Electronic Supplementary Information

Nanoscaled porphyrinic metal-organic frameworks: photosensitizer delivery systems for photodynamic therapy

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Content

Figure S1. Typical size distributions along the major axis of nanoMOF-A (top), nanoMOF-B (middle), and nanoMOF-C (bottom) measured by TEM.

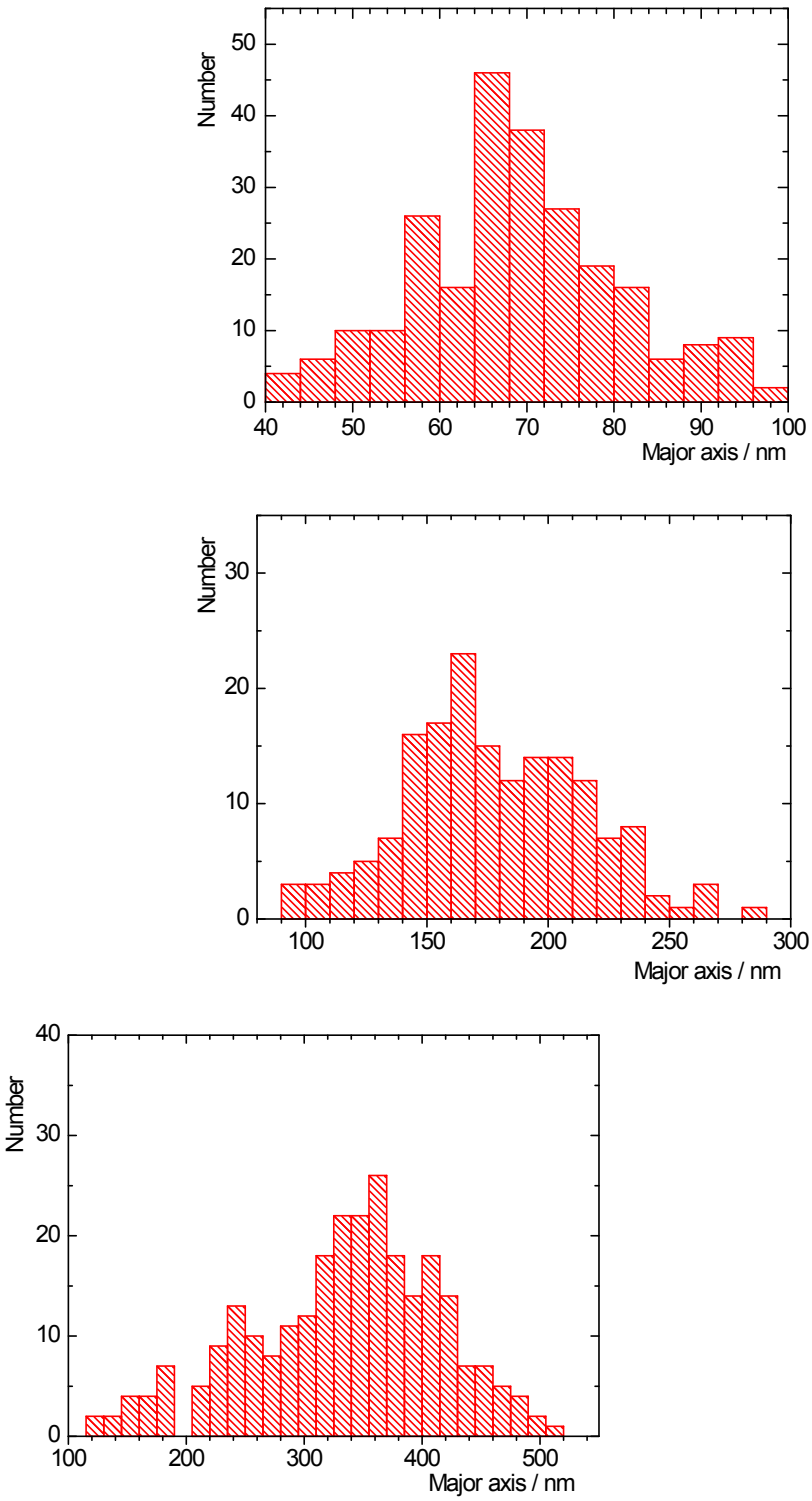


Figure S2. SEM images of nanoMOF-A (A), nanoMOF-B (B), nanoMOF-C (C), and polydisperse cubic nanoparticles of MOF-525 (D).

Scanning electron microscopy (SEM) was performed on a FEI Nova NanoSEM with a Through Lens detector in the secondary electrons mode at an accelerating voltage 5-10 kV. The samples for SEM were prepared by the deposition of dispersed nanoparticles in ethanol onto a silicon wafer chip. Prior the deposition, the nanoparticles were well dispersed using an ultrasonic bath.

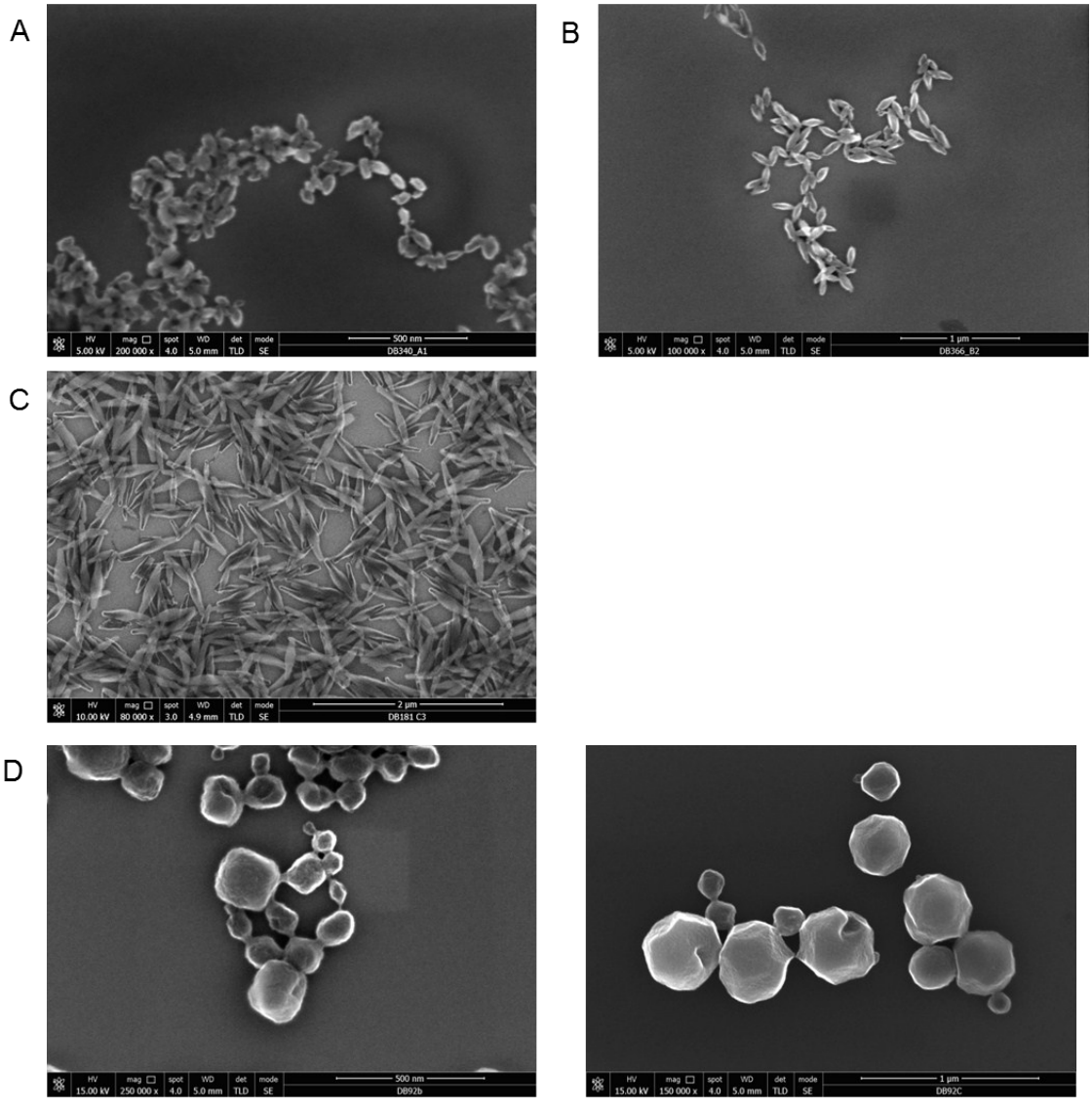


Figure S3. Powder XRD patterns of nanoMOF-A (a) and nanoMOF-C (b) compared with the theoretical XRD pattern of PCN-222 (CCDC 893545; black bars).

Powder XRD was recorded using a PANalytical X'Pert PRO diffractometer in the transmission setup equipped with a conventional Cu X-ray tube (40 kV, 30 mA).

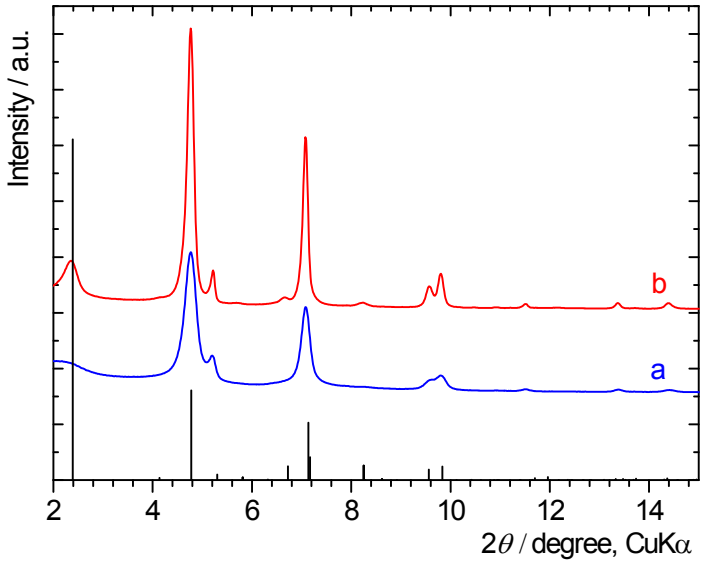


Figure S4. DLS size distribution of nanoMOF-A (top) and nanoMOF-C (bottom) in water dispersions at room temperature.

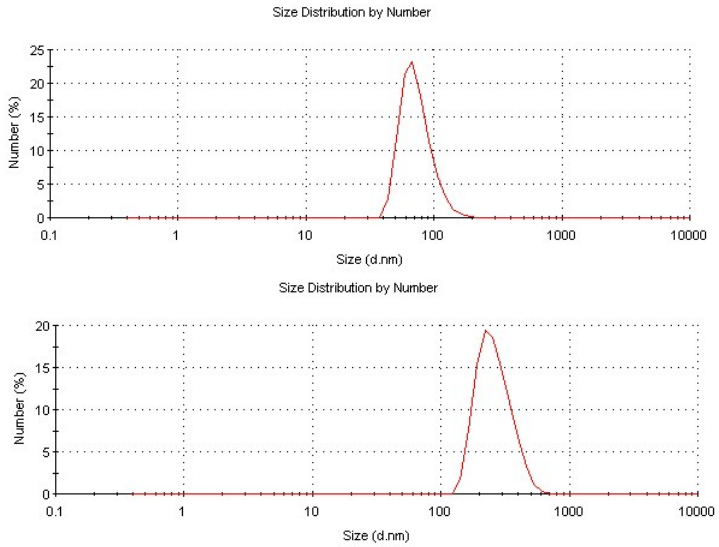
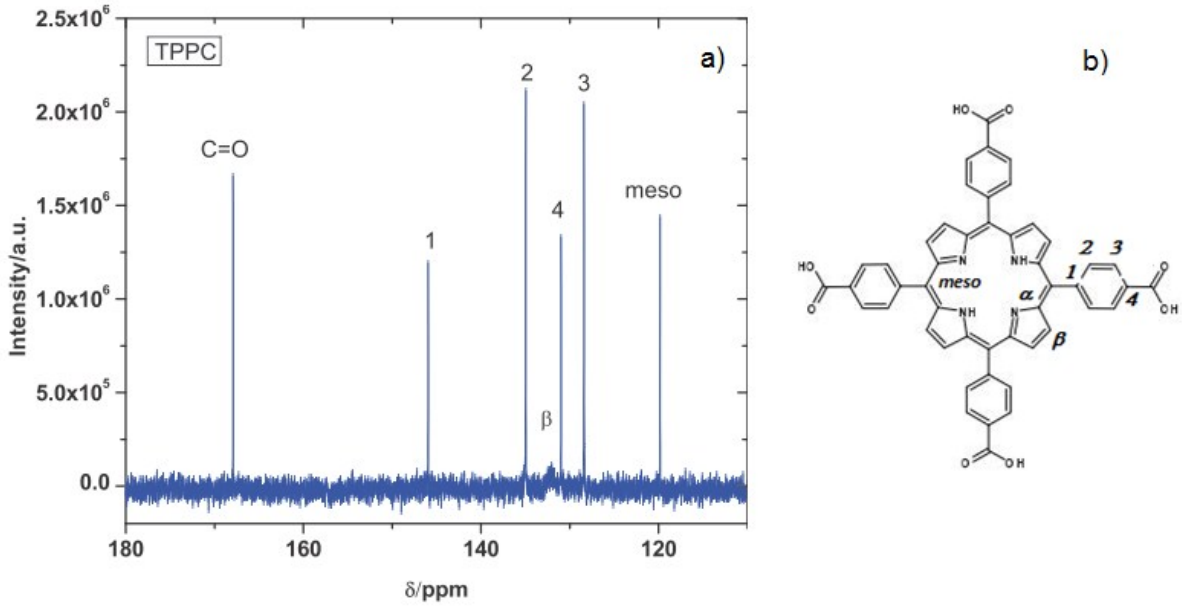


Figure S5: a) Liquid-state ^{13}C NMR spectrum of 5,10,15,20-tetrakis(4-carboxyphenyl)porphyrin (TPPC) in DMSO-d_6 at room temperature. The lines were assigned to the corresponding carbon atoms as labeled in the schematic representation of TPPC molecule (b). The assignment of the ^{13}C NMR spectrum was achieved by means of HSQC and HMBC ^{1}H-^{13}C spectra. The peaks corresponding to the pyrrole carbons are broadened considerably probably as a result of the tautomeric proton exchange: the β carbon atoms are located at 132 ppm and α carbon atoms are expected to resonate at around 150 ppm.



^{13}C NMR cross-polarization spectra under the magic angle spinning conditions (Figure 1B) were recorded using a Bruker Avance III HD spectrometer (Bruker BioSpin GmbH) operating at magnetic field of 11.75 T (500.5 MHz and 125.8 MHz for the ^{1}H and ^{13}C basic Larmor frequency, respectively). The sample diameter was 2.5 mm and the sample spinning frequency was 20 kHz. ^{1}H 90 deg excitation pulse duration was 1.95 μs, the Hartmann-Hahn condition for ^{1}H and ^{13}C was matched at the amplitude of the transverse magnetic field of $\omega_1/2\pi$ = 78 kHz, the optimal cross-polarization period was found to be 10 ms. SPINAL-64 was used for ^{1}H decoupling during acquisition at the power level corresponding to the transverse field amplitude of 128 kHz. The recycle delay was set to 5 s, and about 40,000 transients were accumulated for each sample.

Figure S6. Nitrogen adsorption isotherms of nanoMOFs and microcrystalline PCN-222 at 77 K.

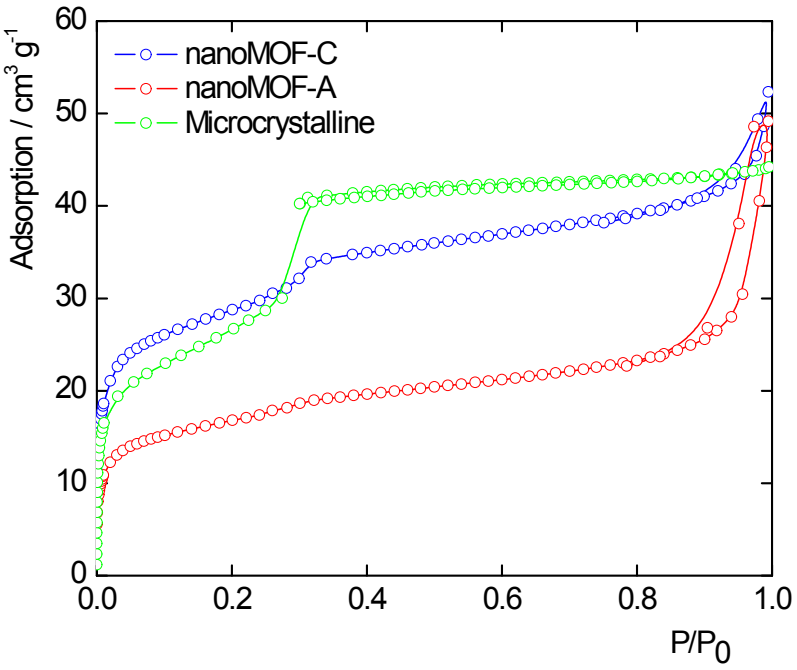


Figure S7. Pore size distribution calculated from nitrogen adsorption isotherms of nanoMOFs and microcrystalline PCN-222 presented in Figure S6.

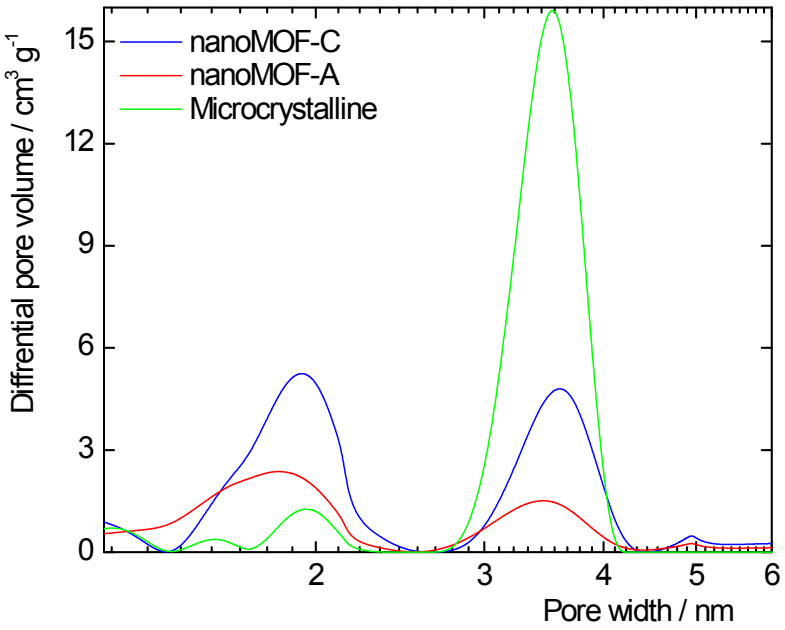


Figure S8. Normalized UV-vis spectra of nanoMOF dispersions compared with the corresponding spectrum of monomeric TPPC, all in absolute ethanol.

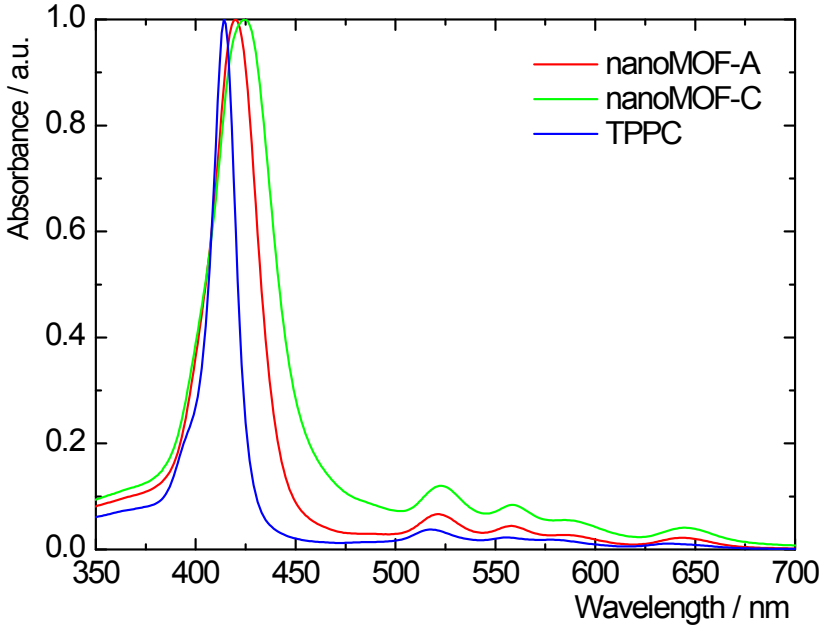


Figure S9. Normalized fluorescence emission spectra of nanoMOF dispersions and TPPC in ethanol. Excitation wavelength was 520 nm.

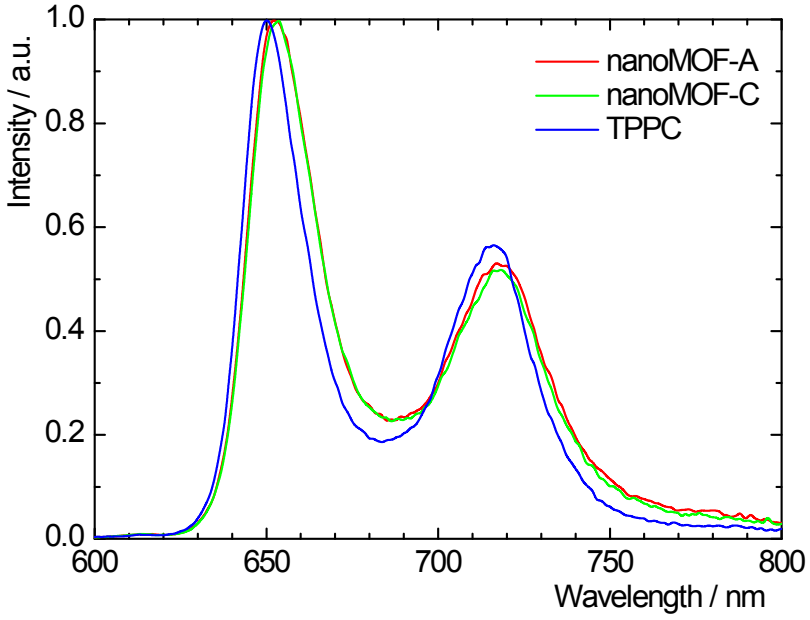
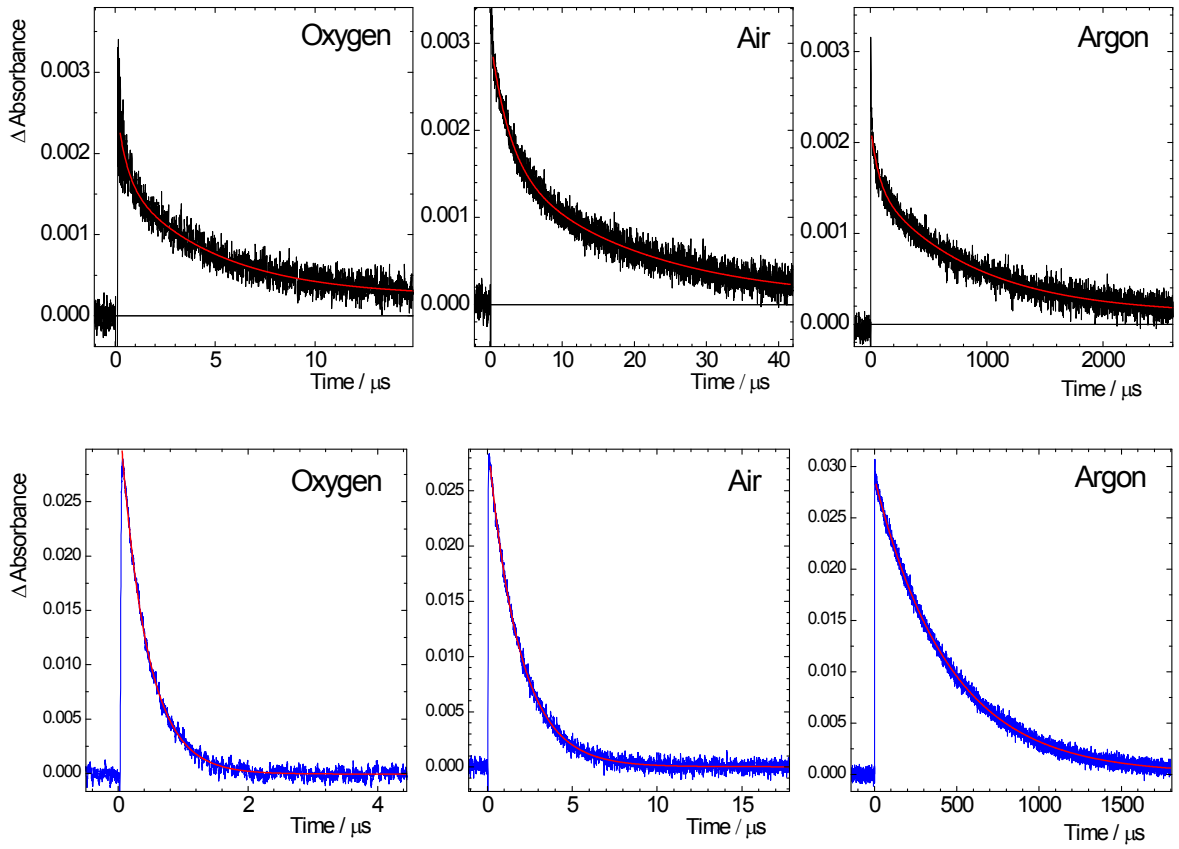


Figure S10. Kinetics of the triplet states of nanoMOF-A (top) and 5,10,15,20-tetrakis(4-sulfonatophenyl)porphyrin (middle) in oxygen-, air, and argon-saturated D_2O. Red lines are exponential fits to the experimental data. The Stern-Volmer plots of the triplet states quenching of 5,10,15,20-tetrakis(4-sulfonatophenyl)porphyrin (a) and nanoMOF-A (b) in D_2O (bottom). Excitation wavelength was 308 nm.

The transient absorption of the porphyrin triplet states was recorded on a laser kinetic spectrometer LKS 20 (Applied Photophysics, U.K.) equipped with a 150 W Xe lamp (Phillips) and R928 photomultiplier (Hamamatsu). The rate constants k_{O2} of the triplet state quenching by oxygen were calculated using the Stern-Volmer equation: $1/\tau_T = 1/\tau_T^{Ar} + k_{O2}\,[O_2]$, where τ_T is the triplet state lifetime in oxygen- or air-saturated D_2O and τ_T^{Ar} is the lifetime in argon-saturated D_2O. The concentration of molecular oxygen is 0.28 mM in air-saturated water.



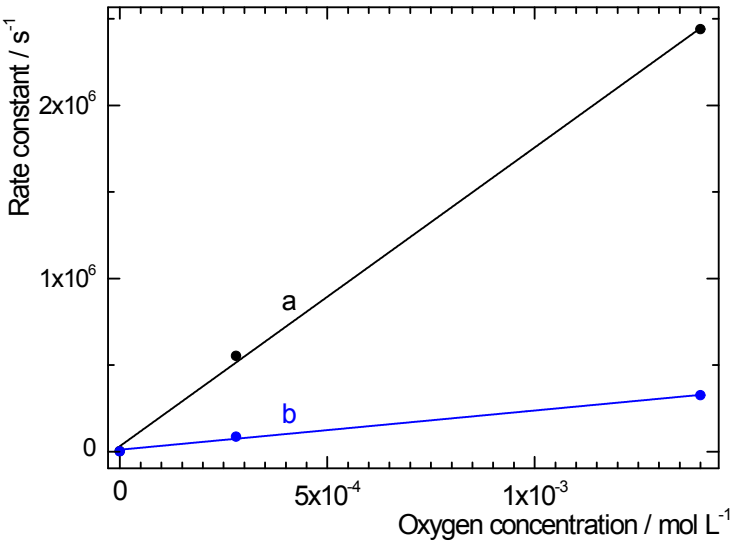

Rate constant / s-1
2x10^6
1x10^6
0
a
b
0
5x10^-4
1x10^-3
Oxygen concentration / mol L-1

Figure S11. Kinetics of $O_2(^1\Delta_g)$ decay after excitation of nanoMOF-A by a 308 nm laser pulse in oxygen-saturated acetonitrile. Red line is the corresponding single exponential fit. Singlet oxygen has a long lifetime in acetonitrile, making the detection of $O_2(^1\Delta_g)$ more sensitive in this solvent than in ethanol or aqueous dispersions.

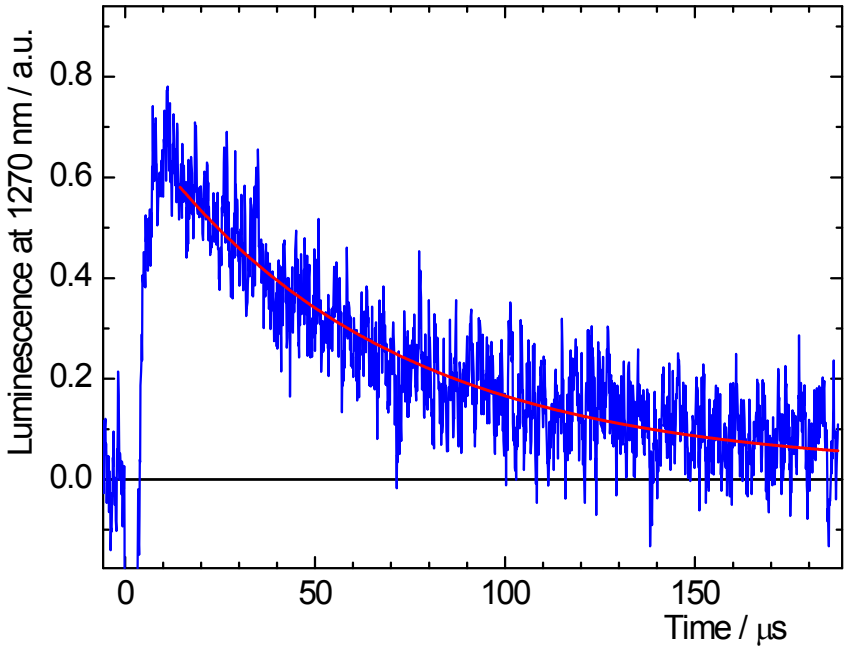


Figure S12. Comparison of $O_2(^1\Delta_g)$ luminescence intensities photogenerated by 5,10,15,20-tetrakis(4-sulfonatophenyl)porphyrin (a) and nanoMOF-A (b) adjusted to the same absorbance at the excitation wavelength of 308 nm in oxygen saturated D_2O.

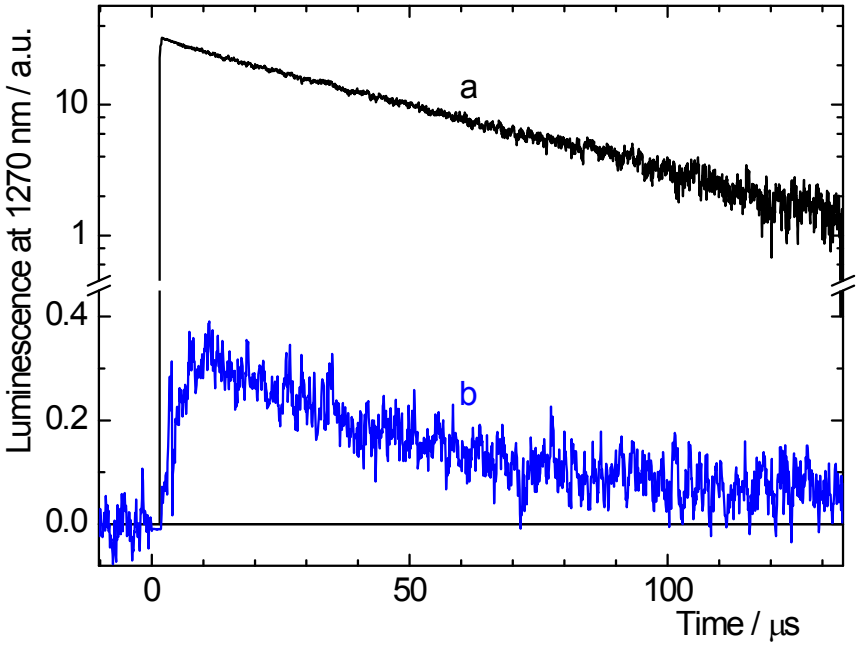


Figure S13. Confocal microscopy analysis of nanoMOF-A (A, B, C), nanoMOF-B (D, E, F), nanoMOF-C (G, H, I) localization in HeLa cells after 4 h incubation; A, D, G) Confocal sections stained with membrane marker FITC-WGA (green); B, E, H) Fluorescence of nanoMOFs; C, F, I) Merging of the two panels on the left. Scale bars: 10 μm.

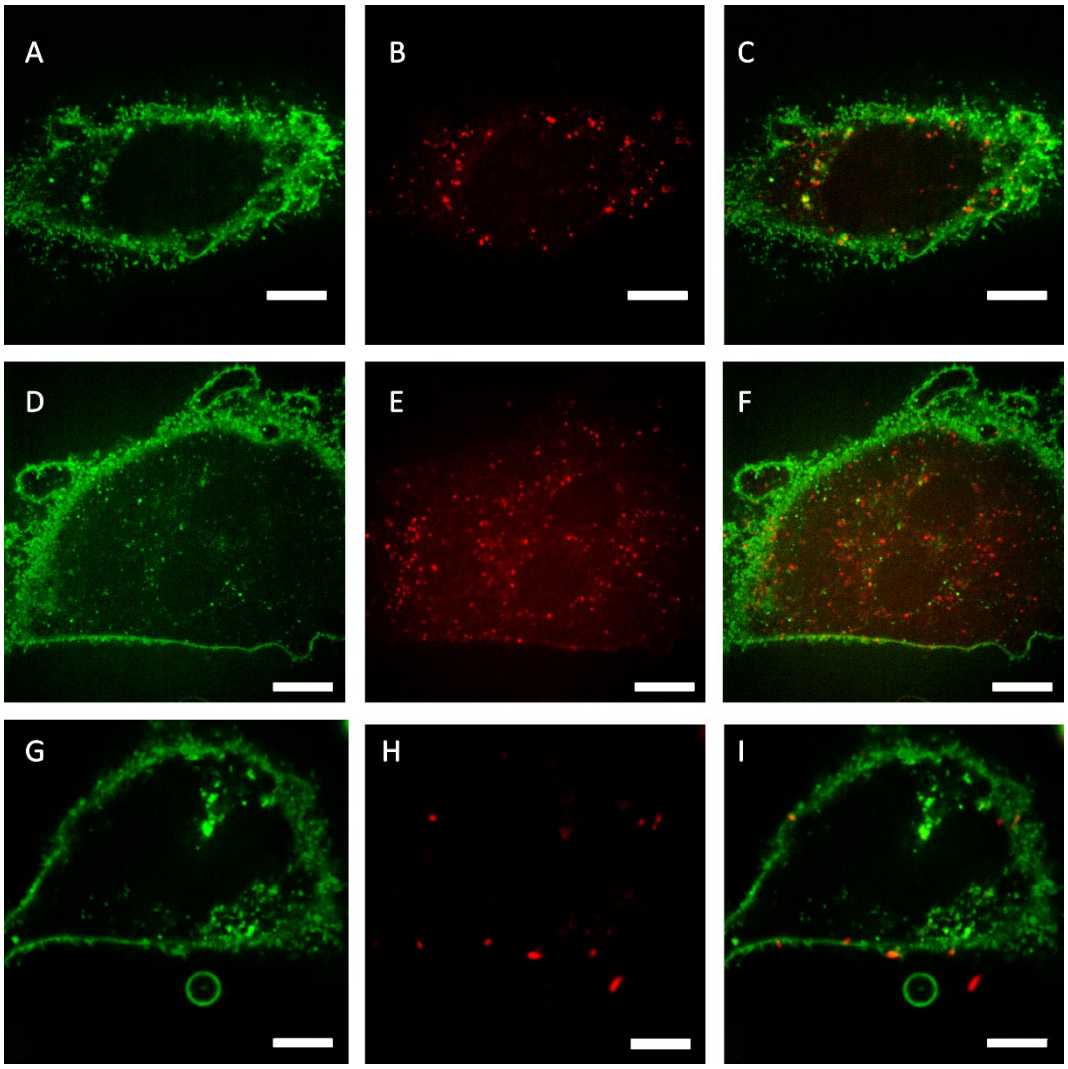


Figure S14. Flow cytometry histograms: A) HeLa cells incubated with nanoMOF-A for 10, 30, 60, and 120 min (from light green to dark green; red is the control), porphyrin concentration is 2 μM; B) HeLa cells incubated with 1, 2, or 4 μM nanoMOF-A for 120 min (from grey to green, dark grey color is the control).

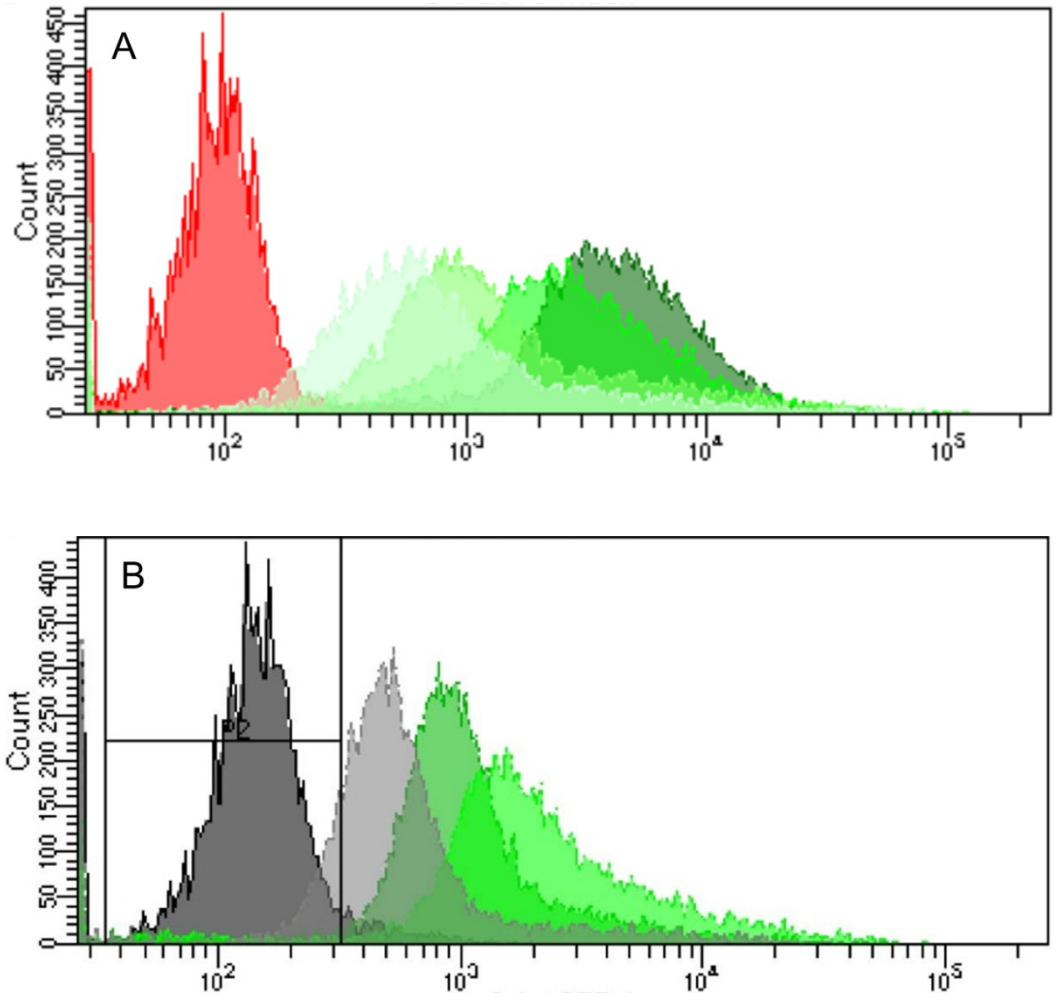


Figure S15. Flow cytometry histograms: HeLa cells were incubated with nanoMOF-A (red), nanoMOF-B (green), and nanoMOF-C (blue) for 60 min (the control is in shadow color), porphyrin concentration is 2 μM.

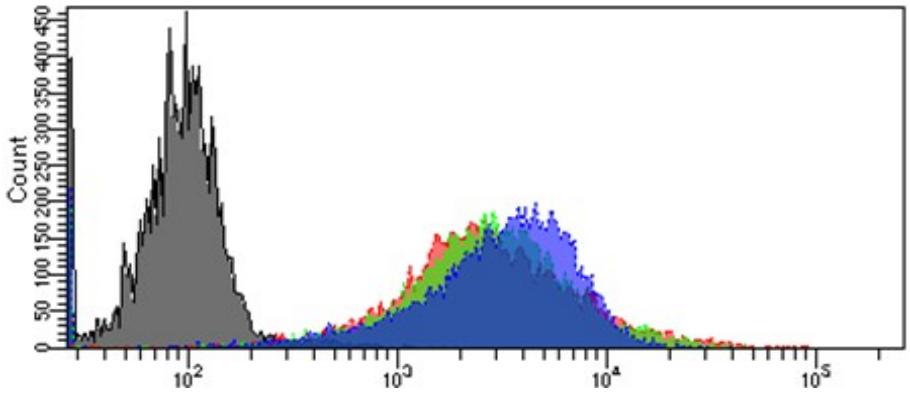


Figure S16. Viability of HeLa cells treated with nanoMOF-B for various time intervals followed by 15 min irradiation (> 600 nm) and measured after next 24 h.

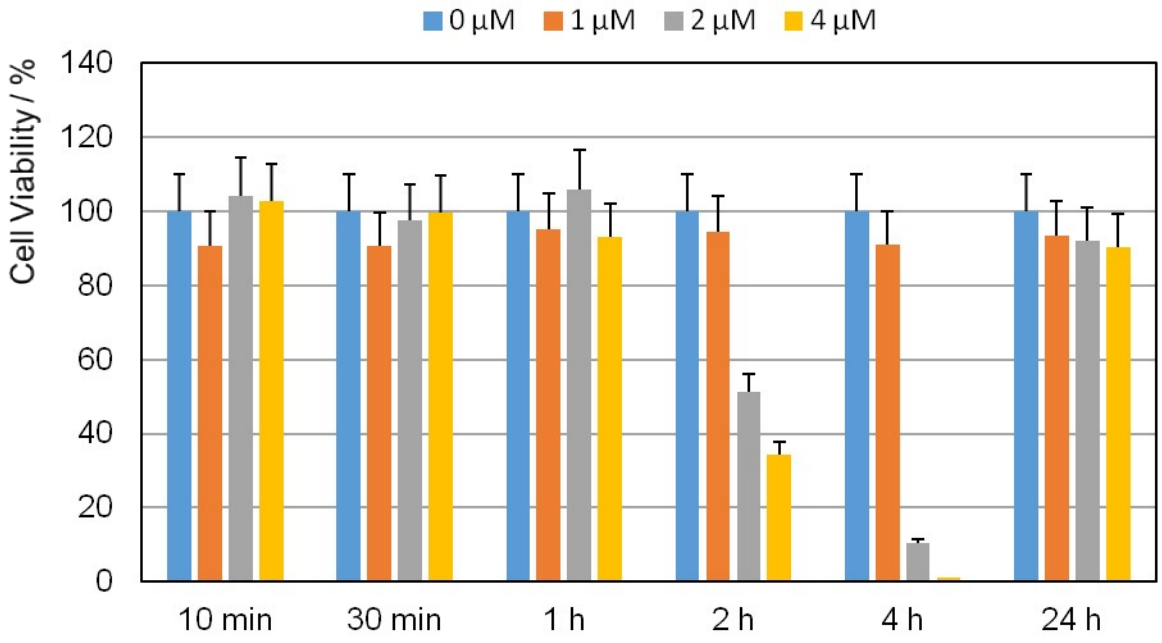
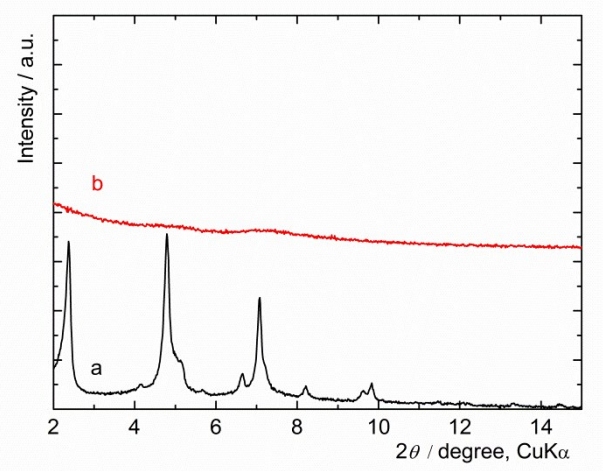


Figure S17. Stability of nanoMOF-C (left) and PCN-224 nanoparticles (average size = 55 nm, right) in the EMEM medium: Powder XRD patterns before (a) and after 4 h treatment (b).



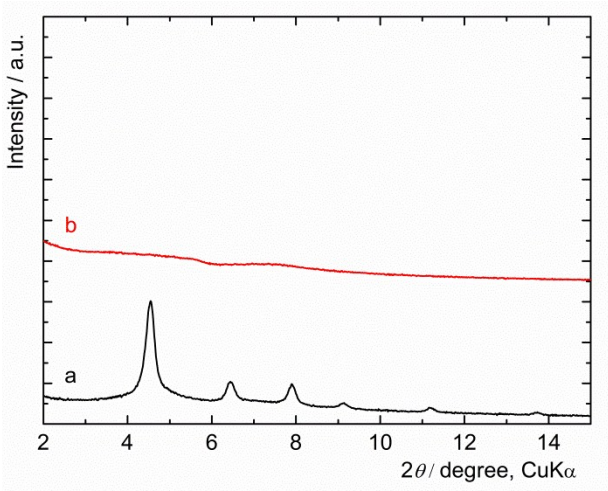


Figure S18. Stability of nanoMOFs and PCN-224 in the EMEM medium: TEM micrographs of nanoMOF-A (top), nanoMOF-C (middle), and PCN-224 (bottom) before (left) and after 4 h treatment (right).

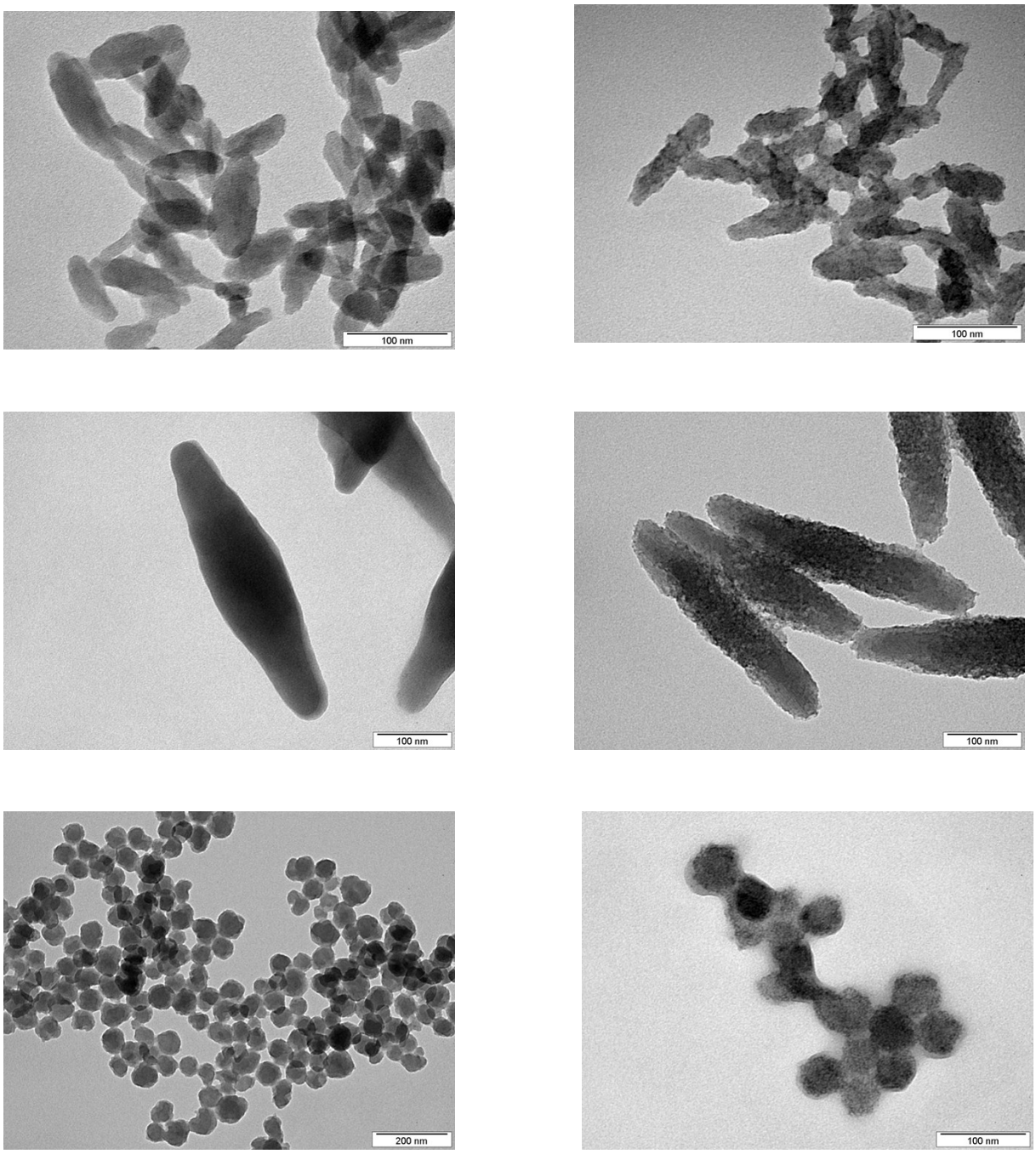
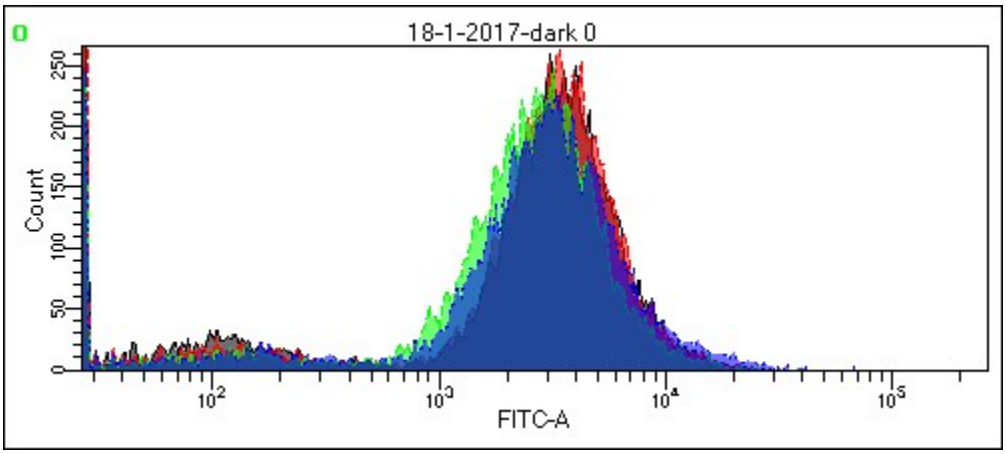


Figure S19. Flow cytometry histograms document the production of intracellular reactive oxygen species in the presence of nanoMOFs. HeLa cells were treated with nanoMOFs (2 μM) for 2 h, loaded with 10 μM 2',7'-dichlorodihydrofluorescein diacetate for 10 min, followed by either incubation in dark (top) or 15 min irradiation with a 630 nm LED source at a power density of 9 J cm^{-2} (bottom). Fluorescein fluorescence was measured immediately after irradiation using fluorescence-assisted cell sorting analysis.

Dark experiment: Control (black), nanoMOF-A (red), nanoMOF-B (green), nanoMOF-C (blue).



After irradiation: Control (black), nanoMOF-A (red), nanoMOF-B (green), nanoMOF-C (blue).

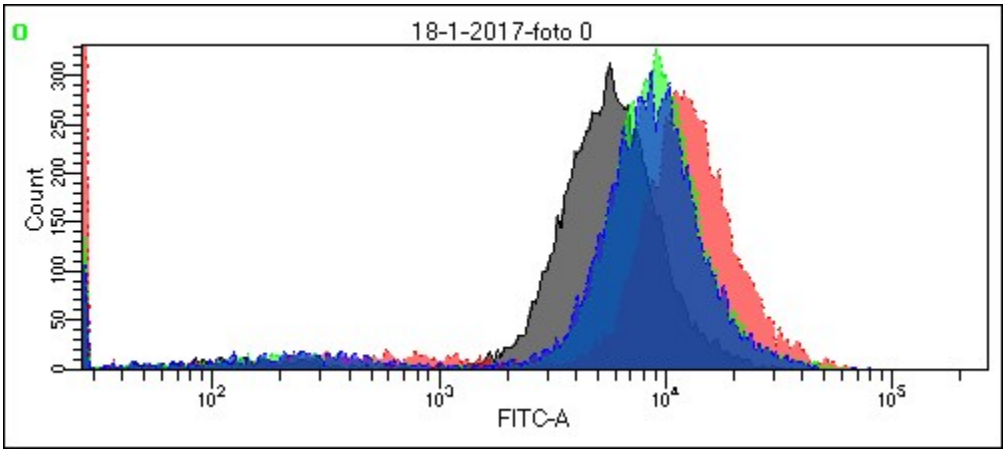


Figure S20. Immediate phototoxicity of nanoMOF-A, nanoMOF-B, 5,10,15,20-tetrakis(4-carboxyphenyl)porphyrin (TPPC), and PCN-224 nanoparticles (average size = 55 nm) for HeLa cells. 2 h incubation, 15 min irradiation (> 600 nm).

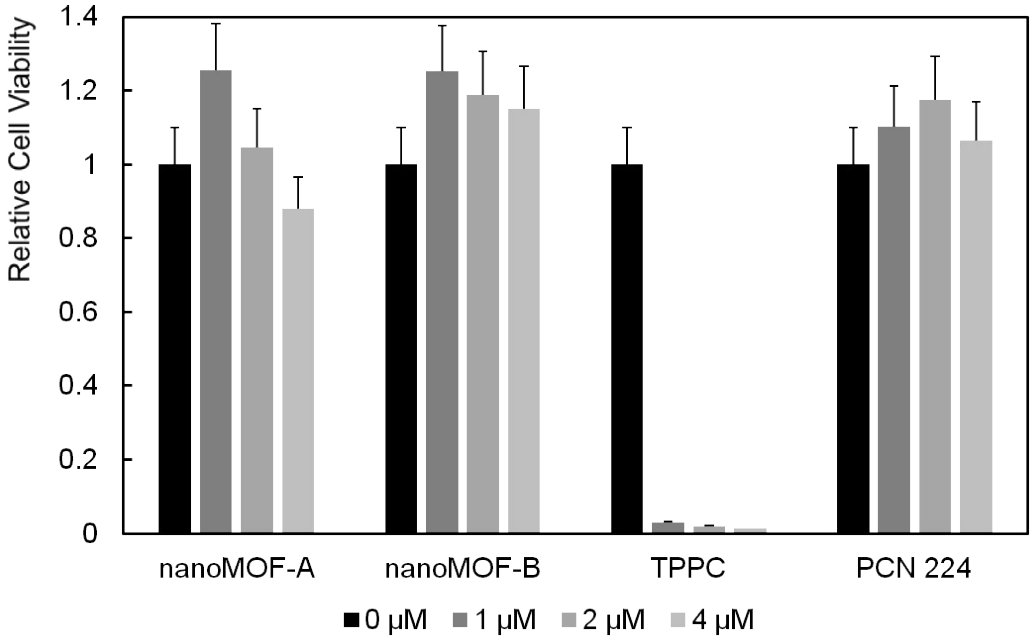


Figure S21. Phototoxicity of 4 μM nanoMOF-A and 5,10,15,20-tetrakis(4-carboxyphenyl)porphyrin (TPPC) for HeLa cells based on flow cytometry analysis: the percentage of apoptotic, necrotic, and normal cells 1 h after 15 min irradiation (> 600 nm).