

Supplementary Information

Table S1. Sonication parameters for MONPs and MOMP stock suspensions in dH₂O.

Stock suspension	Concentration	Volume	Sonication time	Amplitude	DSE (J/mL)
	(mg/mL)	(mL)	(min)	(%)	
Uncoated ZnO NPs (US3580) ^a	5	8	2.25	40	655
Uncoated ZnO NPs (5811HT)	5	50	14	40	655
APTES-coated ZnO NPs (5812HT)	5	50	14	40	655
Stearic acid-treated ZnO NPs (8412DL)	5	50	14	40	655
ZnO MPs (US1003M) ^a	5	8	2.25	40	655
Uncoated CuO NPs 544868 ^a	1	8	1.9	10	109.5
Uncoated CuO NPs (US3070)	1	8	1.9	10	109.5
PVP-coated CuO NPs (US3070)	1	8	1.9	10	109.5
Silane-coated CuO NPs (US3070)	1	8	3.8	10	219
CuO MPs (US1140M) ^a	1	8	1.9	10	109.5
Uncoated MnO ₂ NPs (4910DX)	5	8	1.5	40	440
MnO ₂ MPs (4930DX)	5	8	1.5	40	440
Uncoated NiO NPs (US3355)	5	8	1.5	60	733
Uncoated NiO NPs (US3352)	5	8	1.5	60	733
PVP-coated NiO NPs (US3352)	5	8	1.5	60	733
Stearic acid-coated NiO NPs (US3352)	5	8	1.5	60	733
Silane-coated NiO NPs (US3352)	5	8	3	60	1466
NiO MPs (US1014M)	5	8	1.5	60	733
Uncoated Al ₂ O ₃ NPs (544833)	5	8	3	55	1270
Al ₂ O ₃ MPs (1331DL)	5	8	3	55	1270
Uncoated CeO ₂ NPs (US3136)	5	8	4	60	1953
Uncoated CeO ₂ NPs (US3036)	5	8	4	60	1953
PVP-coated CeO ₂ NPs (US3037)	1	100	12	60	469
Stearic acid-coated CeO ₂ NPs (US3037)	1	100	12	60	469
CeO ₂ MPs (2118CG)	5	8	4	60	1953
Uncoated TiO ₂ NPs ^b	5	50	15	55	1013
TiO ₂ MPs (US1017M) ^b	5	50	15	55	1013

Uncoated Fe ₂ O ₃ NPs (US3160)	1	100	10	55	338
Fe ₂ O ₃ MPs (US1139M)	1	100	10	55	338

^aSonicator parameters published in [34]. ^bPreviously published in [54]. Conditions were optimized from Avramescu et al. [38, 39]. The sonicator was operated for 8 seconds on with 2 seconds off. DSE: Delivered sonication energy. $DSE = (P \times T)/V$. P=power (W), T=time (seconds), V=volume (mL).

Table S2. HD, PDI and ZP in dH₂O determined by DLS and ELS.

MONPs	H ₂ O		
	HD	PDI	ZP
	(nm)		(mV)
Uncoated ZnO NPs (US3580)	271 ± 25.7	0.32 ± 0.05	21.1 ± 0.76
Uncoated ZnO NPs (5811HT)	255 ± 43.7	0.23 ± 0.04	21.52 ± 1.69
APTES-coated ZnO NPs (5812HT)	408 ± 57.7	0.36 ± 0.05	14.4 ± 0.49
Stearic acid-treated ZnO NPs (8412DL)	272 ± 43.5	0.31 ± 0.06	19.41 ± 0.49
Uncoated CuO NPs (544868)	647 ± 43.7	0.46 ± 0.06	-9.85 ± 0.54
Uncoated CuO NPs (US3070)	343 ± 21.4	0.39 ± 0.04	-9.85 ± 0.54
PVP-coated CuO NPs (US3070)	309 ± 31.18	0.33 ± 0.05	11.9 ± 0.58
Silane-coated CuO NPs (US3070)	552 ± 62.1	0.45 ± 0.06	36.9 ± 0.91
Uncoated MnO ₂ NPs (4910DX)	134 ± 1.53	0.20 ± 0.03	-15.3 ± 1.71
Uncoated NiO NPs (US3355)	204 ± 10.1	0.31 ± 0.06	32.7 ± 3.70
Uncoated NiO NPs (US3352)	174 ± 2.38	0.21 ± 0.02	47.2 ± 0.67
PVP-coated NiO NPs (US3352)	179 ± 1.44	0.16 ± 0.02	41.0 ± 0.69
Stearic acid-coated NiO NPs (US3352)	260 ± 5.23	0.28 ± 0.03	38.0 ± 0.75
Silane-coated NiO NPs (US3352)	199 ± 6.66	0.26 ± 0.04	48.1 ± 0.98
Uncoated Al ₂ O ₃ NPs (544833)	350 ± 43.3	0.37 ± 0.06	29.5 ± 2.70
Uncoated CeO ₂ NPs (US3136)	185 ± 7.85	0.29 ± 0.04	34.0 ± 1.05
Uncoated CeO ₂ NPs (US3036)	189 ± 10.4	0.33 ± 0.05	-42.7 ± 3.63
PVP-coated CeO ₂ NPs (US3037)	410 ± 14.7	0.35 ± 0.05	33.0 ± 0.84
Stearic acid-coated CeO ₂ NPs (US3037)	399 ± 19.6	0.42 ± 0.06	-5.39 ± 1.16
Uncoated TiO ₂ NPs	150 ± 2.08	0.14 ± 0.01	27.93 ± 0.96
Uncoated Fe ₂ O ₃ NPs (US3160)	187 ± 15.5	0.33 ± 0.04	-38.6 ± 1.60

Table S3. % Solubility in DMEM cell culture medium, and SSA of all MO particles. NPs: nanoparticles. MP: microparticles. % Solubility data from Avramescu et al. [38, 41].

Particle (Catalog numbers)	% Solubility 10 µg/mL	% Solubility 100 µg/mL	SSA (m ² /g)
Uncoated ZnO NPs (US3580)	94.5	19.3	27.268
Uncoated ZnO NPs (5811HT)			21.715
APTES-coated ZnO NPs (5812HT)			16.52
Stearic acid-coated ZnO NPs (8412DL)			28.279
Uncoated ZnO MPs (US1003M)		11.8	5.85
Uncoated CuO NPs (544868)	12.6	51.6	10.343

Uncoated CuO NPs (US3070)			7.2
PVP-coated CuO NPs (US3070)			8.779
Silane-coated CuO NPs (US3070)			6.11
Uncoated CuO MPs (US1140M)		1.17	0.797
Uncoated MnO ₂ NPs (4910DX)	4.79	3.87	42.164
Uncoated MnO ₂ MPs (4930DX)		1.366	2.547
Uncoated NiO NPs (US3355)	0.94	1.81	36.602
Uncoated NiO NPs (US3352)			30.155
PVP-coated NiO NPs (US3352)			36.675
Stearic acid-coated NiO NPs (US3352)			14.629
Silane-coated NiO NPs (US3352)			16.537
Uncoated NiO MPs (US1014M)		0.067	2.518
Uncoated Al ₂ O ₃ NPs (544833)	1.11	0.73	145.292
Uncoated Al ₂ O ₃ MPs (1331DL)		0.021	22.32
Uncoated CeO ₂ NPs (US3136)			26.475
Uncoated CeO ₂ NPs (US3036)	1.12	0.42	14.057
PVP-coated CeO ₂ NPs (US3037)			67.114
Stearic acid-coated CeO ₂ NPs (US3037)			32.854
Uncoated CeO ₂ MPs (2118CG)			4.48
Uncoated TiO ₂ NPs (NIST)	0.17	0.045	52.734
Uncoated TiO ₂ MPs (US1017M)		0.0005	10.759
Uncoated Fe ₂ O ₃ NPs (US3160)		0.0205	44.876
Uncoated Fe ₂ O ₃ MPs (US1139M)			9.521
NPs included in BMC analysis			
Particle (Catalog numbers)			SSA (m²/g)
Silica-coated TiO ₂ NPs (5422HT)			39.218
Silica and alumina-coated TiO ₂ NPs (5423HT)			28.607
Silica and stearic acid-coated TiO ₂ NPs (5424HT)			39.534
Silica and silicone oil-coated TiO ₂ NPs (5425HT)			17.541
Uncoated TiO ₂ NPs (MKNA005)			150.100
Uncoated TiO ₂ NPs (MKNA050)			62.937
Uncoated TiO ₂ NPs (MKNR050P)			23.798

Table S4. Endpoint ranking based on µg metal/mL concentration normalized NOEC values. Where NOEC values were not present, LOEC values were used. Red: uncoated NPs. Green: coated NPs. Black: uncoated MPs. Blue: dissolved metal equivalent.

Metal	Comet 4 h (NOEC / LOEC Ranking)	Micronucleus 40 h (NOEC / LOEC Ranking)
Zn	ZnO US3580 ~ ZnO 5811HT ~ ZnO 5812HT ~ ZnO 8412DL > ZnO US1003M ~ ZnCl ₂	ZnO US3580 ~ ZnO 8412DL > ZnO 5812HT > ZnO US1003M > ZnCl ₂
Cu	CuO 544868 ~ CuO US3070 ~ CuO US3070P ~ CuO US3070Si > CuO US1140M ~ CuCl ₂	CuO 544868 > CuO US3070Si ~ CuO US1140M > CuO US3070P > CuCl ₂
Mn	MnSO ₄ > MnO ₂ 4910DX > MnO ₂ 4930DX ^(a)	MnO ₂ 4910DX > MnSO ₄ > MnO ₂ 4930DX ^(a)
Ni	NiO US3352St > NiO US3355 ~ NiO US3352 ~ NiO US1014M ~ NiO US3352Si > NiO US3352P > NiCl ₂	NiO US3355 > NiO US1014M > NiO US3352St > NiCl ₂ > NiO US3352P
Al	Al ₂ O ₃ 544833 ~ Al ₂ O ₃ 1331DL ~ AlCl ₃	AlCl ₃ > Al ₂ O ₃ 544833 > Al ₂ O ₃ 1331DL
Ce	CeO ₂ US3136 ~ CeO ₂ US3036 ~ CeO ₂ US3037P ~ CeO ₂ 2118CG ~ CeCl ₃ > CeO ₂ US3037St	CeCl ₃ > CeO ₂ US3037St > CeO ₂ US3036 ~ CeO ₂ US3037P ~ CeO ₂ 2118CG
Ti	TiO ₂ 5423HT ~ TiO ₂ MKNR050P > TiO ₂ NIST ~ TiO ₂ 5422HT ~ TiO ₂ 5424HT ~ TiO ₂ 5425HT ~ TiO ₂ MKNA005 ~ TiO ₂ MKNA050 ~ TiO ₂ US1017M	TiO ₂ NIST ~ TiO ₂ US1017M ^(b)
Fe	Fe ₂ O ₃ US3160 ~ Fe ₂ O ₃ US1139M	Fe ₂ O ₃ US3160 > Fe ₂ O ₃ US1139M ^(b)

^(a): Ranking is biased due to low concentration range for MnSO₄.

^(b): Interference seen.

TiO₂ NIST NPs is also referred as “uncoated TiO₂ NPs” in the main text.

Table S5. Endpoint ranking based on cm² particle / cm² well plate concentration normalized NOEC values. Where NOEC values were not present, LOEC values were used. Red: uncoated NPs. Green: coated NPs. Black: uncoated MPs.

Metal	Comet 4 h (NOEC / LOEC Ranking)	Micronucleus 40 h (NOEC / LOEC Ranking)
Zn	ZnO US1003M > ZnO 5812HT > ZnO 5811HT > ZnO US3580 > ZnO 8412DL	ZnO US1003M > ZnO US3580 > ZnO 8412DL ~ > ZnO 5812HT
Cu	CuO US3070Si > CuO US3070 > CuO US1140M > CuO US3070P > CuO 544868	CuO US1140M > CuO 544868 > CuO US3070Si > CuO US3070P
Mn	MnO ₂ 4930DX > MnO ₂ 4910DX	MnO ₂ 4910DX ~ MnO ₂ 4930DX
Ni	NiO US1014M > NiO US3352St > NiO US3352Si > NiO US3352 > NiO US3355 > NiO US3352P	NiO US1014M > NiO US3355 > NiO US3352St > NiO US3352P
Al	Al ₂ O ₃ 1331DL > Al ₂ O ₃ 544833	Al ₂ O ₃ 1331DL > Al ₂ O ₃ 544833
Ce	CeO ₂ 2118CG > CeO ₂ US3036 > CeO ₂ US3136 > CeO ₂ US3037St > CeO ₂ US3037P	CeO ₂ 2118CG > CeO ₂ US3036 > CeO ₂ US3036St > CeO ₂ US3036P
Ti	TiO ₂ US1017M > TiO ₂ MKNR050P > TiO ₂ 5423HT > TiO ₂ 5425HT > TiO ₂ 5422HT > TiO ₂ 5424HT > TiO ₂ NIST > TiO ₂ MKNA050 > TiO ₂ MKNA005	TiO ₂ US1017M > TiO ₂ NIST ^(a)
Fe	Fe ₂ O ₃ US1139M > Fe ₂ O ₃ US3160	Fe ₂ O ₃ US1139M > Fe ₂ O ₃ US3160 ^(a)

^(a): Interference seen.

TiO₂ NIST NPs is also referred as “uncoated TiO₂ NPs” in the main text.

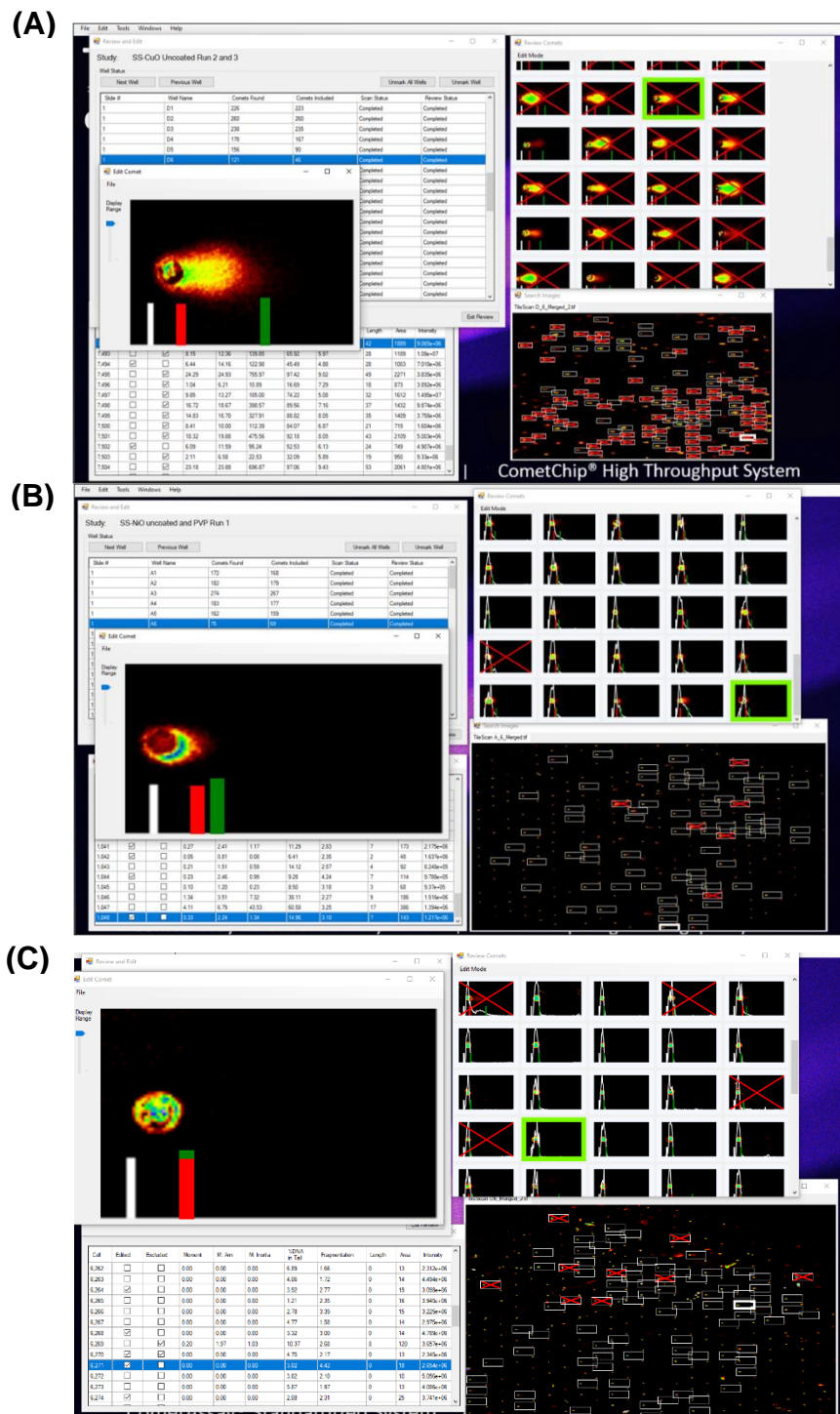


Figure S1. Representative images of the interference of some MONPs with the SYBR® Gold staining and the analysis of the comet assay at high concentrations. (A) Uncoated CuO NPs (US3070). (B) Uncoated NiO NPs (US3352). (C) Uncoated Fe₂O₃ NPs (US3160). Analysis was conducted using the Trevigen Comet Software 1.3d.

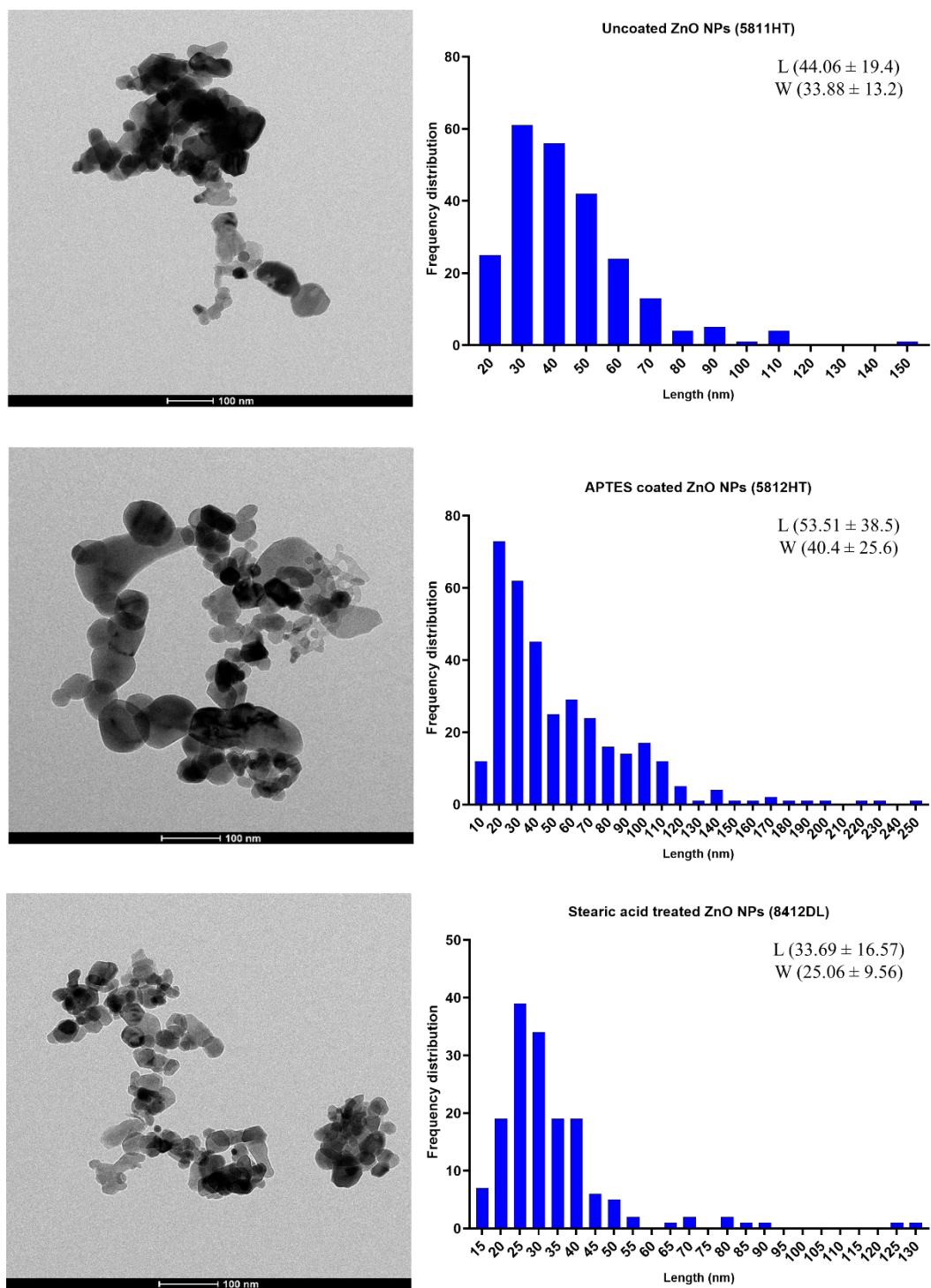


Figure S2. Representative TEM images and frequency size distribution of ZnO NPs variants. L: Length, W: Width. Scale bar: 100 nm.

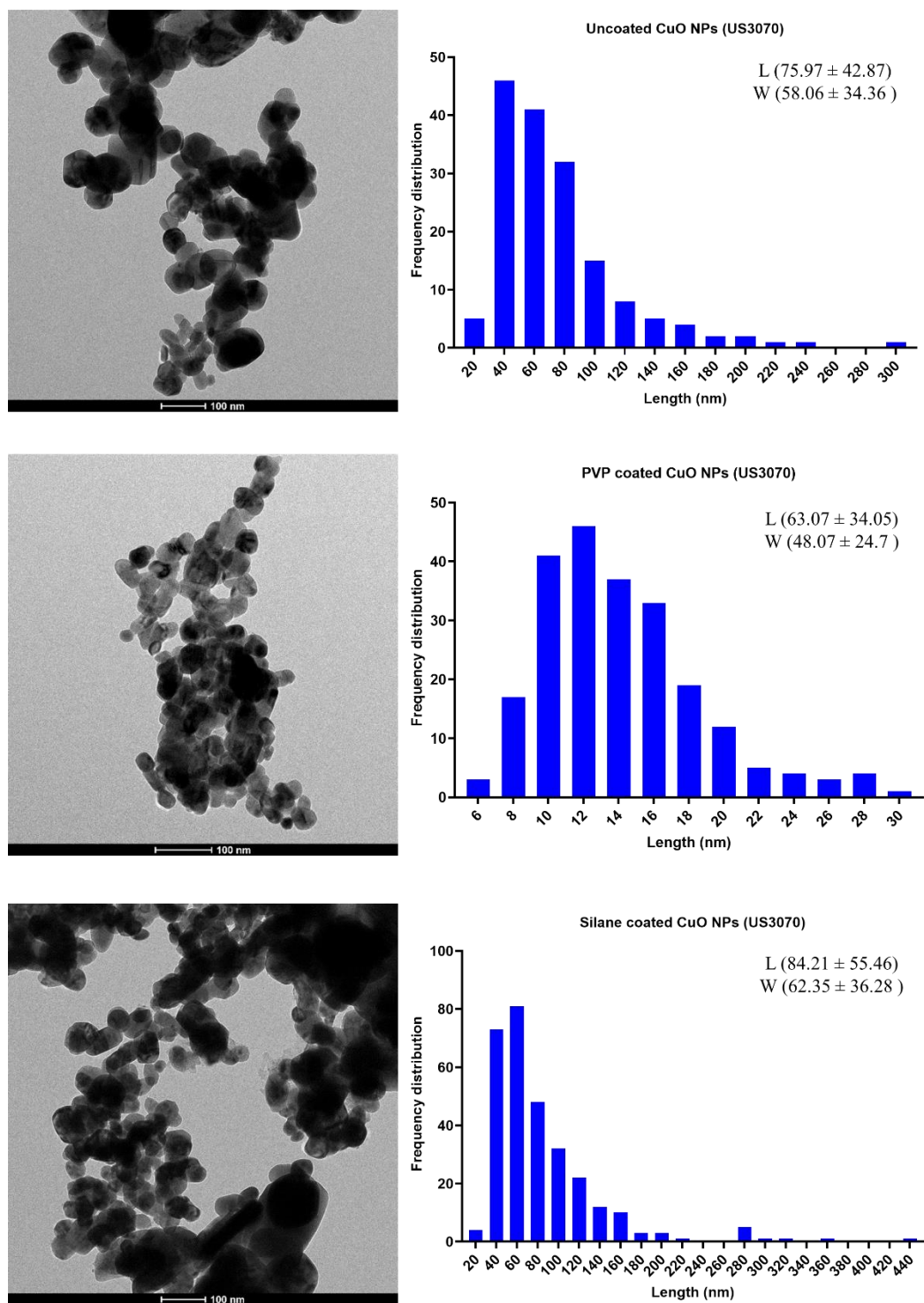


Figure S3. Representative TEM images and frequency size distribution of CuO NPs variants. L: Length, W: Width. Scale bar: 100 nm.

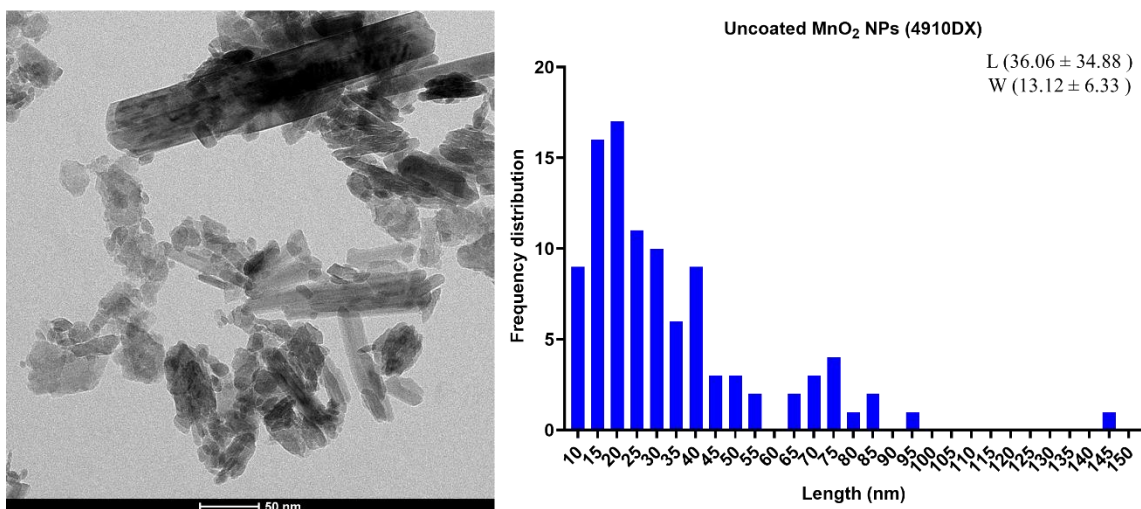


Figure S4. Representative TEM image and frequency size distribution of MnO₂ NPs. L: Length, W: Width. Scale bar: 50 nm.

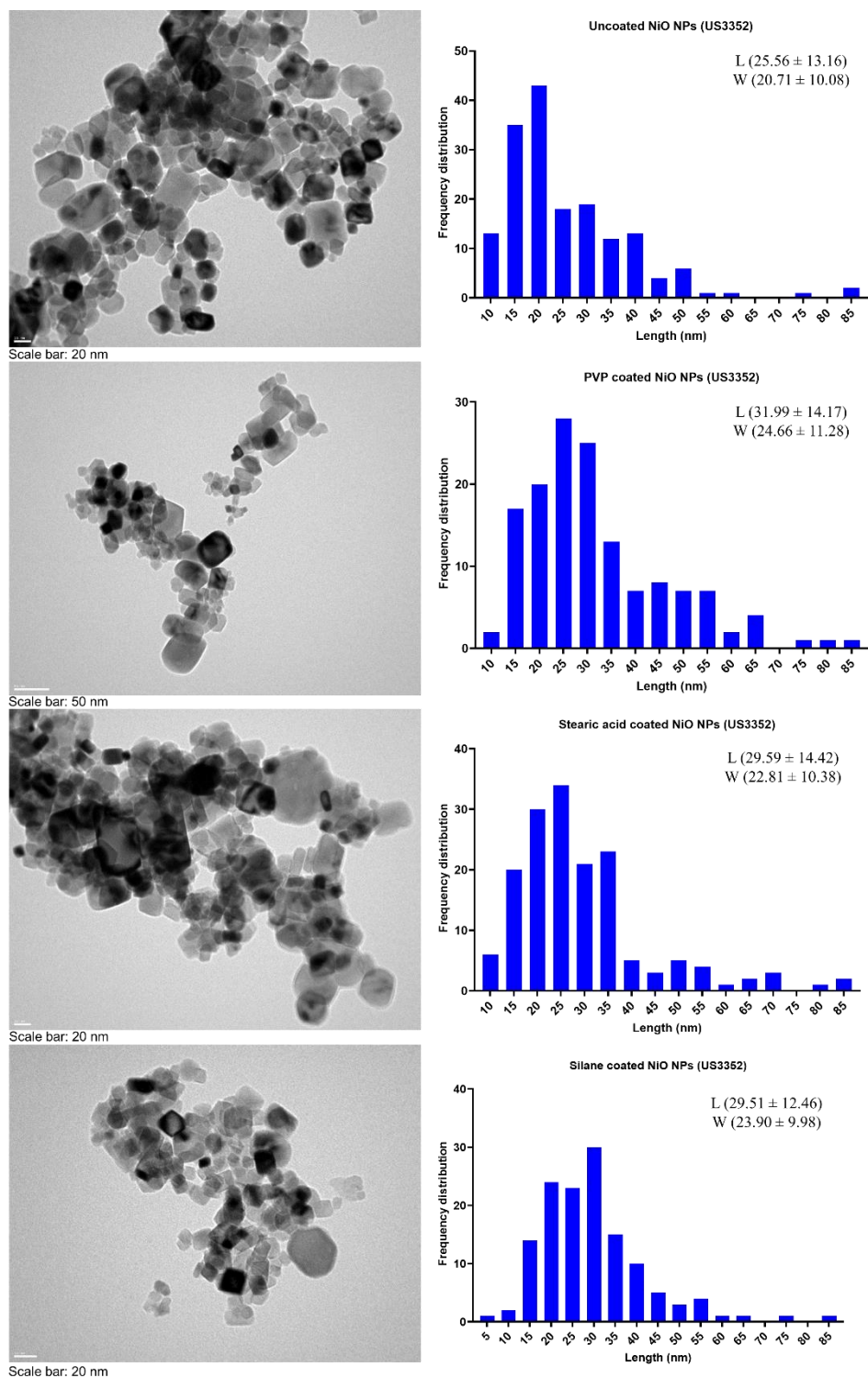


Figure S5. Representative TEM images and frequency size distribution of NiO NPs variants. L: Length, W: Width.

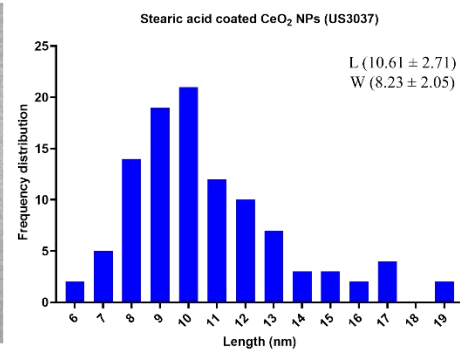
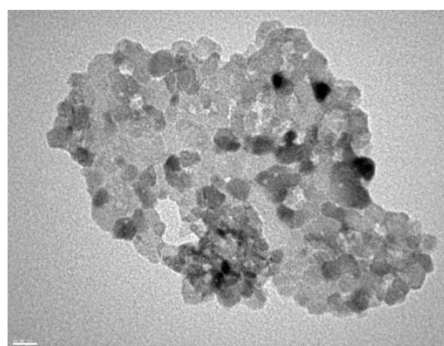
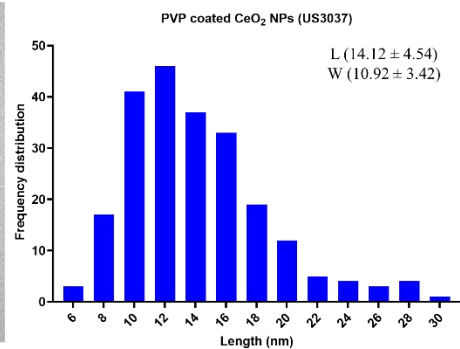
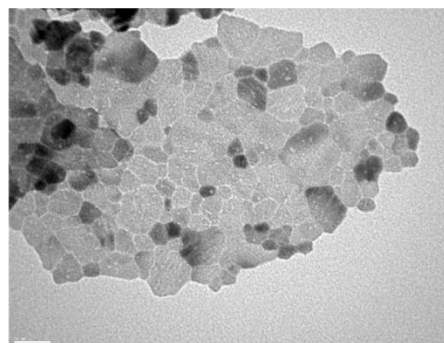
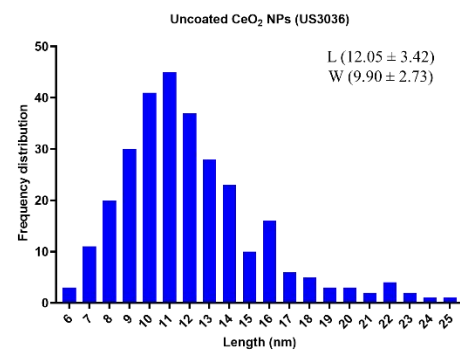
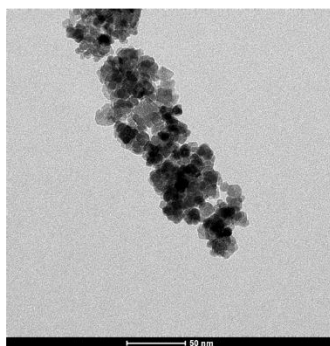
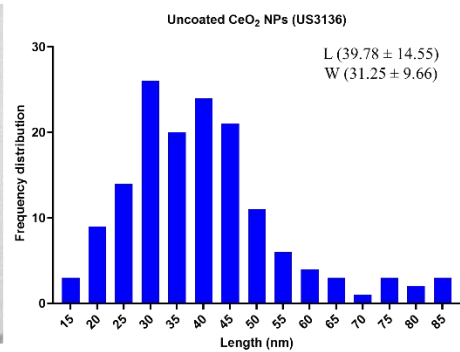
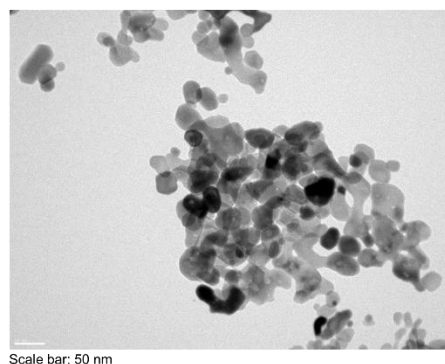


Figure S6. Representative TEM images and frequency size distribution of CeO₂ NPs variants. L: Length, W: Width.

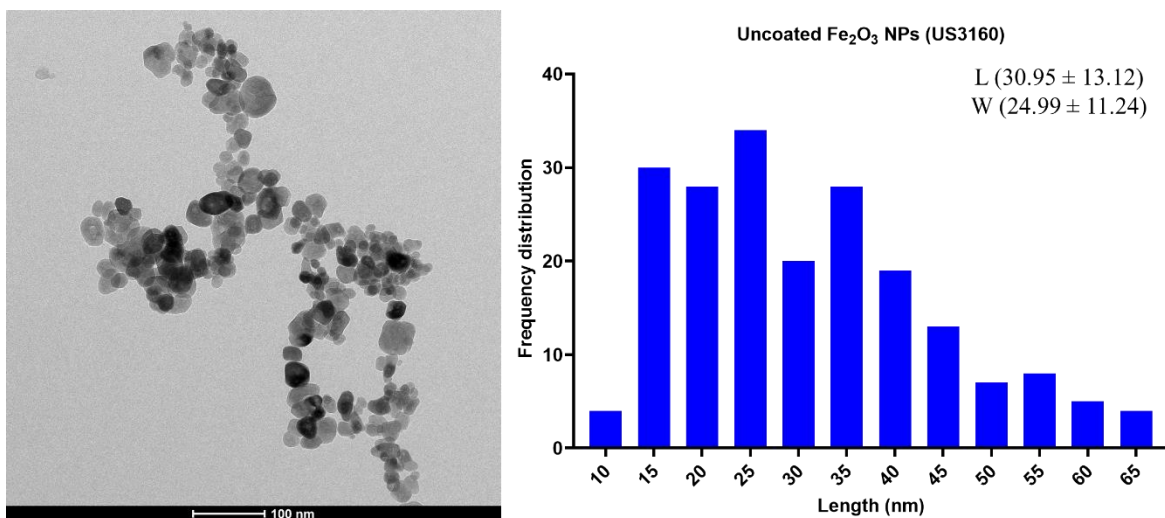
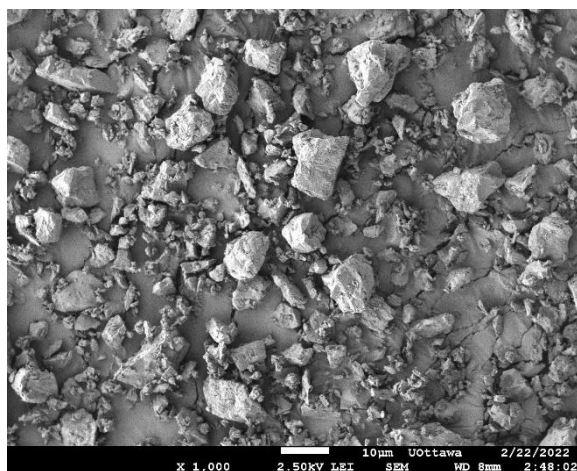
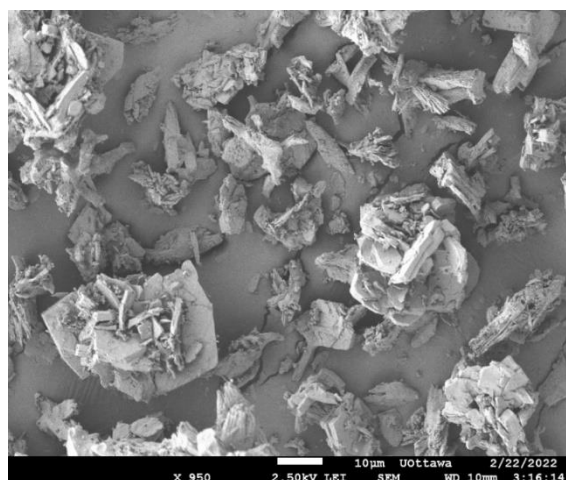


Figure S7. Representative TEM image and frequency size distribution of Fe₂O₃ NPs. L: Length, W: Width. Scale bar: 100 nm.

MnO₂ 4930DX MOMP



CeO₂ 2118CG MOMP



Fe₂O₃ US1139M MOMP

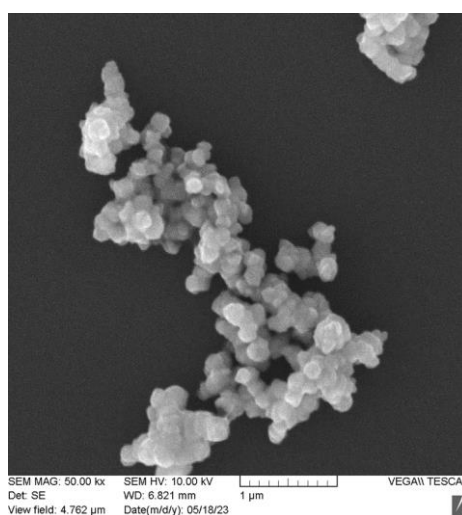


Figure S8. Representative SEM images of MnO₂ MPs, CeO₂ MPs and Fe₂O₃ MPs.

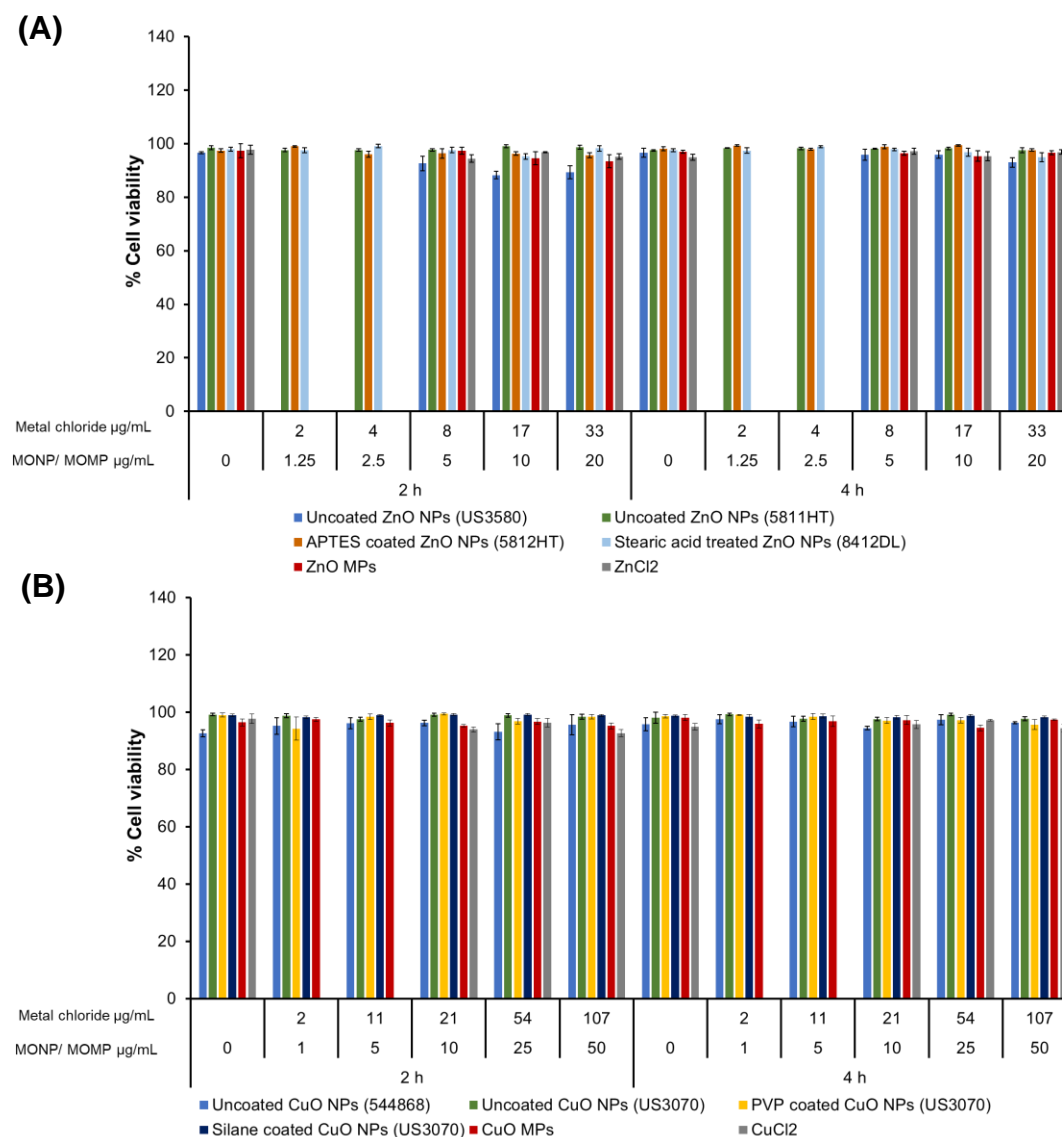


Figure S9. Percentage of cell viability after exposure to **(A)** ZnO variants and ZnCl₂, **(B)** CuO variants and CuCl₂. Trypan Blue exclusion method was conducted after 2 and 4 h of exposure. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test. Uncoated ZnO NPs (US3580), ZnO MPs, ZnCl₂, uncoated CuO NPs (544868), CuO MPs, and CuCl₂ were previously published [34].

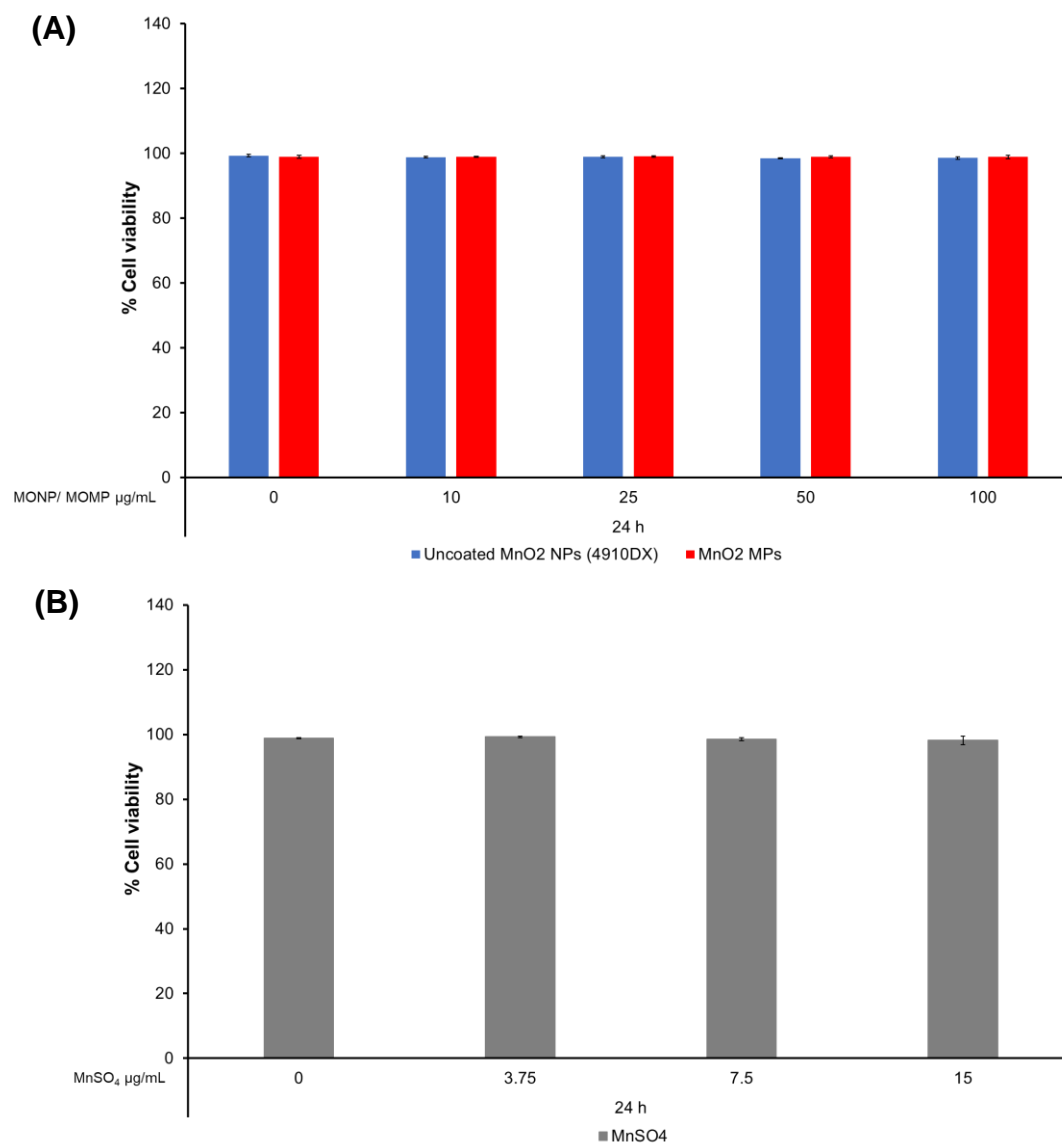


Figure S10. Percentage of cell viability after exposure to **(A)** MnO₂ variants and **(B)** MnSO₄ for 24 h. Trypan Blue exclusion method. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test.

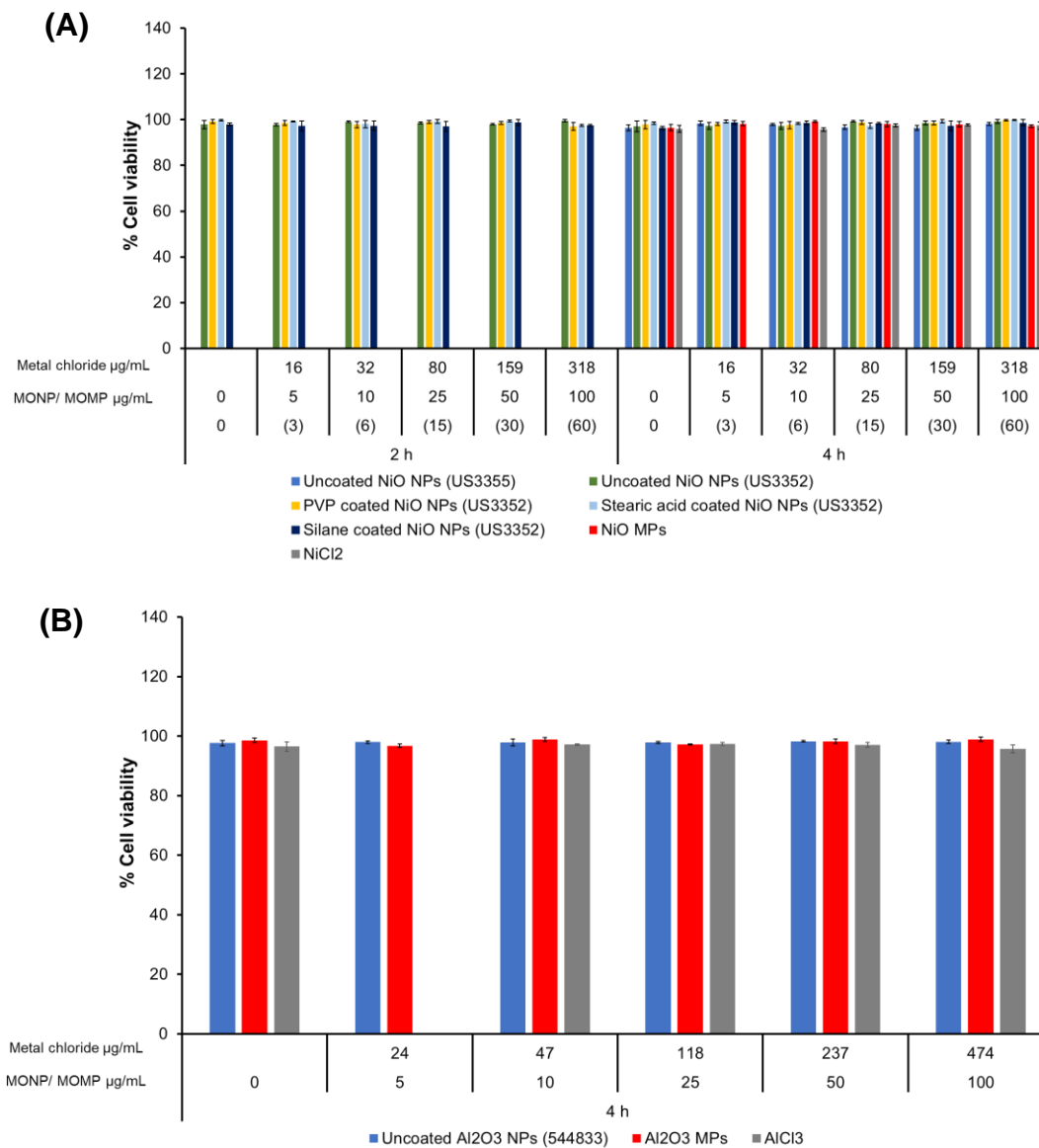


Figure S11. Percentage of cell viability after exposure to **(A)** NiO variants and NiCl₂ for 2 and 4 h, **(B)** Al₂O₃ variants and AlCl₃ for 4 h. Trypan Blue exclusion method. **(A)** Data in parenthesis indicates the concentration of stearic acid-coated NiO NPs. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test.

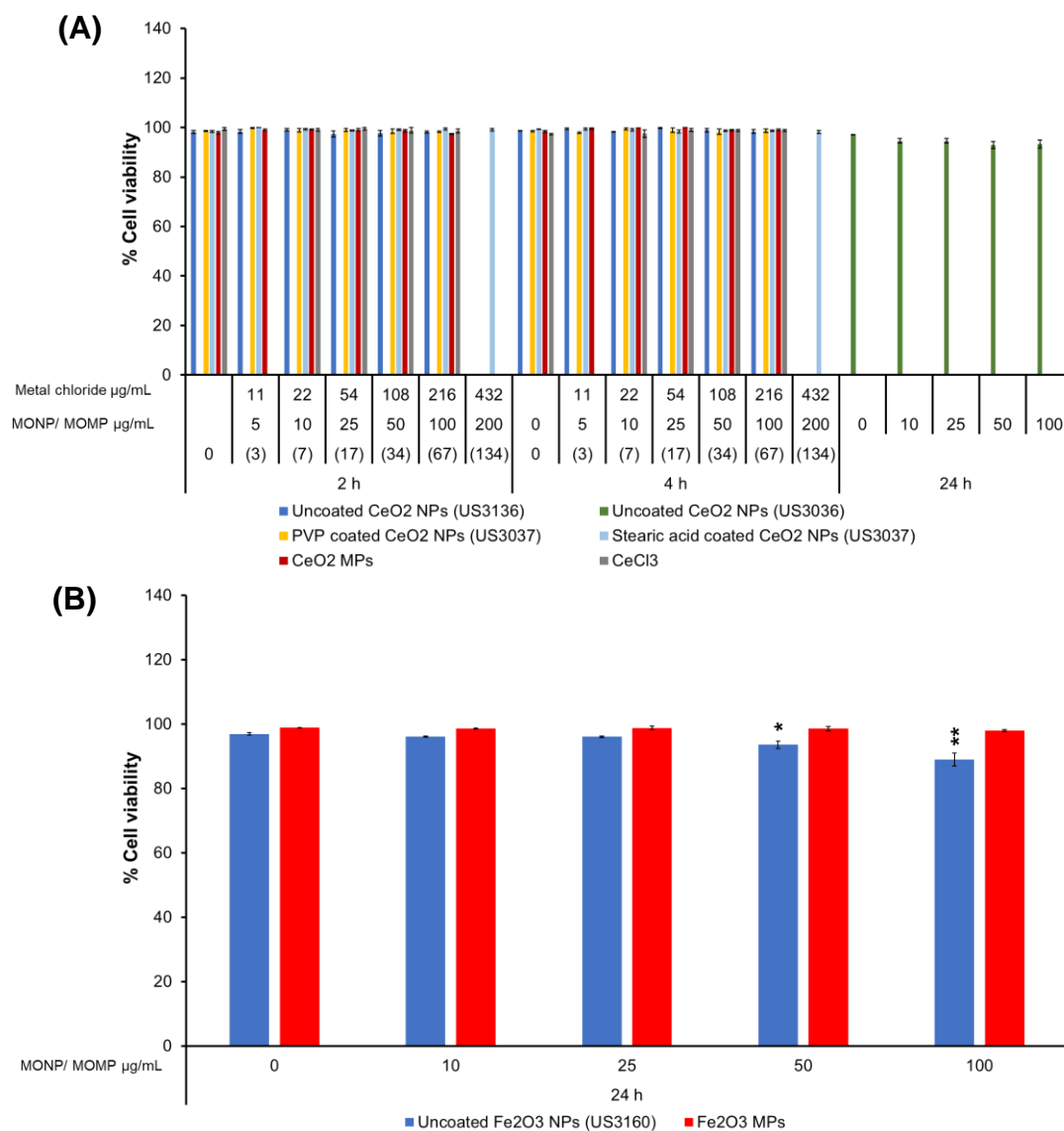


Figure S12. Percentage of cell viability after exposure to **(A)** CeO₂ variants and CeCl₃, **(B)** Fe₂O₃ variants. Uncoated CeO₂ NPs (US3036) and Fe₂O₃ variants were only evaluated at 24 h. Uncoated CeO₂ (US3136), coated CeO₂ NPs and CeCl₃ were evaluated after 2 and 4 h of exposure. Trypan Blue exclusion method. **(A)** Data in parenthesis indicates the concentration of stearic acid-coated CeO₂ NPs. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test with a Dunnett’s post hoc. * $p < 0.05$, ** $p < 0.01$.

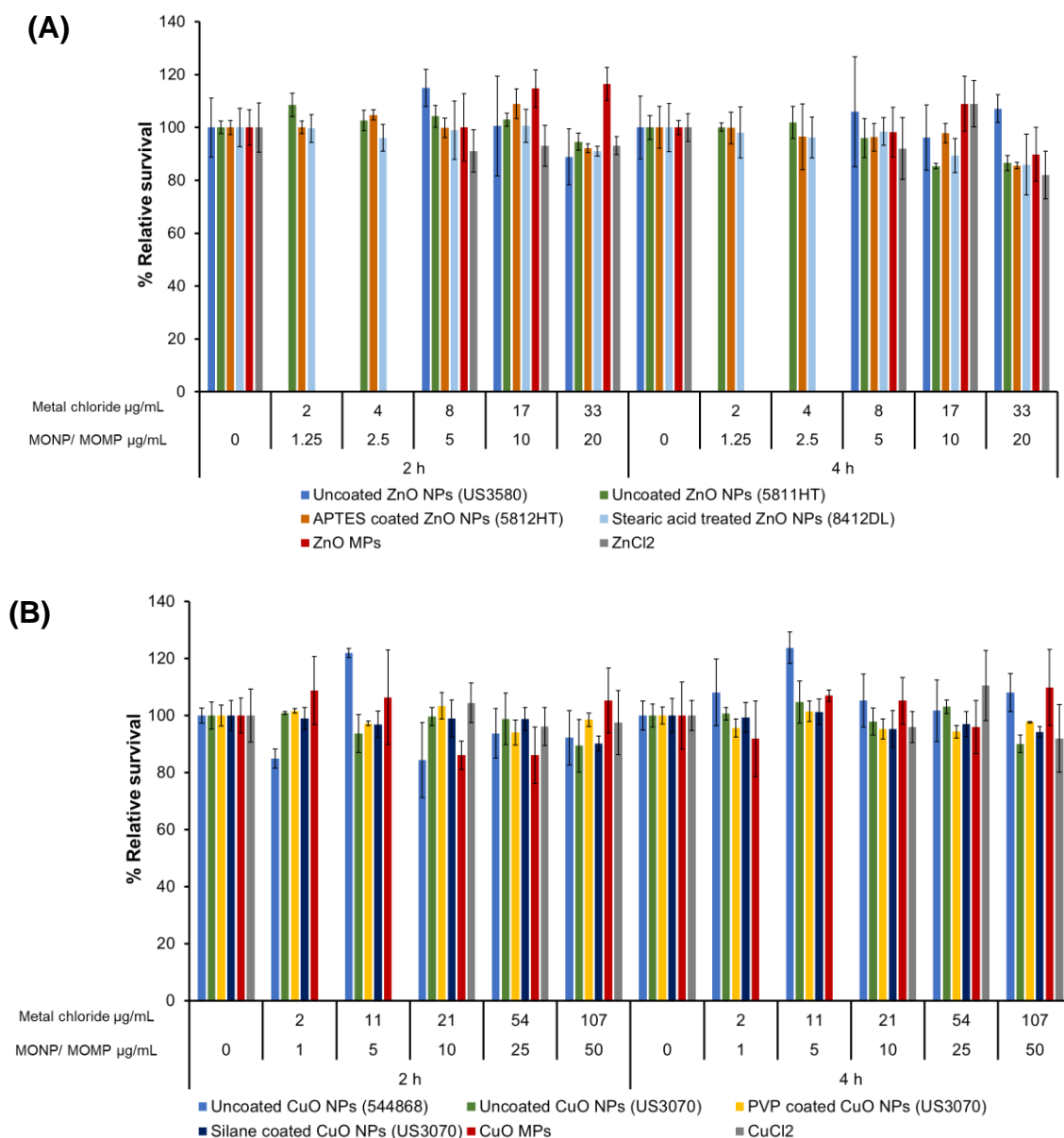


Figure S13. Percentage of relative survival after exposure to (A) ZnO variants and ZnCl₂, (B) CuO variants and CuCl₂. Trypan Blue exclusion method was conducted after 2 and 4 h of exposure. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test.

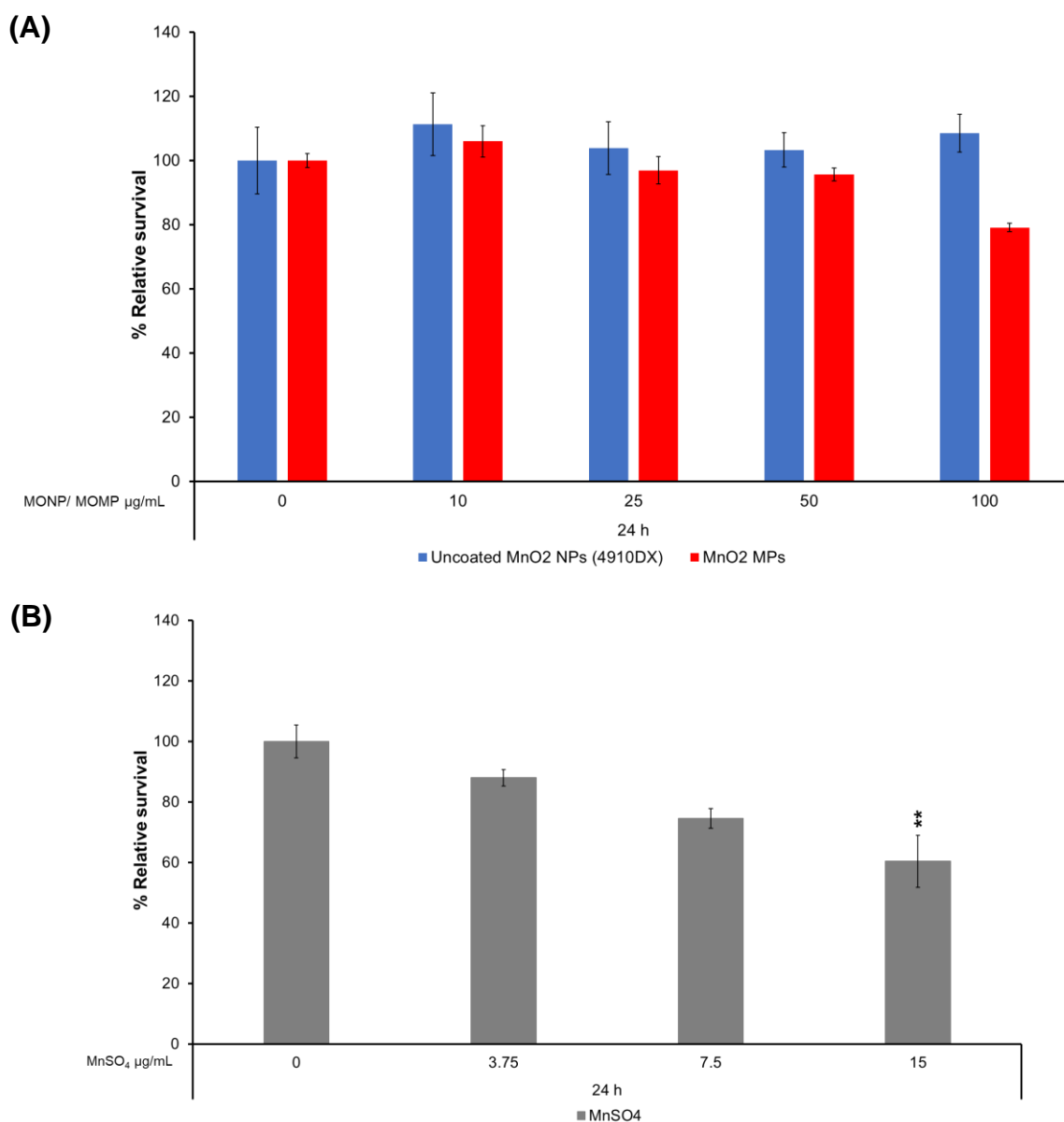


Figure S14. Percentage of relative survival after exposure to **(A)** MnO₂ variants and **(B)** MnSO₄ for 24 h. Trypan Blue exclusion method. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test with a Dunnett’s post hoc. ** $p < 0.01$.

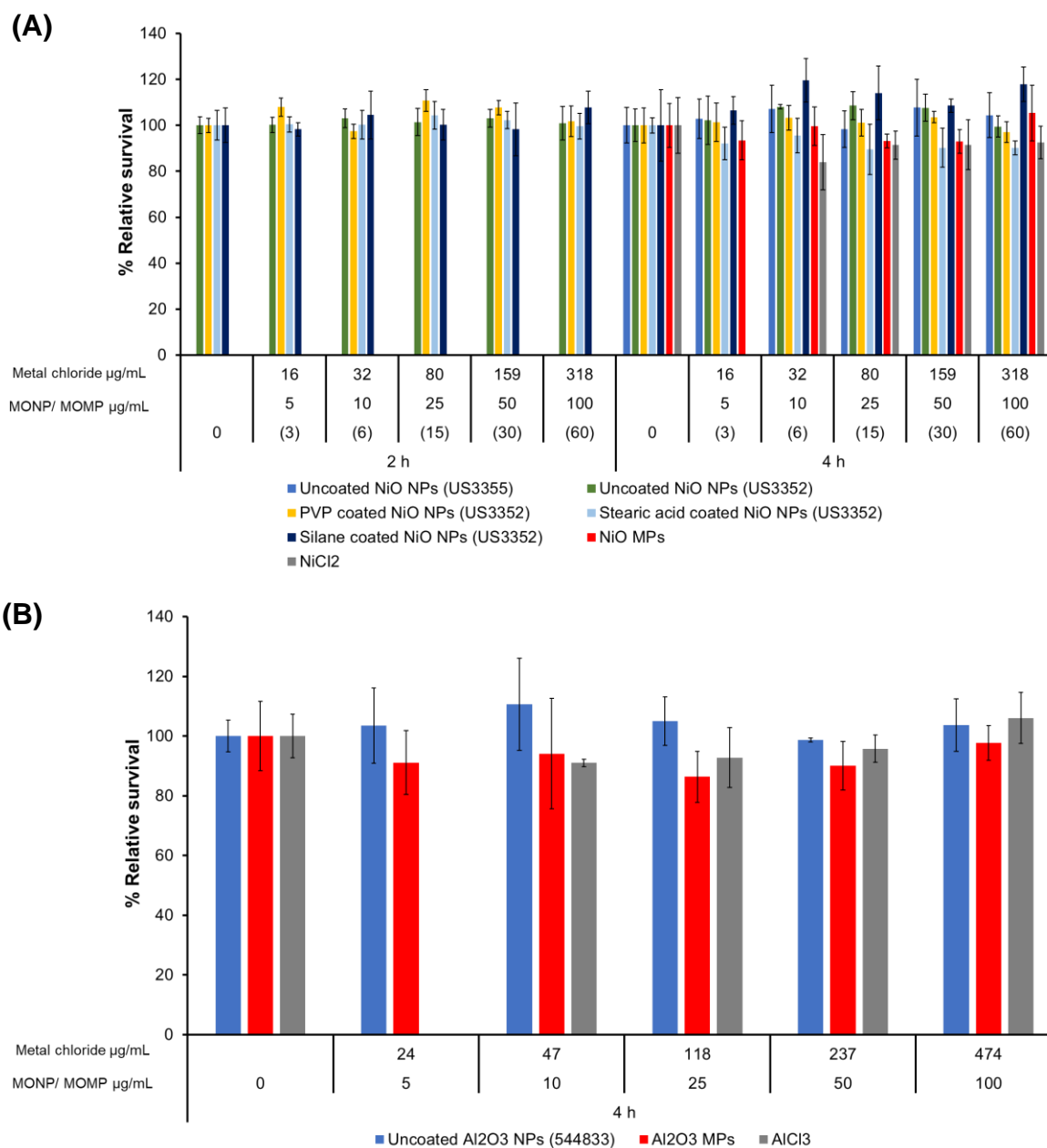


Figure S15. Percentage of relative survival after exposure to **(A)** NiO variants and NiCl₂ for 2 and 4 h, **(B)** Al₂O₃ variants and AlCl₃ for 4 h. Trypan Blue exclusion method. **(A)** Data in parenthesis indicates the concentration of stearic acid-coated NiO NPs. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test.

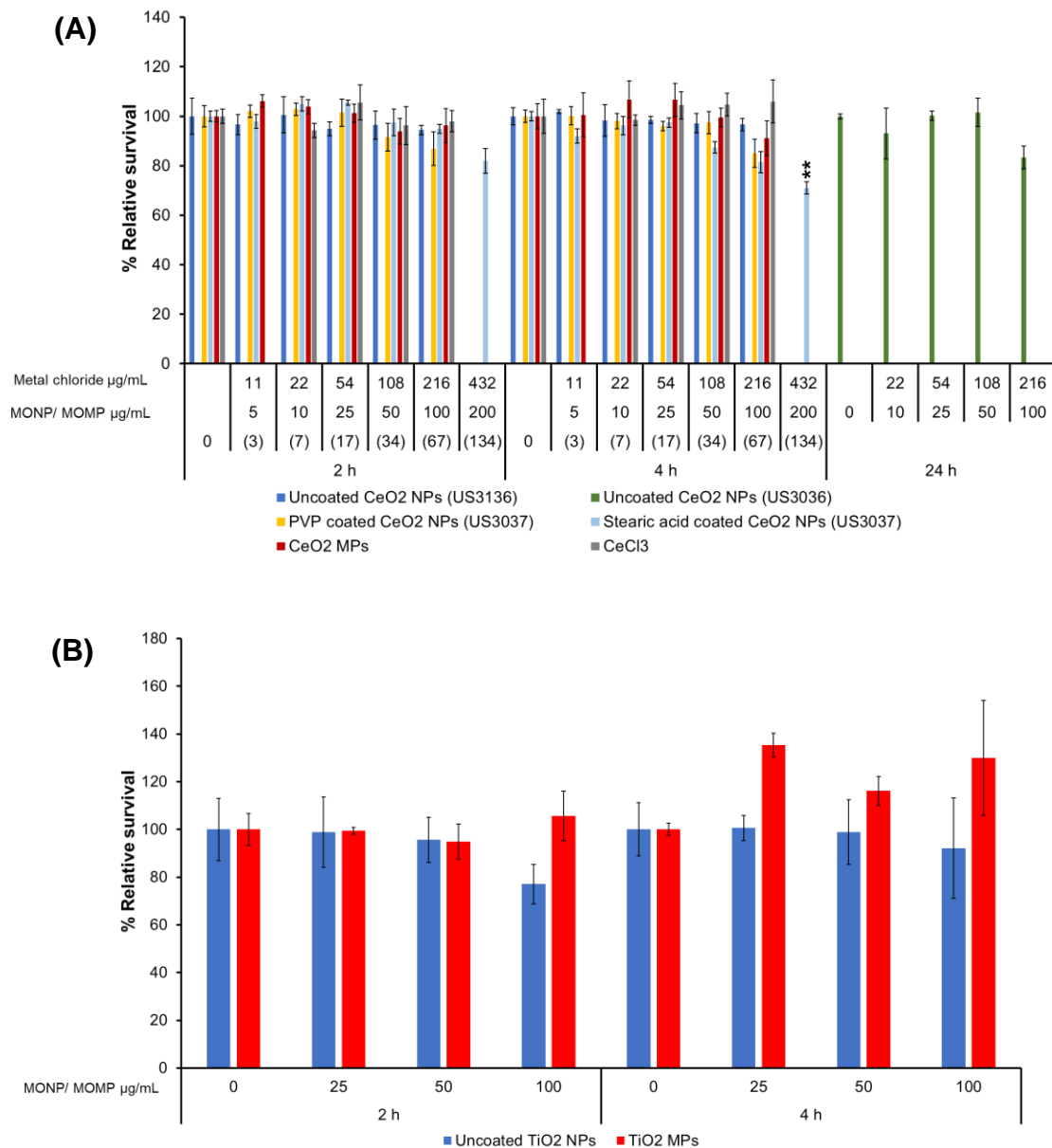


Figure S16. Percentage of relative survival after exposure to (A) CeO₂ variants and CeCl₃ and (B) TiO₂ variants for 2 and 4 h. Uncoated CeO₂ NPs (US3036) were only evaluated after 24 h of exposure. Trypan Blue exclusion method. (A) Data in parenthesis indicates the concentration of stearic acid-coated CeO₂ NPs. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test with a Dunnett’s post hoc. ** $p < 0.01$.

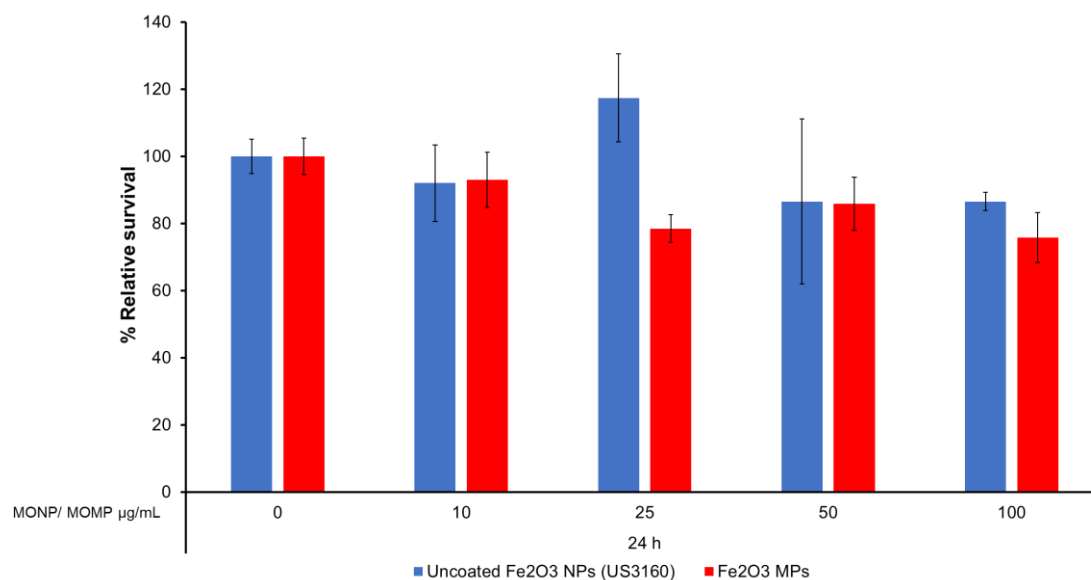


Figure S17. Percentage of relative survival after exposure to Fe₂O₃ variants for 24 h. Trypan Blue exclusion method. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through Kruskal–Wallis test.

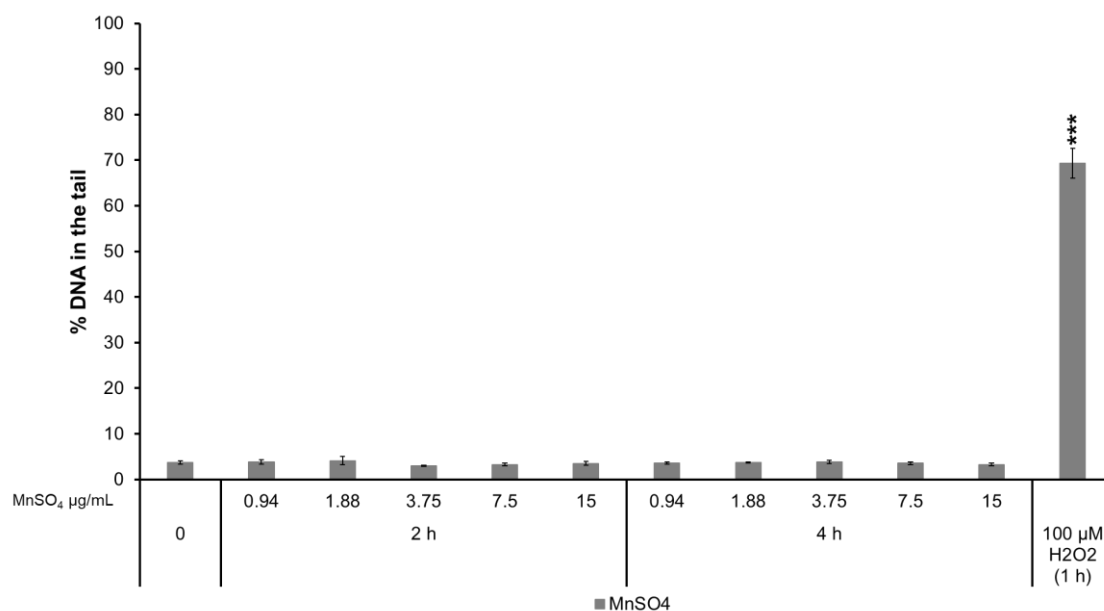


Figure S18. Percentage of DNA in the tail in FE1 cells after exposure to MnSO₄ at 2 and 4 h. Data are presented as mean and standard error ($n = 3-4$). Statistically significant differences between the exposed samples and the matched negative control were determined through one-way ANOVA with a Dunnett's post hoc. *** $p < 0.001$.

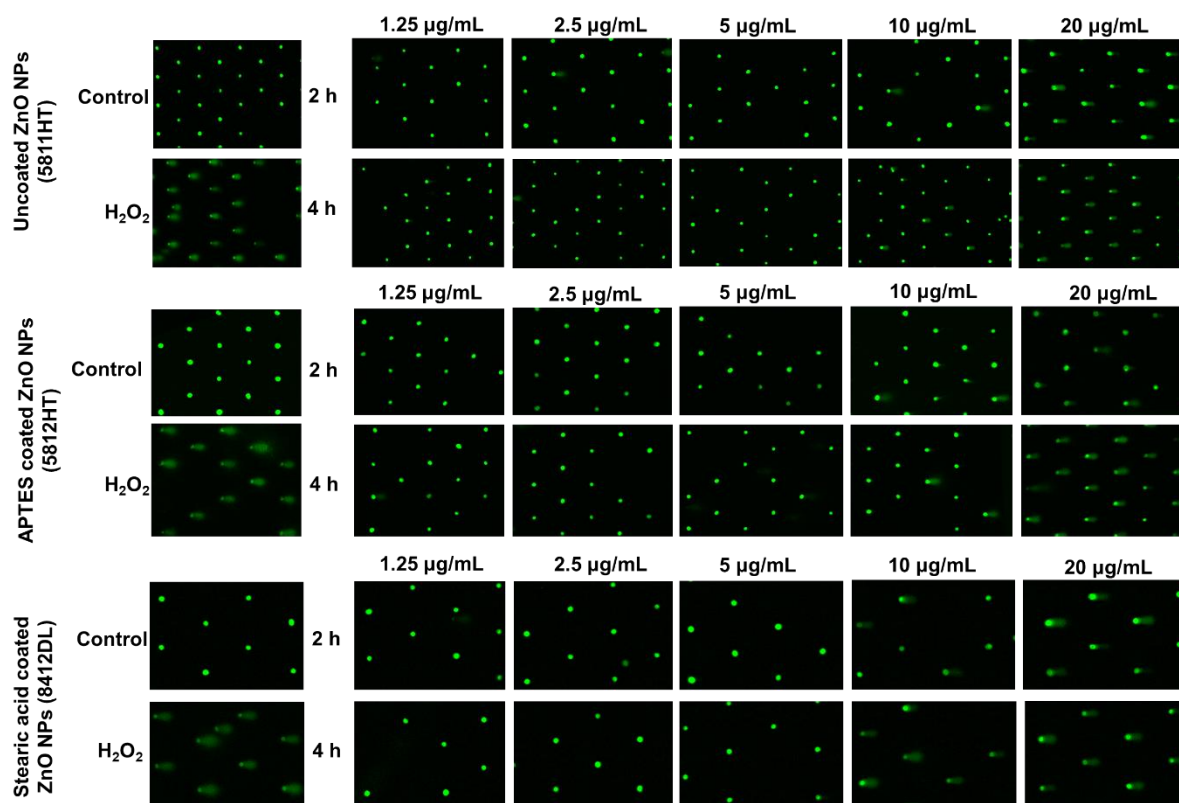


Figure S19. Representative images of comets after exposure to uncoated ZnO NPs (5811HT), APTES-coated ZnO NPs (5812HT), and stearic acid-coated ZnO NPs (8412DL). SYBR® Gold staining. Leica DMI8 automated confocal fluorescence microscope 5×.

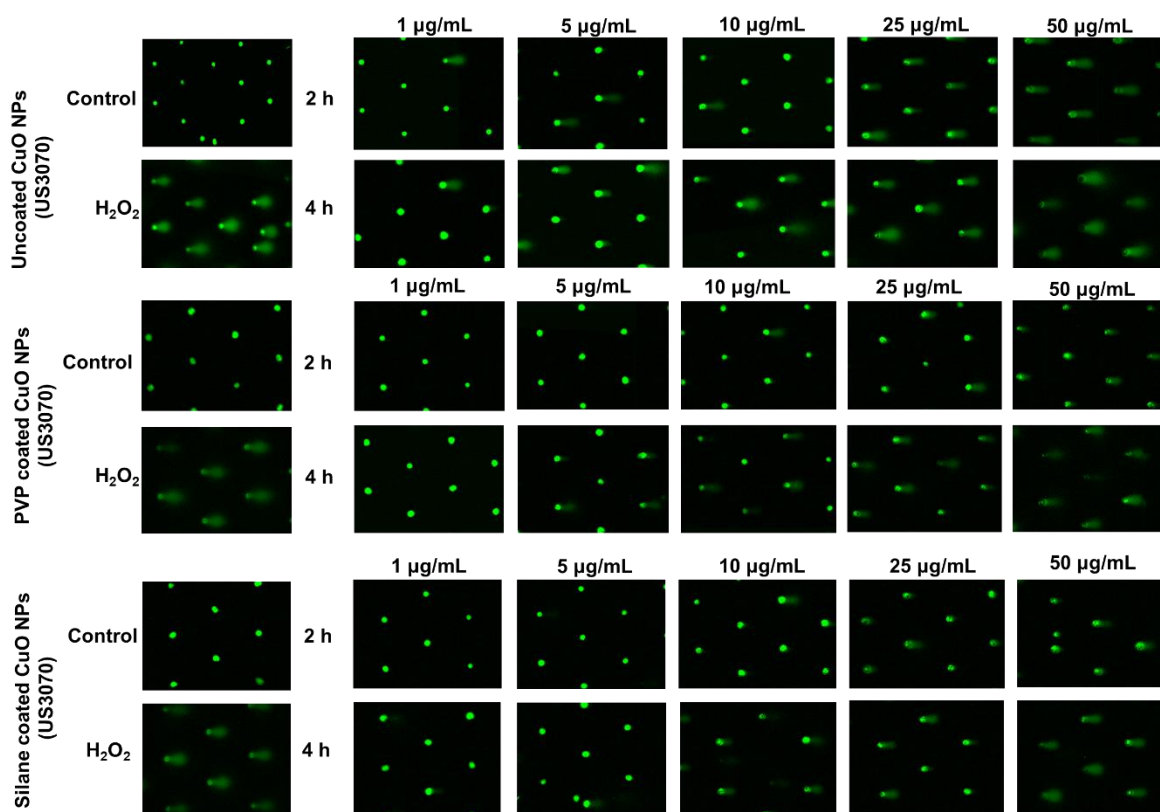


Figure S20. Representative images of comets after exposure to uncoated CuO NPs (US3070), PVP-coated CuO NPs (US3070), and silane-coated CuO NPs (US3070). SYBR® Gold staining. Leica DMI8 automated confocal fluorescence microscope 5×.

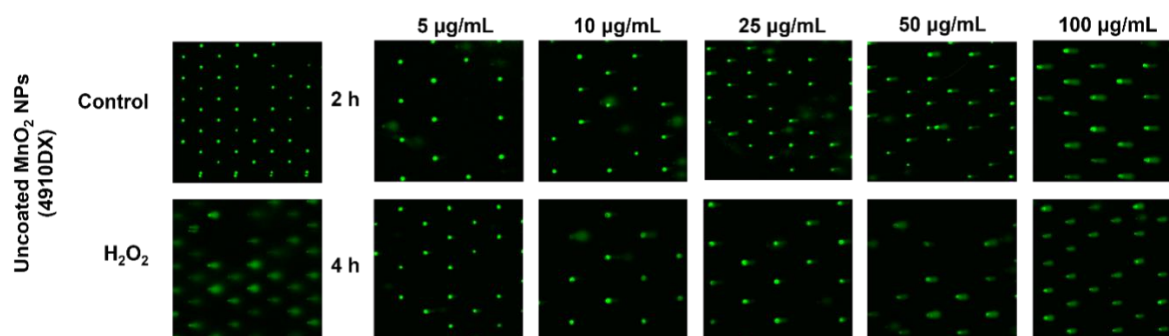


Figure S21. Representative images of comets after exposure to uncoated MnO₂ NPs (4910DX). SYBR® Gold staining. Leica DMI8 automated confocal fluorescence microscope 5×.

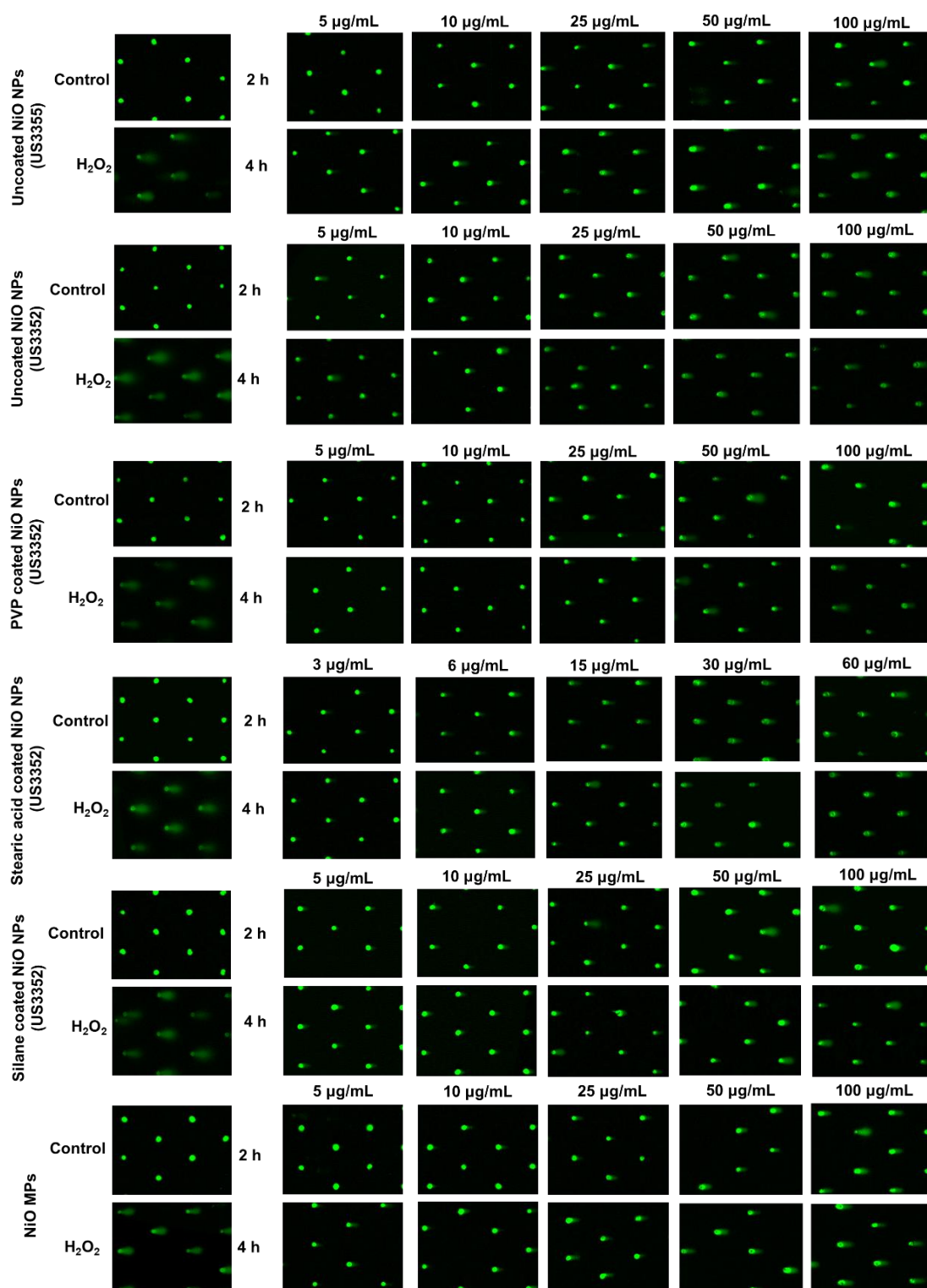


Figure S22. Representative images of comets after exposure to NiO variants. SYBR® Gold staining. Leica DMI8 automated confocal fluorescence microscope 5×.