Comparing the benefits of Doubly Curved Crystal (DCC) and Polycapillary optics

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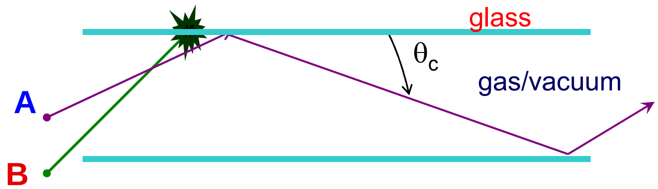
Outline

- Physical principles and geometry of Polycapillary optics and DCC
- Comparison and trade-offs
- Application Examples
- Integration and Optimization of Optic to Source
- Conclusions

Polycapillary Optics

Propagation of x-rays by "total external reflection"

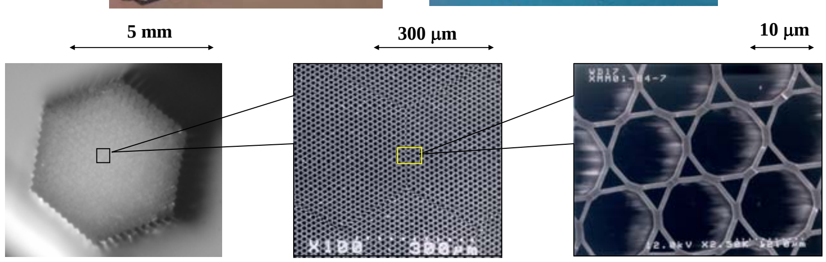


Incident photon "**A**" angle ≤ critical angle (θ_c)
Incident photon "**B**" angle > critical angle (θ_c)

for silicate glass: $$\theta_c\,(mrad) \cong \frac{30}{energy(keV)}$$

XOS

Monolithic polycapillary



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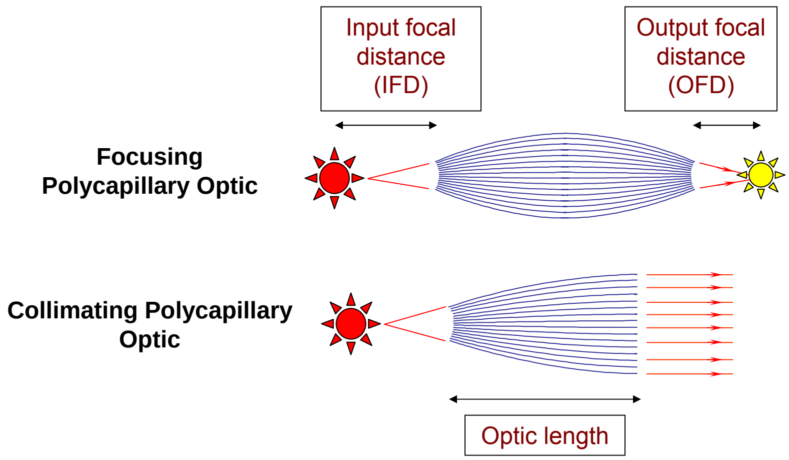
Monolithic polycapillary: Focusing and Collimating



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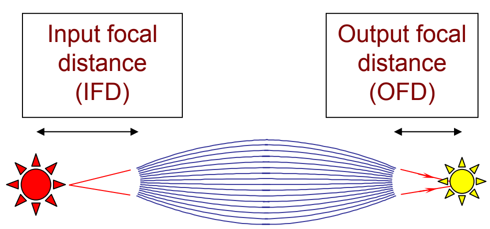
Characteristics of focusing monolithic optics

For point to point focusing:

- **Shorter input focal distance ➔ Larger collection angle**
- **Shorter output focal distance ➔ Smaller focal spot size**
- **Transmission efficiency:**
  up to 30 %, depending on the geometry and energy.



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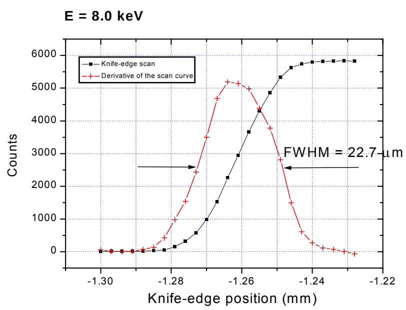
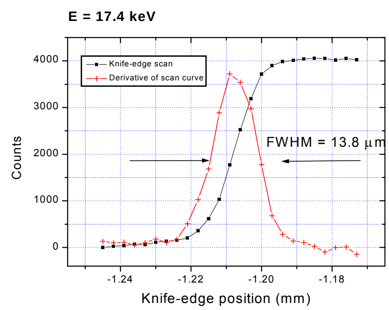
Focal spot size is energy dependent

23 micron FWHM	14 micron FWHM
Working Distance: 4mm	Working Distance: 4mm
E = 8.0 keV (Cu Kα)	E = 17.4 keV (Mo Kα)



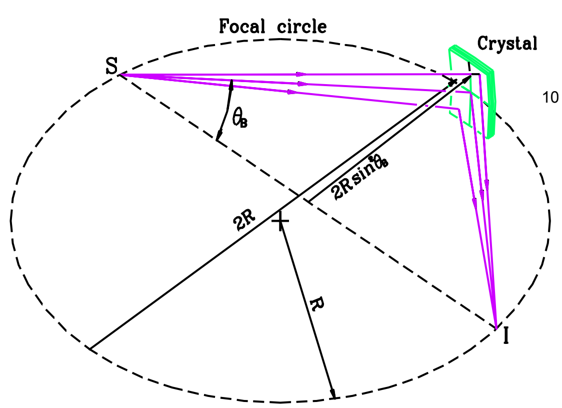


Doubly Curved Crystal (DCC)

Toroidal Johann geometry: planes parallel to surface

Crystal bending radius in horizontal plane

$R_{horizontal} = 2R$

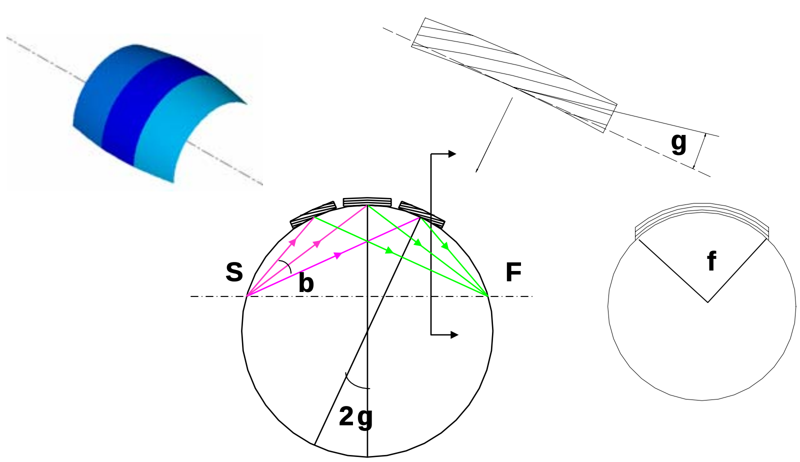


10 mm X 40 mm

Nominal operating parameters for DCC

Optic	Energy (keV)	Source Power (W)	θ Bragg (º)	Capture Angle (sr)	Nominal focal spot size, FWHM (μm)	Flux (cps)	Working Distance (mm)
Cr1 Ge 220	5.4	14	35.1	0.03	80	2 x 10^9	100
Cu1 Si 111	8.0	14	14.2	0.015	50	1 x 10^9	130
Cu2 Si 111	8.0	50	14.2	0.01	150	2 x 10^9	130
Cu 3 Ge 220	8.0	14	22.7	0.01	50	3 x 10^8	15
W1 Lα Si 220	8.4	10	22.6	0.01	20	1 x 10^8	60
Mo1 Si 220	17.5	14	10.6	0.01	60	1 x 10^8	100

Multiple Asymmetric Cut Point-focusing DCC



Characteristics of Polycapillary and DCC

	Polycapillary Optic	Doubly Curved Crystal (DCC)
Energy Range	0.1 – 25 keV	1.5 – 35 keV
Band Width	Broadband	2 – 50 eV
Convergent Beam	Yes	Yes
Parallel Beam	Yes	N/A
Spot Size	15μm, Dependent on working distance, relatively independent of source size.	50μm, Relatively independent of working distance, dependent on source size.
Working Distance	4 mm - ∞	50 – 500 mm

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Polycapillary Optics for XRD Applications

	XRD
Energy Range	5.4 keV (Cr), 8.04 keV (Cu), 17.4 KeV (Mo)
Parallel Beam	Yes
	Beam Size: 1-10 mm
Slightly Focusing Beam	Adjustable to match sample/ monochromator requirement
	Spot Size: 50 μm to 1 mm

Examples of applications:

(i) Parallel Beam for texture analysis and Phase ID, (ii) Convergent beam for Single Crystal and Powder diffraction.

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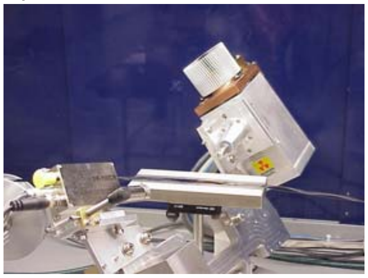
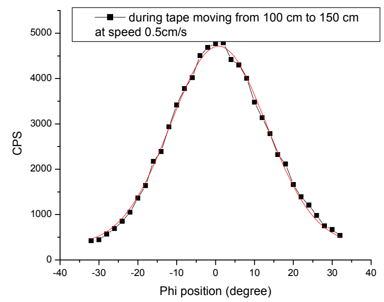
Parallel Beam Application

Setup of in-situ texture measurement



Collimating optic with 1.5 mm beam size, and source power at 50W.

Phi scan for moving tape



Recommended Talks:

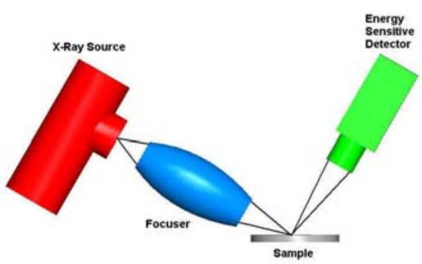
4:10pm D131

Thursday p.m. (Evergreen B) SESSION D-6 INDUSTRIAL APPLICATIONS

TEXTURE MEASUREMENTS ON LONG-LENGTHS OF HIGH TEMPERATURE SUPERCONDUCTORS

J.L. Reeves, V. Selvamanickam, SuperPower Inc., Schenectady, NY
H. Huang, J. Burdett, X-Ray Optical Systems, East Greenbush, NY
R.L. Snyder, Georgia Institute of Technology, Atlanta, GA

Polycapillary Optics for MXRF Application



Why?

- **Small Spot Size: 15μm, Mo Kα**
- **High Flux Density**

Examples of applications:

(i) MXRF (for small feature and high resolution elemental mapping), (ii) Film Thickness Measurement, (iii) XRF in SEM.

Recommended Talks:

XRF Poster Session, Wednesday, 6 August (Evergreen)

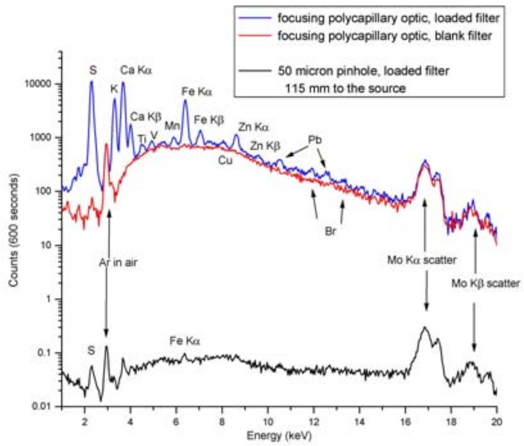
6:30 p.m.

DUAL-CAPILLARY OPTIC MXRF

G J. Havrilla, Los Alamos National Laboratory, Los Alamos, NM, USA

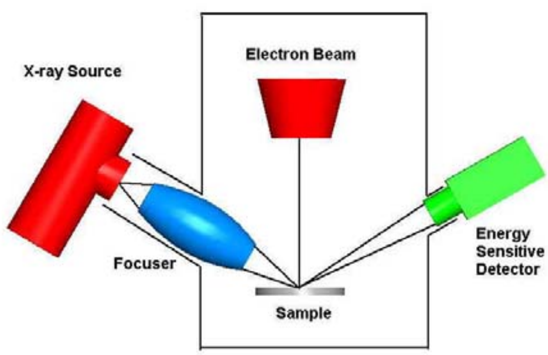
N. Gao, X-Ray Optical Systems, East Greenbush, NY USA

Large flux gain vs. pinhole aperture for MXRF



50μm air particulate on filter

XRF in an electron microscope



Recommended Talks:

XRF Poster Session, Wednesday, 6 August (Evergreen)

6:30 p.m.

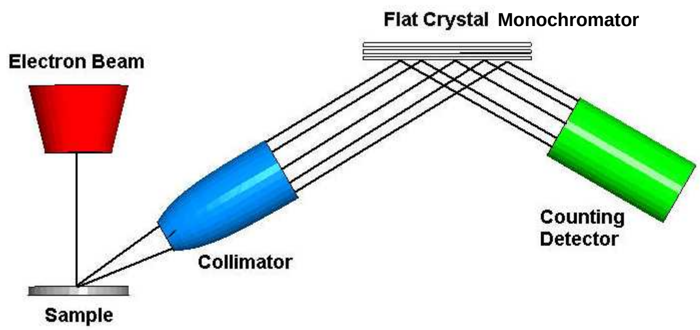
XRF IN THE SEM - HOW AND WHY

B. Cross, CrossRoads Scientific, El Granada, CA

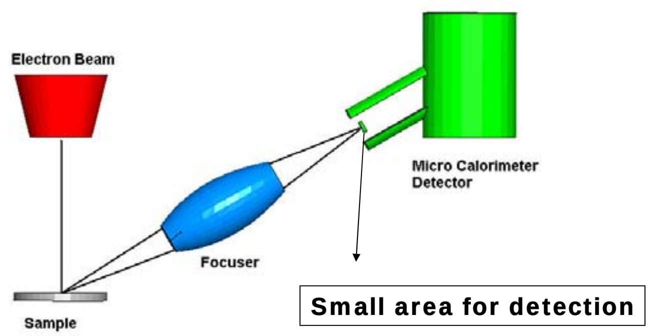
K. Witherspoon, IXRF Systems, Inc., Houston, TX

Polycapillary Optics for Collection-side

Scanning WDS ➔ Polycapillary Optics

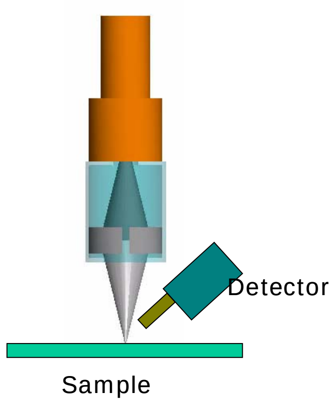


Energy dispersive spectroscopy (EDS) using a microcalorimeter detector



➔ **Best efficiency with a focused beam**

DCC for MMXRF Application



Why?

- **Narrow bandwidth, 2-50 eV**
- **Spot Size: 50 μm**
- **Very High sensitivity**

Examples of applications:

(i) MMXRF, (ii) Thin Film Metrology, (iii) Elemental Mapping.

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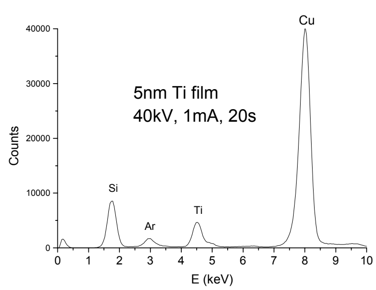
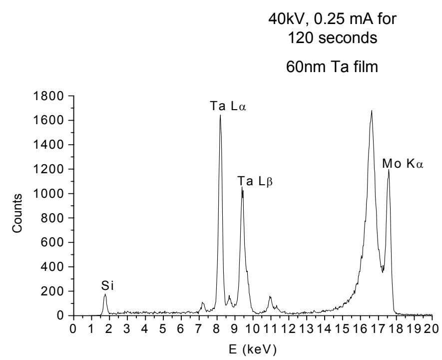
DCC for MMXRF Application



Cu Excitation



Mo Excitation

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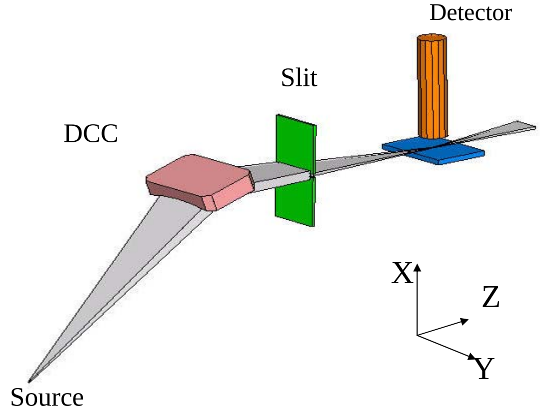
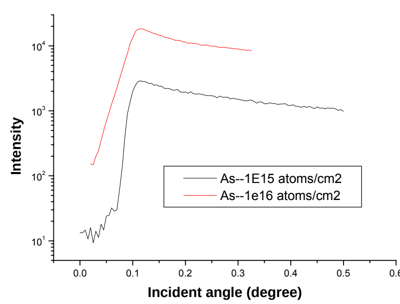
TXRF Application → DCC

- Local surface analysis
  - Surface contamination
  - Particles
  - Residues
  - Shallow dopants
- Compact
- Detection limits ~10^8 atoms

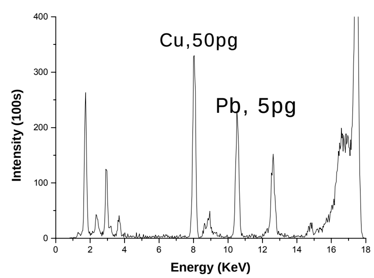


Surface and Subsurface Analysis by Focused Beam TXRF

As dopants under the Si surface



Cu, Pb residues on Si surface



Recommended Talks:
Thursday a.m.
(Evergreen D)
SESSION F-2 TXRF
9:30 a.m. F36

FOCUSED BEAM TXRF SYSTEM USING DOUBLY CURVED CRYSTAL OPTICS

Z.W. Chen

Conclusions

- **Polycapillary Optics:**
  - Polychromatic beam
  - Focusing – MXRF type applications
  - Collimating – (i) Parallel Beam, (ii) Slightly Focusing
  - Can be used for Excitation and Collection side
- **Doubly Curved Crystal (DCC):**
  - Monochromatic beam
  - High sensitivity - MMXRF, TXRF

XOS

Integration and Optimization of Optic to Source

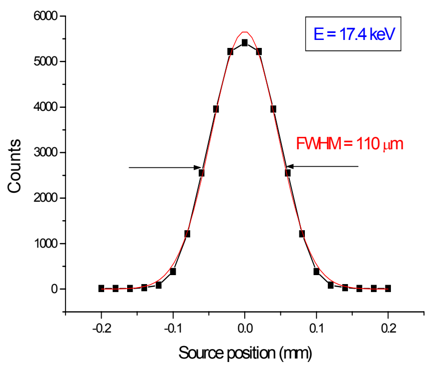
XOS

Outline

- Issues related to source-optic integration
- Design considerations for source-optic combinations
- Results achievable with source-optic combinations

Issues to be addressed for the use of source-optic combinations in commercial instrumentation

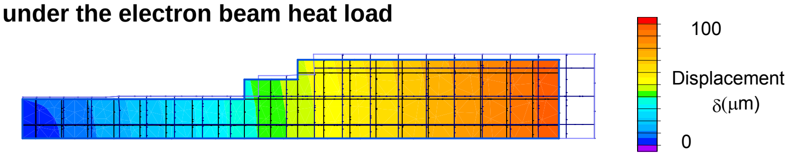
- Optics must be aligned to the source in order to fully realize the flux density gains.
- Any small change in alignment during or between experiments will affect the quantitative capabilities of an instrument.



- Significant results have been reported with the use of source-optic combinations where alignment is achieved using stages.
- Active real time alignment options are limited.

Conventional source-optic alignment is power dependant

- X-ray tube focal spot position changes occur due to target expansion under the electron beam heat load



Expansion of a typical x-ray tube anode under electron beam load. Part of an overall finite element model

- For a conventional source-optic combination the position of the tube focal spot moves by 38 microns between operation at 50W and operation at 5W
- This misalignment results in a 25% drop in output intensity

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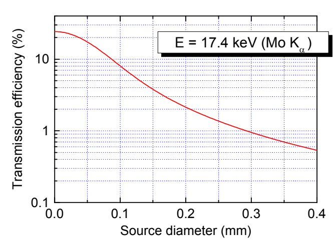
Choosing the right x-ray tube for integration



- High brightness
  - Optimum combination of source size and tube power
- Short access distance
  - Matching of source scan width to source size
- High stability, both output intensity and spot position
  - Don't waste stability gains from alignment with poor source stability

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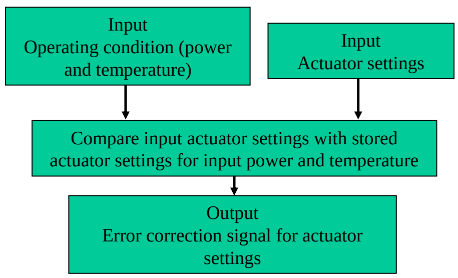
Alignment and output stability with X-Beam

- **Provide a method of alignment which can be built into a source-optic combination and provides compensation for variation in optic and x-ray source manufacture.**
- **Alignment of the optic to the overall package allows the beam to always point at the same place.**
- **Once aligned provide compensation for changes in operating condition.**

Integral kinematic mount.

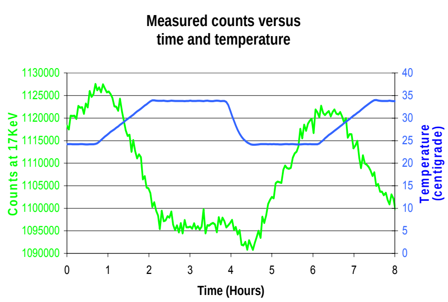


Control algorithm embedded in the X-Beam controller CPU. X-Beam contains integrated sensors and actuators

The controller can provide additional diagnostics

Temperature stability analysis

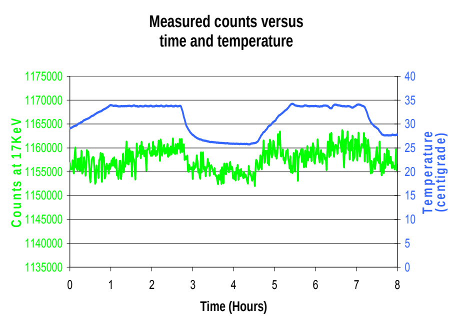
Conventional source-optic combination



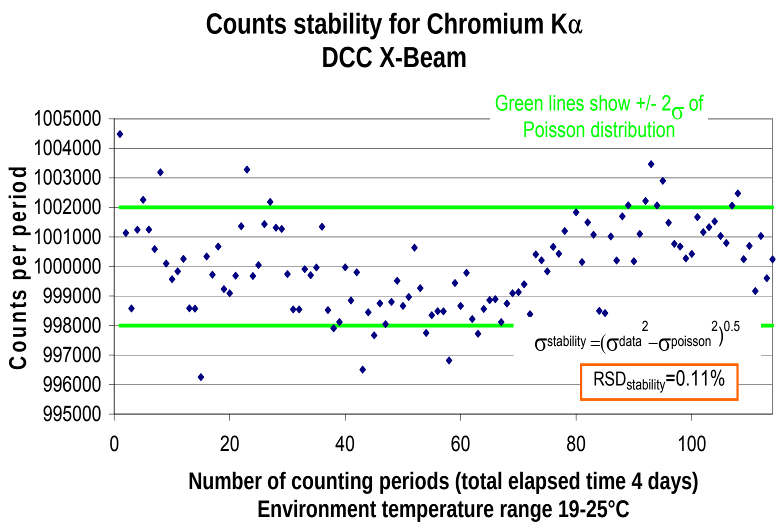
The output response of a coupled polycapillary optic is shown for both a conventional source and for an X-Beam source.

Ambient temperature is varied as shown on the secondary Y axis of both graphs and by the solid blue lines.

X-Beam



Stability data from DCC X-Beam



Conclusions

- Issues associated with source-optic integration can be addressed through the use of the correct x-ray tube together with suitable control and alignment systems.
- Stability suitable for demanding quantitative applications can be achieved with optics
- Stability control systems can be designed to give additional diagnostic benefits such as optic alignment testing.
- By taking an overall system approach to source-optic integration addition benefits such as “plug and play” can be achieved.