2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Python Software-Guided Small Animal Precision Irradiator Quality Assurance Procedure for Improved Efficacy in Preclinical Research

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ABSTRACT

PURPOSE
Routine and pre-treatment clinical irradiator quality assurance (QA) is vital for ensuring safe, accurate, and reproducible patient care. A primary factor limiting statistical significance in preclinical research is the lack of reproducibility, mainly due to unestablished small animal (SA) irradiator QA programs. Presented is a comprehensive Klio platform to guide the user through, and track, SmART+ irradiator QA.

METHODS
Klio is a user-friendly browser-based QA system used to create a guide and inventory for both clinical and preclinical QA, allowing the user to track performance over time and make the required corrections. In addition to routine alignment protocols, output constancy checks are executed, including monthly ion chamber absolute dose, HVL, and end-effect measurements. Water vial measurements evaluate the dynamic range, allowing recalibration of CT imager presets.

RESULTS
Upon QA completion, absolute reference dosimetry measurements and correction factors are calculated from inputted data. Temperature-pressure correction (T_{TP}), ion collection efficiency (P_{ion}), electrometer polarity correction (P_{pol}) and electrometer measurement (P_{elec}) provide corrected readings. Backscatter factor (B_w) is calculated by trilinear interpolation of 3D precomputed table of B_w at various distances and HVLs. In addition to providing historical comparisons for WL and projection maps, the software presents changes in HVL, P_{pol}, P_{elec}, B_w, T_{TP}, M_{raw}, ΔT, and HU since the previous QA entry.

CONCLUSION
Being able to routinely correct for inconsistencies and track changes in SA-irradiator performance allows for vastly improved reproducibility and accuracy in preclinical research.

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INTRODUCTION

In 2016, the NIH released a mandate on rigor and reproducibility, a serious issue in preclinical research, largely due to non-standardized small animal irradiator quality assurance (QA) procedures.

Consequences of neglecting routine can QA lead to **dose delivery errors, poor calibration**, and **inconsistent irradiator performance.**

Klio is used to guide the user through irradiator QA, incorporating recommendations from AAPM TG-61 and existing SmART+ software protocols.[1]

METHODS & MATERIAL

MONTHLY GENERAL PROTOCOLS
- Visual inspection of collimators and filters
- Test emergency stop and door interlock system

MONTHLY ALIGNMENT VERIFICATION PROTOCOLS
- **Tube** with 5mm circular collimator (example shown in **FIGURE 1**)
- **Gantry** with digital level (0.1° tolerance)
- **Lasers** with BB phantom
- **Stage** with BB phantom

MONTHLY MECHANICAL PROTOCOLS
USING BB PHANTOM
- **Winston-Lutz (WL) map alignment** (shown in **FIGURE 2**)
- **Projection map calibration**
- **Magnification (Mag) factor verification**

MONTHLY SYSTEM OUTPUT CHECKS
USING ION-CHAMBER SET-UP AS SHOWN IN **FIGURE 3**
- **Absolute dose measurements (M_{raw})**
- **Copper Half-value layer (HVL) measurements**
- **End effect (ΔT) measurements**

YEARLY ON-BOARD IMAGER PROTOCOLS
FOR EACH IMAGING PRESET
- **Water vial measurements** (shown in **FIGURE 4**)
- **Flood field calibration**
- **Defect maps**

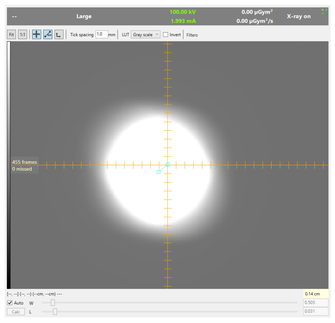

FIGURE 1. *Screenshot of tube alignment verification. Center of 5mm circular collimated field within 2mm of center of flat panel detector in both U and V directions.*

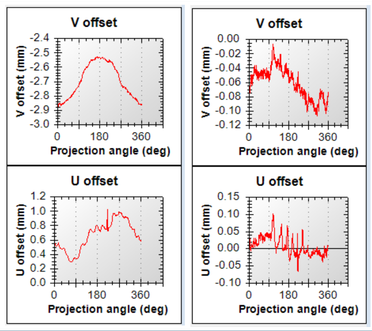

FIGURE 2. *WL map alignment check for U and V offsets before and after correction.*

MONTHLY QA WORKFLOW

SESSION INFO
Name of user and Date

↓

SYSTEM ISOCENTER VERIFICATION
Tube, Gantry, Laser, Stage

↓

TUBE AND ION-CHAMBER WARM-UP

↓

CORRECTION FACTORS
Temperature/Pressure
Electrometer

↓

COLLIMATOR AND FILTER INTEGRITY
X-ray safety tests
Emergency stop and Door Interlock System

↓

MECHANICAL & SYSTEM FLEX
Projection Map Calibration
Magnification Factor
WL Map Calibration

↓

ION CHAMBER MOUNTED FOR SYSTEM OUTPUT
System Output Check [tolerance ±3%],
End Effect Analysis [tolerance ±5%],
HVL Cu Shim Measurements [tolerance ±0.02mm]
Backscatter Factor (by Trilinear Interpolation)

↓

MASS ENERGY-ABSORPTION COEFFICIENTS
Conversion ratio (water/air) by 4th-order polynomial

↓

WATER VIAL SCANS
Upload Each Scan for Each Imaging Preset
to Automatically Calculate Slope and Intercept
[tolerance ±40 HU]

↓

QA OVERVIEW & SUMMARY/SAVING

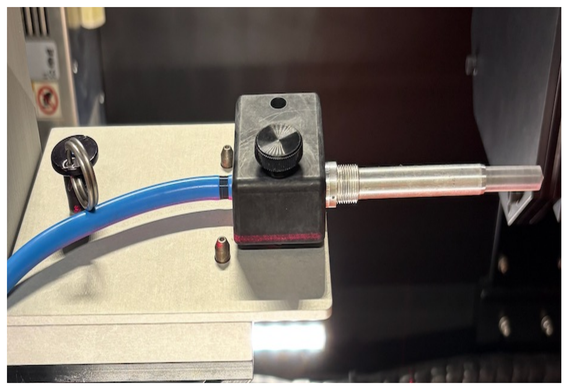

FIGURE 3. *Picture of the ion-chamber set-up in the SmART+ irradiator for a monthly QA procedure.*

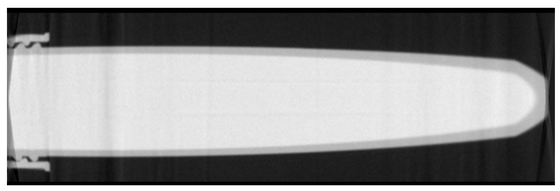

FIGURE 4. *Example slice from water vial imaging protocols.*

DISCUSSION

The routine small animal irradiator QA program has been in place for over 8 months now at UCLA. Routine QA's have already caught issues such as laser mis-alignment to system isocenter and miscalibration of stage coordinate system. A screenshot of the QA dashboard is shown in **FIGURE 5.**, **FIGURE 6.** and **FIGURE 7** show irradiator performance trends for output consistency and imager consistency, respectively.

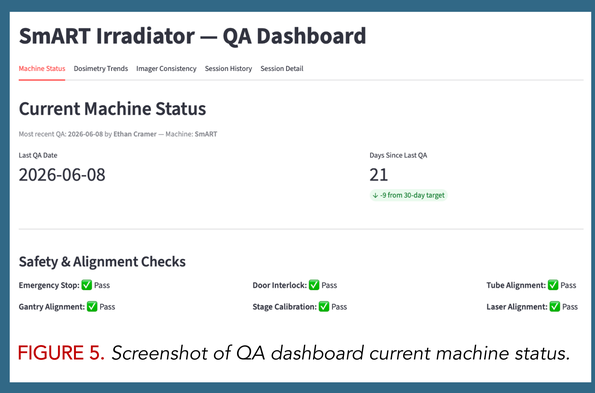

FIGURE 5. *Screenshot of QA dashboard current machine status.*

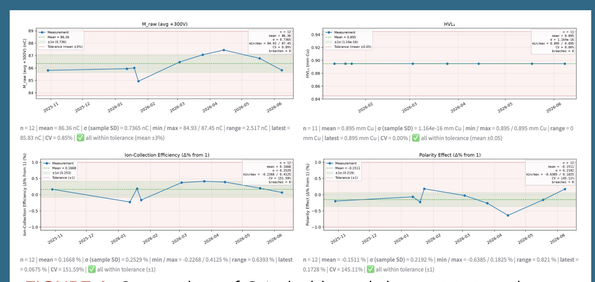

FIGURE 6. *Screenshot of QA dashboard dosimetric trends including monthly datapoints for Mraw, HVL1, ion-collection eff., and polarity effect with tolerance should by the red dotted lines.*

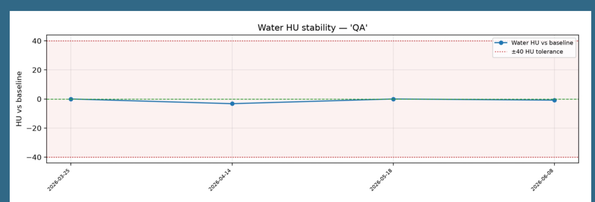

FIGURE 7. *Screenshot of QA dashboard QA imaging preset HU consistency in water vial scans.*

CONCLUSION

Automated measurement acquisition, real-time validation, online approvals and long-term trending bring small animal irradiator system QA in line with clinical instrumentation.

REFERENCES

1. Ma, C.-.-M., Coffey, C.W., DeWerd, L.A., Liu, C., Nath, R., Seltzer, S.M. and Seuntjens, J.P. (2001), AAPM protocol for 40–300 kV x-ray beam dosimetry in radiotherapy and radiobiology. Med. Phys., 28: 868-893. https://doi.org/10.1118/1.1374247