Challenges in dose measurements with industrial electron beam

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DOSE MEASUREMENTS IN E-BEAM

- Routine processing in electron beam relies on qualifications studies that relate doses measured in products traceable to national standards to routine doses measured at intervals during processing.
- Types of measurements made with dosimeters:
    - Relative measurements – Energy, Scan Width, Uniformity, Spot Size, Process Interruptions
    - Absolute measurements – Dose vs Speed, Minimum, Maximum, and Monitoring doses
- All of these measurements together demonstrate that a process is capable and in a state of control

LIST OF CHALLENGES

- Good in theory BUT… E-Beam provides some additional challenges
    1. For complex devices, how do I know where to put my dosimeters?
    2. High Dose Gradients – How precise does my dosimeter placement need to be?
    3. Dosimeter resolution – If my max or min area is smaller than my dosimeter, how do I measure it?
    4. Dosimeter variability – I've managed to put a dosimeter in the right spot, but will it reliably give me the same dose?
    5. Dose map repeatability – What are the chances that I can do it all exactly the same multiple times with multiple products?
- And that was just dose mapping….

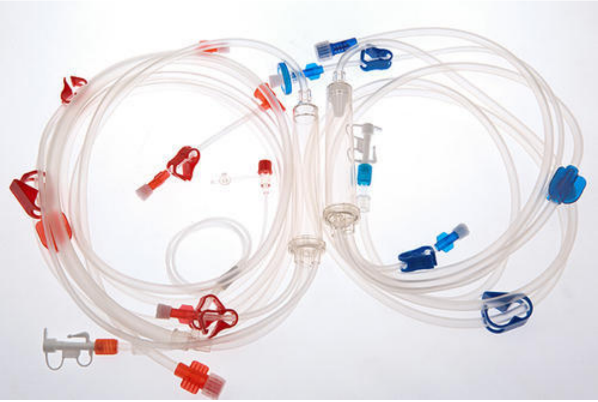
MORE CHALLENGES FOR DOSIMETRY

- Energy measurements
  - Conventional Aluminum wedges leave room for error
  - Energy measurement is performed offline to processing
  - Measurement based on equations in ASTM Standard, of questionable origin, and poorly defined below 5MeV
- Routine dose measurements
  - If dosimeter is placed on box, can have very high level of variability due to product
  - If placed off-carrier captures no information about dose delivered to product itself

DOSE MAPPING

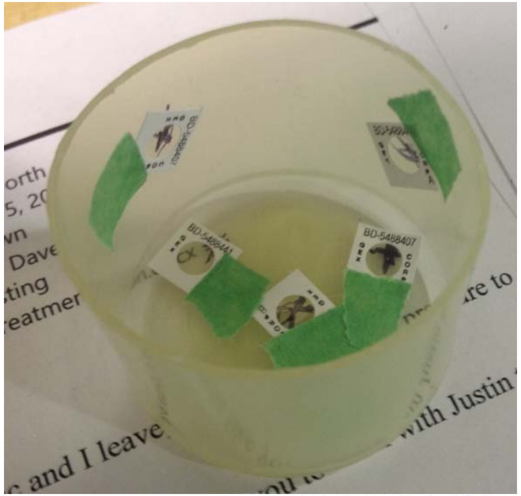
WHERE DOSIMETRY FALLS SHORT

WHAT SORT OF THINGS DO WE NEED TO DOSE MAP?



SIMPLE SMALL PLASTIC BOTTLE EXAMPLE

- Mevex dose mapped small plastic bottles at 5MeV
- Preliminary dose maps placed bottles on their sides with dosimeters placed on interior surfaces only.
    - 90º intervals
    - DUR on sides 1.05
- Re-dose mapped outside
    - 45º intervals
    - DUR 1.36



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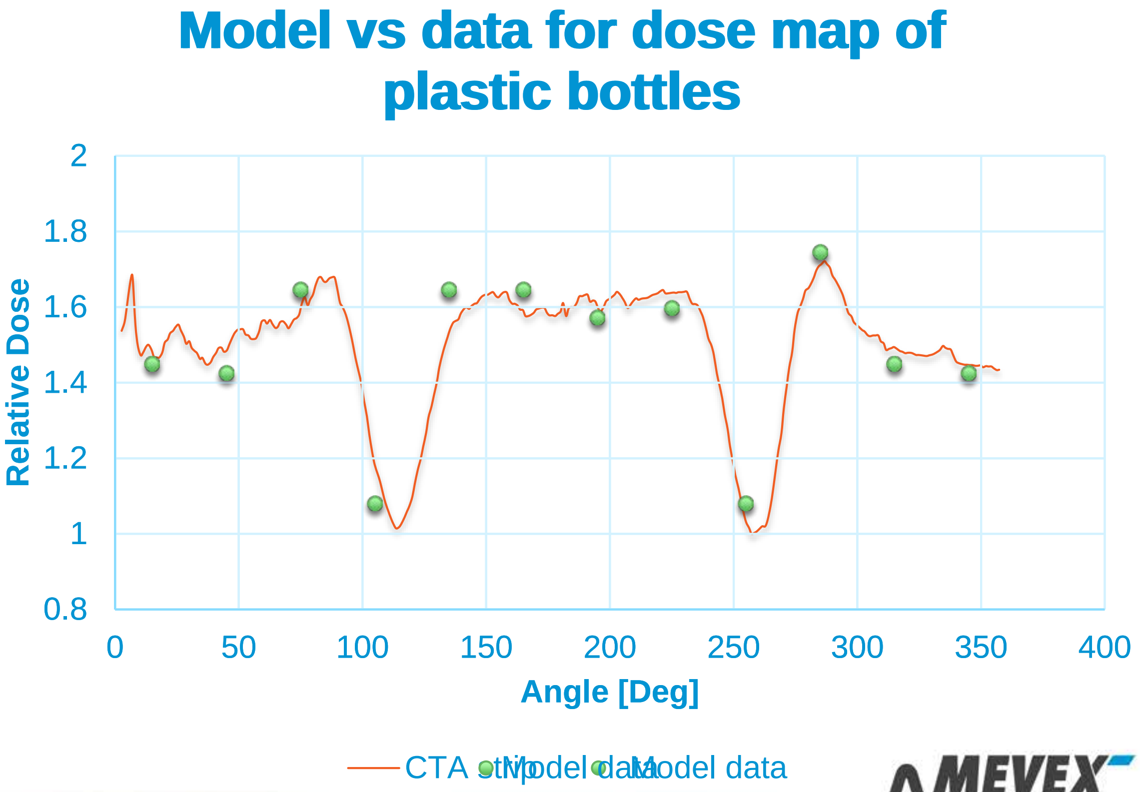
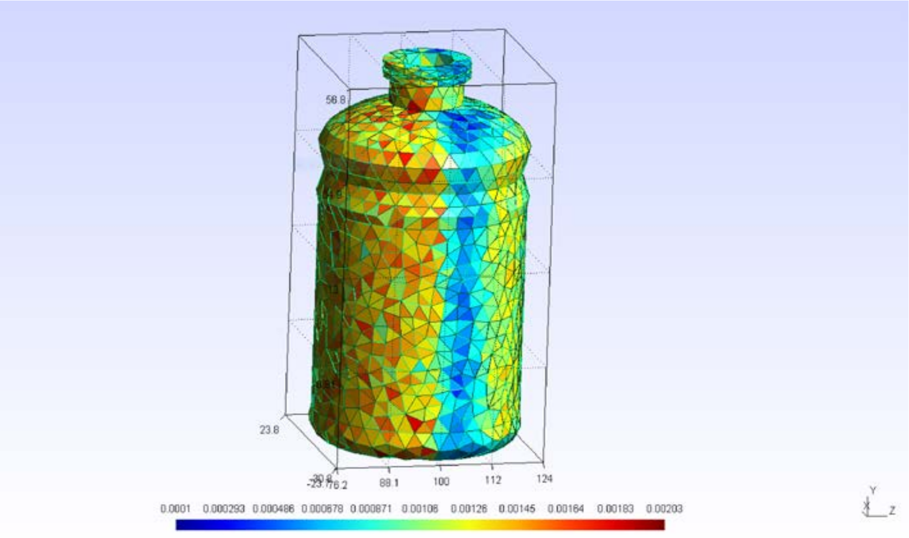
MODEL VS CTA

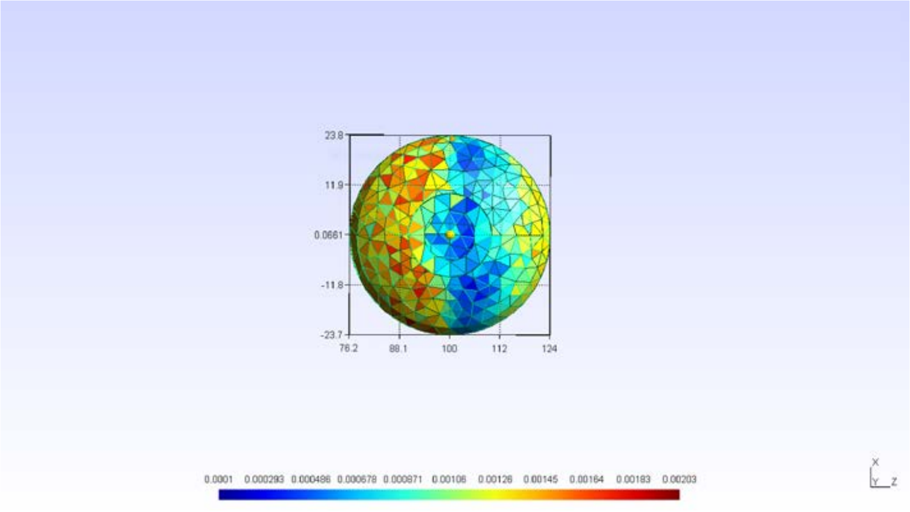
- Modeled exterior surface of bottle using EGSnrc
- Model shows sharp dose gradients around outside surface of bottle
- CTA film used to confirm suspected dose profile
- Conventional dosimetry would not measure this



MORE MONTE CARLO

- More sophisticated modelling, 400,000 particle histories, CAD input





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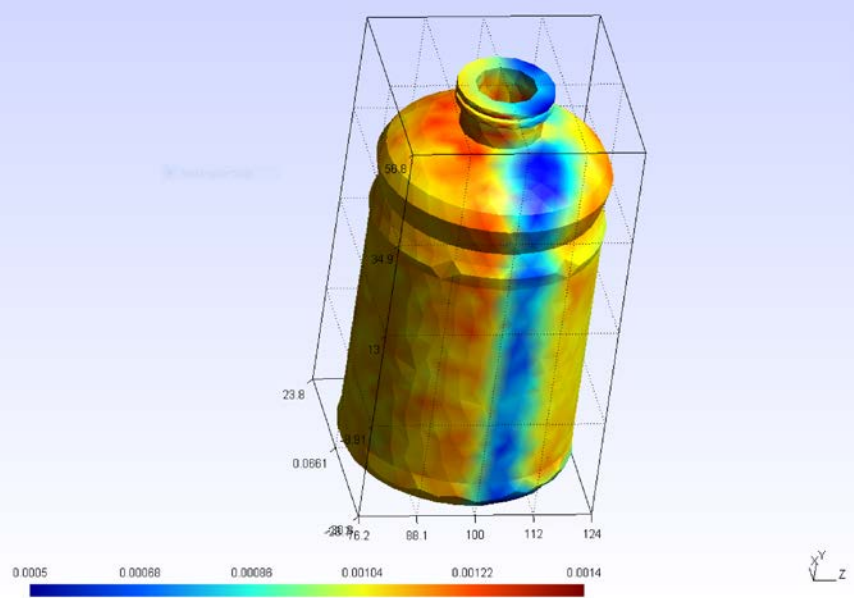
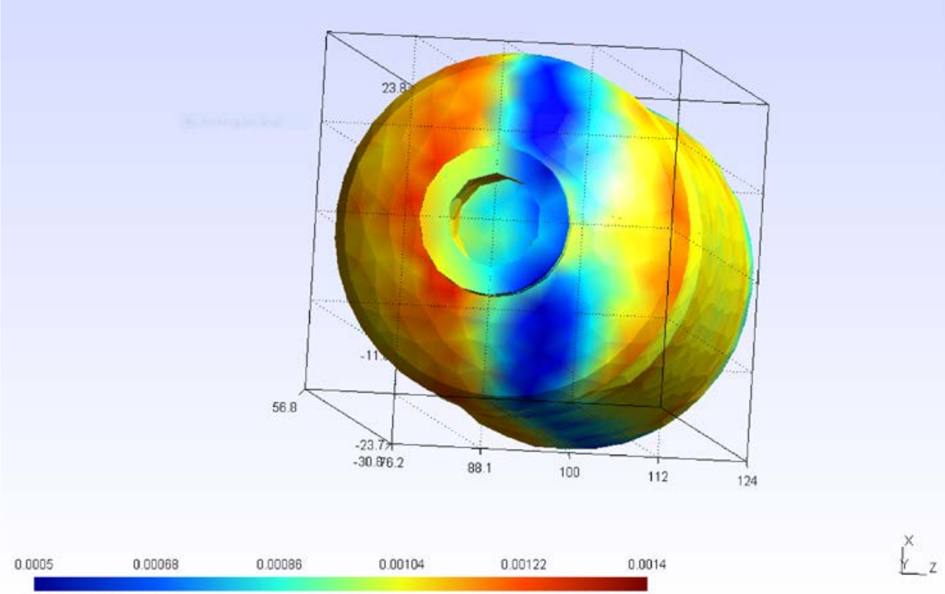
MORE HISTORIES, MORE ACCURATE RESULTS

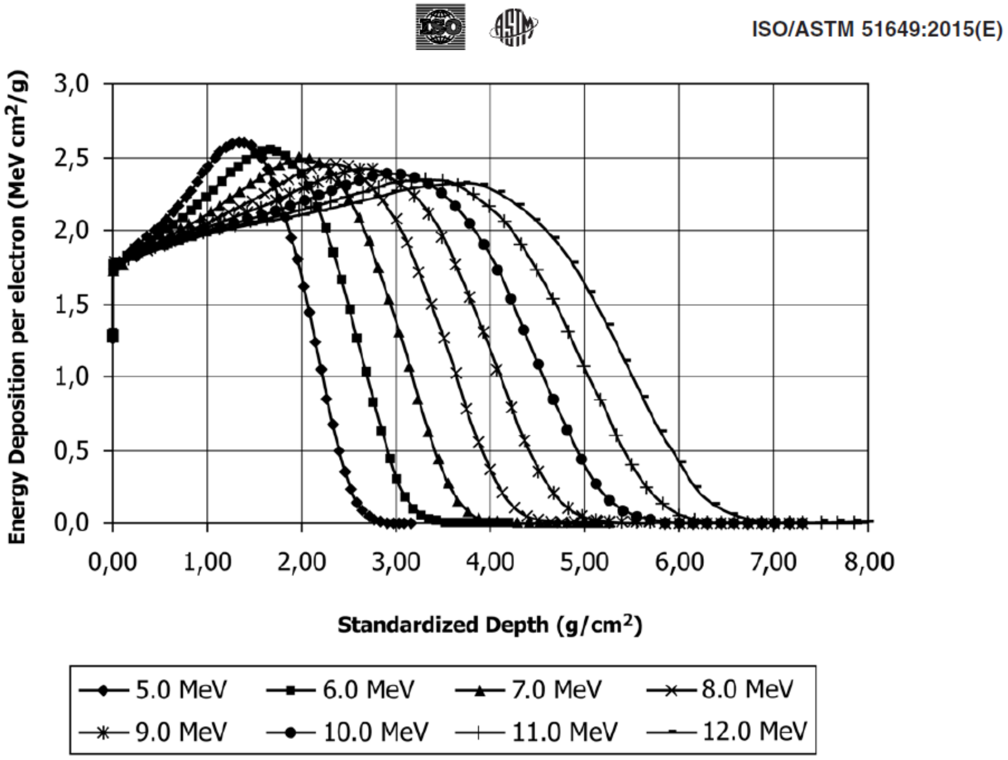
- 1,600,000 particles





MATHEMATICAL MODELLING: PART OF THE PROCESS

- Monte Carlo models can provide very accurate dose information but are cumbersome to make and take a long time to run
- Simple Point Kernel models can be used as a first order approximation for DUR expectations and maximum and minimum dose locations.



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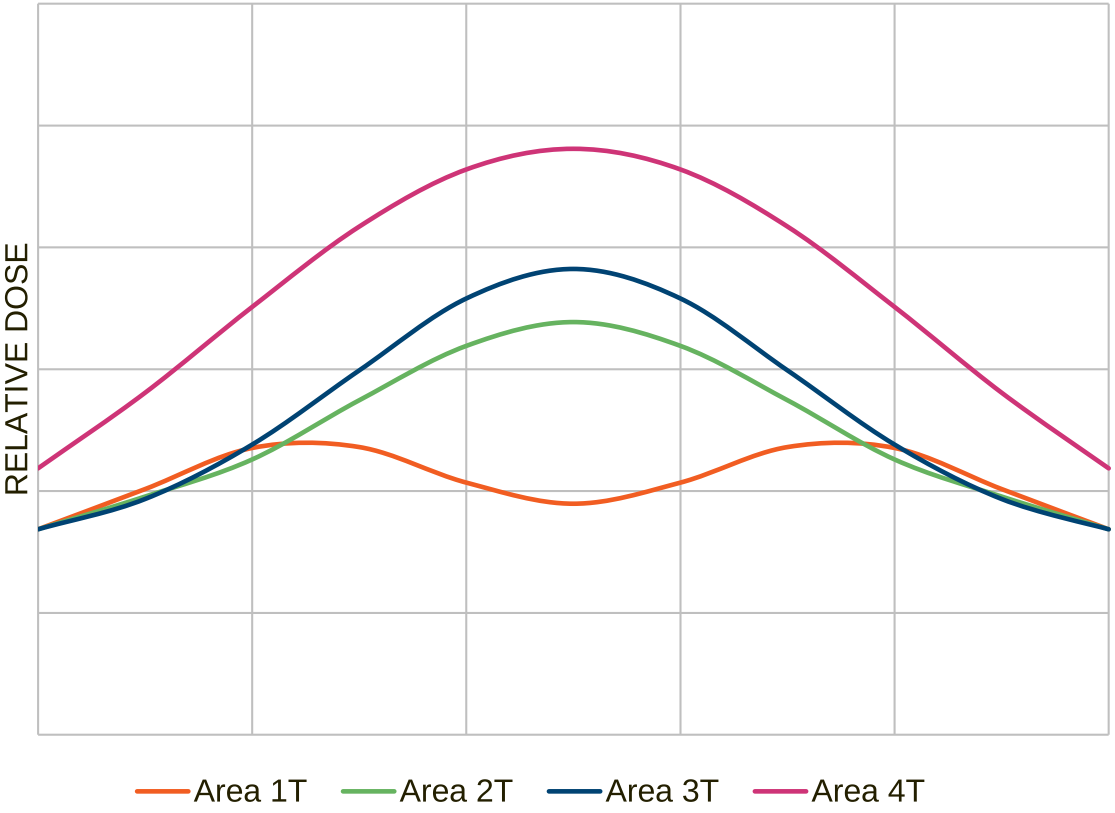
SIMPLE MODELS

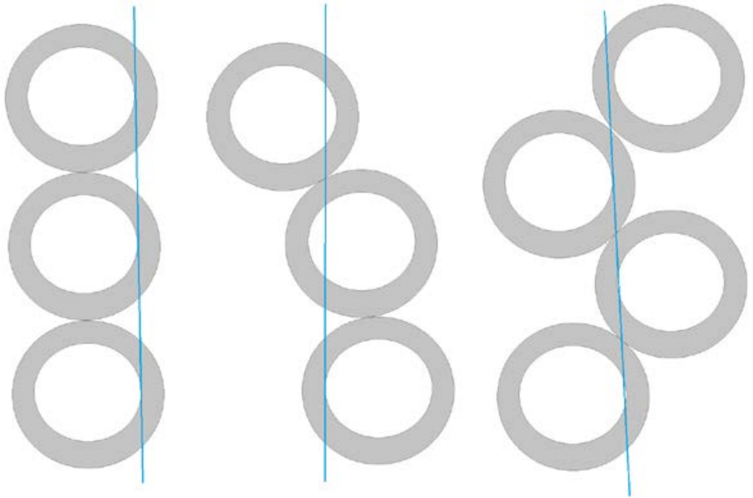
- Double Sided, Variable density
- Graph shows 4 separate regions of package:
  - Area 1T – 0.32 g/cc
  - Area 2T – 0.3 g/cc
  - Area 3T – 0.28 g/cc
  - Area 4T – 0.2 g/cc
- Overall DUR = 2.85 for package thickness 25 cm, 10 MeV



EXISTING GUIDANCE AVAILABLE INADEQUATE

- Placement strategies for dosimeters where millimeters count
- Definition of replicates in products where placement consistency is impossible
- Guidance on when sensitivity of energy counts depending on where you are on the depth dose curve

Examples of electron paths through flexible tubing coils, variability in path lengths



WHERE DO WE GO FROM HERE?

- Our ability to model has improved our ability to dose map, but what happens when we find out we've been giving higher doses than we thought?
- Consider concept of dose limits specific to areas of the product
- Examples:
  - Minimum dose area may only apply to fluid path (inside tube or syringe)
  - Minimum doses inside solid materials not relevant
  - Maximums dose to parts of device that are less radiation sensitive may be allowed, such as metal parts, or more radiation resistant polymers
  - Consider the function of the device as a whole after irradiation with predicted DURs

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NEXT LEVEL OF DOSE MAPPING

- Modelling as a replacement of or enhancement to Process Qualification Studies
  - Identify max and min locations to minimize dose mapping requirements
  - Optimize packaging and/or product orientation before mapping begins
  - Estimate doses in areas that are impossible to measure
- Product consistency
  - Model anticipated variations in product settling/orientation/placement within package
  - Scan or image products as part of routine processing to ensure specifications will be met

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ROUTINE DOSIMETRY

NO MORE CART PUSHING THE HORSE

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MEASUREMENTS WITHOUT DOSIMETERS

- What if we can measure everything we need to know about dose without using dosimeters?
- Dose is influenced by:
  - Conveyor speed
  - Beam current
  - Beam energy
  - Beam positioning
  - Product and placement

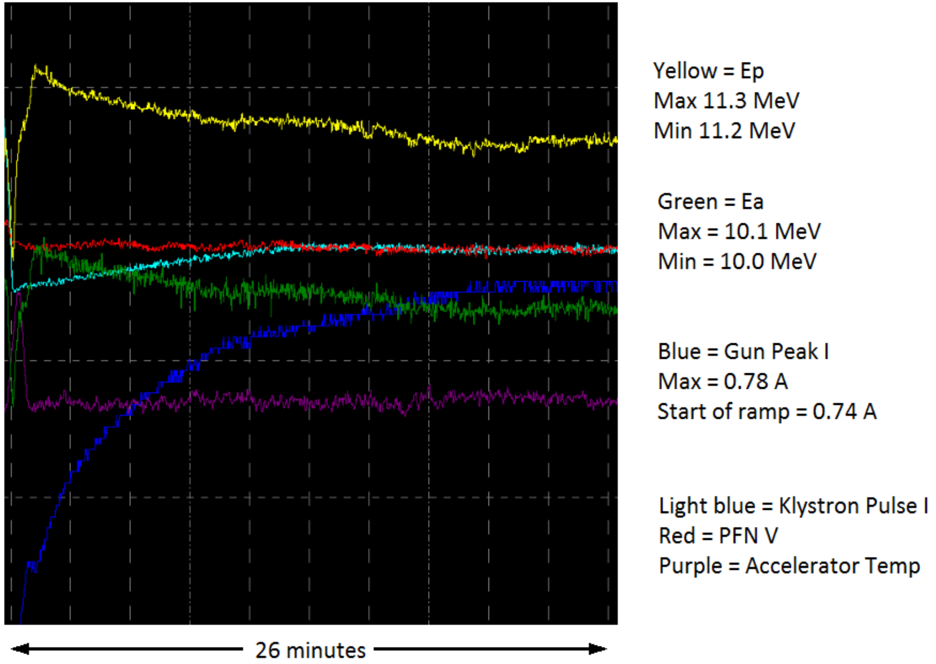
These influences are all that are measured with routine dosimetry in many e-beam systems

Relies on good process by manufacturer to make sure consistent

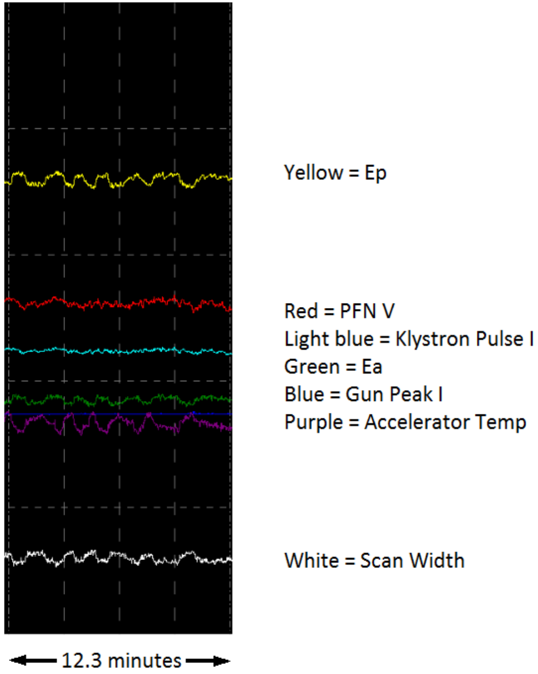
REAL-TIME ENERGY MONITORING

- Real-time energy monitoring is the missing link in the ability of an e-beam system to detect changes in output
- Consider a minimally invasive energy and beam position monitoring system
    - Real-time measurement of beam position and spot size indication
    - Correlation with scan current provides energy measurement
    - Spot size change with scan position provides indication of energy spectrum

PROTOTYPE OUTPUTS CAPTURE EXPECTED VARIATION



Energy varies during ramp-up by 0.1MeV as gun current increases



Energy variations seen with changes in accelerator temperature

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SUMMARY

WHAT NEXT?

CURRENT STATUS AND FUTURE DIRECTION

Measurement	Present methodology	Future prospect
Energy	Aluminum wedge depth dose	Beam monitor calibrated against Aluminum wedge over range of energies, demonstrate stability over time, replace conventional energy measurement
Process Qualification studies	Replicate dose maps, estimate or try to measure machine variability	Use modelling to direct or replace dose mapping studies, rely on machine parameter trending to actively measure machine variability
Routine dose measurements	Routine dosimeter apparatus RDA independent of product	Demonstrate routine doses are correlated to Energy, beam, position, conveyor measurements, replace RDAs
Product loading in containers	Relies on administrative controls	Imaging of individual boxes to ensure that product consistently matches qualified configurations
Product release	Dosimeter used to measure process is in control and doses have been delivered	Parametric release based on machine measured parameters.

WHAT ARE THE INDUSTRY NEEDS?

- An open mind to using online monitoring in electron beam systems to demonstrate that a system is in a state of control
- Better benchmarking and support for modelling tools, using both CAD and scanned images
- Calibration support for online energy monitoring
- Guidance and support for product testing with actual maximum dose distributions

THANK YOU

Questions?