Radiation protection for PET/CT

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Acknowledgement

- Dr P. L. Khong, PET/CT center, HKU
- Dr Martin Law, MPU/COD/QMH
- Dr Mark Madsen, Radiology, University of Iowa.
- Dr Jon Anderson, Radiology, University of Texas Medical Center at Dallas.
- Radiation Health Unit/ Department of Health / HKSAR

Motivation for Task Group 108

- Explosion of PET and PET/CT facilities since 2000.
- Conflicting advice from physicists and manufacturers.
- AAPM Leadership Role

Reference: AAPM Task Group 108: PET and PET/CT Shielding requirements. Med. Phys. 33(1), Jan2006

Courtesy of Dr Mark Madsen

Comparison of x-rays and Annihilation Radiation

- X-rays
- Limited duration
  - CT Scan Time (minutes per patient)
- Low energy
  - 60 – 100 keV
- Easily shielded
  - 1.5 mm of Pb yields 1000 x dose reduction

- Annihilation Radiation
- Always “on”
  - Patient is main source
  - Clinic time > 1 hour/patient
- High energy
  - 511 keV
- Substantial shielding
  - 10 mm of Pb provides x 4 reduction

Courtesy of Dr Mark Madsen

Who (or what) needs protection?

- **PET Technologists and Nurses**
  - Radiation workers in the PET center
- **Facility employees**
  - Radiation workers (Non-PET)
  - Non-radiation workers
- **General public**
  - Relatives and associates of patients
- **Radiation detection equipment**
  - Probes, well counters, gamma cameras

Courtesy of Dr Mark Madsen

What specific areas should be considered?

- Radionuclide storage & disposal
- Radiopharmaceutical administration
- Uptake room
- Tomograph room
  - Control room
- Patient bathroom
- Surrounding areas (especially uncontrolled areas with high occupancy factor).

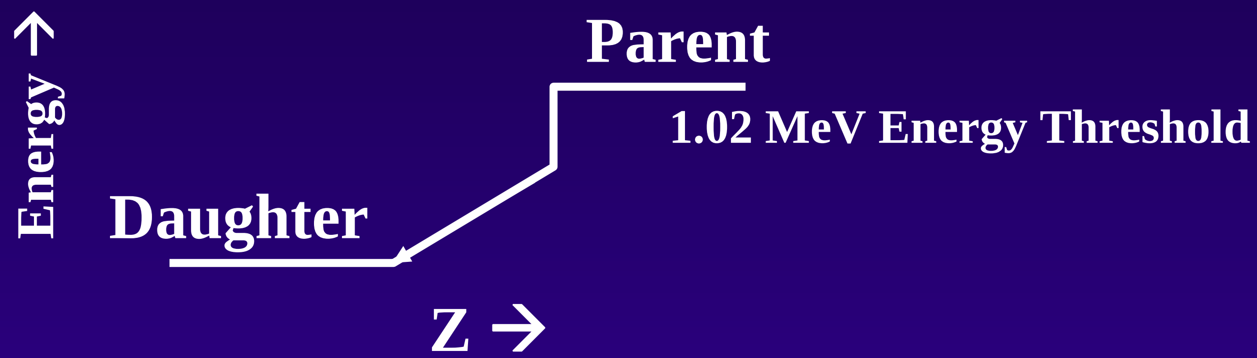
Courtesy of Dr Mark Madsen

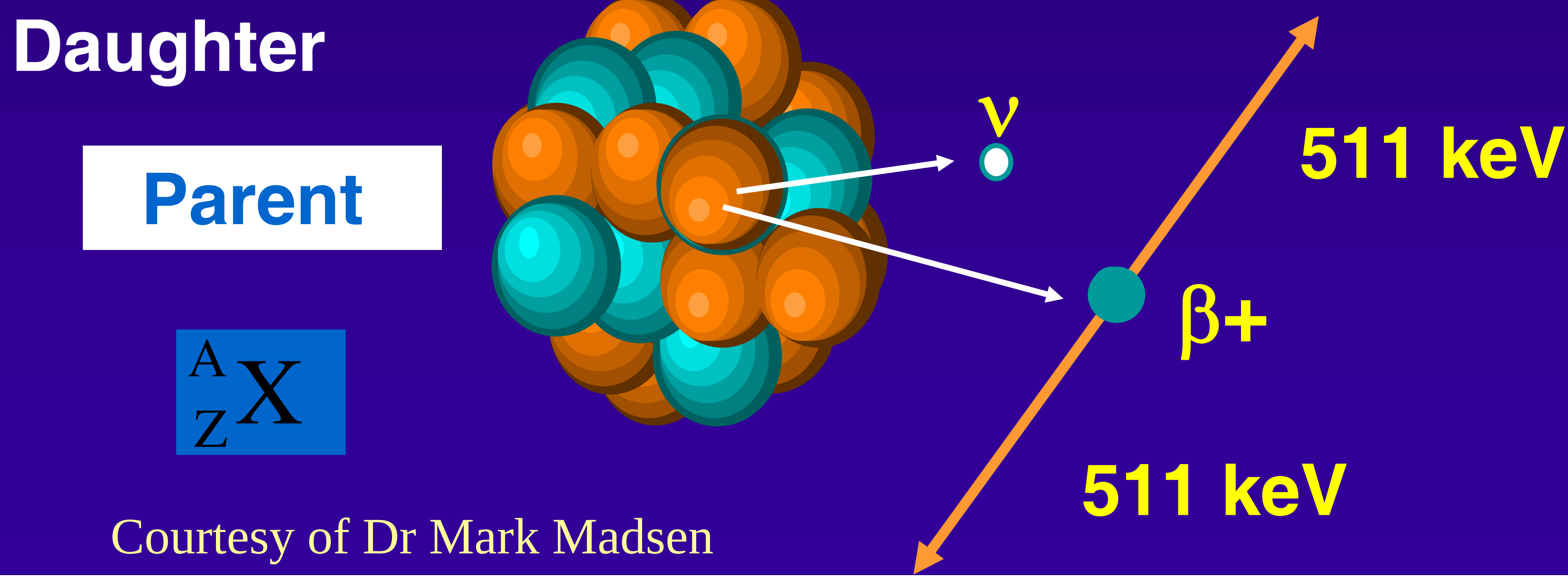
FACTORS AFFECTING RADIATION PROTECTION

- **Radionuclide**
  - Half life, emissions
- **Procedure protocol**
  - Administered activity, uptake time, scan time
- **Dose rate from the patient**
  - Dose constants, patient attenuation, decay, number of patients per week.
- **Facility layout**
  - Controlled vs uncontrolled areas, occupancy factors, detection instrumentation
- **Regulatory Limits**

Courtesy of Dr Mark Madsen

Positron (β+) Decay





Courtesy of Dr Mark Madsen

PET Radionuclides

	$T_{1/2}$	Decay Mode	Eβmax (MeV)	Energy (keV)	photons/decay
^{11}C	20.4 m	β+	0.96	511	2.00
^{13}N	10.0 m	β+	1.19	511	2.00
^{15}O	2.0 m	β+	1.72	511	2.00
^{18}F	109.8 m	β+ ,EC	0.63	511	1.93
^{82}Rb	76 s	β+, EC	3.35	511	1.90,
				776	0.13
^{68}Ga	68.3 m	β+, EC	1.9	511	1.84
^{64}Cu	12.7 h	β-, β+, EC	0.65	511	0.38
				1346	0.005
^{124}I	4.2 d	β+, EC	1.54, 2.17	511	0.5
				603	0.62
				1693	0.3

Courtesy of Dr Mark Madsen

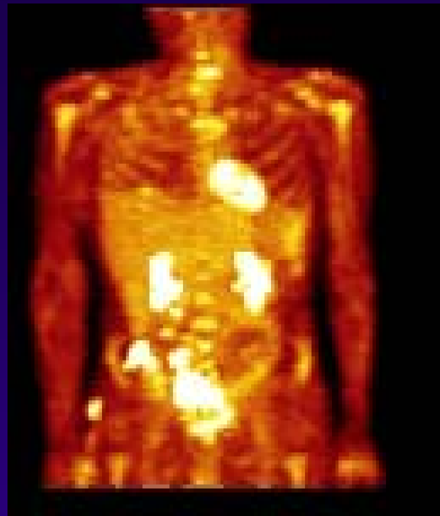
What types of studies should be considered?

- Myocardial Perfusion
  - ^{82}Rb, ^{13}N-Amonia
- Neurological Studies
  - ^{15}O-Water Cognitive Activation
  - Receptor imaging (^{18}F-Fluorodopa)
- Oncologic Research
  - ^{11}C-Methionine, ^{11}C-Choline
- Clinical Onology
  - ^{18}F-Fuorodeoxyglucose (FDG)

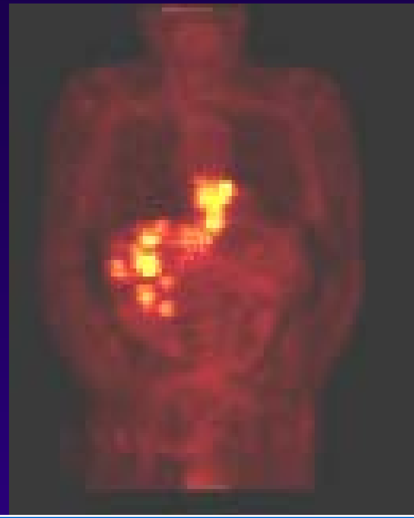
Courtesy of Dr Mark Madsen

Oncologic Imaging with F-18 FDG

Lung Cancer

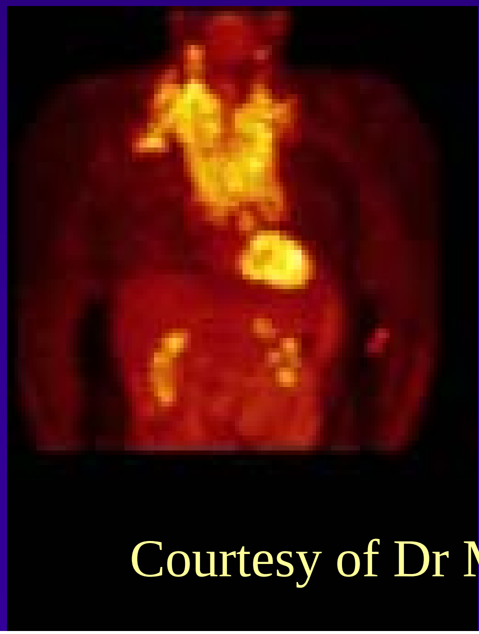


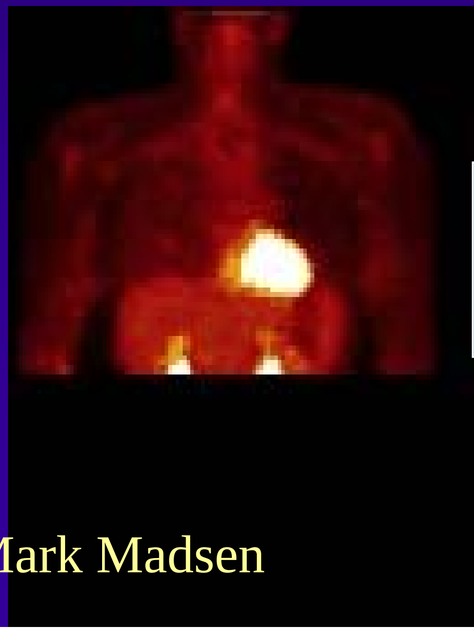
Colon Cancer



Esophageal Cancer

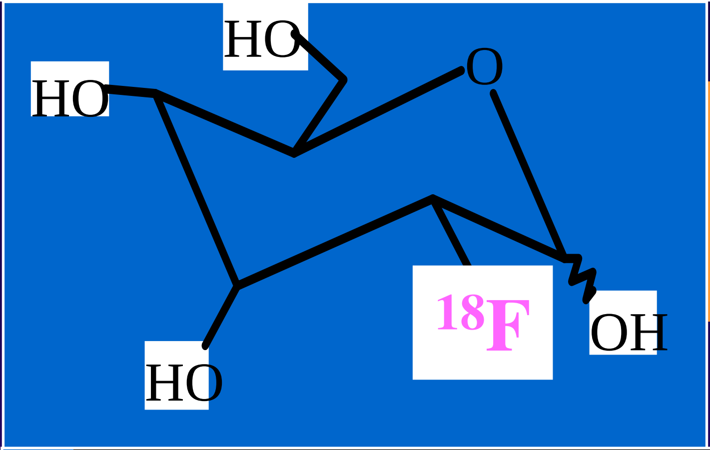
Hodgkins Lymphoma Pre-Treatment





Hodgkins Lymphoma Post-Treatment

Courtesy of Dr Mark Madsen



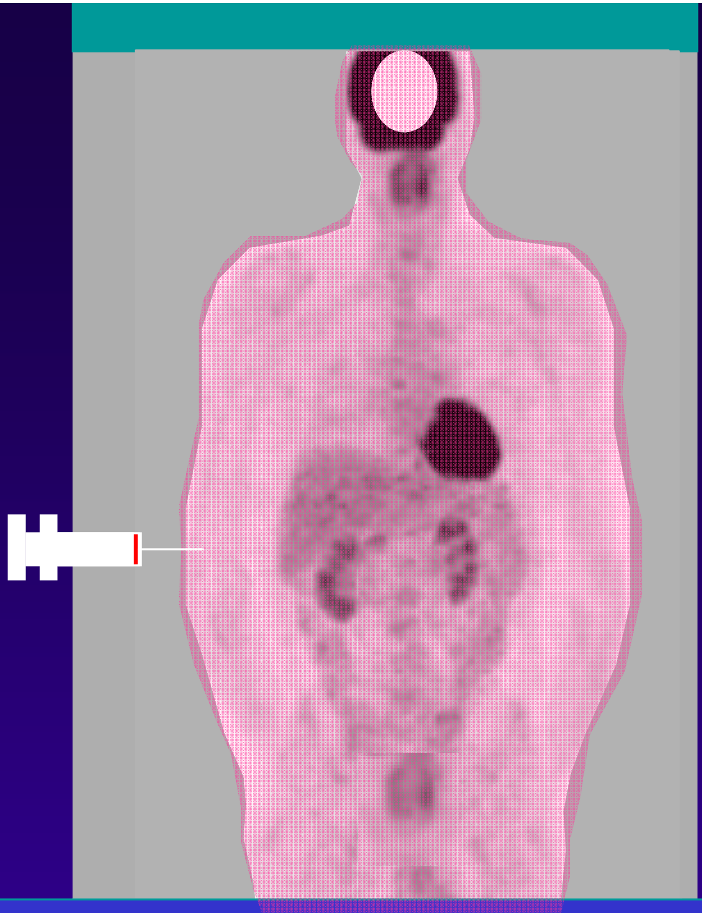
Fludeoxyglucose F18 (^{18}F-FDG)

	Production	Half-life	Decay constant	Decay mode	Principle emissions (MeV)	γ ray constant (R-cm^2/mCi-hr)
^{18}F	^{18}O(p,n)^{18}F	109.8 min	0.0063 min^{-1}	β^+, EC	0.65 β^+(97%) 0.511 γ(194%)	5.73

Mechanism of Action

- **FDG is a glucose analog that competes with glucose for hexokinase phosphorylation to FDG-6-phosphate (FDG-6-P).**
- **Because FDG-6-P is not a substrate for further glycolytic pathways and has a low membrane permeability, the tracer becomes entrapped within the tissues in proportion to the rate of glucose utilization of that tissue.**

Courtesy of Dr Mark Madsen



•Patient is positioned on imaging system.
•CT transmission acquired 1st, then PET emission.
•Patient is released.

^{18}F FDG Oncologic Studies

- Patient is administered ~ 555 Mbq of F-18 FDG in a quiet, low light room.
- Patient remains at rest for 30-90 minutes prior to PET study.
  - No walking or other muscular activity
- Patient voids prior to imaging

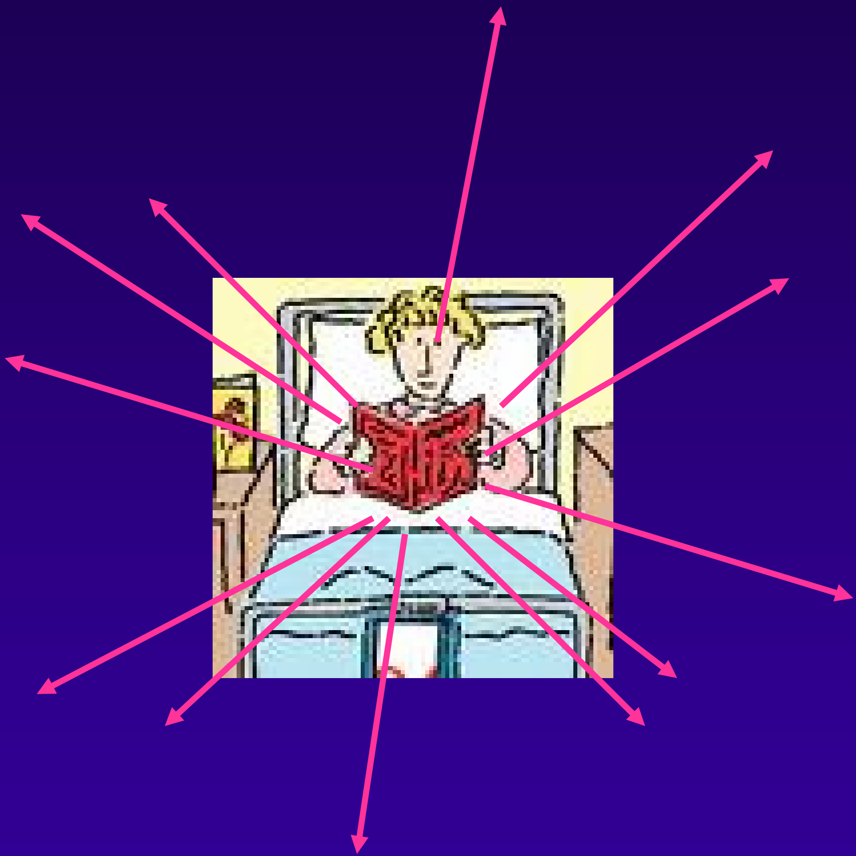
Courtesy of Dr Mark Madsen

Patient Dose Constant

- Unshielded ^{18}F source constant is 0.143 $\mu Sv\ m^2/MBq\ h$
- Self absorption when distributed in patient.
- Wide variation in measured values reported in published reports.
- Task Group 108 recommends using 0.092 $\mu Sv\ m^2/MBq\ h$

Courtesy of Dr Mark Madsen

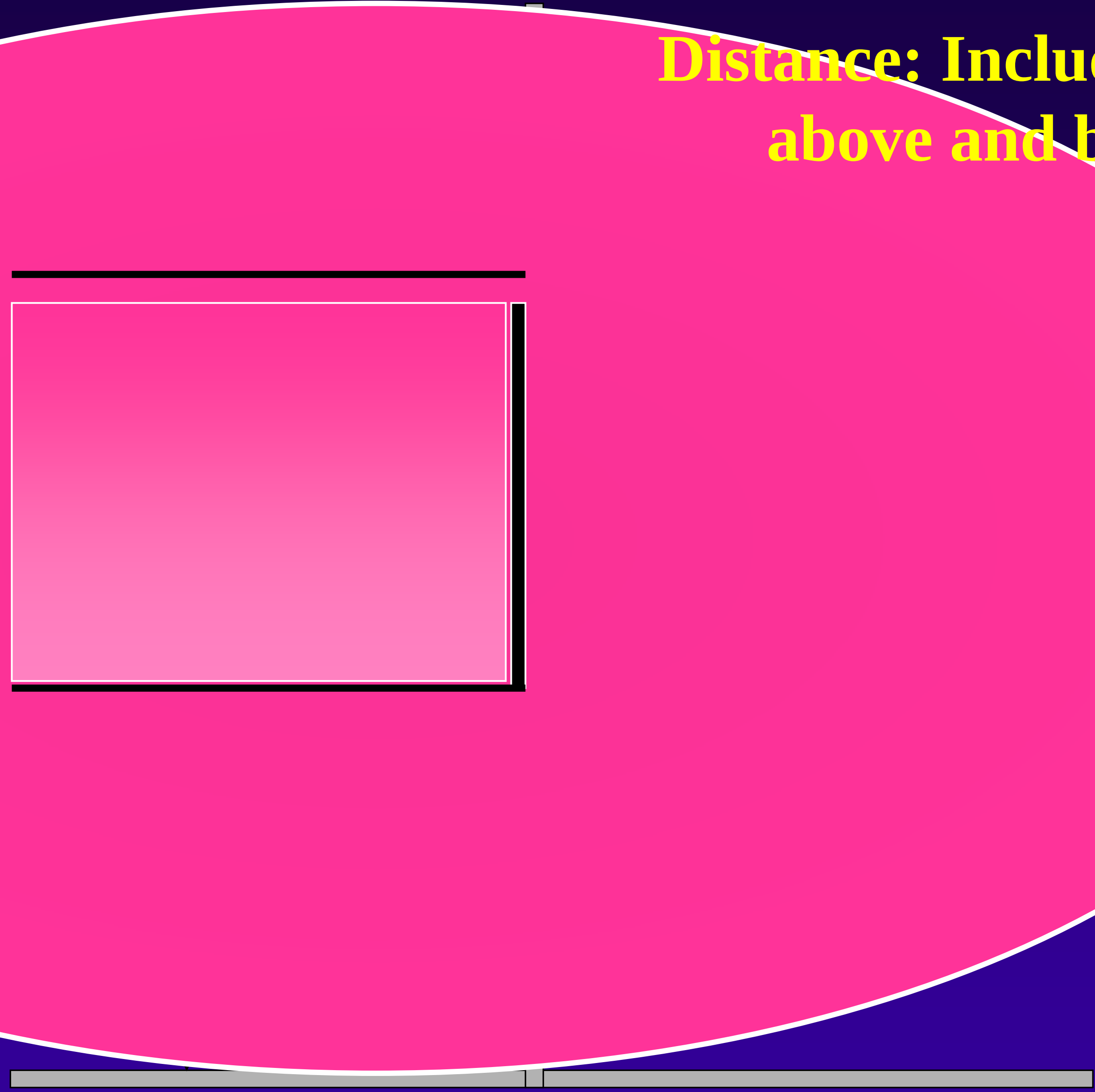
Patient as a source of radioactivity



- The patient associated dose rate depends on:
  - Number of patients
    - **50 patients/week**
  - Administered activity
    - **370 - 740 MBq**
  - Procedure time
    - **Uptake time: 1hour**
    - **Scanning time: 0.5 hour**

Courtesy of Dr Mark Madsen

Distance: Include rooms above and below



Distances to be used in shielding calculations

Courtesy of Dr Mark Madsen

P values based on NRC 10CFR20.1201 & 10CFR20.1301

Occupational: 1000 μSv/week

ALARA (typical): 100 μSv/week

Public: 20 μSv/week

Courtesy of Dr Mark Madsen

Patient Voiding

- Patients typically eliminate at least 15% of the remaining activity from their bladder when they void after the uptake period.
- Note: A bathroom should be available within the immediate PET facility. Problems are often encountered when a radioactive PET patient walks through a nuclear medicine clinic.

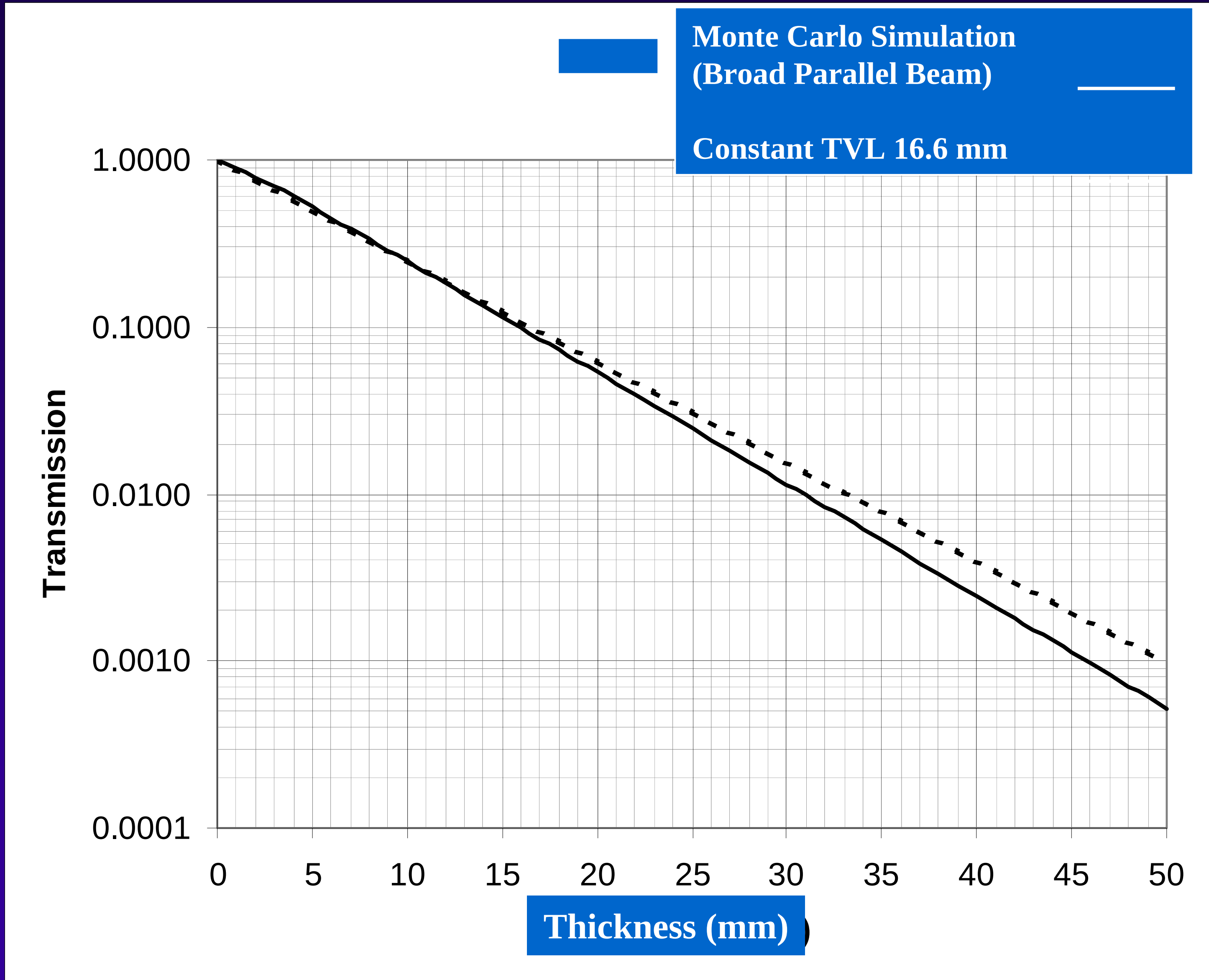
Courtesy of Dr Mark Madsen

Shielding Transmission Factors

- Shielding information is available in the scientific literature, but …
  - Variability among authors
  - Insufficient methodological information
- Task Group 108 relied on the Monte Carlo calculations of Doug Simpkin.
  - Mathematical model is known
  - All calculations were performed consistently

Courtesy of Dr Mark Madsen

Lead Transmission Factors



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Courtesy of Dr Mark Madsen

What is different when you have PET/CT in your facility

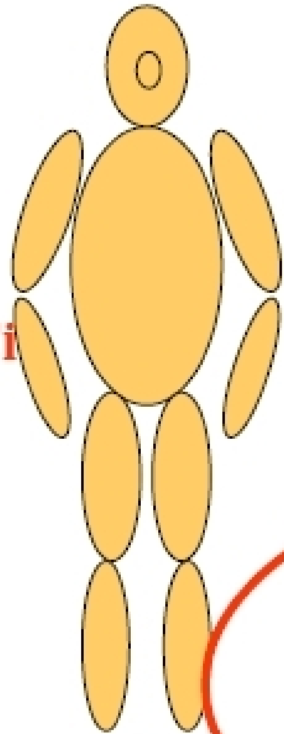
- 511 keV energy
  - Increases exposure rate from doses and patients.
  - Greatly increases thickness of required shielding.
- Requirements for patient handling during injection and uptake phase.
- Combined modality scanners (PET/CT) require consideration of both gamma-ray and x-ray hazard.

The ^{18}F-Injected Patient as a Source

(average of different investigators, 2003)

Superior 0.075 (μSv/hr)/MBq
0.279 (mrem/hr)/mCi

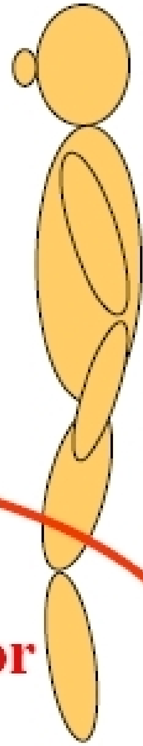
Lateral
0.104 (μSv/hr)/MBq
0.383 (mrem/hr)/mCi



not as anisotropic as it might seem

Inferior 0.018 (μSv/hr)/MBq
0.065 (mrem/hr)/mCi

all at 1 m from surface of body, average value from all applicable reports



Anterior
0.103 (μSv/hr)/MBq
0.383 (mrem/hr)/mCi

compare this to 0.014 (μSv/hr)/MBq or 0.05 (mrem/hr)/mCi for ^{99m}Tc: factor of 8!

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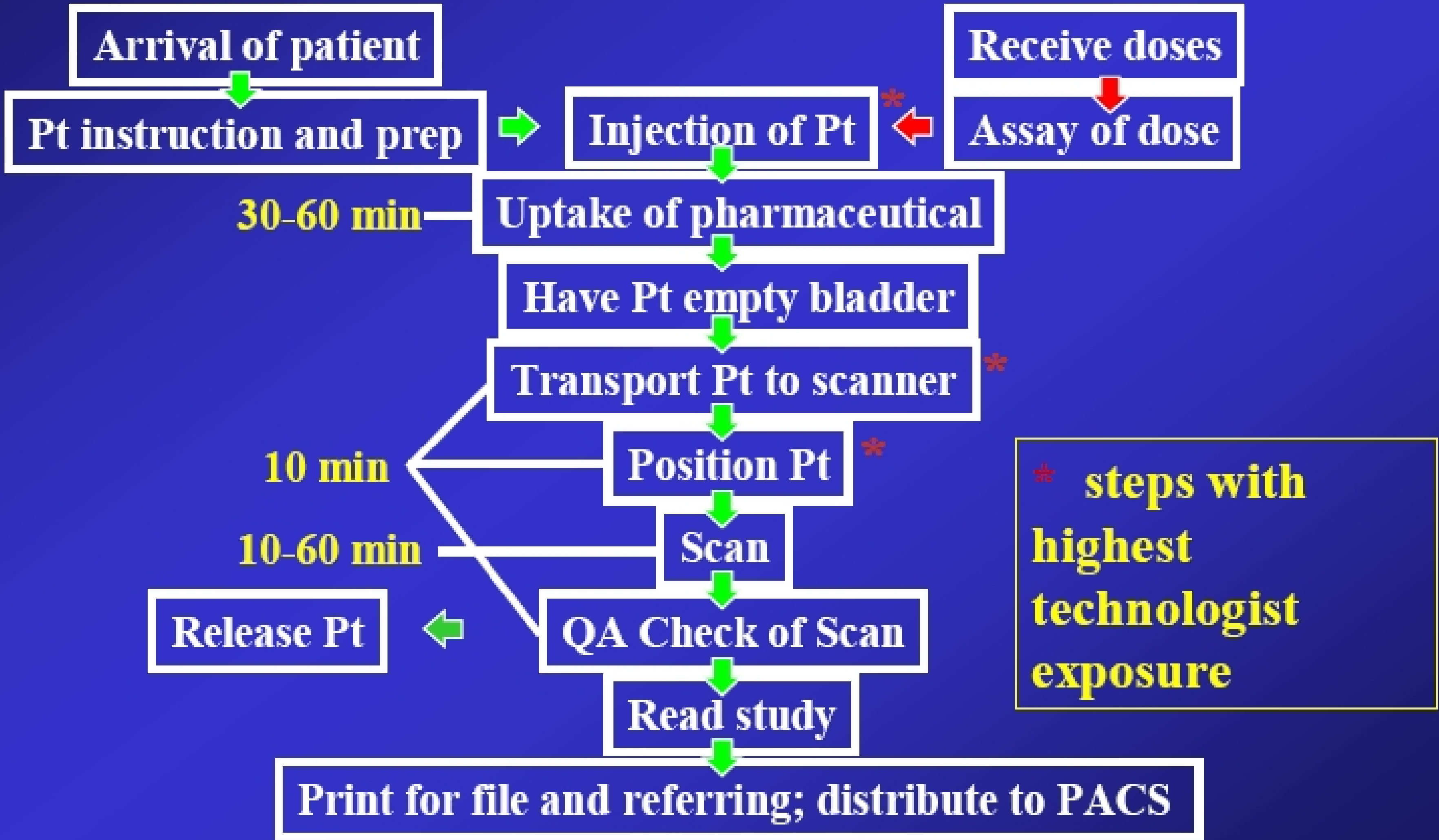
A Revealing Comparison of Lead Requirements: X-Ray *vs* PET

#HVL's	Lead Thickness Required mm (in)	
	X-ray [1] (average primary for rad room)	PET[2]
1	0.044 (< 1/16)	5.3 (1/4)
2	0.103 (< 1/16)	9.9 (7/16)
4	0.278 (< 1/16)	19.0 (3/4)
8	0.718 (< 1/16)	32.5 (1 5/16)
10	1.366 (< 1/16)	46.0 (1 13/16)

Even a single half-value layer for PET is an expensive proposition!

1. NCRP 147: Structural Shielding Design for Medical X-Ray Imaging Facilities
2. Simpkin, 2004, developed for AAPM Task Group on PET Facility Shielding

Workflow at the PET Center (FDG Whole Body Scans)



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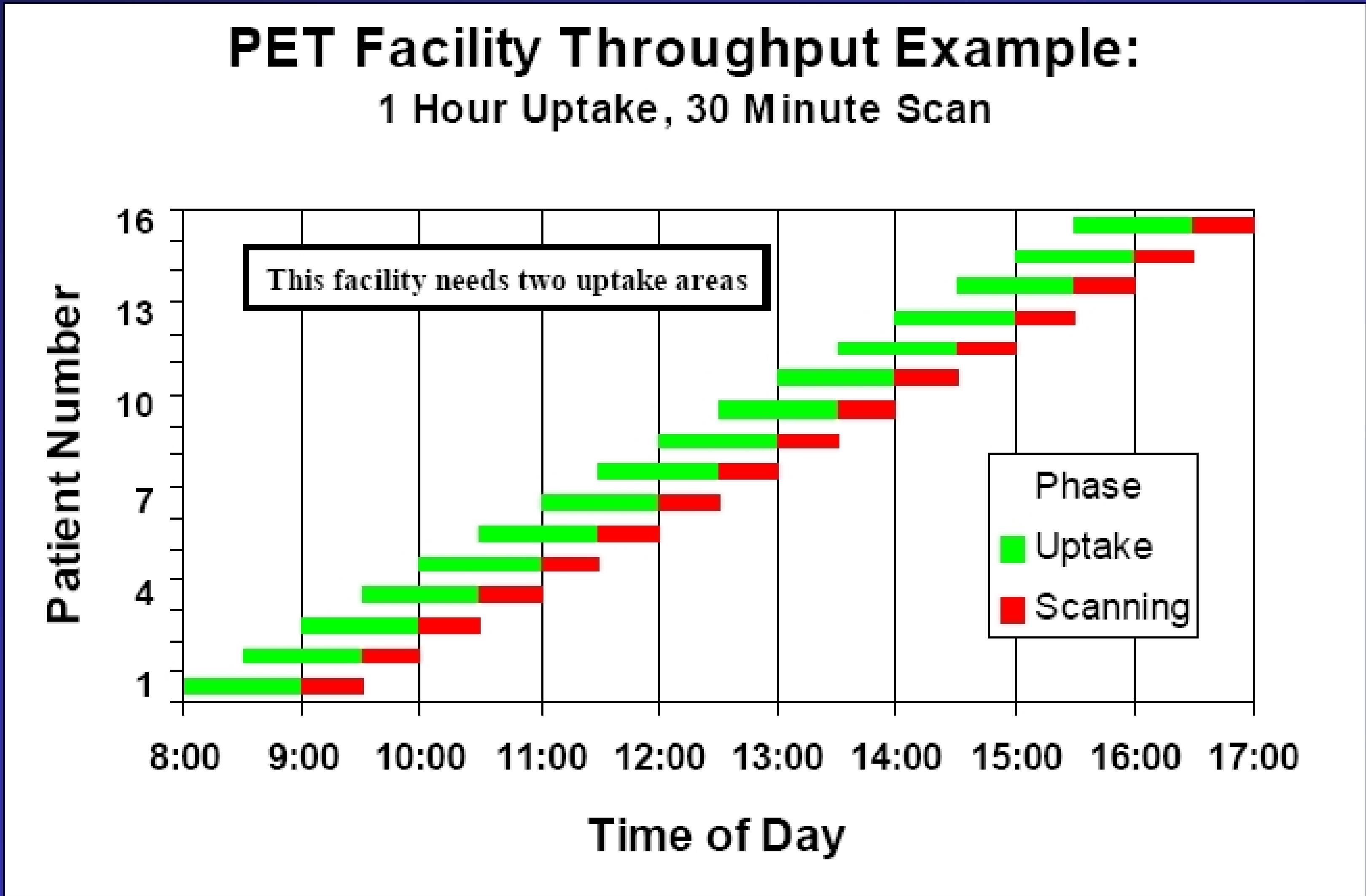
N: Maximum Workload Estimation



$\#pts/day = (T_{work} - T_{uptake})/T_{scan\_rm}$ $\quad$ $\#\ uptake\ areas = T_{uptake}/T_{scan\_rm}$

Examples of Shadow Shields

from JA Anderson, RJ Massoth, and LL Windedahl, 2003 AAPM

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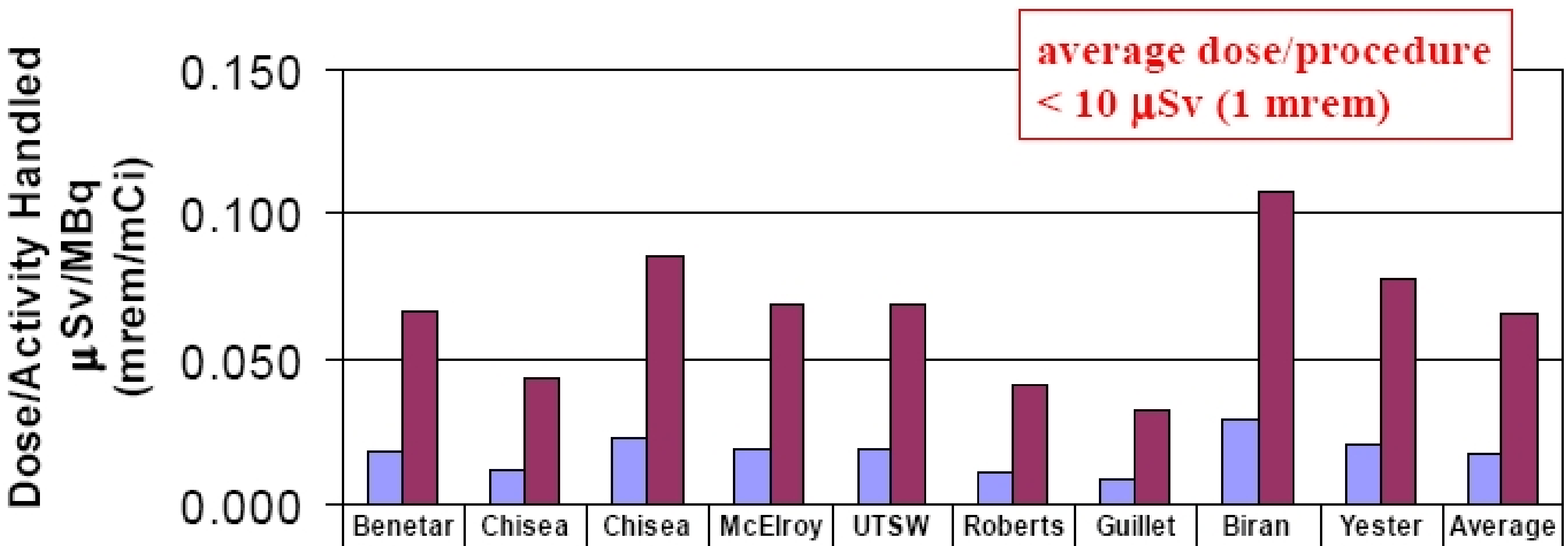
Magnitude of Technologist Exposure

Consistent with conventional nuclear medicine practice, most of technologist dose comes from positioning, transport, and injection.

Technologist Doses



	Benetar	Chisea	Chisea	McElroy	UTSW	Roberts	Guillet	Biran	Yester	Average
SI Units	0.018	0.012	0.023	0.019	0.019	0.011	0.009	0.029	0.021	0.018
Conventional Units	0.067	0.044	0.085	0.069	0.069	0.041	0.032	0.107	0.077	0.066

Reference

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More on Technologist Exposure

1) It is often seen that the technologist dose per mBq handled drops as a function of experience in the PET clinic.

A 2004 update to the previous UTSW data for the same two technologists as shown on preceding slide showed a normalized WB dose of 0.011 μSv/MBq (0.041 mrem/mCi), down by 40% since 2002.

2) Assuming an average dose of 0.018 μSv/MBq injected, 8 pt/day and 370 MBq (10 mCi) injected/pt, this would yield a yearly dose of 13.3 mSv (1330 mrem), within regulation but above usual ALARA investigational limits. Over nine months, it would be 10.4 mSv (1040 mrem), well above the declared pregnancy limit.

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PET- CT *Imaging*

The University of Hong Kong

PET/CT in HKU

Method of radiation protection in PET/CT HKU

- Primary barrier design
- Lead sheet, lead apron, lead glass and lead door
- Radiation controlled area
- Source delivery route
- L-block for source preparation.
- Syringe shield and lead box for injection.

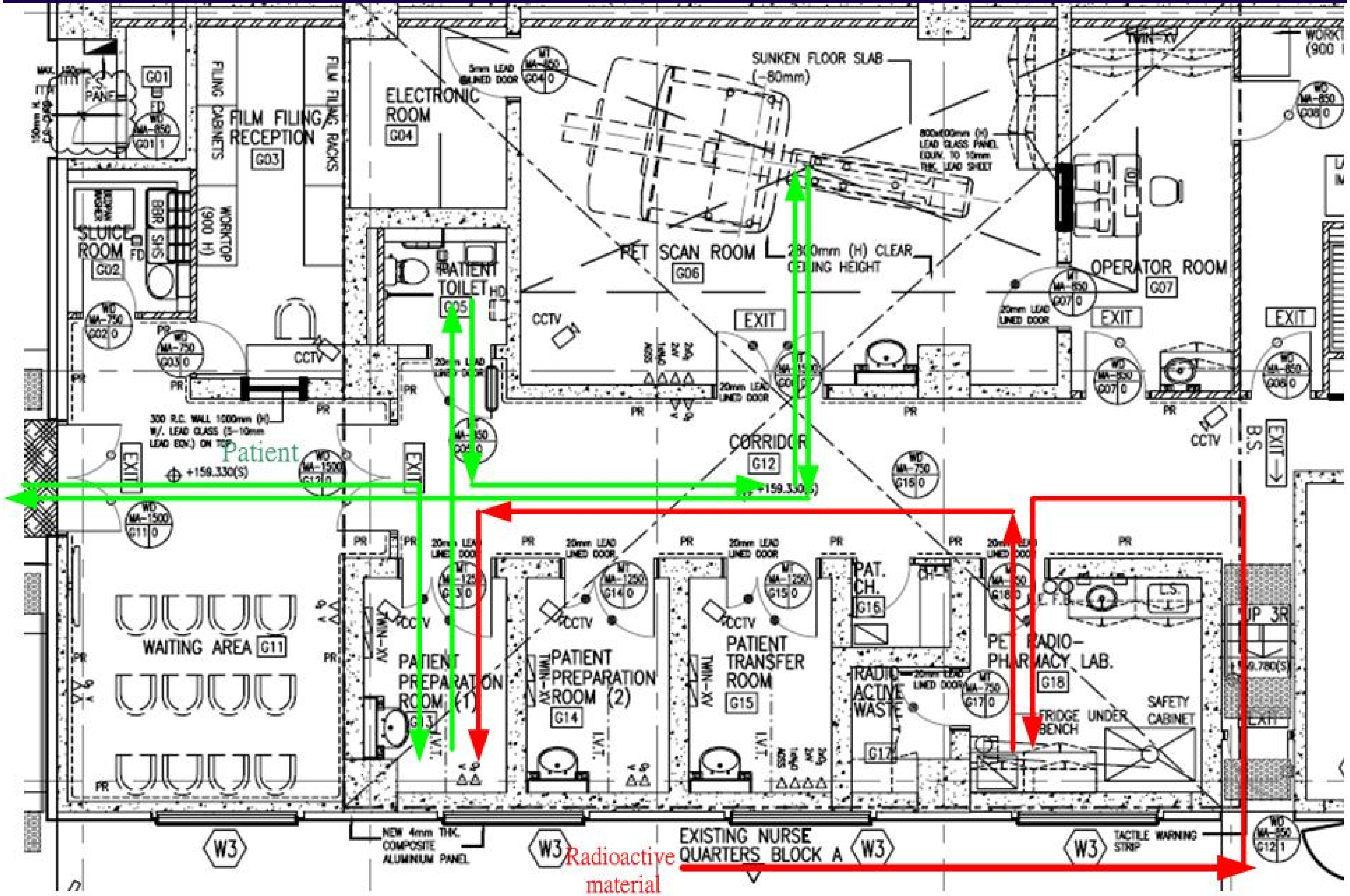
Method of radiation protection in PET/CT HKU

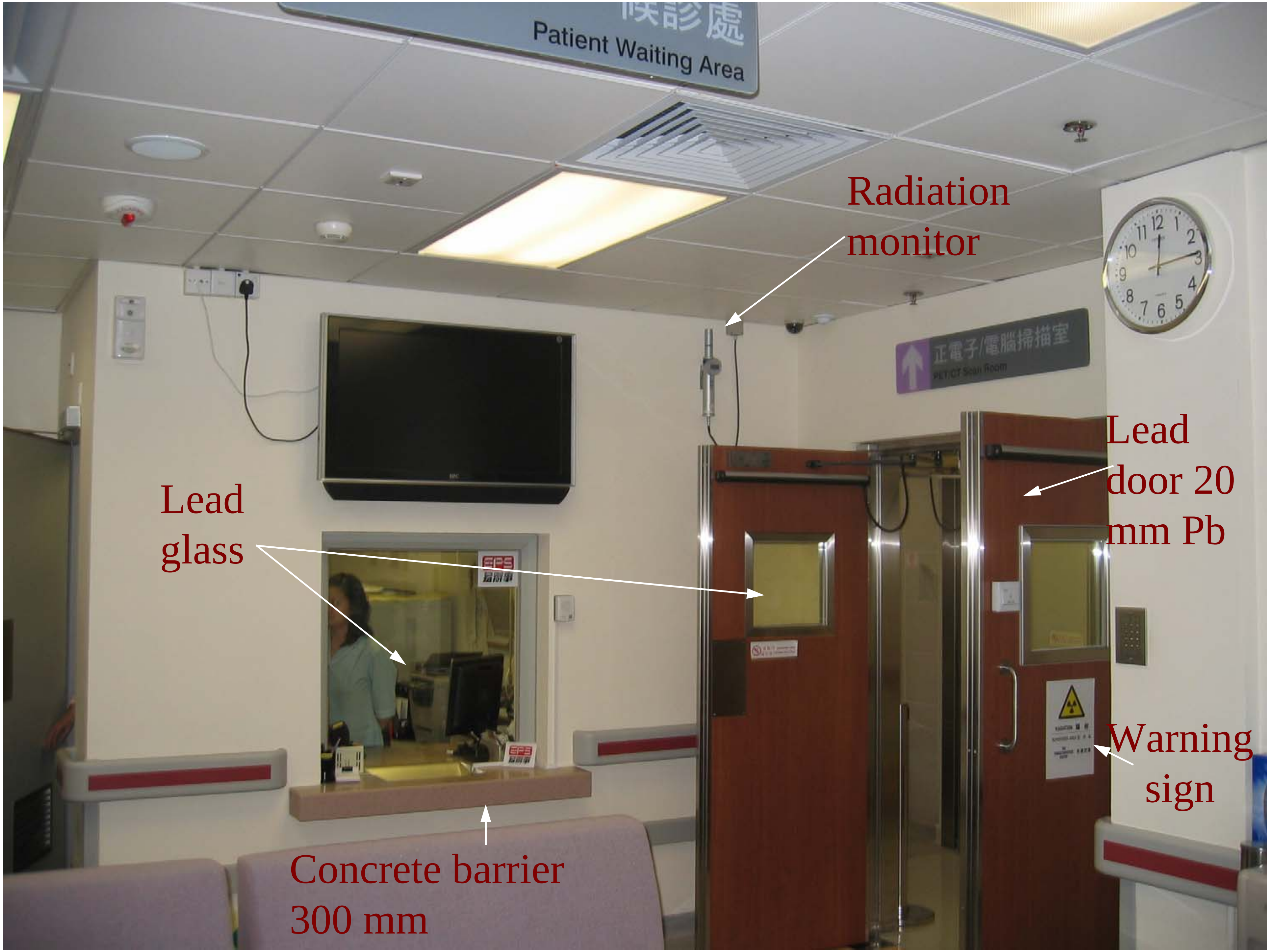
- Remote controlled radiation monitoring
- Personal monitoring
- Radiation warning sign
- Decontamination kit.
- Decontamination shower

Method of radiation protection in PET/CT HKU

- Minimizing radiation risk in working procedure
- Minimizing time with radioactive patient (Pre-injection briefing, intercom, CCTV etc)
- Minimizing positioning time.
- Follow local radiation protection rules

Delivery route and Patient flow




Patient Waiting Area
Radiation monitor
Lead glass
Lead door 20 mm Pb
Warning sign
Concrete barrier 300 mm

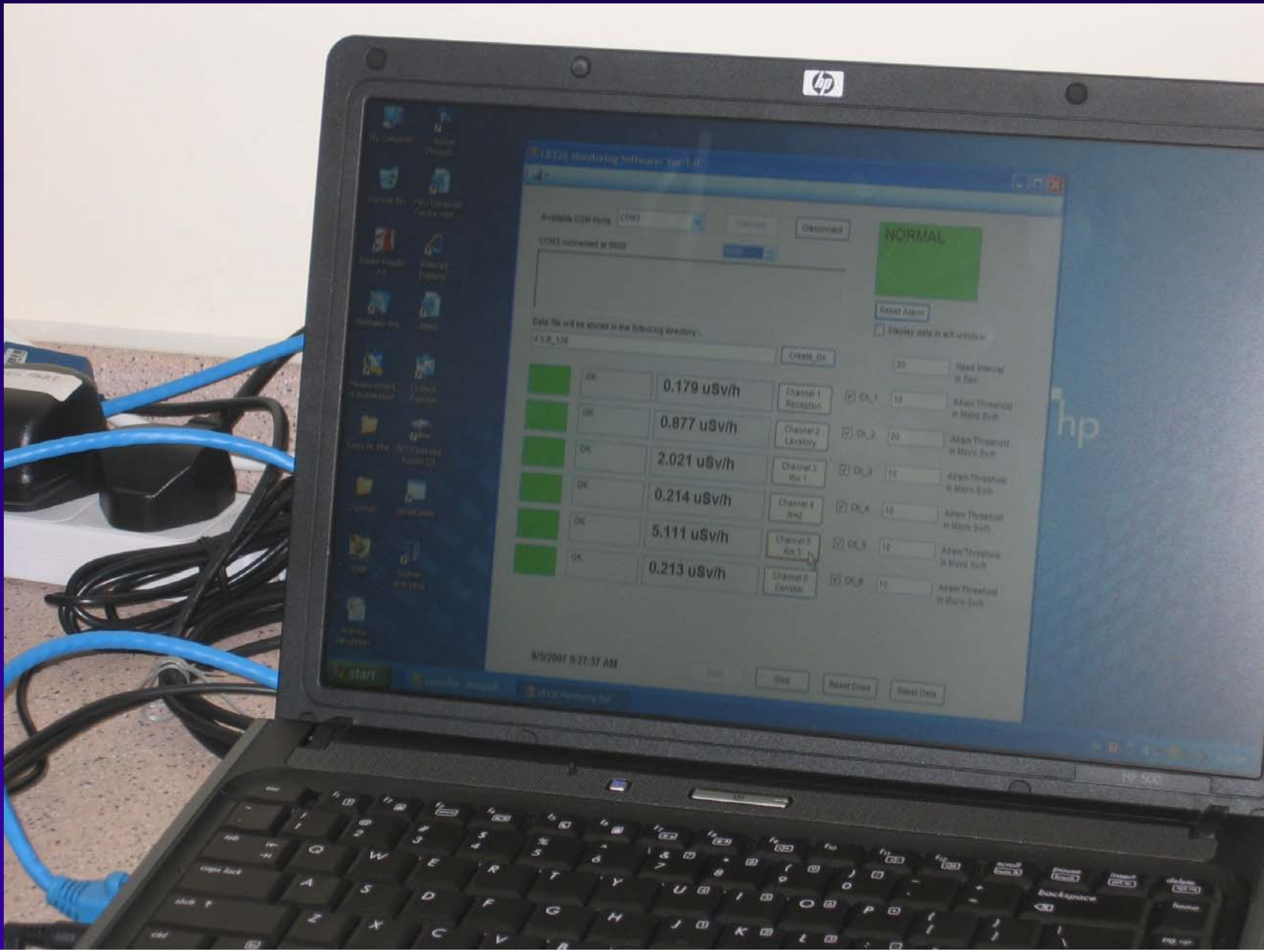
Control access in Radiation controlled area

Radiation monitoring

- Geiger counters installed in preparation room, corridor, waiting area and patient toilet.

Radiation monitoring

Computer display of Geiger counter measurement



New radiopharmaceutical temporary storage

Temporary storage of FDG

2 cm Pb equivalent

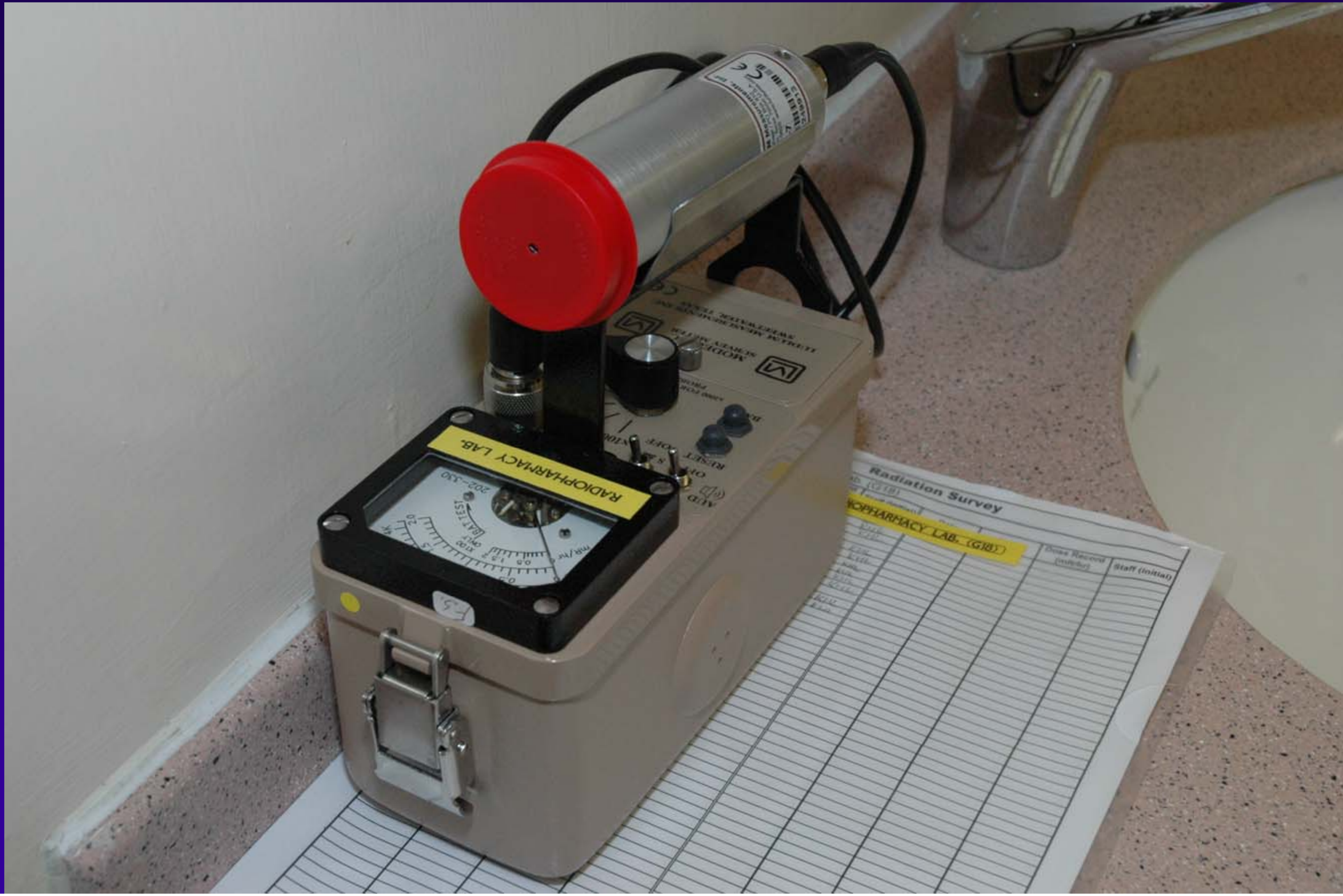
Storage for radioactive waste

Storage for decayed radioactive waste

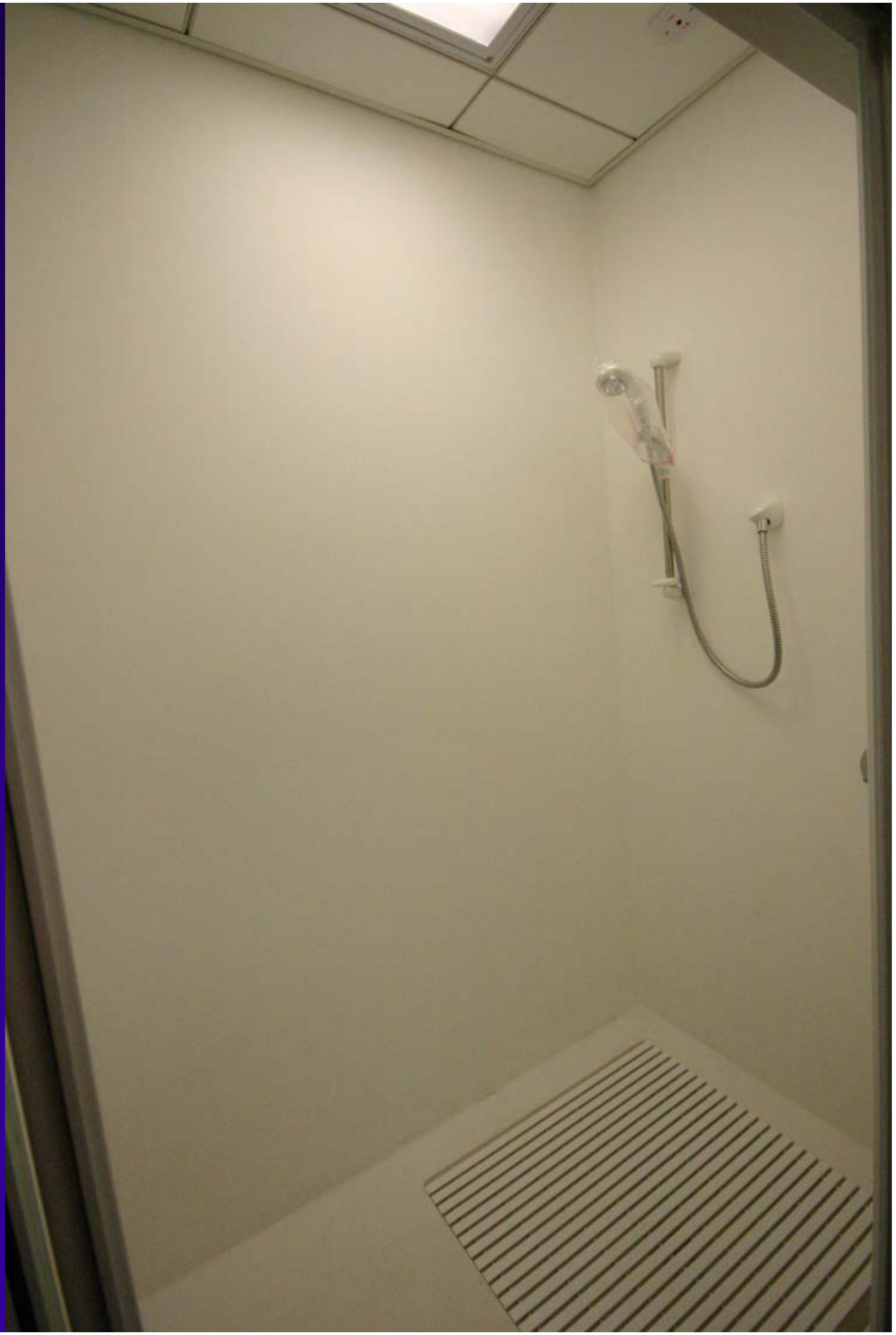
Hot lab: Dose assay and preparation area

Tungsten syringe shield

Radiation monitor for contamination check

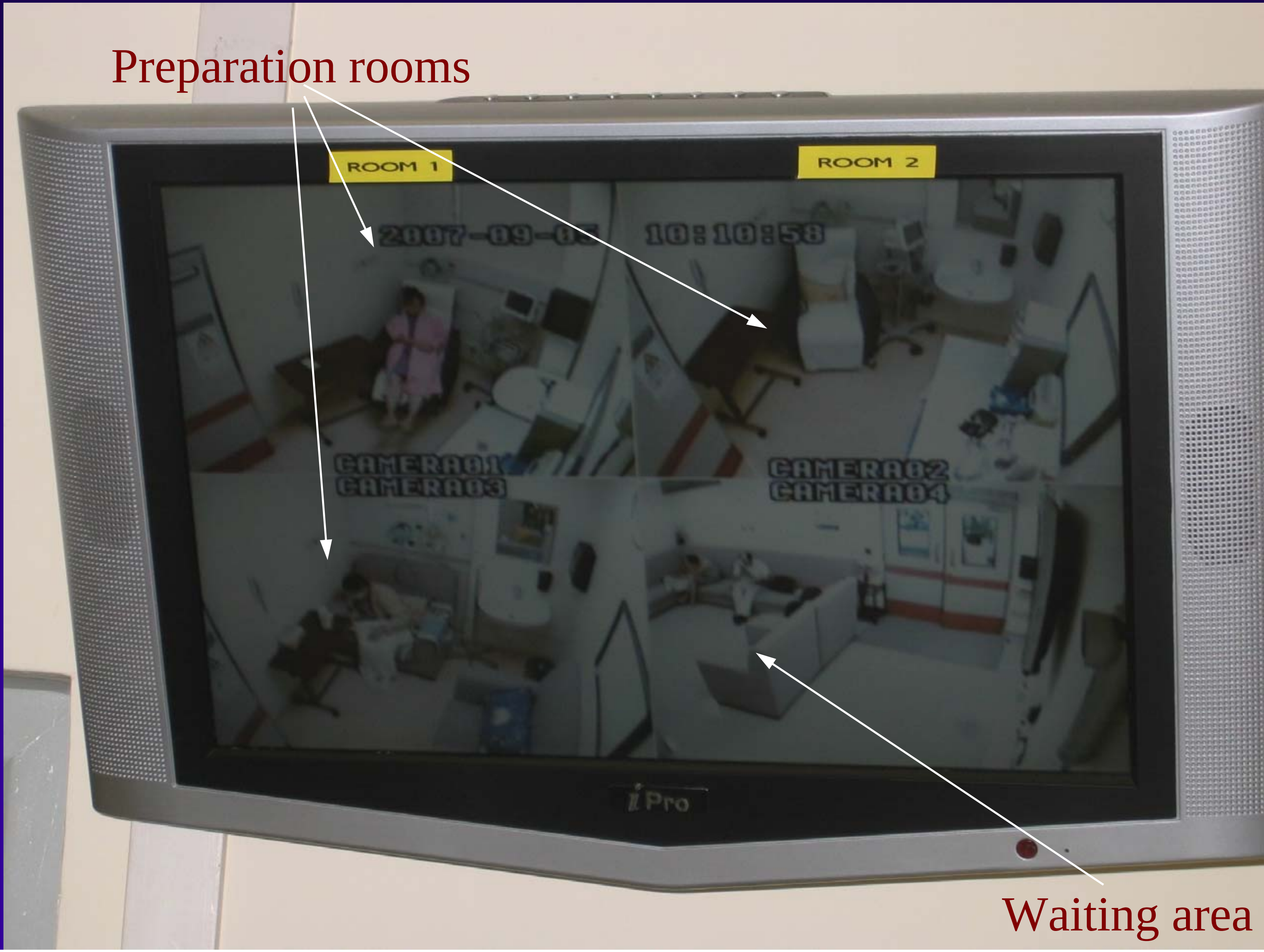


Shower room for decontamination

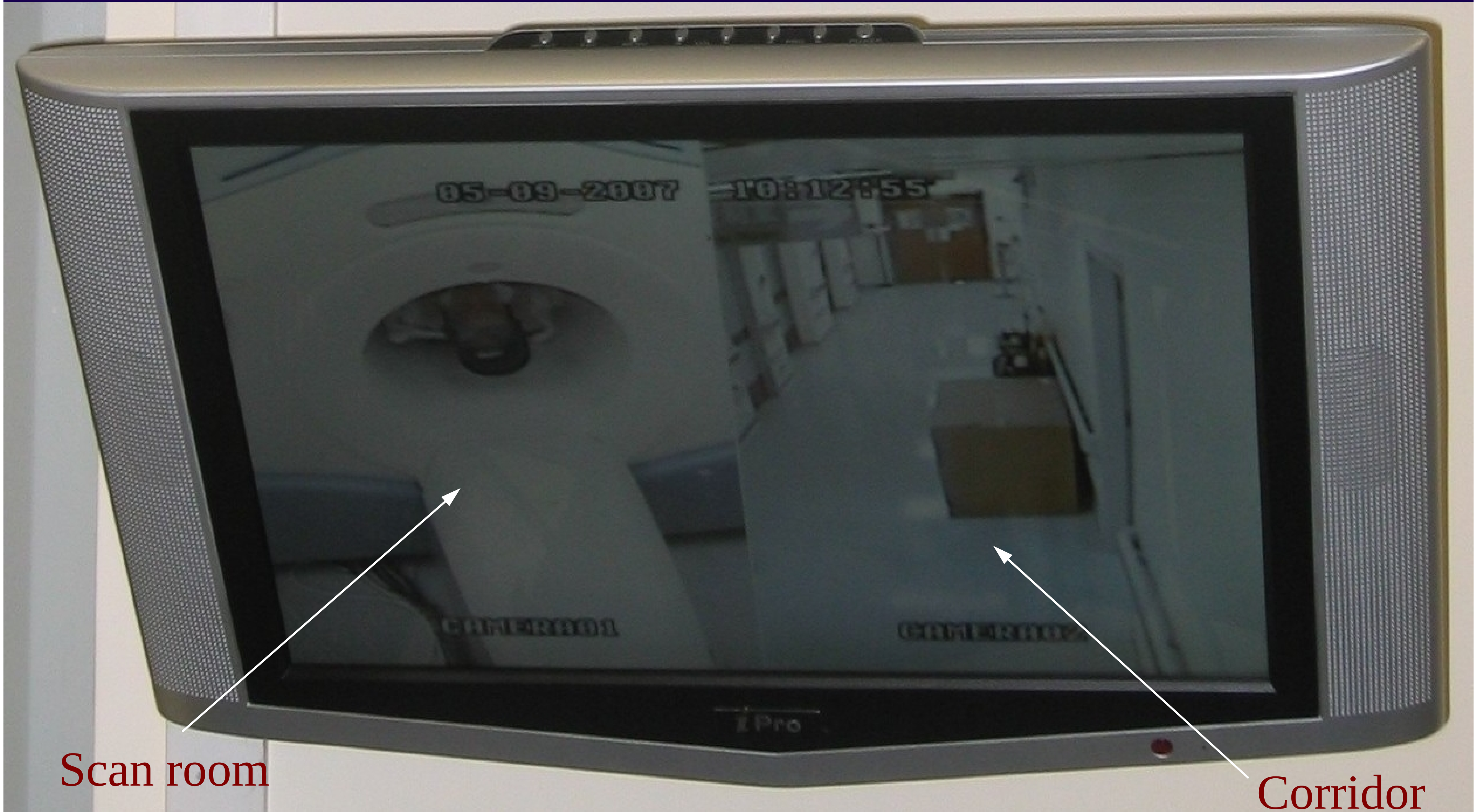


Lead door for PET/CT

Patient monitoring through CCTV



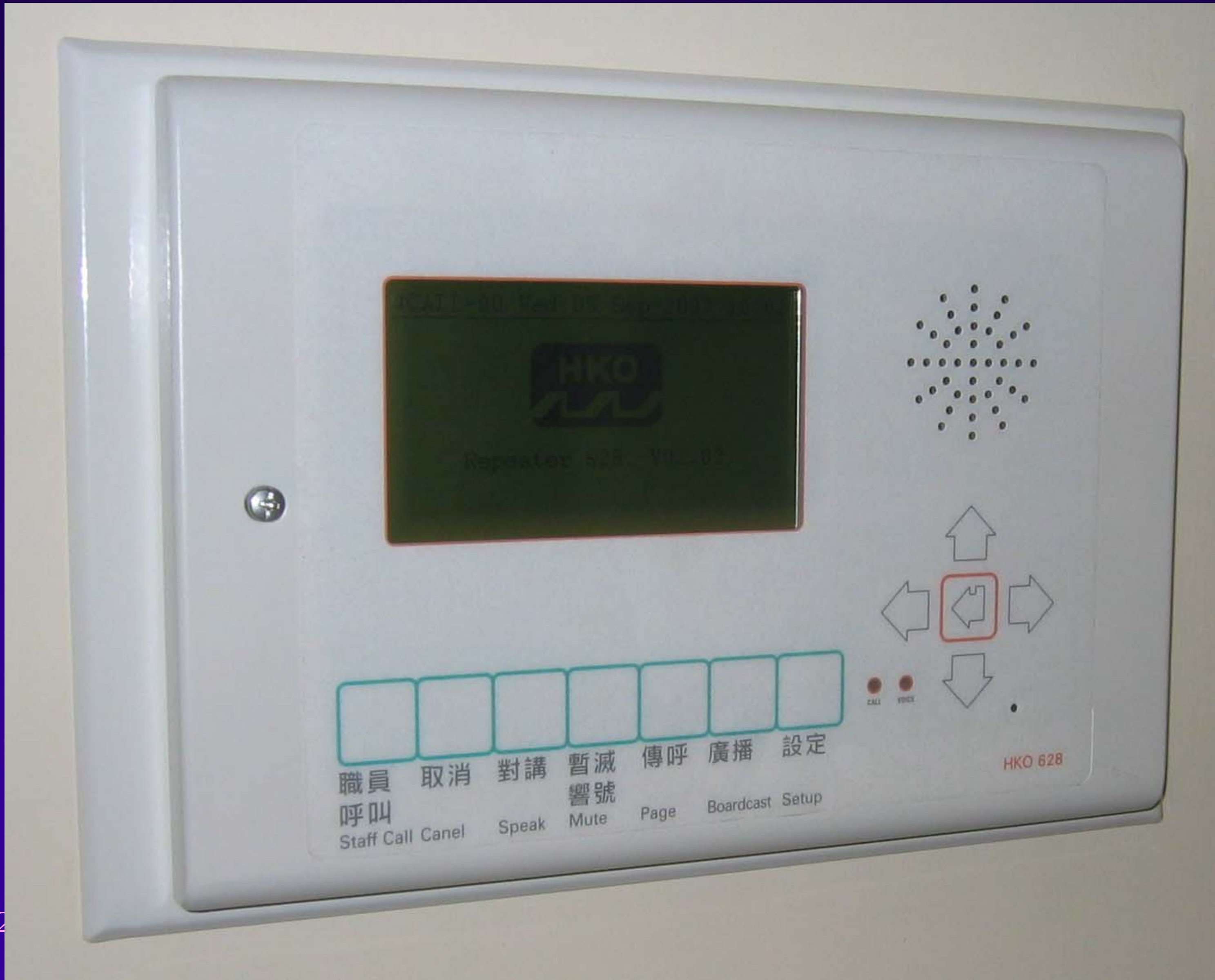
Patient monitoring through CCTV



Scan room

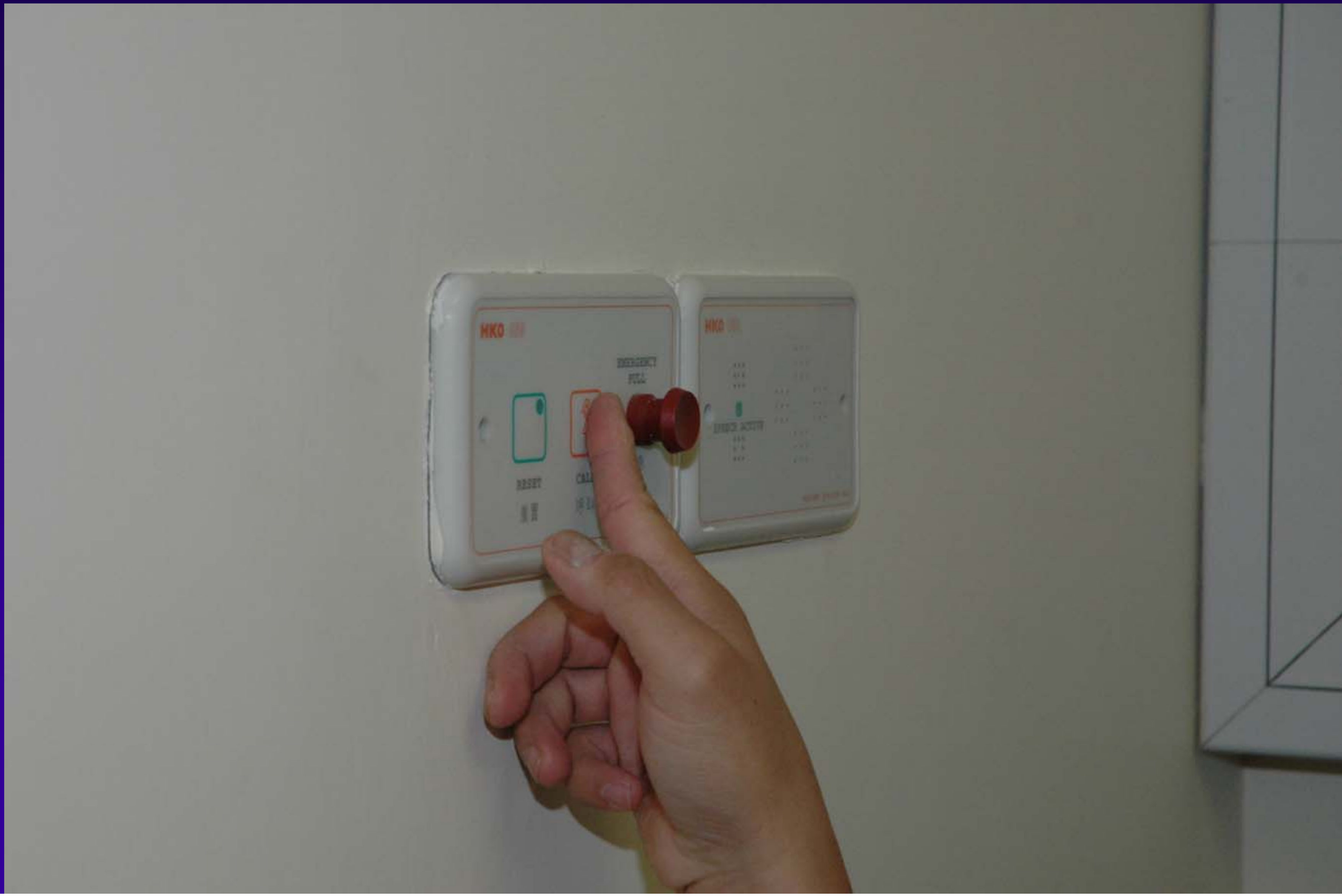
Corridor

Inter-com at control room



Inter com at uptake room

Nurse call at uptake room



Lead apron in PET/CT

- Useful for some paediatric patients under CT but not PET

Patient setup and positioning

Patient setup and positioning

Patient setup and positioning

Patient setup and positioning

Patient setup and positioning

To minimize the risk of spill by using SAFSITE® Needle-free system

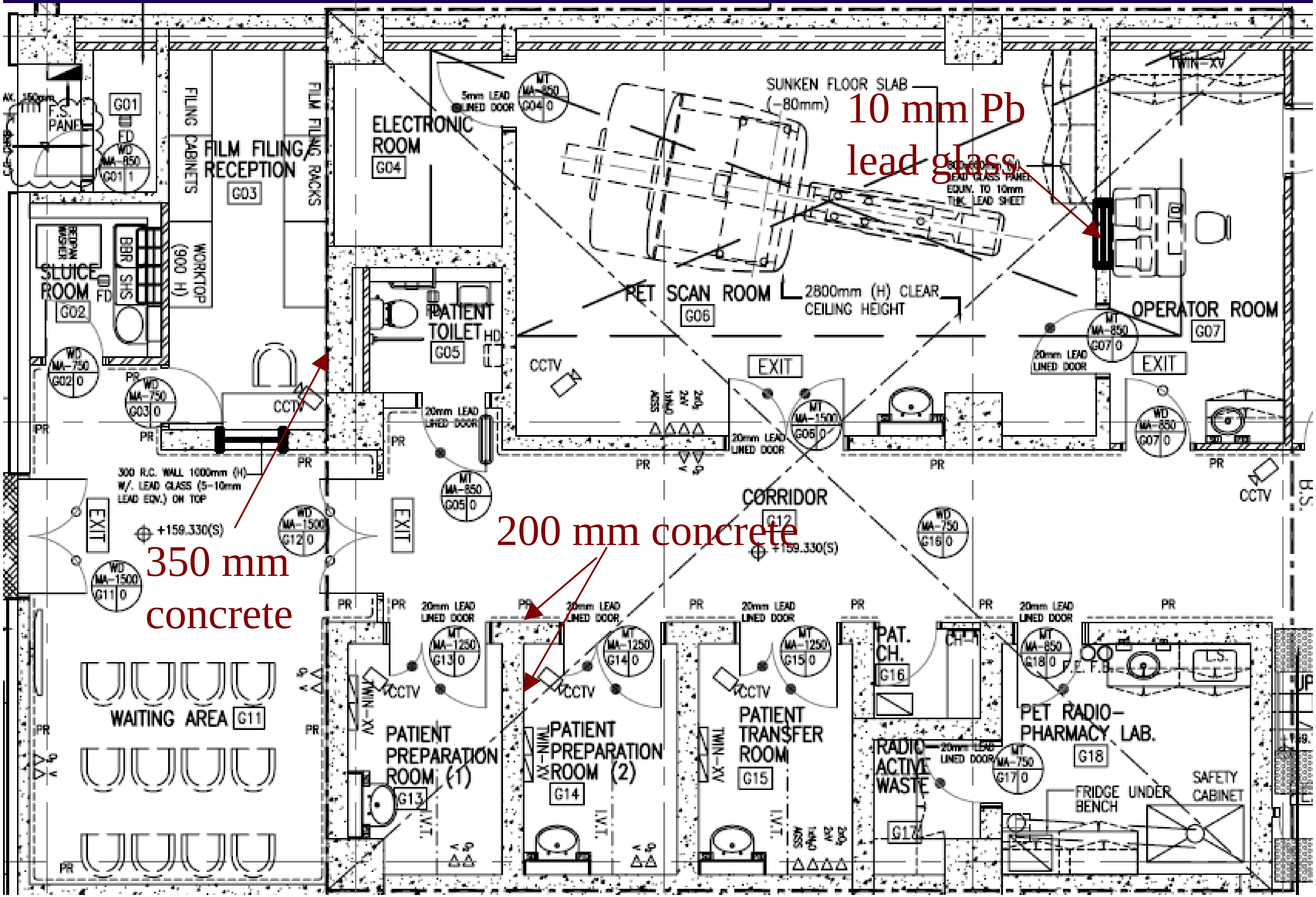
Local licensing requirement

Design criteria

- < 1 μSv/h at public area (uncontrolled area)
- < 3 μSv/h at radiation controlled area

Remark: Workload, Use factor and Occupancy factor would also be considered.

PET/CT center at HKU



The site of PET/CT center at HKU

Opening for cable trunking

Opening at the source preparation room to the MRI unit at the upper floor

Corridor of PET/CT center

Lead lining for air duct and trunking

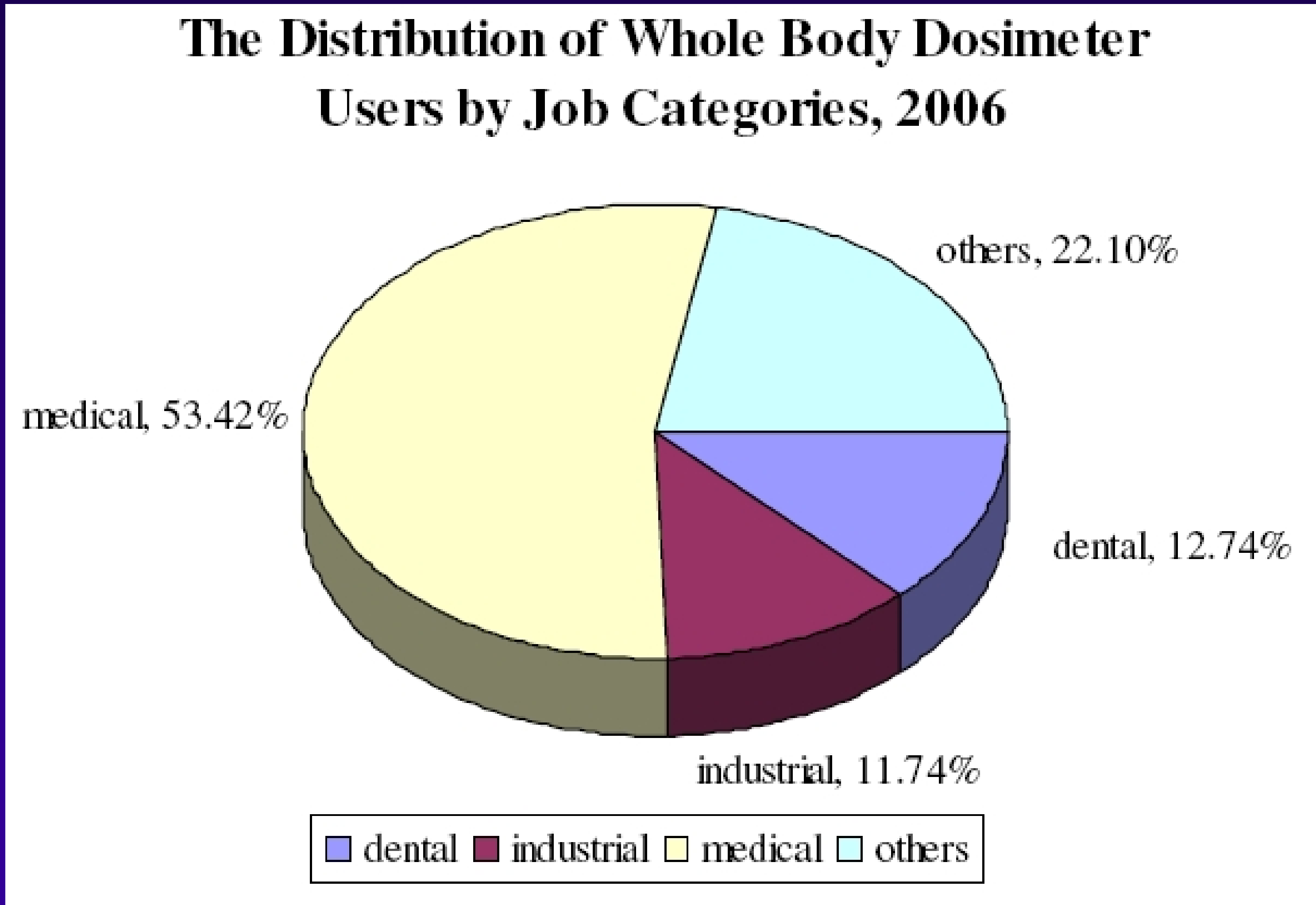
Confirm the transmission factor of concrete wall and ceiling by using radioactive source

Lead-lined walls PET/CT room

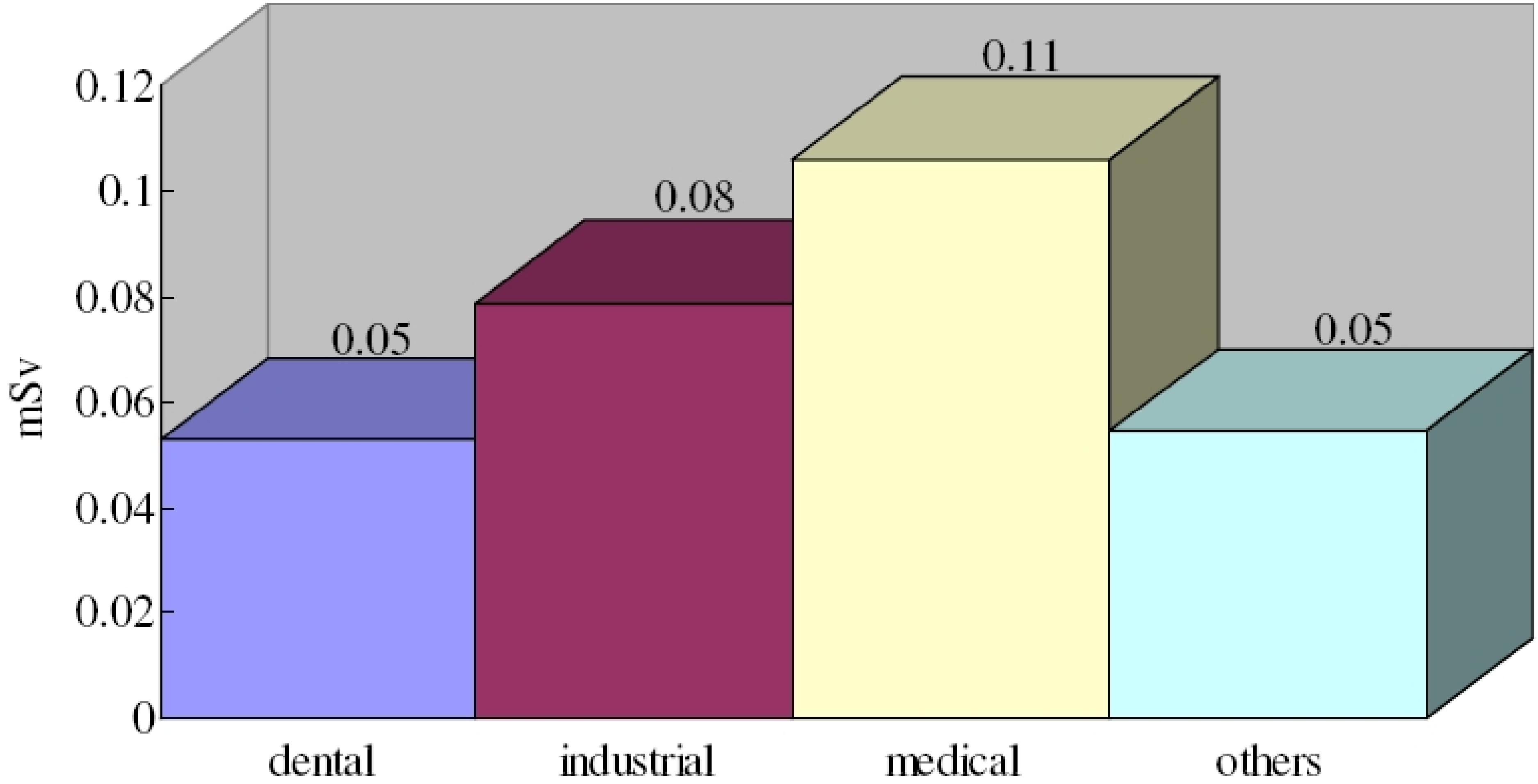
Radiation measurement for concrete wall at reception

Dose comparison with other radiation workers

http://www.info.gov.hk/dh-rhu/Report2006e.pdf



The Average Annual Occupational Whole Body Dose by Job Categories, 2006



Courtesy of Radiation Health Unit/DH/HKSAR

The Distribution of Whole Body Dose by Gender, 2006

	x<=0.17 mSv	0.17<x<=0.75	0.75<x<=1.5	1.5<x<=3.0	3.0<x<=6.0	6.0<x<=10	10<x
Male	3589	394	64	23	17	1	0
Female	3258	359	36	10	6	0	0
Total	6847	753	100	33	23	1	0

Dose distribution by job types

	x≤0.17 mSv	0.17<x ≤ 0.75	0.75<x ≤ 1.5	1.5<x ≤ 3.0	3.0<x ≤ 6	6<x ≤ 10	10<x
Consultant	52	6	4	0	0	0	0
Delivery	11	0	0	1	1	0	0
Dentist	354	23	2	0	1	0	0
Dental assistant	310	14	0	0	0	0	0
Industrial radiographer	27	18	2	2	1	0	0
Medical officer	755	106	14	6	2	0	0

Courtesy of Radiation Health Unit/DH/HKSAR

Dose distribution by job types

	x≤0.17 mSv	0.17<x ≤ 0.75	0.75<x ≤ 1.5	1.5<x ≤ 3.0	3.0<x ≤ 6	6<x ≤ 10	10<x
Medical Technologist	35	1	2	0	1	0	0
Nurse	950	135	14	5	1	0	0
Physicist	37	7	7	1	0	0	0
Diagnostic radiographer	1055	132	18	5	13	1	0
Therapeutic radiographer	92	20	5	0	0	0	0
Radiologist	49	6	1	0	0	0	0

Courtesy of Radiation Health Unit/DH/HKSAR

Personal radiation monitors record at PET/CT center / HKU

Dose (μSv)	Rad1	Rad2	Rad 3	Nurse 1	Nurse 2	Nurse 3	Nurse 4	Nurse 5
June07	117	159	170	12	63	17	45	36
July07	114	156	118	14	25	12	44	61
Aug07	129	190	195	33	38	21	41	45

Courtesy of staff from PET/CT HKU

Summary on occupational exposure PET/CT HKU

	Average monthly occupational exposure (μSv)	Projected annual occupational exposure (μSv)	Remark
Doctor	0	0	Doctors not involved in dose injection and scanning.
Nurse	34	408	1 out of 5 nurses on rotation basis
Radiographer	150	1800	3 radiographers worked on full time basis

Courtesy of staff from PET/CT HKU

Summary on occupational exposure PET/CT HKU

	Projected annual occupational exposure (μSv)	Radiation risk to the staff	Remark
Nurse	408	2.3×10^{-5}	1 out of 5 nurses on rotation basis
Radiographer	1800	1.0×10^{-4}	3 radiographers worked on full time basis

Reference in ICRP 1991: Total risk of cancer and hereditary effects for work force = 5.6% Sv^{-1}

Courtesy of staff from PET/CT HKU

Typical risks from well known activities

Activity	Risk of death per year
Travelling 300 miles by car	10^{-5}
Work accidents	2×10^{-5}
Home accidents	10^{-4}
Smoking 10 cigarettes a day	1.5×10^{-4}
Coal mining	1.5×10^{-4}
Deep sea fishing	2×10^{-3}

Reference from Dendy, p297 Physics for Diagnostic Radiology

Thank you.