CIRMS

2018

Council on Ionizing Radiation Measurements and Standards

Low Energy (80-300 keV) Electron Beam Calibration

Gary Pageau

GEX Corporation
Centennial, Colorado USA

ISO 9001 certified manufacturer of dosimetry products and NVLAP ISO 17025 accredited lab services, serving customers since 1999


ORI

Orion Registrar, Inc., USA
Certificate of Registration

This is to certify the Quality Management System of

GEX Corporation
7330 S. Alton Way, Suite 12i
Centennial, Colorado 80112
USA

Has been assessed by Orion Registrar and found to be in compliance with the following Quality Standard:

ISO 9001:2008

NVLAP®
LAB CODE 600080-0

Discussion

- Calibration Experience with Dosimetry for Low-Energy (80-300 keV) Electron Beam Applications
- Calibration Market Overview
- Traceability to National Dose Standards
- International Dose Comparison Equivalency
- Issues in Calibration of Low-Energy Dosimetry
- 10 Year Experience with Dµ
- Future Issues of Low Energy Calibration

Calibration Experience Since 2000

- Serve 25% of Industry User Base with Calibration Support Services
  - Requirements and Specifications
  - Protocol Development
  - Calibration Fixtures Including Phantoms
  - Transfer Standard Dosimeters
  - Curve Fitting and Analysis
  - Uncertainty Estimation
  - Final Calibration Report

Dosimetry System Calibration Market Overview

- >4,000 high-dose industrial irradiation processing facilities are operating today around the globe
- <400 of these facilities use dosimetry
- <300 users actually calibrate dosimetry systems
- <20 of those are low-energy e-beam facilities
- <2,000 calibration dose points are provided annually by HDRLs around the world
- <200 HDRL dose points are used by 80-300keV sites

Low energy electrons (80 – 300 keV)

Industrial Radiation Processing Applications

- curing inks and coatings
- crosslinking plastic foils
- laminating materials
- surface sterilization

Application Dosimetry

- Some processes may only require a **<u>generic dosimetry system calibration function</u>** for use in demonstrating process reproducibility is achieved at an acceptable level.

- Sterilization, however, requires dosimetry **<u>traceable to a national dose standard</u>** to satisfy ISO 11137 requirements for IQ/OQ/PQ as well as routine process monitoring.

Sterilization Traceability Requirement

ISO 11137 Sect. 4.3.4:

"Dosimetry used in the development, validation and routine control of the sterilization process **shall have measurement traceability to national or international standards and shall have a known level of uncertainty**."

ISO metrological traceability definition:

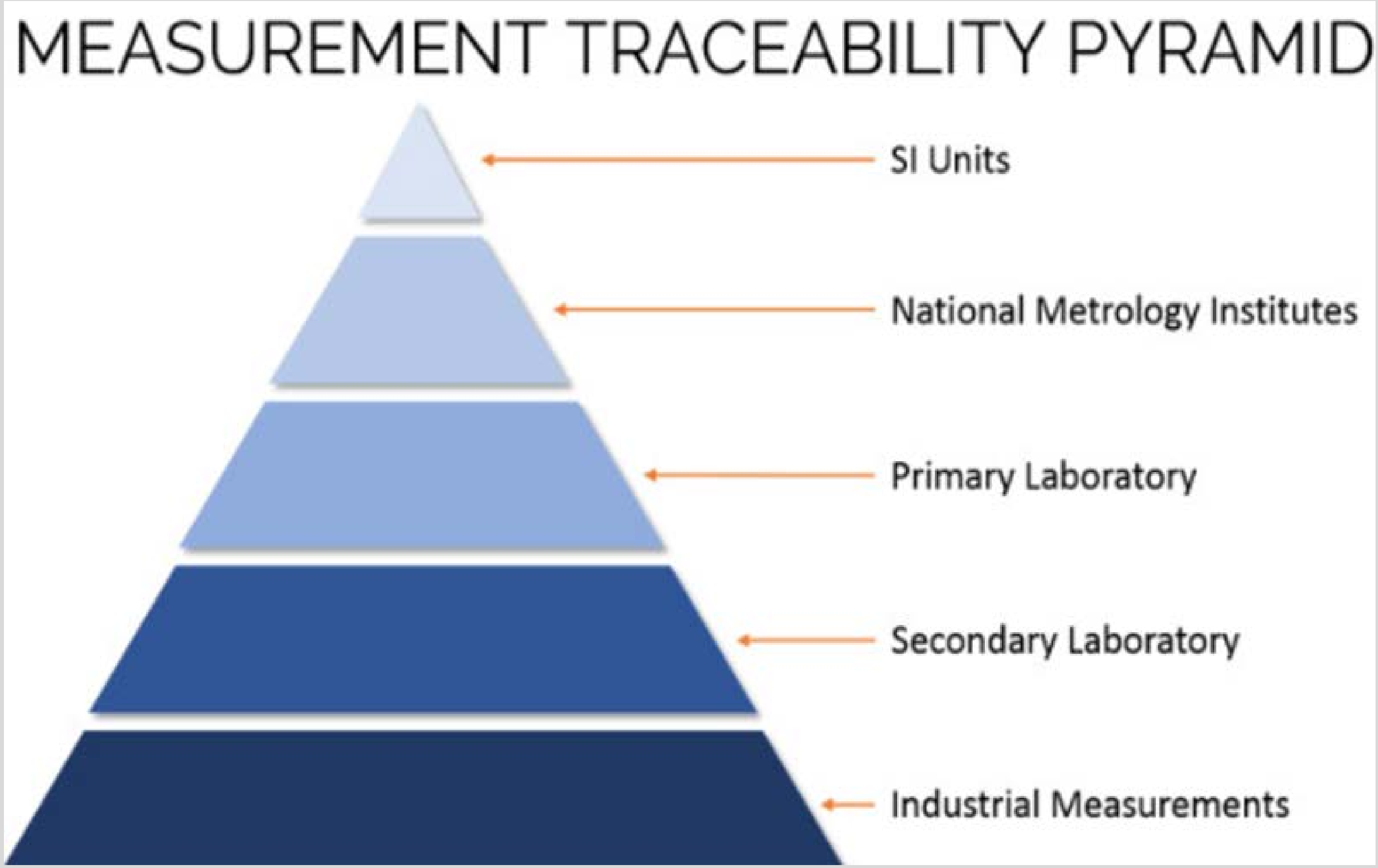
"property of a measurement result whereby the result can be **related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty**"

Traceability to National Dose Standards

ISO/ASTM 51261 – Industry Calibration Process

1. Irradiate Representative Dosimeter Batch Samples to Specific Reference Standard Doses
   a. Irradiate under fixed dose rate and temperature conditions followed by verification audit under actual usage conditions
   b. Irradiate under actual variable dose rate and temperature conditions
2. Measure Routine Dosimeter Responses
3. Determine the Calibration Coefficients for Response as a function of Dose
4. Determine the Associated Batch Calibration Uncertainties
5. Measure Routine Dosimeter Responses and Estimate Doses with their Associated Uncertainties

Measurement Traceability



Uncertainty Propagation

Measurement Equivalency
BIPM - CIPM – CCRI - MRA

The BIPM or International Bureau of Weights and Measures (Bureau international des poids et mesures) is an intergovernmental organization established to maintain the International System of Units (SI).

- International Committee for Weights and Measures (CIPM)
- Consultative Committee for Ionizing Radiation (CCRI)
- Mutual Recognition Arrangement (CIPM MRA) provides the means of conformity assessment.

CCRI NPL/NIST Intercomparison Results

Metrologia **48** (2011) *Tech. Suppl.* 06009

Table 2. Results for the NIST dosimeters

T_{ref} = 24 °C, 0.14 %/K at 1 kGy

0.11 %/K at 5 kGy, 15 kGy, 0.12 %/K at30 kGy

Irradiating lab	Dosim ref	Lab est / kGy	Temp / °C	NIST est / kGy
NPL	47	0.9987	25.0	1.015
	48	0.9987	25.0	1.014
	45	5.020	25.0	5.053
	46	5.020	25.0	5.063
	43	15.08	25.0	15.248
	44	15.08	25.0	15.196
	41	30.15	25.0	30.074
	42	30.15	25.0	30.152

Table 3. Results for the NPL dosimeters

T_{ref} = 25 °C, 0.14 %/K at all dose levels

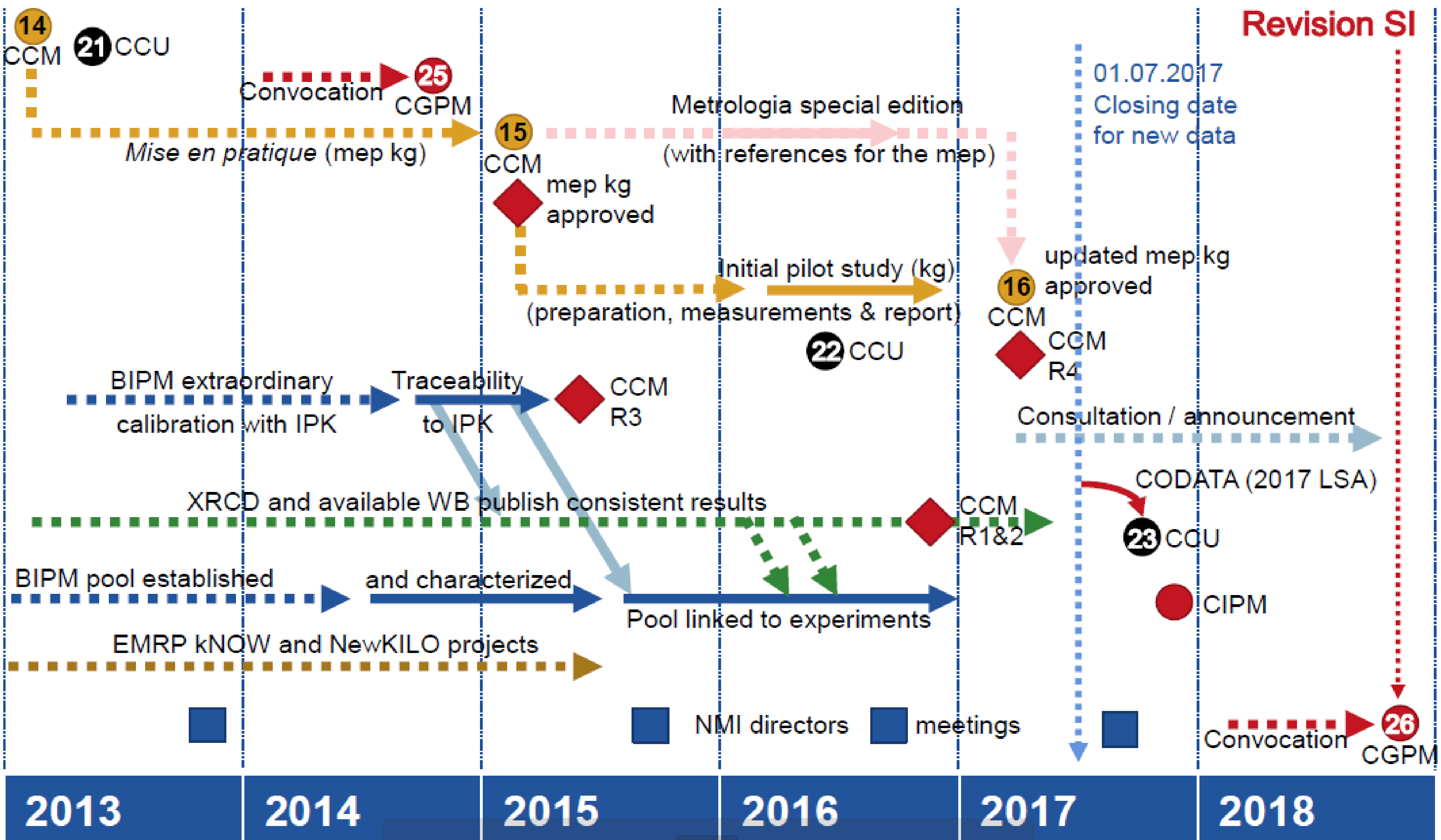
Irradiating lab	Dosim ref	Lab est / kGy	Temp / °C	NPL est / kGy
NIST	1412	1.00	23.7	0.997
	1413	1.00	23.8	0.990
	1414	5.00	23.7	4.946
	1415	5.00	23.8	4.948
	1416	15.00	23.8	14.920
	1417	15.00	23.6	14.906
	1418	30.00	23.5	29.380
	1419	30.00	23.6	29.711

Future International Dose Comparisons

The next CCRI Intercomparison is currently being planned with a number of national standards labs and their secondary standards labs expected to participate.

The new SI revision eliminating the kilogram may also involve a round of testing to compare ionizing radiation dosimetry results once again.

Joint CCM and CCU roadmap for the new SI



Field Use Intercomparison Study

GEX carried out a HDRL intercomparison study in 2016 using reference transfer standard alanine provided by:

- **NPL**
- **NIST**
- **GEX**
- **DTU Risø**

Target dose irradiations were performed under "real-world" conditions encountered in commercial irradiation facilities:

- **Fixed dose rate and temperature customer Gammacell 220 irradiator**
- **Large scale 10 MeV industrial irradiator**

Results of the Four Lab Intercomparison Testing

Cal ID#	Irradiated	Target kGy	°C Temp$_{corr}$	DTU Risø	NIST	NPL	GEX
3451	8/17/2016	7.5	32.5	7.55	7.45	7.38	7.39
3451	8/18/2016	25.0	32.5	25.1	24.8	24.6	25.0
3451	8/18/2016	45.0	32.5	45.3	45.1	44.6	45.2
3452	8/16/2016	0.5	27.5	0.81	0.807	0.83	0.84
3452	8/16/2016	2.5	27.5	2.30	2.30	2.27	2.29
3452	8/16/2016	6.0	30.0	5.53	5.56	5.44	5.48
3452	8/16/2016	12.0	32.5	11.1	11.0	10.9	11.1
3452	8/16/2016	20.0	36.0	18.6	18.7	18.3	19.3
3452	8/16/2016	45.0	47.5	47.4	47.7	46.6	47.9
3452	8/16/2016	70.0	57.5	70.0	72.5	69.4	70.8

Associated Dose Measurement Uncertainty (k=1)		
Lab	"fixed" field	"variable" field
NIST	0.900	0.090
NPL	1.200	1.200
GEX	1.065	1.350
DTU Risø	1.750	1.750

Conclusions of Field Intercomparison

- Historical National Measurement Institute interlab dose comparison testing though BIPM has demonstrated agreement of 1.0% or less using NPL & NIST alanine transfer dosimeters.
- The NIST and NPL dose chains have been field tested and demonstrated equivalent within their normally expected uncertainty limits.
- Industrial Radiation Processing dosimetry systems can be reliably calibrated traceable to either NPL and NIST with highly predictable results.

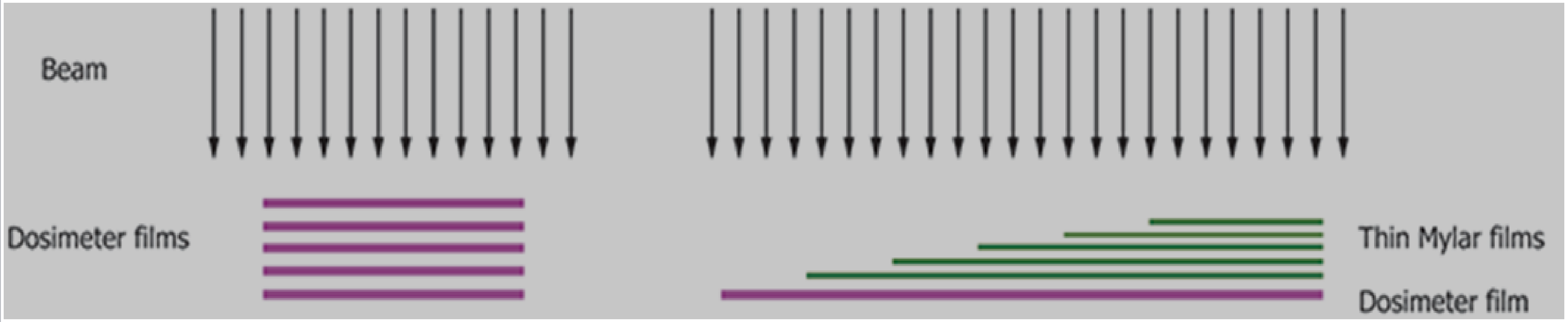
Outlook

- The Radiation Processing Industry’s future relies on continuing government investment in radiation therapy, baggage and cargo inspection development funding of NMIs in order to maintain the current level of ionizing radiation metrology.
- It is hoped that Hopewell Design’s fixed dose rate and temperature irradiator comes to fruition in order to replace the discontinued and aging base of Gammacell 220 irradiators to alleviate industry concern of ongoing calibration service availability from the HDRLs.

80-300 keV Dose Gradient Issue

Irradiation with low-energy electrons (80 – 300keV) results in dose gradients across the thickness of the dosimeters that are typically used for dose measurement at these energies. This leads to different doses being measured with different thickness dosimeters irradiated to the same actual doses.

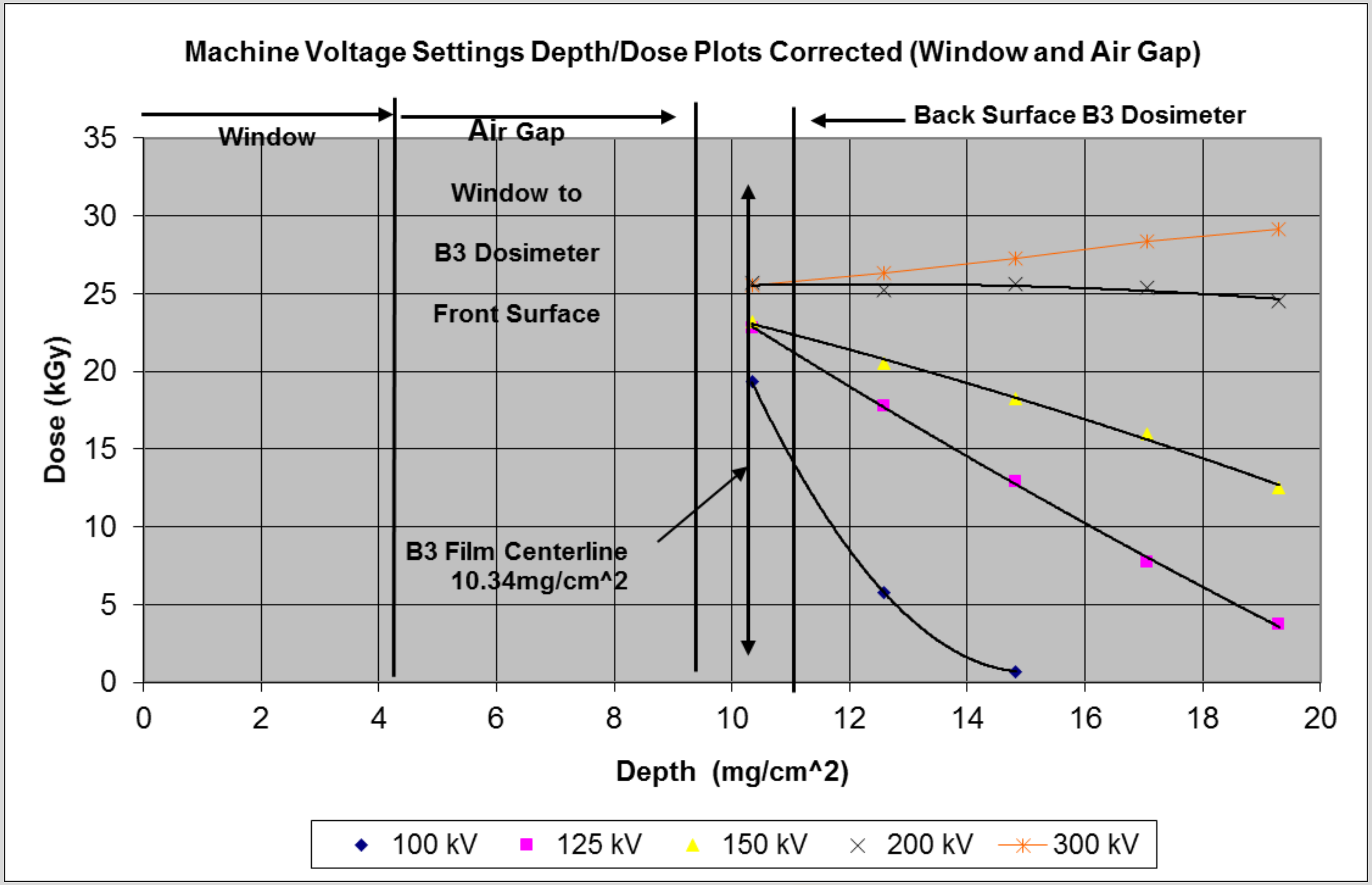
Depth/Dose Energy Measurement



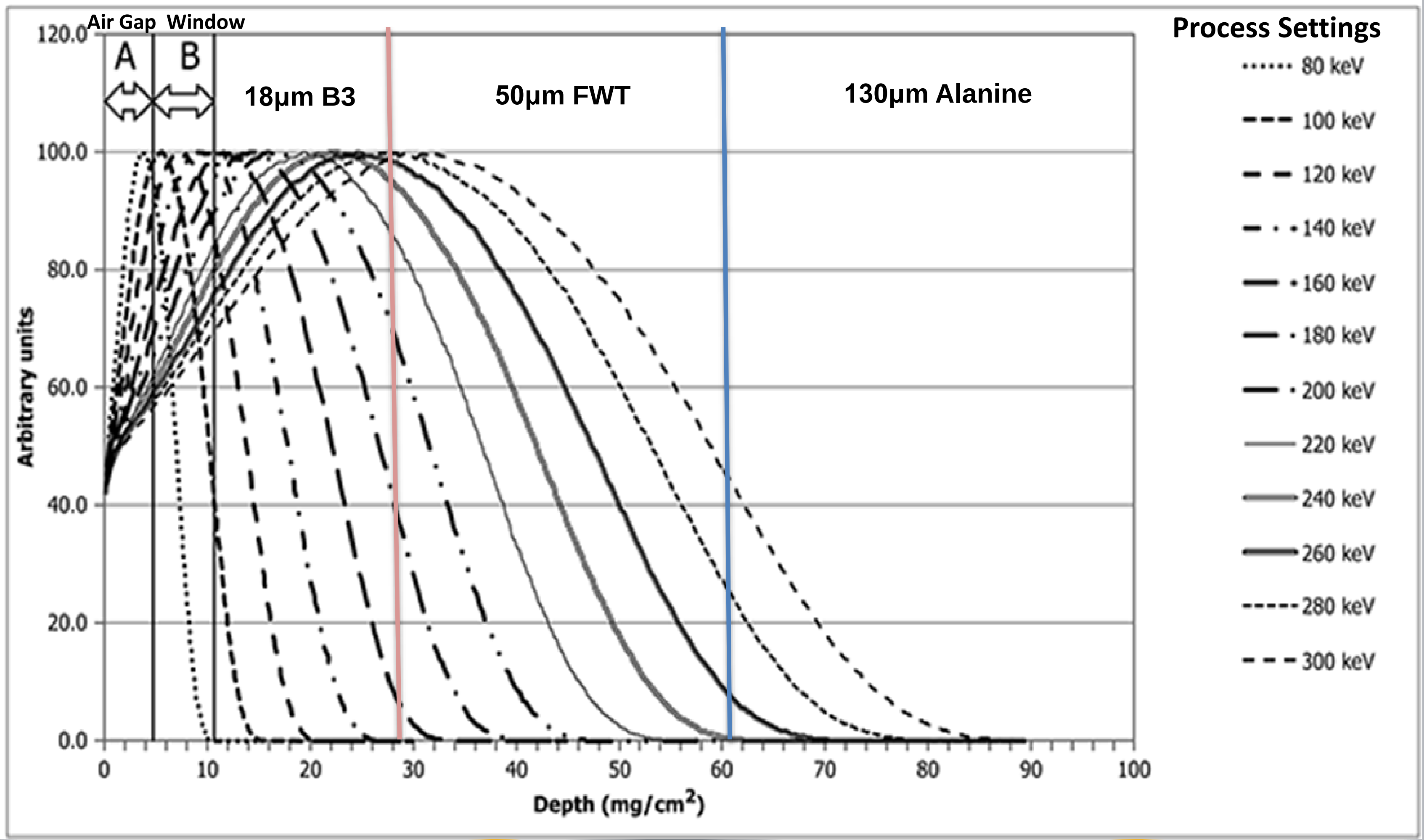
Left: A stack of thin dosimeter films.
Right: A dosimeter film under increasing layers of thin plastic (Mylar) films.

Physical depth/dose measurements are made using stacks of thin (18 micron) radiochromic film dosimeters, or strips of radiochromic film with graduated length thin Mylar strips

100-300keV Depth/Dose Actuals



80-300 keV Depth/Dose Model



The Dμ Solution

The dose to the transfer standard reference alanine dosimeter is adjusted to account for dose gradient bias.

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D_μ—A new concept in industrial low-energy electron dosimetry

Jakob Helt-Hansen [a], Arne Miller [a,*], Peter Sharpe [b], Bengt Laurell [c], Doug Weiss [d], Gary Pageau [e]

[a] Risø High Dose Reference Laboratory, Risø-DTU, DK-4000 Roskilde, Denmark
[b] National Physical Laboratory, Teddington TW11 OLW, UK
[c] Electron Crosslinking AB, SE-302 44 Halmstad, Sweden
[d] 3M Corporate Research, St. Paul, MN 55144-1000, USA
[e] GEX Corporation, Centennial, CO 80112, USA

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A B S T R A C T

Irradiation with low-energy electrons (100–300 keV) results in dose gradients across the thickness of the dosimeters that are typically used for dose measurement at these energies. This leads to different doses being measured with different thickness dosimeters irradiated at the same electron beam,

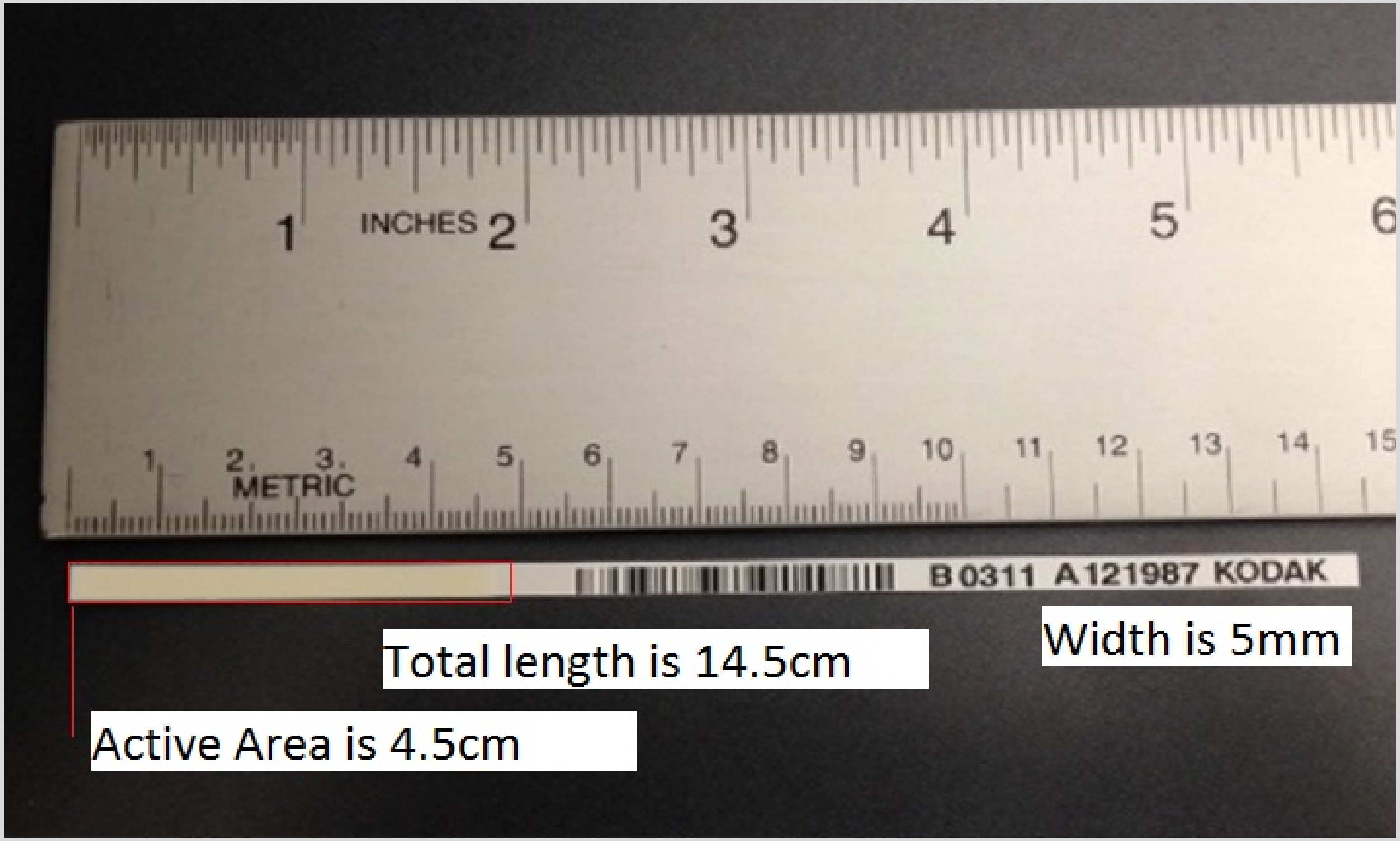
Surface dose, Dμ

The relationship between $\mathbf{D_{\mu}}$ and the **apparent dose** $\mathbf{D_{app}}$ depends on:

- **Depth dose curve in the dosimeter:**
  - **dosimeter thickness,**
  - **radiation energy,**
  - **accelerator window material and thickness,**
  - **distance window to dosimeter,**
  - **and temperature of air between window and dosimeter.**
- **Dosimeter response function**
  - **dose**

The relationship must be calculated for each set of irradiation conditions!

Transfer Alanine Film Dosimeter



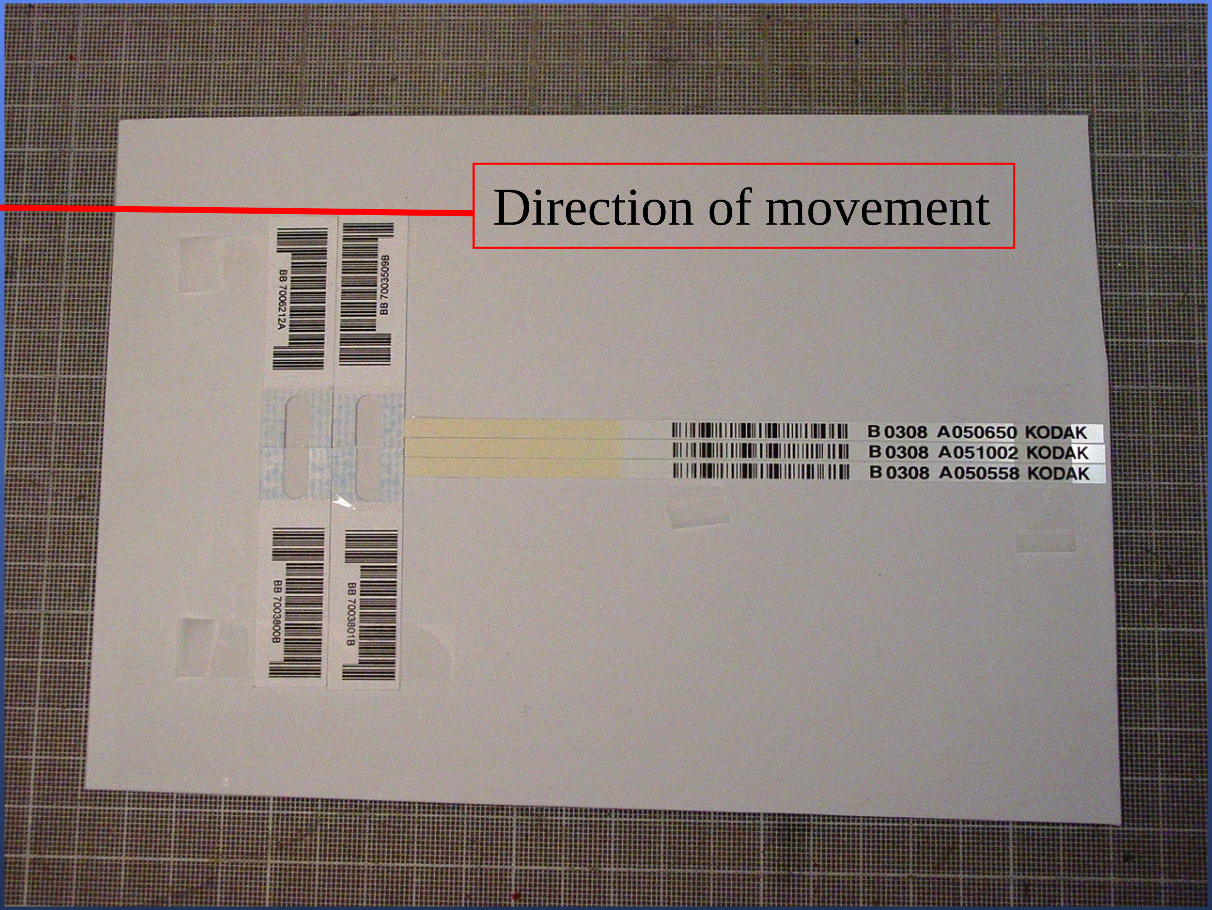
Routine Radiochromic Dosimeter

In-plant calibration

Reference geometry for
low energy e-

Reference dosimeters: Alanine film

Routine dosimeters: GEX DoseStix



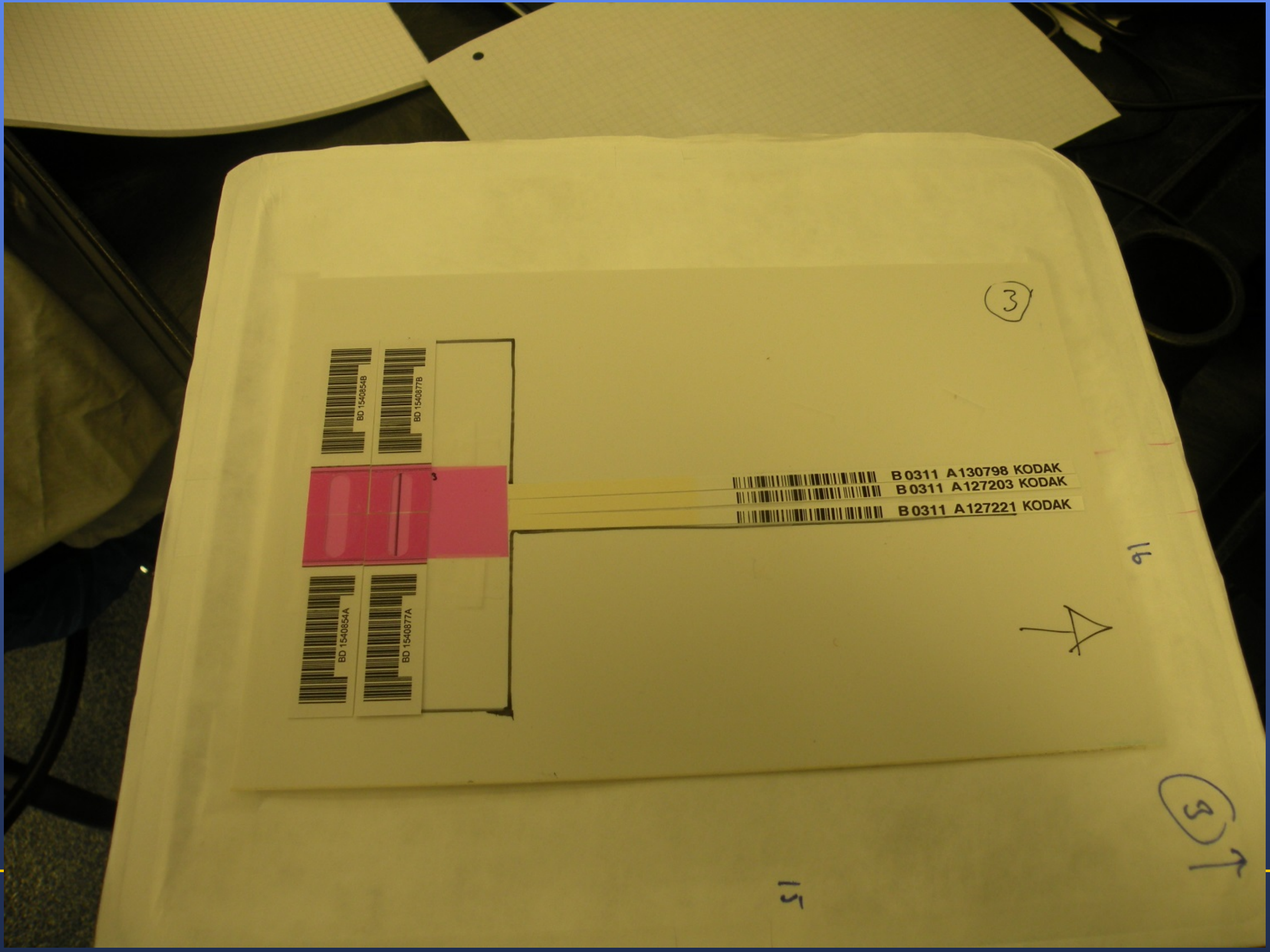
In-plant calibration

Calibration dosimeters placed on top of tub

Reference dosimeters: Alanine film

Routine dosimeters: GEX DoseStix

Dose map dosimeters: Risø B3



Low Energy Calibration Concerns

- DTU Risø HDRL is a sole source of Dμ certified traceable doses
- Bruker has discontinued sale of their Kodak manufactured alanine film, leaving Steris/Gamma Services also as a sole source alanine film supplier
- Will appropriate investments be made going forward with such a small market potential

Questions

THANK YOU