

Leksellův gama nůž Icon konečně v ČR – přejímací zkouška a první zkušenosti



Josef Novotný Jr., Ph.D.

Evolution of gamma knife radiosurgery

~ 2015



~ 2006



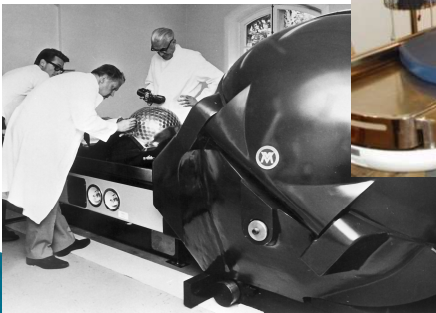
~ 2000



~ 1990



~ 1970




What was missing in the previous Leksell Gamma Knife?

- No verification of small frame shifts that may occur
- Fractionation treatment was rather limited and workflow for some patients slow
- Very limited in extra cranial treatments (no motion control)



Image guidance and motion management!

Milestones in Leksell Gamma Knife Icon

- **2011** 10th ISRS Congress Paris France (1st expert board panel meeting)
 - **2015** the first treatment at the University Hospital La Timone, Marseille, France
 - **2019** installation and the first treatment at Na Homolce Hospital, Prague, Czech Republic
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What is new in Leksell Gamma Knife Icon?

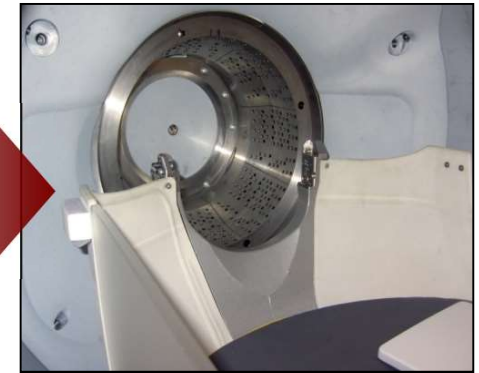
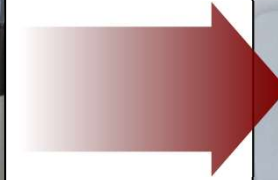


Leksell Gamma Knife Perfexion



Identical radiation unit as Leksell Gamma Knife Perfexion™

- 4, 8, 16 mm collimators
- 192 Co-60 sources
- Cylindrical source geometry



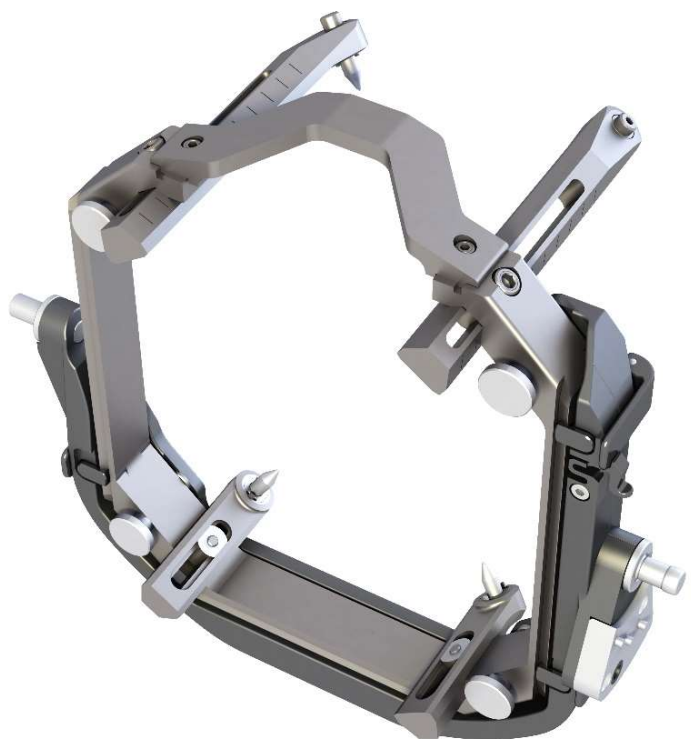
Search **Watch on YouTube** ed

<https://youtu.be/N5q8ThYYoc8>



Patient head fixation

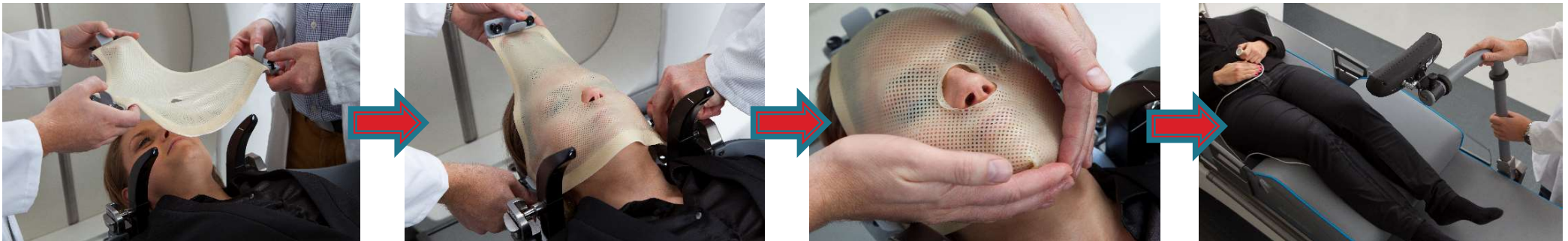
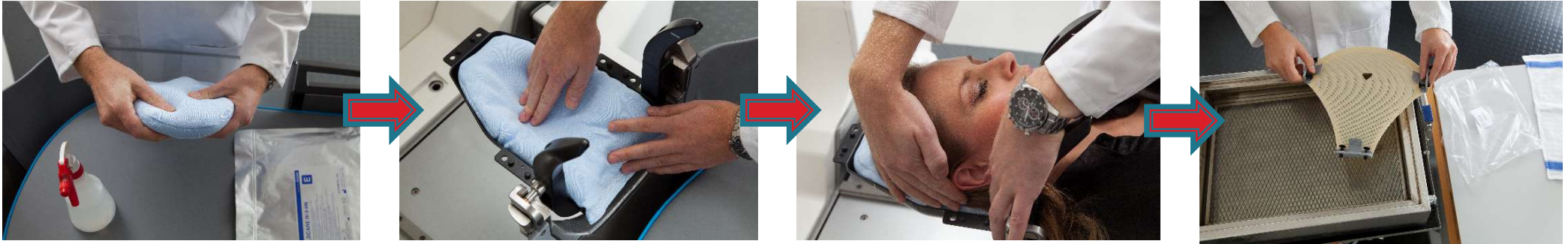
Leksell stereotactic frame



Mask fixation



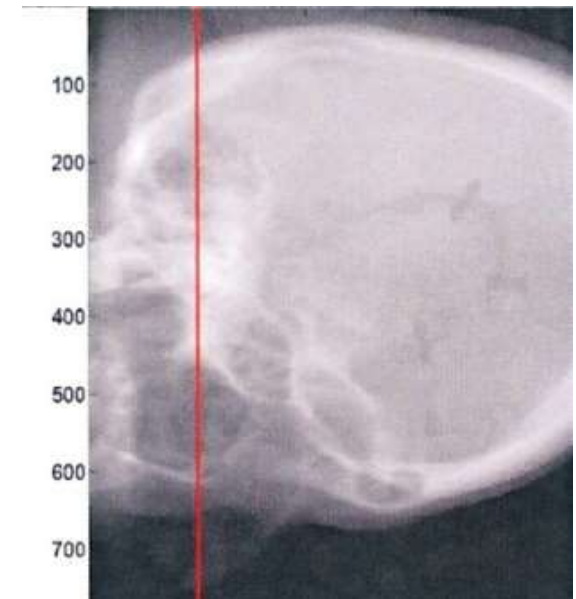
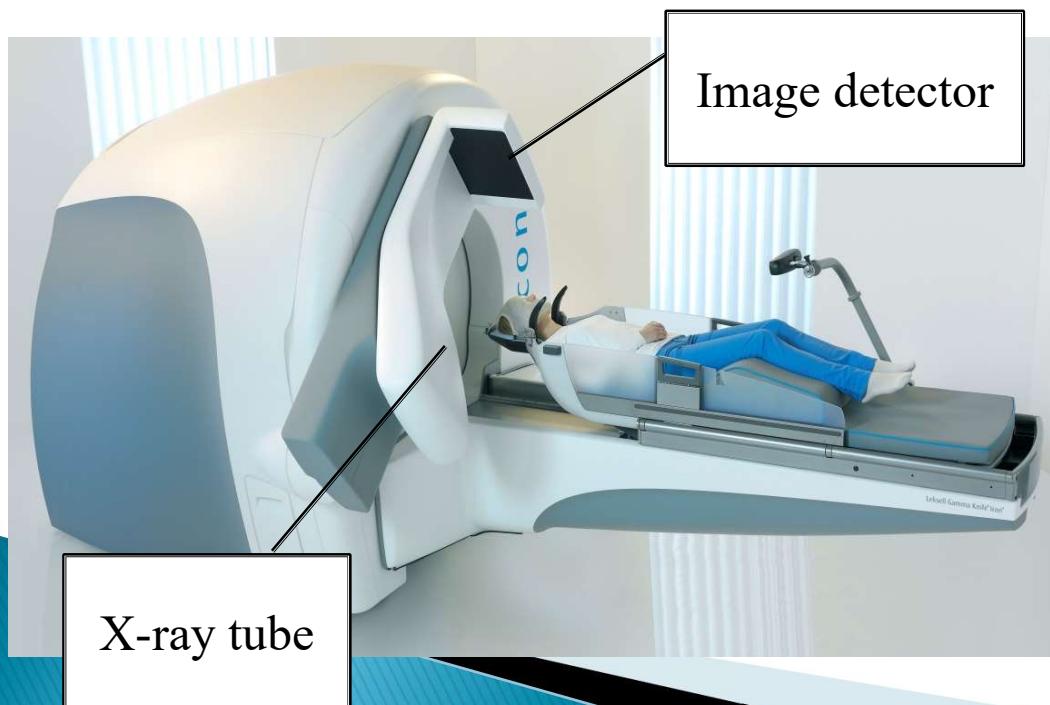
Mask fixation with Leksell Gamma Knife[®] Icon[™]



Design and performance of CBCT for Leksell Gamma Knife[®] Icon[™]

- Limit of the rotational scan range of the C-arm is about 200 degrees

Components	Properties
Detector	Layers: Csl, TFT(amorphous Si) 780 x 720 pixels (binned mode). Pixel resolution = 0.368 mm
X-ray tube	Energy range: 70-120 kVp. Spot size: 0.6 mm Weight: 17kg



Design and performance of CBCT for Leksell Gamma Knife[®] Icon[™]

Characteristics	Value
Source to axis distance (SAD)	790mm
Source to detector distance (SDD)	1000mm
Magnification factor	1.27
Reconstructed volume	224 x 224 x 224mm ³
Cone beam angle	15°
Fan angle	16°
Scan time	30s
Flex	< 0.2mm

	Preset 1	Preset 2
mAs/projection	0.4	1.0
kVp	90	90
Number of projections	332	332
Image volume (voxels)	448 ³	448 ³
Voxel size	0.5mm	0.5mm
Resolution	7 lp/cm	8 lp/cm
CTDI	2.5mGy	6.3mGy
CNR	1	1.5



Leksell Gamma Knife® Icon™ – “Real Dose Delivery”

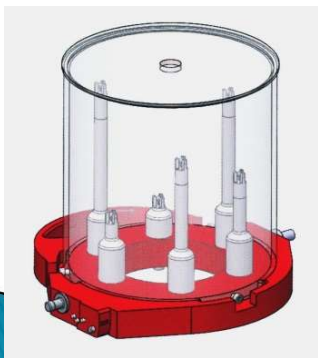
- Integrated stereotactic CBCT calibrated to the patient positioning system which is capable to determine stereotactic coordinates
- The rigid transformation is based on the co-registration of the planning and the reconstructed CBCT images. It describes the transition and rotation of the patient and is used to accomplish the correction of each shot



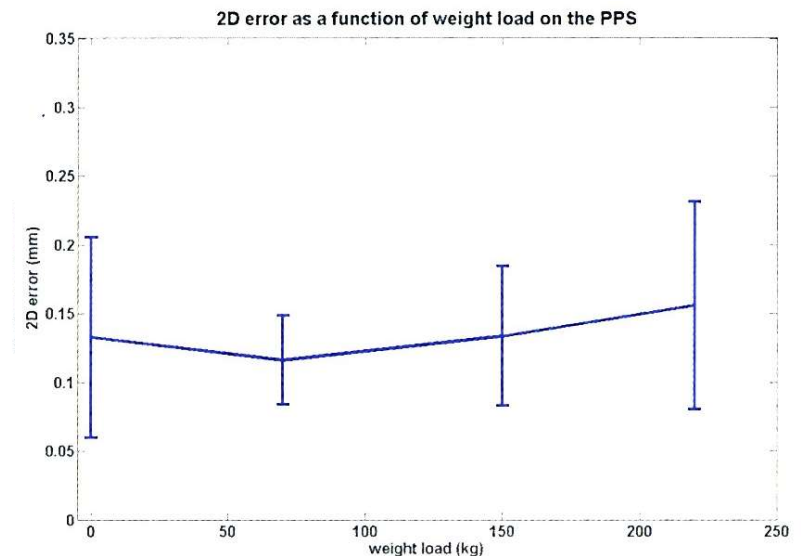
Position accuracy of the stereotactic reference defined by the CBCT on Leksell Gamma Knife[®] Icon[™]

- The CBCT image defines the stereotactic Leksell coordinates in a treatment plan
- High requirements on accuracy, calibration and system repeatability
- Special calibration tool with six ball bearings with measured coordinates in the Leksell coordinate system
- End-to-end test is performed with a special tool (5 radiochromic films placed at different positions), it measures the geometric uncertainty of the CBCT system

Special calibration tool

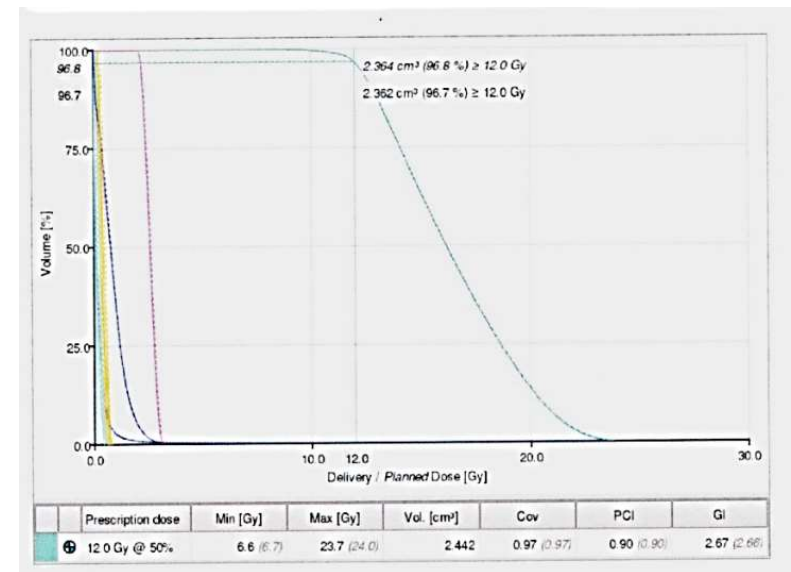
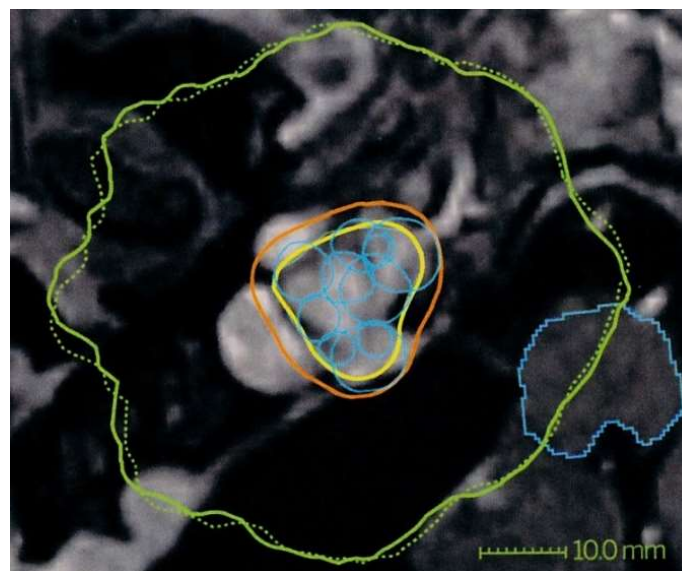


End-to-end tool with irradiated film



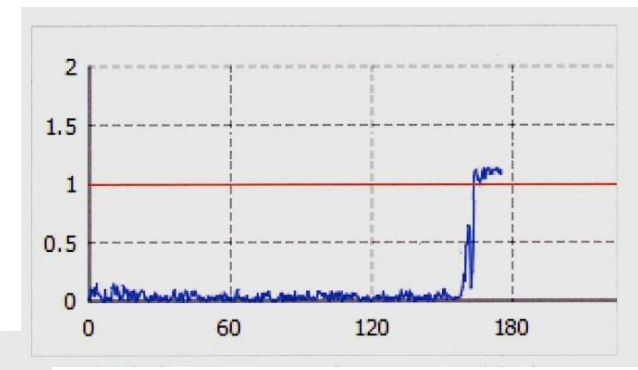
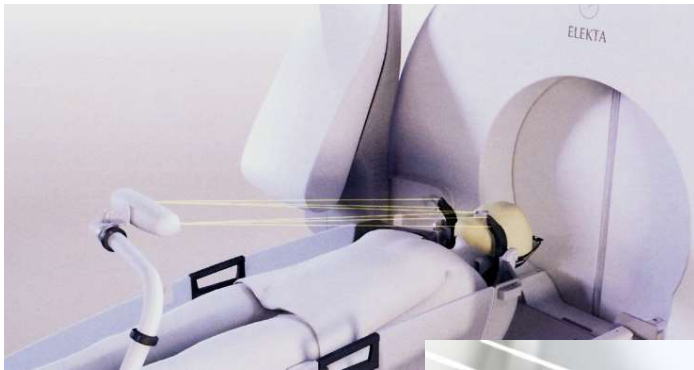
Leksell Gamma Knife[®] Icon[™] – “Online Dose Evaluation”

- The online Dose Evaluation enables to compare the dose distribution that is about to be delivered to the dose that is planned to be delivered
- It is done right at the console and plan can be adapted online quickly and easily



Leksell Gamma Knife[®] Icon[™] – “Real-time HD Motion Management”

- Intra-fraction motion management system based on stereoscopic infrared camera monitors the patient in real time during treatment with less than 0.15 mm accuracy
- If the patient moves out of the pre-set threshold, the system’s gating functionality instantly blocks the radiation, if the patient moves back into position, the system resumes dose delivery after 3 seconds
- Infrared camera tracks at frequency 20 Hz four reference markers and one patient marker attached to the tip of the nose



Leksell Gamma Knife® Icon™



Treatment workflow with Leksell Gamma Knife[®] Icon[™]

Frame-based workflow with fiducial based registration



Frame-based workflow with stereotactic CBCT based registration



Mask-based workflow with stereotactic CBCT based registration



Leksell Gamma Knife[®] Icon[™] – installation at Na Homolce Hospital

- 10 days installation and acceptance
- 5 days commissioning
- (90) days license (over 130 pages) State Office for Nuclear Safety



Leksell Gamma Knife[®] Icon[™] commissioning

- 2 parts – radiotherapy and diagnostic (CBCT)
- 2 independent subjects with independent permissions from State Office for Nuclear Safety
- National Radiation Protection Institute dosimetry audit

Leksell Gamma Knife® Icon™ commissioning radiotherapy part

- **FUNCTIONALITY AND SAFETY**

- beam on/off indication
- emergency circuits, power failure, UPS, emergency manual pull out of the patient simulation
- PAUSE and EMERGENCY STOP
- video and audio intercom system
- interlocks and standard operation and function of the system (simulation of the treatment)
- radiation exposure in the treatment and operator's room (selected points)

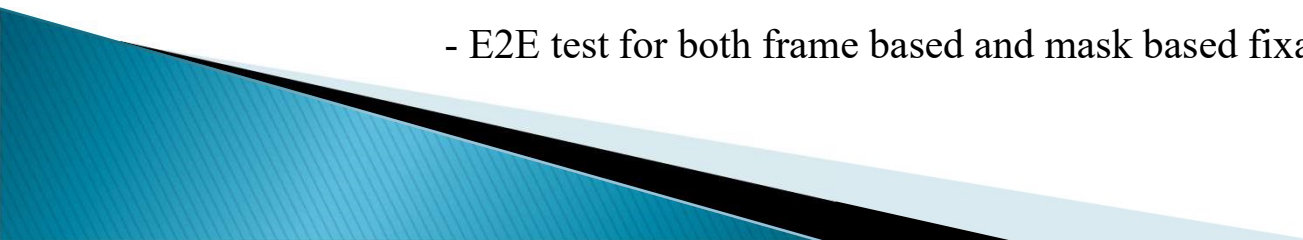
- **MECHANICAL ACCURACY**

- isocenter verification for 4 mm, 8 mm, 16 mm

- **CALIBRATION AND DOSIMETRY**

- output calibration (dose rate measurement for 16 mm)
- dose profiles
- output factors
- timer accuracy, constancy and linearity

- **VERIFICATION OF THE WHOLE TREATMENT CHAIN**

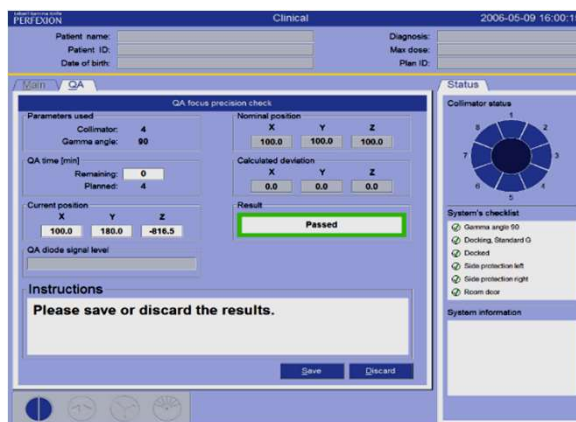
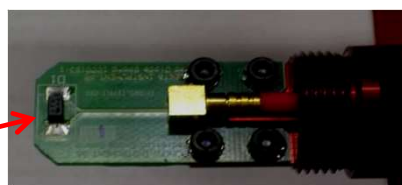
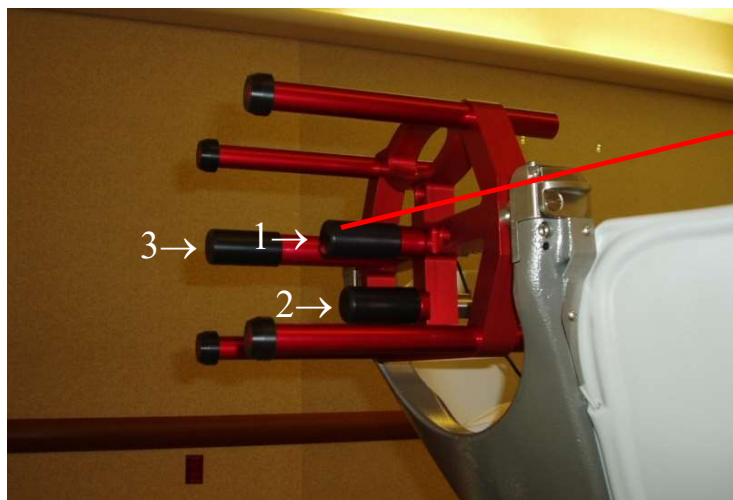
- E2E test for both frame based and mask based fixation (imaging, treatment planning, dose delivery)
- 

Leksell Gamma Knife[®] Icon[™] commissioning radiotherapy part

- MECHANICAL ACCURACY

Service Diode Test Tool (available for PMs)

Focus Test Tool (available permanently on-site)



- 1- Central Diode
- 2 - Short Diode
- 3 - Long Diode

X=100,	Y=100,	Z=100
X=100,	Y=50,	Z=115
X=160,	Y=100,	Z=22

RESULTS:

$$\Delta X = 0.0 \pm 0.1 \text{ mm}$$

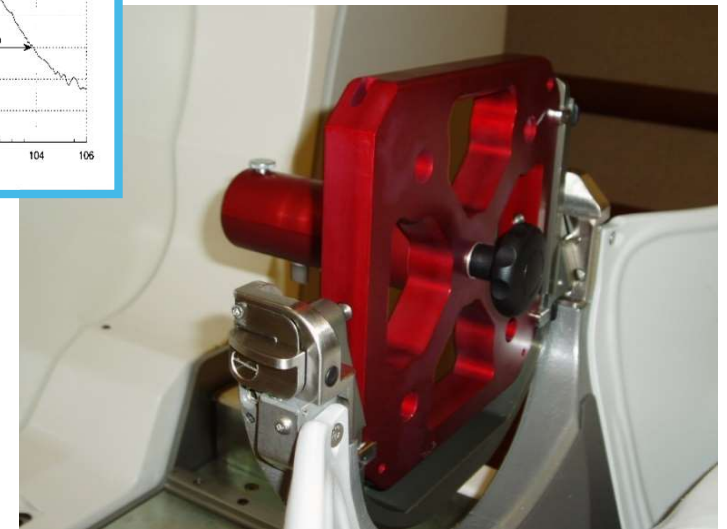
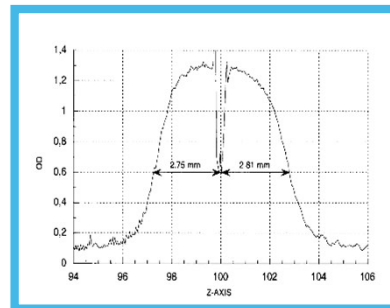
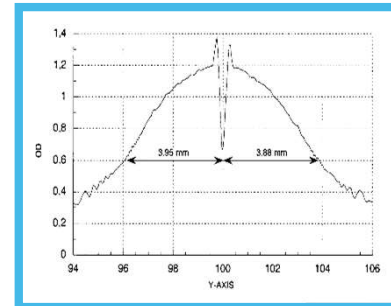
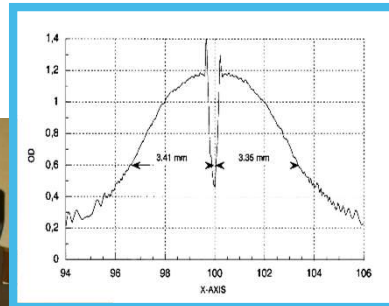
$$\Delta Y = 0.0 \pm 0.0 \text{ mm}$$

$$\Delta Z = 0.0 \pm 0.0 \text{ mm}$$

$$\text{RADIAL} = 0.0 \pm 0.1 \text{ mm}$$

Leksell Gamma Knife[®] Icon[™] commissioning radiotherapy part

- MECHANICAL ACCURACY



RESULTS (center (100, 100, 100) position measurement):

$$\Delta X = 0.270 \text{ mm}$$

$$\Delta Y = 0.005 \text{ mm}$$

$$\Delta Z = 0.088 \text{ mm}$$

$$\text{RADIAL} = 0.28 \text{ mm}$$

RESULTS (off center (40, 160, 100) position measurement):

$$\Delta X = 0.220 \text{ mm}$$

$$\Delta Y = 0.010 \text{ mm}$$

$$\Delta Z = 0.030 \text{ mm}$$

$$\text{RADIAL} = 0.22 \text{ mm}$$

Leksell Gamma Knife[®] Icon[™] commissioning radiotherapy part

- CALIBRATION AND DOSIMETRY

$$D_{w,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} N_{D,w,Q_0}^{f_{ref}} k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$$

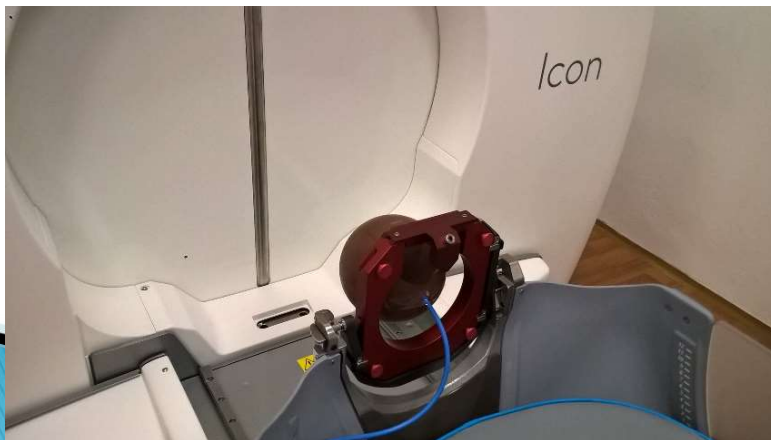
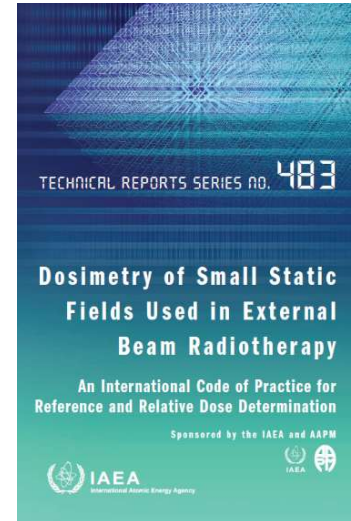


TABLE 14. CORRECTION FACTORS $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ FOR THE GAMMA KNIFE MODELS PERFEXION AND 4C [110, 153]

Chamber type	Perfexion $f_{msr} = 16 \text{ mm } \varnothing$			4C $f_{msr} = 18 \text{ mm } \varnothing$		
	Solid Water	ABS	Water	Solid Water	ABS	Water
PTW T31010	1.0037	1.0146	1.0001	0.9958	0.9990	0.9924
PTW T31016	1.0040	1.0110	0.9991	1.0014	1.0025	0.9964
Exradin A1SL	1.0046	1.0138	1.0006	1.0009	1.0014	0.9967
Exradin A14SL	1.0154	1.0194	1.0112	1.0116	1.0060	1.0058
Exradin A16	1.0167	1.0295	1.0127	1.0163	1.0217	1.0104
IBA CC01	1.0213	1.0292	1.0169	1.0203	1.0208	1.0157
IBA CC04	1.0107	1.0117	1.0062	1.0086	1.0049	1.0040
Capintec PR05-P 4.7	1.0059	1.0070	1.0010	1.0007	0.9960	0.9951
Capintec PR05-P 7.6	1.0025	1.0126	0.9976	0.9885	0.9972	0.9844



Leksell Gamma Knife® Icon™ commissioning radiotherapy part

- CALIBRATION AND DOSIMETRY

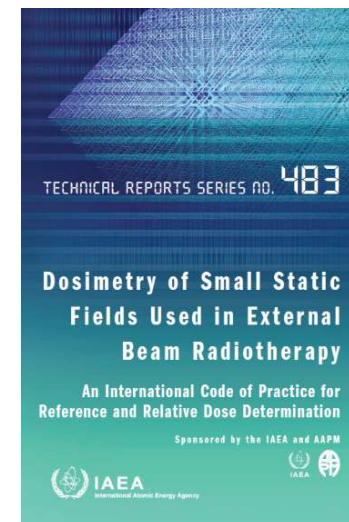
$$\Omega_{Q_{\text{clin}}, Q_{\text{msr}}}^{f_{\text{clin}}, f_{\text{msr}}} = \frac{M_{Q_{\text{clin}}}^{f_{\text{clin}}}}{M_{Q_{\text{msr}}}^{f_{\text{msr}}}} k_{Q_{\text{clin}}, Q_{\text{msr}}}^{f_{\text{clin}}, f_{\text{msr}}}$$



TABLE 25. FIELD OUTPUT CORRECTION FACTORS $k_{Q_{\text{clin}}, Q_{\text{msr}}}^{f_{\text{clin}}, f_{\text{msr}}}$ FOR THE GAMMA KNIFE MODEL PERFECTION, AS A FUNCTION OF THE DIAMETER OF THE CIRCULAR COLLIMATOR [179]

Model	Type	4 mm Ø	8 mm Ø	16 mm Ø
PTW T31006	Ionization chamber	— ^a	1.025	1.000
PTW T31014	Ionization chamber	— ^a	1.030	1.000
PTW T31015	Ionization chamber	— ^a	— ^a	1.000
PTW T31016	Ionization chamber (PinPoint 3D)	— ^a	1.032	1.000
PTW T60008	Diode (photon/shielded)	0.951	0.971	1.000
PTW T60012	Diode (electron/unshielded)	0.965	0.996	1.000
PTW T60016	Diode (photon/shielded)	0.958	0.981	1.000
PTW T60017	Diode (electron/unshielded)	0.961	0.997	1.000
PTW T60003	Diamond detector (natural)	— ^a	1.006	1.000
PTW T60019	Diamond detector (synthetic)	0.993	1.005	1.000

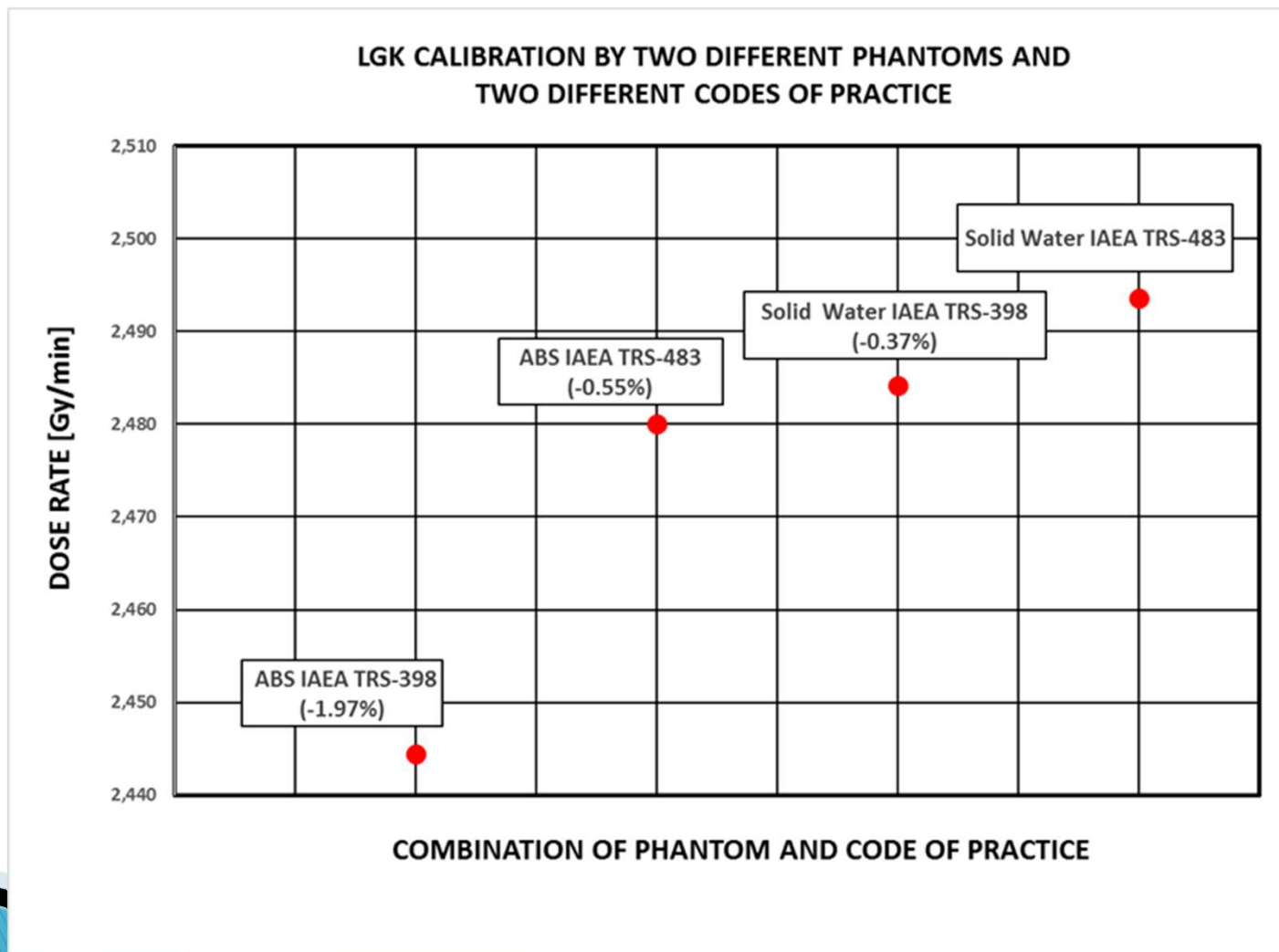
^a A large correction factor makes this chamber unsuitable for output measurements with this collimator.



Leksell Gamma Knife[®] Icon[™] commissioning radiotherapy part

- CALIBRATION AND DOSIMETRY

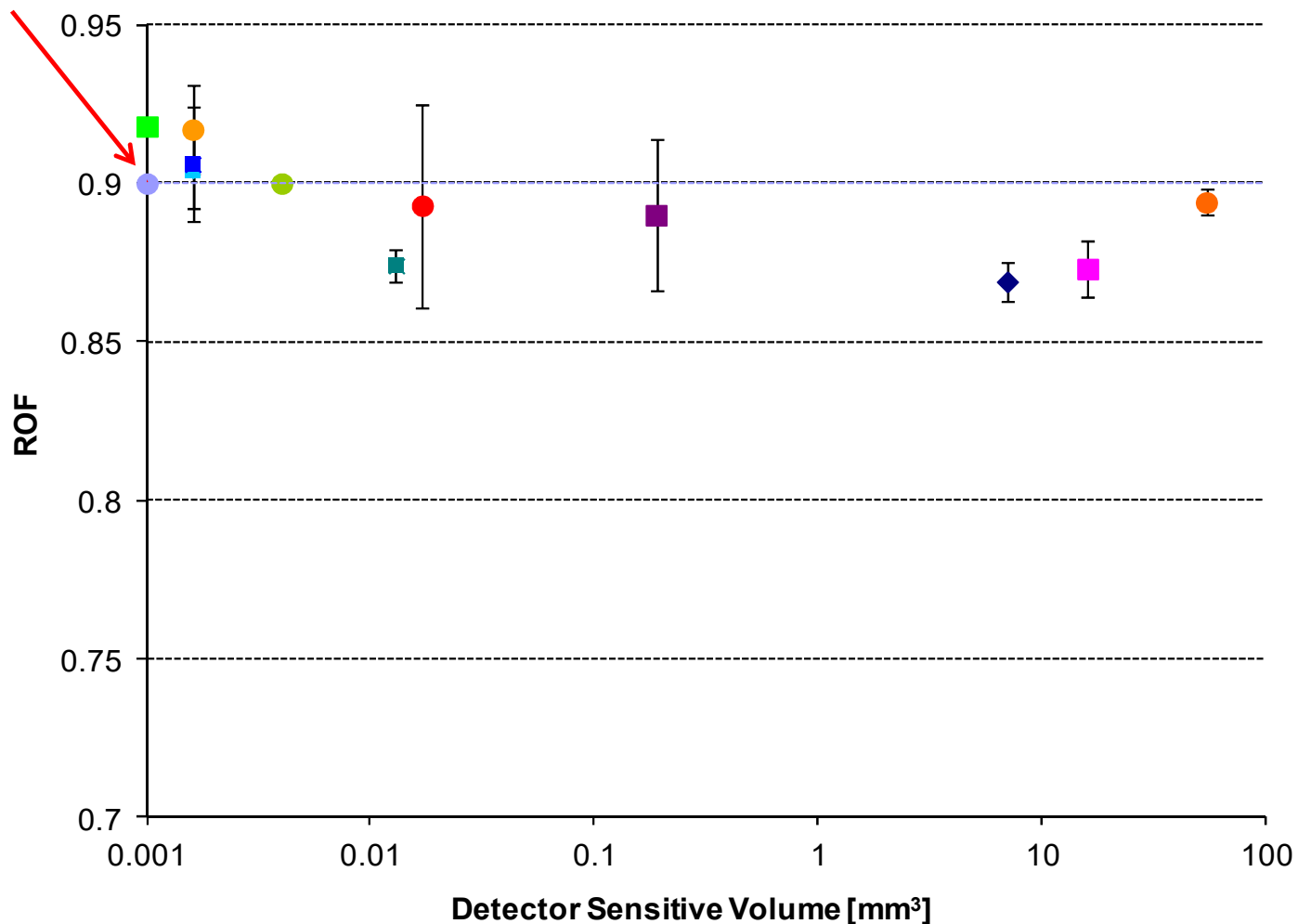
- change in existing IAEA TRS 398 calibration by 1.44%



Relative output factor for 8 mm collimator

8 mm collimator ROF

Elekta's default value

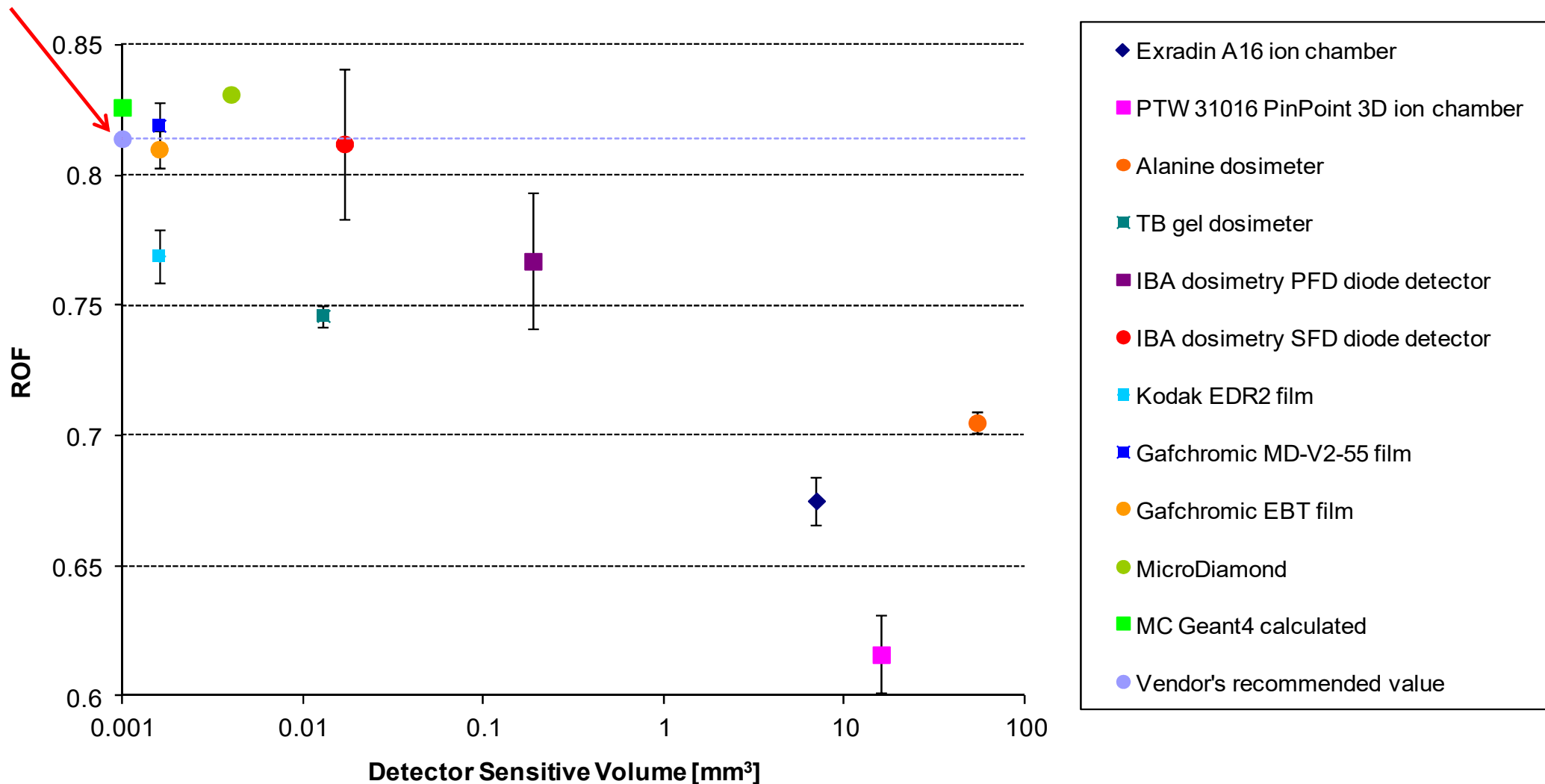


- ◆ Exradin A16 ion chamber
- ◆ PTW 31016 PinPoint 3D ion chamber
- Alanine dosimeter
- TB gel dosimeter
- IBA dosimetry PFD diode detector
- IBA dosimetry SFD diode detector
- Kodak EDR2 film
- Gafchromic MD-V2-55 film
- Gafchromic EBT film
- MicroDiamond
- MC Geant4 calculated

Relative output factor for 4 mm collimator

Elekta's default value

4 mm collimator ROF



Relative output factor for 8 a 4 mm summary

Detector	Measured 4 mm ROF	Measured 8 mm ROF	Deviation to vendor's values [%]	
			4 mm ROF	8 mm ROF
ELEKTA value	0,814	0,900		
Exradin A16 ion chamber	0,675 ± 0,009	0,869 ± 0,006	-17,1	-3,4
PTW 31016 PinPoint 3D ion chamber	0,616 ± 0,015	0,873 ± 0,009	-24,3	-3,0
Alanine dosimeter	0,705 ± 0,004	0,894 ± 0,004	-13,4	-0,7
TB gel dosimeter	0,746 ± 0,004	0,874 ± 0,005	-8,4	-2,9
IBA dosimetry PFD diode detector	0,767 ± 0,026	0,890 ± 0,024	-5,8	-1,1
IBA dosimetry SFD diode detector	0,812 ± 0,029	0,893 ± 0,032	-0,2	-0,8
Kodak EDR2 film	0,769 ± 0,010	0,904 ± 0,012	-5,5	0,4
Gafchromic MD-V2-55 film	0,819 ± 0,009	0,906 ± 0,018	0,6	0,7
Gafchromic EBT film	0,810 ± 0,007	0,917 ± 0,014	-0,5	1,9
MicroDiamond	0,825 ± 0,001	0,905 ± 0,001	1,4	0,6
MicroDiamond	0,831 ± 0,001	0,900 ± 0,001	2,1	-0,1

Leksell Gamma Knife[®] Icon[™] commissioning diagnostic part

- FUNCTIONALITY AND SAFETY

- beam on/off indication
- EMERGENCY STOP
- interlocks and standard operation and function of the system (simulation of the treatment)
- radiation exposure in the treatment and operator's room (selected points)


- MECHANICAL ACCURACY

- CBCT precision check

- CBCT IMAGE QUALITY

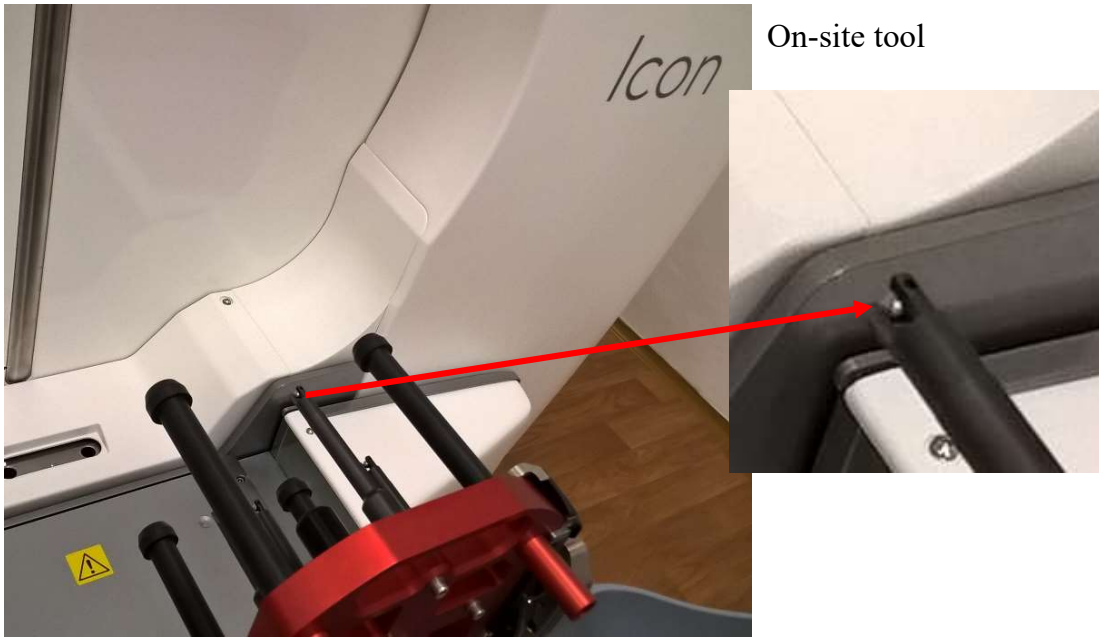
- resolution (line pairs per cm)
- contrast to noise ratio (low-contrast resolution)
- uniformity

- RADIATION OUTPUT TESTS

- X-ray tube kVp voltage
 - the incident air kerma at the detector
 - 1st half value layer
 - CTDI computed tomography dose index
- 

Leksell Gamma Knife® Icon™ commissioning diagnostic part

- CBCT MECHANICAL ACCURACY



On-site tool



Installation (PM) tool

QA CBCT precision check

Maximum deviation in image volume [mm]: **0.06**

Calculated fiducial deviation [mm]

	X	Y	Z	Vector
1	0.03	-0.02	0.02	0.04
2	0.03	-0.01	0.02	0.04
3	0.03	-0.01	0.03	0.04
4	0.03	-0.01	0.01	0.03

Result

Passed

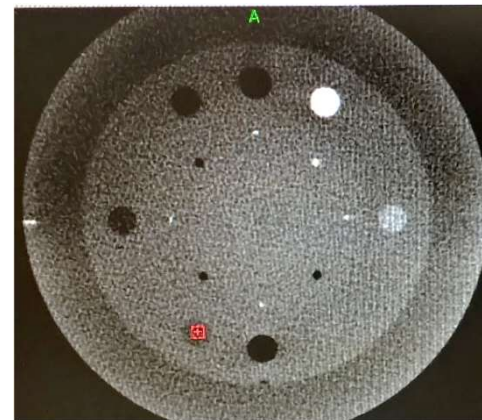
- 4 (6) ball bearings positioned in exact and known spatial position

Leksell Gamma Knife® Icon™ commissioning diagnostic part

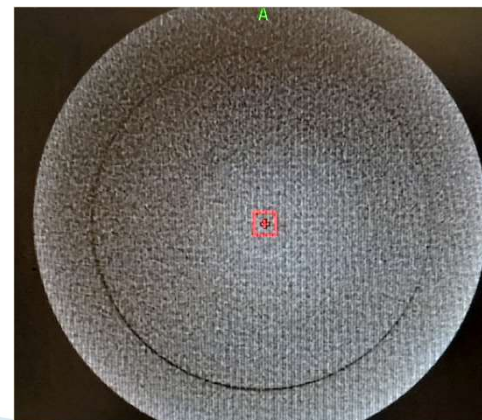
- CBCT IMAGE QUALITY



CTDI 2.5 mGy 7 lp/cm
CTDI 6.3 mGy 8 lp/cm
Specification: ≥ 6 lp/cm



CTDI 2.5 mGy CNR 1.02
CTDI 6.3 mGy CNR 1.57
Specification:
CTDI 2.5 mGy CNR > 0.5
CTDI 6.3 mGy CNR > 0.8

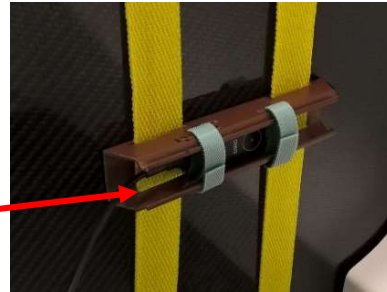


CTDI 2.5 mGy uniformity 11.6%
CTDI 6.3 mGy uniformity 11.7%
Specification: < 21%

- CatPhan 503 that contains sections with:
 - line pairs
 - inserts with different HU
 - homogenous part

Leksell Gamma Knife® Icon™ commissioning diagnostic part

- RADIATION OUTPUT TESTS



- non – invasive kVp meter with multisensor

X-ray tube kVp voltage:

91.2 kV (for 2.5 mGy CTDI)

91.7 kV (for 6.3 mGy CTDI)

Specification: 90 kV (deviation < 3%)

1st half value layer:

HVL 7.36 mm Al (for 2.5 mGy CTDI)

Specification: HVL \geq 2.8 mm for 80 kV,
HVL \geq 3.6 mm for 100 kV

The incident air kerma at the detector:

2.3 mGy (for 2.5 mGy CTDI)

5.8 mGy (for 6.3 mGy CTDI)

Specification: 2.5 mGy and 6.3 mGy (deviation < 35 %)



CTDI computed tomography dose index:

2.55 mGy (for 2.5 mGy CTDI)

6.65 mGy (for 6.3 mGy CTDI)

Specification: 2.5 mGy and 6.3 mGy (deviation < 20 %)

Leksell Gamma Knife[®] Icon[™] dosimetry audit

• VERIFICATION OF THE WHOLE TREATMENT CHAIN

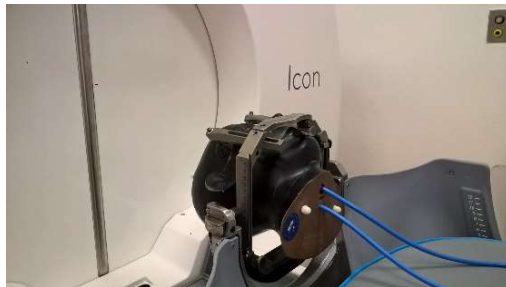
E2E test for both frame based and mask based fixation (imaging, treatment planning, dose delivery)

PHANTOM PREPARATION AND FIXATION

Head phantom preparation



Frame fixation



Mask fixation



Stereotactic CT



IMAGING

Stereotactic CBCT



Phantom treatment in frame



DOSE DELIVERY

Phantom treatment in mask



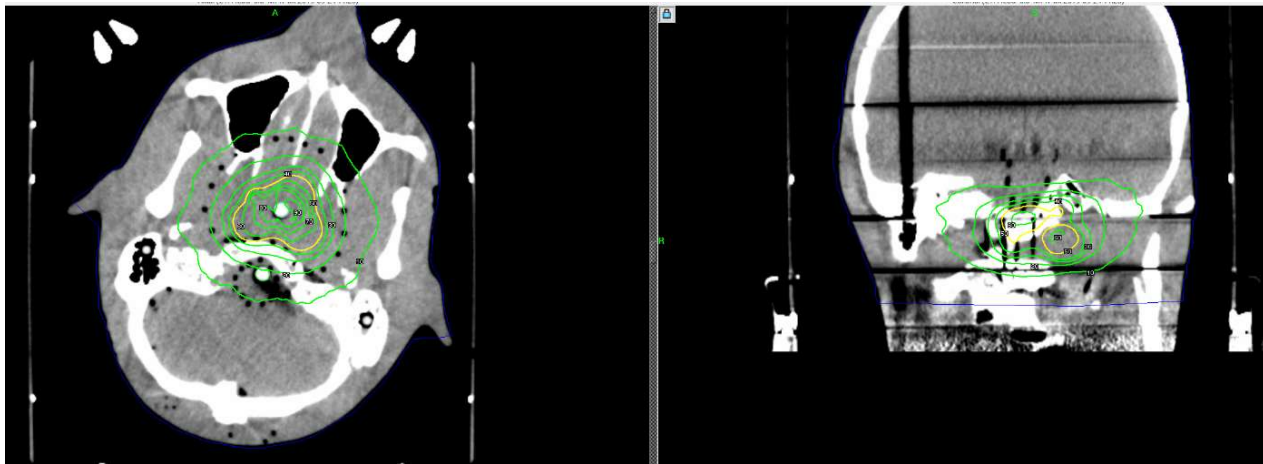
Leksell Gamma Knife[®] Icon[™] dosimetry audit

- VERIFICATION OF THE WHOLE TREATMENT CHAIN

E2E test for both frame based and mask based fixation (imaging, treatment planning, dose delivery)

TREATMENT PLANNING

Frame fixation



Mask fixation



Leksell Gamma Knife[®] Icon[™] dosimetry audit

- VERIFICATION OF THE WHOLE TREATMENT CHAIN

E2E test for both frame based and mask based fixation (imaging, treatment planning, dose delivery)

TREATMENT PLANNING

Mask fixation



Ion chamber 1

Ion chamber 2

Dosimetry film

Leksell Gamma Knife® Icon™

- Fractionation for all patients with very efficient workflow
- Offers new treatment workflows
- Offers effective QA for the stereotactic frame fixation and stereotactic imaging
- Verifies stereotactic imaging and offers solutions when MR imaging fails (artefacts, patient movement)
- Treatments in extracranial locations within Perfexion physical reach (head and neck, C - spine)



