Electronic Supplementary Material (ESI) for RSC Advances.


# Gamma radiation effects on AG MP-50 cation exchange resin and sulfonated activated carbon for the separation of actinium-225 and bismuth-213

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# Supporting Information (SI)

**SEM**

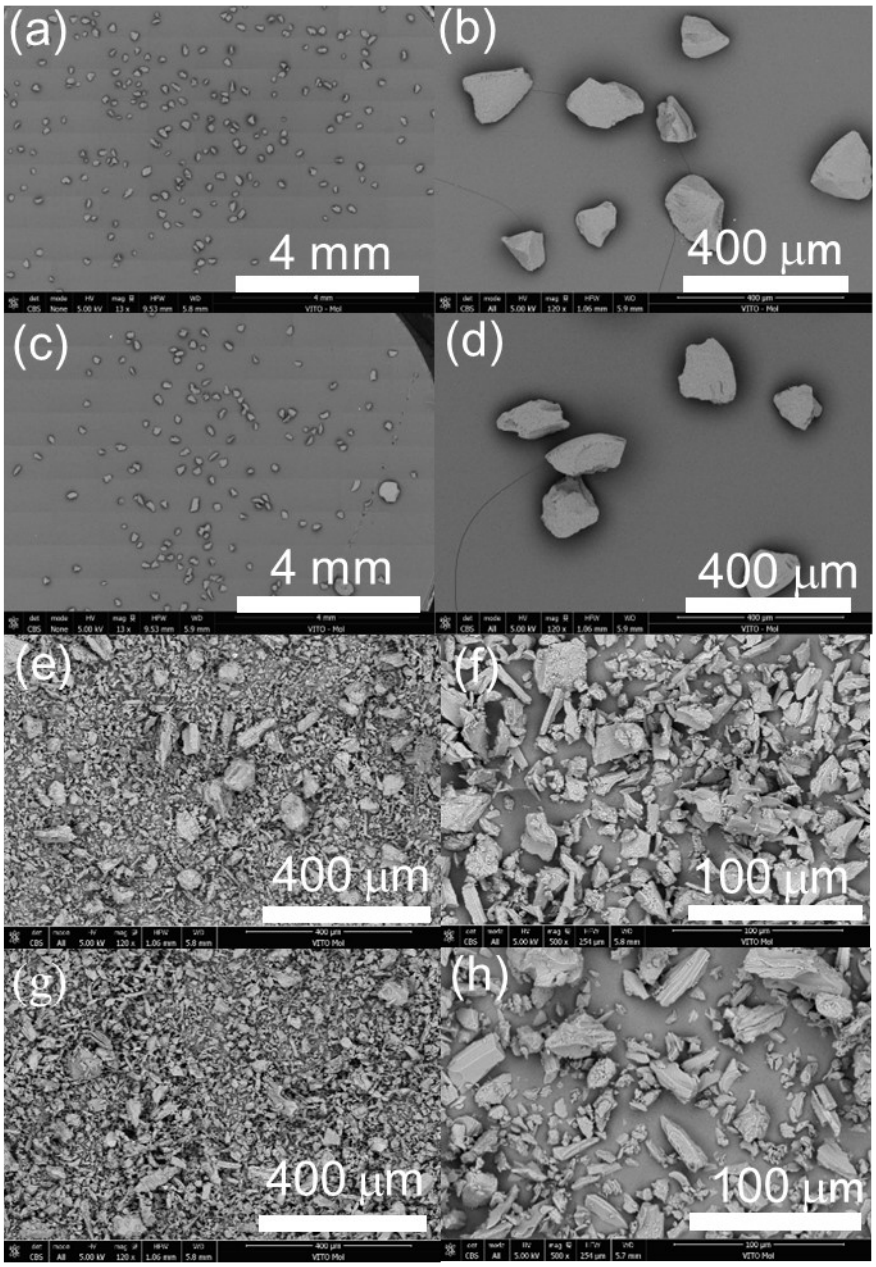


**Fig. S1.** SEM images of AG MP-50 (1 MGy (a and b), and 2 MGy (c and d)) and SAC (1 MGy (e and f), and 2 MGy (g and h)) before and after exposure to gamma radiation.

## XPS experimental details

X-ray photoelectron spectra were collected on a Kratos Axis Supra photoelectron spectrometer with a monochromated Al Kα X-ray source (1486.7 eV), hybrid (magnetic/electrostatic) optics, hemisphere analyzer and delay-line detector. The spectrometer was operated in fixed analyzer transmission mode, with survey scans taken at a pass energy of 160 eV and high-resolution spectra at a pass energy of 20 eV. Samples were analyzed under charge neutralization conditions, using a low energy electron gun within the field of the magnetic lens. All spectra were acquired at normal emission. The resulting spectra were charge referenced to C-C at 284.5 eV for SAC samples due to the graphitic nature of the carbon 1s peak and 284.8 eV for AG MP-50 samples. Spectra were analyzed using CasaXPS version 2.3.25.

Elemental quantification was performed using empirical relative sensitivity factors supplied by Kratos Analytical. The resulting elemental composition is the equivalent homogeneous composition, with no correction for sample topography or matrix effects.

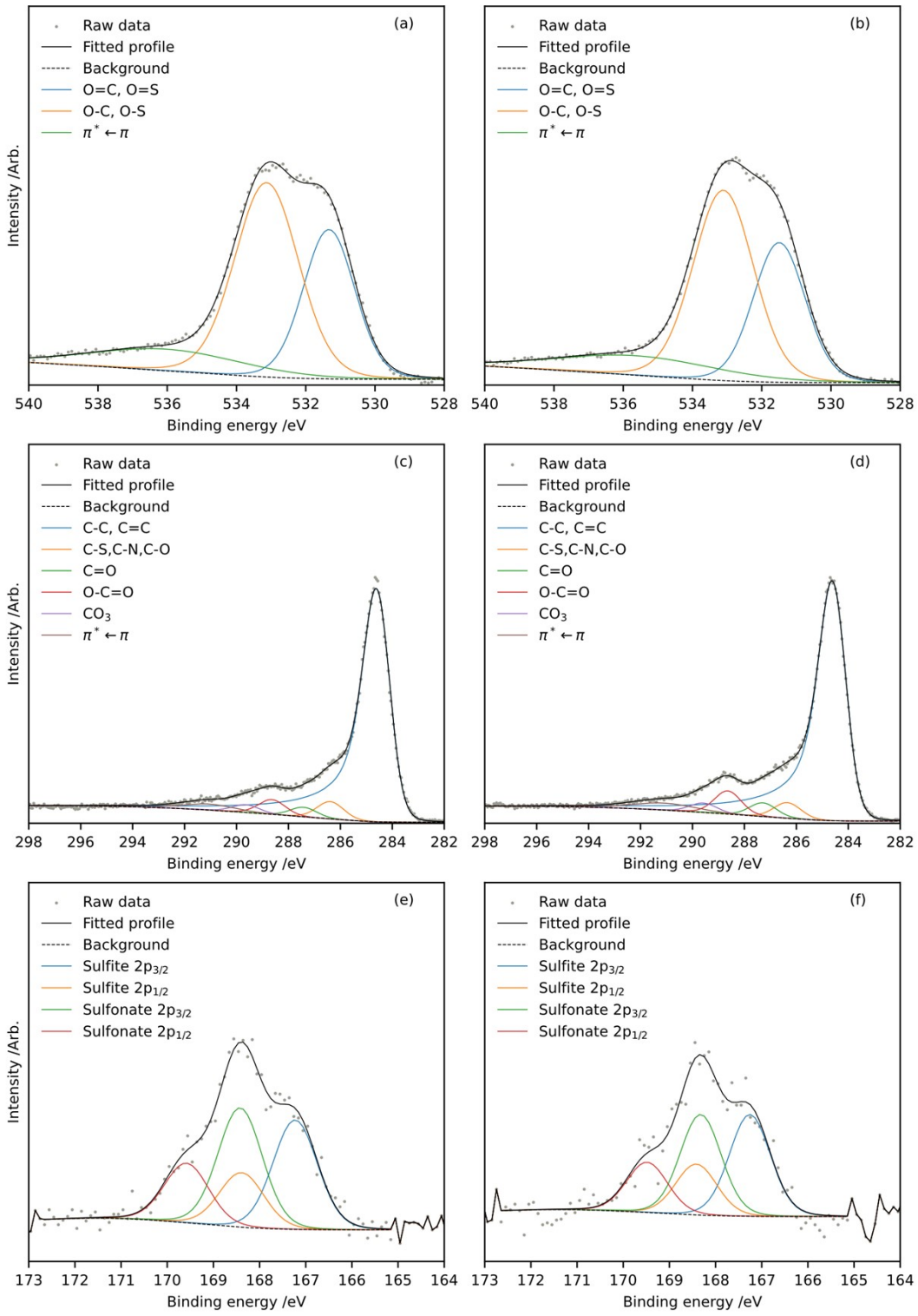


**Fig. S2.** High-resolution XPS O 1s spectra of SAC after receiving a dose of 1 MGy (a) and 11 MGy (b); C 1s spectra of SAC after receiving a dose of 1 MGy (c) and 11 MGy (d); and S 2p spectra of SAC after receiving a dose of 1 MGy (e) and 11 MGy (f). Spectra were taken from one sample area and are representative for each sample.

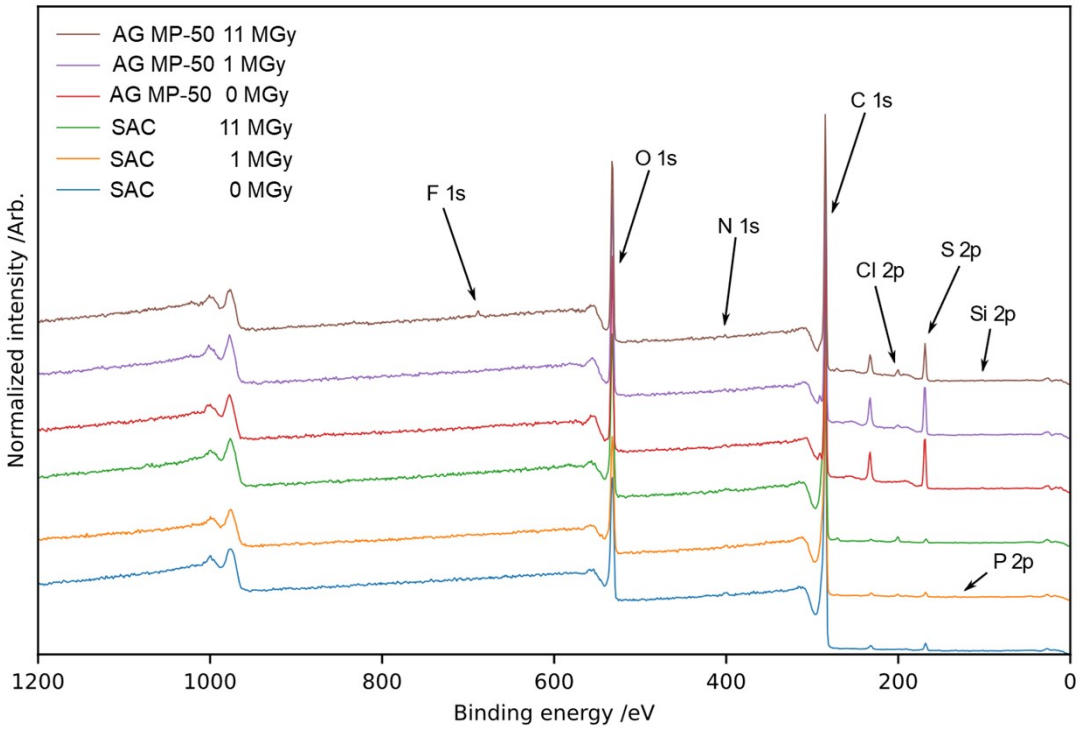


**Fig. S3.** XPS survey spectra of all samples.

Table S1. Elemental composition of the samples after gamma irradiation as determined by XPS.

| Sample | Reveived dose (MGy) | Atomic concentration /% | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Na 1s | O 1s | N 1s | C 1s | Cl 2p | S 2p | P 2p | Si 2p |
| SAC | 1 | - | 14.3 ± 0.3 | 0.3 ± 0.0 | 84.7 ± 0.2 | 0.1 ± 0.1 | 0.5 ± 0.0 | 0.1 ± 0.0 | - |
| | 11 | - | 17.4 ± 0.1 | 0.3 ± 0.1 | 81.4 ± 0.1 | 0.4 ± 0.1 | 0.5 ± 0.1 | 0.1 ± 0.1 | - |

Table S2. Carbon environments present in the sulfonated activated carbon samples after gamma irradiation as determined from high resolution carbon 1s XPS.

| Sample | Received dose (MGy) | Component | Binding energy /eV | FWHM /eV | Concentration /at.% |
|---|---|---|---|---|---|
| SAC | 1 | C–C, C=C | 284.5 ± 0.0 | 1.2 ± 0.0 | 70.2 ± 1.3 |
| | | C–N, C–O, C–S | 286.2 ± 0.2 | 1.2 ± 0.0 | 4.3 ± 0.6 |
| | | C=O | 287.4 ± 0.1 | 1.2 ± 0.0 | 2.6 ± 0.6 |
| | | O–C=O | 288.6 ± 0.0 | 1.2 ± 0.0 | 3.2 ± 0.1 |
| | | $CO_3$ | 289.6 ± 0.0 | 1.2 ± 0.0 | 2.1 ± 0.5 |
| | | π*←π | 291.1 ± 0.0 | 2.2 ± 0.2 | 2.3 ± 0.4 |
| | 11 | C–C, C=C | 284.5 ± 0.0 | 1.2 ± 0.0 | 66.1 ± 0.6 |
| | | C–N, C–O, C–S | 286.5 ± 0.2 | 1.2 ± 0.0 | 3.4 ± 0.3 |
| | | C=O | 287.4 ± 0.1 | 1.2 ± 0.0 | 2.3 ± 0.7 |
| | | O–C=O | 288.6 ± 0.0 | 1.2 ± 0.0 | 4.5 ± 0.2 |
| | | $CO_3$ | 289.5 ± 0.1 | 1.2 ± 0.0 | 2.0 ± 0.2 |
| | | π*←π | 291.1 ± 0.0 | 2.7 ± 0.2 | 3.1 ± 0.3 |

Table S3. Oxygen environments present in the sulfonated activated carbon samples after gamma irradiation as determined by high resolution oxygen 1s XPS.

| Sample | Received dose (MGy) | Component | Binding energy /eV | FWHM /eV | Concentration /at.% |
|---|---|---|---|---|---|
| SAC | 1 | O=C, $SO_x$ | 531.3 ± 0.0 | 1.8 ± 0.0 | 4.5 ± 0.2 |
| | | O–C, O–S | 533.1 ± 0.0 | 2.3 ± 0.1 | 8.3 ± 1.1 |
| | | Shake-up | 536.3 ± 0.4 | 4.2 ± 1.4 | 1.5 ± 0.7 |
| | 11 | O=C, SOx | 531.5 ± 0.0 | 1.8 ± 0.0 | 6.2 ± 0.6 |
| | | O–C, O–S | 533.1 ± 0.0 | 2.0 ± 0.1 | 8.9 ± 0.3 |
| | | Shake-up | 535.7 ± 0.1 | 5.1 ± 0.6 | 2.3 ± 0.2 |

Table S4 Sulfur environments in the sulfonated activated carbon samples after gamma irradiation as determined by high resolution sulfur 2p XPS.

| Sample | Received dose (MGy) | Component | Binding energy /eV | FWHM /eV | Concentration /at.% |
|---|---|---|---|---|---|
| SAC | 1 | $2p_{3/2}$ Sulfite, sulfinic acid | 167.3 ± 0.0 | 1.1 ± 0.0 | 0.2 ± 0.0 |
| | | $2p_{1/2}$ Sulfite, sulfinic acid | 168.4 ± 0.0 | 1.1 ± 0.0 | 0.1 ± 0.0 |
| | | $2p_{3/2}$ Sulfonate, sulfate | 168.4 ± 0.1 | 1.1 ± 0.0 | 0.2 ± 0.0 |
| | | $2p_{1/2}$ Sulfonate, sulfate | 169.5 ± 0.1 | 1.1 ± 0.0 | 0.1 ± 0.0 |
| | 11 | $2p_{3/2}$ Sulfite, sulfinic acid | 167.3 ± 0.0 | 1.1 ± 0.0 | 0.2 ± 0.0 |
| | | $2p_{1/2}$ Sulfite, sulfinic acid | 168.4 ± 0.0 | 1.1 ± 0.0 | 0.1 ± 0.0 |
| | | $2p_{3/2}$ Sulfonate, sulfate | 168.3 ± 0.0 | 1.1 ± 0.0 | 0.1 ± 0.0 |
| | | $2p_{1/2}$ Sulfonate, sulfate | 169.5 ± 0.0 | 1.1 ± 0.0 | 0.1 ± 0.0 |