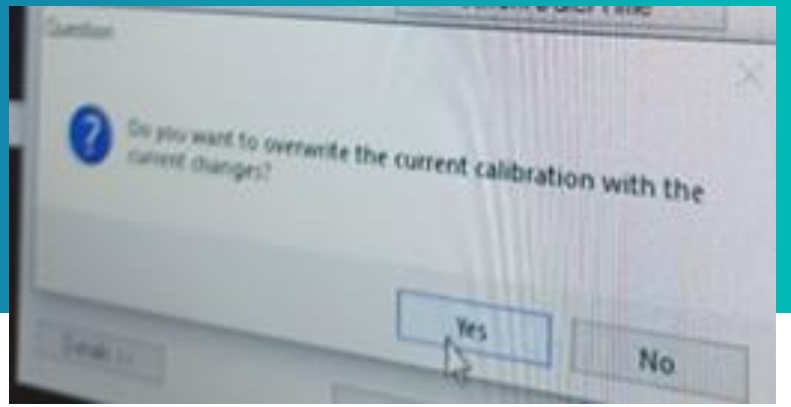
ICTP-IAEA Workshop on Reference Dosimetry in EBRT and Brachytherapy

CODE OF PRACTICE FOR WELL-TYPE CHAMBER CALIBRATION AND SOURCE STRENGTH MEASUREMENTS

6 Nov 2025, Vappu Reijonen/Medical Physicist, PhD



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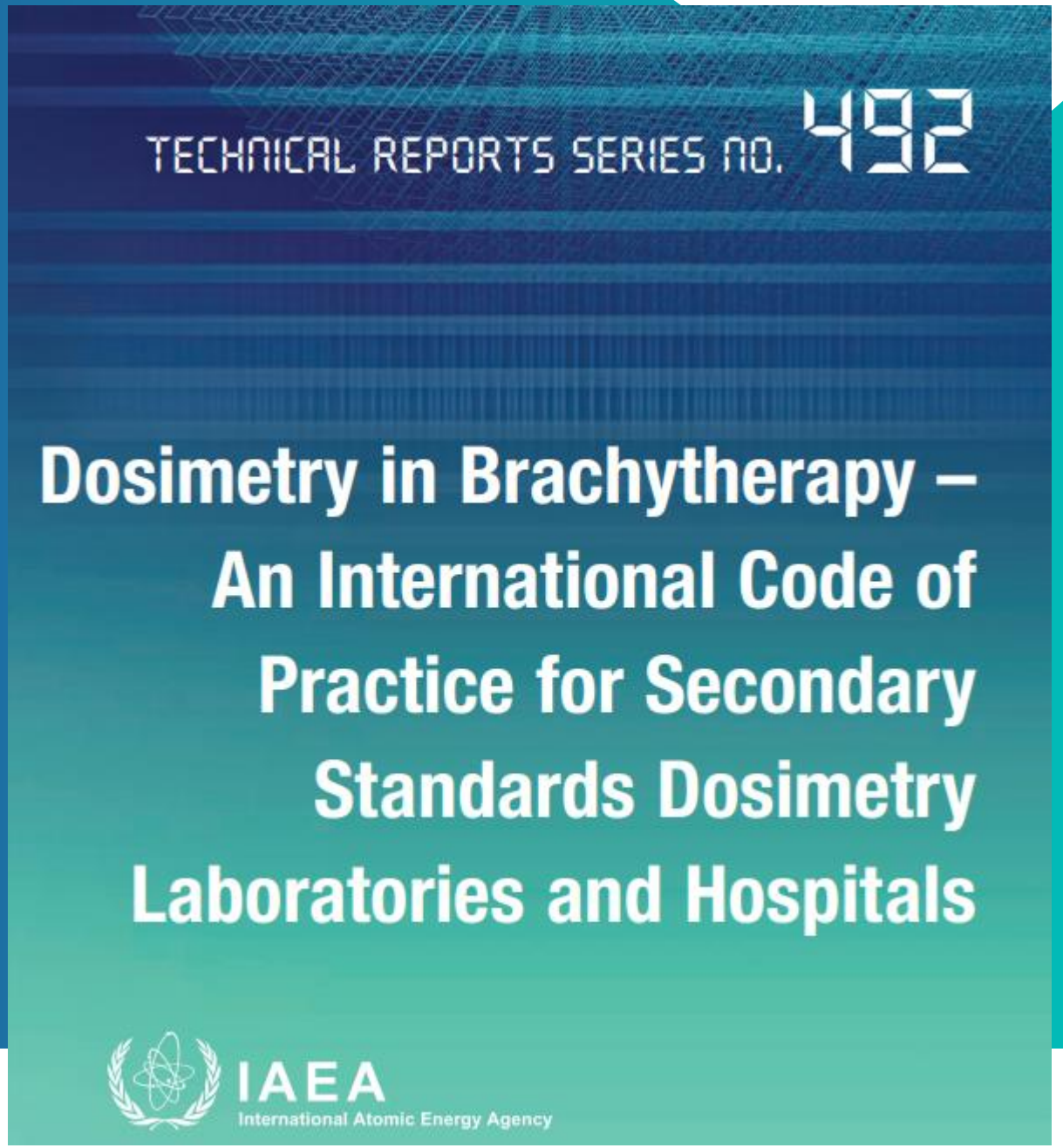
HUS & HELSINGFORS UNIVERSITET I SAMARBETE
A COLLABORATION BETWEEN HUS & UNIVERSITY OF HELSINKI

Topic in TRS 492:

- Chapter 8



CODE OF PRACTICE

- "*A common measurement procedure is laid out below that can be used by SSDLs, clinical medical physicists and manufacturers*"
- "*Best practice recommendations*"

- The measurement: **ionization current** generated by a **brachytherapy source** inserted in a **well-type chamber**
  - **Calibration** of the dosimetry system
  - Subsequent source strength measurements with this dosimetry system
    - When **receiving a new source** to be used in treatments (acceptance test)
    - **Regular** QC checks (periodical tests of **sources in use**) or whenever **suspecting a problem** with a source (leak, change in geometry, etc.)

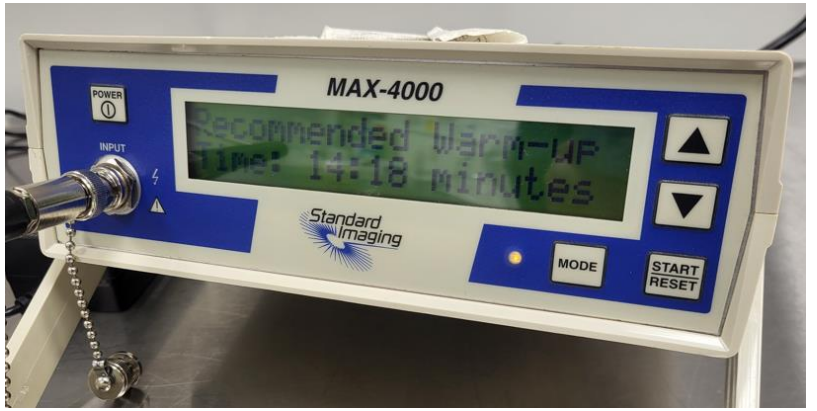
SET-UP AND PREPARATION

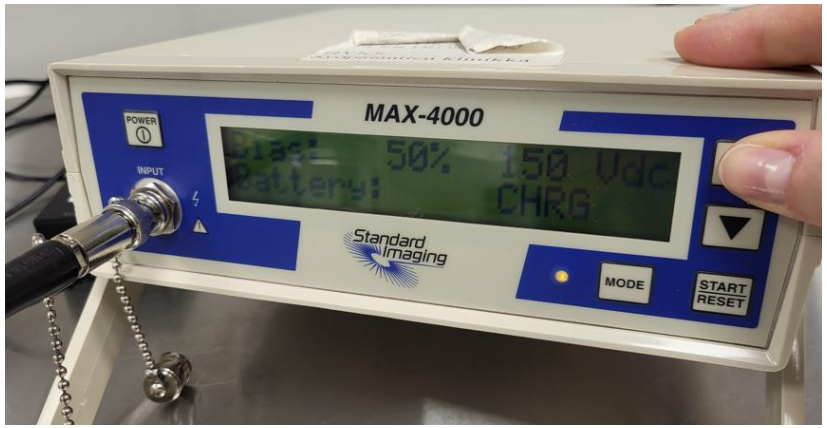
Measurements should be…

- …carried out in a (shielded) room with steady **background radiation level**
  - Well-type chambers do not typically have strong external shielding of their own, so any external radiation sources will cause disturbance and may bring crude errors in the measurements!
- …performed in a **minimum scatter environment**
  - Chamber minimum distance of 1 m from any wall or floor
  - E.g. a plastic or wooden table <15 mm thickness
  - Not as crucial for low-energy LDR sources
- …in constant **ambient** temperature (change <0.5 °C/h) and relative humidity (20%...70%), also air pressure needs to be **monitored**

SET-UP AND PREPARATION

- The chamber and source holder(s) need to **reach equilibrium** with the ambient conditions **before the measurements**
  - At least 30 min is usually needed, overnight better
  - E.g. mentioned that SI HDR 1000 Plus needs 400 min to settle from a 4 °C temperature difference
- Also electrometer needs to **stabilize** after switching on
  - Usually announces the warm-up time, but make sure
  - Setting the correct voltage gradient (also polarity!) and measuring mode
  - Zeroing & leakage current measurement
    - "…*after having applied the appropriate polarizing voltage for at least 10 minutes*" (8.2.3.4)





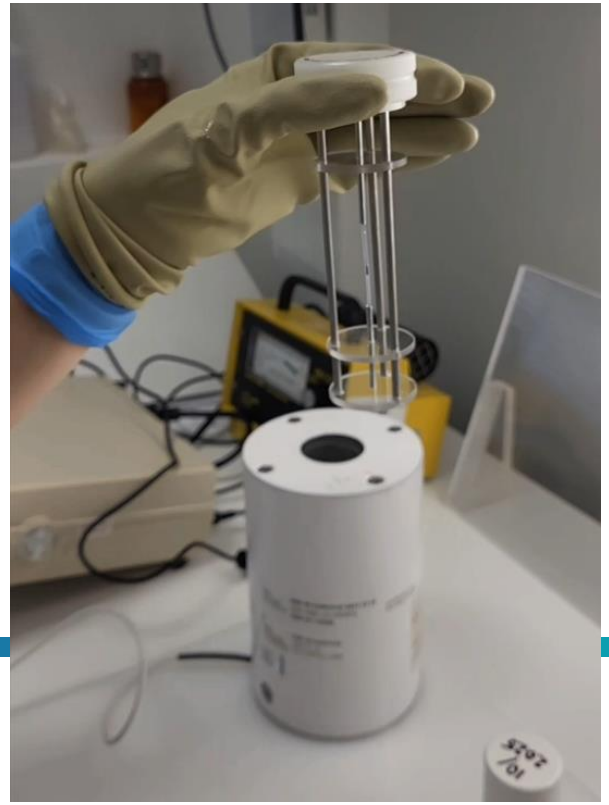
E.g. HDR Ir-192 source

PRE-OPERATIONAL FUNCTIONS:

Warm up Mode:
- Fifteen minute automatic countdown.

Range Selection Mode:
- Select High or Low, with arrow keys.

Zero Mode:
- With *nothing* connected to the input jack, press START/RESET at the prompt.
- Zero at any time by holding the MODE button in for one full second.



E.g. LDR I-125 seed

CALIBRATION OF OUR INSTRUMENTATION?

- **Calibration** of our well-type chamber instrumentation (= chamber + source holder + electrometer + cables + etc.) is performed by an **independent SSDL**
  - In our case in the neighboring country Sweden's radiation and nuclear safety authority until May 2025, now from Finland's corresponding **authority** "STUK"
  - We get **RAKR** (Eq. 23) **calibration coefficients** from there
    - Stated in the **calibration certificate** for the specific measurement chain, including the **traceability to a PDSL**

Kalibrointitodistus

Dosimetrialaboratorio

16.5.2025

stuk
RADIATION AND NUCLEAR SAFETY AUTHORITY

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HUS

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Mushrooms 2025 campaign

Take part in scientific research – Submit an edible mushroom sample to the Radiation and Nuclear Safety Authority.

Read more on the campaign →

https://stuk.fi/en/frontpage

What is radiation? >

For the user of Radiation >

Nuclear safety >

Radon >

SCAN ME

KALIBROINNIN TULOKSET

Taulukko 1. Kalibrointitulokset referenssi-ilmakermanopeudelle ^{192}Ir-säteilyllä perusolosuhteissa 20,0 °C ja 101,325 kPa.

Kaivokammio	**PTW HDR Chamber 200 cm^3 TM33004-000570**
Pidike/katetri	Kammion oma lähteen pidike
Elektrometri	PTW Unidos E T10008-082072[1]
Jälkilatauslaite / ^{192}Ir-lähde	HUS Flexitron HDR FT002207, Flexisource Ir-192
Kalibrointikerroin referenssi-ilmakermanopeudelle N_{RAKR}	**271,2 Gy/C**
Epävarmuus (k=2)	4,1 Gy/C 1,5 %
Jänniteasetus	+400 V
Mitatun virran polariteetti	positiivinen
Kammion referenssipiste	Kammion referenssipiste (sweet spot), joka määritettiin mittauksen alussa, 135 käytetyllä katetrilla
Huomioita kalibroidun laitteen kunnossa	Ei

1) Elektrometrin mittausalueena oli "High" ja mitattu virta oli noin 64 nA.

Some more Finnish learning… ;)

tulokset = results
kaivokammio = well chamber
pidike = [source] holder
epävarmuus = uncertainty

KALIBROINTIOLOSUHTEET

Taulukko 2. Kalibrointiolosuhteet.

Lämpötila	22,1 °C
Ilmanpaine	101,0 kPa
Kosteus	23 % rh
Referenssi-ilmakermanopeus (referenssiaika)	29,9 mGy/h (1.4.2024 klo 12:00)
Kalibrointipaikka	HUS kaivokammiomittauksissa käytettävä mittaushuoneen metallinen kärry

JÄLJITETTÄVYYS

Kalibrointitulokset ovat metrologisesti jäljitettäviä kansainväliseen mittayksikkö-järjestelmään (SI) kansallisten mittanormaalien kautta.

Taulukko 3. Jäljitettävyys.

Suure ja yksikkö	Laite	Jäljitettävyys, viimeisin kalibrointi
Referenssi-ilmakermanopeus (Gy)	Standard Imaging HDR 1000 PLUS 90008-A232750, SH ^{192}Ir A232750	National Physics Laboratory (NPL), UK 2024040145-1 2.5.2024
Varaus (C), virta (A)	Keithley 263-426240	VTT MIKES, FI M-24E263 11.6.2024
Lämpötila (°C)	Delta Ohm HD2127.1-17020334	VTT MIKES, FI M-25T014 26.2.2025
Paine (Pa)	Vaisala PTB330-M0850251	Vaisala (VTT MIKES, FI) K008-J00969 25.2.2025

HUS

Some more Finnish learning… ;)

olosuhteet = ambient conditions
paikka = place
jäljitettävyys = traceability
viimeisin = latest

VTT MIKES = Finnish national metrology institute
https://www.vttresearch.com/en/industries/metrology-vtt-mikes

> “VTT Mikes administers the maintenance and development of the International System of Units, or SI system, at the national level.

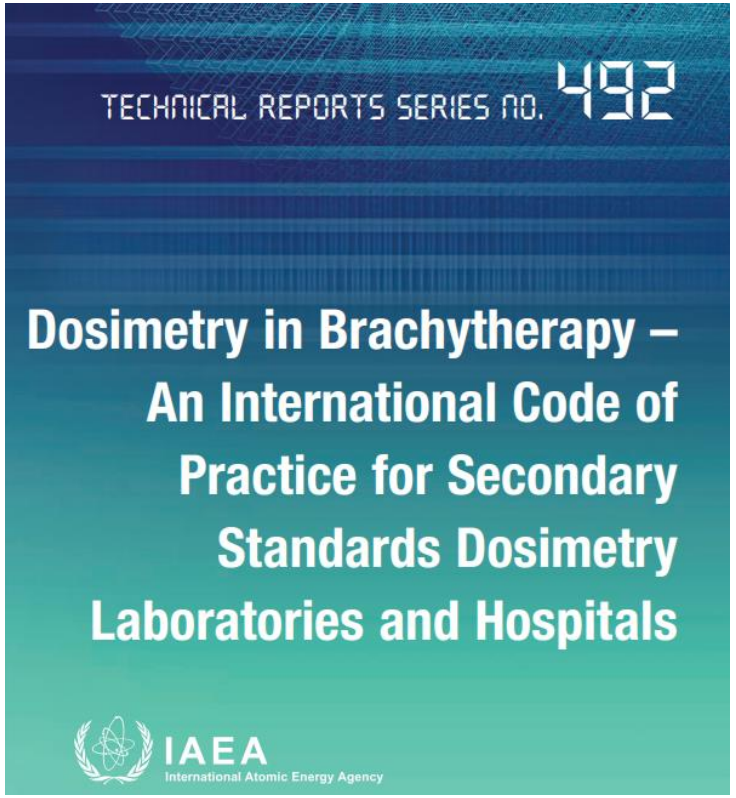
"Attachment 1. Description of the methods"

Liite 1. Menetelmän kuvaus

Kalibrointimenetelmä

Kalibrointikerroin referenssi-ilmakermanopeudelle N_{RAKR} ^{192}Ir-säteilykeilassa annetaan kalibrointitodistuksen taulukossa 1. Kalibrointi suoritettiin ^{192}Ir-säteilykeilassa soveltaen viitettä [1]. Kalibroinnin olosuhteet on annettu kalibrointitodistuksen taulukossa 2.

…of course:



VIITTEET

[1] IAEA, International Atomic Energy Agency. Dosimetry in Brachytherapy – An International Code of Practice for Secondary Standards Dosimetry Laboratories and Hospitals, Technical Reports Series no. 492, Vienna 2023

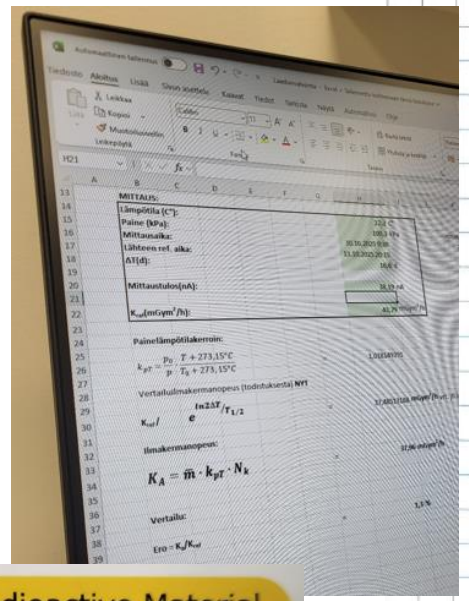
SOURCE EXCHANGE

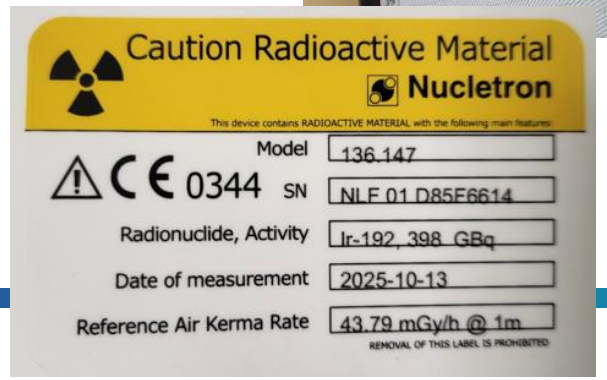
- Here's a concrete example of the procedure for a new HDR Ir-192 source
  - Acceptance test measurements

← Mechanical testing of the afterloader by an engineer before the new source is installed

Hand-written notes → from a measurement

- A more official & detailed documentation + calculation in Excel format…↓





AR
2 VR, PI

LÄHTEEN ILMAKERMAMITTAUS 30.10.2025

BRAKY 1, Silta, #L 52, Lähde D85F6614, PTW

$\dot{K}_{30.10.2025}$ = 43.79 mGy h^{-1} m^{-2}

lask. $\dot{K}_{30.10.2025}$ = 37.49 mGy h^{-1} m^2 / laite 37.49

Ilmakerma nopeuden mittaus

Lähteen paikka	m(nA)	paikka	m(nA)
120	-37.38	132	-38.15
125	-37.81	133	-38.17
130	-38.07	134	-38.19
135	-38.[illegible]	135	-38.19 ← m
140	-38.09	136	-38.19
145	-37.83	137	-38.18
150	-37.39	138	-38.16

T = 22,3°C p = 752,3 mm Hg = 100,3 kPa

$\dot{K}_{mit} = N_k \cdot k_{pT} \cdot m$

$= 9{,}7632 \cdot 10^5$ Gy m^2/hA · 1,018 · 38,19 nA

≃ 37,96 mGy m^2/h => + 1,3 % OK!

Lähteen paikka OK/SS

Turvalaitteet:

ovi	OK
hätäseis	OK
interrupt	OK
sät. mittari	OK
kannettava sät.mit.	OK
valot, ääni, kuva	OK
tarra, säiliö, pinsetit	OK

Tiedot syötetty:
Oncentra Prostate
Oncentra Brachy

THE VENDOR SOURCE CERTIFICATE

Saapunut 23.10.2
Vaihdettu 29.10.2

Certificate for Sealed Sources

FL52
G2-00025Z

Serial Number of Afterloader: FT00922
Customer Name and Address: HUH CANCER CENTER
[redacted]
00290 HELSINKI
FINLAND
Issue Date 2025-10-17 (1)
Model Designation: REF 136.147
Serial Number: SN D85F6614
Production Code: LOT 85185/03 (DRN 7785)
Manufacturer Code: NLF 01 (7)
Serial Number of Transport Container: [redacted]
Serial Number of Check Cable: 10333
Certificate Number: [redacted]

SOURCE SPECIFICATIONS

Reference Air Kerma Rate: 43.79 mGy h^{-1} +/- 5% at 1 m (2)
Measured at: 2025-10-13 19:15 CET(1)
Estimated Content Activity: 398.1 GBq (10.76 Ci) at date of measurement (3,4)
Source Type: FLEXISOURCE Ir-192
Capsule Dimensions: 0.86 mm diameter, 4.6 mm length
Source Pellet Dimensions: 0.6 mm diameter, 3.5 mm length
Source Pellet form: solid iridium
Radionuclide: Ir-192, gamma radiation source
Encapsulation: single
Capsule Material: stainless steel, AISI 316L
ISO 2919 Classification: ISO/12/C63311
Special Form Certificate Number: Not applicable
Recommended Working Life: 30 000 transits or 100 obstructions whichever comes first

THE VENDOR SOURCE CERTIFICATE

QUALITY CONTROL

Cable Visual Inspection:	passed	
Source Visual Inspection:	passed	
Laser Weld Visual Check:	passed	
Leakage Test:	passed (5)	Measured at: 2025-10-13 (1)
Surface Contamination Test:	< 185 Bq (5nCi) (6)	Measured at: 2025-10-13 (1)

The undersigned, authorized officer of Curium Netherlands B.V., certifies that this source complies with the requirements of ISO2919 and that all of the information given in this certificate is true and correct at date of issue.

[redacted]
GMP Controller

2025 -10- 17

Approved by..... [redacted]

(1) Date format yyyy-mm-dd.
(2) At confidence level of 99.7%. The reference air kerma rate is measured with a calibrated measurement setup, calibrated with a calibration source of the same source model, measured at the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, in accordance with the ICRU report 90 recommendations.
(3) The estimated content activity is determined by applying a conversion factor (0.110 mGy $m^2h^{-1}GBq^{-1}$) to the measured gamma radiation output of the sealed source.
(4) The estimated content activity is the activity for the specified radionuclide, other radionuclides are not detectable.
(5) Leakage test method according to ISO9978 method Liquid nitrogen bubble test (6.2.4).
(6) Surface contamination test in accordance to ISO9978 method Wet Wipe Test (5.3.1).
(7) European manufacturer's code in accordance with European council directive 2013/59/Euratom.

Manufactured by Curium Netherlands B.V. * Westerduinweg 3 * 1755 LE Petten * The Netherlands * Telephone +31 224 567890
On behalf of Nucletron B.V. (an Elekta subsidiary)* Waardgelder 1 * 3905TH * Veenendaal * The Netherlands * +31 318 557 133

Source vendor certificate:

SOURCE SPECIFICATIONS

Reference Air Kerma Rate: 43.79 mGy h^{-1} +/- 5% at 1 m [2]

Measured at: 2025-10-13 19:15 CET[1]

Let's start to measure at the hospital! We have this earlier calibration for the specific set-up (from SSDL):

KALIBROINNIN TULOKSET

Taulukko 1. Kalibrointitulokset referenssi-ilmakermanopeudelle ^{192}Ir-säteilyllä perusolosuhteissa 20,0 °C ja 101,325 kPa.

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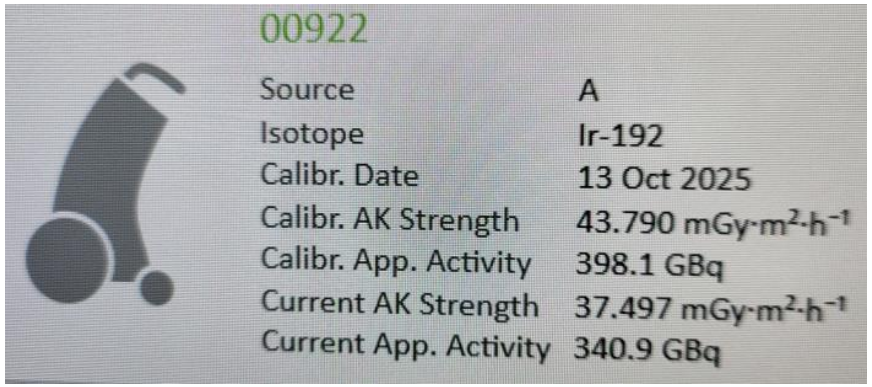
Kalibrointikerroin referenssi-ilmakermanopeudelle N_{RAKR}	**271,2 Gy/C**

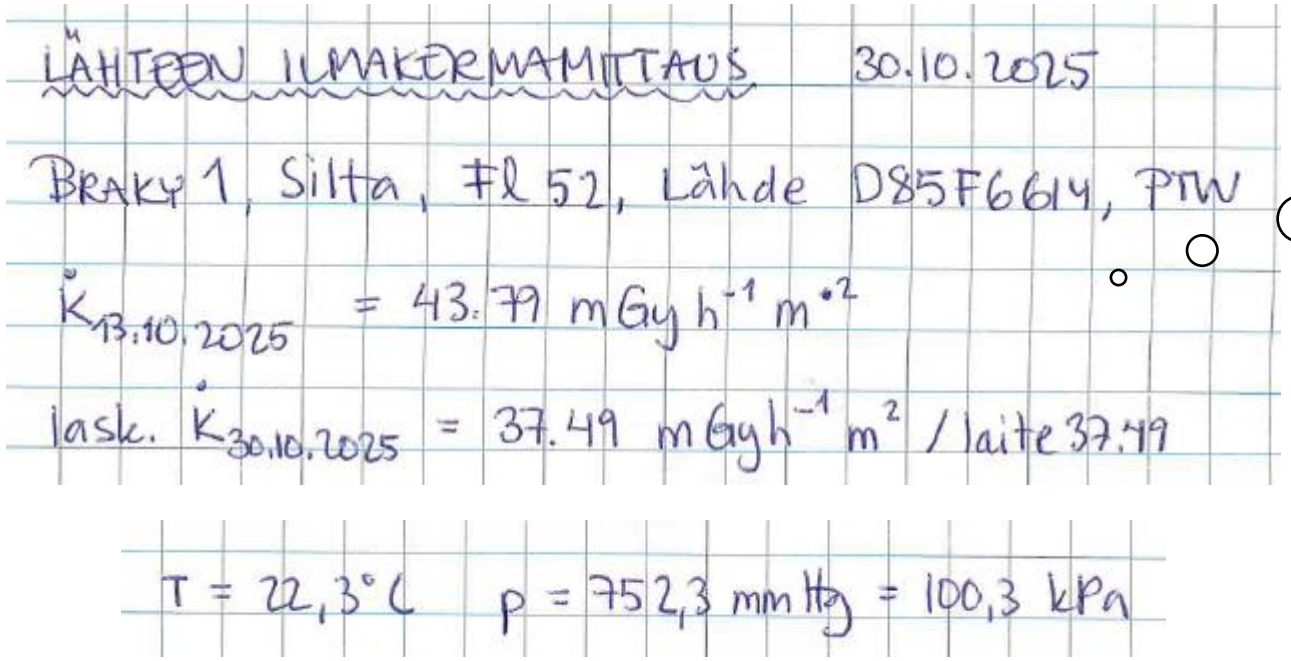
SOURCE SPECIFICATIONS

Reference Air Kerma Rate: 43.79 mGy h^{-1} +/- 5% at 1 m (2)

Measured at: 2025-10-13 19:15 CET(1)



On the measurement day at the hospital:



+ humidity ok

…what was the unit again?

$$S_K = \dot{K}(d)d^2$$

- **RAKR** = reference air kerma rate
  - $\dot{K}_{\delta,R}$, convenient unit mGy/h
  - Always defined at 1 m distance from the source
- **AKS** = air kerma strength
  - S_K, unit U = cGy · cm^2/h

SWEET SPOT DETERMINATION

Lähteen paikka	m(nA)	paikka	m(nA)	
120	-37.38	132	-38.15	
125	-37.81	133	-38.17	
130	-38.07	134	-38.19	
135	-38.19	135	-38.19	← max
140	-38.09	136	-38.19	
145	-37.83	137	-38.18	
150	-37.39	138	-38.16	

- Sweet spot (max) found at location 135 mm
  - Current reading there: -38.19 nA

MEASUREMENT TECHNIQUES FOR CURRENT

Uncorrected measurements with the electrometer $M_{sm,\,raw}$ can be performed in two different ways:

(a) Measuring ionization current once the source has reached the point of measurement and the displayed ionization current has stabilized.

(b) Collecting the ionization charge for a specific time interval, starting and stopping it with the source stationary at the well-type chamber sweet spot (no source transit dose). Current is then obtained dividing the collected charge by the acquisition time.

In both cases, measurements with the source at the sweet spot of the well-type chamber should be performed.

(a)

(b) Charge integration mode: Cumulative charge ΔQ during time interval Δt → I = ΔQ/Δt

- "*At both SSDLs and hospitals with photon emitting HDR sources,* ***at least three*** *source insertions to the chamber sweet spot will be made.*"

CORRECTION FOR INFLUENCE QUANTITIES

$$\dot{K}_{mit} = N_k \cdot k_{pT} \cdot m$$

Now T_0 and P_0(on the day of calibration):

perusolosuhteissa 20,0 °C ja 101,325 kPa.

While on the day of measurement:

$T = 22,3°C \quad p = 752,3\ mm\ Hg = 100,3\ kPa$

k_{TP} = … = 1.018

8.2.3.1. Air density correction factor

For high energy photon sources, the standard relation for the air density correction factor k_{TP} given for EBRT can be used:

$$k_{TP} = \frac{(273.15+T)}{(273.15+T_0)} \frac{P_0}{P} \qquad (28)$$

where P_0 and T_0 are the reference pressure and temperature, respectively, and P and T are the actual pressure and temperature that are recorded at the time of measurement.

- Check always the definition of T_0 & P_0
  - T_0=20 or 22 °C, or…
- Pay attention to possible weather fronts & swift changes in air pressure
  - May be a good idea to check barometer reading at least in the beginning and in the end of measurements

CORRECTION FOR INFLUENCE QUANTITIES

$$M_{sm} = M_{sm,\ \mathrm{raw}}\, k_{TP}\, k_{\mathrm{alt}}\, k_{\mathrm{leak}}\, k_{\mathrm{elec}}\, k_{\mathrm{pol}}\, k_{\mathrm{s}} \qquad (27)$$

A brief discussion of each single influence quantity is provided below.

8.2.3.2. Altitude correction factor

$k'_{TP} = k_{TP} k_{\mathrm{alti}}$

- Extra correction for high altitudes!

8.2.3.3. Relative humidity correction

- If in an adequate range, no need

8.2.3.4. Leakage currents correction factor

- In the hospital, if the leakage signal < 0.1%, no need

8.2.3.5. Electrometer calibration coefficient

- If the electrometer and ionization chamber are calibrated together as a unit, no need

8.2.3.6. Polarity correction factor

- If the same polarity is always used, no need

8.2.3.7. Ion recombination correction factor

- For HDR sources usually small

$\dot{K}_{mit} = N_k \cdot k_{pT} \cdot m$

$= 9{,}7632 \cdot 10^5$ Gy m²/hA · 1,018 · 38,19 nA

Kalibrointikerroin referenssi-ilmakermanopeudelle N_{RAKR}	**271,2 Gy/C**

[A] = [C/s]

= 271.2 Gy/C*3600 s/h = 976320 Gy/(hA)

$\dot{K}_{mit} = N_k \cdot k_{pT} \cdot m$

$= 9{,}7632 \cdot 10^5$ Gy m²/hA · 1,018 · 38,19 nA

$\approx$ 37,96 mGy m²/h => + 1,3 % ok!

SOURCE SPECIFICATIONS

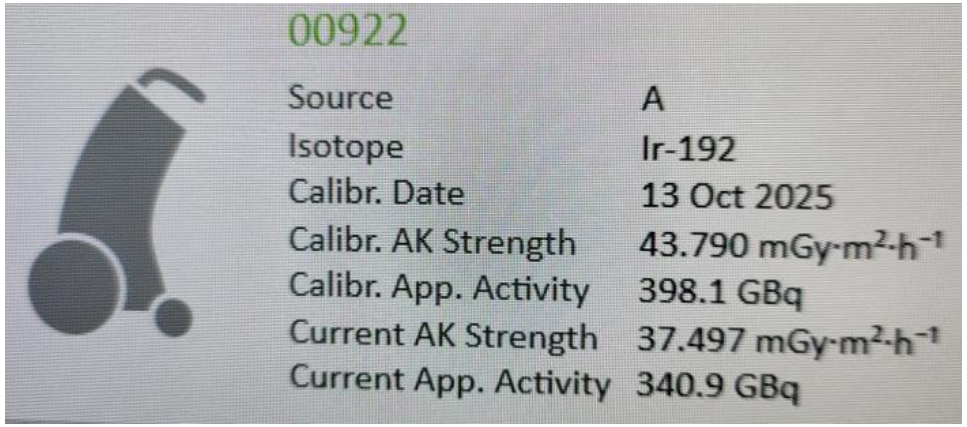
Reference Air Kerma Rate: 43.79 mGy h^{-1} +/- 5% at 1 m [2]

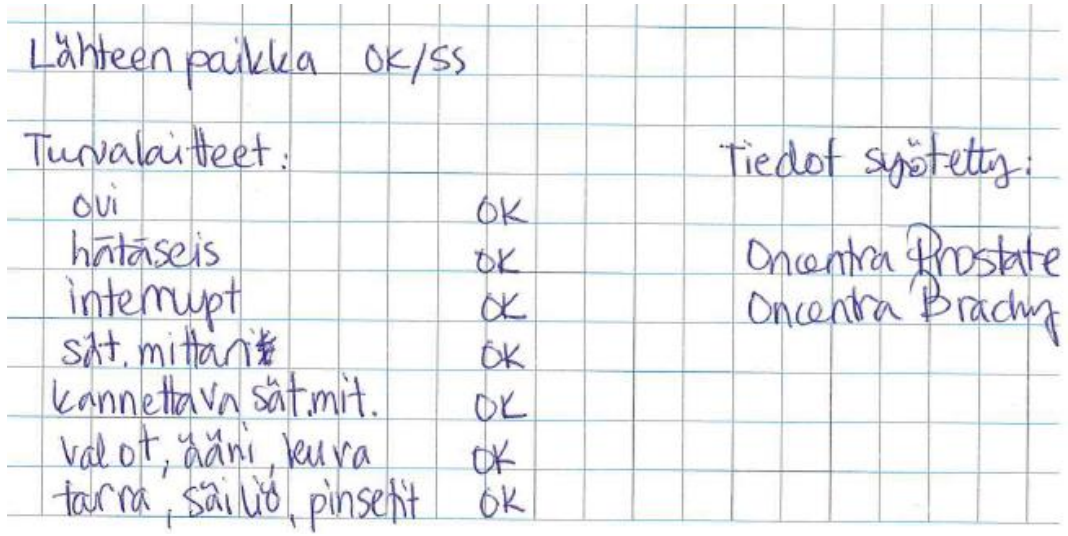
Measured at: 2025-10-13 19:15 CET[1]

Estimated Content Activity: 398.1 GBq (10.76 Ci) at date of measurement [3,4]

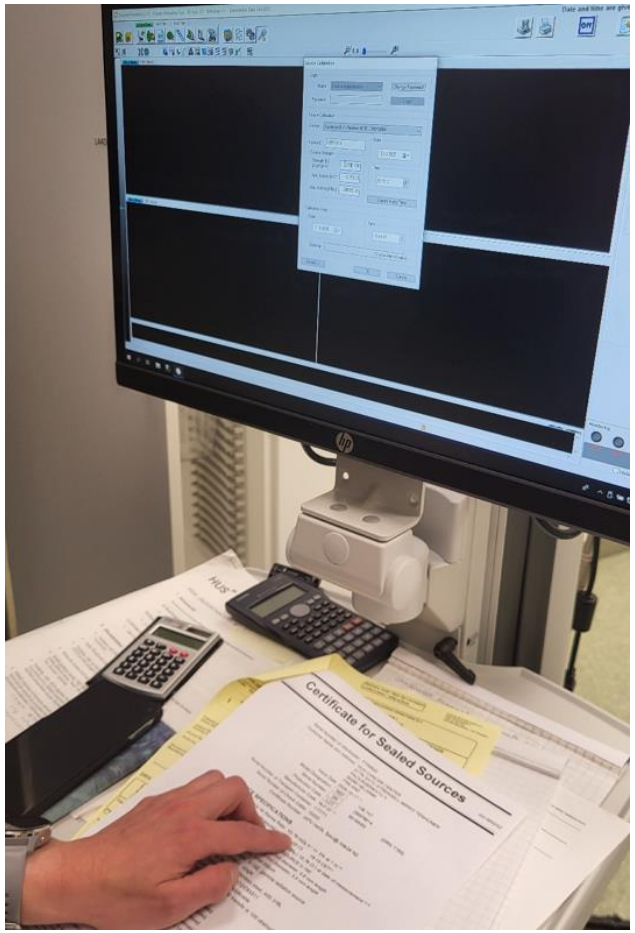
laskk. $\dot{K}_{30.10.2025}$ = 37.49 mGy h^{-1} m² / laite 37.49

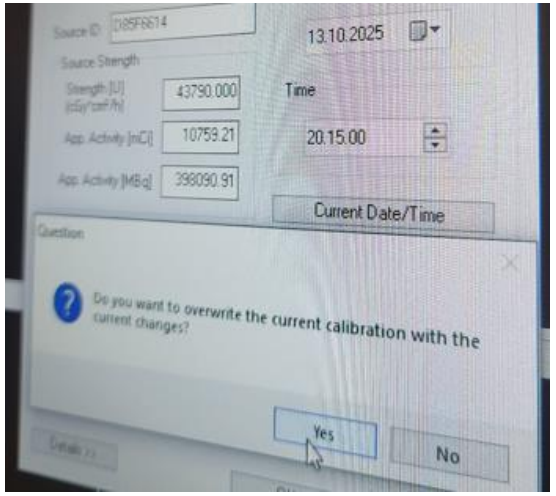
- Discrepancies >3% should be investigated
- Discrepancies >5% do not treat!

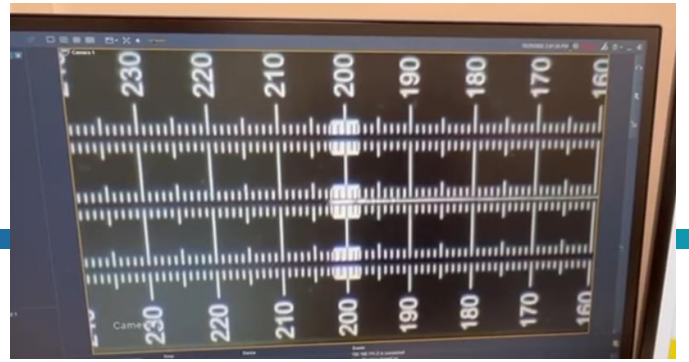




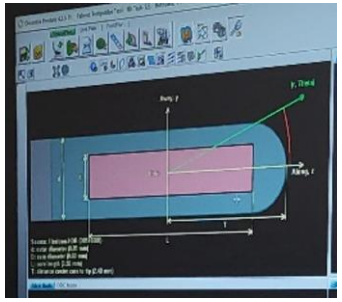
- The source location accuracy test is ok
- The source data has been inserted to treatment planning system ok
- The safety tests are ok







SOURCE MODEL CORRECTION



- If the model of the source is **different** between the calibration laboratory and the end user (hospital), one needs to apply source model correction $k_{sm,sm0}$, which depends on:
  - The type of source used at the calibration lab
  - The type of source measured by the end user
  - The type of well-type chamber
  - The type of source holder

See examples on Table 8

- If to be applied, this should be made **clear** and **recorded** on the well-type chamber calibration certificate!
  - Agreed and communicated between the cal lab & the end user!

QA OF THE INSTRUMENTATION

- Short term repeatibility, long term stability
- Ensure proper operation of the system and level of confidence
  - Compatibility with the calibration
- Stability checks "*at least for times per year*"
  - Two independent systems regularly compared, if feasible?
    - Constancy within ±0.1% of the running mean
  - Use mechanically (and timewise) stable check sources
    - Contancy within 0.5% from the baseline

END OF PART II

Q&A