The Journal of Open Source Software

Conjuror: A DICOM RT Plan generator for linac machine QA

João Silveira[1], **James R. Kerns**[1], **and Hasan Ammar**[1]

1 Radformation, New York, NY, United States of America

DOI: DOIunavailable

Software

- Review
- Repository
- Archive

Editor: Pending Editor

Reviewers:

- @Pending Reviewers

Submitted: N/A
Published: N/A

Summary

Machine quality assurance (QA) of linear accelerators (linacs) is a critical component of safe and effective external beam radiation therapy (RT). QA procedures often require the delivery of standardized treatment plans to verify machine performance, including geometric accuracy, dosimetric consistency, and imaging system alignment. As QA methodologies evolve, new test patterns and procedures are regularly introduced, increasing the need for flexible and extensible approaches to plan generation. While the Digital Imaging and Communications in Medicine (DICOM) standard defines how radiotherapy treatment plans (RT Plans) should be represented (National Electrical Manufacturers Association, n.d.), constructing valid RT Plan files for QA purposes is challenging due to the complexity of the standard and the need for machine-specific configurations.

Conjuror is a Python toolkit that enables the creation of DICOM RT Plans tailored for Varian linac machine QA. The toolkit provides an accessible and reproducible way to generate test plans for routine and specialized QA procedures, eliminating the need for manual authoring or reliance on proprietary planning systems.

Statement of need

Routine and end-to-end QA of linacs requires standardized test plans that examine key performance characteristics, such as multileaf collimator (MLC) positioning, imaging isocenter coincidence, and mechanical accuracy. These requirements are formalized in guidelines such as AAPM Task Groups 142 (Klein et al., 2009), 198 (Hanley et al., 2021), and 332 (Smith et al., 2025), as well as AAPM Medical Physics Practice Guidelines 8.a (Smith et al., 2017) and 8.b (Krauss et al., 2023). The implementation and interpretation of these QA procedures are primarily the responsibility of medical physicists involved in clinical operations, commissioning, and ongoing QA. Beyond routine compliance testing, contemporary machine QA increasingly involves systematic studies that characterize machine behavior under controlled parameter variations, supporting the evaluation of performance across a range of delivery configurations.

In current clinical and research practice, medical physicists typically generate QA plans either by (1) manual construction within proprietary treatment planning systems, or (2) by relying on vendor-provided test plans. These approaches can be time-consuming, opaque, and difficult to adapt or update in response to institution-specific protocols, research studies, newly proposed QA methodologies, or emerging technologies. Such local customization is explicitly encouraged in guidance such as AAPM-RSS Medical Physics Practice Guideline 9.b (Cirino et al., 2025), which recognizes the need for institution-specific QA strategies in advanced techniques such as SRS and SBRT. Additionally, QA plans are often distributed across multiple files, making it cumbersome to assemble all required beams in a single cohesive plan and hindering streamlined, automated workflows.

Conjuror addresses this gap by offering an open-source, Python-based framework for generating DICOM RT Plans specifically for Varian linacs. An open-source approach is particularly valuable for machine QA, as it enables transparency in plan construction, reproducibility of QA procedures across institutions, and community-driven development as new tests and measurement patterns are introduced. By exposing plan generation through a programmable interface, Conjuror supports both routine clinical QA and research into novel QA strategies. The library enables:

- Customization of commonly used QA plans based on pre-prepared procedures.
- Aggregation of multiple procedures into a single RT plan file, enabling a streamlined QA workflow.
- Visualization of the expected fluence and the sequence of control points of each beam.
- Integration with Python QA ecosystems (e.g. Pylinac (Kerns, 2023)), supporting automated analysis and research into novel QA strategies.
- Built on established Python packages such as pydicom (Mason et al., 2023), ensuring compatibility with the broader medical imaging software ecosystem.

State of the field

Several open-source projects address aspects of linac QA, but none focus on generating valid DICOM RT Plan objects for test delivery. For example, pylinac (Kerns, 2023) and pymedphys (Biggs et al., 2022) provide robust tools for analyzing machine QA data but assume that test plans have already been generated and delivered. As a foundational dependency, pydicom (Mason et al., 2023) enables reading and writing of DICOM files, but it does not provide domain-specific functionality for radiotherapy QA plan creation.

In contrast, Conjuror bridges this gap by directly supporting the programmatic generation of DICOM RT Plans for Varian linac QA. By enabling the creation of test plans that can be delivered, analyzed, and iteratively refined, Conjuror helps complete the QA workflow from plan generation through delivery and assessment. This focus on reproducible, automated test plan creation complements existing QA analysis software and contributes to a more complete open-source ecosystem for medical physics research and clinical practice.

Software design

- **RT beams:** A `Beam` represents a DICOM RT Beam and defines its Control Point Sequence (monitor units, MLC/jaw positions, gantry/collimator/couch axes).
- **QA procedures:** A `QAProcedure` groups one or more `Beam` instances into domain-specific tests (e.g., a Winston–Lutz procedure with multiple beams at different gantry/collimator/couch angles).
- **Plan synthesis:** A `PlanGenerator` builds an RT Plan dataset containing all beams across procedures. Since a QA procedure is not part of the DICOM RT Plan hierarchy, beams are stored as a sequential list.
- **Fluence simulation (dosimetric verification):** An imager simulator computes expected beam fluence from control points using configurable pixel sampling and source-to-imager distance, supporting verification of intended dose delivery patterns.
- **Motion and control-point visualization (geometric verification):** Plotting helpers (Plotly) enable animation of MLC motion and visualization of control-point dynamics to inspect beam geometry and sequencing behavior.

Research impact statement

Conjuror enables QA procedures to be defined and customized programmatically, allowing researchers and clinical physicists to generate reproducible RT Plan variants for systematic testing. By facilitating controlled variation of beam delivery parameters, the toolkit supports

QA studies that systematically explore machine behavior across different delivery configurations. This capability accelerates the development, refinement, and assessment of novel QA strategies by reducing the overhead associated with plan creation. Conjuror has been applied in a collaborative workflows to generate customized plans for testing a range of delivery types, including VMAT, static open fields, and MLC-based test patterns such as picket-fence fields, across multiple settings beyond the fixed configurations available in vendor-provided QA plans.

AI usage disclosure

No generative AI tools were used in the conceptual design or QA procedure domain logic. Generative AI was used to assist with minor code suggestions (e.g., unit-test scaffolding) and language polishing of this manuscript; all changes were reviewed by the authors.

Acknowledgements

We thank Radformation for continuing to support the open-source work of this project.

References

Biggs, S., Jennings, M., Swerdloff, S., Chlap, P., Lane, D., Rembish, J., McAloney, J., King, P., Ayala, R., Guan, F., Lambri, N., Crewson, C., & Sobolewski, M. (2022). PyMedPhys: A community effort to develop an open, python-based standard library for medical physics applications. *Journal of Open Source Software*, *7*(78), 4555. https://doi.org/10.21105/joss.04555

Cirino, E., Benedict, S. H., Dupre, P. J., Halvorsen, P. H., Kim, G. G.-Y., Reyhan, M. L., Schneider, C. W., Wang, L., Weaver, C. P., & Yoo, S. (2025). AAPM-RSS medical physics practice guideline 9.b: SRS-SBRT. *Journal of Applied Clinical Medical Physics*, *26*(4), e14624. https://doi.org/https://doi.org/10.1002/acm2.14624

Hanley, J., Dresser, S., Simon, W., Flynn, R., Klein, E. E., Letourneau, D., Liu, C., Yin, F.-F., Arjomandy, B., Ma, L., Aguirre, F., Jones, J., Bayouth, J., & Holmes, T. (2021). AAPM task group 198 report: An implementation guide for TG 142 quality assurance of medical accelerators. *Medical Physics*, *48*(10), e830–e885. https://doi.org/https://doi.org/10.1002/mp.14992

Kerns, J. R. (2023). Pylinac: Image analysis for routine quality assurance in radiotherapy. *Journal of Open Source Software*, *8*(92), 6001. https://doi.org/10.21105/joss.06001

Klein, E. E., Hanley, J., Bayouth, J., Yin, F.-F., Simon, W., Dresser, S., Serago, C., Aguirre, F., Ma, L., Arjomandy, B., Liu, C., Sandin, C., & Holmes, T. (2009). Task group 142 report: Quality assurance of medical accelerators. *Medical Physics*, *36*(9Part1), 4197–4212. https://doi.org/https://doi.org/10.1118/1.3190392

Krauss, R. F., Balik, S., Cirino, E. T., Hadley, A., Hariharan, N., Holmes, S. M., Kielar, K., Lavvafi, H., McCullough, K., Palefsky, S., Sawyer, J. P., Smith, K., Tracy, J., Winter, J. D., & Wingreen, N. E. (2023). AAPM medical physics practice guideline 8.b: Linear accelerator performance tests. *Journal of Applied Clinical Medical Physics*, *24*(11), e14160. https://doi.org/https://doi.org/10.1002/acm2.14160

Mason, D., scaramallion, mrbean-bremen, rhaxton, Suever, J., Vanessasaurus, Orfanos, D. P., Lemaitre, G., Panchal, A., Rothberg, A., Herrmann, M. D., Massich, J., Kerns, J., Golen, K. van, Robitaille, T., Biggs, S., moloney, Bridge, C., Shun-Shin, M., … Wortmann, J. (2023). *Pydicom/pydicom: Pydicom v2.4.0* (Version v2.4.0) [Computer software]. Zenodo. https://doi.org/10.5281/zenodo.8034250

National Electrical Manufacturers Association. (n.d.). *NEMA PS3 / ISO 12052, digital imaging and communications in medicine (DICOM) standard*. NEMA; https://www.dicomstandard.org/current/.

Smith, K., Balter, P., Duhon, J., White Jr., G. A., Vassy Jr., D. L., Miller, R. A., Serago, C. F., & Fairobent, L. A. (2017). AAPM medical physics practice guideline 8.a.: Linear accelerator performance tests. *Journal of Applied Clinical Medical Physics*, *18*(4), 23–39. https://doi.org/https://doi.org/10.1002/acm2.12080

Smith, K., Blasi, O., Casey, D., Chan, M., Dieterich, S., Dresser, S., Kennedy, C., Kielar, K., Lowenstein, J., Pawlicki, T., Popple, R., Solodkin, A., Sutlief, S., & Weiser, M. (2025). AAPM task group report 332: Verification of vendor-provided data, tools, and test procedures in radiotherapy. *Medical Physics*, *52*(6), 3509–3527. https://doi.org/https://doi.org/10.1002/mp.17879