



## INTRODUCTION

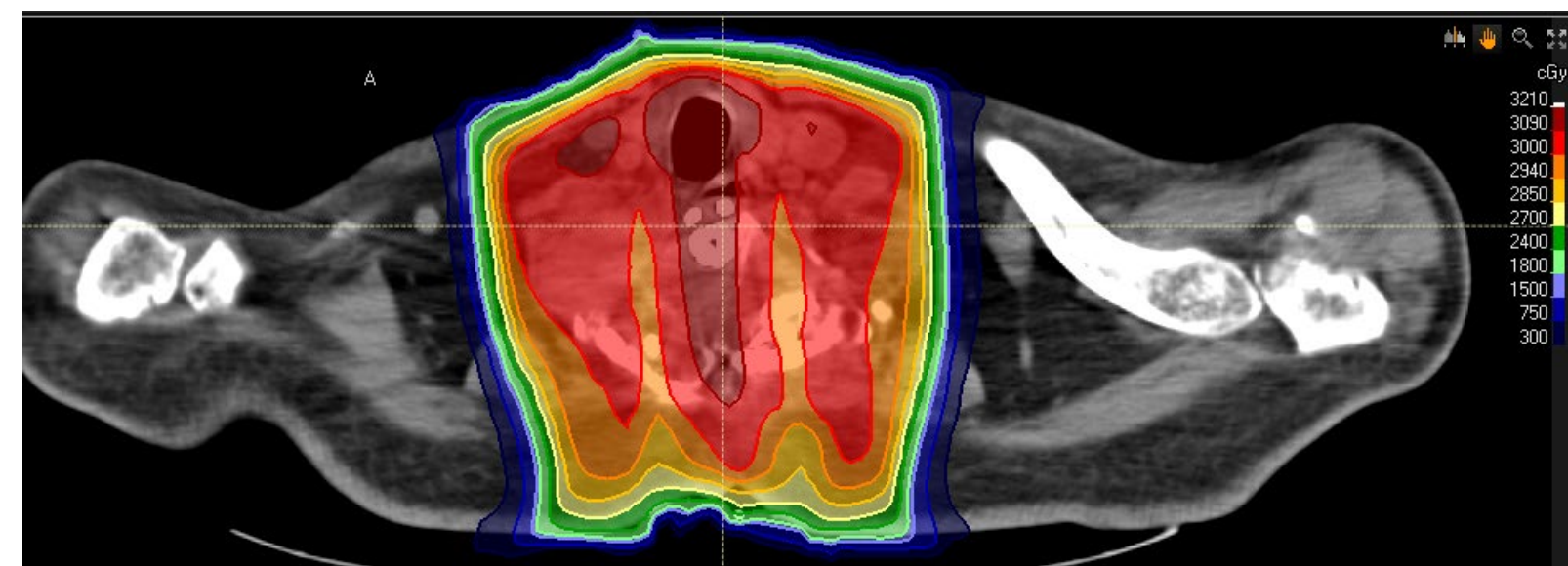
This work showcases an innovative spot delete method to remove spots from a previously treated spinal cord, reducing high LET and mitigating RBE uncertainty.

A 59-year-old patient with Hepatocellular Carcinoma presented for proton therapy for recurrent lower cervical spine metastasis.

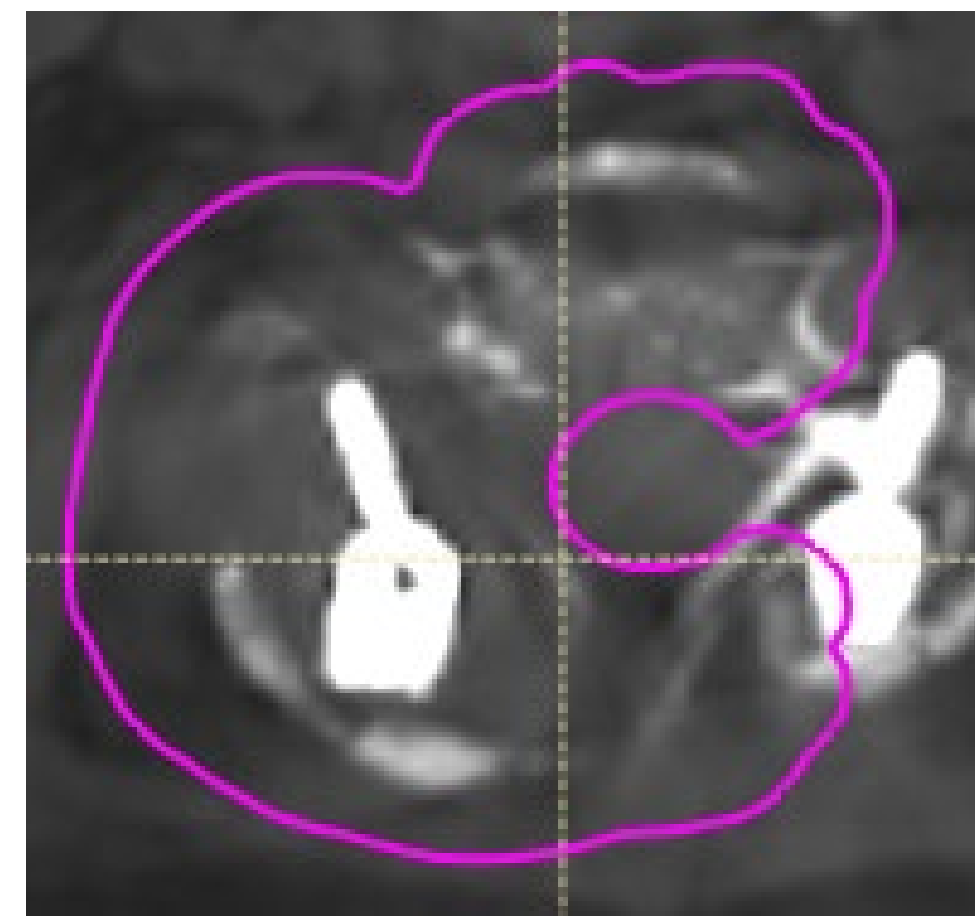
Post partial hepatectomy in 2021, an MRI in 2023 revealed a metastatic mass at the cervicothoracic junction, leading to a C6-T1 laminectomy and C-spine radiotherapy.

The patient has spinal hardware from C4-T2.

Subsequent MRIs in 2024 showed metastatic disease at C5 and C7.



**Figure 1.** Previous treatment with photons: Patient received a total dose of 30Gy in 10 fractions over 13 calendar days. AP/PA portals were utilized. Total cord dose was 31.40Gy. There was complete overlap of the prior dose with the proton target.



**Figure 2.** Proton target. Proton prescription- 30Gy<sub>RBE</sub> in 5 fractions:

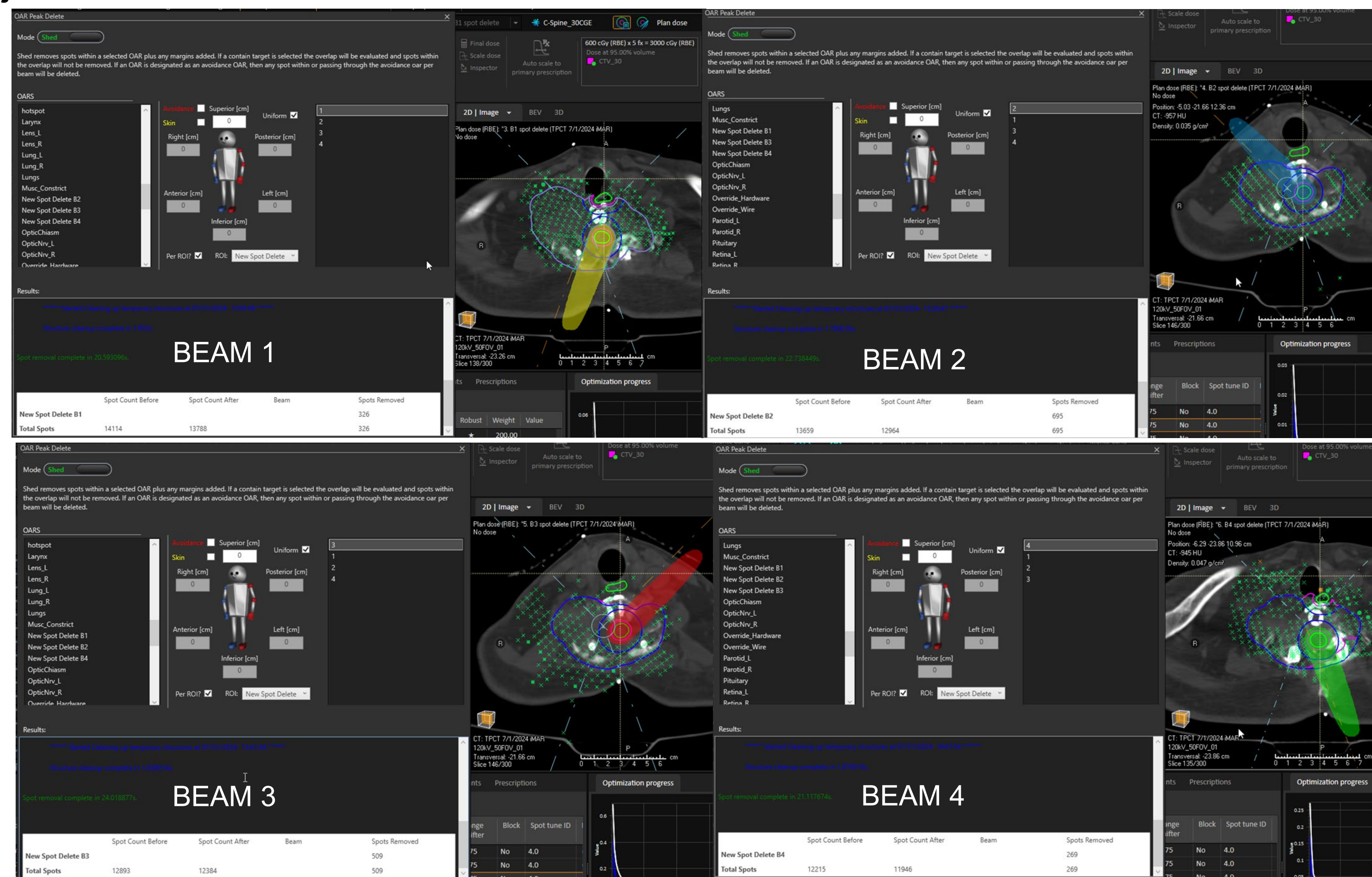


**Figure 3.** Extent of implanted hardware. Hardware consists of titanium rods and screws.

## METHODS

Treatment planning, 30Gy<sub>RBE</sub> in 5 fractions, used RayStation v23b. The radiation oncologist wanted the previously treated spinal cord to receive only an additional 10 Gy<sub>RBE</sub>. To mitigate RBE uncertainty, the physician wanted no Bragg peaks (spots) ending on or proximal to the spinal cord, but spots were allowed to treat through the cord to ensure distal target coverage. Apertures were deemed suboptimal.

An innovative beam-specific spot delete method was developed using RayStation tools and an in-house developed Python script. Given the extent of spinal hardware, a four-field X-beam arrangement was deemed optimal. A beam-specific contour was created with a 0.5 cm lateral target margin in the beam’s eye view, a 10 cm proximal margin, and a 0.5 cm distal margin along the beam path. Spots within the beam-specific contour were removed using the spot-delete script, and optimization continued to meet objectives.

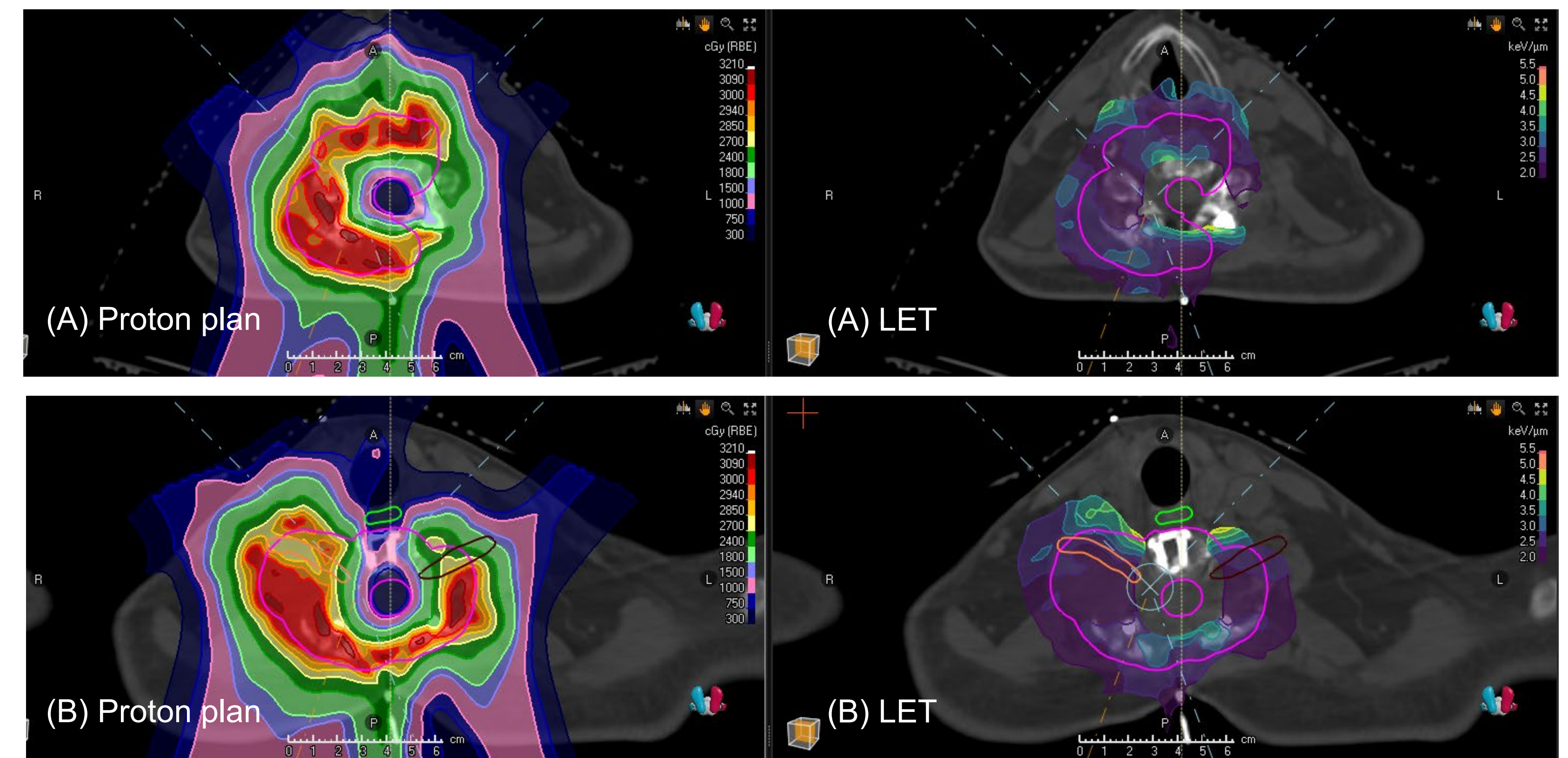


**Figure 4.** Spot delete for each beam, removing spots proximal to the cord. Spots deposited distally to promote target coverage.

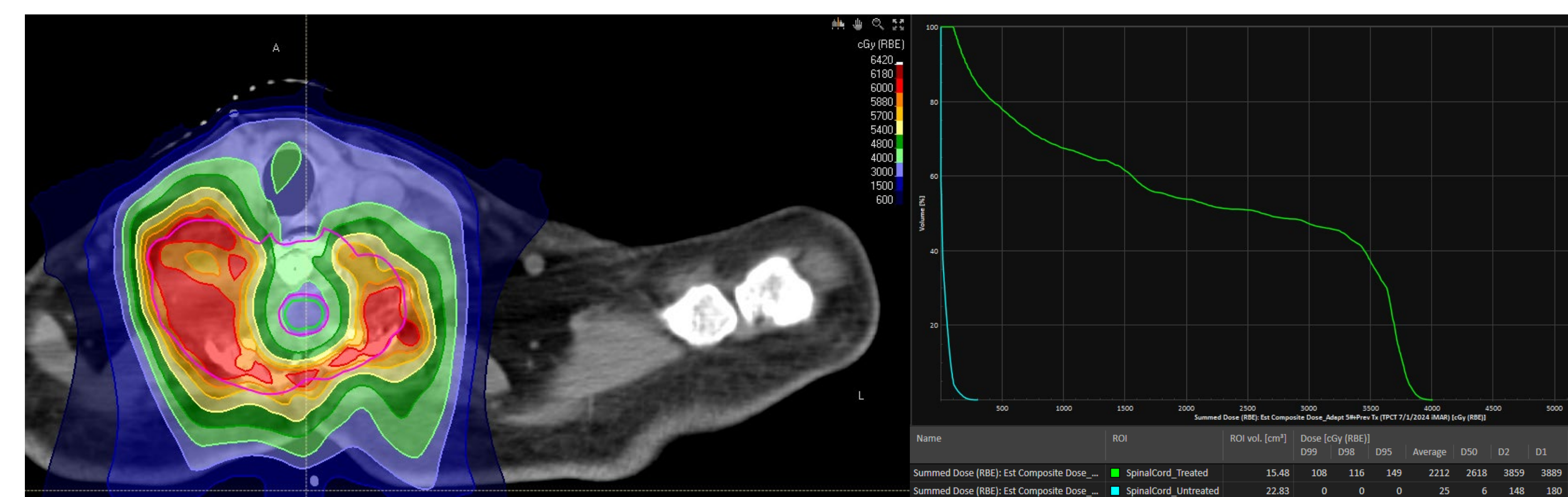
Robust optimization was applied to the target and the spinal cord, using independent beams in all directions with 0.3cm shifts and 3.5% range uncertainty. LET, calculated in RayStation, was reviewed to ensure high LET levels, greater than 4.0 keV/μm were absent within and near the spinal cord edges.

## RESULTS

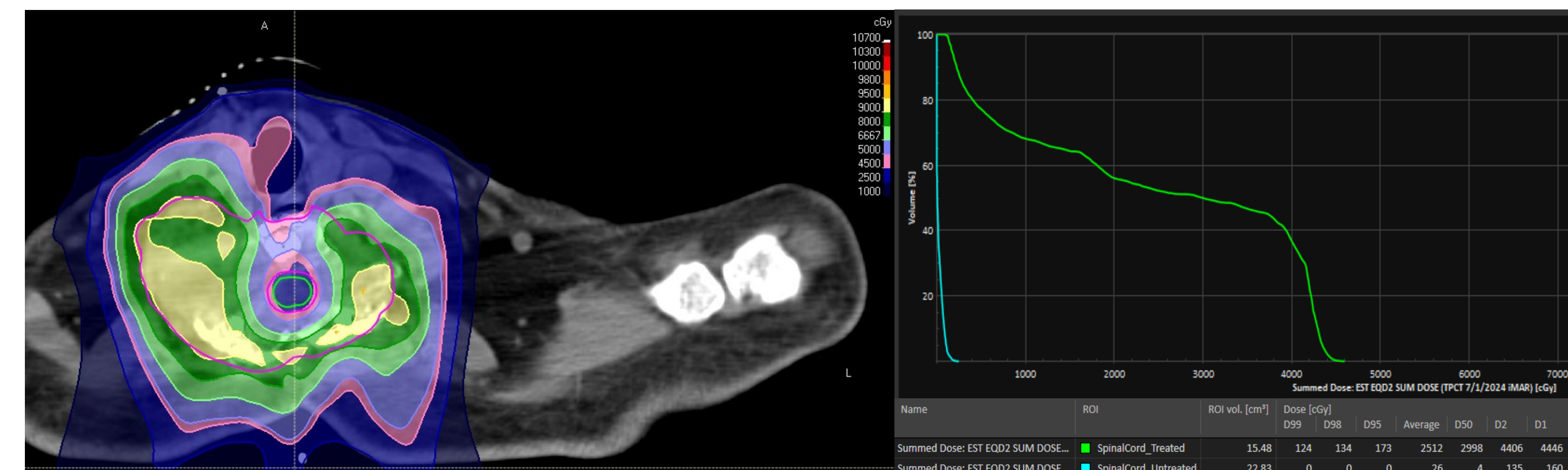
Using this technique, target coverage and OAR sparing met the physician’s requirements on the RBE = 1.1 plan and LET was less than 4 keV/um within the 24Gy<sub>RBE</sub> threshold in and around the spinal cord. Our evaluation also demonstrated that this technique did not significantly increase the optimization time, nor impact robustness.



**Figure 5 (A) and (B).** Proton Treatment planning distributions at 2 levels. LET distribution shows dose threshold set at 80% of the prescription dose. Levels above 2 keV/μm were reviewed. All levels of spinal cord received less than 2 keV/μm.



**Figure 6.** Estimated composite dose of Proton+Previous Photon. EQD2 not taken into account. Previously treated spinal cord received 39.45 Gy<sub>RBE</sub>.



**Figure 7.** Estimated composite dose of Proton+Previous Photon. EQD2 taken into account. Previously treated spinal cord received 45.06 Gy<sub>RBE</sub>.

## CONCLUSIONS

This innovative spot delete method effectively removed spots from the previously treated spinal cord, reducing high LET without compromising robustness or optimization time. This approach highlights the novelty and effectiveness of using beam-specific spot deletion in complex cases involving spinal hardware and previously irradiated regions.

## REFERENCES

Hedrick, Samantha G., Bryant Walker, Bart Morris, Scott Petro, and Marc Blakey. Scripted spot removal in PBS proton therapy planning. *Journal of Applied Clinical Medical Physics* 23, No. 2 (2022): e13491.

## CONTACT INFORMATION

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