Analysis of Reference Dosimetry Audits for 6 MV FFF Beams: Comparison of C-Arm vs O-Ring Linac Results

Egor Titovich, PhD[1]; Godfrey Azangwe, PhD[1]; Liset de la Fuente Rosales, PhD[1]; Maria Del Sol Quintero Castelan, PhD[1]; Jamema Swamidas, PhD[1] Mauro Carrara, PhD[1]

[1] Dosimetry and Medical Radiation Physics Section, Division of Human Health, International Atomic Energy Agency, Vienna, Austria

ABSTRACT

Purpose. To compare dosimetry audit results for 6 MV flattening-filter-free (FFF) photon beams between conventional C-arm linear accelerators (linacs) and ring-based (O-ring) architectures, using IAEA/WHO postal dosimetry audit results [1].

Methods. Retrospective analysis of 6 MV FFF audits (2017–2025). Radio-photoluminescent dosimeters (RPLDs) were irradiated to a dose of 2 Gy [2],[3]; percent dose deviation from the IAEA-measured dose (D_{ratio} %) was compared between linac types.

Results & Conclusion. Across 754 audits, mean dose deviation did not differ between architectures (p = 0.60), but O-ring linacs showed significantly greater variability and a higher proportion of results outside ±5% (8.6% vs 2.4%, p < 0.001). Findings reinforce the need for independent reference dosimetry audits as new technologies are rapidly introduced.

KEY FINDINGS

- **No systematic bias** between C-arm and O-ring mean output (p = 0.60).
- **Higher variability** for O-ring beams (SD 10.5% vs 3.0%; p < 0.001).
- **Higher out-of-tolerance rate** for O-ring (8.6% vs 2.4%; p < 0.001).

STUDY AT A GLANCE

754 FFF audits analyzed

2017–25 audit period

532 C-arm audits

222 O-ring audits

INTRODUCTION

Independent dosimetry audits are essential for verifying accurate radiotherapy dose delivery. The IAEA/WHO postal dosimetry audit program checks each institution's output calibration by having sites irradiate mailed RPLDs to a nominal 2 Gy under reference conditions.

FFF beams are now widely used, and ring-based **O-ring** platforms — TomoTherapy ®, Halcyon™ and Ethos™ — are being adopted rapidly alongside conventional **C-arm** linacs.

This study compares IAEA audit results for C-arm and O-ring linacs for 6 MV FFF beams. **54.8%** of these audits were conducted in LMICs.

METHODS & MATERIALS

A retrospective analysis of 6 MV FFF beam dosimetry audits (2017–2025):

- RPLDs irradiated to a nominal **2 Gy** to verify beam output in reference conditions.
- Percent dose deviation calculated relative to the IAEA-measured dose (**D_{ratio} %**); audits beyond **±5%** were followed up.
- Audits grouped by linac type — **C-arm** vs **O-ring** (TomoTherapy®, Accuray; Halcyon™ and Ethos™, Varian).

Statistical analysis

- **Mann–Whitney U** test — distributions.
- Median-based **Levene's** test — variability.
- **Two-proportion z-test** — out-of-tolerance rates.

RESULTS

A total of **754 FFF audits** (532 C-arm, 222 O-ring) were analyzed. Mean ± SD D_{ratio} % was **−0.6 ± 3.0** for C-arm and **−0.2 ± 10.5** for O-ring linacs; the difference in means was not statistically significant (p = 0.60).

O-ring linacs exhibited **significantly greater variability** (p < 0.001). The proportion of audits beyond ±5% was **2.4%** for C-arm and **8.6%** for O-ring (p < 0.001). Among O-ring LINACs, 16 of the 19 audits beyond ±5% occurred in LMICs. Of the out-of-tolerance audits followed up, **79%** were within tolerance on the second attempt, with no difference between groups.

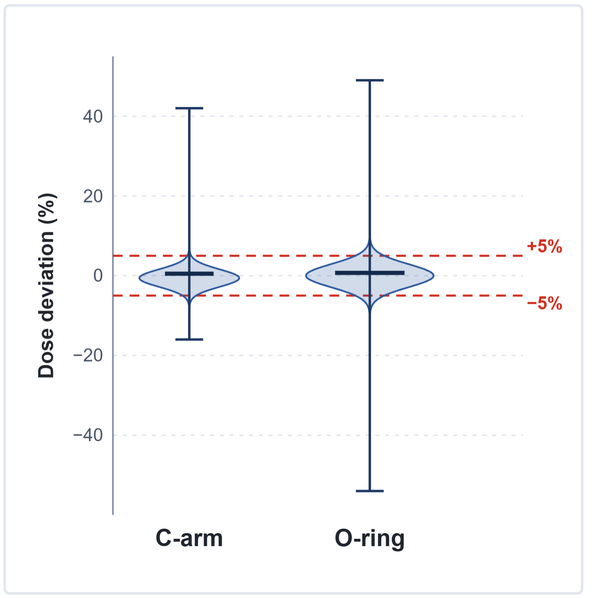

Figure 1. Distribution of audit dose deviations by linac type. Both medians lie near 0%, but O-ring audits show a broader distribution with heavier tails beyond ±5% (red).

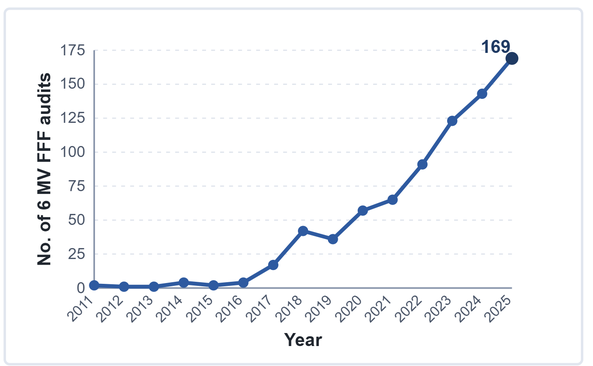

Figure 2. Number of 6 MV FFF audits per year. Volume rose ~10×, from <20 per year before 2017 to 169 in 2025.

DISCUSSION

Mean reference-output accuracy was **comparable** between C-arm and O-ring linacs, indicating no systematic dose deviation attributable to gantry architecture.

However, the O-ring beams audited by the IAEA exhibited markedly greater dispersion. This finding highlights the need for dedicated training on the physical characteristics and specific properties of these machines, particularly in low- and middle-income countries (LMICs), where the IAEA conducts most of its dosimetry audits.

Since most of out-of-tolerance audits resolved on repeat, the deviation may largely reflect correctable setup or other non-persistent factors rather than systematic issues — underscoring the value of routine independent verification.

CONCLUSIONS

1. No systematic dose bias exists between C-arm and O-ring linacs for 6 MV FFF reference beams.
2. The O-ring linacs audited by the IAEA exhibited significantly greater variability and a higher proportion of results outside tolerance.
3. Findings reinforce the need for independent reference dosimetry audits and dedicated training, particularly as new technologies are rapidly introduced into the clinic.

Metric	C-arm	O-ring	p
Audits (n)	532	222	—
Mean ± SD (%)	−0.6 ± 3.0	−0.2 ± 10.5	0.60
Out-of-tolerance (>±5%)	2.4%	**8.6%**	**<0.001**
Variability (Levene's)	reference	**greater**	**<0.001**

Table 1. Summary of 6 MV FFF reference-output audit statistics by linac architecture.

REFERENCES

[1] IAEA/WHO TLD/RPLD Postal Dose Audit Programme; [2] IAEA TRS-398 Rev.1; [3] AAPM TG-51

ACKNOWLEDGMENTS

CONTACT

Mauro Carrara· m.carrara@iaea.org AAPM 2026 Annual Meeting · Abstract ID: 23214