



Mgr. Andrej Babič, PhD.
Mgr. Dušan Kamas, PhD.
Mgr. Erik Vanko
Ing. Dušan Šalát, PhD.

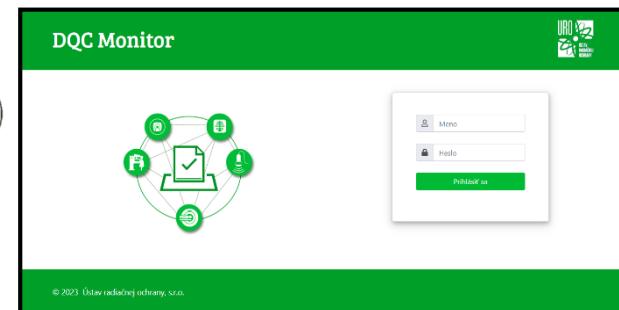
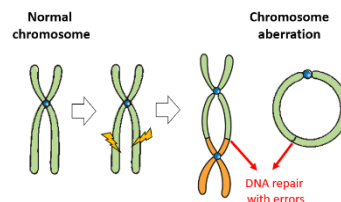
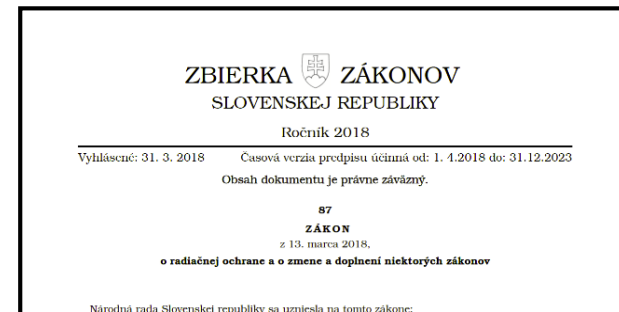
Ústav radiáciej ochrany, s. r. o.
Staničná 1062/24
SK – 911 05 Trenčín
Slovenská republika

Meranie profilov radiácieho poľa lineárnych urýchľovačov

Dny radiáciej ochrany 2023

Tábor, 6. 11. 2023

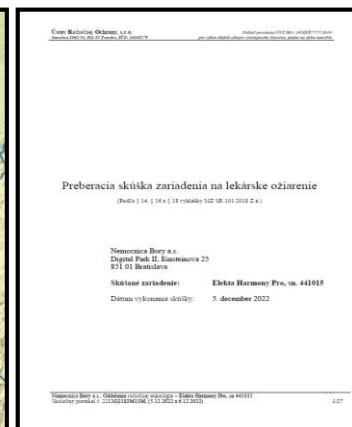
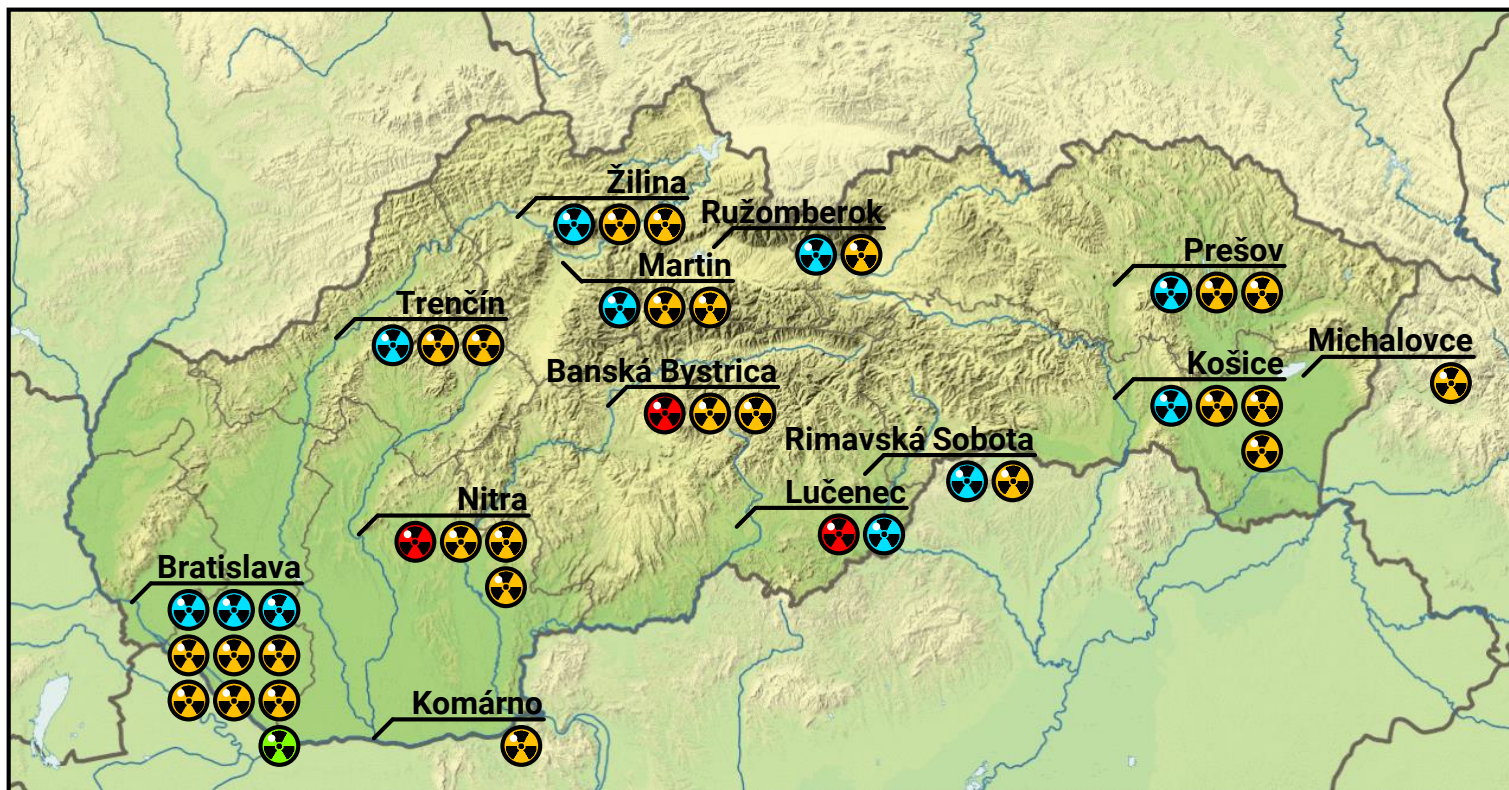
- **História:** MEDICONTROL (1991) → ÚRO (2005): www.uro.sk
- **Organizácia:** Trenčín, Piešťany, Žarnovica, Košice (~ 20 👤)
- **Legislatíva:**
 - Zákon č. 87/2018 Z. z. o RO
 - Vyhláška MZ SR č. 101/2018 Z. z.
- **Školenia:** Odborná príprava (expert RO)
- **DQC:** Sledovanie ožiarenia pacientov
- **Skúšky zdrojov (RDG, RT):** PS, SDS, SPS
- **Projekty RO:** Monitorovanie
- **1. akreditované RBL v SR:**
 - Chromozómové aberácie v krvi



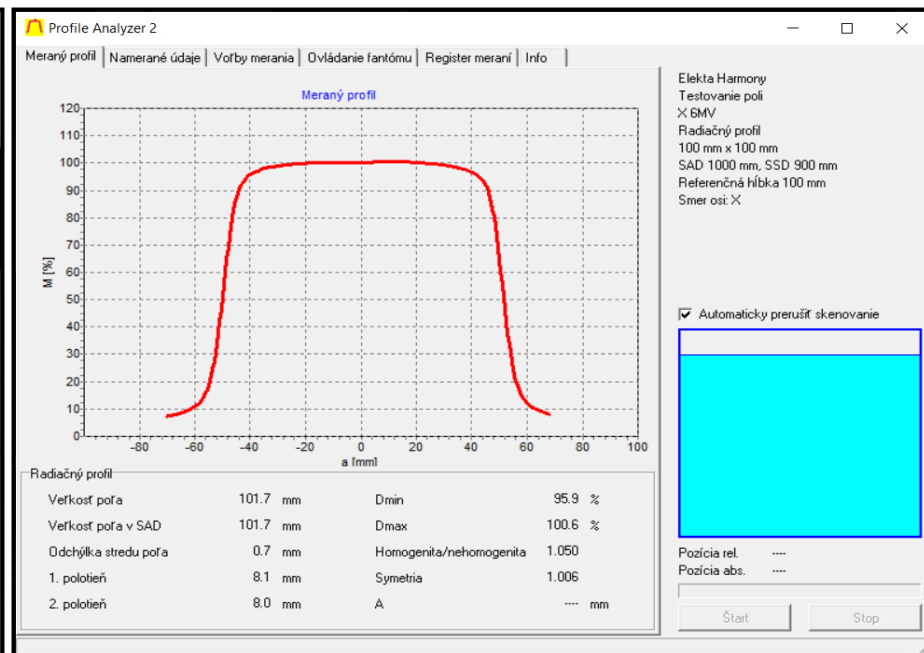
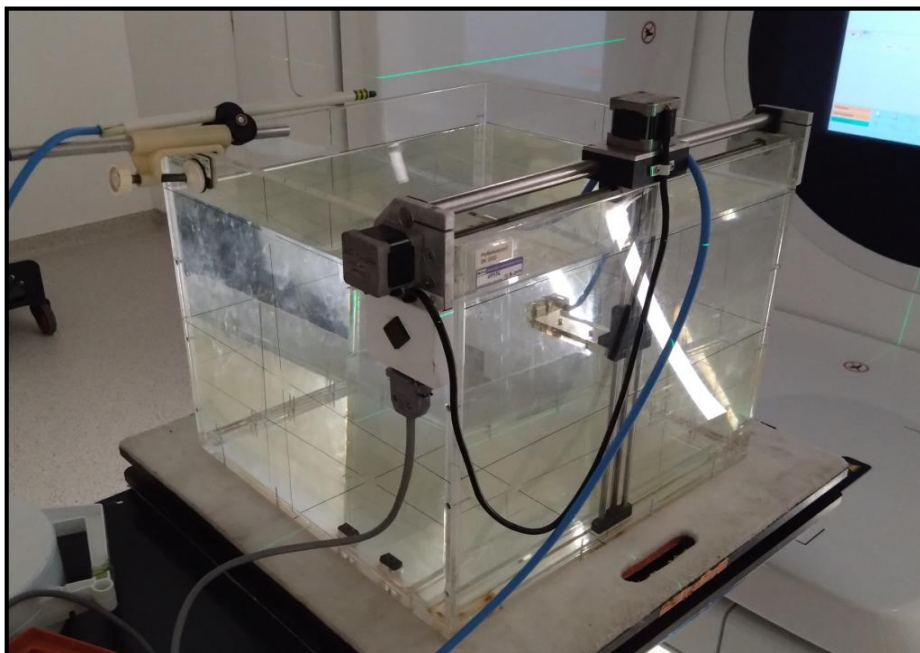
Oddelenie rádioterapie

2

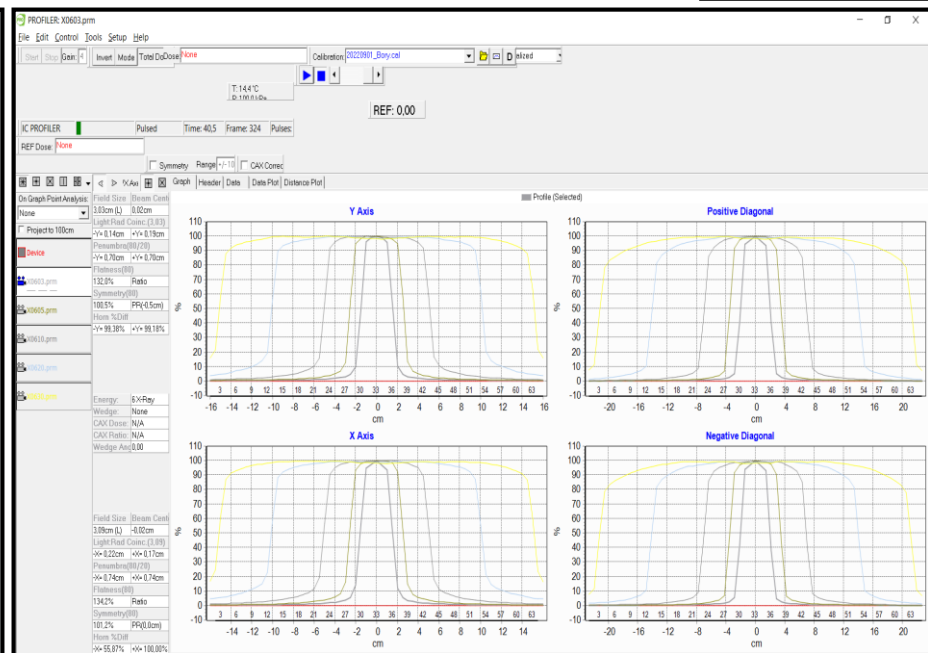
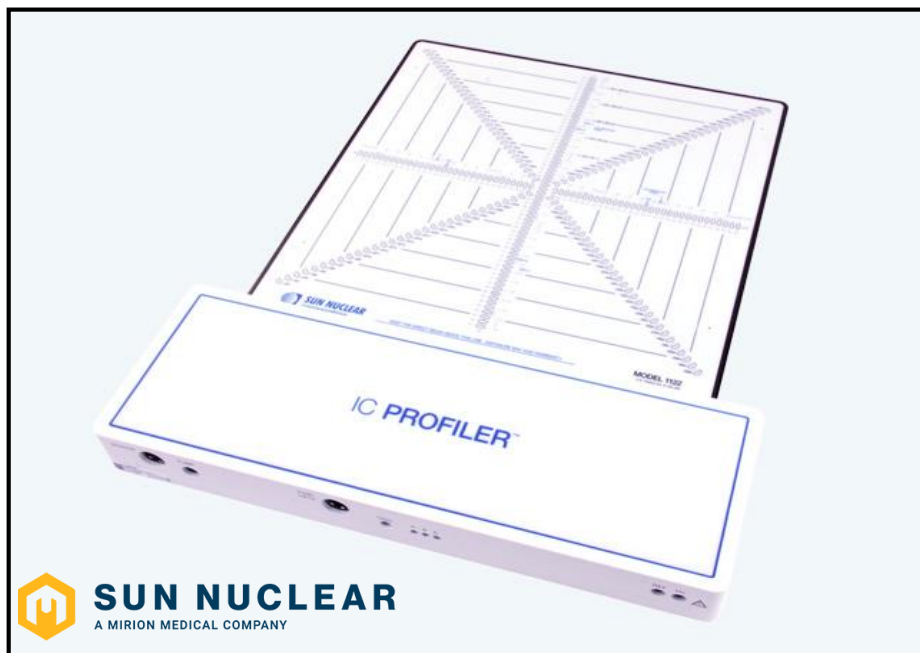
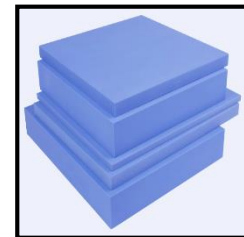
- **SR:** ~ 40 zariadení na onkologických klinikách
- **Povolenie ÚVZ SR č.:** 00ZPŽ/7777/2010
- **Vybavenie:** Fantómy, IK, káble, dozimetre...
- **Protokoly:** PS, SDS (platnosť 6 mesiacov)



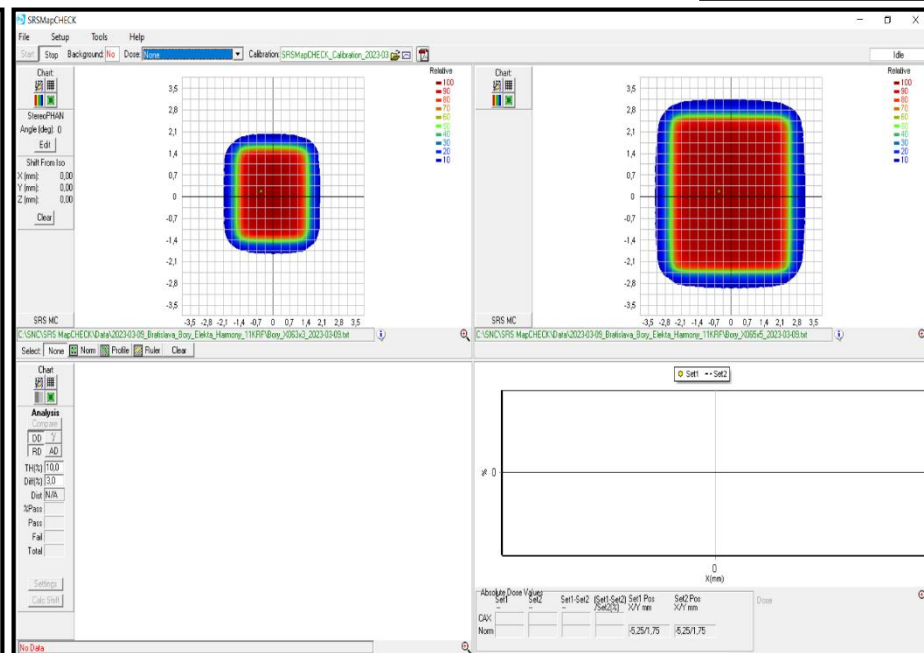
- **H₂O:** „Zlatý štandard“ pre absolútnu dozimetriu v rámci PS
- **Určenie:** Meranie 1D profilov a hĺbkových kriviek
- **Využitie:** –17 cm až +17 cm (horizontálne), 25 cm (vertikálne)
- **Príslušenstvo:** IK PTW Semiflex 31010 (0,125 cm³)
- **Software:** Profile Analyzer 2 (ovládanie, meranie a analýza)



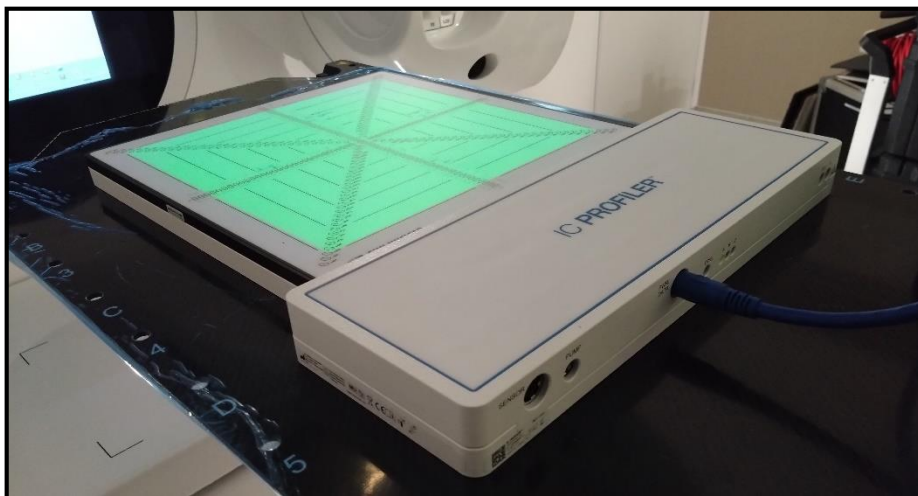
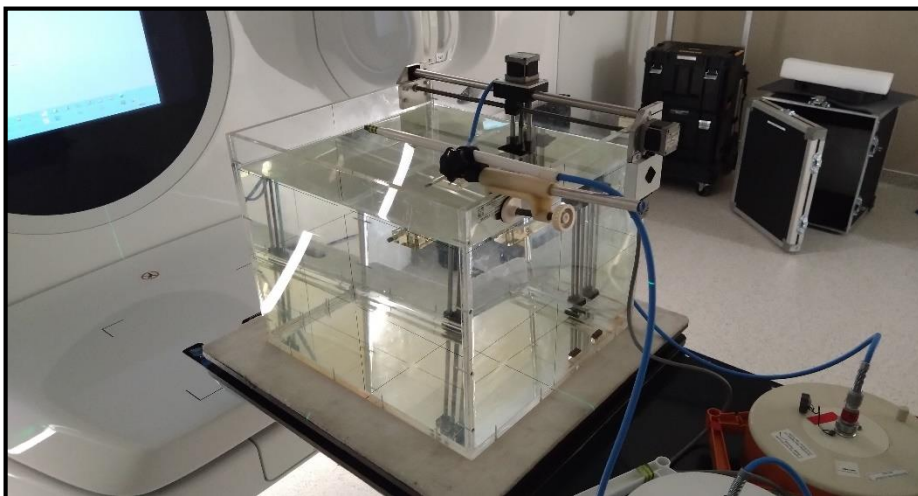
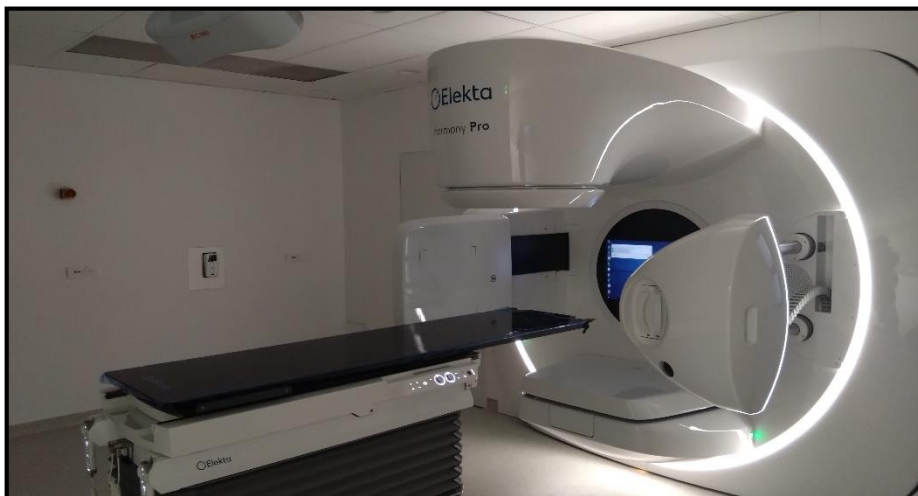
- **2D array:** 251 IK, $\Delta = 5 \text{ mm}$, $32 \times 32 \text{ cm}^2$
- **Určenie:** Commissioning, ATP, QA
- **Využitie:** Meranie dávky súčasne v 4 osiach (X, Y, /, \) bez H₂O
- **Príslušenstvo:** Solid Water® HE (0,5 % H₂O ekviv.)
- **Software:** PROFILER (meranie a analýza profilov)



- **2D array:** 1 013 diód, $\Delta = 2,47 \text{ mm}$, $7,7 \times 7,7 \text{ cm}^2$
- **Určenie:** SRS & SBRT QA bez RTG filmu, E2E test, CyberKnife®
- **Využitie:** Husté meranie malých polí ($3 \times 3 \text{ cm}^2$, $5 \times 5 \text{ cm}^2$)
- **Príslušenstvo:** Rotačný fantóm StereoPHAN™
- **Software:** SNC Patient (podpora pre CyberKnife®)



- Elekta Harmony Pro (NNG Bory, Bratislava, 8. 3. – 9. 3. 2023)
- X-ray 6 MV (FF), SAD = 100 cm (SSD 90 cm + buildup 10 cm)

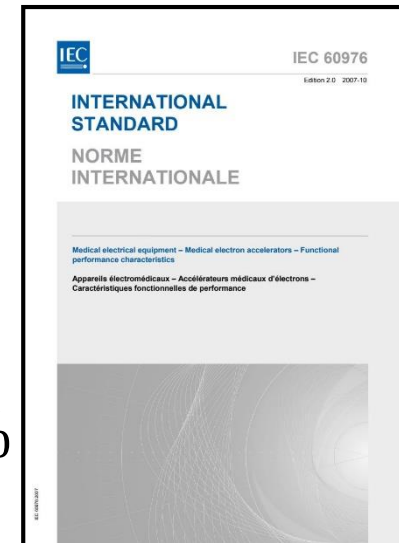


- **Norma:** IEC 60976
- **Stred zväzku [Beam Center]:** $BC \pm FWHM/2$
- **Veľkosť poľa [Field Size]:** $FS = FWHM$
- **Polotieň [Penumbra]:** $P: 20 \% < \frac{D(x)}{\max D(x)} < 80 \%$
- **Homogenita [Flatness]:** $x \in 80 \% FWHM$

$$F = \frac{\max D(x)}{\min D(x)} \times 100 \%$$

- **Symetria [Symmetry]:** $x \in 80 \% FWHM$

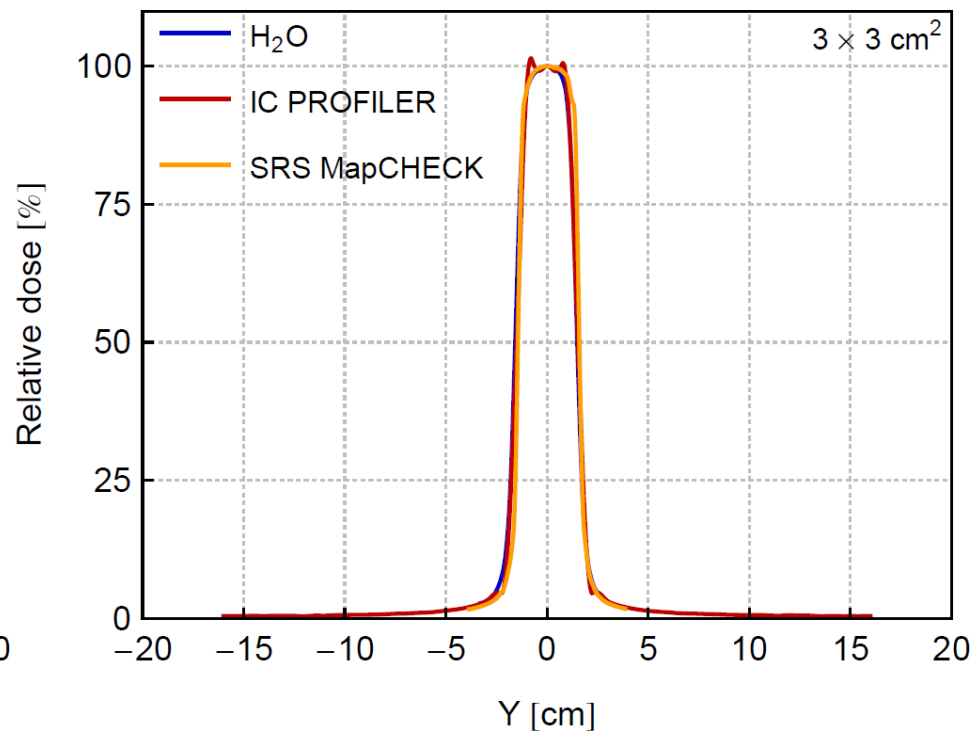
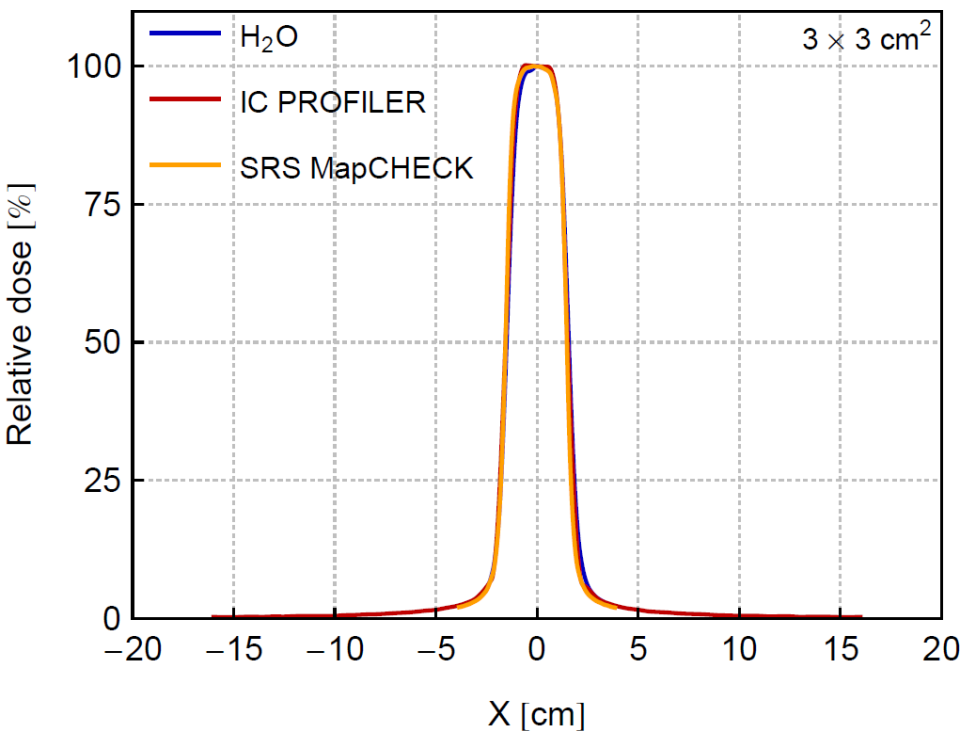
$$S = \max \frac{\max[D(x), D(-x)]}{\min[D(x), D(-x)]} \times 100 \%$$



| Param. | Kritérium |
|--------|--|
| BC | $\leq 2 \text{ mm od CAX}$ |
| FS | $\leq 2 \text{ mm} / 1 \% \text{ od } FS_{\text{ind}}$ |
| P | $\leq 2 \text{ mm od } P_{\text{ref}}$ |
| F | $\leq 106 \%$ |
| S | $\leq 103 \%$ |

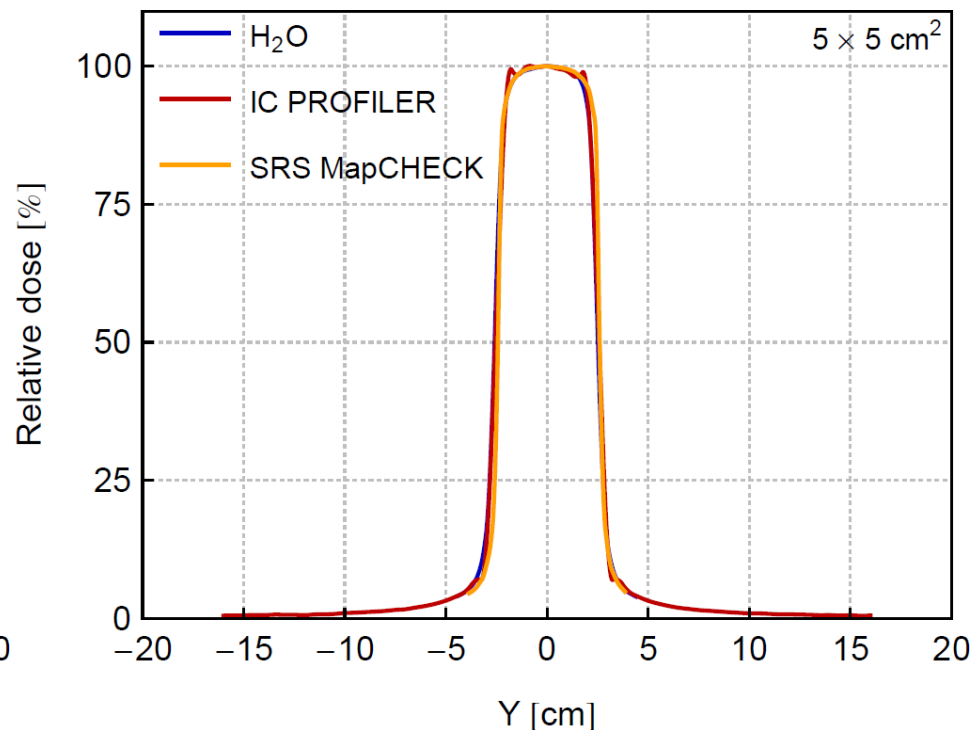
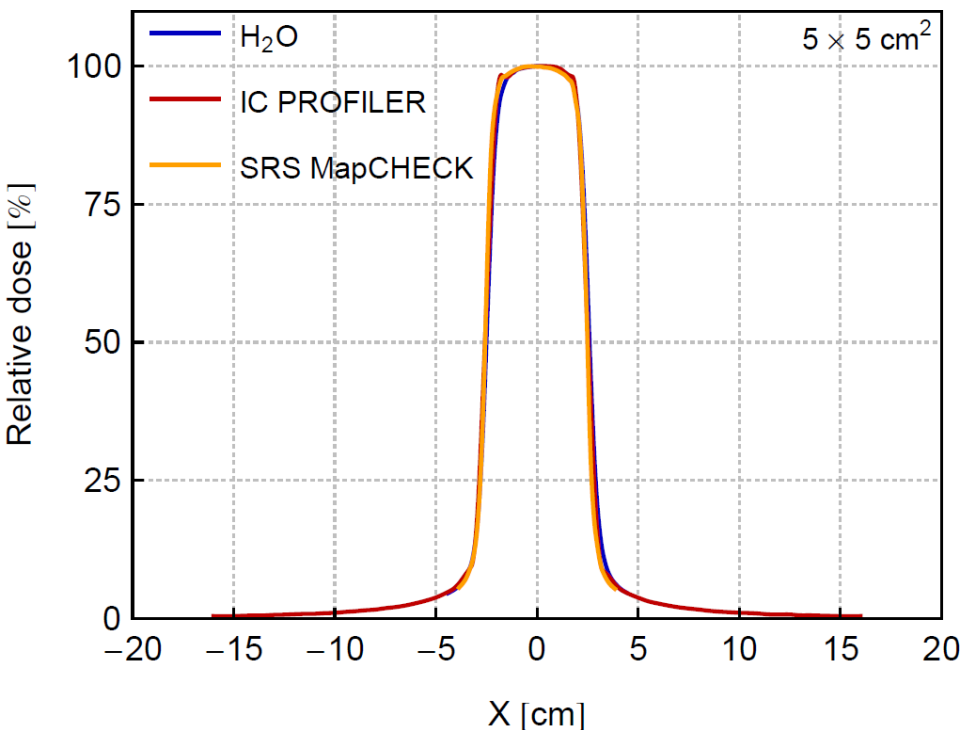
Profily radiačného poľa $3 \times 3 \text{ cm}^2$

8



| Detektor | BC [mm] | FS [cm] | X | | F [%] | S [%] |
|------------------|---------|---------|---------------------|---------------------|-------|-------|
| | | | P ₋ [cm] | P ₊ [cm] | | |
| H ₂ O | 0,4 | 3,07 | 0,67 | 0,67 | 101,2 | 100,7 |
| IC PROFILER | -0,2 | 3,09 | 0,68 | 0,68 | 102,6 | 100,5 |
| SRS MapCHECK | -0,4 | 3,03 | 0,52 | 0,50 | 100,7 | 100,3 |
| Y | | | | | | |
| H ₂ O | -0,4 | 3,07 | 0,56 | 0,56 | 101,0 | 100,3 |
| IC PROFILER | 0,2 | 3,03 | 0,63 | 0,64 | 100,9 | 100,3 |
| SRS MapCHECK | 0,9 | 3,04 | 0,32 | 0,32 | 100,5 | 100,3 |

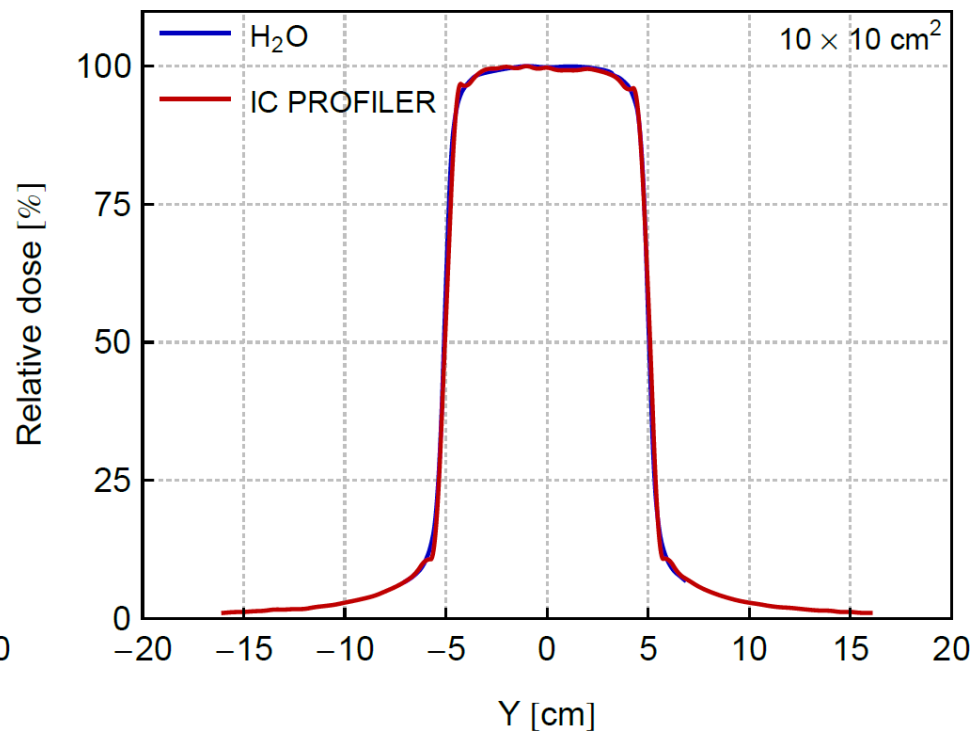
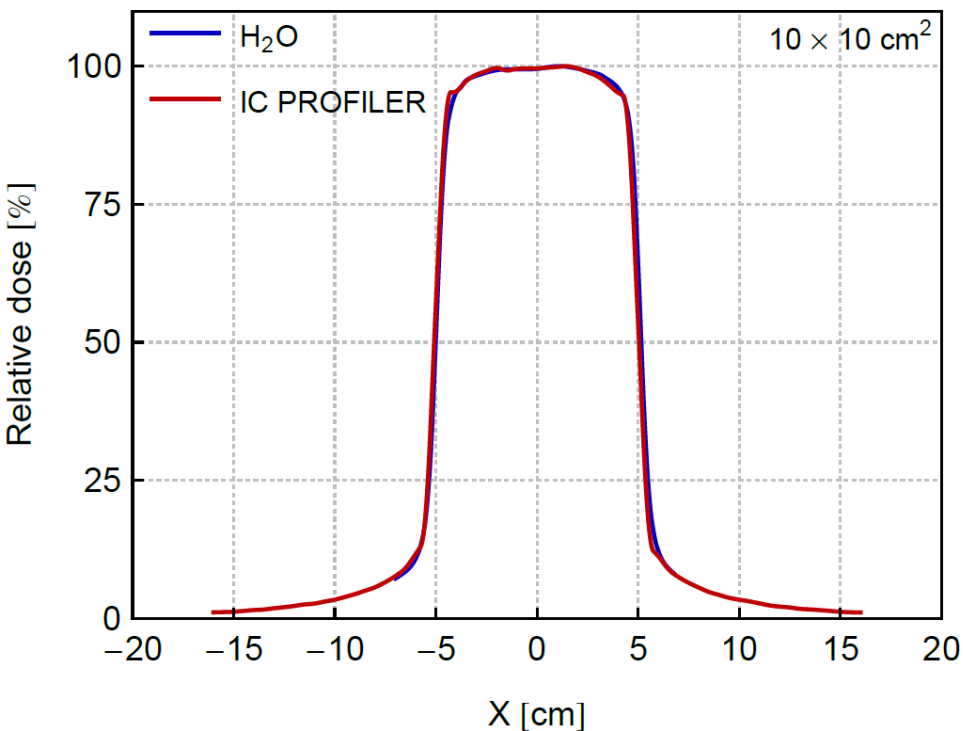
Profily radiačného poľa $5 \times 5 \text{ cm}^2$



| Detektor | BC [mm] | FS [cm] | P ₋ [cm] | P ₊ [cm] | F [%] | S [%] |
|------------------|---------|---------|---------------------|---------------------|-------|-------|
| X | | | | | | |
| H ₂ O | 0,5 | 5,10 | 0,72 | 0,73 | 102,2 | 100,3 |
| IC PROFILER | -0,3 | 5,11 | 0,71 | 0,72 | 102,3 | 100,9 |
| SRS MapCHECK | -0,4 | 5,06 | 0,55 | 0,55 | 102,1 | 100,3 |
| Y | | | | | | |
| H ₂ O | -0,3 | 5,11 | 0,60 | 0,61 | 101,9 | 100,3 |
| IC PROFILER | 0,2 | 5,15 | 0,67 | 0,66 | 102,0 | 100,9 |
| SRS MapCHECK | 0,9 | 5,03 | 0,35 | 0,34 | 101,8 | 100,3 |

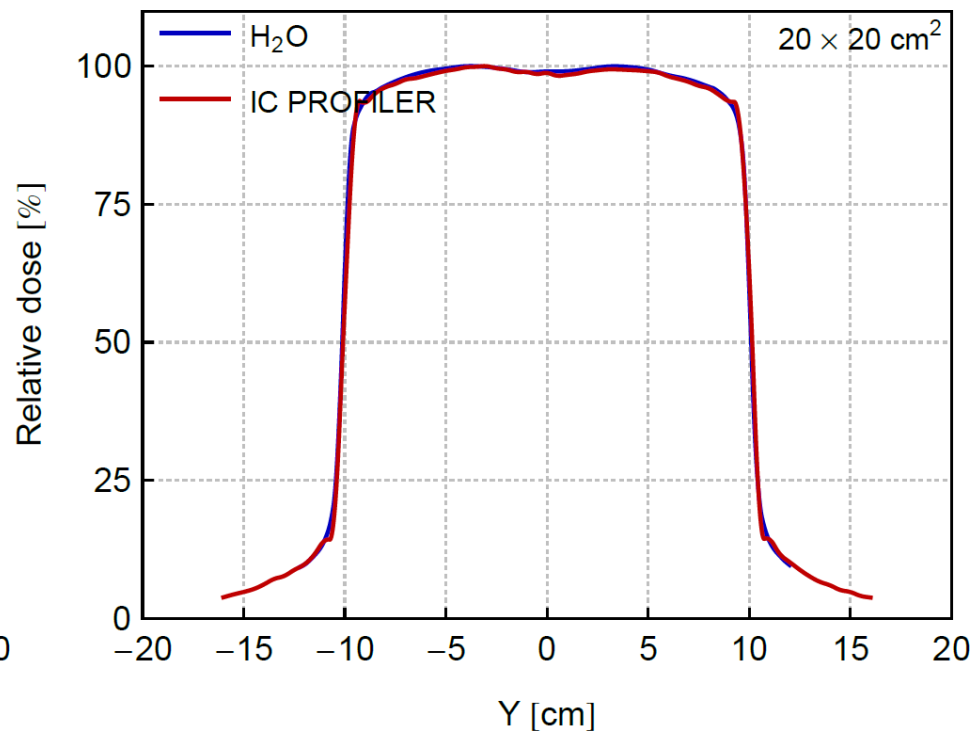
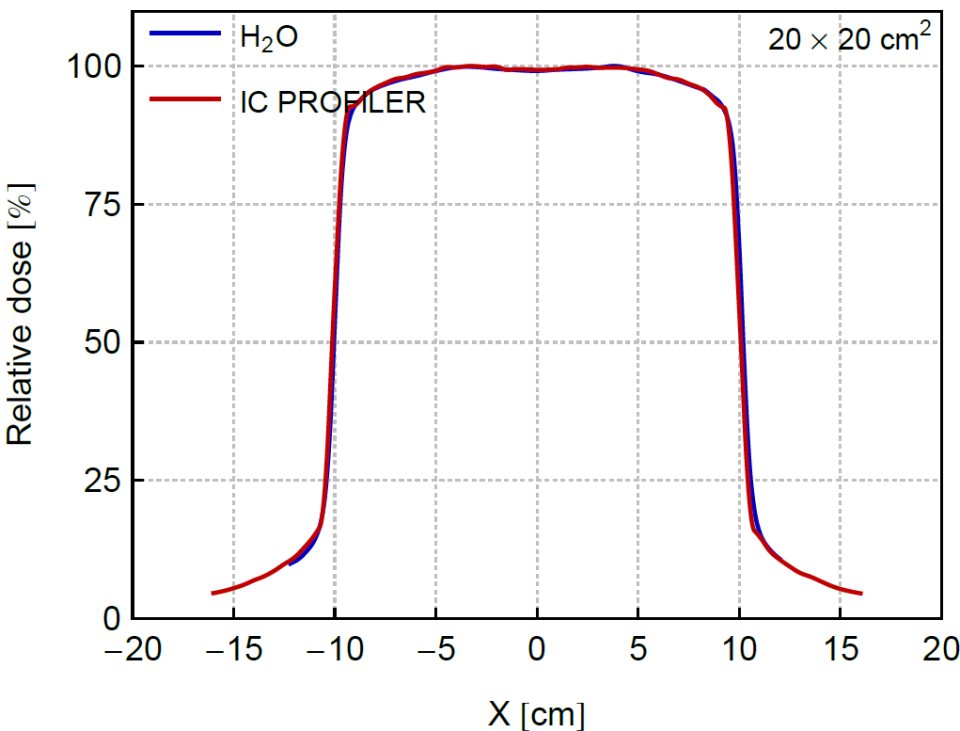
Profily radiačného poľa $10 \times 10 \text{ cm}^2$

10



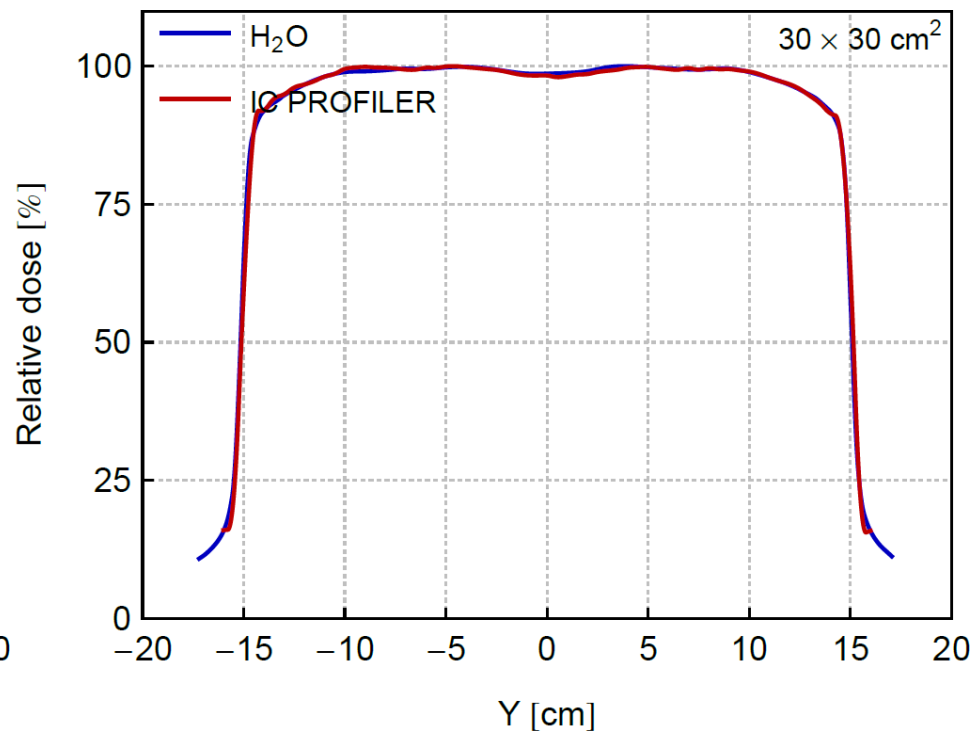
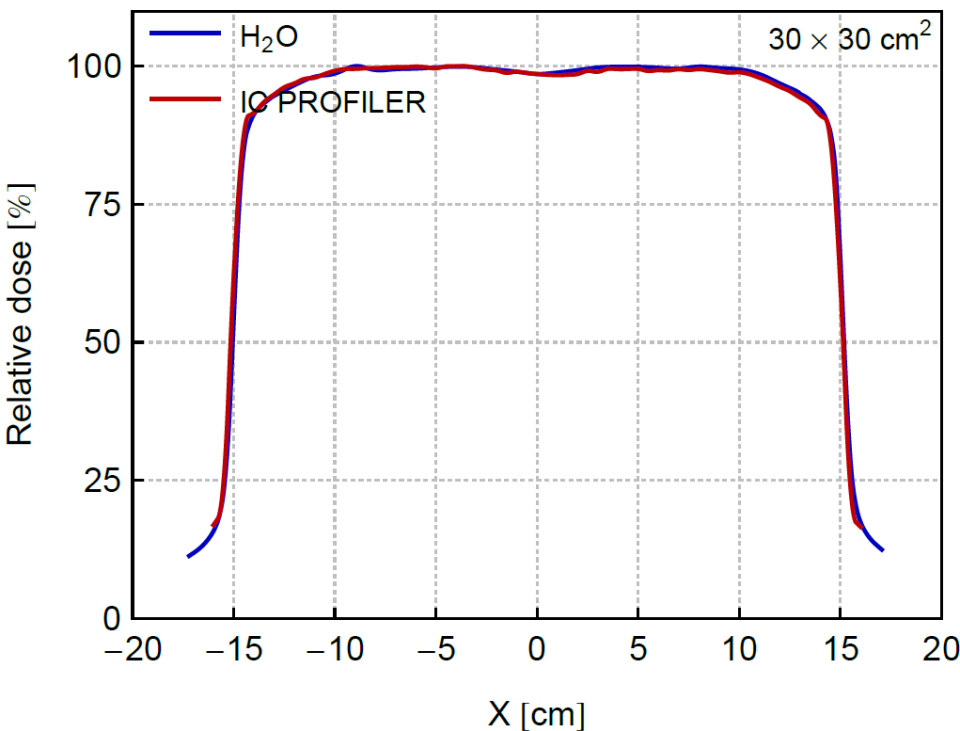
| Detektor | BC [mm] | FS [cm] | X | | F [%] | S [%] |
|------------------|---------|---------|---------------------|---------------------|-------|-------|
| | | | P ₋ [cm] | P ₊ [cm] | | |
| H ₂ O | 0,7 | 10,17 | 0,81 | 0,80 | 105,0 | 100,6 |
| IC PROFILER | -0,2 | 10,14 | 0,79 | 0,79 | 105,2 | 100,8 |
| Y | | | | | | |
| H ₂ O | -0,2 | 10,14 | 0,68 | 0,68 | 104,0 | 100,4 |
| IC PROFILER | 0,3 | 10,16 | 0,73 | 0,72 | 104,5 | 101,0 |

Profily radiačného poľa 20 × 20 cm²



| Detektor | BC [mm] | FS [cm] | X | | F [%] | S [%] |
|------------------|---------|---------|---------------------|---------------------|-------|-------|
| | | | P ₋ [cm] | P ₊ [cm] | | |
| H ₂ O | 0,8 | 20,25 | 0,91 | 0,92 | 104,3 | 100,3 |
| IC PROFILER | -0,2 | 20,22 | 0,89 | 0,88 | 104,4 | 100,4 |
| Y | | | | | | |
| H ₂ O | -0,1 | 20,23 | 0,78 | 0,78 | 104,0 | 100,6 |
| IC PROFILER | 0,3 | 20,25 | 0,80 | 0,77 | 104,5 | 100,6 |

Profily radiačního poľa 30 × 30 cm²



| Detektor | BC [mm] | FS [cm] | X | | | |
|------------------|---------|---------|---------------------|---------------------|-------|-------|
| | | | P ₋ [cm] | P ₊ [cm] | F [%] | S [%] |
| H ₂ O | 0,7 | 30,25 | 0,99 | 1,00 | 103,7 | 100,7 |
| IC PROFILER | -0,1 | 30,32 | 0,93 | 0,91 | 104,1 | 100,7 |
| Y | | | | | | |
| H ₂ O | -0,3 | 30,26 | 0,88 | 0,87 | 103,7 | 100,5 |
| IC PROFILER | 0,2 | 30,30 | 0,85 | 0,81 | 103,7 | 100,5 |

- Zjednodušenie a zrýchlenie meraní bez straty kvality?
- Vodný fantóm a RTG filmy (~ 2 – 3 h) vs. 2D arrays (~ 1 h)
- Zhoda profilov dostačujúca pre všetky praktické účely
- Monthly QA → -1 h (3 ICP, 3 kliniky, 14+ fyzikov, 4 roky):

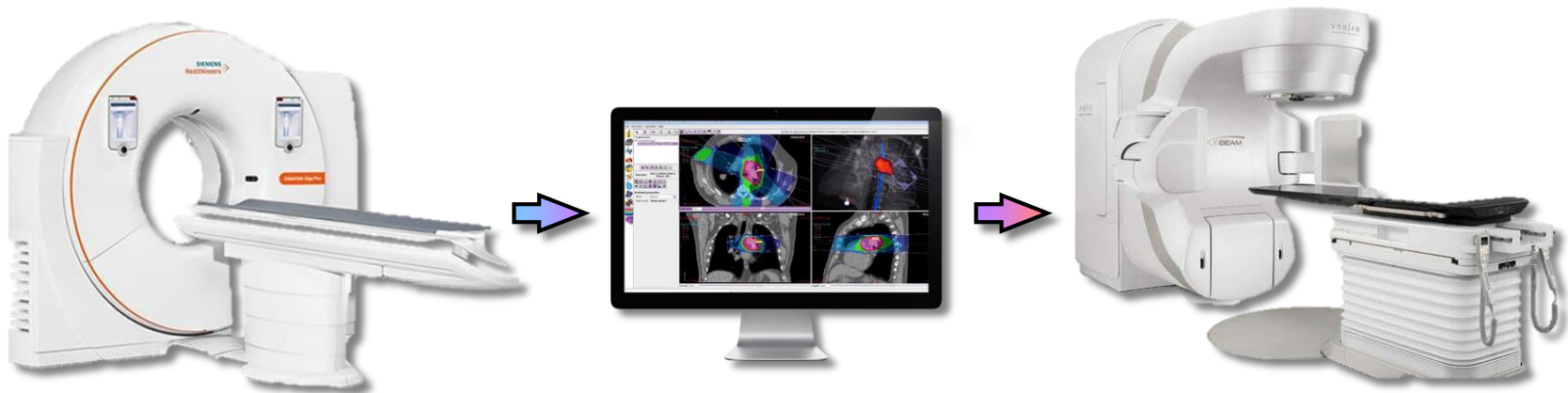
$$(D_{ICP} - D_{H_2O})/D_{H_2O} = 0,22 \% \pm 0,66 \% (N = 1\ 452), -0,02 \% \pm 0,38 \% (N = 533)$$

[SNC Webinar: "Before and After: Standardizing Physics with the SunCHECK® QA Platform" (D. Barbee, NYU Langone, 26/10/2023)]



| Model | Detektory | Počet | Rozlíšenie [mm] | Rozmery [cm ²] |
|--------------------------------|-------------------|----------------|-----------------|----------------------------|
| Sun Nuclear ArcCHECK | Polovodičové det. | 1 386 | 10 | 21 × 21 |
| Sun Nuclear SRS MapCHECK | Polovodičové det. | 1 013 | 2,47 | 7,7 × 7,7 |
| Sun Nuclear IC PROFILER | Ionizačné komory | 251 | 5 | 32 × 32 |
| PTW OCTAVIUS Detector 1600 SRS | Ionizačné komory | 1 521 | 5 | 15 × 15 |
| PTW OCTAVIUS Detector 1500 | Ionizačné komory | 1 405 | 7,1 | 27 × 27 |
| PTW STARCHECK | Ionizačné komory | 527 | 3 | 26 × 26 |
| IBA MatriXX Resolution | Ionizačné komory | 1 521 | 6,5 | 25,3 × 25,3 |
| IBA StarTrack Detector | Ionizačné komory | 453 | 5 | 27 × 27 |
| IBA myQA SRS | Polovodičové det. | 105 000 | 0,4 | 12 × 14 |

- **Plánovací systém (TPS):**
 - Program na plánovanie liečby v rádioterapii
 - 3D vizualizácia pacienta → návrh ožarovacieho poľa
 - Predpísaná dávka v nádore, minimálna v zdravom tkanive
- **End-to-end (E2E) test:**
 - Skúška reťazca (užívateľ): CT simulátor → TPS → linac
 - Cieľ odhaliť klinickú chybu v komplexnom systéme

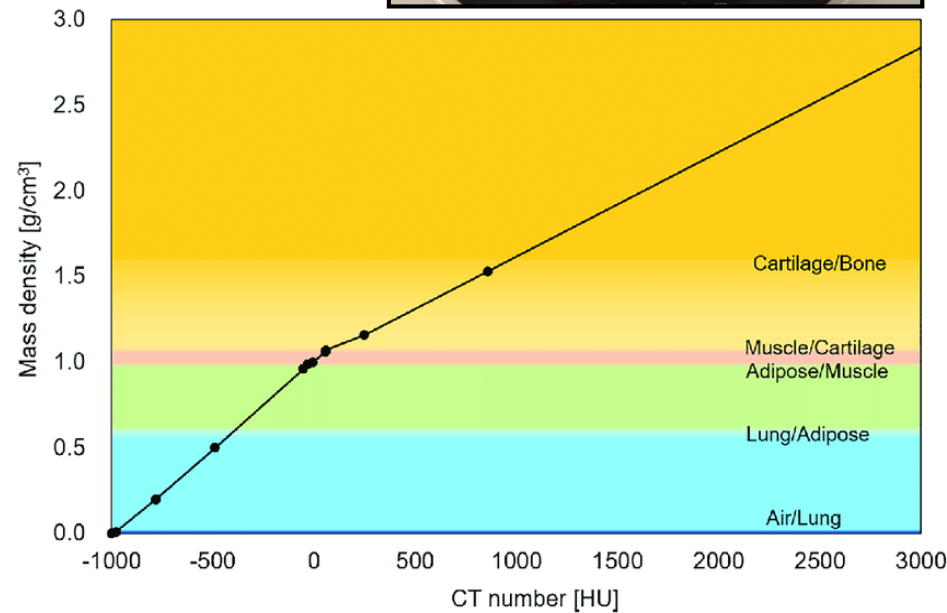
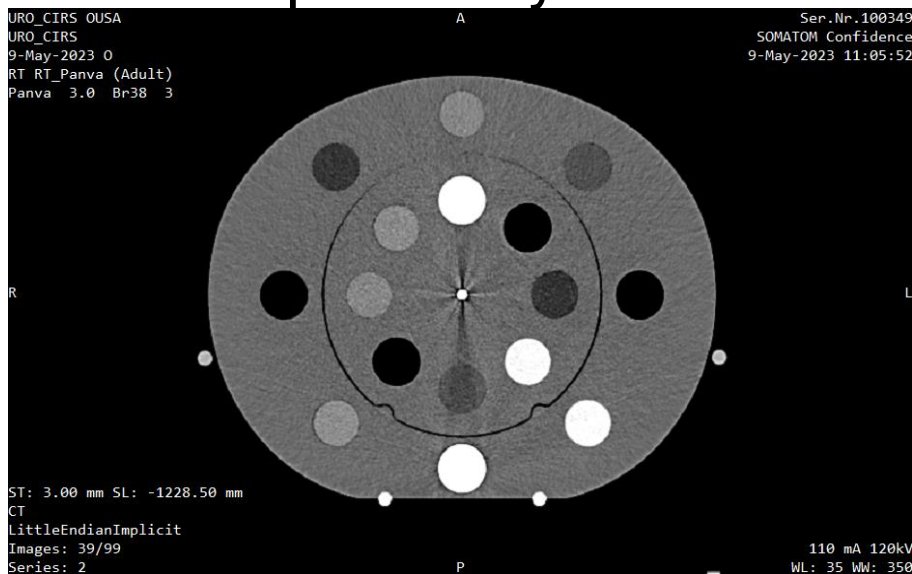


- **CT simulátor:**

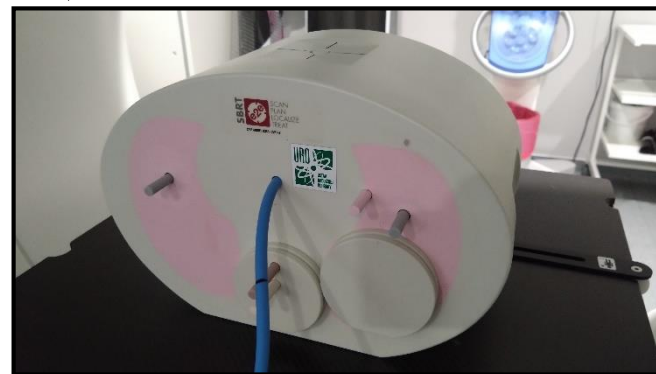
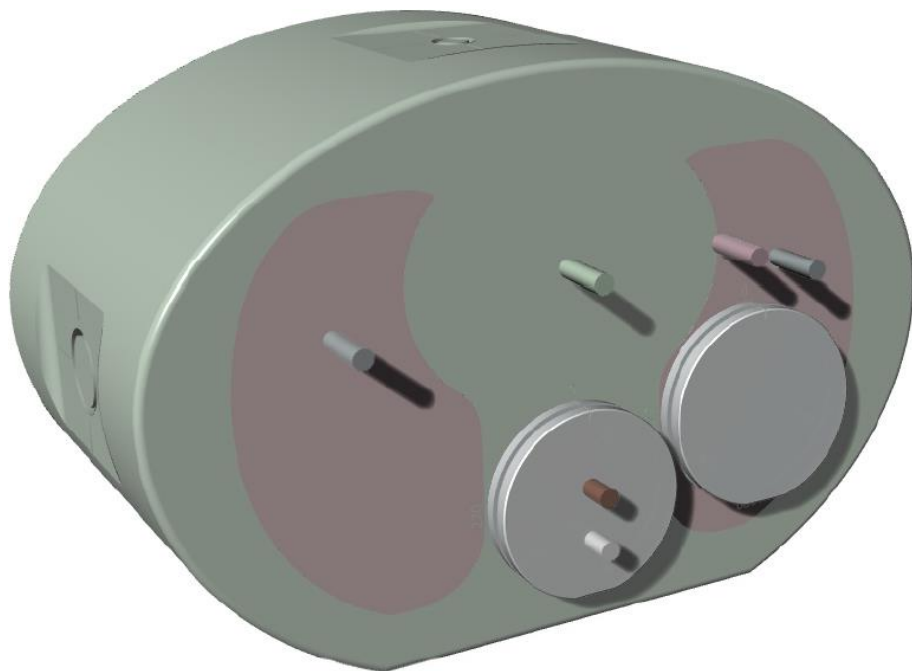
- Vstupné DICOM dáta pre TPS (voxely)
- Contouring (PTV), planning, výpočet...

- **CT kalibračná krivka:**

- CT číslo [HU] vs. ρ [g/cm³], RED [1/cm³]
- 1× pre každý CT simulátor



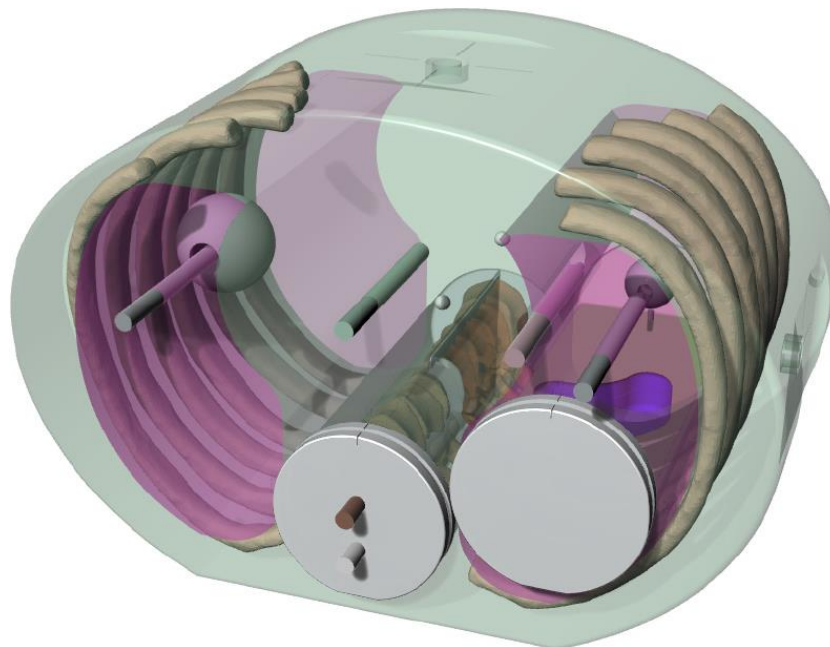
- **CIRS E2E[®] SBRT Phantom with Removable Spine (036S):**
 - Antropomorfný tkanivovo-ekvivalentný fantóm hrudníka: chrbtica, rebrá, miecha, mediastínium, pľúca a dve lézie
 - Šesť otvorov na ionizačnú komoru (dutiny + výplne), rádiochromický film (chrbtica a pľúca), nanoDot[™] OSL



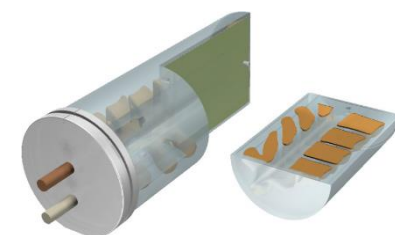
| | |
|-----------------|--|
| DIMENSIONS: | 16.5 cm x 30 cm x 20 cm 6.5" x 11.8" x 7.9" |
| PHANTOM WEIGHT: | ~7 kg (15 lb) |
| MATERIALS: | Proprietary Epoxy Resins |

E2E fantóm (špecifikácia)

| Material | Density, g/cc | Electron Density x 10 ²³ , per cc | Ratio to H ₂ O |
|-------------------------------|---------------|--|---------------------------|
| Plastic Water [®] DT | 1.04 | 3.35 | 1.003 |
| Lung | 0.21 | 0.67 | 0.201 |
| Cortical Bone | 1.91 | 5.95 | 1.782 |
| Trabecular Bone | 1.20 | 3.86 | 1.156 |
| Soft tissue target | 1.06 | 3.43 | 1.028 |



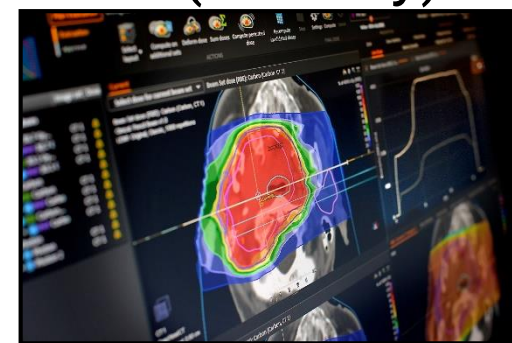
| Location | Target | Target Material | Plug Material | Plug Color |
|----------|-------------------|---------------------------|-----------------|------------|
| CV1 | ø 40 mm | Soft Tissue | Soft Tissue | Gray |
| CV2 | Mediastimum | PWDT | PWDT | Green |
| CV3 | Lung/ Soft Tissue | Lung/ PWDT | Lung | Pink |
| CV4 | ø 20 mm | Soft Tissue | Soft Tissue | Gray |
| CV5 | Vertebrae | Trabecular/ Cortical Bone | Trabecular Bone | Brown |
| CV6 | Spinal Cord | Spinal Cord | Spinal Cord | White |



- **Imaging:** CT simulátor (E2E fantóm + IK)
- **Planning:** PP, BOX, klíny, MLC, VMAT, IMRT, ...
- **Calculation:** Algoritmy (Eclipse AAA, XiO, PB...)
- **Setup:** E2E fantóm, IK, kábel, elektromer
- **Verification:** CBCT (matching), gating, ...
- **Delivery:** X-ray 6 MV, Gantry 90°, Collimator 0°, PTW Semiflex 3D 31021 (0,07 cm³), SSD 100 cm, 10 × 10 cm², Head First-Supine, Table (X, Y, Z, °), Min/Max/Mean Dose in PTV, MU, 2 Gy × 1 frakcia (izodózy)



PTW UNIDOS

PTW Semiflex 3D 31021
(0,07 cm³)

$$\delta = \frac{D - D_{\text{TPS}}}{D_{\text{TPS}}}$$

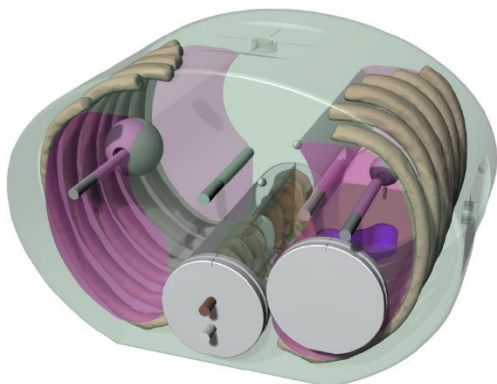
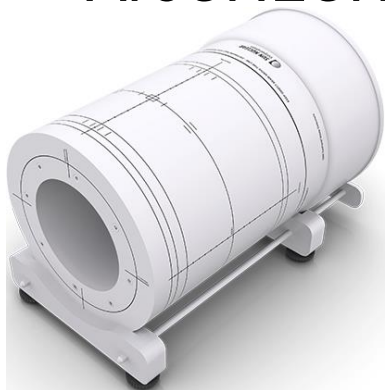
$$|\delta| \leq 2\% - 5\%$$

$$k_{T,P} = \frac{(273,2 \text{ K} + T) P_0}{(273,2 \text{ K} + T_0) P}$$

$$T_0 = 20^\circ\text{C}$$

$$P_0 = 101,3 \text{ kPa}$$

- **Skúšky dlhodobej stability pre TPS (jedenkrát za 2 roky):**
 - Nezávislá kontrola presnosti a odhalenie klinickej chyby
 - Návrh efektívnych plánov vhodných pre všetky pracoviská
 - ArcCHECK[®], E2E[®], QUASAR[™], StereoPHAN[™], STEEV[™], ...



Fantómy

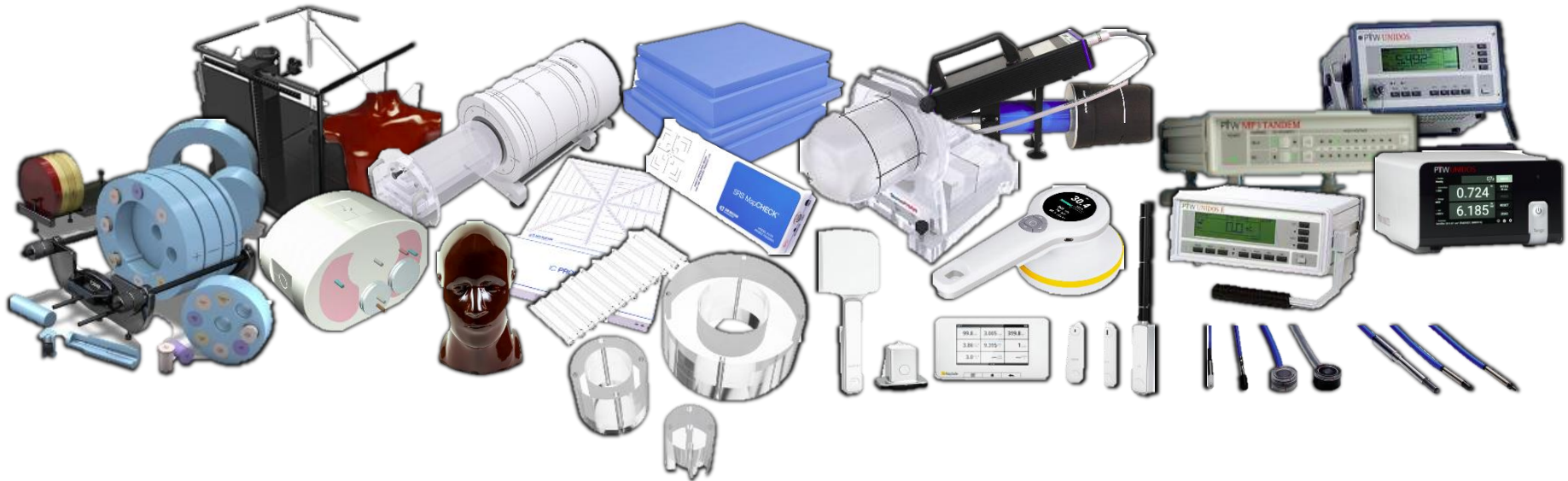
CIRS CBCT Electron Density & Image Quality
CIRS E2E SBRT
Profile Analyzer (vodný fantóm)
RaySafe Pro-CT Dose (CTDI fantóm)
RSD Antropomorphic Head
RSD Antropomorphic Thorax
SNC ArcCHECK
SNC IC PROFILER + Solid Water HE
SNC SRS MapCHECK + StereoPHAN

Detektory

PTW Farmer
PTW microDiamond
PTW Roos
PTW Semiflex
PTW Semiflex 3D
PTW Soft X-Ray
PTW STEP
RaySafe 452
RaySafe X2

Elektromery

PTW TANDEM
PTW UNIDOS
PTW UNIDOS E
PTW UNIDOS Tango



Ďakujem za pozornosť!

Backup 1/3: E2E fantóm (spredu)

