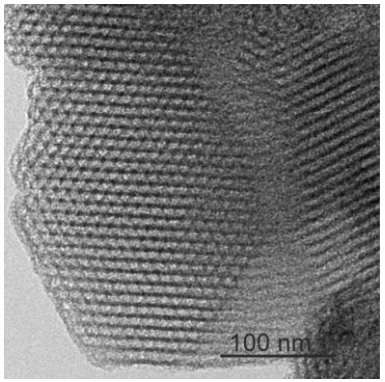
EXPERIMENTAL STUDIES ON MESOPOROUS SILICA NANOMATERIALS AT IFJ PAN

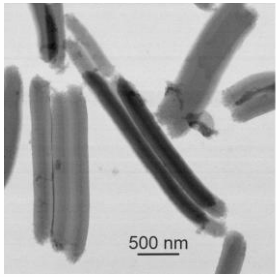


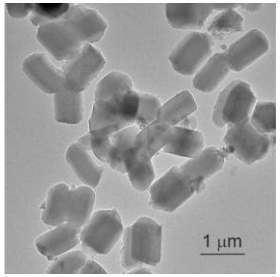


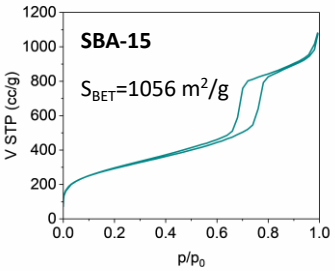


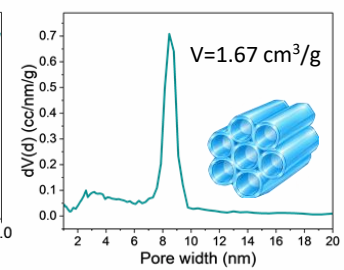


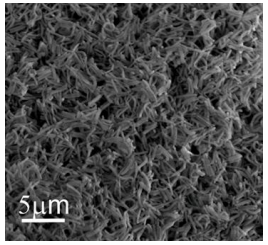




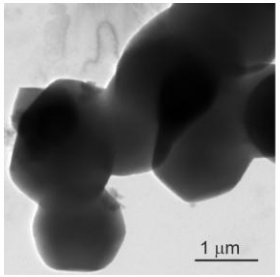


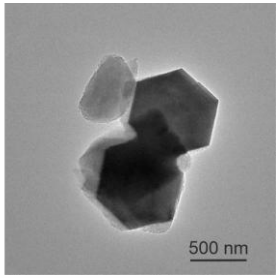


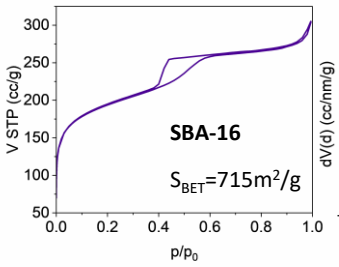


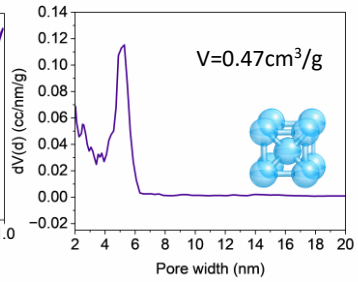


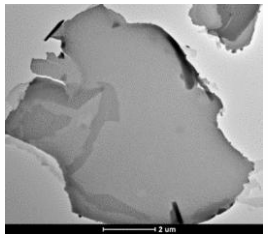


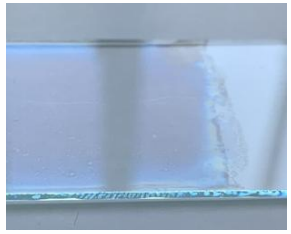




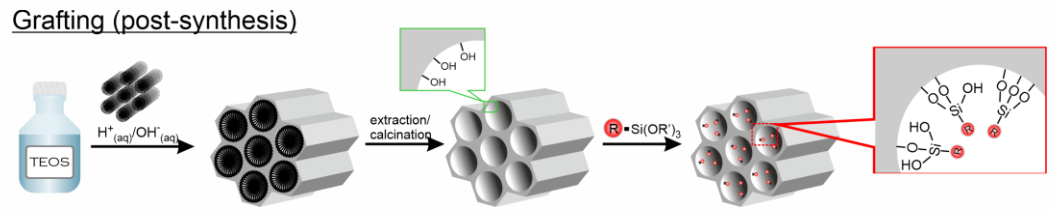


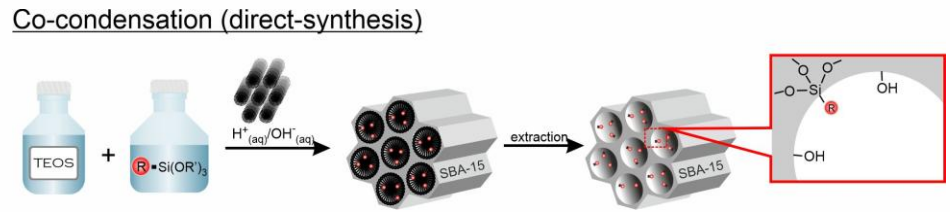


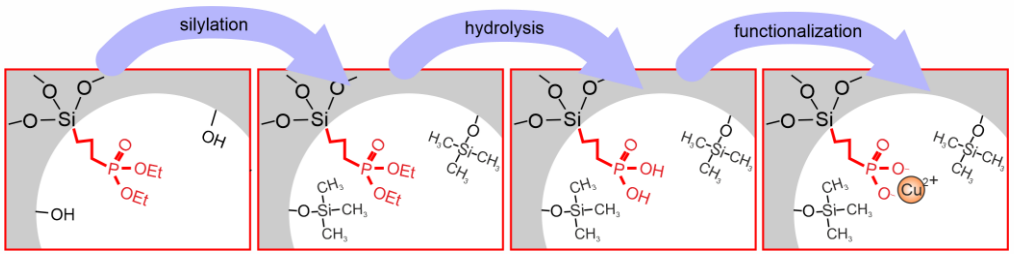


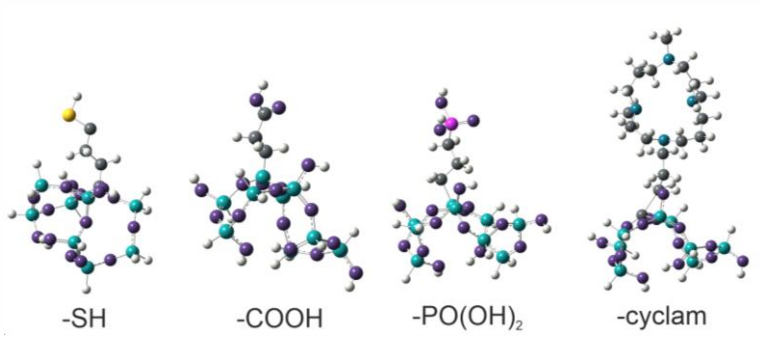


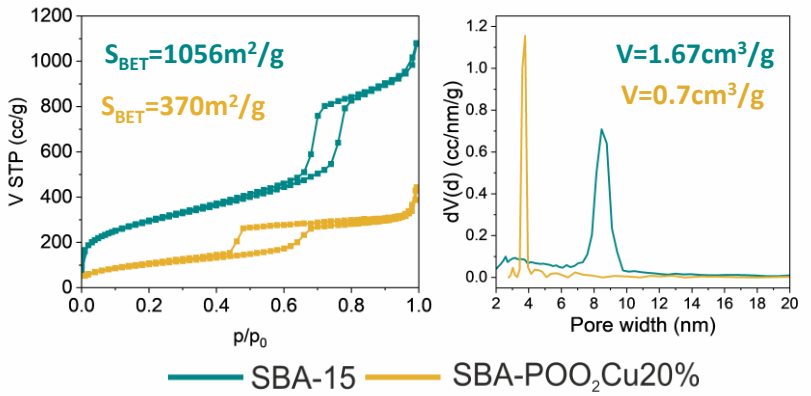
SURFACE FUNCTIONALIZATION





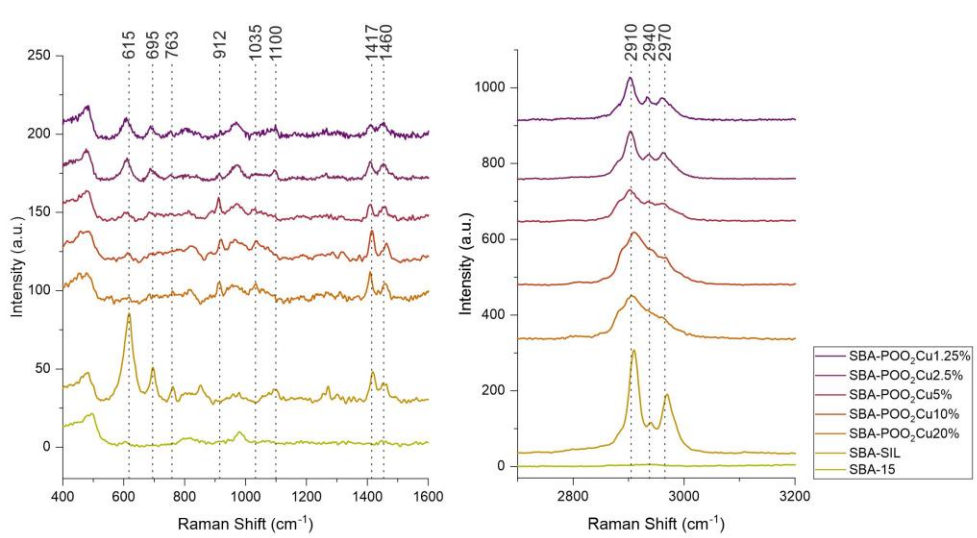


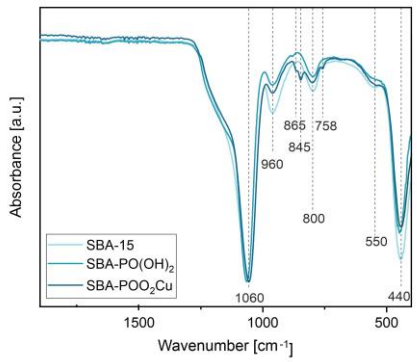


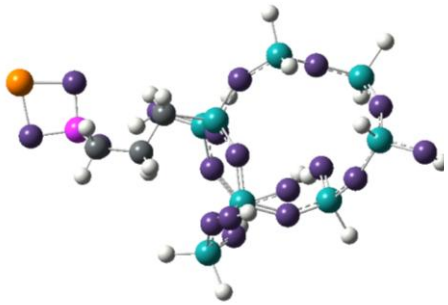


VERIFICATION OF SURFACE FUNCTIONALIZATION

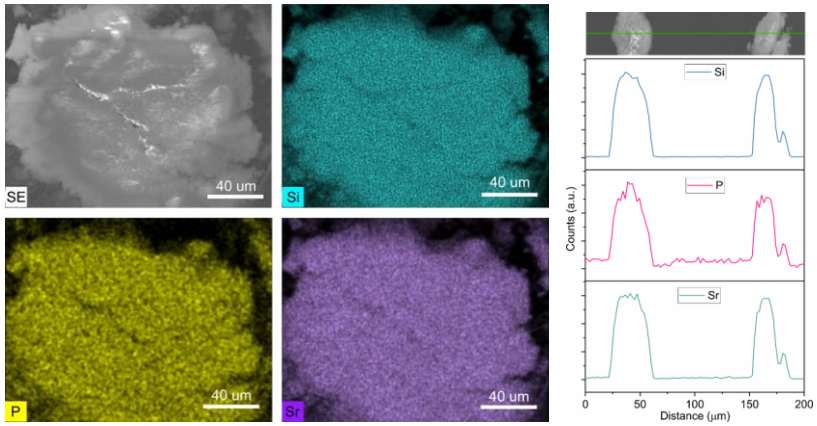
Vibrational spectroscopy supported by DFT calculations



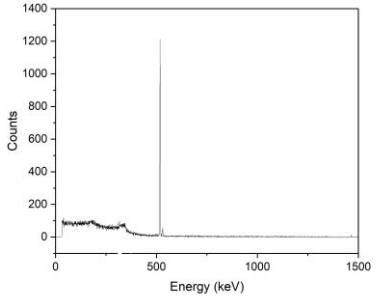


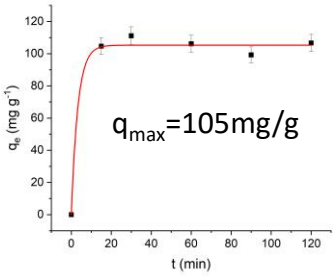


Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy (SEM–EDS)



Radiolabeling and Gamma Spectrometry





FUTURE PERSPECTIVES

Combining functionalized mesoporous silica with access to a wide range of diagnostic and therapeutic radionuclides opens new opportunities for:

- Targeted alpha therapy – development of nanocarriers for ^{211}At and ^{225}Ac
- Targeted beta therapy – development of nanocarriers for ^{67}Cu, ^{89}Sr, ^{131}I, and ^{177}Lu
- Diagnostic imaging – development of silica-based drug delivery systems with PET, SPECT, and multimodal (combined with MRI or CT) imaging capabilities using ^{64}Cu, ^{203}Pb
- Theranostic nanoplatforms – combining diagnostic and therapeutic functions within a single silica-based platform using ^{64}Cu, ^{117m}Sn, ^{177}Lu
- Multifunctional drug delivery systems – integrating radionuclide therapy, conventional drugs, imaging, and molecular targeting

CONCLUSION

The wide variety of silica structures, particle sizes and shapes, surface functional groups, and available radionuclides offers almost endless possibilities for designing and tailoring nanomaterials to specific needs, making silica-based nanomaterials particularly promising for applications in nuclear medicine.

THANK YOU FOR YOUR ATTENTION!