Helmholtz-Zentrum Berlin, BESSYII,
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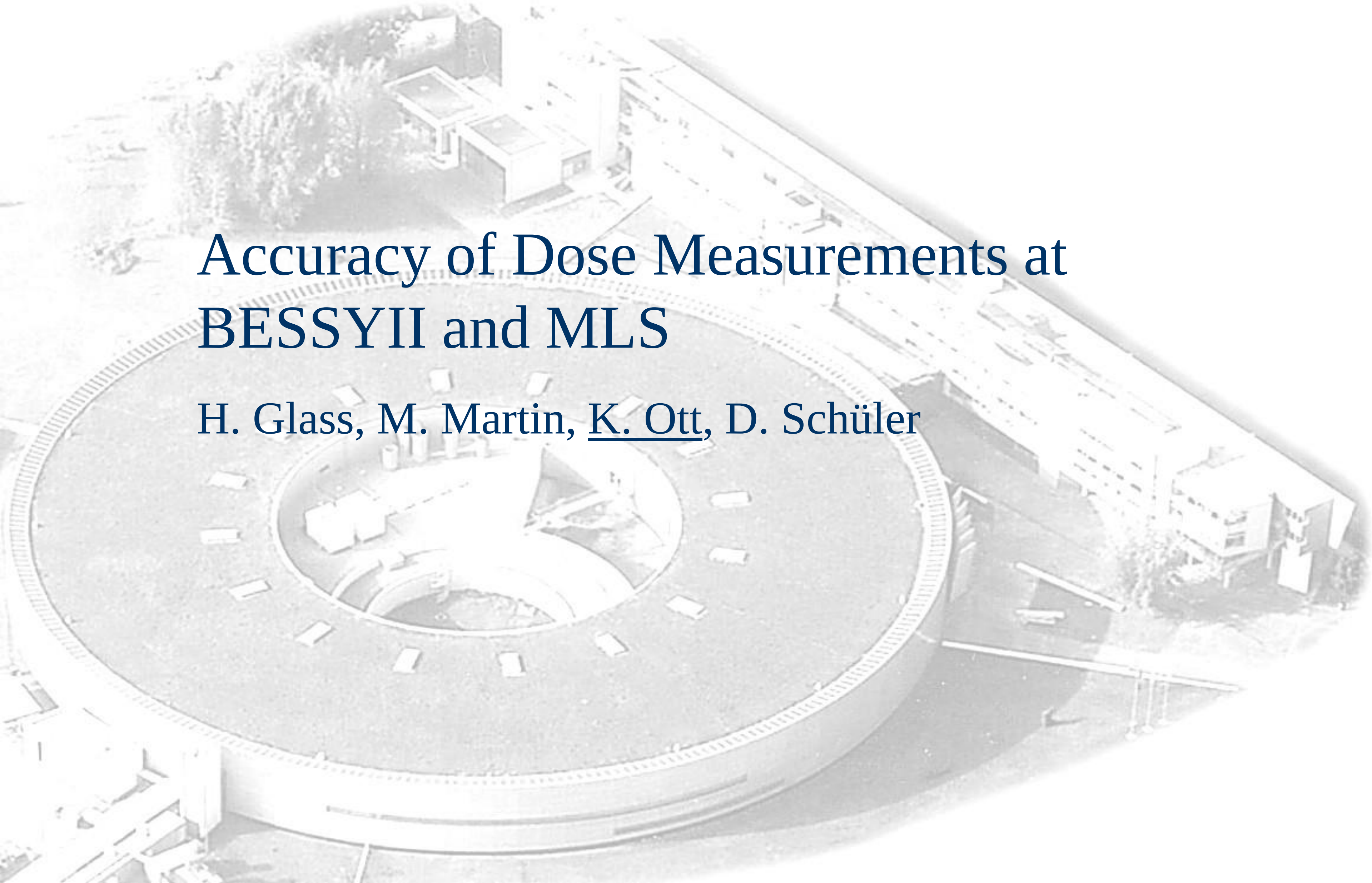


Accuracy of Dose Measurements at BESSYII and MLS

H. Glass, M. Martin, K. Ott, D. Schüler

Introduction

- BESSY and MLS preview
- Measurement system
- Neutron spectra
- Pulsed radiation
- Summary

BESSY GmbH

In numbers (2008)

Founded 1979

1982- 1999 BESSY I in Berlin - Wilmersdorf

since 1998 BESSY II in Berlin - Adlershof

since 2000 Member of the Leibniz-Society

1.1.2009 Merger with Hahn-Meitner-Institut Berlin

to Helmholtz-Zentrum Berlin

Former BESSY: 230 Employees
(90 Scientists)

Helmholtz-Zentrum Berlin für Materialien und Energie

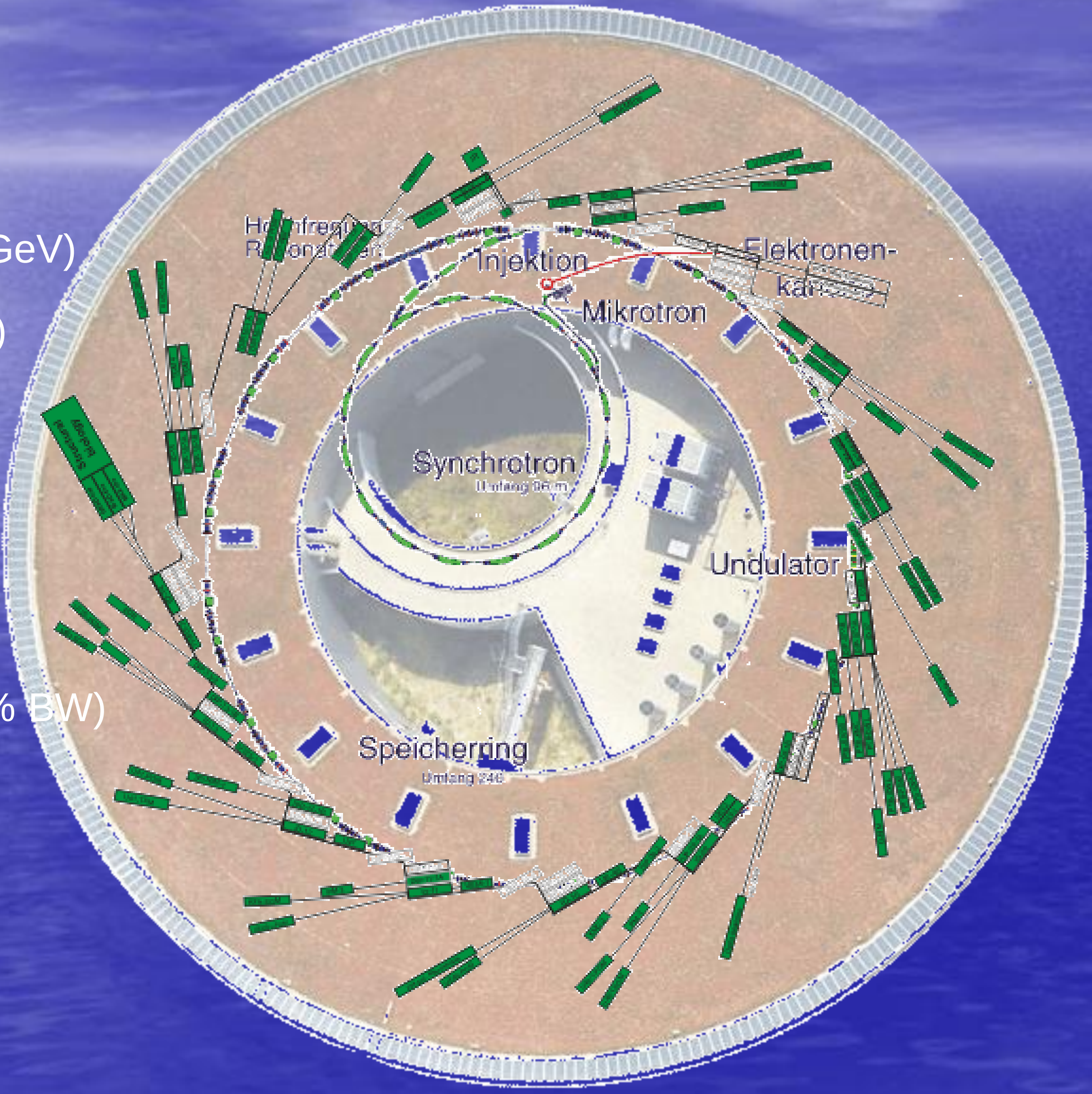
- Foundation: 1. Jan. 2009 Merger of BESSY with HMI (Hahn – Meitner – Institut, Berlin)
- 1100 employees

- Operates BESSYII , BERII (research reactor) and a cyclotron for eye-tumor therapy
- > 2500 users/a

- Scientific Program:
  Magnetic materials
  Functional materials
  Materials for solar technology
  Improvements of accelerators and reactor
  Eye-tumor therapy since 1998, 200 patients/a
  >90% successful, cooperation with Charité Berlin

- Funding 90% by German State, 10 % by Berlin

Parameter und Beamlines



Electron energy (GeV)	0.9 – 1.9
Circumference (m)	240
Emittance (mrad)	6 x 10^{-9}
Straight sections	16
ID's	14
Brilliance (Ph/mm^2/mrad^2/0.1% BW)	ca. 10^{19}
Beamlines	49

BESSY

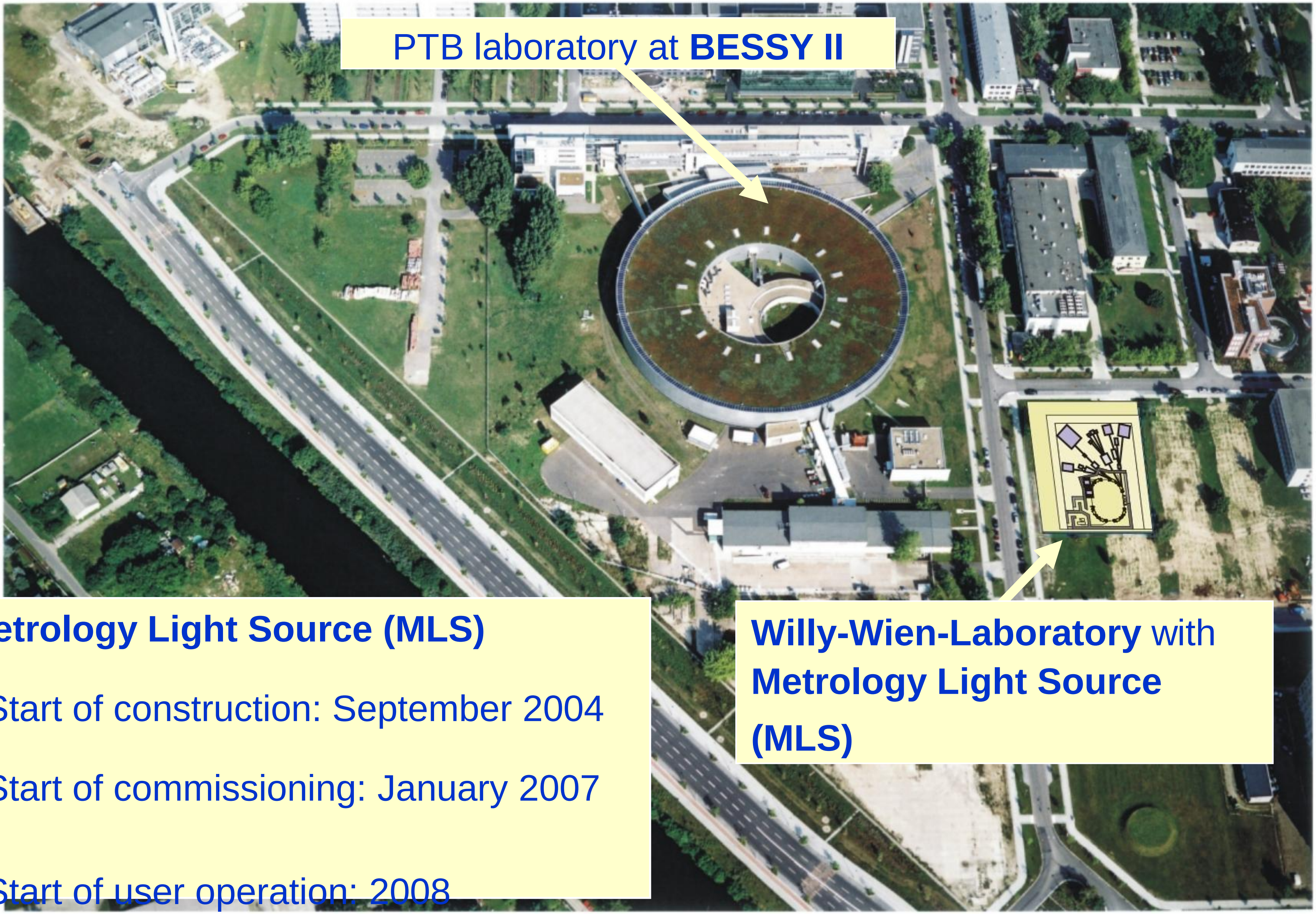
In the experimental hall

in 2009 49 Beam lines in operation

PTB in Berlin-Adlershof: Metrology with synchrotron radiation

PTB

Photon Radiometry



PTB laboratory at **BESSY II**

Metrology Light Source (MLS)

- Start of construction: September 2004
- Start of commissioning: January 2007
- Start of user operation: 2008

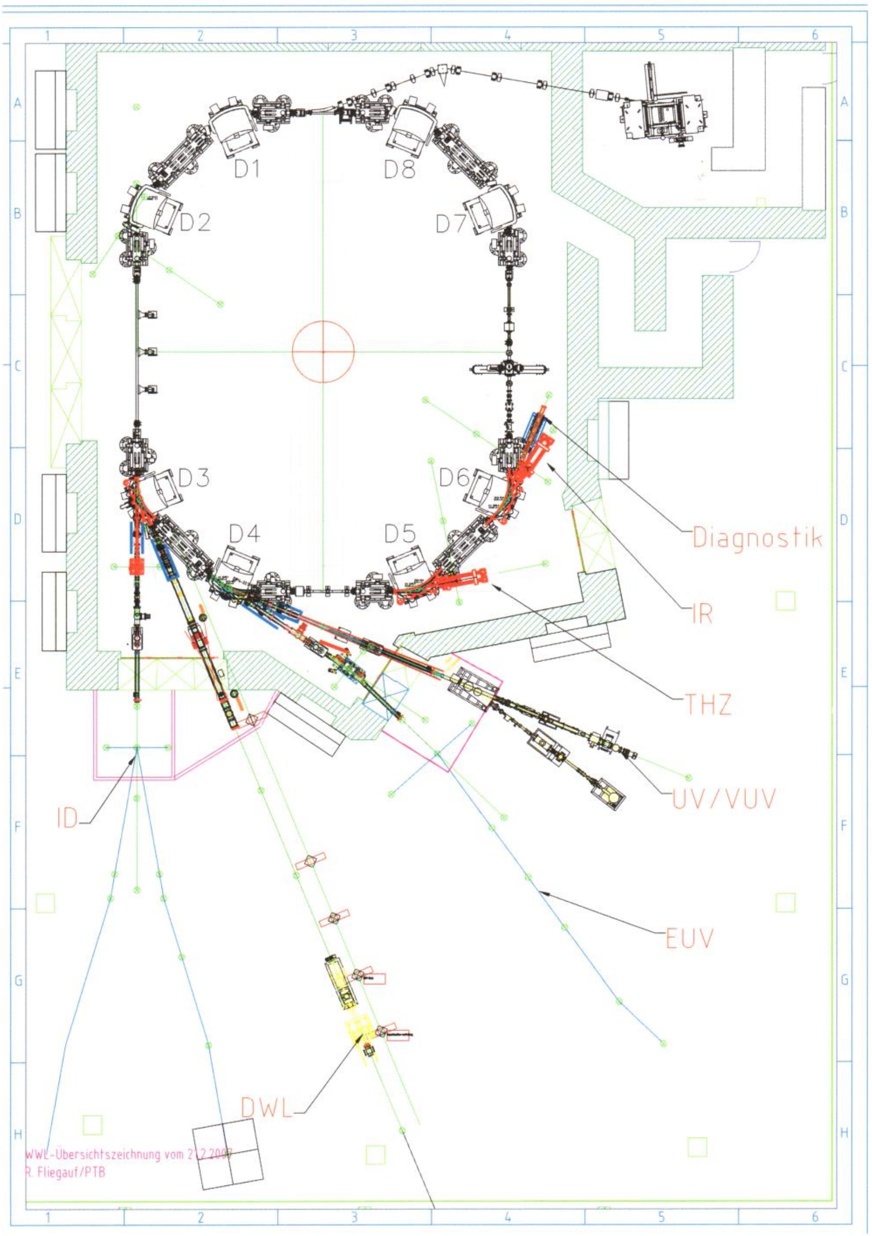
Willy-Wien-Laboratory with **Metrology Light Source (MLS)**

MLS in the Willy-Wien-Laboratory

Photon Radiometry

Metrology Light Source

Photon Radiometry



Microtron

100 MeV, <100 nA@10Hz, t_{acc}<1 µs

Storage Ring MLS

- 48 m circumference
- electron energy

  200 MeV to 600 MeV
- charact. photon energy

  12 eV to 314 eV
- beam current

  1 pA to 200 mA
- natural emittance (600 MeV)

  100 nm rad

Measurement problems at synchrotron light sources

- High energy parts of the spectrum (esp. neutrons)
- Pulsed radiation (300nsec @10Hz, BESSY)
  150nsec @10 Hz MLS)
- Pulsed radiation at low rep. rate (esp. ionisation chambers, e.g. 30mHz Top-Up)
- Radiation flashes (beam dumps with open beamshutters)

Measurement system

- Gamma / Neutrons

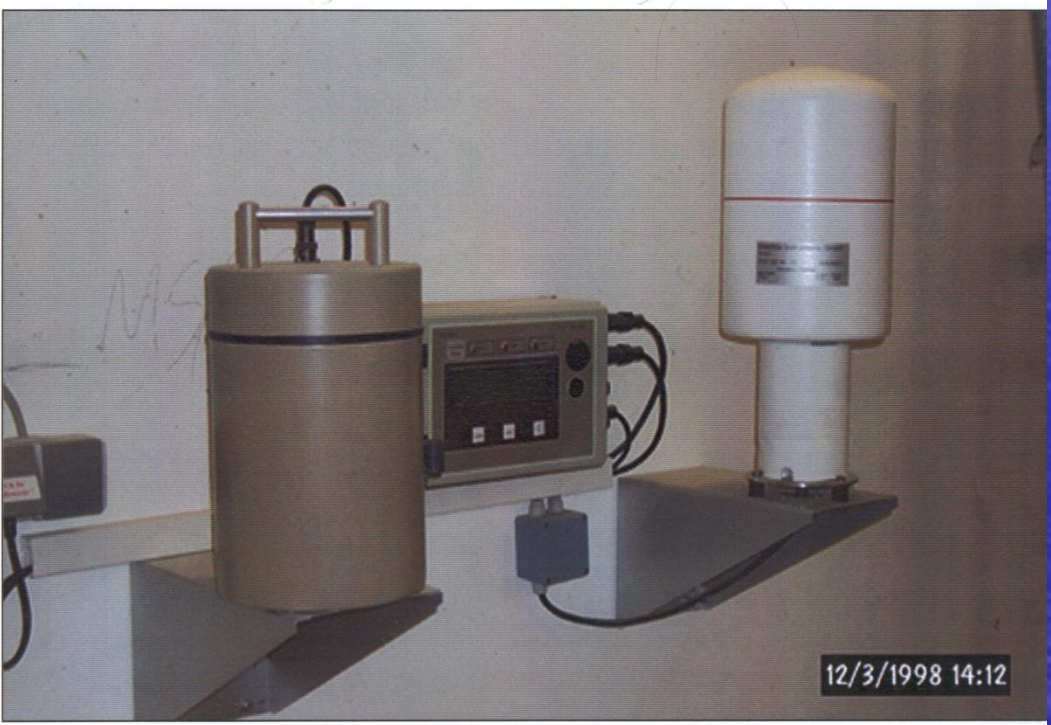
Ionisation chamber

BF3 Counter

Electronic

16 positions in E-hall

(shielding wall closest transversal distance to Storage ring)



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Ionisation chambers

Dose rates: 10 nSv/h – 10 Sv/h

(pulsed rad. 300 ns@10 Hz)

E: 35 keV – 7 MeV

600 – 900 pulses / injection

Current (fA) is measured between two synchronisation pulses by integration (U at condensor). Synchronisation times and C's range dependent .

7 Measurement ranges with synchronisation times (50, 5, 0.5,….,0.5) sec

Neutron counters

- BF3, pressure 867 mbar, 96% B10
- V = 56.1 ccm
- 0.025 eV – 10 MeV   H(*10)
- Max dose rate: 0.4 Sv/h
- Cal. Factor 1.78 µSv/h /cps
- Detection by $^{10}B(n_{th},alpha)^{7}Li$

Neutron doses from semi-empirical formulas (90°, Cu and Fe(1), Cu(2))

$$Hr^2 = 9.55\cdot 10^{-16}\cdot E\cdot e^{-d\cdot\rho/\lambda_g} + \eta_1\cdot 4.0\cdot 10^{-17}\cdot E\cdot e^{-d\cdot\rho/\lambda_h}$$

Formula 1: Sv/primary electron K. Tesch Part.Acc.9 (1979),Rad.Prot.Dos. 22,1 (1988)

$$Hr^2 = \eta_2\cdot 1.11\cdot 10^{-15}\cdot E\cdot e^{-d\cdot\rho/\lambda_g} + 1.4\cdot 10^{-17}\cdot E\cdot e^{-d\cdot\rho/\lambda_h}$$

Formula 2: Sv/primary electron Landolt-Börnstein vol11, Springer, Berlin (1990)

$$Hr^2 = a_1\cdot 10^{-16}\cdot E\cdot e^{-d\cdot\rho/\lambda_g} + a_2\cdot 10^{-17}\cdot E^{1.1}\cdot e^{-d\cdot\rho/\lambda_h}$$

$$a_1 = 2.4\cdot 10^{-17}\cdot A^{2/3}(0.33 + 0.67\cdot\sin\theta)$$

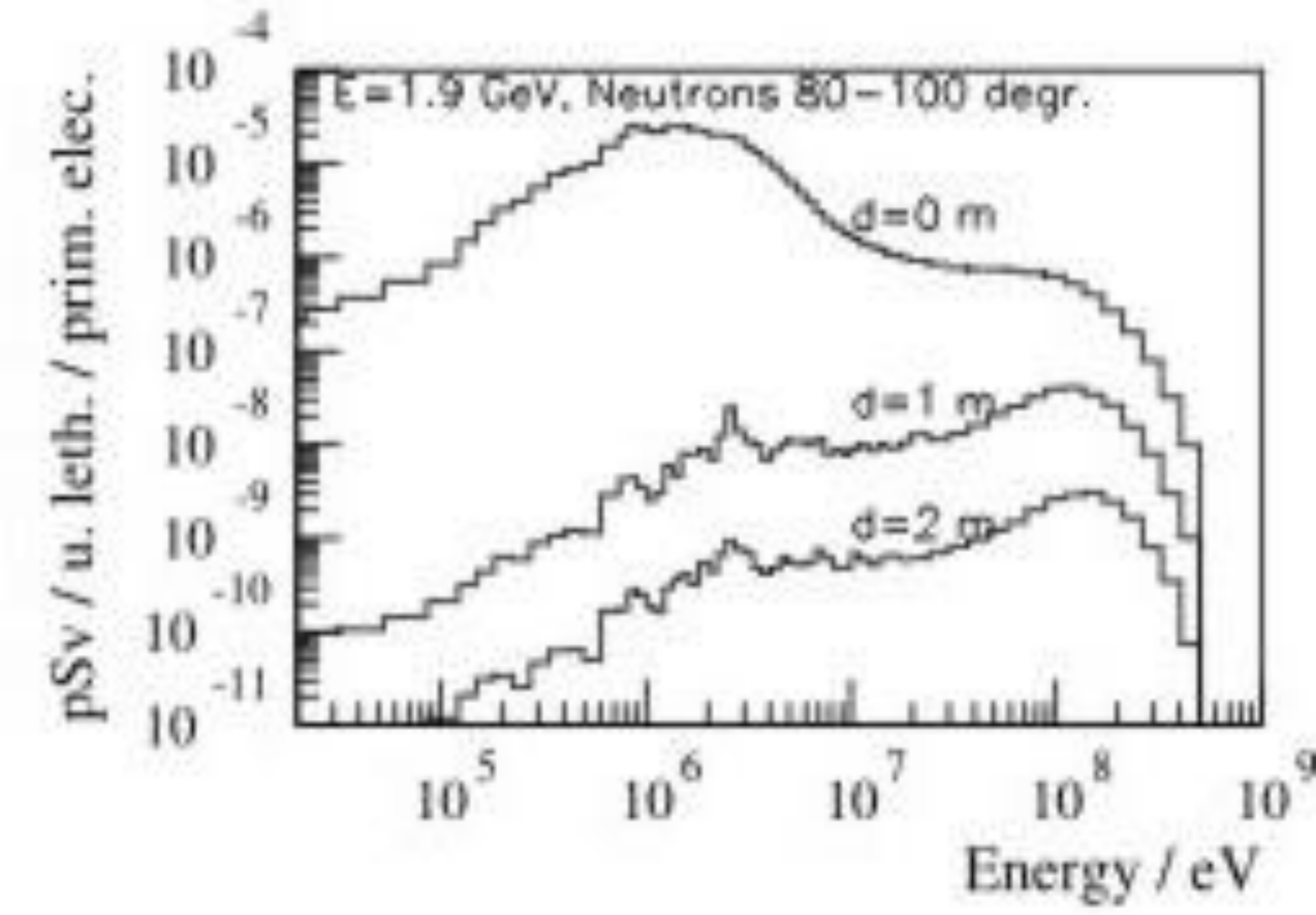
$$a_2 = 2.3\cdot 10^{-15}\cdot A^{-2/3}(0.07 + 0.93\cdot e^{-\theta/31^0})$$

$$\lambda_h = 91 + 53\cdot e^{-\theta/33^0}$$

Formula 3: Sv/primary electron H. Dinter et al NIM A 455 (2000)

FLUKA calculations of neutron spectra at thick Cu Target

- Hollow sphere
- Thick Cu Target
- Fluence to dose conv. ICRP74 H*(10)+Pell. data
- H>10/H<10 = 2.72 (1m)
  = 3.65 (2m)



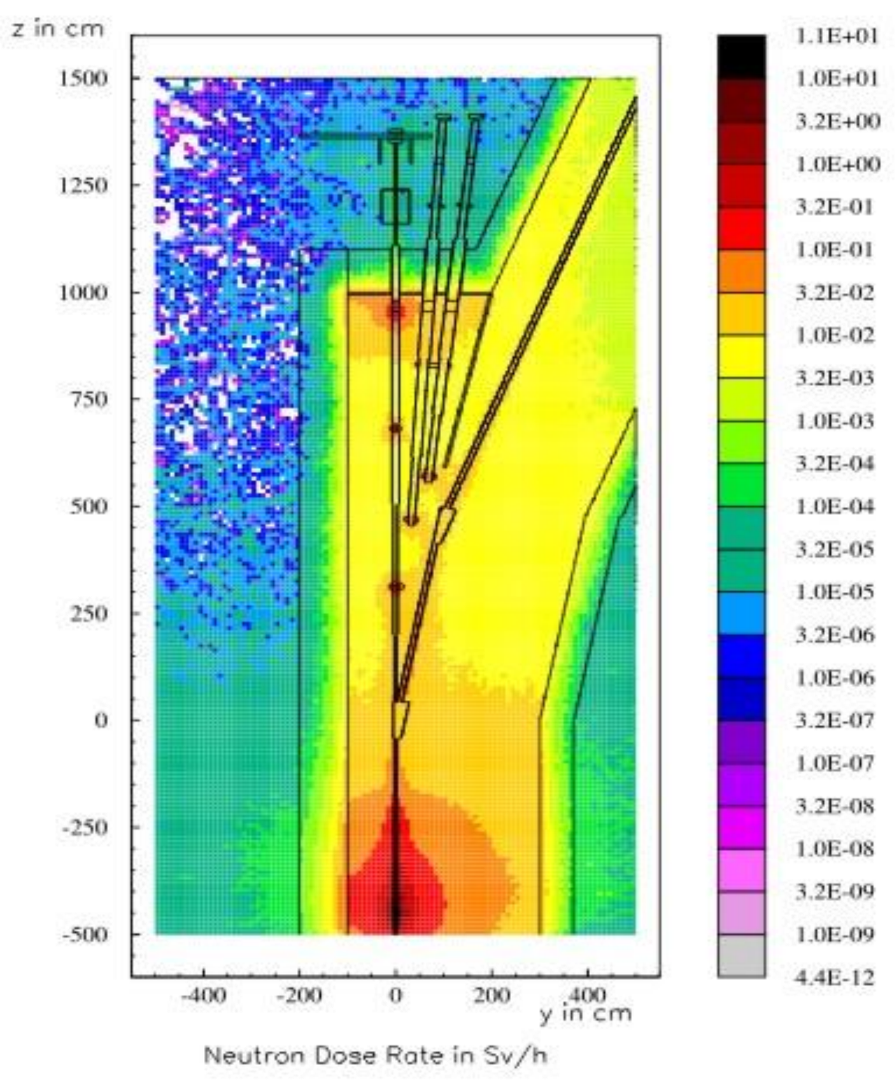
Thick Cu target, spherical geometry

d/m	H<10MeV	H>10MeV	H>10/H<10	
0	5.44E-05	2.34E-06	**0.043**	
1	2.52E-08	7.01E-08	**2.787**	
2	1.38E-09	5.05E-09	**3.653**	
d/m	HΣ	H form.1	H form.2	H form.3
1	**9.53E-08**	3.13E-07	3.48E-07	9.06E-08
2	**6.43E-09**	1.57E-08	1.17E-08	5.42E-09

Table1: Results for thick Cu target at 90°,H in pSv/prim. e-

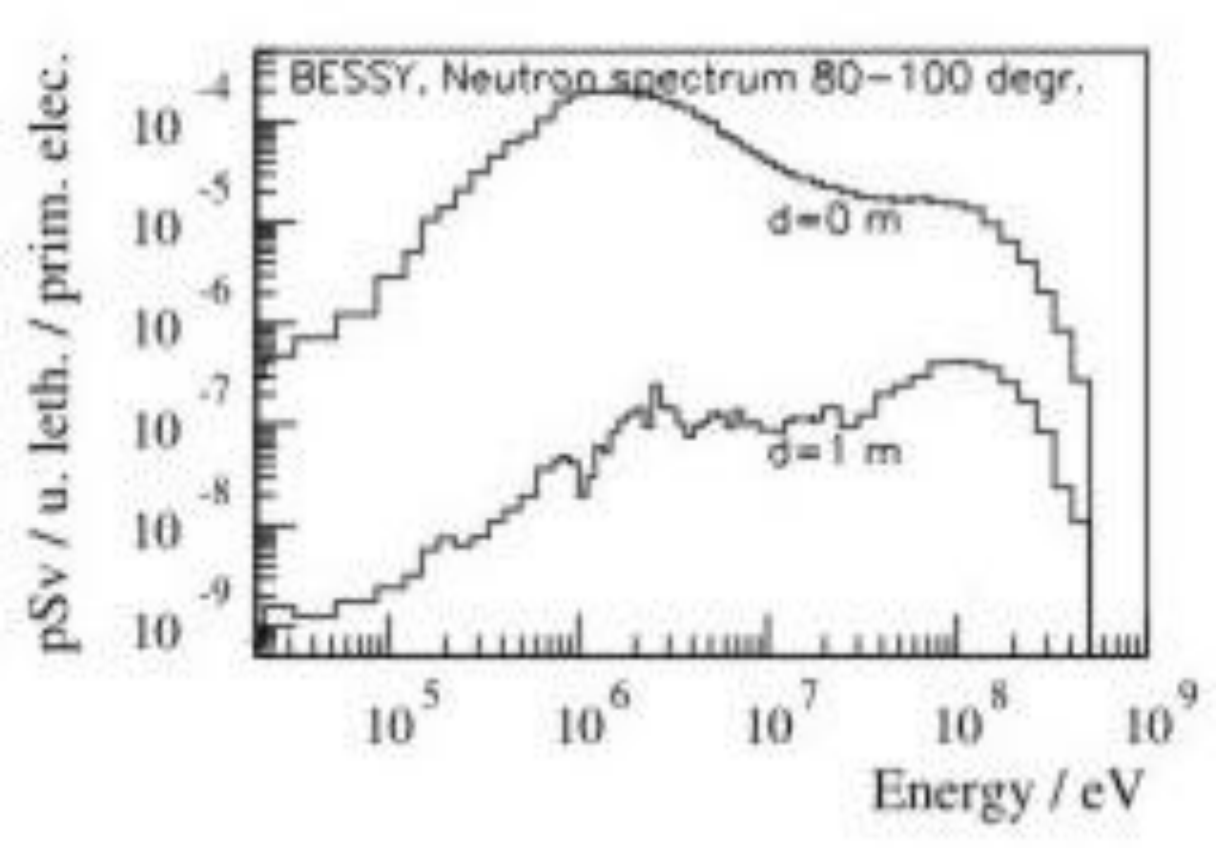
FLUKA Calculations of neutron spectra BESSY geometry

- Target: Undulator chamber Alumium, 1 mrad
- E = 1.9 GeV
- Injection
  3E+10 electrons/sec
- 100 % losses (crash)



Neutron spectrum Al-target

- Real Al Target BESSY undulator chamber 1.7GeV
- Fluence to dose conv. ICRP74 H*(10) +Pell. Data
- H>10/H<10 = 2.64



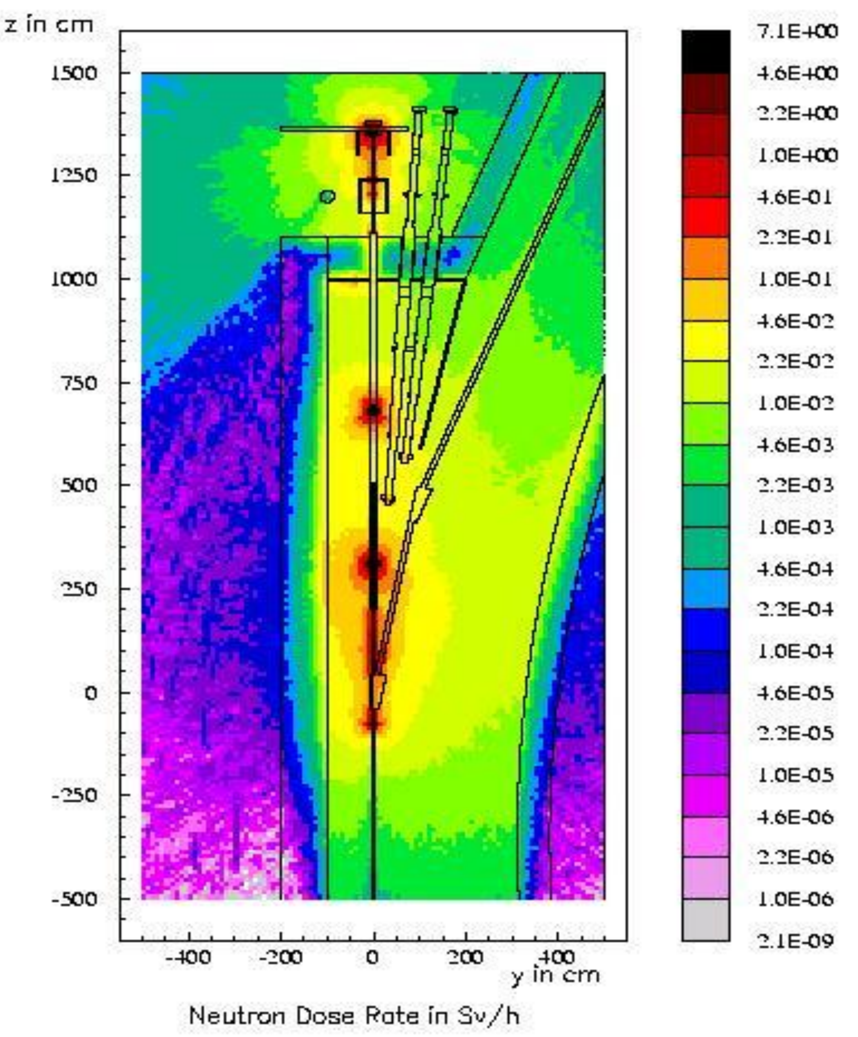
Al target, undulator vac. chamber, angle=1 mrad, BESSY geometry

d/m	H<10MeV	H>10MeV	H>10/H<10	
0	4.55E-04	5.61E-05	0.123	
1	2.85E-07	7.53E-07	2.637	
d/m	HΣ	H form.1	H form.2	H form.3
1	**1.04E-06**	4.98E-06	2.53E-06	**1.40E-06**

Table2: Results for thick Al target at 90°,H in pSv/prim. e-

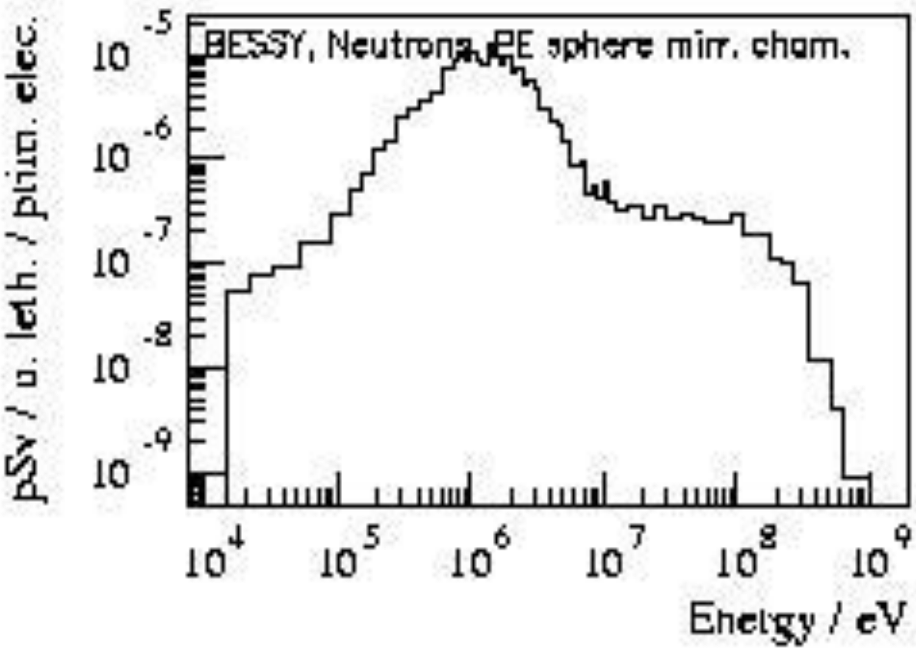
FLUKA calculations of neutron spectra BESSY geometry sc.2

- Target: dipole chamber Fe, 1 rad. length
- E = 1.9 GeV
- Injection
  3E+10 electrons/sec
- 100 % losses (crash)



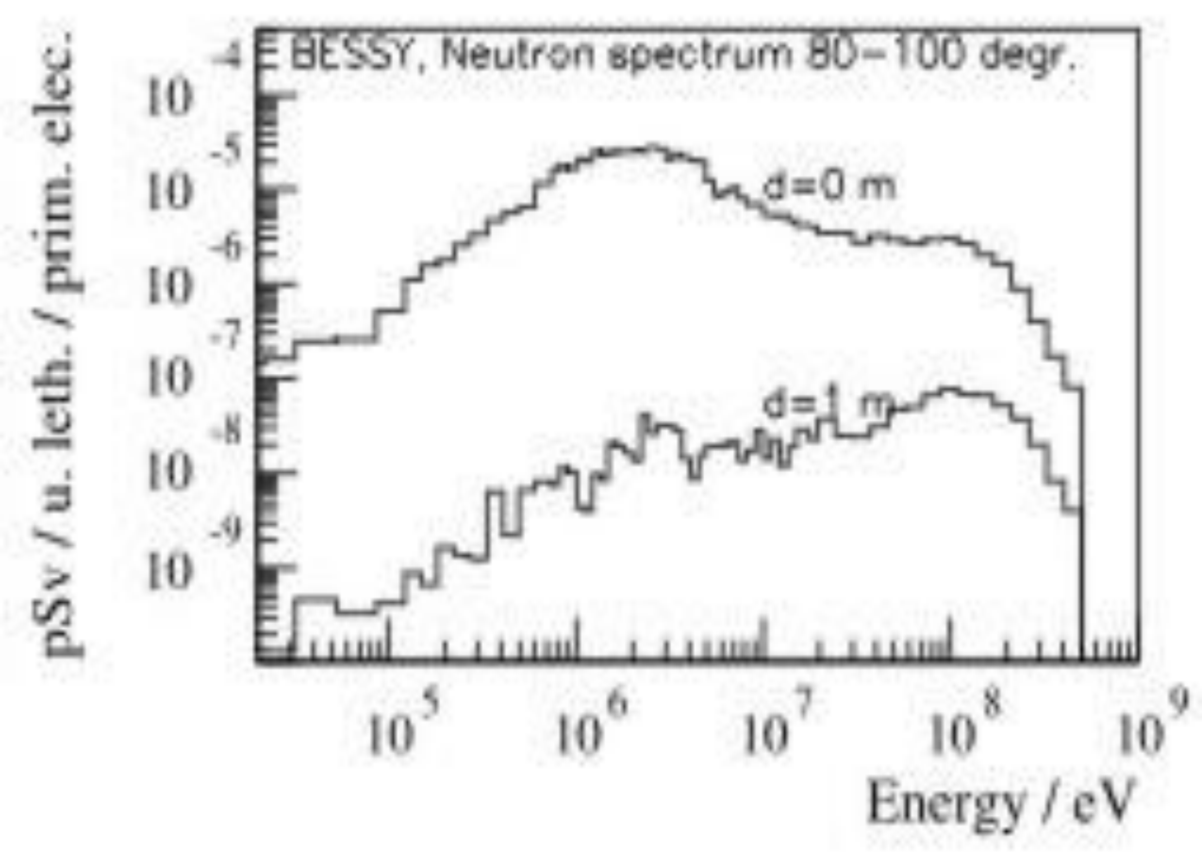
Neutron spectrum at PE sphere

- Thin Fe target
- Opened BS
- Besides mirror chamber
- H>10/H<10 =0.043



Neutron spectrum thin Fe target

- Thin Fe Target BESSY dipole chamber 1.9 GeV
- Fluence to dose conv. ICRP74 +Pell. Data, H*(10)
- H>10/H<10 = 2.66



Thin Fe target, dipole vac. chamber, angle=5.6°, 2 cm, BESSY geometry

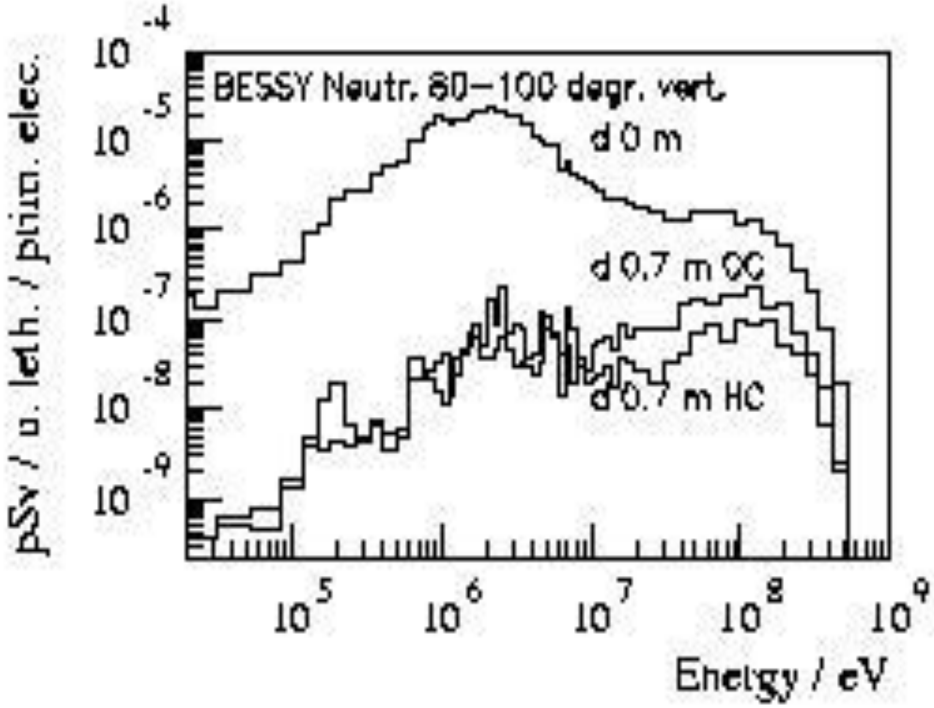
d/m	H<10MeV	H>10MeV	H>10/H<10	
0	5.94E-05	9.75E-06	**0.164**	
1	5.38E-08	1.43E-07	**2.655**	
d/m	$H\Sigma$	H form.1	H form.2	H form.3
1	**1.97E-07**	2.82E-06	2.53E-06	**8.89E-07**

Table2: Results for thin Fe target at 90°,H in pSv/prim. e-

Neutron spectra from thin Fe target at storage ring tunnel roof

- Thin Fe target BESSY dipole chamber 1.9 GeV
- Fluence to dose conv. ICRP74 +Pell. data, H*(10)

- H>10/H<10 = 2.00 (OC)
- H>10/H<10 = 1.56 (HC)



Thin Fe target, dipole vac. chamber, angle=5.6°, 2 cm, sr. tunnel roof

d/m	H<10MeV	H>10MeV	H>10/H<10	
0	5.94E-05	9.75E-06	**0.164**	
0.7 OC 0.7 HC	2.02E-07 1.12E-07	4.05E-07 1.78E-07	**2.006** 1.582	
d/m	HΣ	H form.1	H form.2	H form.3
0.7 OC 0.7 HC	**6.07E-07** 2.90E-07	6.54E-06 1.25E-06	6.57E-06 -	**1.29E-06** -

Table2: Results for thin Fe target at 90°,H in pSv/prim. e-

Neutron shielding

- Formula 3 agrees best with Fluka calculations, BUT no HC values given.
- For thin targets formulas 1 and 2 should be used with a target efficiency factor of 0.1 for BOTH terms
- Heavy concrete reduces high energy neutrons better than ordanary concrete

Pulsed Radiation for Rad. Monitors

- Not pulsed (continuous): radiation with time structure of RF systems at accelerators (e.g. 500 MHz, 3 GHz etc)
- Pulsed: $f < 1/t_{dead}$ or $f < 1/t_{pulsewidth}$ (e.g. 20 kHz for Studsvik neutron monitor)
- Pulsed: single shots (e.g. flash from beam dump, X-ray shooting in hospitals etc.)

Correction formulas for Pulsed Radiation (prop. counters)

- Continuous radiation

  $R_{true} = R_{meas} /(1 - R_{meas} * t_{dead})$

- Pulsed radiation (t$_{acc}$ < t$_{dead}$)

  G. F. Knoll (1999): $R_{true} = -f * \ln(1 - R_{meas} / f)$

  Taylor series 1. order

  $R_{true} = R_{meas} /(1 - R_{meas} / f)$

  Only 1 event / acc. pulse can be counted

  Not dependent of acc. pulse width t_{acc}

  Not dependent of detector dead time t_{dead}

Correction formulas 2 (prop. counters)

- Neutrons are stored in the moderator
  $t_{neu} > t_{acc}$
- Pulsed radiation ($t_{dead} < t_{neu}$)
  $R_{true} = R_{meas} /(1 – R_{meas} * t_{dead} / (f * t_{neu}))$
  Dose rate loss from
  $R_{meas} / R_{true} = 1 – R_{meas} * t_{dead} / (f * t_{neu})$

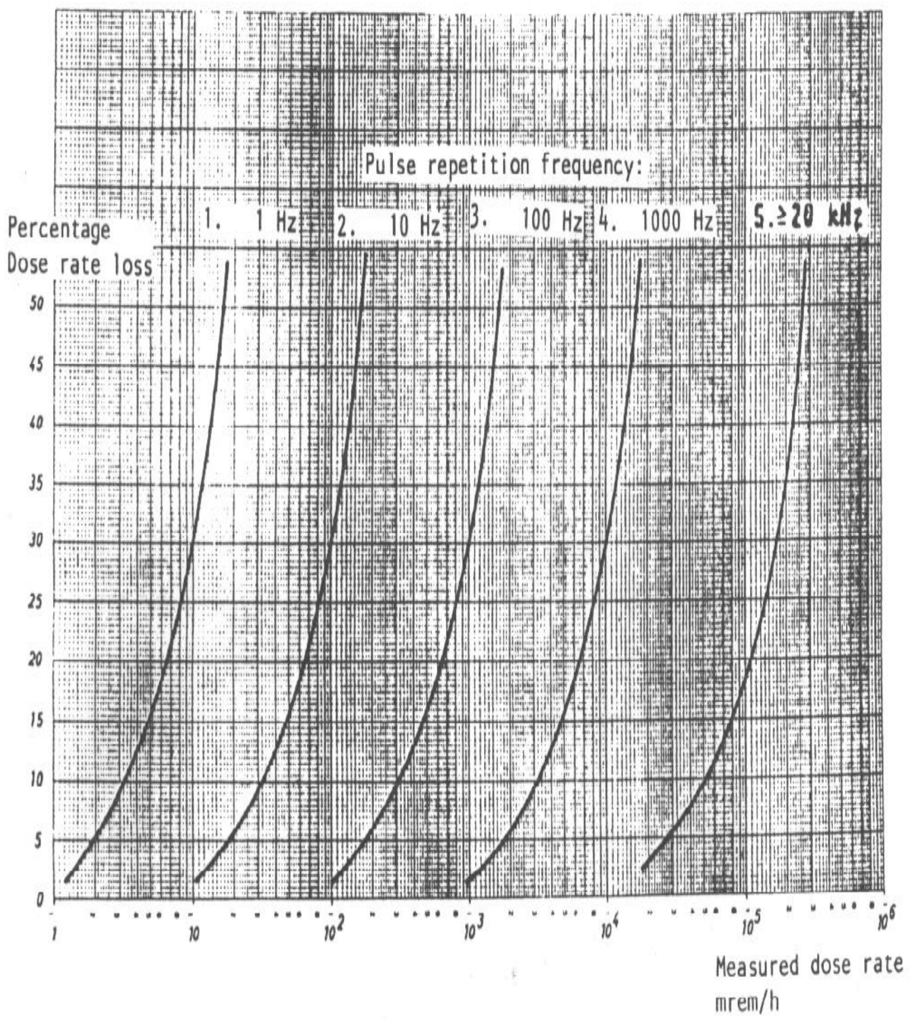
BF3 A-B counter Studsvik dead time effects pulsed rad.

- PDrl = $c*dH_{meas}/dt * t_{dead} / (f * t_{neu})*100\%$
- c = 3.3 cps/(mrem/h)
- Curves with t_{dead}=0.5 µs and t_{neu}= 50 µs

BUT:

- Max dose rate 10000 mrem/h
- Max rate =33000 cps
- t_{dead} = 30.3 µs
- Max dose rate @10 Hz (PDrl =20%)

1 mrem/h = 10 µSv/h



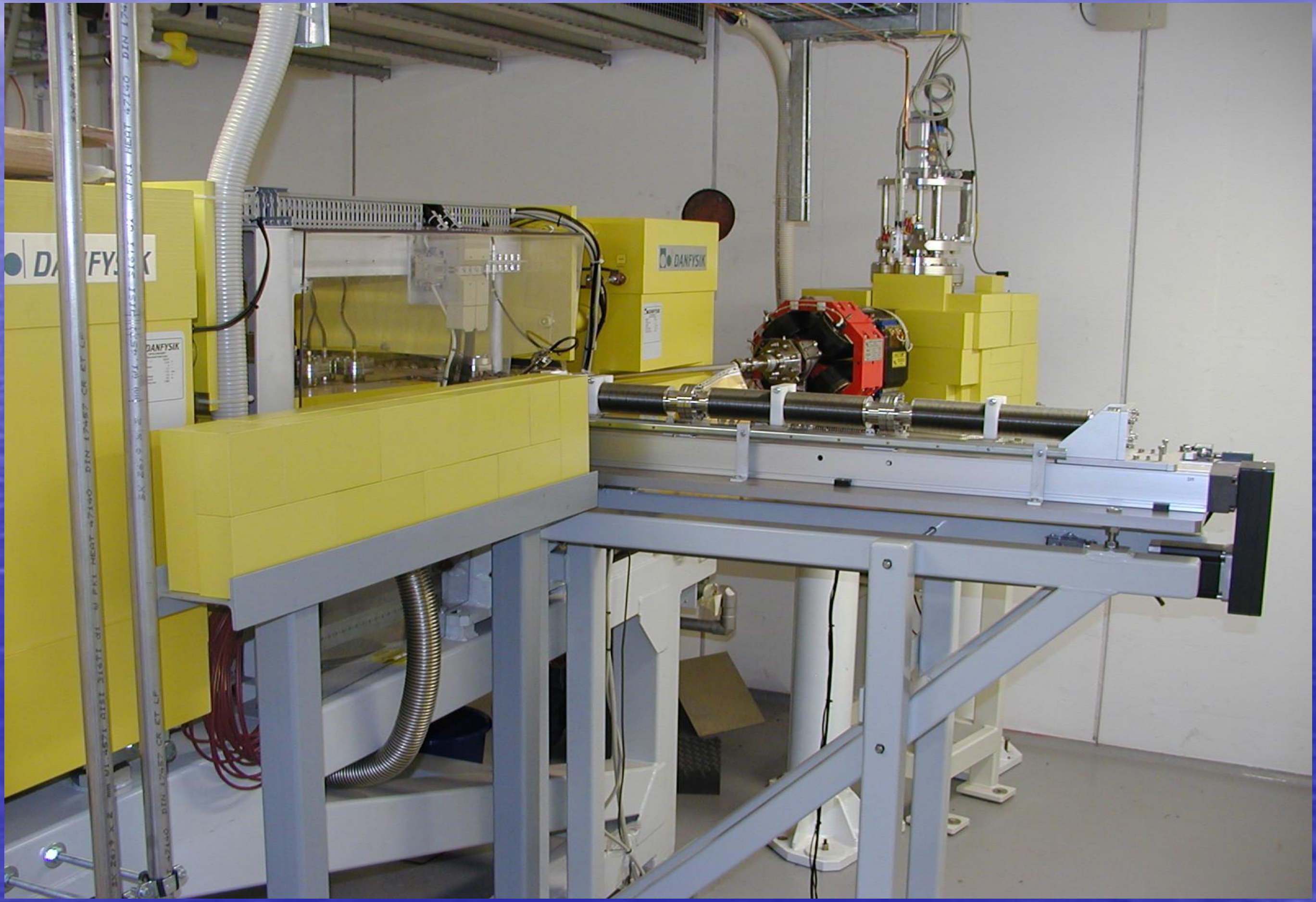
BF3 A-B counter Thermo (Biorem) dead time effects pulsed rad.

- Max dose rate: 400000 µSv/h
- c = 1.78 (µSv/h)/cps
- Max rate = 224719 cps
- t_{dead} = 4.45 µs
- t_{neu} = 50 µs ??
- PDrl = $(dH_{meas}/dt) / c * t_{dead} / (f * t_{neu}) * 100\%$
- Max dose rate @10 Hz (PDrl =20%) =

  40 µSv/h ??

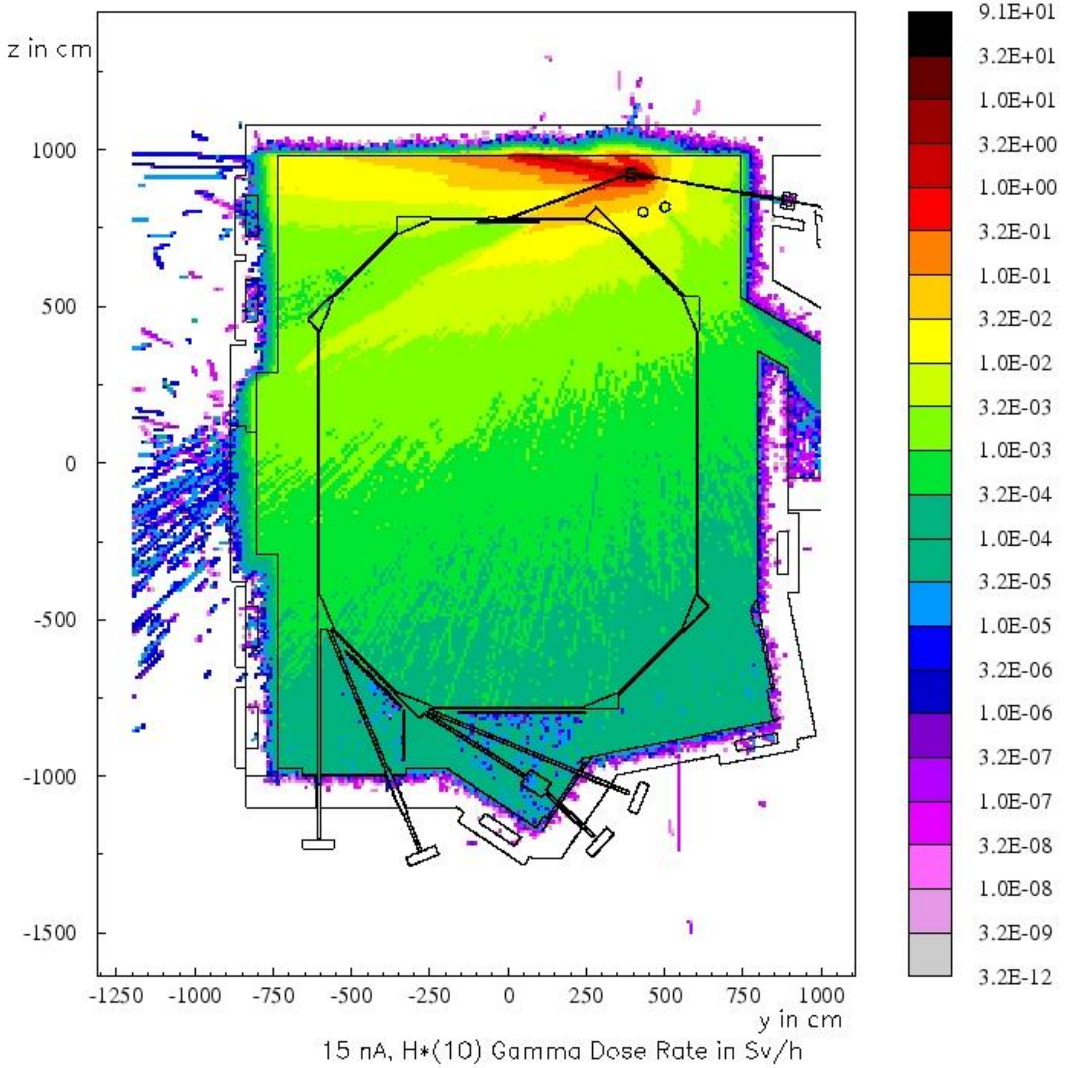
MLS Microtron

- 100 MeV
- 10 mA in Pulse (10 Hz)
- 1 µs P.width
- 100 nA DC
- Gun 80 kV
- 300 mA in Gun pulse (10 Hz)
- 5 µs Gun P. width
- 15 µA DC



Fluka Simulation of Experiment Gamma Rad.

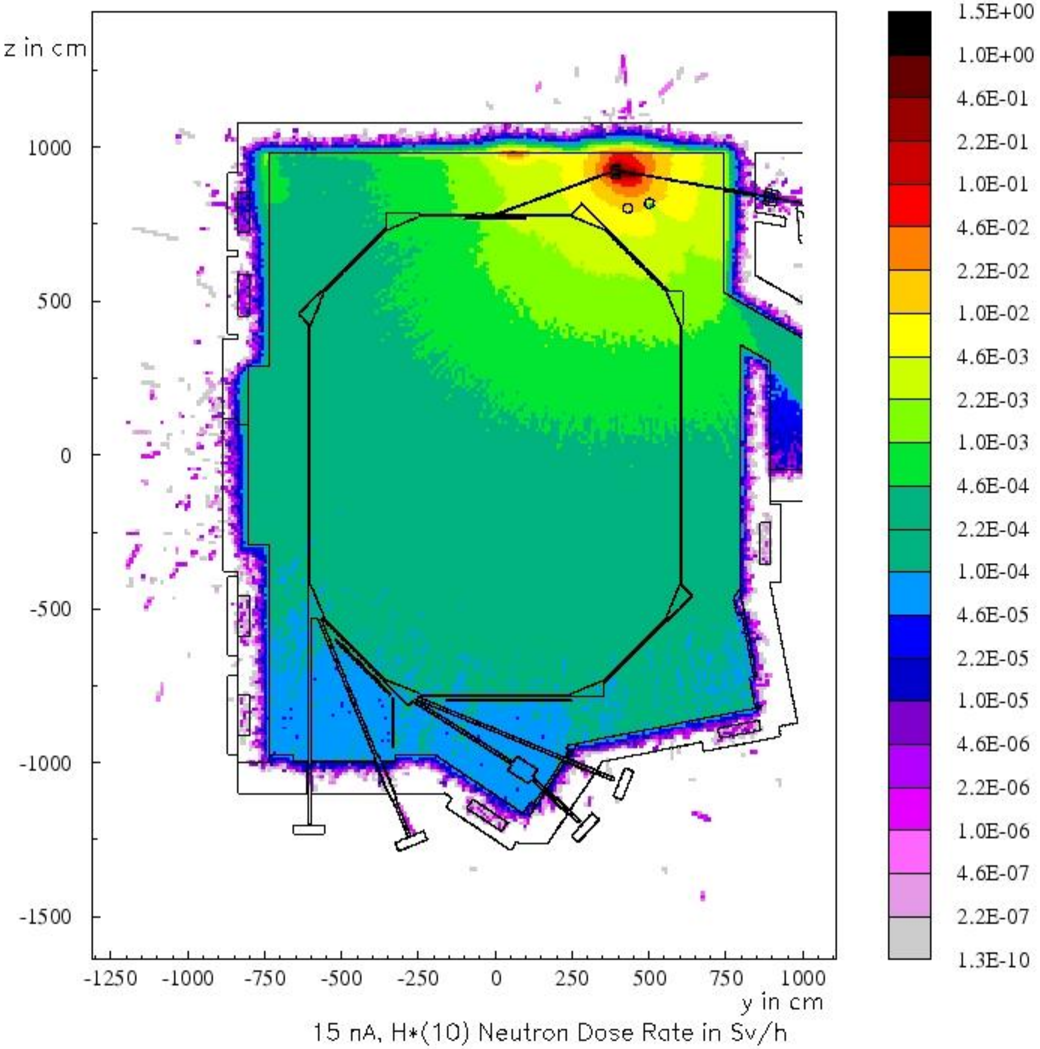
- 100 MeV /15 nA
- 10 Hz
- Closed FOM (Al target 2 cm)
- 1 m distance Biorem to FOM
- H*(10)
- Detailed magnet yoke
- Dose rate at I-chamber (left) <32 mSv/h



15 nA, H*(10) Gamma Dose Rate in Sv/h

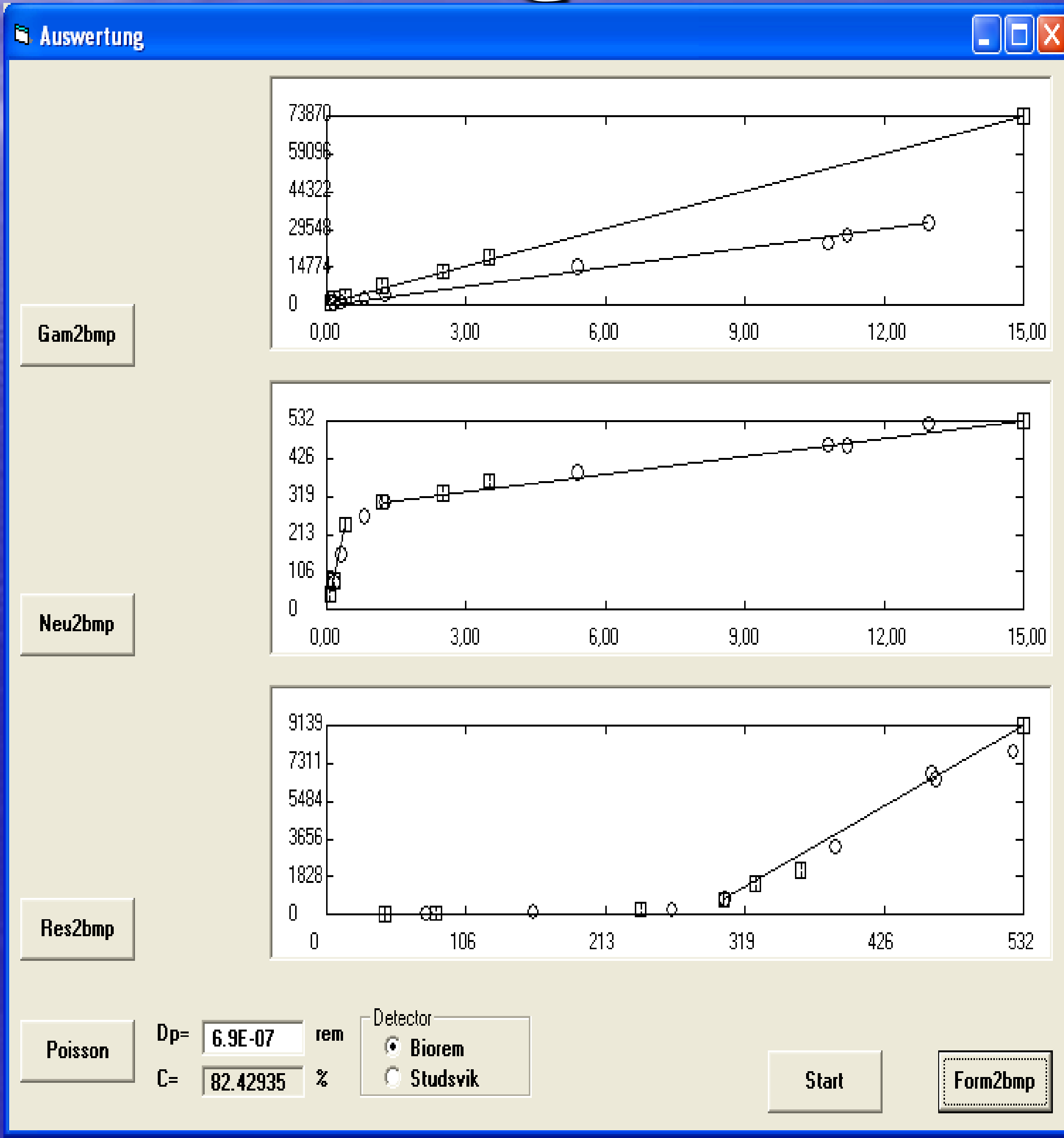
Fluka Simulation of Experiment Neutron Rad.

- 100 MeV /15 nA
- 10 Hz
- Closed FOM (Al target 2 cm)
- 1 m distance Biorem to FOM
- H*(10)
- Detailed magnet yoke
- Neutron detector 30 cm PE ball (right)
- Dose rate < 10 mSv/h



Neutron measurements@MLS

- Gamma measurements linear up to 74 mSv/h (10 Hz)
  Circles: 2nd series, change in I-chamber pos. to reduce gamma-rad
- Neutron measurements linear up to 250 µSv/h (10 Hz) =**6.9 nSv/acc. pulse**
  Not dependent from t_{acc}
- At 532 µSv/h true dose rate already 9.14 mSv/h
  Current <15 nA
- Not dependent from f and pulse width just dose/acc pulse
  t_{neu} must be > 50 µs



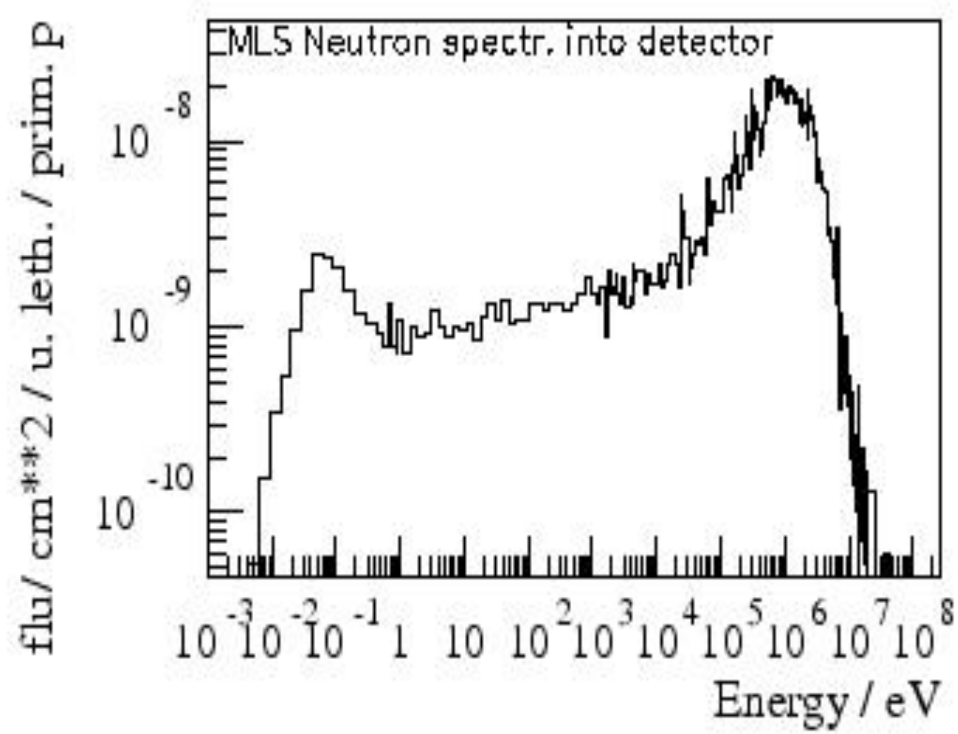
Dp= 6.9E-07 rem

C= 82.42935 %

Detector
● Biorem
○ Studsvik

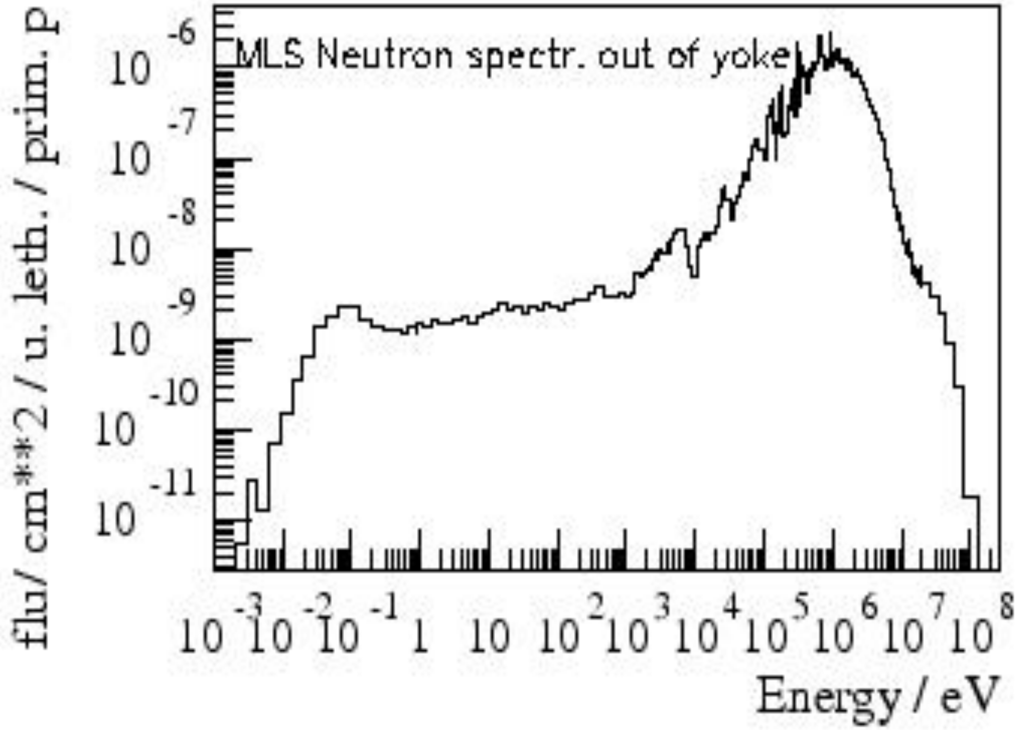
Neutron spectrum @ detector

- 100 MeV
- 1 m distance to FOM
- 30 cm PE sphere
- No counting losses due to high energy neutrons (>10 MeV)



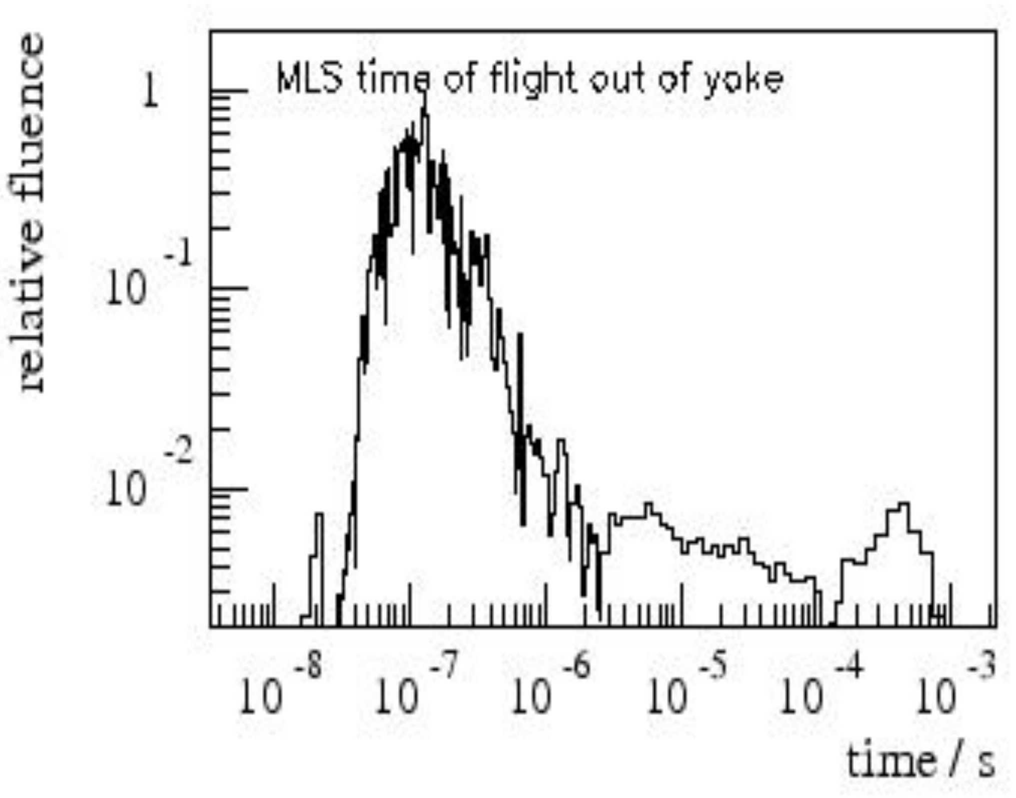
Neutron spectrum out of yoke

- 100 MeV
- 1.4 m distance to Neutr. detector
- No counting losses due to high energy neutrons
- 1 MeV to thermal 3 orders of magnitude



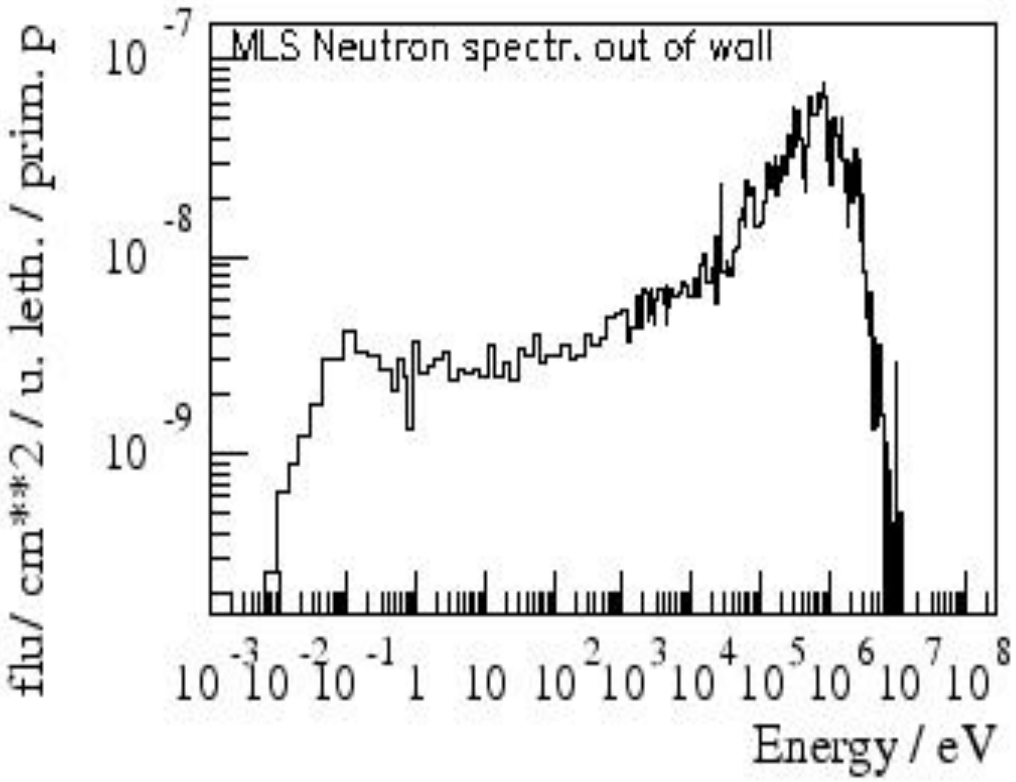
Time of flight from yoke to detector

- 1.4 m distance to detector
- Yoke is main neutron source
- 99 % of the neutrons are in the moderator within 1 t_{dead}



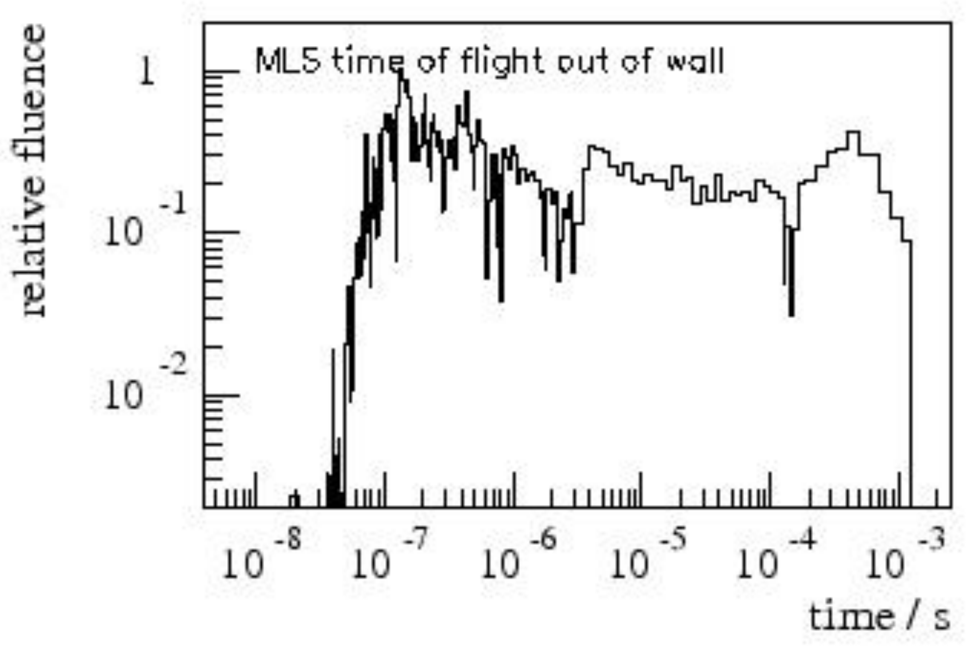
Neutron spectrum out of wall

- Circular area 80° - 100° rel detector
- 1.6 m distance to neutron detector
- 30 cm PE sphere
- 1 MeV to thermal only one order of magnitude



Time of Flight from Wall to Detector

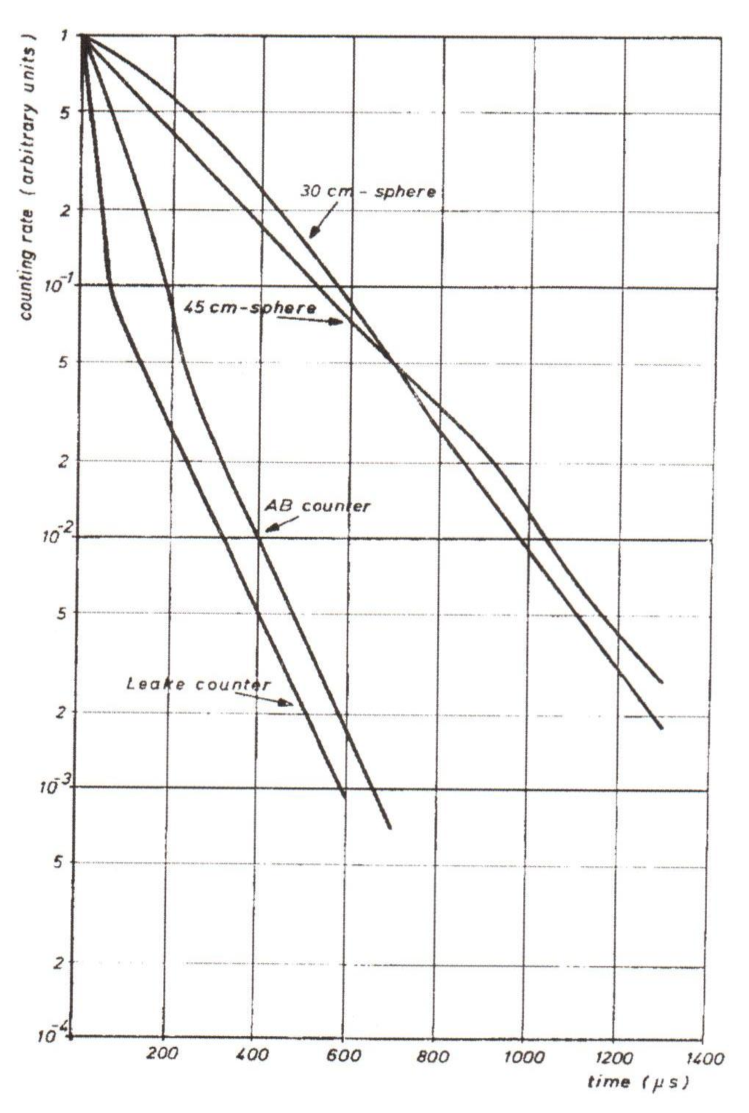
- 100 MeV
- 1.6 m distance to FOM
- 30 cm PE sphere
- No counting losses due to high energy neutrons (>10 MeV)
- Neutrons of wall reach detector up to msec after acc. Pulse
- Fluence out of wall is about 2 orders of magnitude lower than fluence from yoke



Delay inside the moderator

Dinter, Tesch

- Moderation from 1 MeV to 1 eV in 1 μs, to thermal Energies 5 μs
- 1/10 val time ~ Volume of moderator
- AB counter
  1/10 val time1 180 μs
  1/10 val time2 224 μs
- Usage for Poisson distribution



Delay inside the moderator

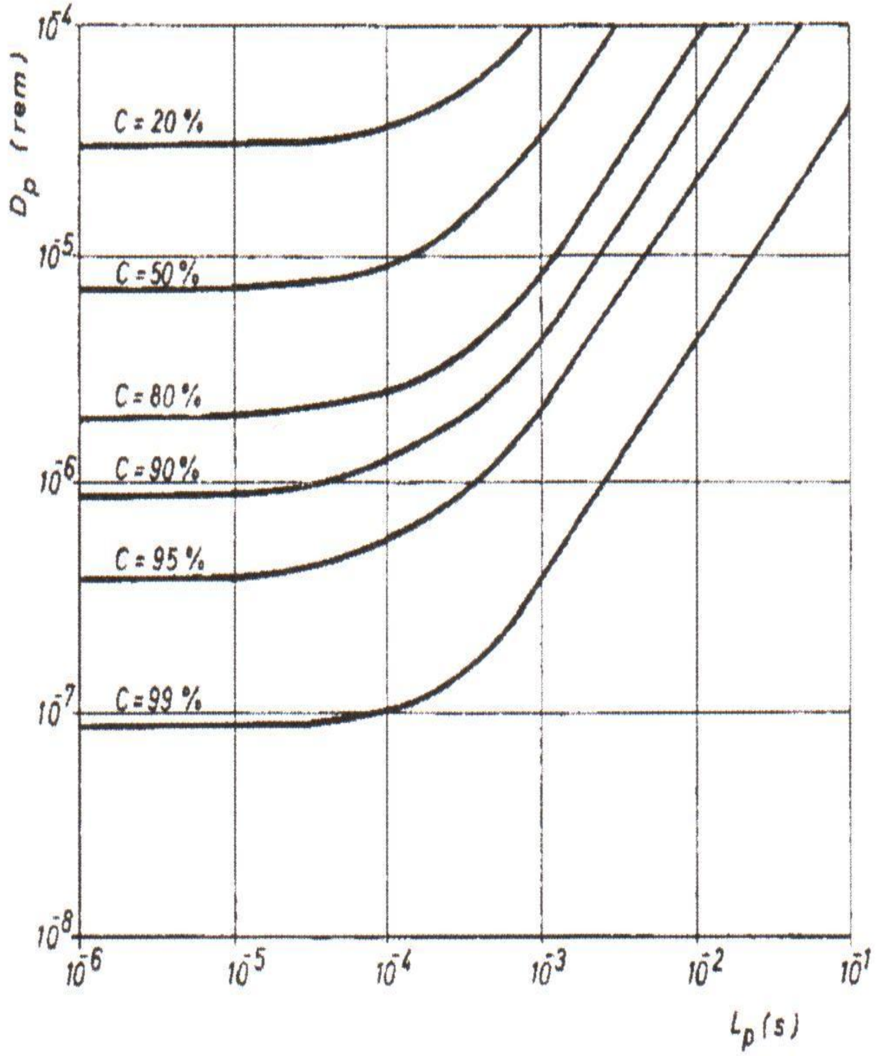
Dinter, Tesch

- Moderation from 1 MeV to 1 eV in 1 µs, to thermal Energies 5 µs
- Poisson Calculation AB Cnt.

  Dp=10 nSv, 1µrem,n=200
  t_{dead} 4 µs C=86 %
  t_{dead} 30 µs C=44 %
- Poisson Calculation Biorem

  Dp=6.9 nSv, n=200

  t_{dead} 4.45 µs C=84 %



Correction formula Biorem

$dH_{meas}/dt\ /\ dH_{true}/dt$

$= 1 - cal * dH_{meas}/dt * t_{dead} / (f * t_{neu})$

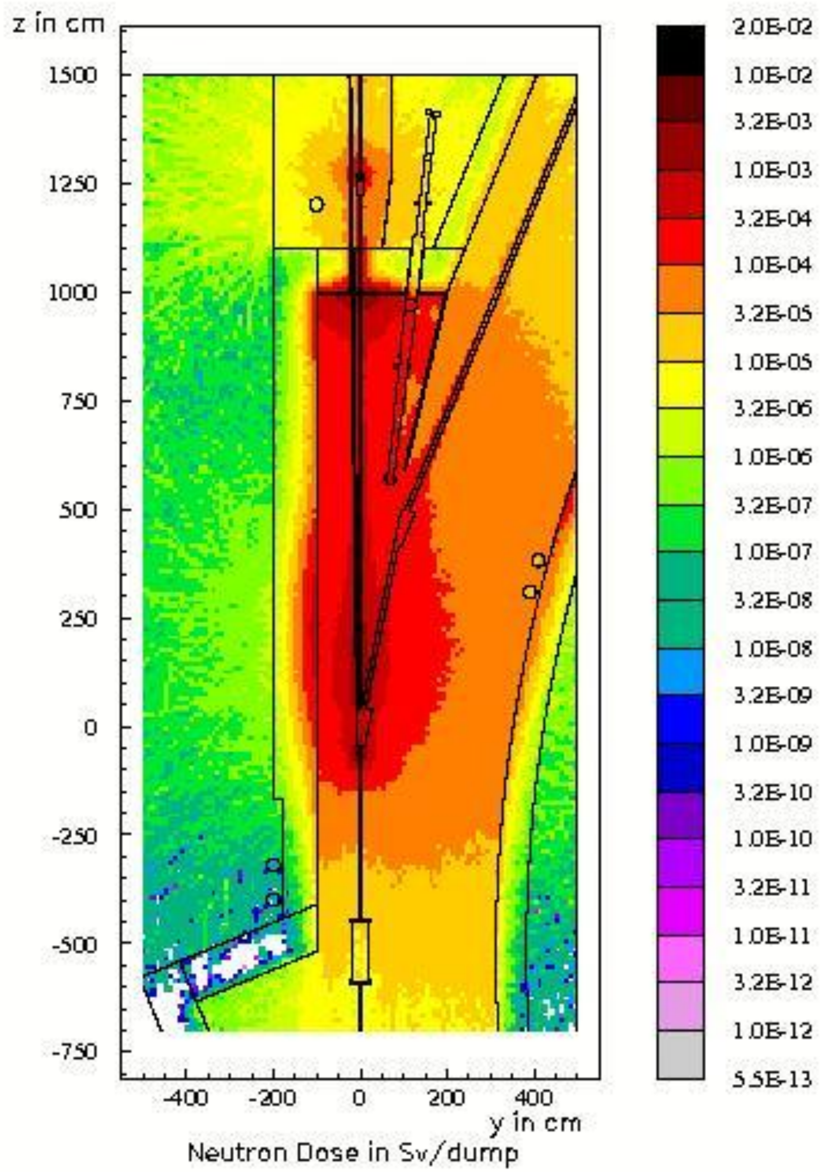
with t_{neu}= 356µs, cal=1 cps /1.78(µSv/h),

t_{dead}=4.45µs

Neutron dose by beamdump

- Target: iron 2cm (dipole chamber half deflection angle)
- E = 1.9 GeV
- Storage ring filling 1E+12 electrons
- About 32 µSv/dump 100 µSv/a (50/16)
- For 32 µSv/dump

  C=0.27% ->86 nSv/dump measured



Summary Neutron spectra

- Calibration factors for undetected high energy neutrons derived
- At d = 1 m we get H10+/H10- 2.65 as mean value. Calibration factor: 3.65
- At d = 0.7 (roof and inner side wall) we get H10+/10- 2.00 (OC) and 1.55 (HC). Calibration factors: 3.00 and 2.55
- Agreement is best with semi-emipirical formula 3 (Dinter, Leuschner et al 2000) with thick targets and OC. (No HC parameters given)
- Semi-empirical formulas for neutrons of Tesch and Landolt-Börnstein should be corrected by the factor of 0.1 (BOTH terms) if the target is thin (< one radiation length)
- Annual dose limit <1 mSv in the accessible part of the experimental hall is still hold
- Usage of calibration factors accepted by our state authority

  (LAGetSi) = Landesamt für Arbeitsschutz, Gesundheitsschutz and technische Sicherheit

Summary Pulsed Radiation

- 6.9 nSv/acc. pulse limit for Biorem, correction formula derived. I-chamber linear up to 74 mSv/h (@10 Hz), no error due to gamma radiation
- At BESSY neutron dose rates > 250 µSv/h (@10 Hz) outside the shielding wall are only possible at crash operation during injection and >90% electron losses close to the detector.
- Error of annual dose < 10% for BESSY, no error for MLS.
- Shielding BESSY 1 m OC, 1 m HC ratchet end wall. At thin walled SR light sources error for annual dose can be considerable due to undetected neutron dose rates at injections.

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Thank you