Activation of Targets and Accelerator Components at PSI

- a Comparison of Simulation and Measurement

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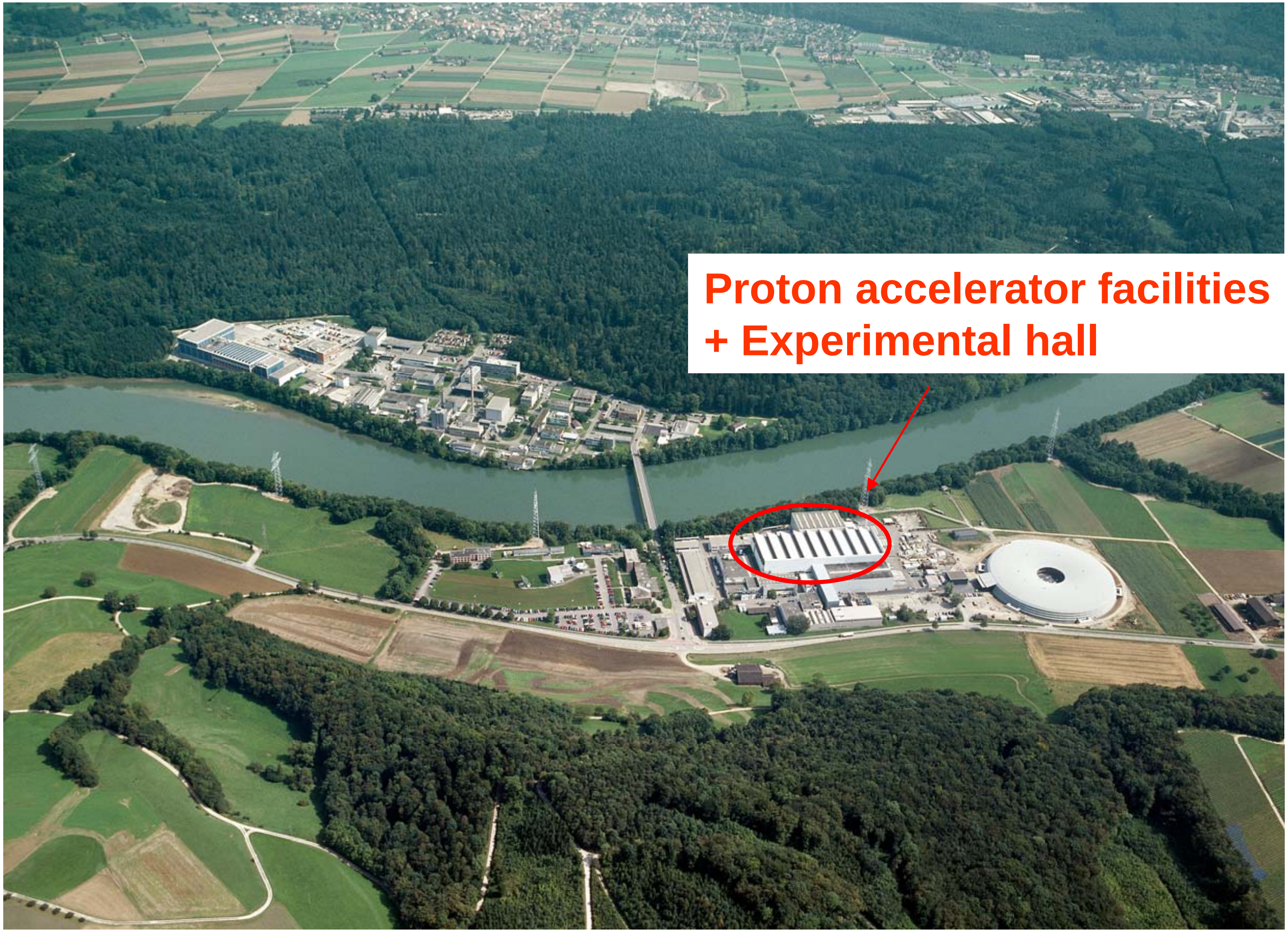
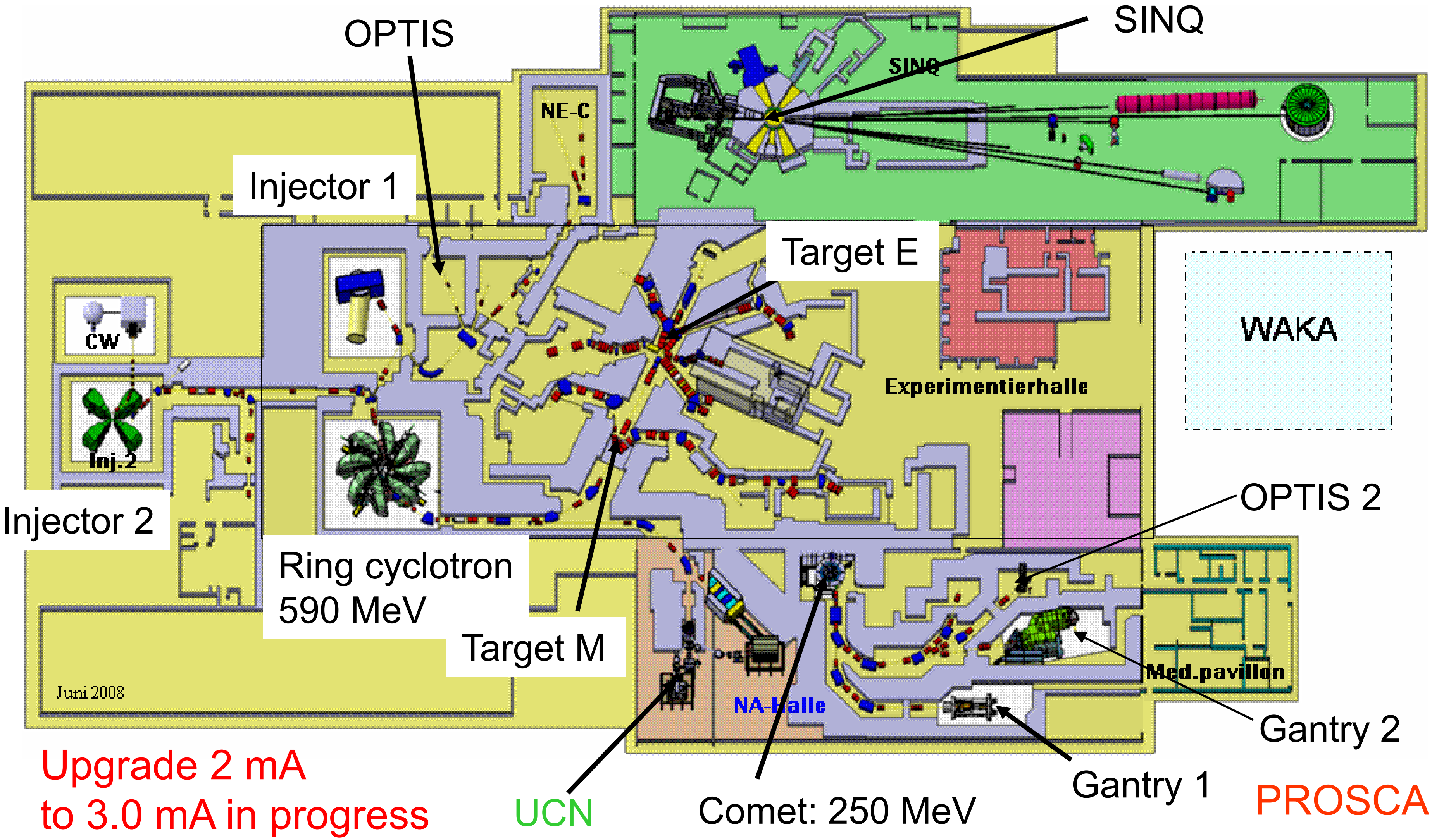
Contents:

- Overview of PSI
- Nuclear reactions
- Codes used at PSI to calculate nuclide inventories, dose rates
- Applications:
  1) Nuclide inventory in samples around SINQ target 3
  2) Dose rates along SINQ target 4
  3) Dose rates at the PIREX beam line
  4) Nuclide inventory in samples from the μE4 beam line
- Comparison of the 2 calculational methods
- Summary

Birds view of the Paul Scherrer Institut (PSI)



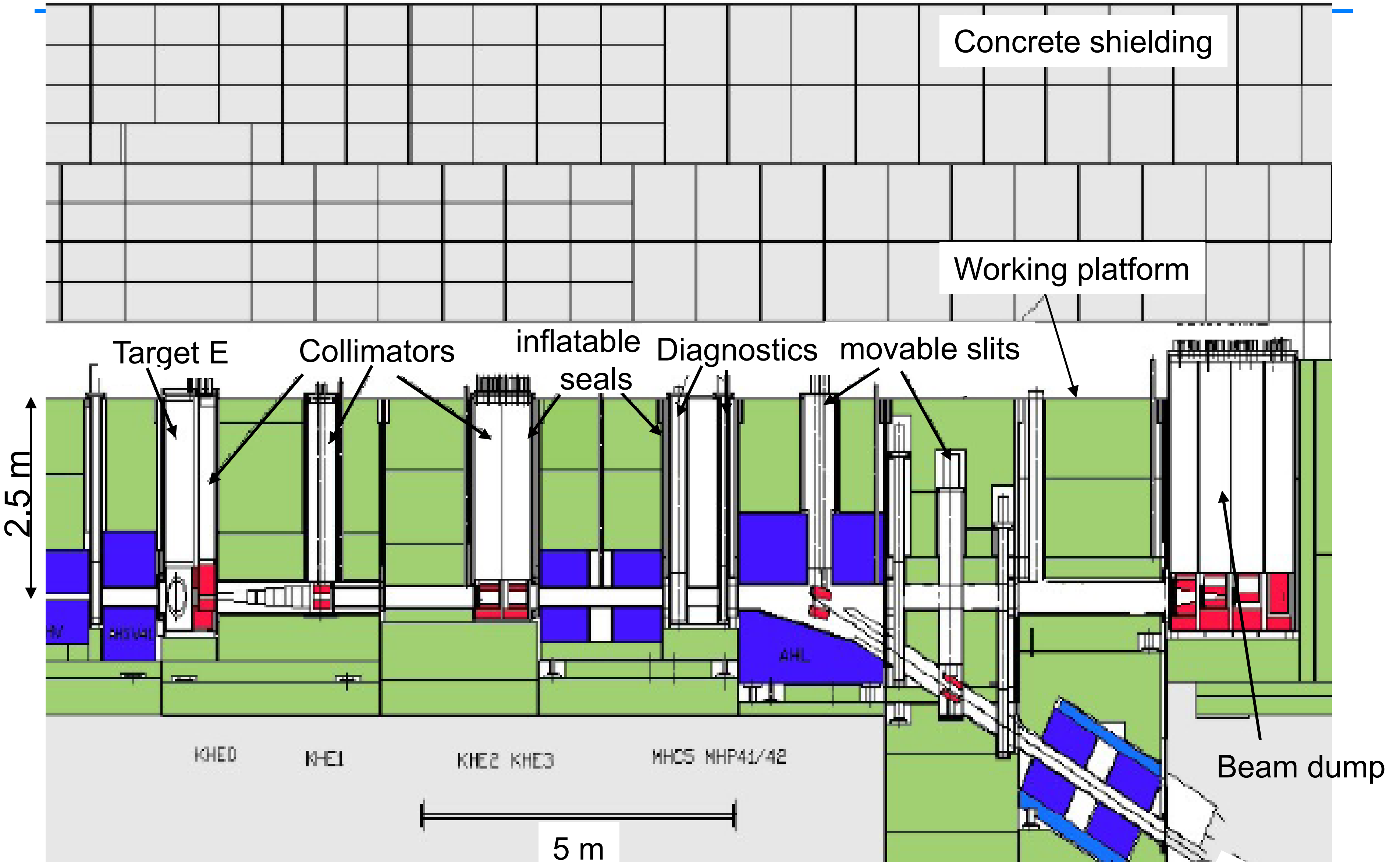
PSI Proton Accelerator Facilities



Upgrade 2 mA
to 3.0 mA in progress

PROSCAN

Beam line from Target E to beam dump (side view)



All beam line components are surrounded by iron shielding.

Components around beam line get activated
... need to be removed eventually

- for replacement → waste
  Nuclide inventory needed before disposal as required by swiss authorities

- for repair/dismantling → planning of work procedures
  dose rate estimation needed

in addition:
for future (planned) installations/facilities:
- estimation of the amount of total waste after operation
- dose rates needed for construction of shielding

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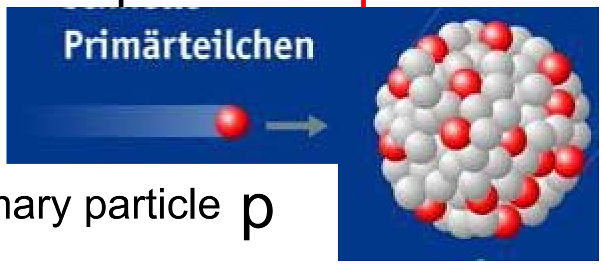
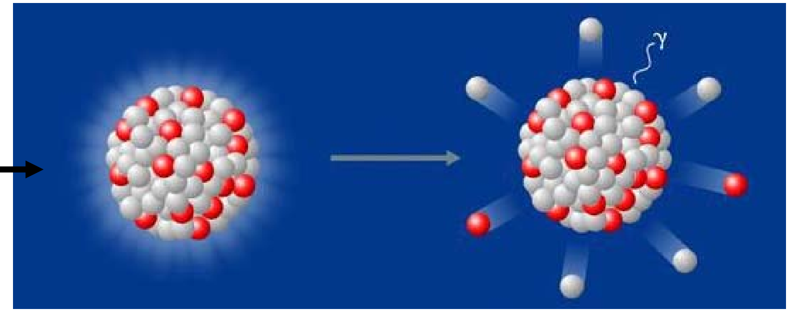
Activation due to

1) Direct irradiation (590 MeV p): at loss points (target, collimators)

main process: spallation



primary particle p



highly excited nucleus spallation

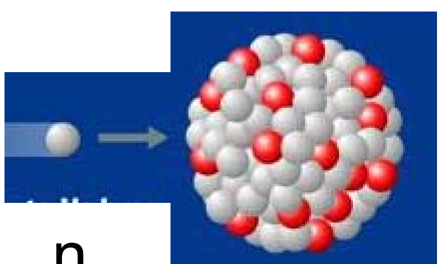
Evaporation of protons, neutrons, also ^{2}H, ^{3}H .. ^{4}He

2) Secondary particle fields:

after penetration of shielding: mainly neutrons,
thermalized in shielding material
→ equilibrated energy spectrum

important process: neutron capture at thermal energies,

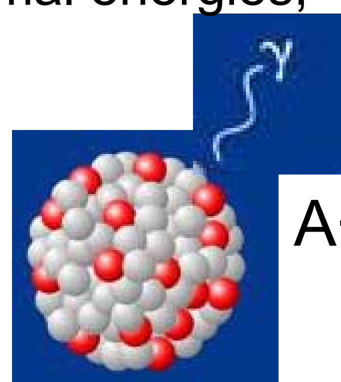
e.g $^{59}Co(n,\gamma)^{60}Co$, $^{107}Ag(n,\gamma)^{108m}Ag$



n

A

excitation



A+1

Calculation of the Activation

case 1: mainly due to primary irradiation

Monte Carlo particle transport program **MCNPX** : n,p,γ,α,π,d,^{3}H....

Input: dedicated geometry, material compositions,
cross sections: for n<20MeV ENDF-B-VI.6, otherwise models

Output: n-fluxes (E<20 MeV), residual nuclei production rates

via Perl script

decay codes: **Cinder'90** or **SP-Fispact** or **Orihet3**

Input: irradiation and cooling history
cross sections: Cinder library, EAF 2003
decay properties of isotopes

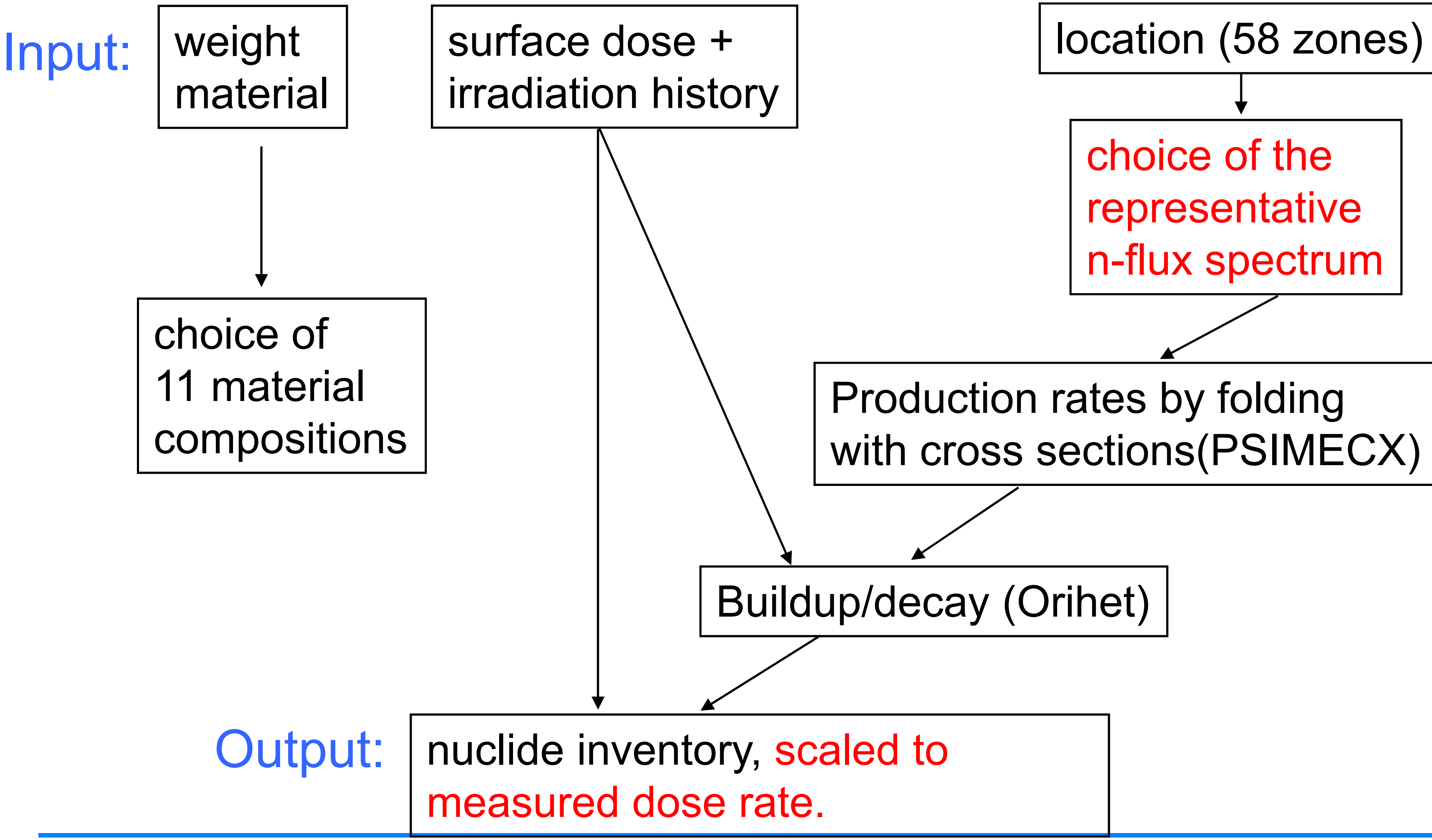
Output: nuclide inventory, photon rate

via Perl script

used as γ–source in **MCNPX** → dose rate

case 2: mainly due to secondary particles → PWWMBS

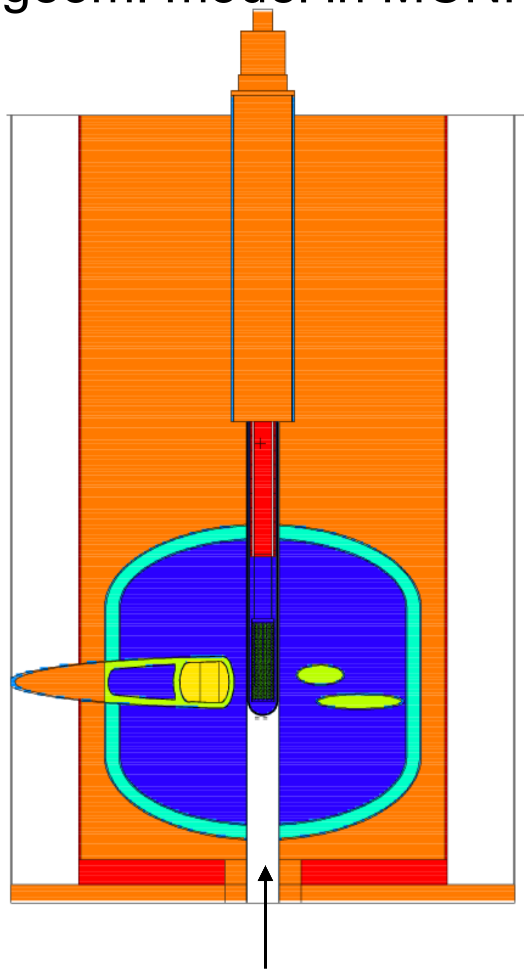
- book-keeping prg. to calculate nuclide inventory
- contains PSIMECX cross section library (developed at PSI)



1. Activation in the close vicinity of the SINQ-Target 3

irradiation: 6.77 Ah for 2 years

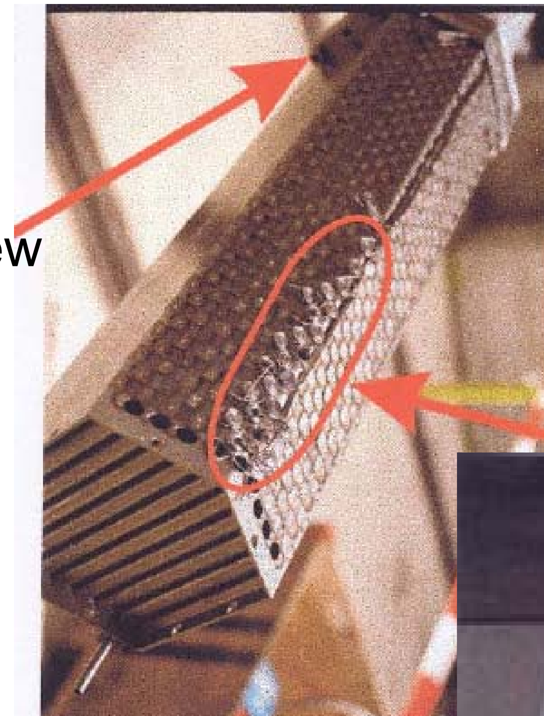
geom. model in MCNPX:



p-beam

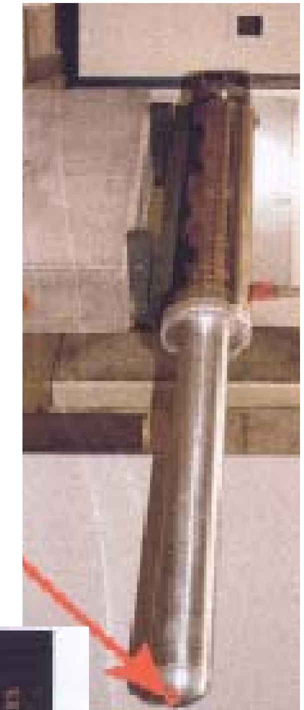
3 samples:

Zr screw



Zr tubes

AlMg3 hull



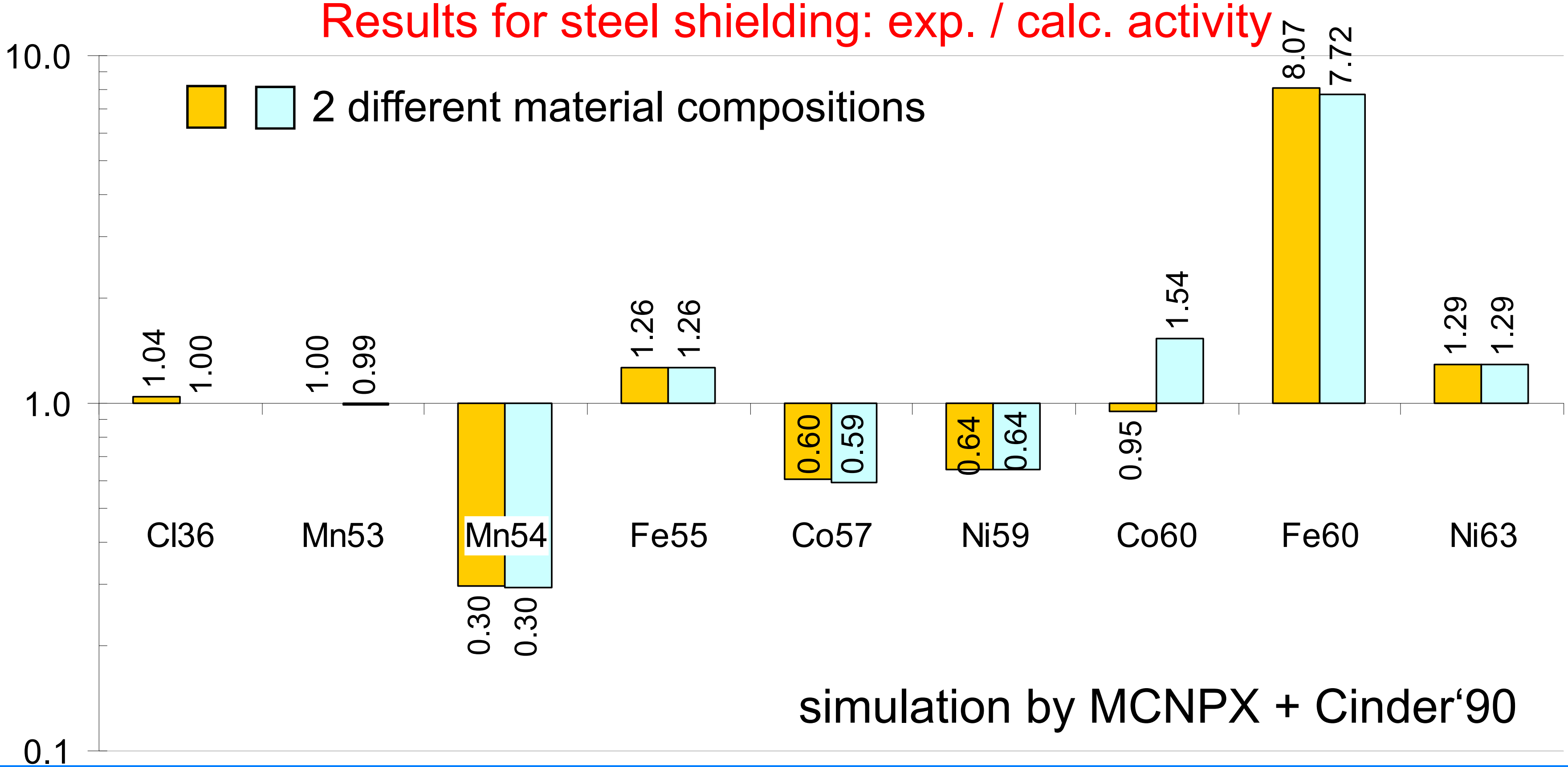
shielding 316L

Nuclide inventory

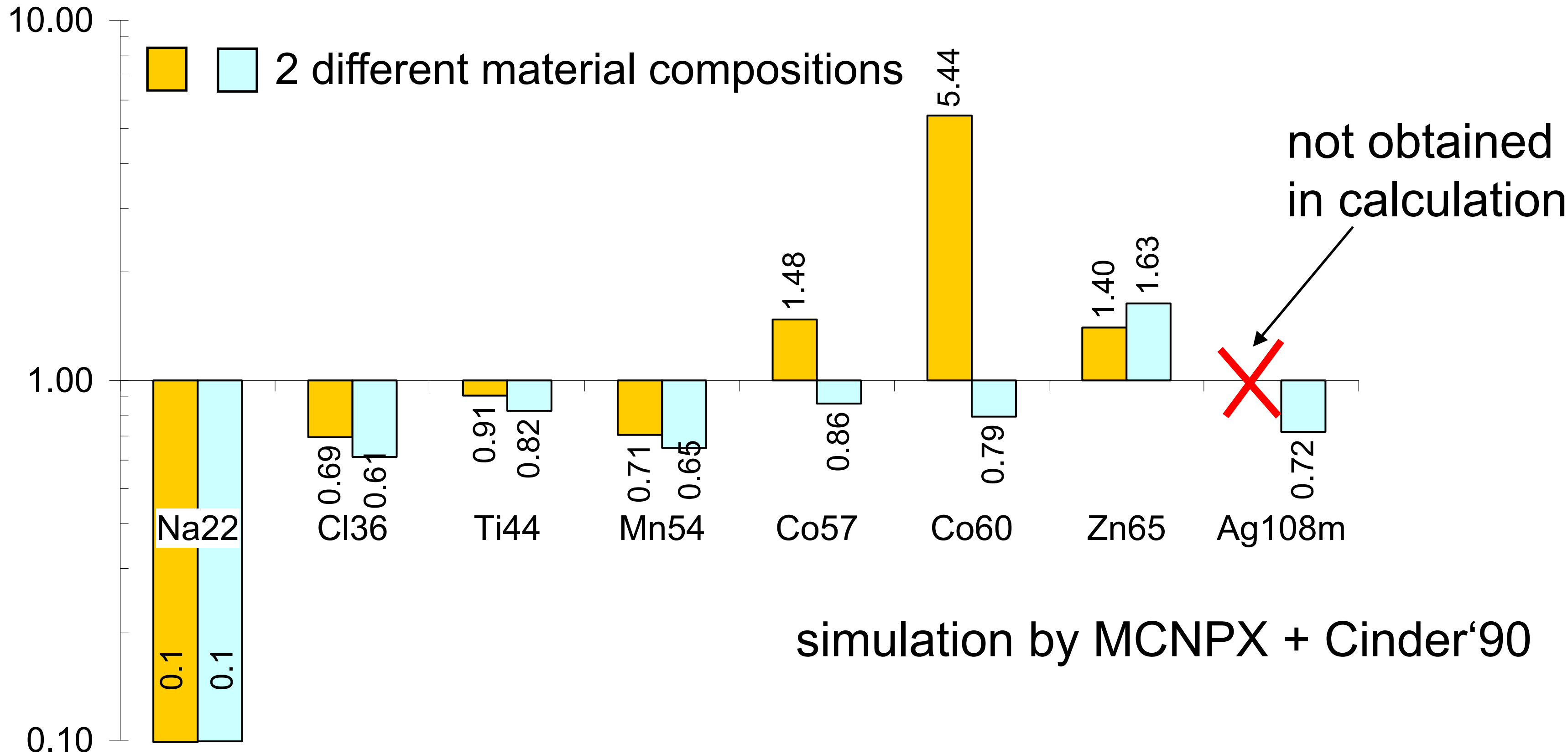
- γ's in Ge-detector
- chemical + quantitative Analysis
  + β measurement in Liquid Scintillator
- Accelerator mass spectrometry (AMS)

measurement done by radiochemist group at PSI in collaboration with AMS groups in Zürich + Munich

Results for steel shielding: exp. / calc. activity



Results for safety hull: exp. / calc. activity



remarks:

- overall good agreement with MCNPX+Cinder'90
- Na22: Data/SP-Fispact = 0.72
- Fe60: deviation of factor 8 seen in many other samples
- the right material composition (including impurities) is important!

2. Planned: New Hot cell at PSI

What is the required wall thickness (shielding) ?

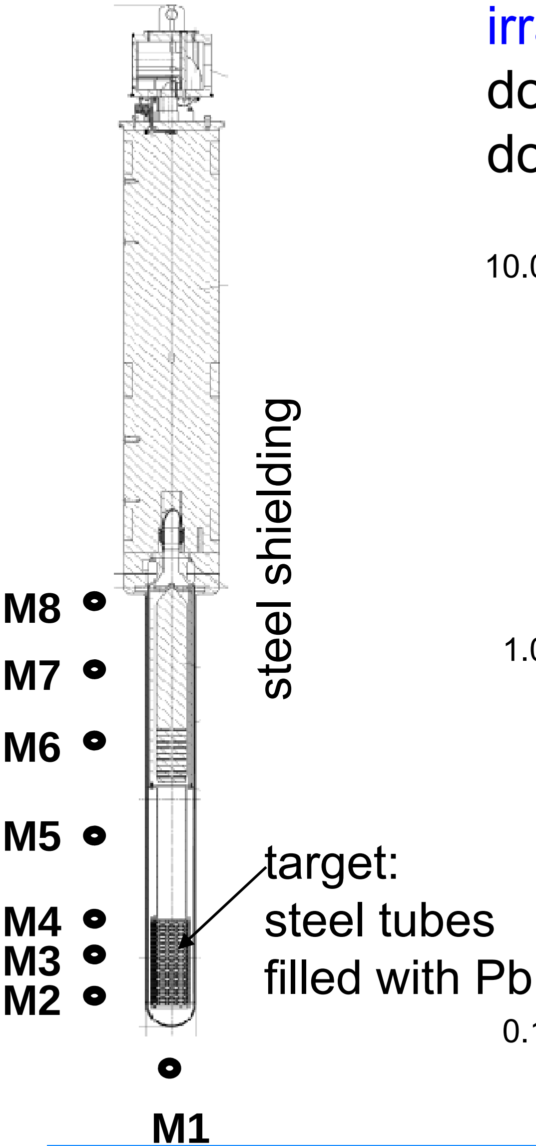
Most activated piece at PSI: SINQ target (Pb in Zr tubes)
→ calculation of the nuclide inventory with MCNPX + Cinder'90
→ calculation of the thickness of the shielding with Microshield

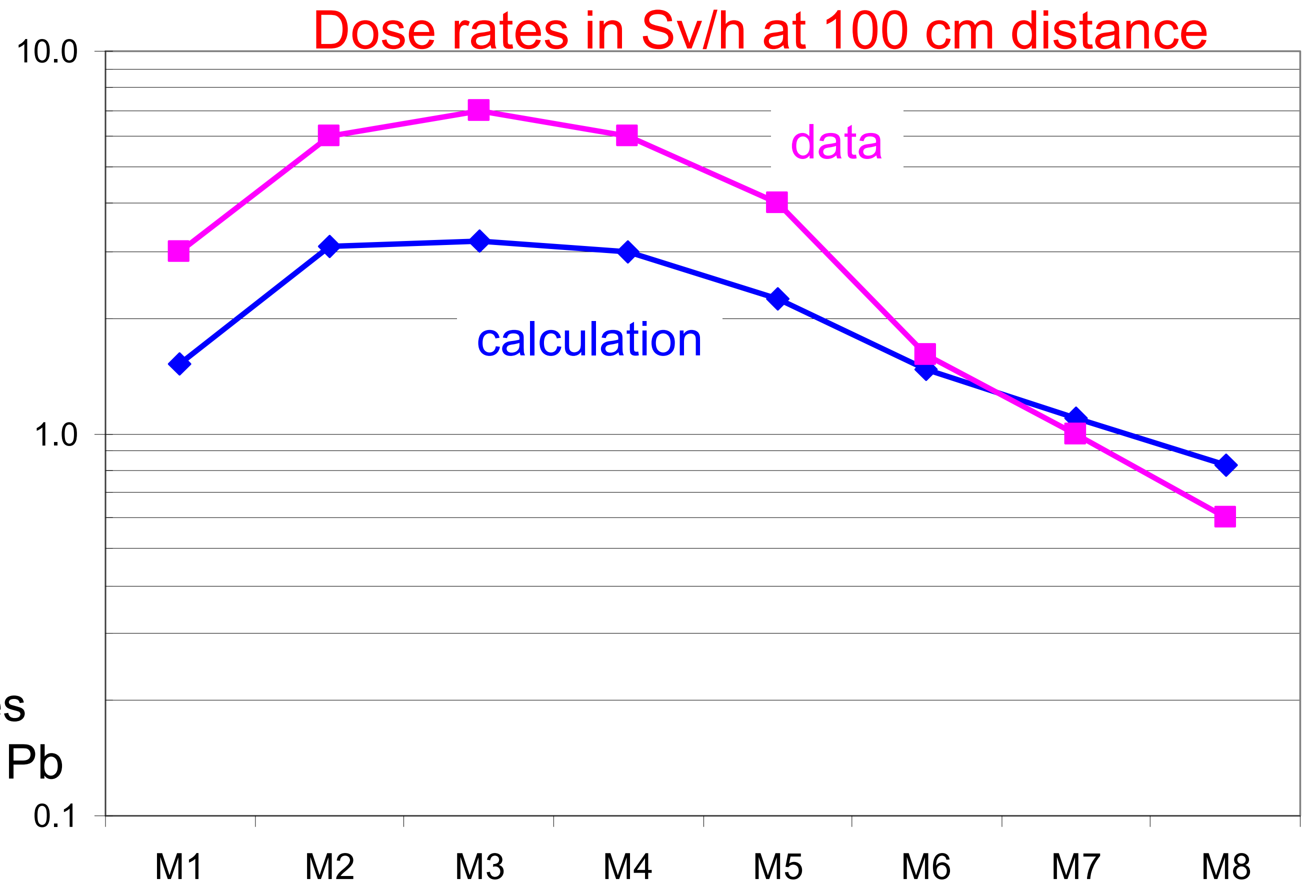
How good are the predictions?
5 SINQ targets were irradiated and dismantled

→ Compare calculated dose rates with measured data

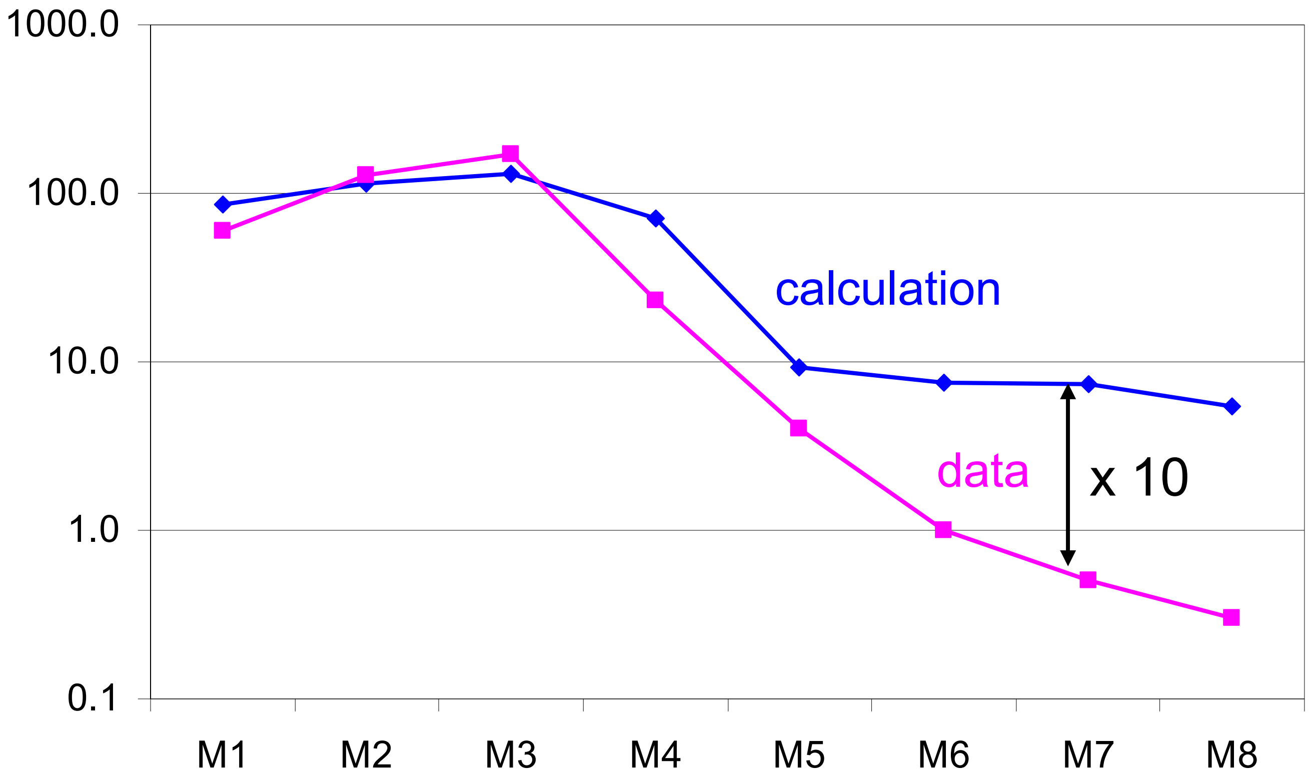
Dose rates at SINQ Target 4

irradiation: 2 years with 10 Ah, cooling: 10 months
dose rates obtained at 3cm, 30cm, 100cm
dose rates calculated with MCNPX + Cinder'90

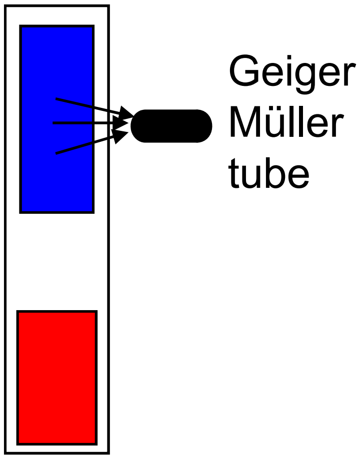




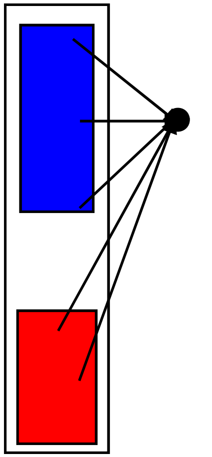
Dose rates in Sv/h at 3 cm distance



measurement:



simulation:



discrepancy:
- factor 2 in the target region
- factor 10 for small distance at the shielding

reason: in calculation contribution also from target region
Geiger Müller tube: smaller solid angle

3. Dose rates at the Pirex beam line at PSI

purpose (1988 - 2004):
material irradiation
and degradation for Gantry 1
2006:
dismantling of the beam line
→ calculation of dose rates with MCNPX
+ comparison with measured doses

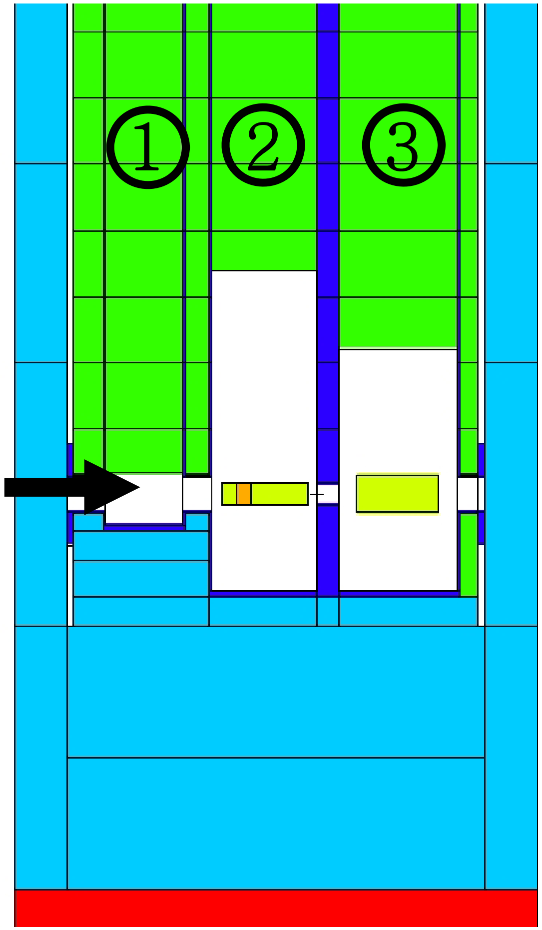
1 Beam current monitor

2 Degrader (Cu + C)

3 Beam Dump (Cu)

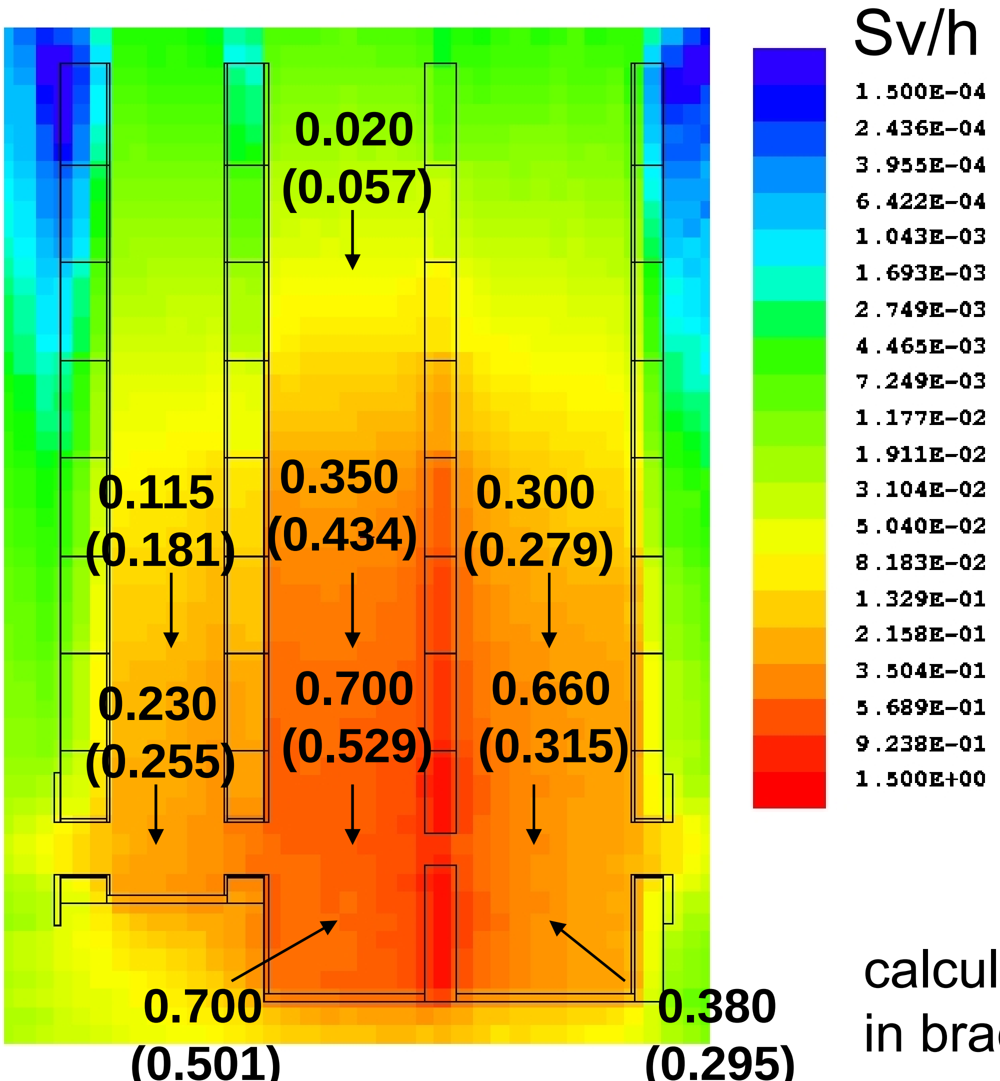
Assumption (made in simulation):
Degrader 2 and Beam dump 3 are always in beam

Irradiation history (simplified):
16.6 y @ 8.3 μA
2.3 y cooling



model in MCNPX of vacuum chamber

Results of dose rate comparison:



Comparison with data:

Overall agreement good

Average ratio 1.13

Two points with ratio > 2:

smaller dose as measured in

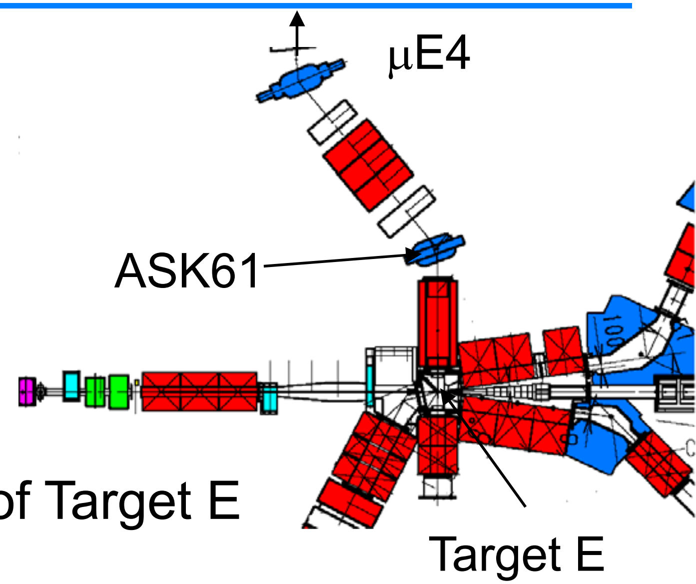
beam dump:

→ degrader was not always in

calculated values by M. Wohlmuther in brackets

4. Activation of samples in the μE4 beam line

2004: Several samples were taken from
- bending magnet ASK61
- shutter behind ASK61
- shielding around shutter

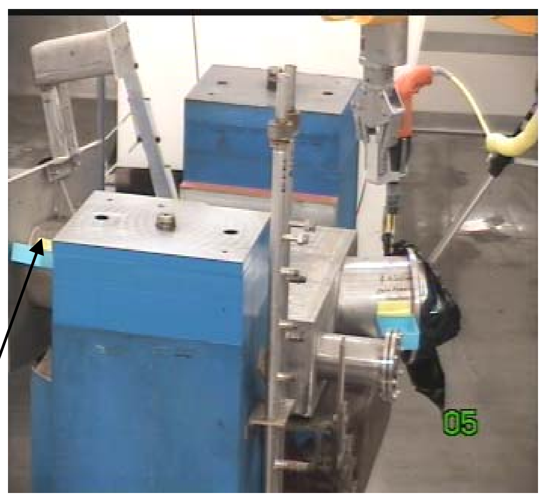


→ components are not directly irradiated

→ calculation of the activity with PWWMBS

use representative n-flux spectrum in vicinity of Target E

bending magnet ASK61 (stainless steel)



beam entry

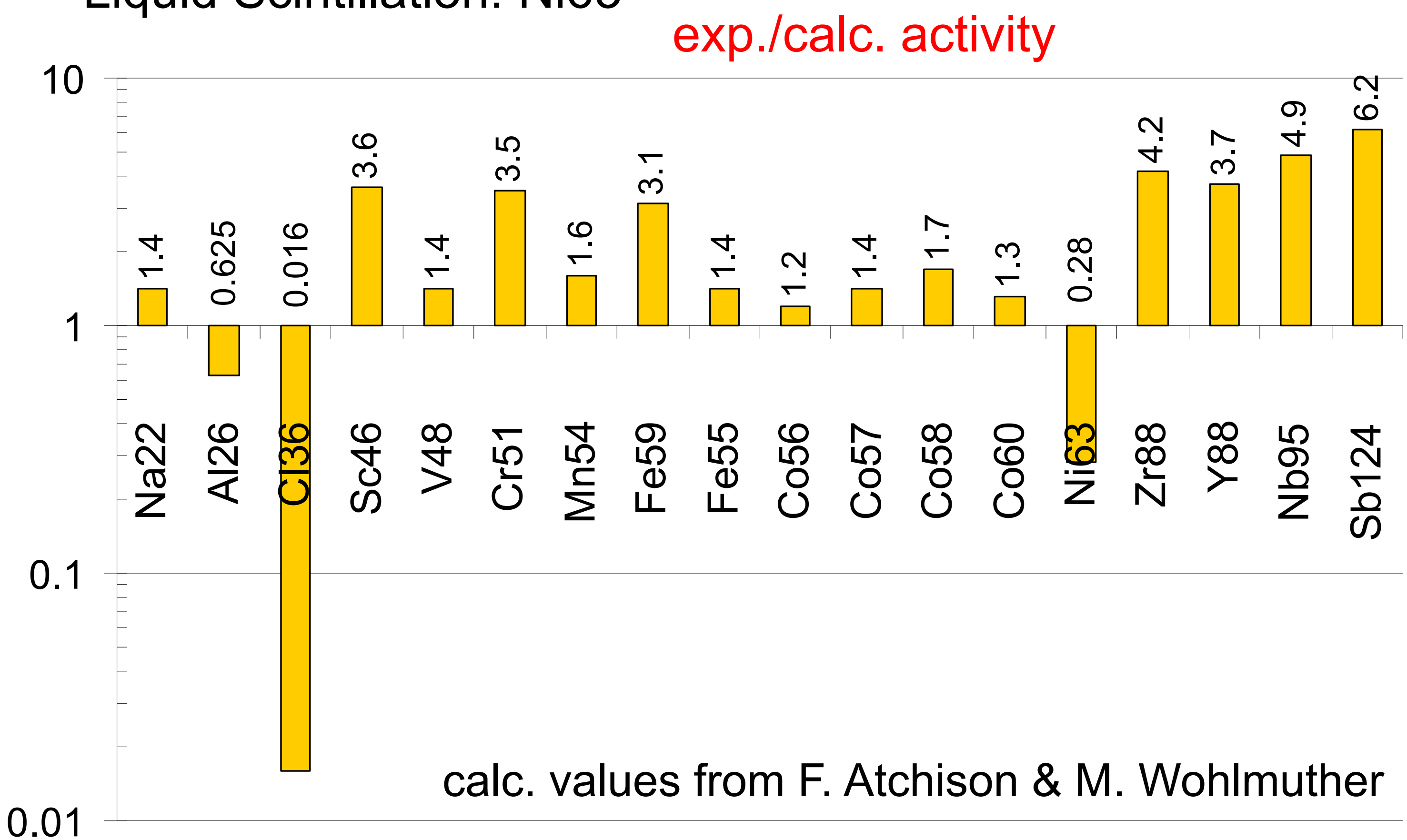
irradiated for 13 years

sample from beam tube

Results for beam entry at ASK61

Measured activities via

- γ detection
- Accelerator mass spectromety for Al26, Cl36, Ni59
- Liquid Scintillation: Ni63



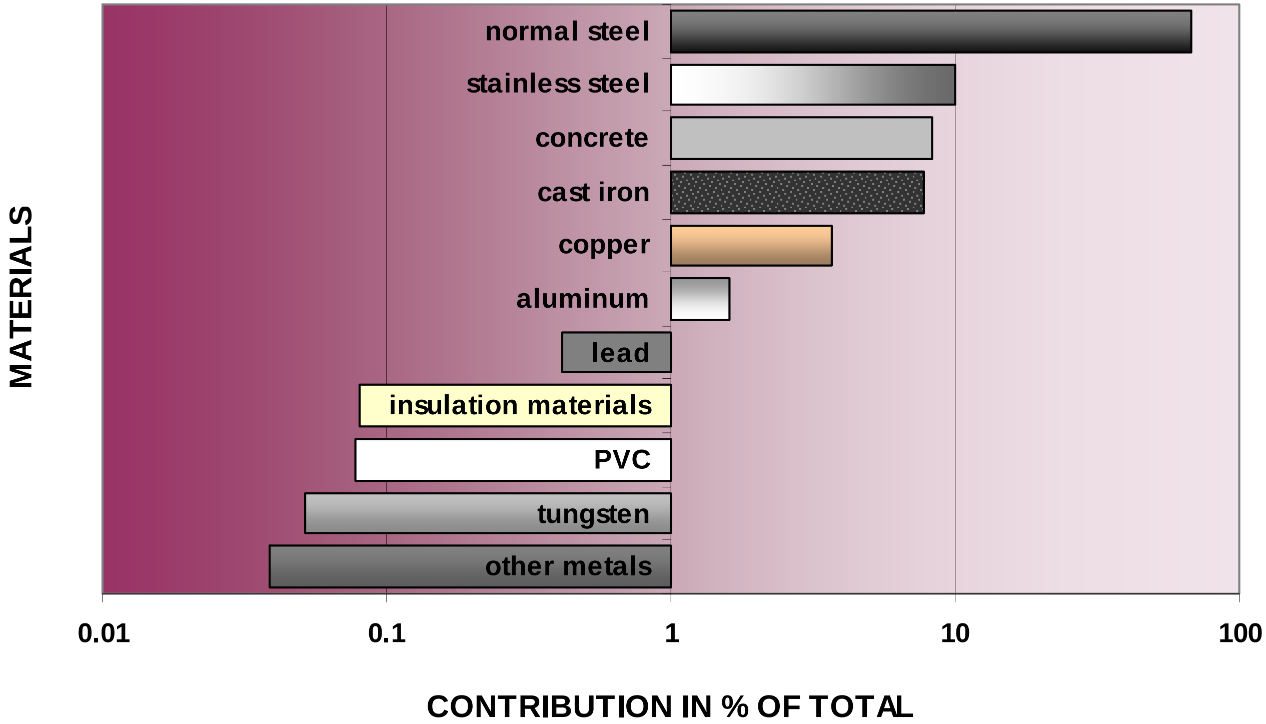
calculation with PWWMBS + typical stainless steel composition

Radioactive waste filled into Containers

- Collimators
- Beam Diagnostic Monitors
- Magnets
- Shielding
- Electrical installations
- Targets
- Vacuum Chambers

Total activity per container: $10^{10} – 10^{12}$ Bq (4.5 t)

Material compositon:



for most of the components: nuclide inventory obtained with PWWMBS

Comparison of the calculational methods

- **PWWMBS:** activation due to secondary particles
  main purpose:
  nuclide activity calculation of radioactive waste

+ fast throughput, user friendly
+ minimizing of personal dose (no detailed measurements or samples)
- no predictions possible (dose rate needed)
- accuracy: factor 10 due to simplified assumptions, sufficient for authorities

- **MCNPX:** activation due to primary irradiated fields
  main purpose:

✓ nuclide inventory calculation
✓ dose rate calculation
✓ energy deposit (input for ANSYS → temperature distribution)
+ predictions possible
- elaborate geometry input
- large cpu time (~1day on 256 - 512 nodes), statistical limitations
+ accuracy: factor ~ 3 (except some outliers)

→ Comparison between simulation and measurement important

Summary:

Predictions/calculations of the nuclide inventory and dose rates important for
- disposal
- personnel work at activated components

Solution at PSI:

direct irradiation:

MCNPX + Cinder'90 (or SP-Fispact, Orihet3)

secondary particle fields:

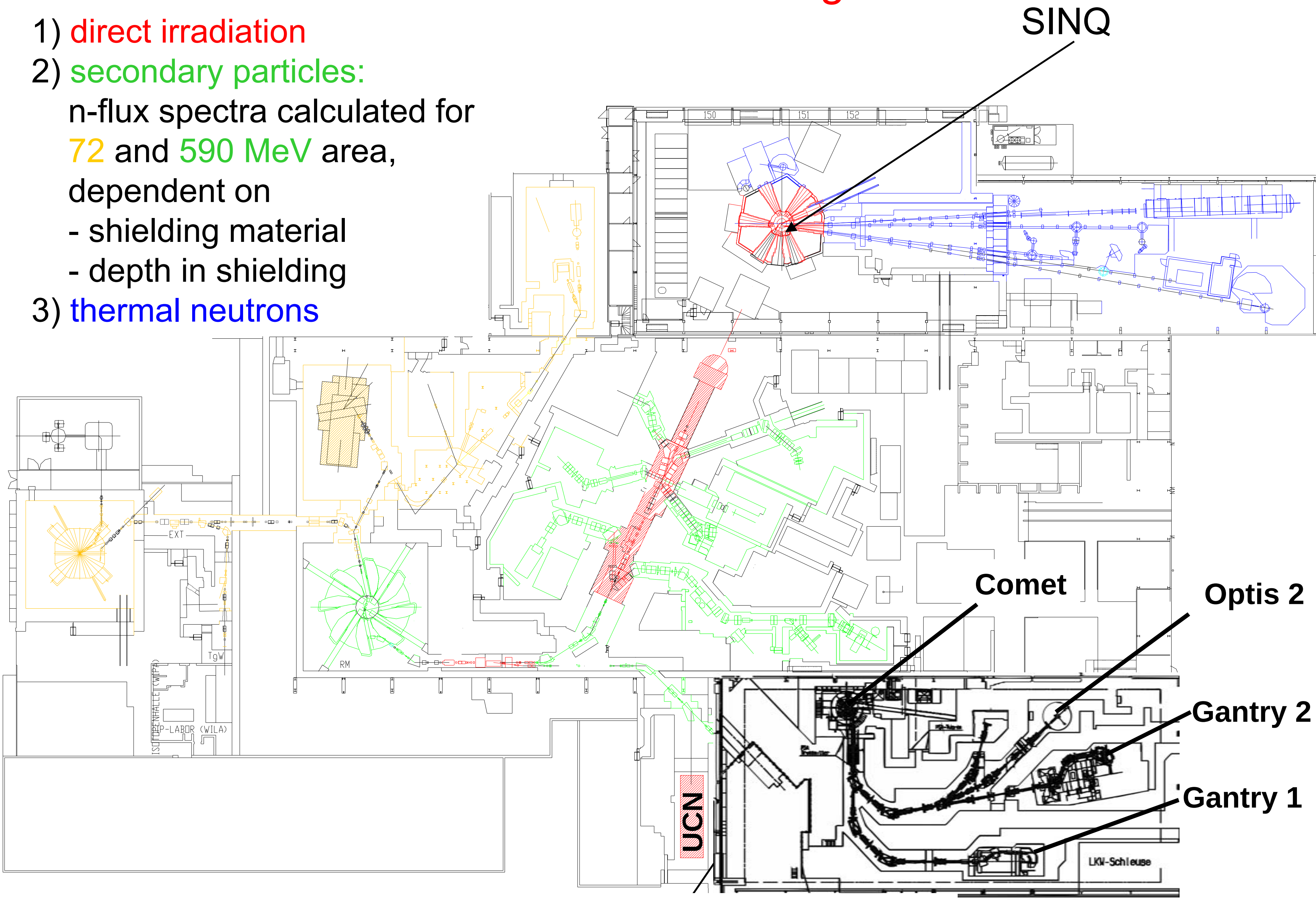
PWWMBS (nuclide inventory only)

Examples:

1) Nuclide inventory of shielding + safety hull of SINQ target 3: good agreement
2) Dose rates along the SINQ target 4 insertion: agreement within factor 2
3) Dose rates in vacuum chamber of PIREX: agreement within factor 2
4) Nuclide inventory of ASK61: exp/calc. < 10, except for Cl36

Division of the area in regions

1) direct irradiation
2) secondary particles:
   n-flux spectra calculated for
   72 and 590 MeV area,
   dependent on
   - shielding material
   - depth in shielding
3) thermal neutrons



Meson Production Area

Access to working platform after removing 3-4 m of concrete roof shielding

Use of remotely controlled shielded exchange flasks to remove defective components.

Repair work done in a hot cell.