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The Development of Local Testing Methodology for Automatic Tube Current Modulation in CT

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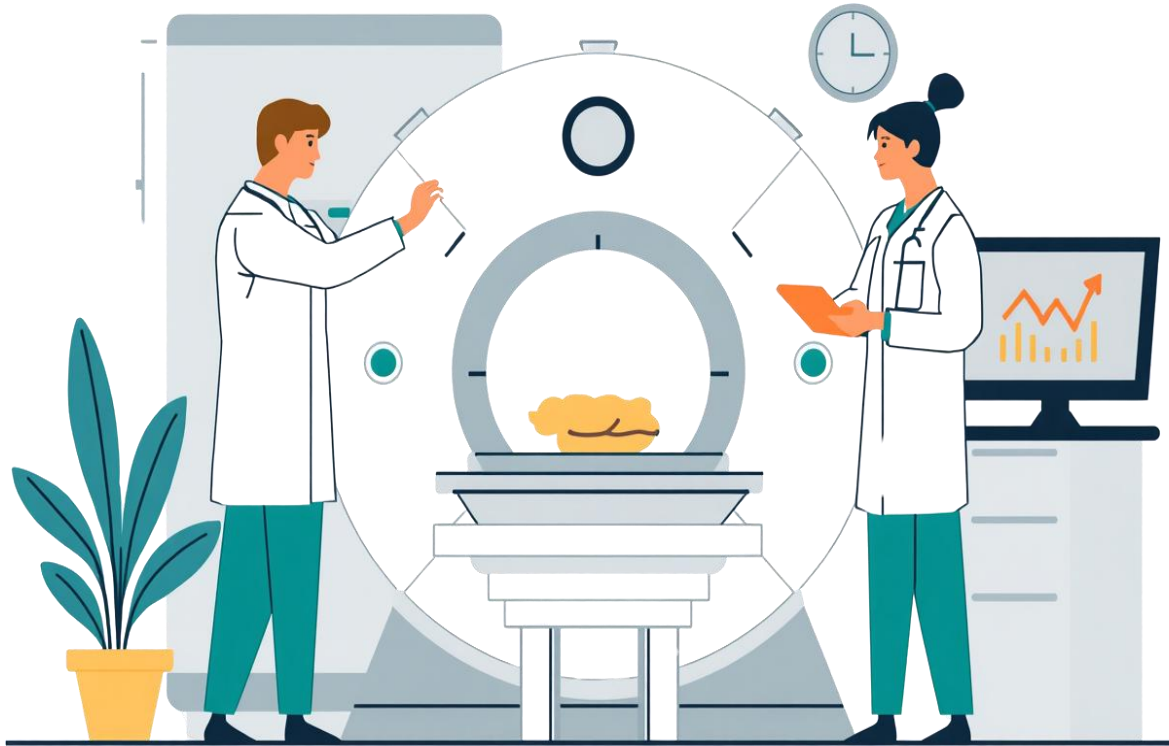
Introduction – Why is this important?

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- CT use continues to increase.
  - Relatively high patient radiation doses – need for dose optimisation.

- One important dose optimisation technology used in modern CT scanners is Automatic Tube current Modulation (ATCM).

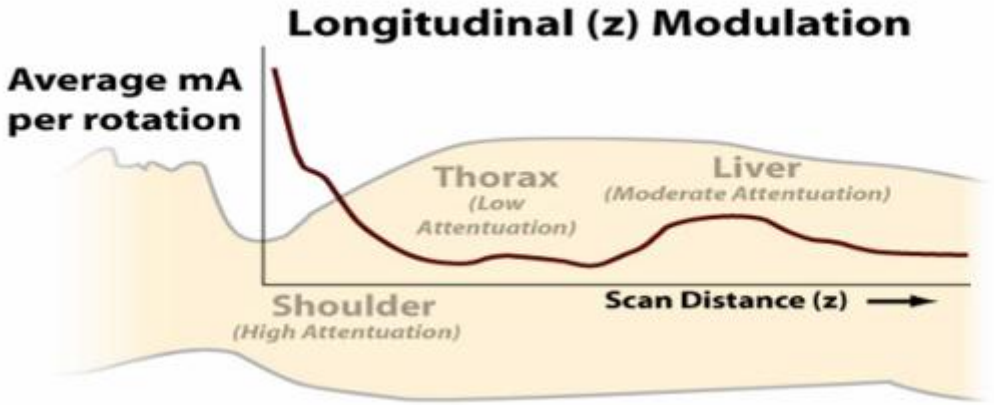




Automatic Tube Current Modulation

- Automatic Tube Current Modulation (ATCM) is used for dose optimisation.
  - ATCM adjusts the tube current according to patient size and attenuation to keep image noise / image quality consistent (target parameters vary between vendors).
  - ➢ By doing this ATCM can help keep doses as low as reasonably practicable.

- Current testing methodology uses the CTDI phantom to test ATCM.
  - Although suitable, it is not designed for ATCM testing.



Source: Supanich (2013)



Summary of existing literature

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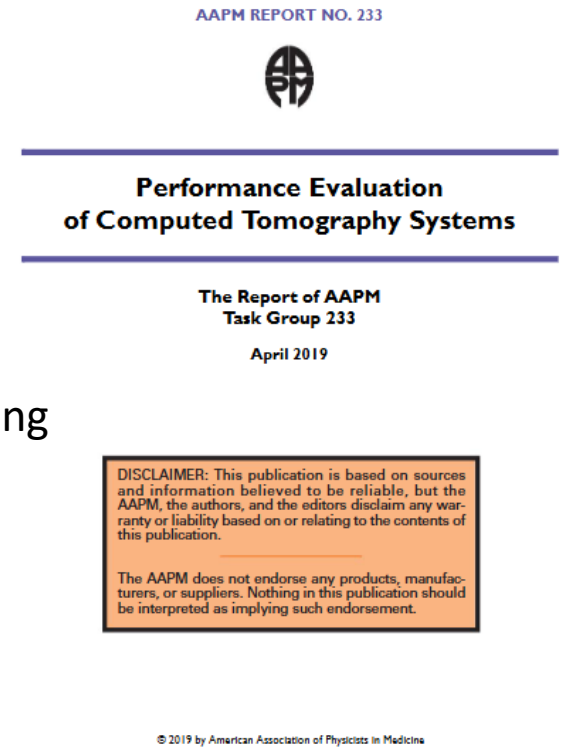
What dose the literature tell us?

- ✓ ATCM reduces patient radiation dose while maintaining image quality.
- ✓ ATCM performance can be assessed by evaluating how tube current and image noise respond to changes in attenuation.
- ✓ Dedicated phantoms have been developed to facilitate ATCM testing

However, no standardised UK QA methodology currently exists.

The American Association of Physicists in Medicine (AAPM report 233) suggests how testing of ATCM should be completed, this project has used this report as guidance.




AAPM REPORT NO. 233

Performance Evaluation of Computed Tomography Systems

The Report of AAPM Task Group 233

April 2019

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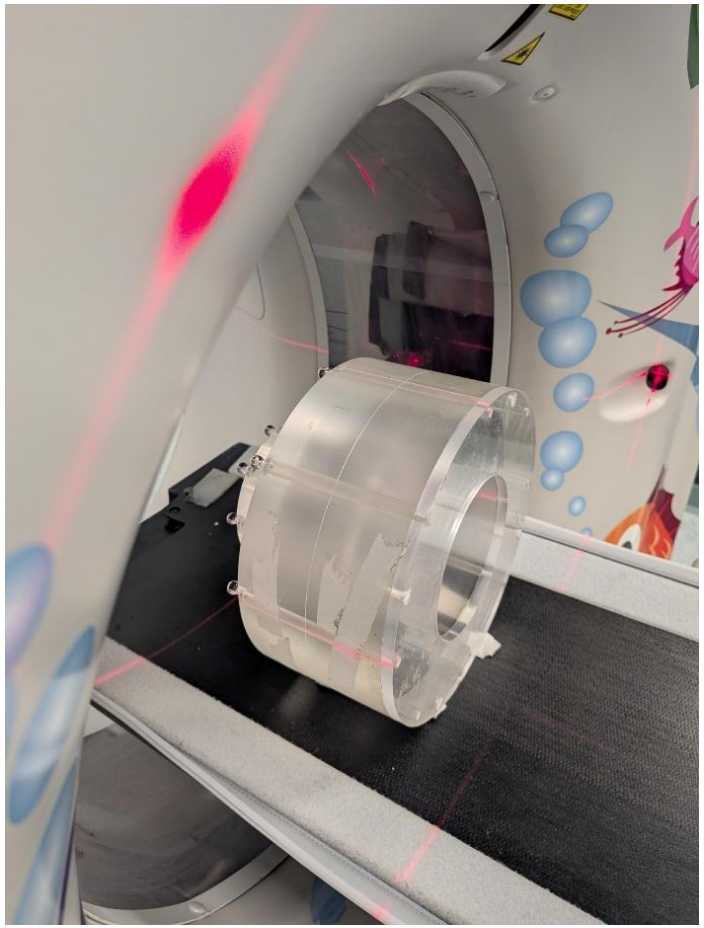
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Source: AAPM (2019a)

Phantoms

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CTDI Phantom



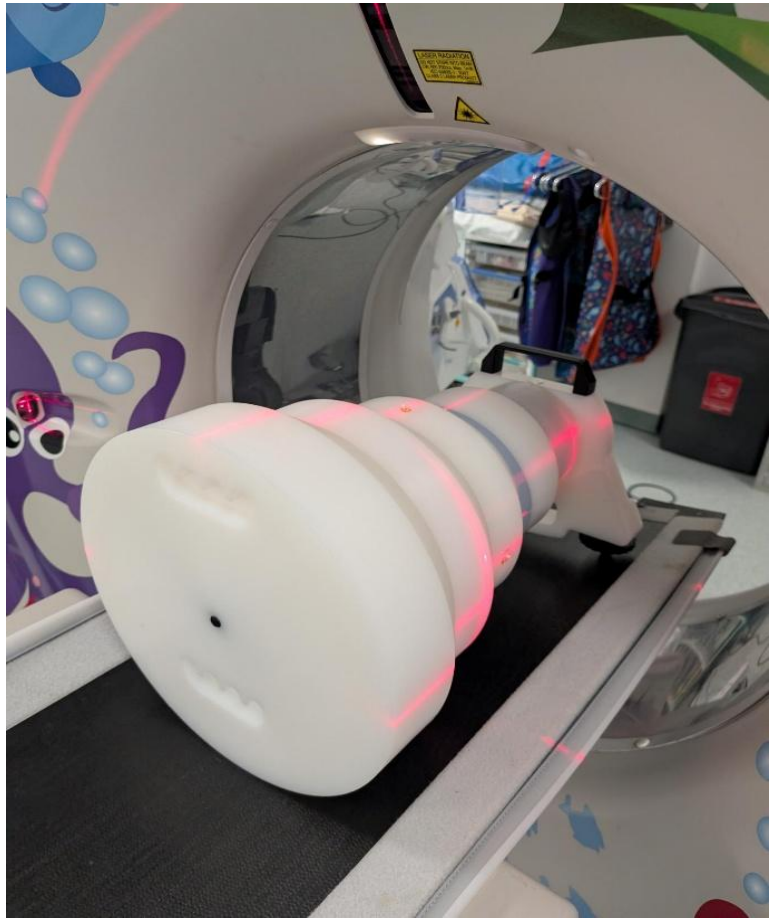
The CTDI Phantom (nested configuration) (Authors own work)

CelT Phantom



The CelT phantom. (Authors own work)

Mercury Phantom



The Mercury phantom. (Authors own work)

Aims

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The aim of this project was to identify and evaluate the most appropriate phantom and testing methodology for characterising the performance of ATCM systems in CT.

Phantom Assessment

Technical Performance

- Ability to demonstrate ATCM response with attenuation (water-equivalent diameter)
- Consistency of image noise
- Repeatability and reproducibility

Practical Usability

- Weight
- Setup time
- Ease of positioning
- Transport/storage requirements



Methods

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Scanner: Canon Aquilion ONE CT scanner.

Approach:

- Scan parameters optimised to maximise ATCM response.

Measurements extracted from each scan:

- Tube current (mA)
- Image noise (SD)
- CT Number
- Water-equivalent diameter (Dw)

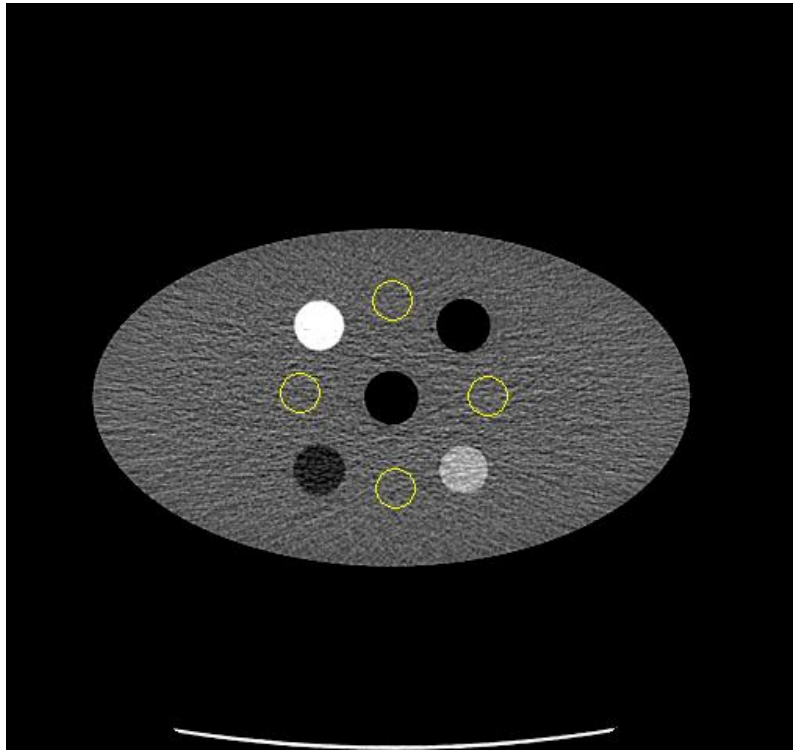
Analysis performed:

- Noise comparison for ATCM vs fixed mA scans
- Noise vs slice location
- Dw vs slice location
- mA vs Dw



Software:

- ImageJ
- DICOM header analysis



Shows four circular ROIs drawn over the CelT phantom for data collection on image J (Authors own work).

Results – Optimisation of scan parameters

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Several scan parameters were found to significantly influence ATCM behaviour, including:

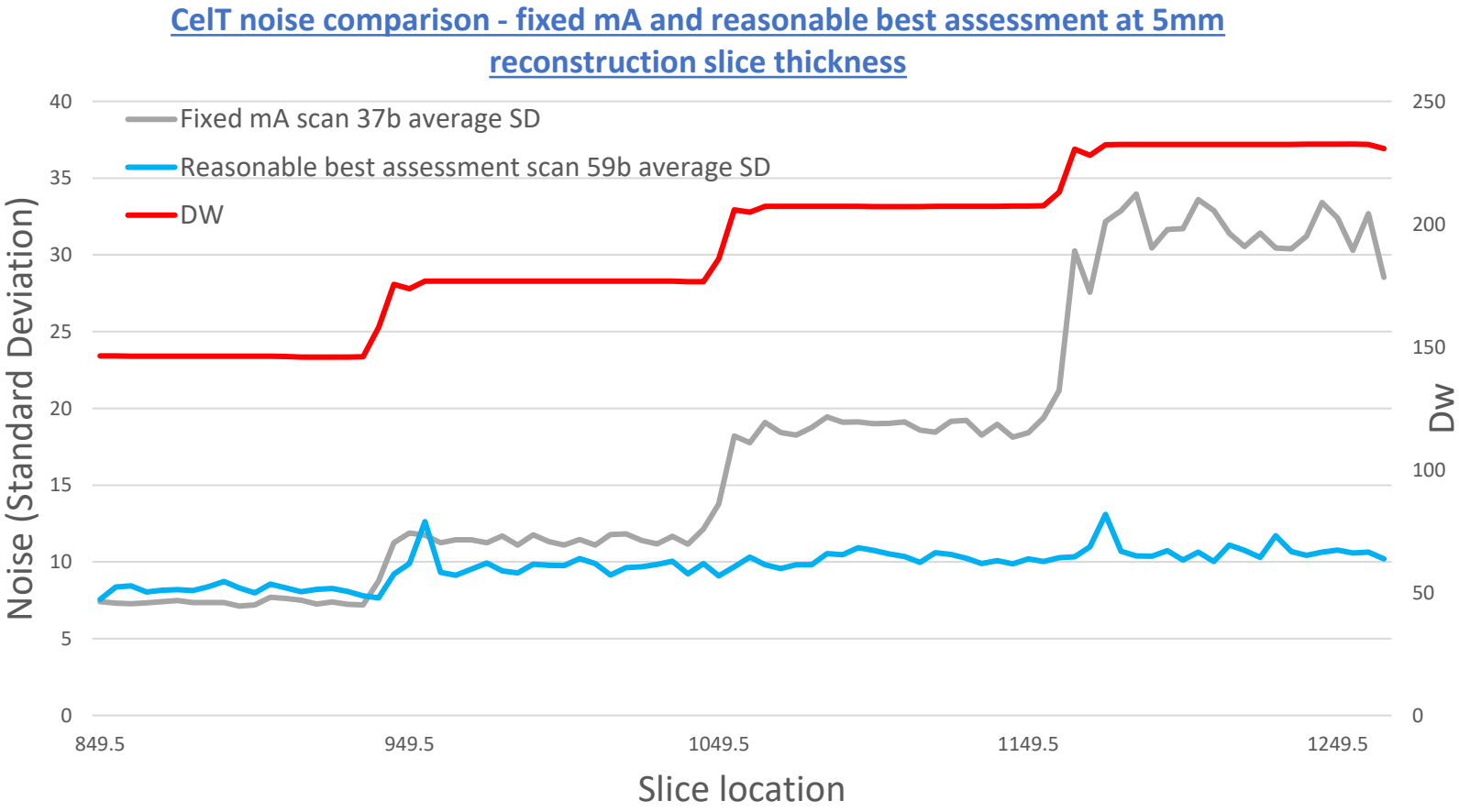
- Noise index (SD number) – This is the target noise value
- Pitch – lower pitch improved ATCM assessment
- Collimation – narrower collimation produced more detailed modulation profiles.
- mA limits – Appropriate minimum and maximum boundaries are essential to observe ATCM behaviour throughout the scan length.
- Localiser radiograph settings and positioning – affected ATCM performance and therefore should remain consistent and clinically relevant.



Results – Noise performance (ATCM vs Fixed mA)

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- All phantoms demonstrated a more uniform noise profile with ATCM switched on, rather than the fixed mA scans.
- CelT phantom showed the clearest distinction between fixed mA and ATCM scans, with ATCM maintaining consistent image noise despite changing attenuation.



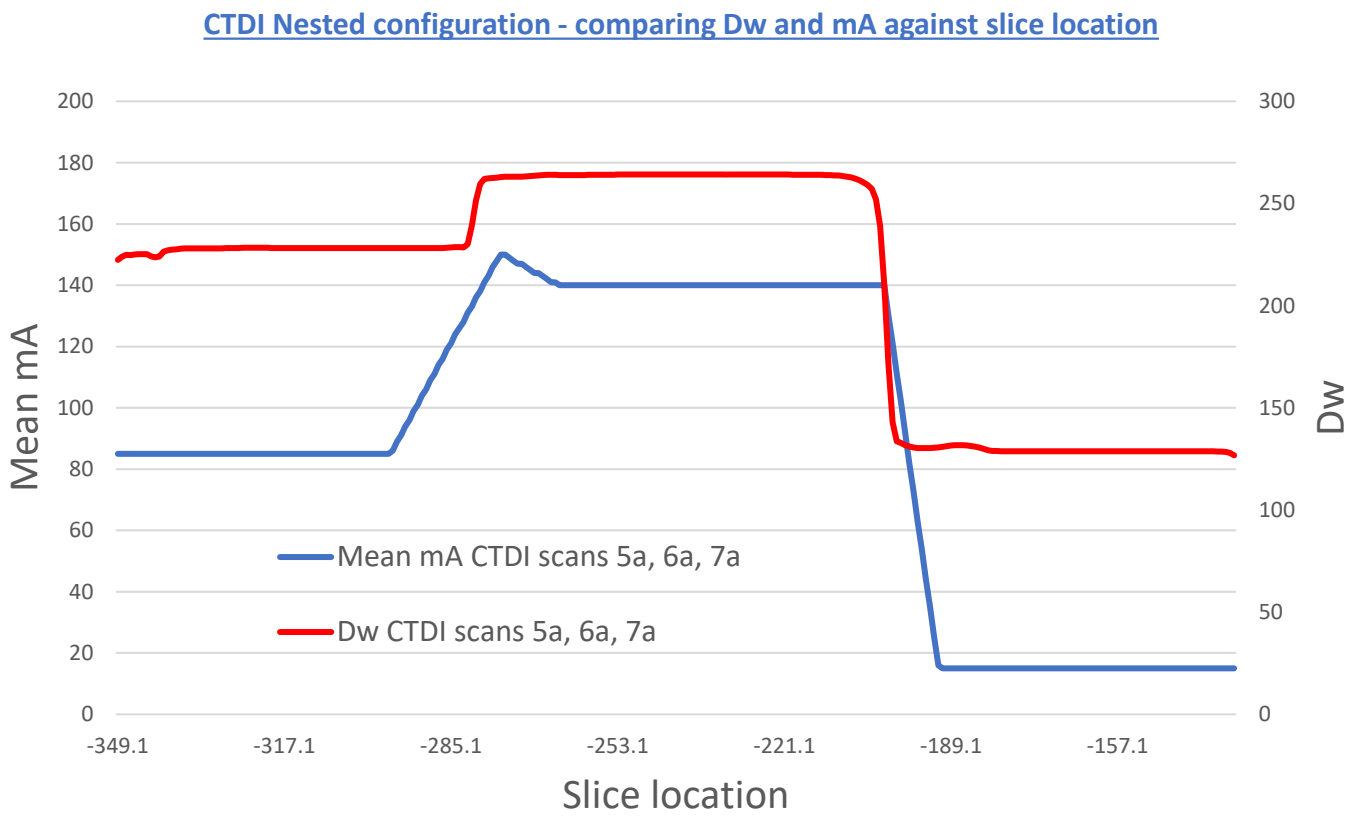
CelT noise comparison, shows fixed mA and reasonable best assessment noise profiles reconstructed at 5mm reconstructed slice thickness.



CTDI Phantom Results – mA and Water equivalent diameter

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Tube current broadly followed water-equivalent diameter, although the abrupt attenuation changes limited how closely modulation could track the phantom geometry.



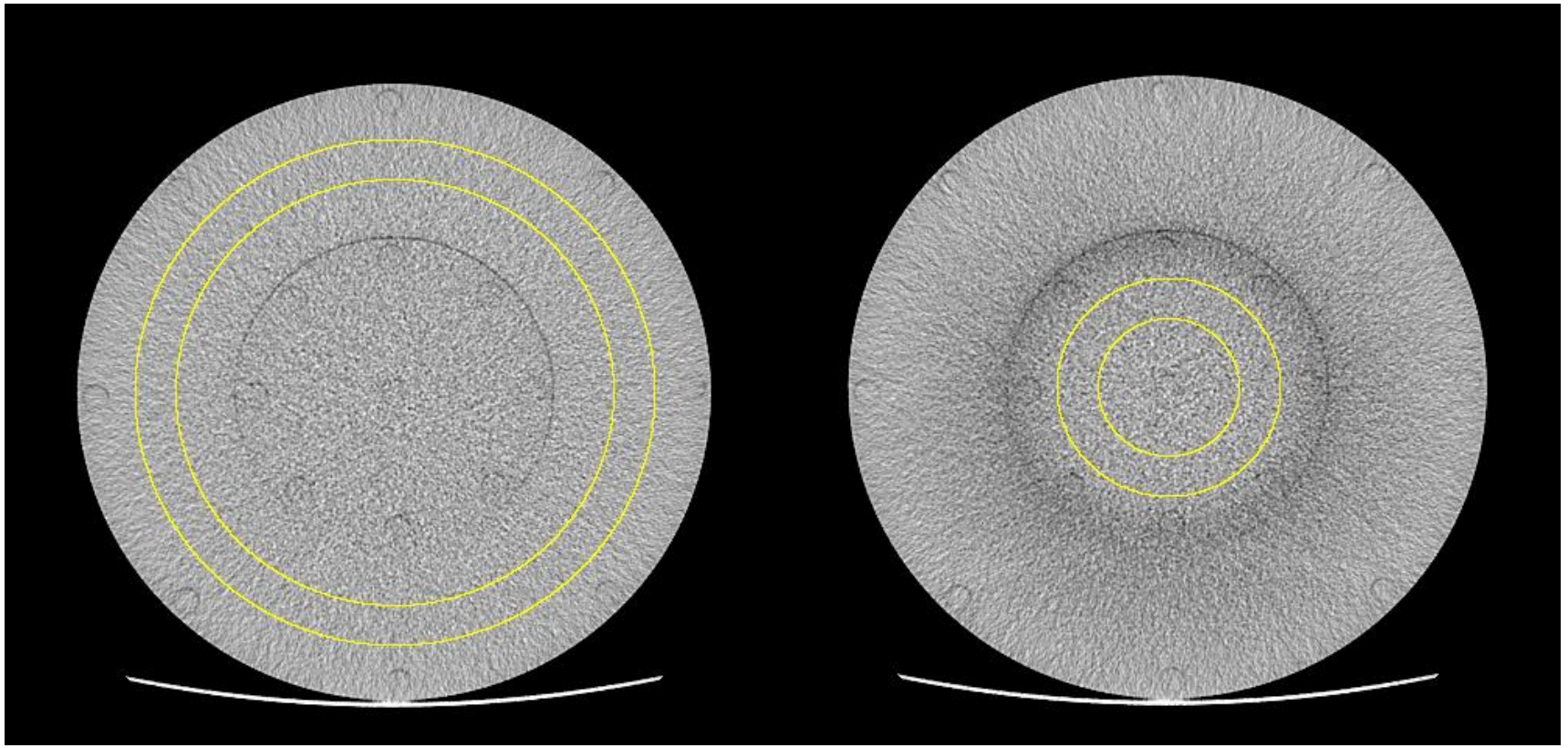
Shows the average Dw and mA plot for the CTDI phantom in the nested configuration.



CTDI Phantom Results – Noise repeatability (ROI)

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- Regions of interest used for noise measurements for the CTDI phantom



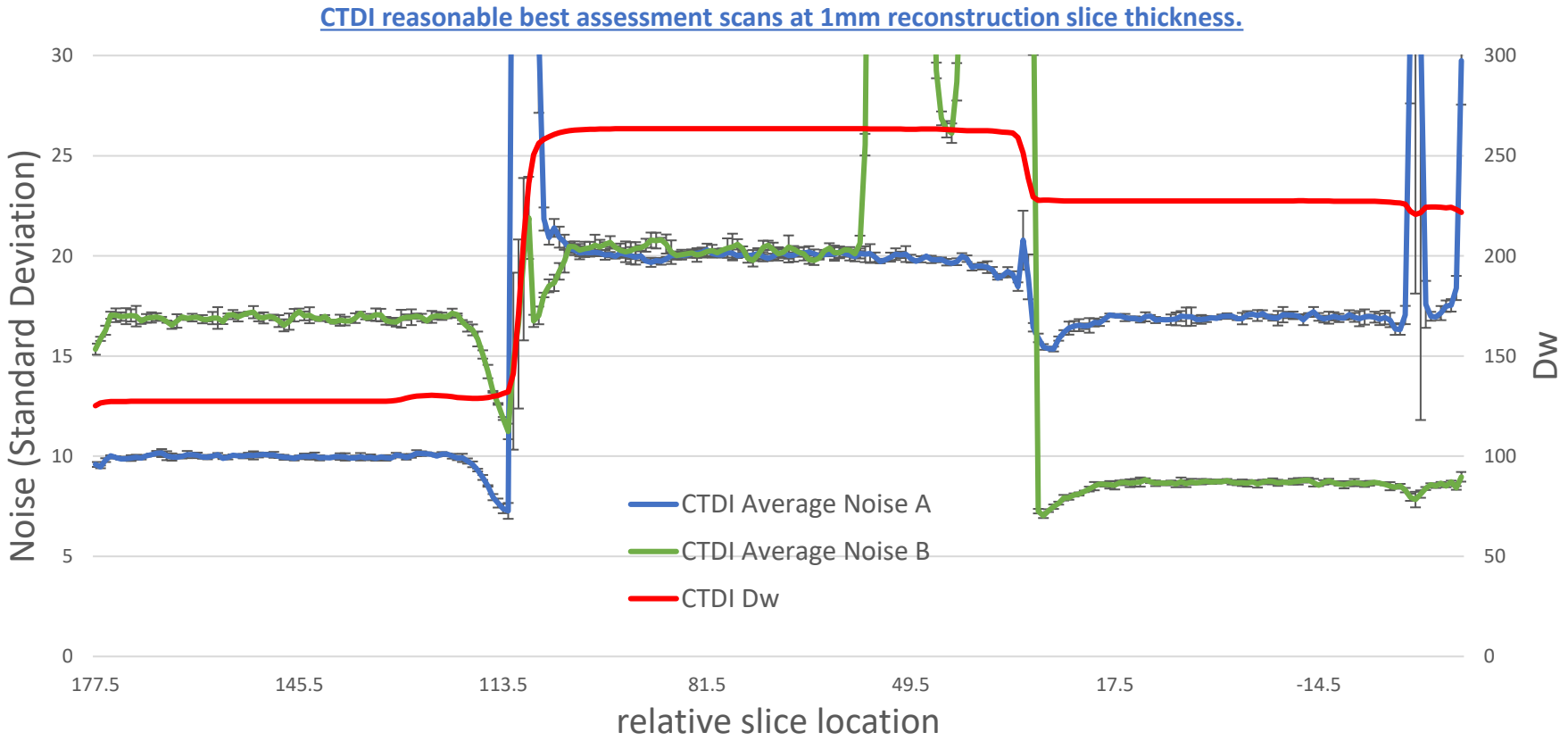
Show two annular ROIs drawn over the CTDI phantom for data collection on image J (Authors own work).



CTDI Phantom Results – Noise repeatability

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Noise profiles showed good repeatability, as indicated by the small error bars, confirming the phantom produces consistent results between repeated acquisitions with the phantom in situ.



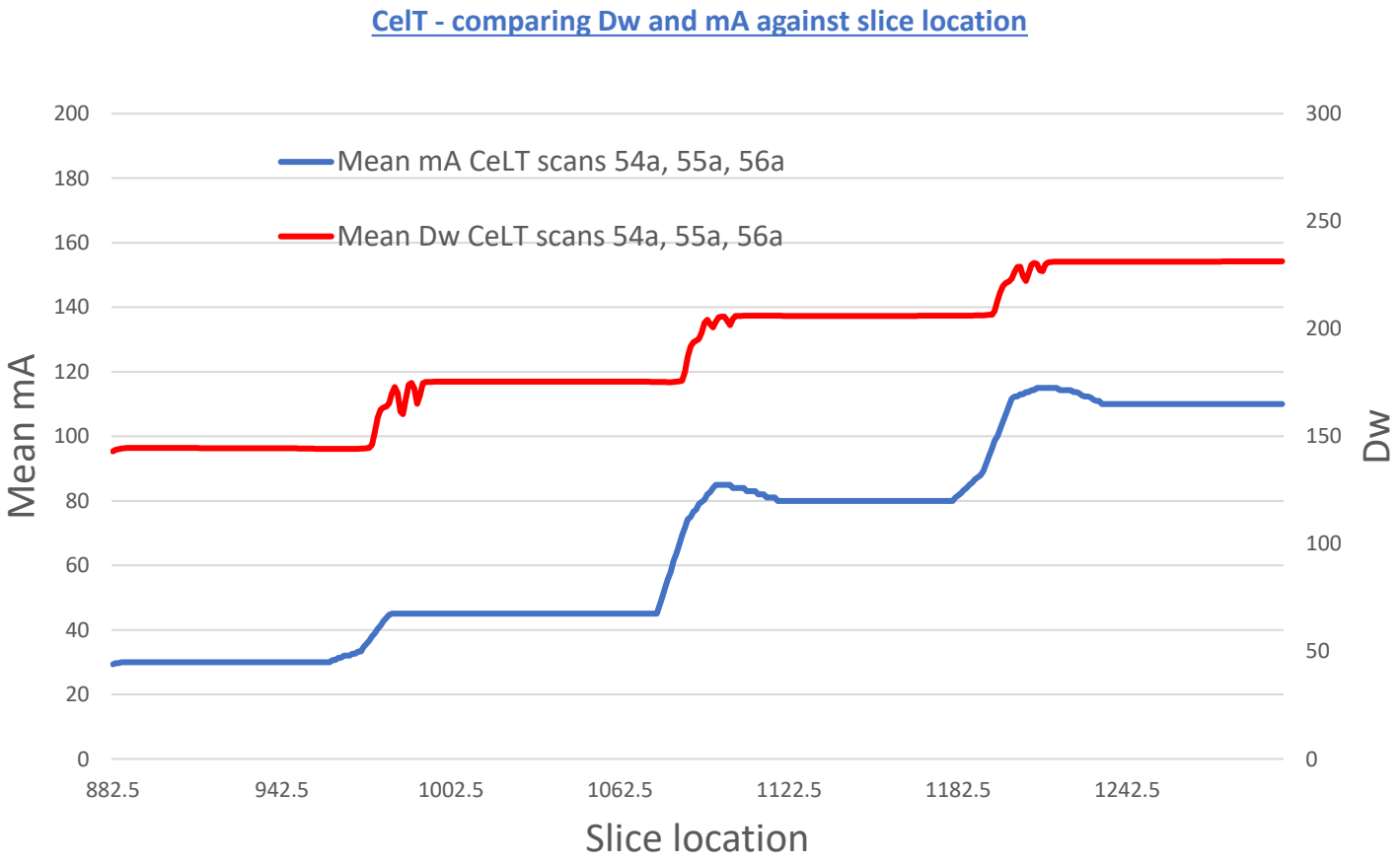
Shows the average Water-equivalent diameter and average noise plot for CTDI repeated reasonable best assessment scans, with error bars of the average standard deviation for both annular ROI.



CelT Phantom Results – mA and Water equivalent diameter

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Tube current closely followed water-equivalent diameter, producing a smooth and easily interpretable modulation profile



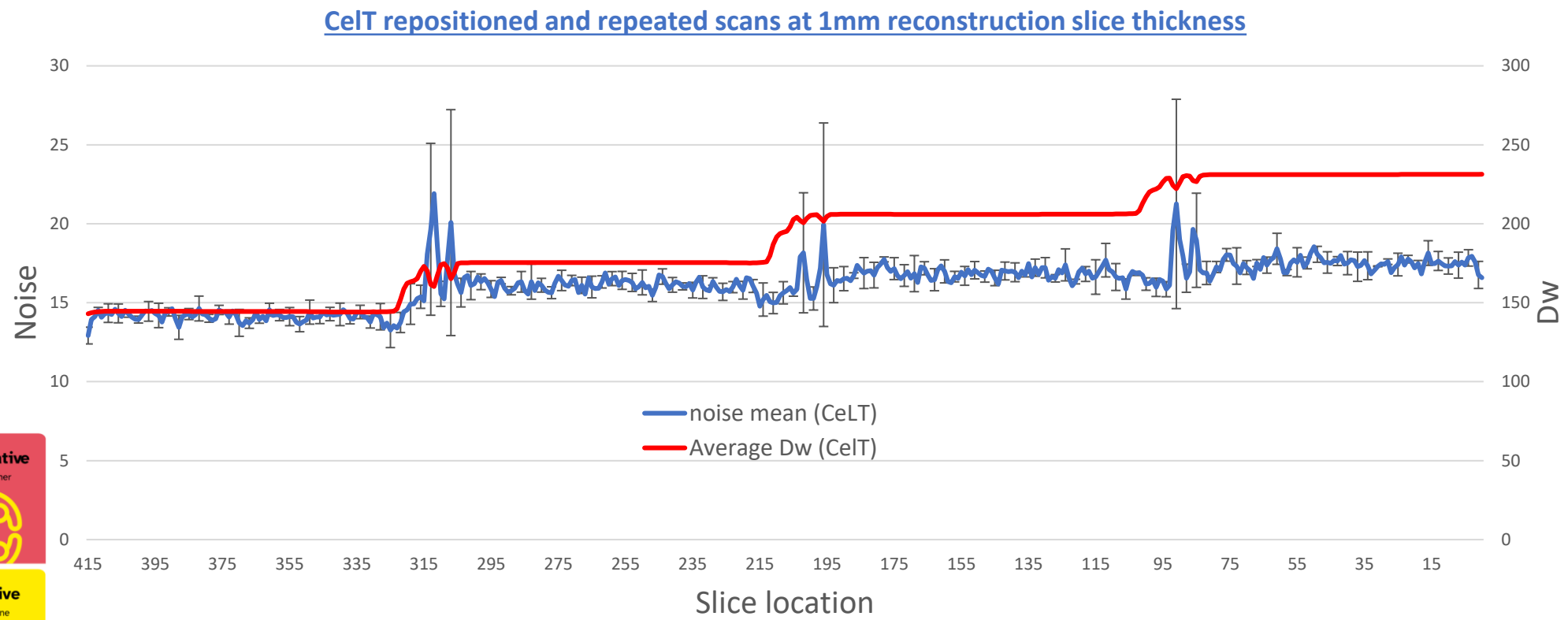
Shows the average Dw and mA plot for the Celt phantom.



CelT Phantom Results – Noise reproducibility

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Noise profiles demonstrated good reproducibility, with minimal variation observed following repeated setup and repositioning. The phantom produced a stable noise profile throughout the scan length, providing a clear and reliable demonstration of ATCM performance.



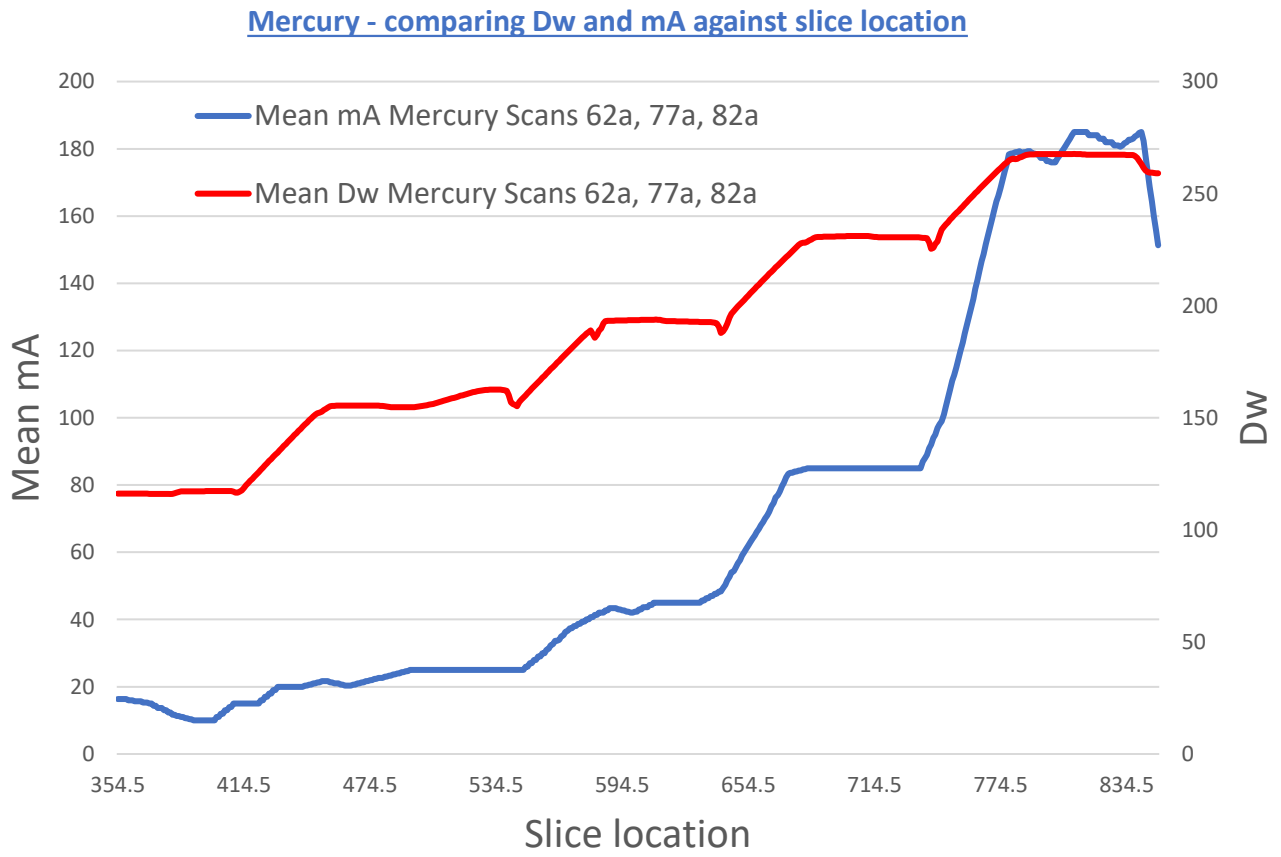
Shows the average water-equivalent diameter and average noise plot for CelT repeated reasonable best assessment scans, with error bars of the average standard deviation for four circular ROI.



Mercury Phantom Results – mA and Water equivalent diameter

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A strong correlation was also observed for the Mercury phantom, demonstrating effective modulation across a wide range of attenuation values.



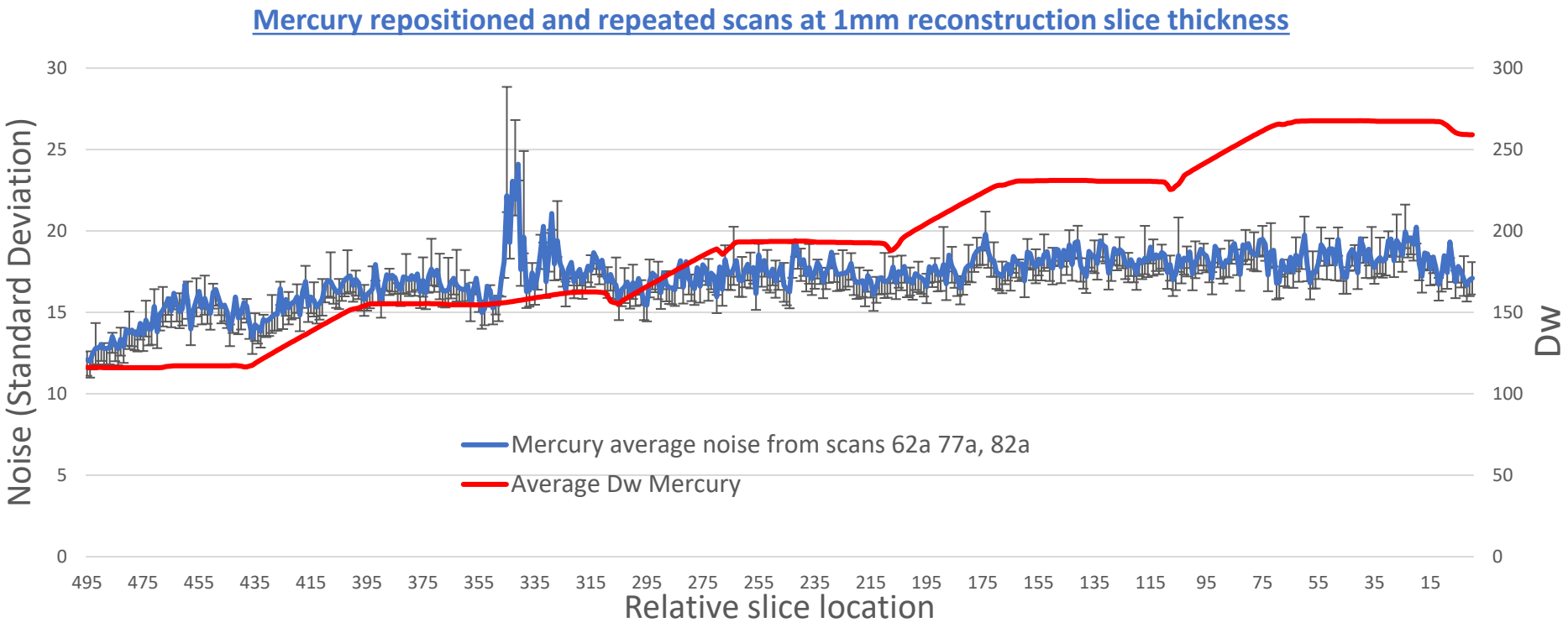
Shows the average Dw and mA plot for the Mercury phantom.



Mercury Phantom Results – Noise reproducibility

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Noise profiles demonstrated good reproducibility, with very little variation observed between scans following phantom repositioning. A stable noise profile was also observed and maintained throughout the scan length, indicating that the phantom provides a reliable method for characterising ATCM behaviour.



Shows the average water-equivalent diameter and average noise plot for Mercury phantom, repeated reasonable best assessment scans, with error bars of the average standard deviation for four circular ROI.

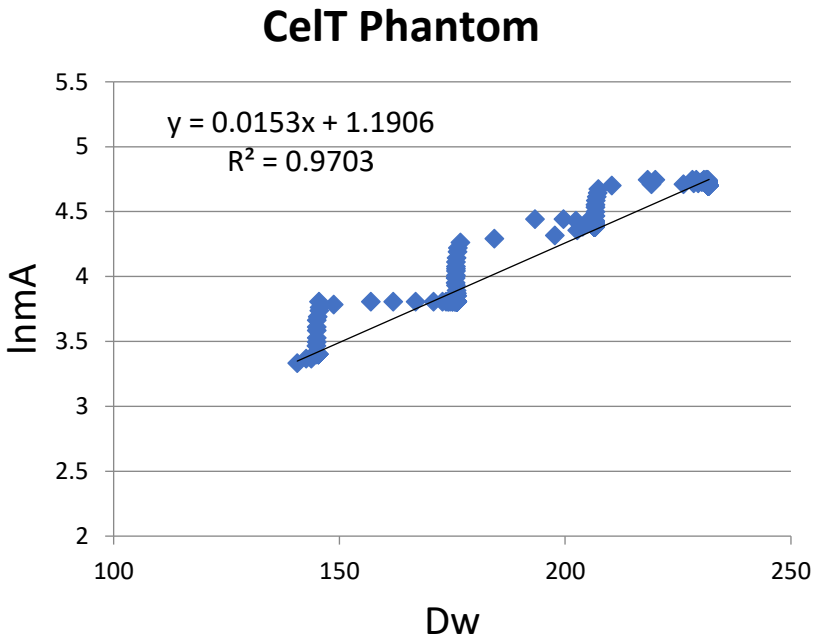


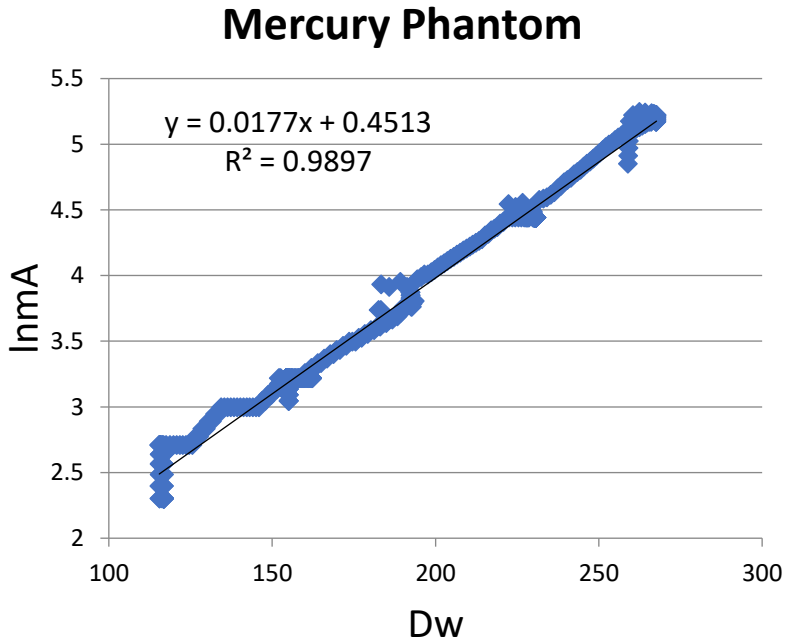
AAPM recommend performance analysis - ln(ma)

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- AAPM report 233 Recommends analysis using ln(mA) against attenuation (Water-equivalent diameter).
- The CelT phantom and the CTDI in the nested configuration are not suitable for this method.
- The Mercury phantom demonstrated a strong linear relationship and was suitable for ln(mA) Analysis.

Graphs show the natural log and water-equivalent diameter relationship of the CelT and Mercury phantoms.



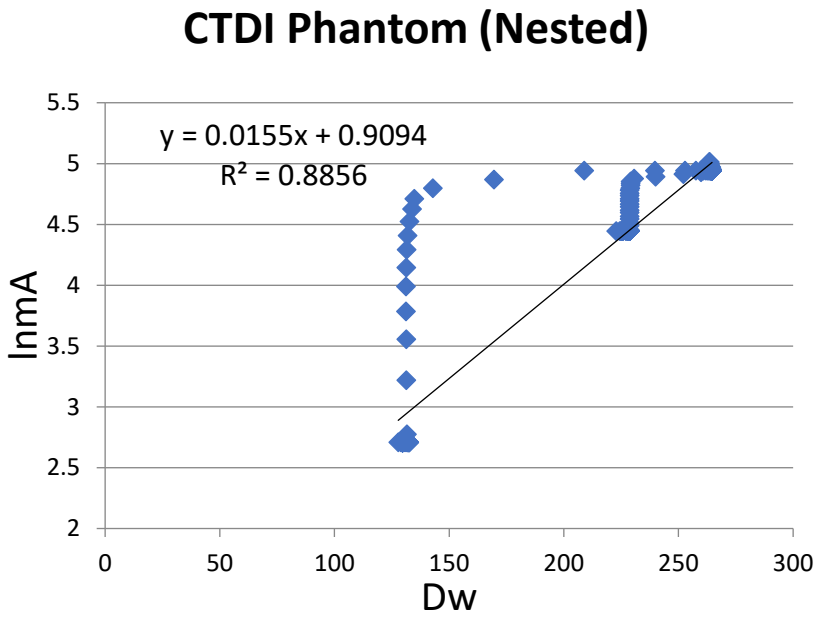


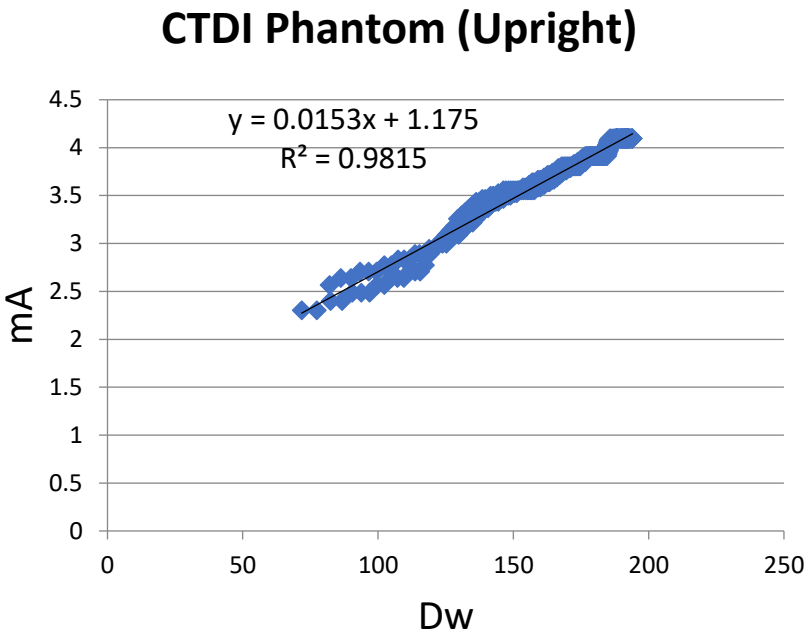
AAPM recommend performance analysis - ln(ma)

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- CTDI Phantom - nested and upright configurations

Graphs show the natural log relationship and water-equivalent diameter of the CTDI Phantom in the upright and nested configuration.





Phantoms - Strengths and Limitations

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Phantom	Strengths	Limitations
CTDI	Forms part of current QA testing equipment. Repeatable. Can be turned upright to complete ln(mA) statistical analysis.	Abrupt changes in attenuation profile – unable to assess ATCM performance consistently across the entire scan length. Phantom Steup is more difficult to consistently position.
Mercury	Most comprehensive ATCM assessment. Suitable for ln(mA) statistical analysis. Repeatable.	Heavy, difficult to transport and position.
CelT	Easy to set up, good repeatability, clear ATCM demonstration.	Unable to reliably complete ln(mA) Statistical analysis.

Conclusion

- All three phantoms successfully characterised ATCM performance.
- Mercury phantom provided the most comprehensive technical assessment.
- CelT phantom provided the best balance between technical performance and practical usability.
- CTDI phantom remains useful but is less suitable for detailed ATCM characterisation due to its discrete attenuation structure.



Limitations and Future Work

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- Only one CT Scanner
- Repeatability and reproducibility testing was limited
- No formal cost benefit analysis performed
- An important area for future work involves further analysis of the Mercury phantom’s structure
- Post UK guidance work.



Thanks for listening

Any questions?



References available upon request