BERTHOLD TECHNOLOGIES

operating worldwide

detect and identify

Air Monitoring at PET Centers

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Overview

- What is PET?
- Pet Nuclides
- Radiation Protection at PET Centers
- Regulatory Requirements
- Air Monitoring Techniques
- Examples
- References

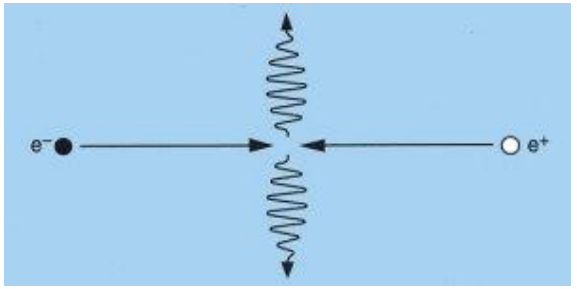
What is PET?

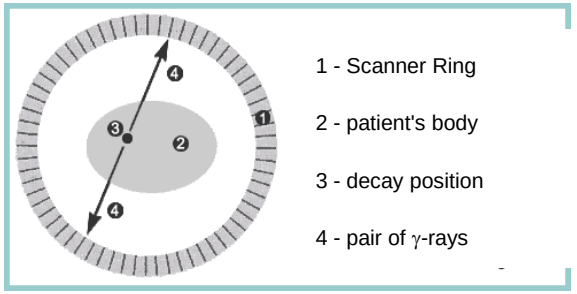
- PET : = Positron emission tomography
- Medical imaging technique
  - nuclear
  - noninvasive
  - image of a radioactive tracer concentration in an organism
- Images of
  - Structures
  - Functional processes
    - Biochemical
    - Physiological

PET-Scanner Siemens

How does it work?

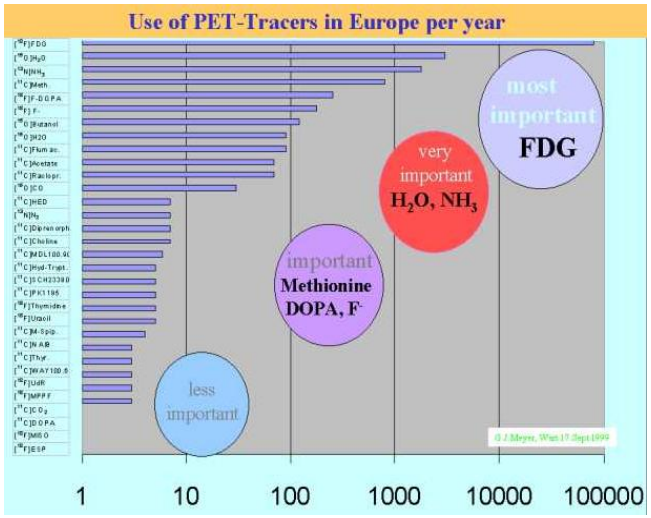
- Positron-emitting radionuclides are used as tracers
  - Positron anti-particle of the electron
  - Positrons annihilate with electrons (their antiparticles)
  - Energy is released by the emission of a pair of gamma rays
    - moving in opposite directions
    - each with 511 KeV
- Detection of gamma rays in coincidence with scintillator crystal arrays (detector rings)





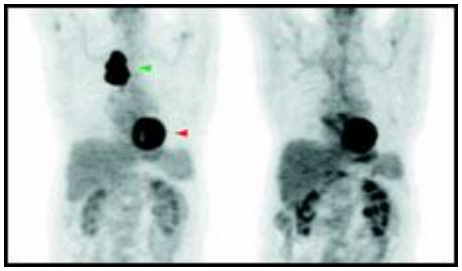
PET Nuclides

- Most important PET Nuclides
  - Radionuclide — Halflife
  - carbon ^{11}C — 20 min
  - nitrogen ^{13}N — 10 min
  - oxygen ^{15}O — 2 min
  - fluorine ^{18}F — 110 min
- Examples tracers
  - FDG - ^{18}F-Fluorodeoxyglucose
  - with ^{18}F labelled glucose analog
  - radioactive ^{15}O for inhalation



Detection and Image Reconstruction

- Radiopharmaceuticals are administered to patients by
  - Injection
  - Inhalation
- Detection of gamma rays
  - Frequently with scintillation counters for example BGO, LuYSiO, LuSiO
  - Coincidence width 10 ns
- Localization of the point of the source along a straight line of coincidence by calculating the line of response (LOR)
- Calculation of image from projections



Tumor in the lobe of the lung

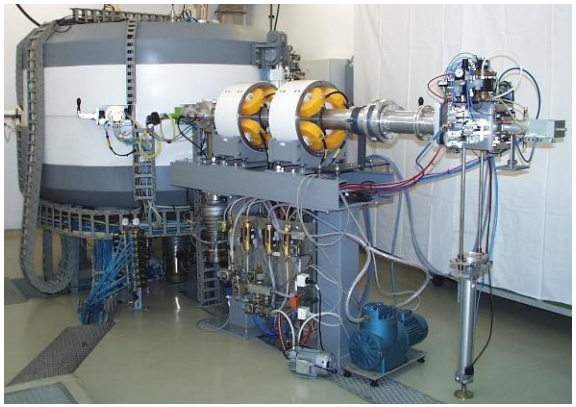
After successful chemo therapy

PET Center

- PET Center facilities
  - Cyclotron for isotope production
  - Hot cells, cells for synthesis
  - Laboratories
  - PET Scanner
- Generation of radionuclides
- Synthesis and analysis of radiopharmaceuticals
- Imaging, diagnosis

Generation of PET-Nuclides

- Generation of short-lived radionuclides at a cyclotron
- Irradiation with protons or deuterons with typical energies 9 to 18 MeV
- Nuclear reactions (p,n), (p,α), (d,n) or (d,α)
- with targets ^{14}N, ^{16}O, ^{18}O or ^{20}Ne
- Typical beam currents
  - 80 µA for protons
  - 35 µA for deuterons



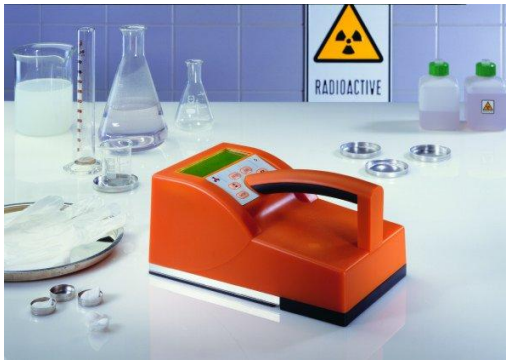
Fabrication des isotopes

Irradiation des cibles par: Protons ($^1H^-$) 18 MeV 40 µA
Deutons ($^2H^-$) 9 MeV 30 µA

Isotope	Cible	Réaction	Molécule
^{18}F	^{18}O ($H_2{}^{18}O$) ^{20}Ne (gaz)	(p,n) (d,α)	$^{18}F^-$ [^{18}F]FDG [^{18}F]F_2 [^{18}F]FDOPA
^{11}C	^{14}N (N_2-gaz)	(p,α)	[^{11}C]CO_2
^{13}N	^{16}O (H_2O)	(p,α)	[^{13}N]NH_3
^{15}O	^{14}N (N_2-gaz)	(d,n)	$H_2{}^{15}O$, $C^{15}O$

Radiation Protection at PET centers

- Contamination monitoring
  - Personal monitors
  - handheld instruments
- Individual dosimetry
- Area dose monitoring
  - gamma
  - neutron
- Airborne Radioactivity Monitoring
  - Release measurement
  - Process monitoring
- Central data acquisition & analysis



PET Stack Monitoring

- Possibility for the release of radioactive gases or contaminated air
- Discharges of radioactive effluents could cause radiation exposures
  - Avoid uncontrolled discharges to the environment
  - In Germany 0.3 mSv concept (§47 Radiation Protection Ordinance)
  - Discharge of radioactive material from nuclear facilities has to be monitored (§ 48 Radiation Protection Ordinance)
  - Measurement of discharged activity concentrations and total activities required

Regulatory Requirements (Germany)

- Radiation Protection Ordinance (§ 47 and § 48)
- Limits for max. activity concentrations depending on stack flow (two groups)

Nuclid		Halflife [min]	E_{max} [MeV]	Limits Radiation Protection Ordinance Attachment VII	
				$Q \leq 10^4$ m^3 h^{-1} [kBq/m^3]	$10^4 < Q \leq 10^5$ m^3 h^{-1} [kBq/m^3]
^{11}C	Carbon-11	20,3	0,96	30	3
^{13}N	Ntrogen-13	9,96	1,20	20	2
^{15}O	Oxygen-15	2,03	1,70	10	1
^{18}F	Fluorine-18	109,8	0,64	5	0,5
^{41}Ar	Argon-41	109,6	1,20	2	0,2

Sampling

- According to German sampling standard DIN 25423
- Position of measuring detector shall be downstream of last confluence
- two types of setups
  - **In-line measurement:** measured directly in the main air stream
  - **Bypass Measurement:** Isokinetic extraction and measurement of partial flow or representative sample from total effluent's flow

Process Monitoring

- Fast detection of discharges from critical zones for instance
  - ventilation exhaust air from hot cells
  - ventilation air from cyclotron bunker
- Effluent control (for example: close duct, …..)
- Requirements
  - small volume and high detection efficiency
  - largest possible ratio between sample and system air flow in a duct or in a stack
  - low external gamma levels (compensation or shielding)
  - Dynamic averaging to achieve fast detection risetime

Environmental Release or Stack Monitoring

- Measurement & documentation of the activity released in the total flow
  - current activity concentration [Bq/m^3]
  - Integrated activity within a specified period of time (for instance Bq per day, week, month, year)
- Requirements
  - Detection limit of the system shall be lower than the regulatory limits for the activity concentrations (for example 0.5 kBq/m^3 for ^{18}F @air flow >10^4 m^3/h)
  - Measurement of flow if it is variable
- if exceeding predefined levels actuation of optical or acoustical alarms or of air control functions

Air Monitoring Detection Methods for PET

- Gamma detection
  - Scintillation counters or gas filled detectors
  - coincidence detection of 511 keV photons
- Charged particle detection (positrons)
  - sealed large area proportional counters
  - cylindrical proportional counter tubes

Air Monitoring Detection Methods for PET

- Gamma detection
  - not well localized because 511 keV photon are everywhere in a PET facility
  - more sensitive against external gamma levels
- Charged particle detection
  - Extremely well localized
  - Not very sensitive against external gamma levels

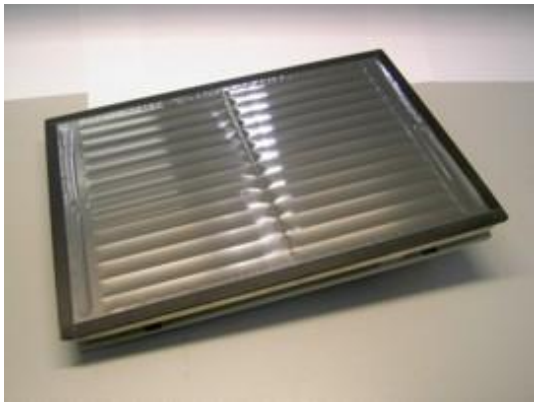
Air Monitoring Detection Methods for PET

- Scintillation detection
  - Temperature drifts
  - more sensitive against external gamma levels
  - Conincidence measurement requires more effort
- Detection with large area proportional counters
  - Relatively large solid angle
  - Lower sensitivity against external radiation fields

Examples large area proportional counters

- Same efficiency for β^+ and β^-
- Active areas up to 1000 cm²
- Assembly on ducts or stacks is straightforward and easy
- Sensitivity is determined by the measured volume
- Argon-Methane filling for lower background counting rate

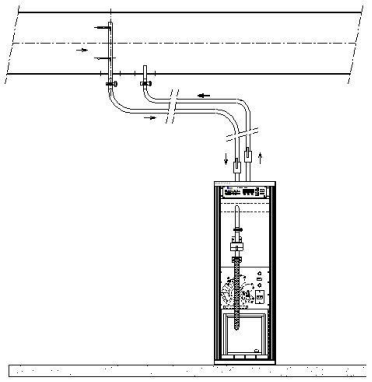
BZ 200 with 200 cm^2

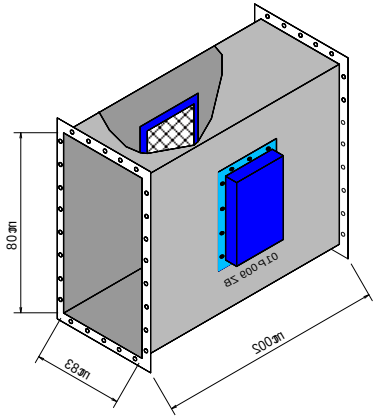


BZ 900 with 900 cm^2

Two different Setups

- Chamber with pump for bypass measurement
  - Volumes 11 or 83 liters (calibrated)
  - 1-4 large area PCs (200 or 900 cm^2)
  - compensation detector or 4π lead shielding (2 cm) optional
- Detection at the ventilation duct
  - standard area cut-out (calibrated)
  - Detectors with 900 cm^2 area
  - compensation detector or rear side lead shielding optional (2cm)





Example

- Duct cross section 800 mm x 360 mm
- Equipped with two large area proportional counters BZ900 each with area 900 cm²
- response to ^{18}F 80 Bq/m³ per cps
- Minimum detectable activities (MDAs) according to table below

Nuclide	**^{18}F**	**^{11}C, ^{15}O**	**Units**
Calibration Factor	80	48	Bq/m³ per cps
MDA 10 s	650	400	Bq/m³
MDA 30 min	50	30	Bq/m³
MDA 1 h	34	20	Bq/m³

Example Measuring Chamber BAI 9109-4

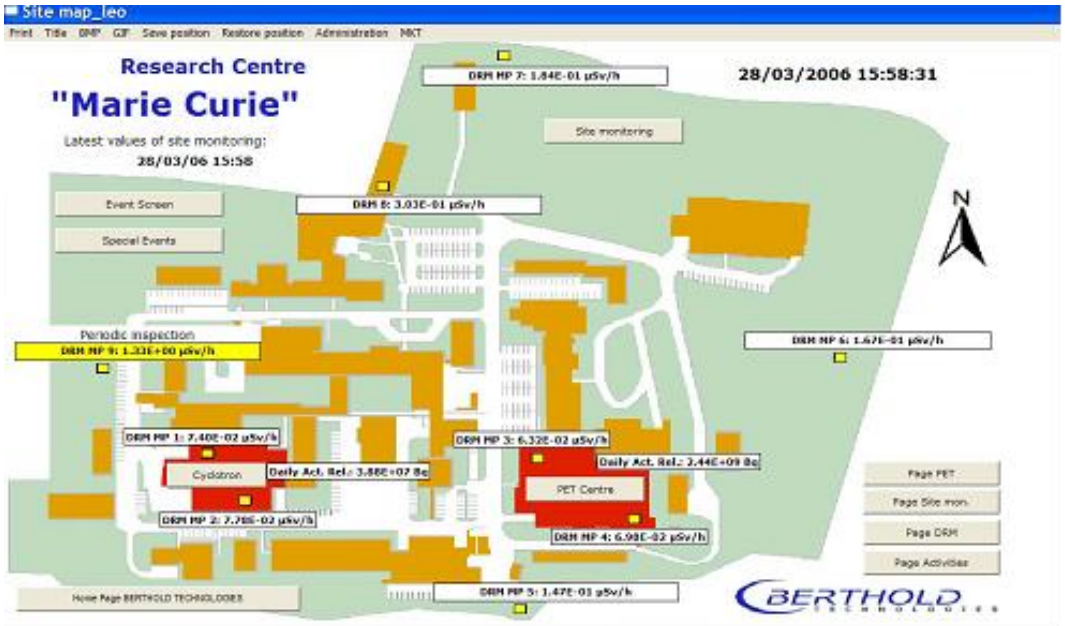
- 11 liter measuring chamber (calibrated)
- 1 to 4 large area proportional counters type BZ 200 each with 200 cm²
- Detection limits according to table

11 liter chamber BAI 9109-4

Nuclide	^{18}F	^{11}C	^{41}Ar	Units
Response	775	420	407	Bq/m³ per cps
MDA 600 s	723	392	380	Bq/m³
MDA 1800 s	418	226	219	Bq/m³
MDA 3600 s	295	160	155	Bq/m³
MDA 7200 s	209	113	110	Bq/m³

Data Acquisition MEVIS Software

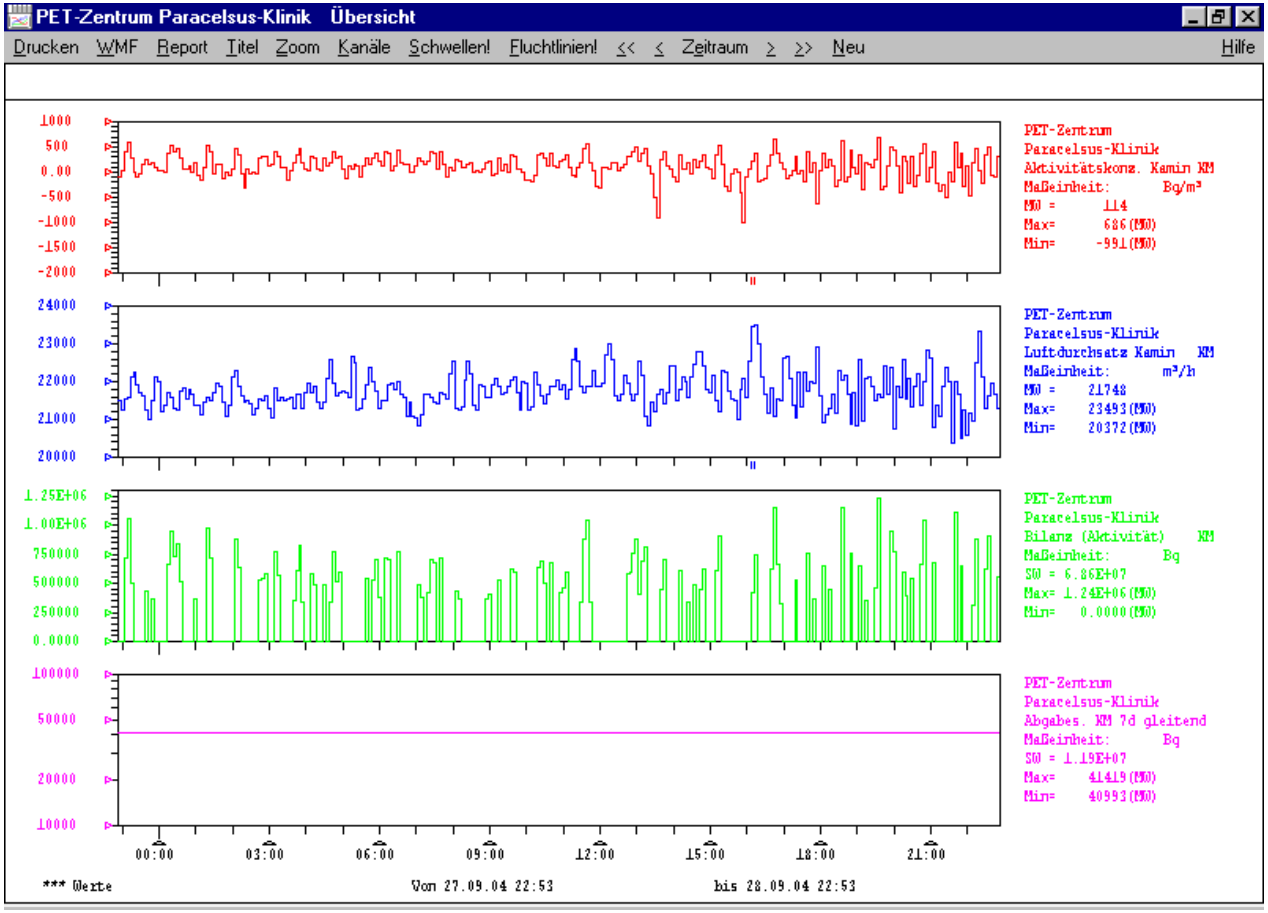
- Control of communication with instruments
- Data Acquisition & display of measured values
- Display data as function of time
- Report generators



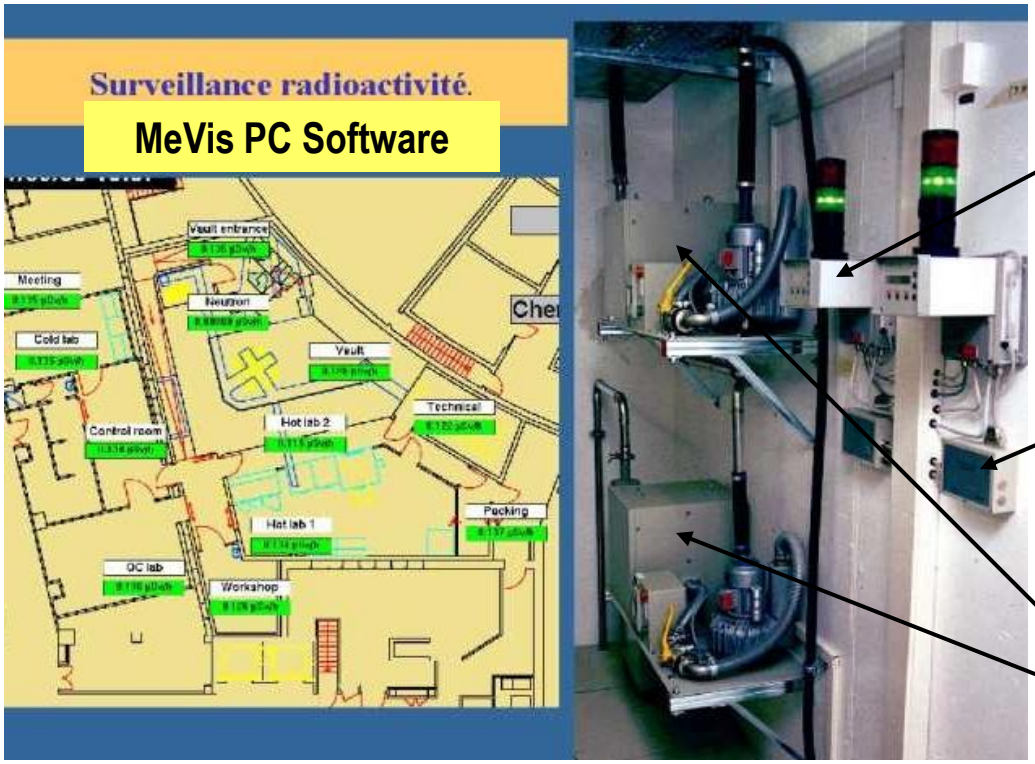
MEVIS Software

Activity Concentration

Air Flow



Examle PET Center Geneva/Switzerland



MEVIS-Data Acquisition System PET-Geneva

LB111 Data Logger
Data Acquisition

RS485 Interface
Connection to central computer via RS485

BAI9109- PET Gas Monitors
11 Liter Volume Measuring Chambers

Some PET References

KfK-Karlsruhe	PET UKRV Berlin	PET-Bonn
KfA-Jülich	PET AKH Vienna	PET-Oak Ridge
University Hannover	PET Bad Berka	ISPN/CEA-Octeville
PET-Center Munic	NYCOMED Amersham	PET-Genf
BTZ, Hamburg	PET-Erlangen	PET-Thoiry
VKTA-Rossendorf	PET-Regensburg	SHFJ Orsay Paris
PET Bad Oeyenhausen	Hopital Depardieu-Paris	PET Complutense Madrid
PET-Tübingen	EuroPET-Berlin	PET-Essen
PET Charite, Berlin	PET-Leipzig	CISBO Schering