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Dose and dose rate measurements for radiation exposure scenarios in nuclear medicine

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Introduction

- Radiation exposure in nuclear medicine caused by…
  - Radioactive sources (syringes, vials…)
  - Patients
- Nuclear medicine faces new challenges in terms of radiation protection
  - „New“ radionuclides (^{90}Y, ^{32}P, ^{188}Re…) with increasing importance
  - New therapeutic strategies using highly radioactive sources (TRT, Radioimmunotherapy…)

Objectives

- What were the objectives of our studies?
  - Dose and dose rate measurements
  - Measurements of radioactive sources
    - Practical radiation protection in nuclear medicine
  - Measurements of patients after application of radiopharmaceuticals
    - There is much concern about the patient as a radioactive source
    - Measurements reported by several authors but:
      - … often based on older measurements
      - … often not systematically carried out
      - … sometimes contradictory
  - …and simply: Interest

Materials and Methods

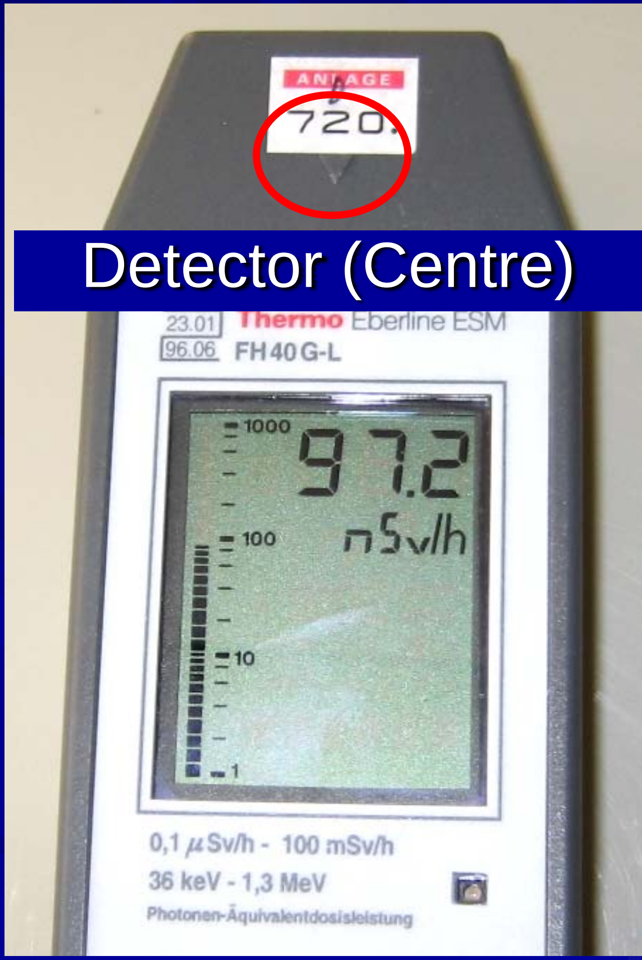
- Systematic study
  - As many patients and sources „as reasonably achievable“
  - Defined distances and times
- We started our studies with
  - **A variety of radionuclides / radiopharmaceuticals**
- We continued our studies with
  - **A variety of dosemeters and electronic personal dosemeters**
  - **…more than 20, including older and even „historical“ instruments**

Materials and Methods

- Sources:
  Typically from the surface to 1 m
- Patients:
  In all cases at the following distances:
  - 0m, 0,5m, 1m, 2m, 3m, 5m
  - Sometimes even up to 7m and 10m
    (30 m measuring tape)
- Measurements 0 h p.i. and 2 h p.i.
  - It is not easy to find the patient 2 hours later…
  - Some days later if practicable
- Same conditions for *all* radionuclides under consideration
  - Diagnostic procedures
    Tc-99m, F-18, In-111, I-123
  - Therapeutic procedures
    I-131, Y-90, P-32, Sm-153

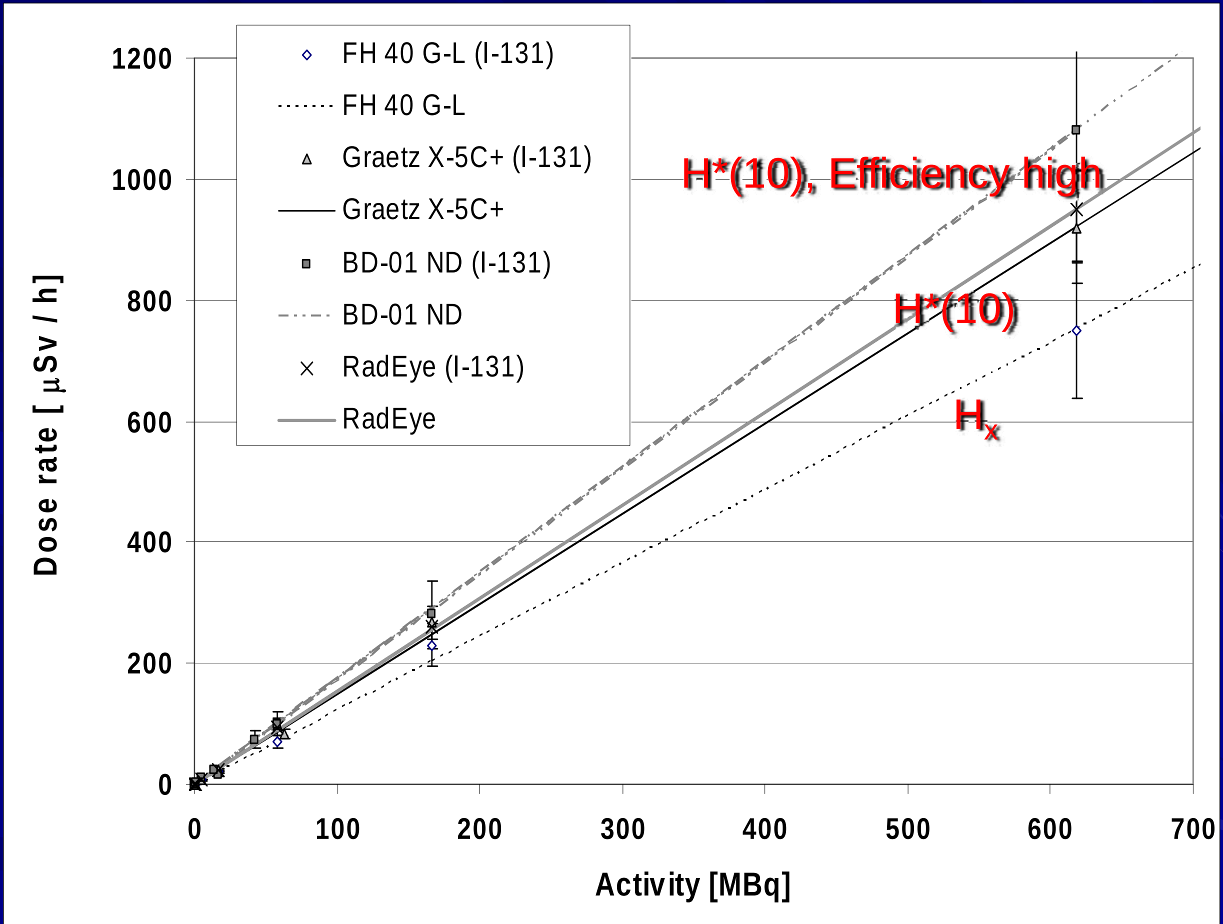
Materials and Methods

- Many measurements were carried out with this dosemeter
  - FH40 G-L (Thermo Scientific)
  - Proportional Counter
  - Good reading accuracy (digits not scales) for H_x
- Several other dosemeters were applied for comparison
  - X5 C (Graetz)
  - RadEye (Thermo Scientific)
  - BD-01 ND / HD (STEP)
  - TOL-F (Berthold)
  - …



Currently …

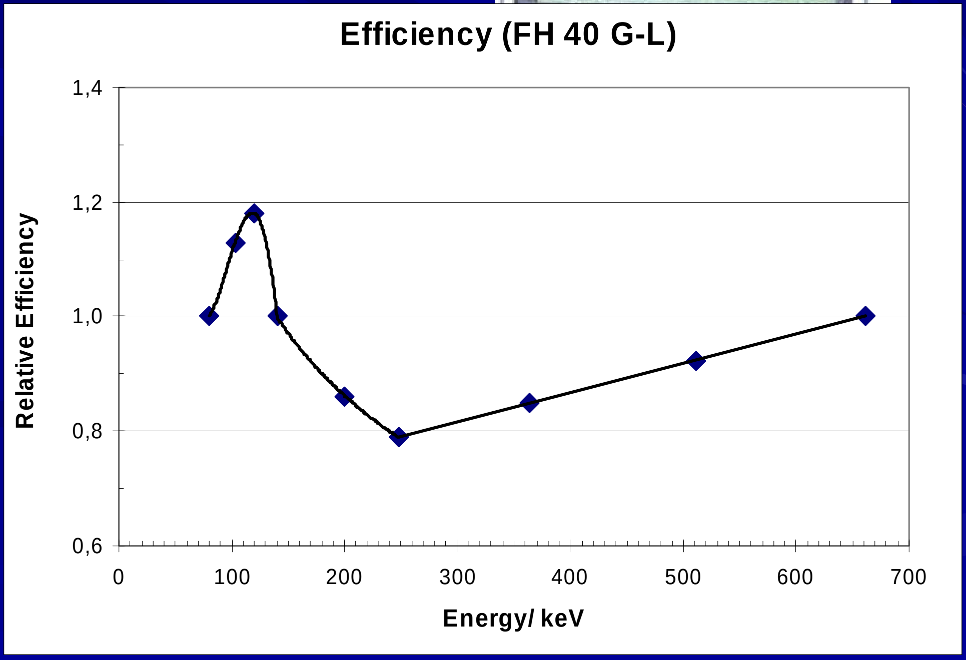
- Collection of available details of the dosemeters
- Which dose rate?
  - Photon dose equivalent
  - Ambient dose equivalent
  - Directional dose equivalent
- Efficiency
- Energy range
- Range of dose rates
- Linearity
- Statistical data (error analysis)



- Dose rate of iodine capsules @ 0.2 m with 4 dosemeters (preliminary analyses)

Material und Methoden

- Background Readings
  - Controlled area
  - Diagnostic investigations: 130 nSv / h
  - Therapy ward: 90 nSv / h
- Detector Efficiency
  - Exemplarily shown for FH40 G-L
  - Specified by manufacturer
- Tested with sources



1. Sources and preparations

^{131}I-MIBG

- Targeted radionuclide therapy (TRT)
- Therapeutic treatment of Neuroblastoma, Phaechromocytoma and Paraganglioma
- 2004 – 2010
  - 33 therapies in Cologne
  - Important aspect for us: internal dosimetry
- Activity per therapy: 6 – 11 GBq

Preparation of ^{131}I-MIBG

- Dose rate measurements
  - Dosemeter: BD-01 HD
  - Capable of measuring H*(10) and H´(0,07)
  - End-window ionisation chamber
- H*(10) and H´(0,07)
  - Vial containing ^{131}I-MIBG

~ 220 mSv / h (3,7 GBq)

~ 3,7 mSv / min (3,7 GBq)

Preparation of ^{131}I-MIBG

- Ring dosimetry
  - Gamma: 1 mSv
  - Beta / Gamma: 5 mSv
- TLD dosimetry
  - Maximum: 2 – 4 mSv
  - Mean:
    - 1,9 mSv left hand
    - 2,3 mSv right hand
  - Homogeneous irradiation

^{90}Y-Zevalin

- Radioimmunotherapy
- Therapeutic treatment of lymphoma (NHL)
- 2004 – 2010:
  - 22 therapies in Cologne
  - Important aspect for us: internal dosimetry
- Activity per therapy: 0,7 – 1,2 GBq
- Preparation up to 2 GBq

Preparation of ^{90}Y-Zevalin

- Dose rate measurements
- Glas vial containing ^{90}Y

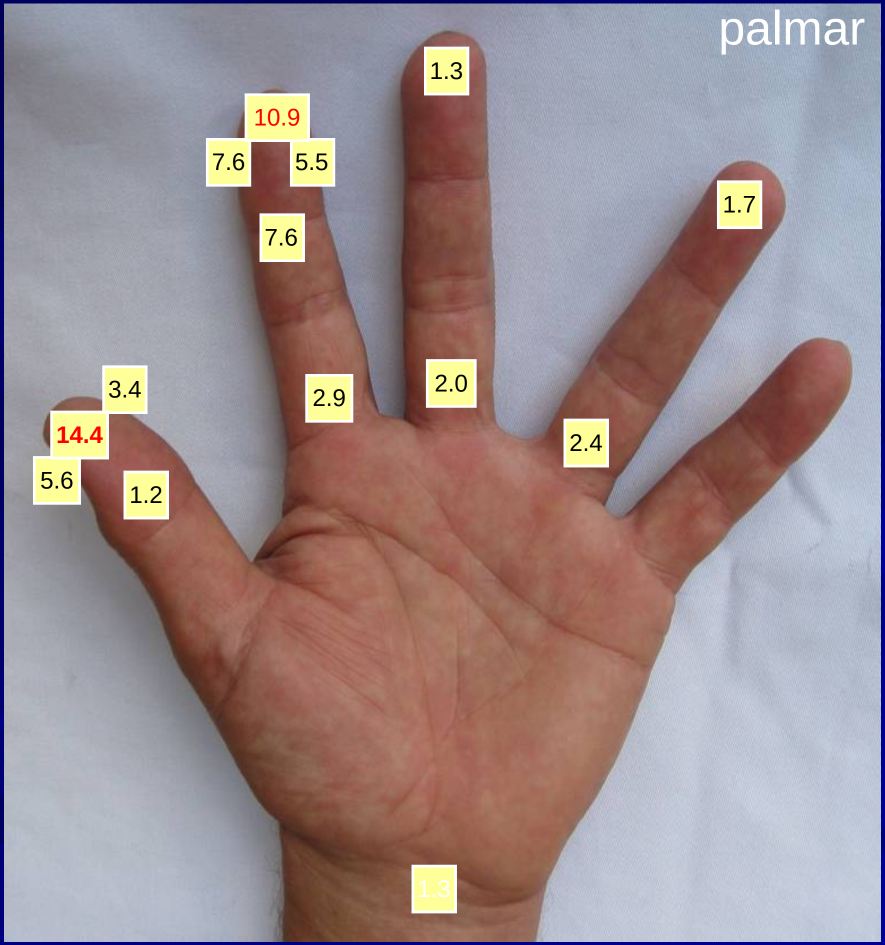
  Activity: 0,325 MBq
  - Dose rate (surface)
  - H*(10) : appr. 26 µSv/h
  - H*(10) + H´(0,07) : appr. 1500 µSv/h
  - H_x (FH40-GL) : appr. 0,2 µSv /h
  - Measurement of H_x only indicates background level and is therefore useless

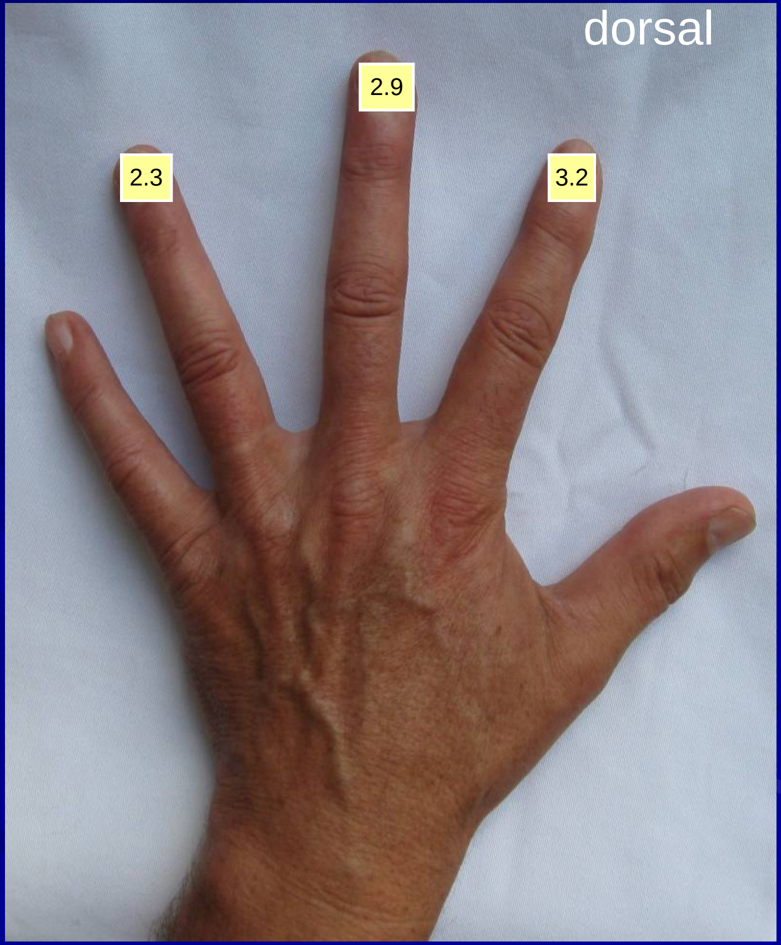
- Extrapolation:
  Syringe containing ^{90}Y

  Activity: 1000 MBq
  H*(10) + H´(0,07) : appr. 4,5 Sv / h
  : appr. 75 mSv / min
  : appr. 1,3 mSv / s

Dose distribution during radioimmuntherapy with Y-90/Zevalin

site: Uniklinik Köln date: 22.01.09
procedure: labelling no. of syringes/patients: 1 total activity: 1.88 GBq



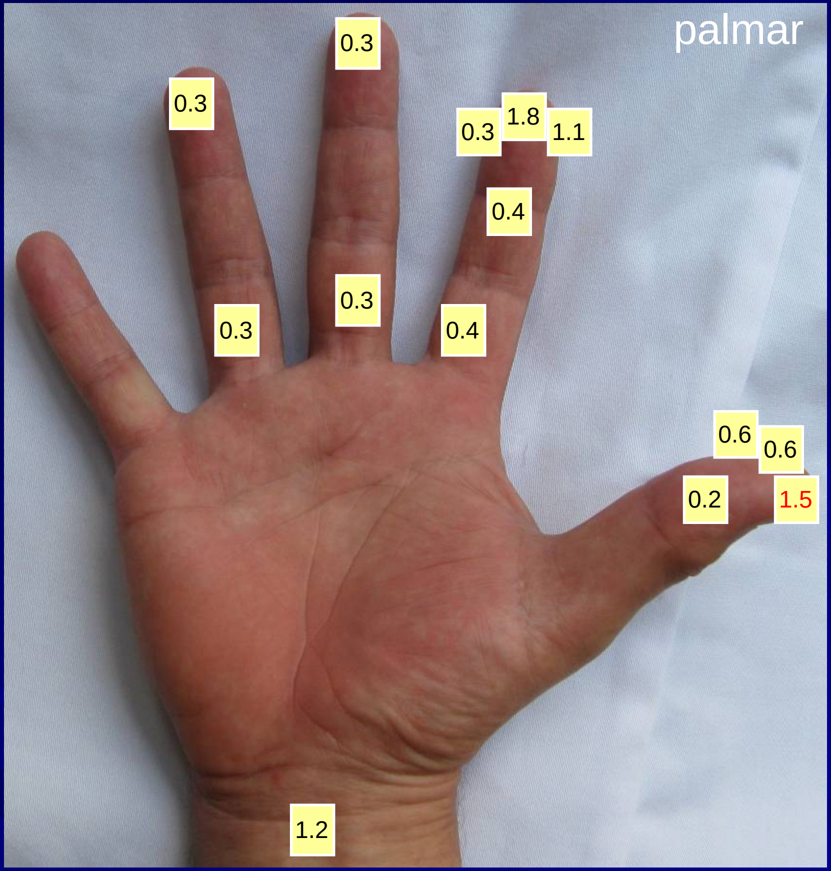


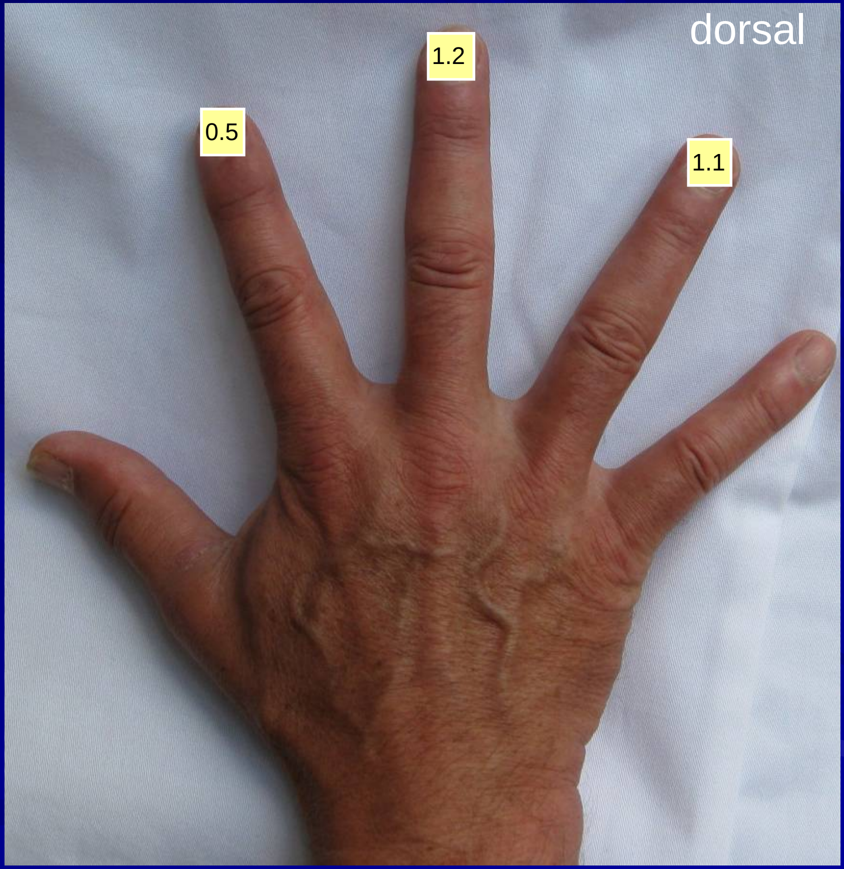
Left hand

Dose distribution during radioimmuntherapy with Y-90/Zevalin

site: Uniklinik Köln date: 22.01.09

procedure: labelling no. of syringes/patients: 1 total activity: 1.88 GBq





Right hand

[^{32}P]-$CrPO_4$

- Department of Neurosurgery
- Therapy of brain tumors with colloidal ^{32}P
  - Cystic craniopharyngioma
  - Stereotactic aspiration of cystic content followed by installation of radionuclides
- Dose rate measurements for the first preparations
- Plastic Filter containing [^{32}P]-CrPO4

Activity: 4 MBq

  - Dose rate (surface of a filter sieve): 16 mSv / h
  - Similar dose rate ^{90}Y
  - Significantly lower than calculated from Delacroix et al. (Handbook)
  - Shielding???

- Skin doses will be measured later-on

Conclusion I

- Preparations with ^{90}Y may lead to a significant skin exposure (cf. dose rates!)
- Working with sufficient shielding is a compulsory exercise
- Training and optimization urgently required!
- Photographic documentation is helpful
- In our case: reduction to 3,7 mSv (maximum dose, preparation) in October 2009

2. Patients

Technetium-99m

HDP / A = 700 MBq / N = 18

Distance	Dose rate immediately after application [μSv/h]	Dose rate 2 hours after application [μSv/h]
0	160	56
0,5	19	8,9
1	6,9	3,6
2	2,6	1,4
3	1,5	1,0
5	0,5	0,3

Thyroid Scintigraphy with 75 MBq:
Dose rate reduced by a factor of 10 (as expected)

Fluorine-18

FDG, A = 370 MBq, N = 21

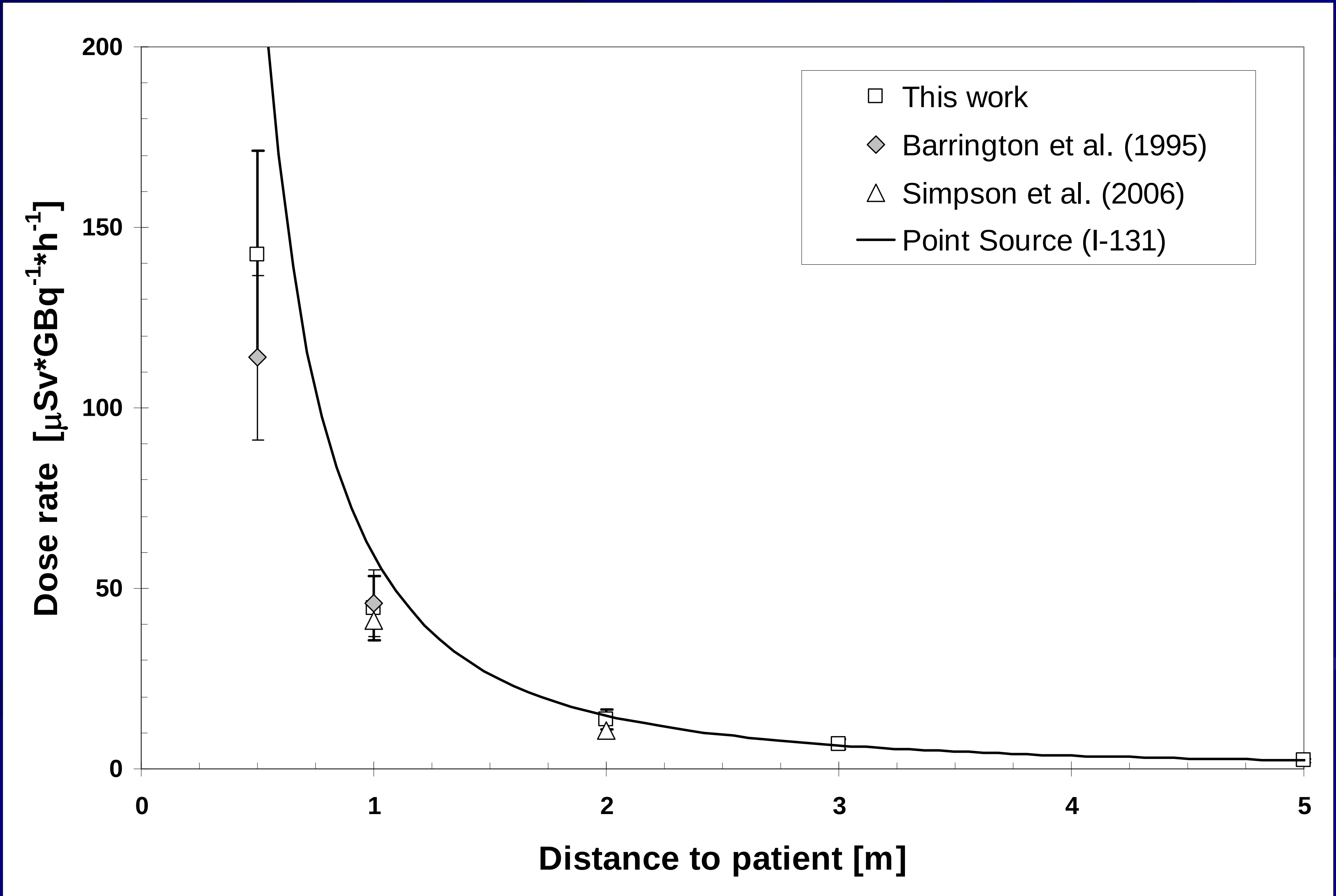
Distance	Dose rate immediately after application [μSv/h]	Dose rate 2 hours after application [μSv/h]
0	590	190
0,5	81	30
1	29	11
2	8,6	3,4
3	4,1	2,1
5	1,5	1,0
7	0,6	0,4

Radioiodiodine therapy (RIT)

- More than 1000 therapies per year (University Hospital of Cologne)
- Application of more than 1 TBq / year
  - Discharge from liquid waste storage 10 – 20 kBq per year!

Year	No.	Malignant vs. benign thyroid disorder	Activity (Malignant) GBq / Pat	Activity (Benign) GBq / Pat
2004	1003	24 : 76	1,8	1
2005	1015	24 : 76	2,3	1
2006	1005	24 : 76	2,0	0,8
Mean	1008	24 : 76	**2 GBq**	**1 GBq**

Therapies with ^{131}I



What happens after discharge?

- Often high activities are administered to the patient
  - Mean value:

  4,8 GBq (Thyroid carcinoma)
  - Duration of the in-patient stay:

  4 days
  - Mean value (effective half-life):

  1,1 d
  - Mean value (whole-body activity at the time of discharge):

  77 MBq
  - Annual doses < 1 mSv for members of the public even for closer contact for a comparatively long time
- Benign Thyroid disorders:
  - Discharge only when whole-body activity < 250 MBq

Therapies with ^{131}I-MIBG

Distance	Dose rate Child [mSv / h] A = 6,5 GBq	Dose rate Adult [mSv / h] A = 10,7 GBq
0	11,3	21,4
0,5	0,8	0,9
1	0,3	0,4
2	0,08	0,1
3	0,05	0,06
5	0,01	0,02
7	-	0,01
10	-	0,005

Dose rate per GBq corresponds to radioiodine therapy

Some radiation exposure scenarios

- Typical dealings in the vicinity of the patient (therapy ward)
  - …accompanied by a dosemeter in the pocket
  - Mean value of dose rate and duration is recorded
- APPROXIMATIONS:
  - Measurement and application of I-131 capsules
    - 110 μSv / year
  - The doctor´s daily visit
    - 170 μSv / year
  - Measurements for dosimetry
    - 220 μSv / year
  - Personal conversation (doctor / patient) before discharge
    (including radiation protection recommendations)
    - 250 μSv / year
  - Several members of the staff are involved
  - → no one receives the whole (extrapolated) annual dose

High energy beta emitters

- For example patients treated with ^{90}Y-Zevalin
  - In an article (2001) we find the following statement:
  - „Radiation exposure is very low to the family members of patients…“
  - „… in the range of background“
  - Measurements of photon dose rates *alone* would confirm this assumption
    - Dose rate ^{90}Y (A = 1132 MBq, N = 11):

      < 10 μSv / h on the surface of the patient

      ^{111}In (pre therapy tracer study) was subtracted
    - Γ_x is very low (1,4 μSv / h * m^2 / GBq)
    - Dose rate ^{32}P (A = 185 MBq, N = 1):

      < 1 μSv / h on the surface of the patient

High energy beta emitters

- The photon dose rate is misleading!
- Dosemeter must be capable of measuring electrons
  - H*(10) and H´(0,07)
  - We do not have so many…
- Dose rate measurements of patients yield in maximum values beyond 1 mSv / h after application
  - Hands (blood vessels) …
- Tracer-Studies regularly show for ^{111}In-Zevalin:
  - Long biological half-life!
  - Dose rate reduction with time very slow

Conclusion II

- A simple message!
  - Dose rates decline significantly with increasing distance to the patient
  - A distance of 2 m (or more) is very effective in order to reduce radiation exposure
- Determination of photon dose rates (e.g. H_x or H*(10) for nuclides with high-energy beta emissions is not appropriate
- Effective half-life of the radiopharmaceutical is also important for estimation of annuals doses (members of the public)

Thank you for your attention