P5-Manganese bath

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'Mn bath' calibration facility

- **Radionuclide neutron sources in terms of emission rate in 4πsr**
- **Operational in primary metrology labs**
- **Neutron activation of ^{55}Mn in a SO_4Mn solution irradiated by the source**
- **Basic relation enabling the determination of neutron fraction interacting with ^{55}Mn**

$$B = [A_m M] / f (1 - \delta)$$

- **P5 : Calculation of $f (1 - \delta)$ and uncertainty**

$$B = [\, A_m M \,] / f\,(1 - \delta)$$

- B : neutron emission rate in 4π sr
- A_m : equilibrium activity of ^{56}Mn per mass unit
- M : total mass of $MnSO_4$ in the tank
- f : fraction of neutrons captured by Mn nuclei over those captured by other nuclei (H, S, O,…)
- δ : correction factor = [O] + [S]+ [L]

  - [O]: fraction of neutrons undergoing (n,α) reactions in oxygen, (n,α) and (n,p) reactions in S.

  - [S] : fraction of neutrons 'recaptured' in the source material and captured in the source cavity assembly.

  - [L] : fraction of neutrons escaping from the solution tank

P5 problem participation

- 7 participants :

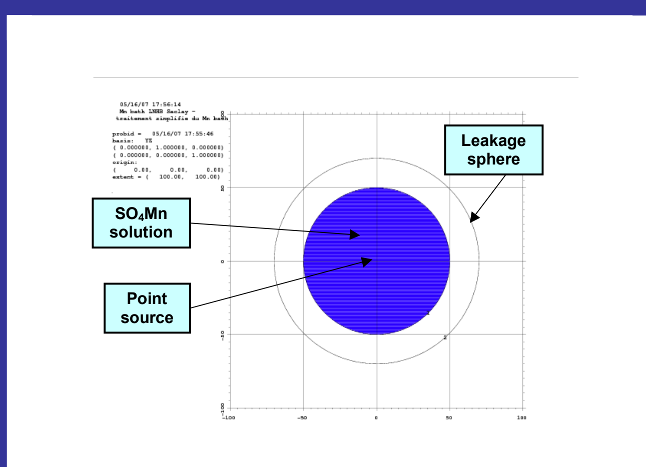
- Brasil : 1	- USA : 2
- Spain : 1	- France : 2
- U.K. : 1	

- Codes: MCNP4-c2, MCNP5, MCNPX 2.5.0 (beta 2.6); Tripoli 4
- 2 models of the Mn bath facility:
- 'Simplified model' solved by all participants
- 'Realistic model' solved by 4 participants, partial results by others

This presentation

- **Summary of results sent by participants without selection (a lot of tables !)**
- **A few exchanges of mails with participants during the results analysis**
- **Only the main features derived from the analysis of results will be presented. (→Proceedings of the Workshop)**
- **1 – Simplified model**
- **2 – Realistic model**
- **3 – Experimentation (Ph. Cassette)**

Simplified model

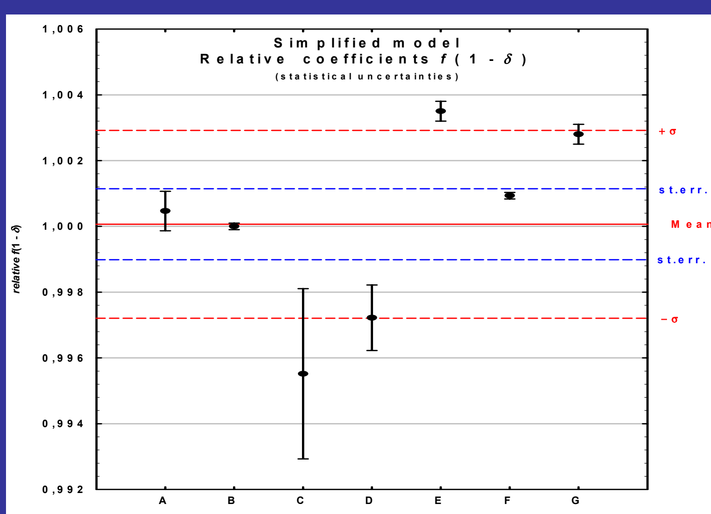


Point (AmBe) source,SO_4Mn sphere, in vacuum

List of calculations (in vacuum)

• **Capture fractions in :**	**Order of magnitude**
SO_4Mn	0.990
Mn(n,γ)	0.430
H(n,γ)	0.510
S(n,γ),(n,p)(n,α),tot	0.022
O(n,α),tot	0.025
[*O*] = S(n,p)+S(n,α)+O(n,α)	0.030
Leakage fluence, [*L*]	1.95 10^{-7}, 0.011 (!)
[*δ*] = [*O*] + [*L*]	0.042
f = Mn(n,γ) / Σ(n,γ)	0.448
f (*1 – δ*)	0.429 (!)

Simplified model : *f* (1 - *δ*)



Simplified model: $f(1 - \delta)$

- Deviations of results / mean value 0.428 are <± 0.4%
- Declared statistical uncertainties are much lower
- How to analyse this inconsistency ?
- Proposal:
- Run the same input file with 2 codes (MCNP5, MCNPX)
- Compare the relative differences of calculated results with assigned uncertainties

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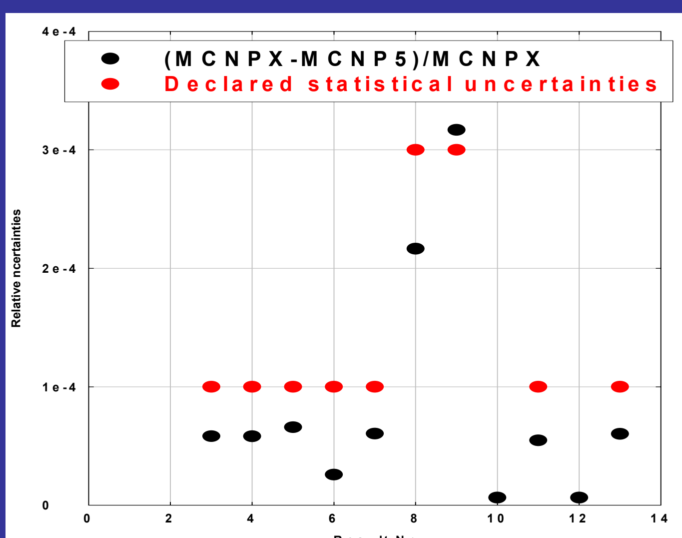
Simplified model



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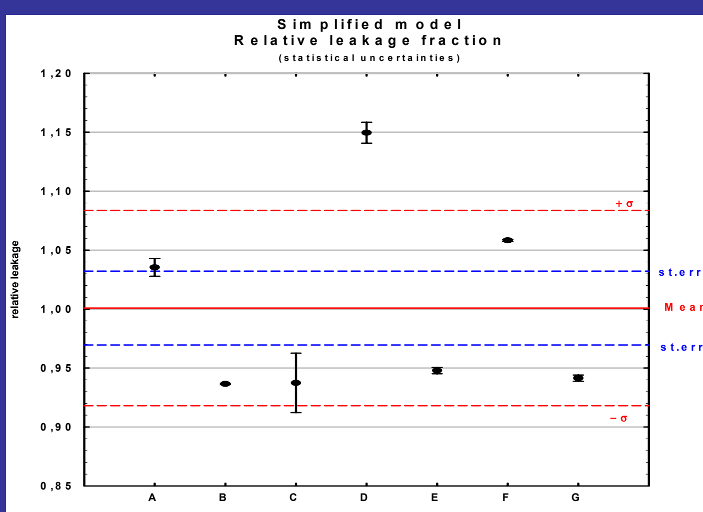
Simplified model

- **Proposal :**
- **'User effect' :**
  - **- same primary input data (booklet)**
  - **- small differences in intermediate input data: tally multipliers FM, cross sections, isotopic compos., ….**

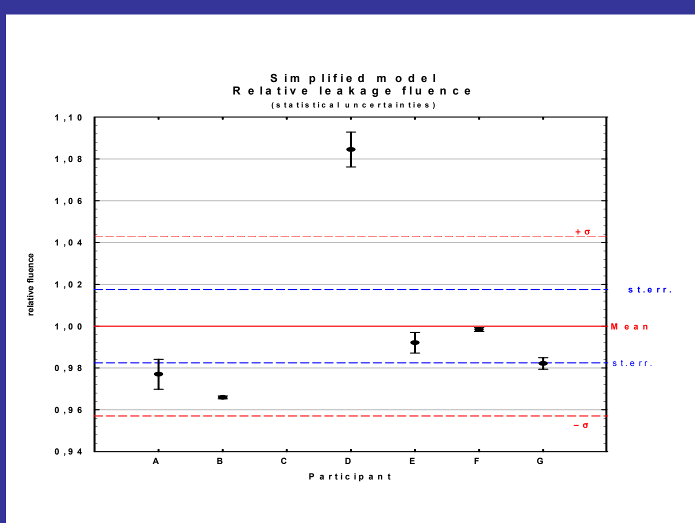
Simplified model : rel. leakage fraction (0.011)



Simplified model : leakage fraction = 0.011

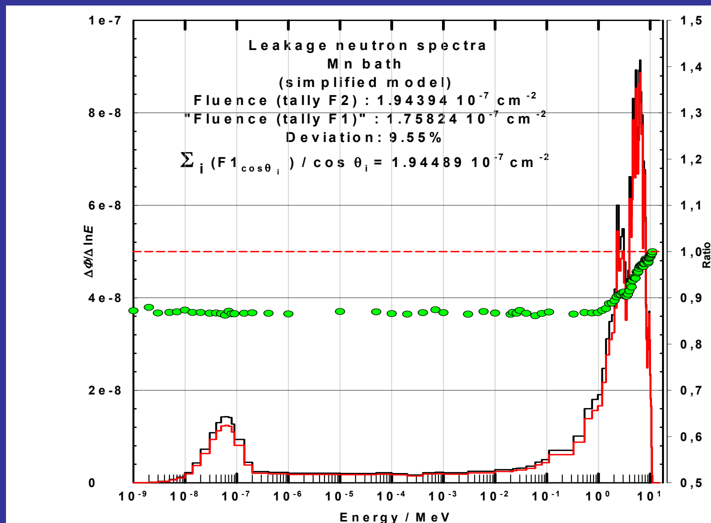
- Same remark: deviations of participants results with respect to the mean value are much larger (up to 15%) than the declared statistical uncertainties
- Another point:
- Leakage fraction : Tally F1 (fraction of neutron crossing a surface)
- Leakage fluence : Tally F2 (units : n/cm^2) takes into account the angular distribution by 'cosine' term
- Leakage fraction and leakage fluence are NOT proportional
- Leakage fluence is NOT equal to the leakage fraction divided by the surface

Simplified model : relative leakage fluence

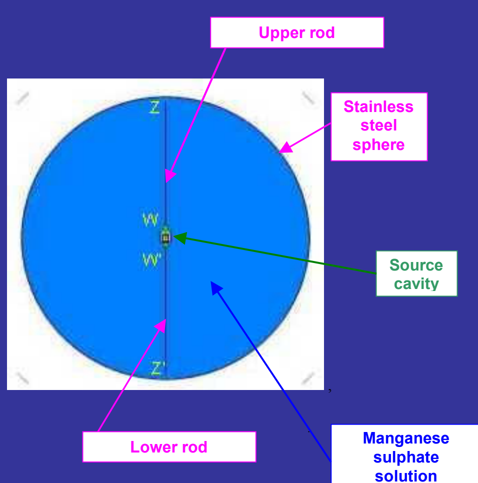


Simplified model : leakage fluence

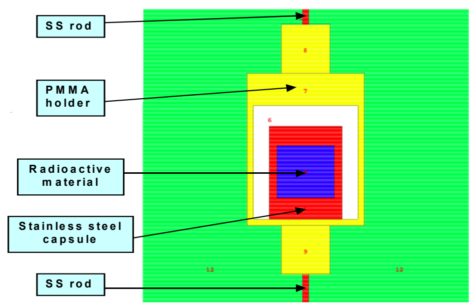
tallies F1 and F2



Realistic model (in vacuum)



Realistic model : source cavity



Volume source in SS capsule;PMMA holder; SS rods

Realistic model

- **<u>Options</u>: - influence of the addition of air and concrete walls**

  - estimation of uncertainties on *f (1 - δ)* due to uncertainties on some input data (as specified in the booklet)

- **<u>Constraint</u>: normalisation to 1 neutron <u>emitted</u> by the source**

Realistic model

- **Representation of an operational set-up**
- **Source is placed in the neutron detecting medium (SO_4Mn solution) and the corresponding perturbation must be estimated.**
- **Perturbation: 'recapture' of emitted neutrons by the source and capsule.**

Realistic model

- **Difficulty in the modelling of the source to comply with:**
  - **- Source size influence (absorption, spectral modif.)**
  - **- ISO 8529-1 recommendations**
- **ISO 8529-1 reference spectrum = emission spectrum of 'small' neutron source**

>>(ISO WG in charge of revision of ISO 8529 Standards)

- **4 source modellings were proposed by participants (see Proceedings) to cope with both requirements**
- **1 - Neutron recapture in the source**
- **2 - Absorption, spectral modifications (→ Proceedings)**

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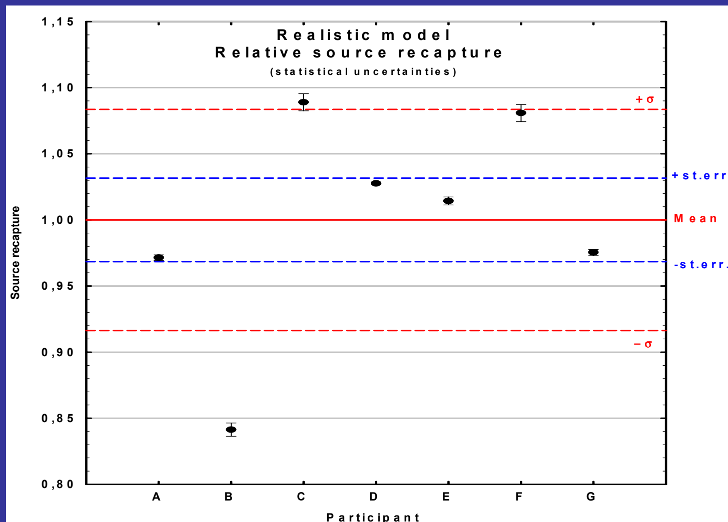
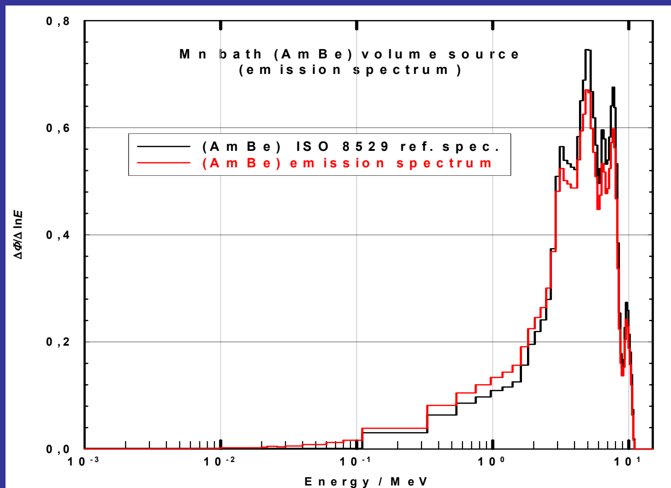
Realistic model : rel. recapture fraction (0.006)



Realistic model : recapture fraction = 0.006

- **Deviations of results up to 15%**
- **Very small statistical uncertainties**
- **'User effect' +**
- **Influence of the (AmBe) source modellings**
- **Different source normalisation factors taking into account the fission and (n,xn) interactions**
- **…..**

Source emission spectrum

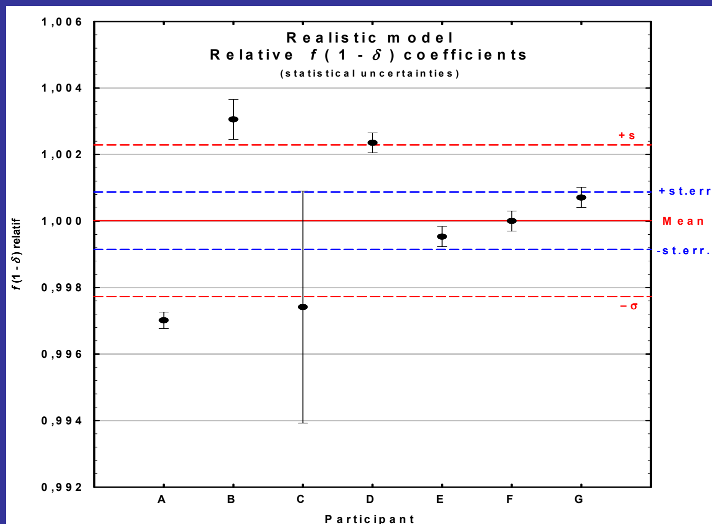


List of calculations (in vacuum)

- **Capture fractions in :** **Order of magnitude**

SO_4Mn	**0.980**
Mn(n,γ)	**0.426**
H(n,γ)	**0.510**
S(n,γ),(n,p)(n,α),tot	**0.022**
O(n,α),tot	**0.023**
[*S*] = [(AmBe)+SS caps.]'recapt.' + PMMA holder+SS rods	**0.008**
[*O*] = S(n,p)+S(n,α)+O(n,α)	**0.030**
Leakage fluence, [*L*]	**$2.15\ 10^{-7}$, 0.012 (!)**
[*δ*] = [*O*] + [*L*] + [*S*]	**0.050**
f = Mn(n,γ) / Σ(n,γ)	**0.448**
$f\,(1-\delta)$	**0.425 (!)**

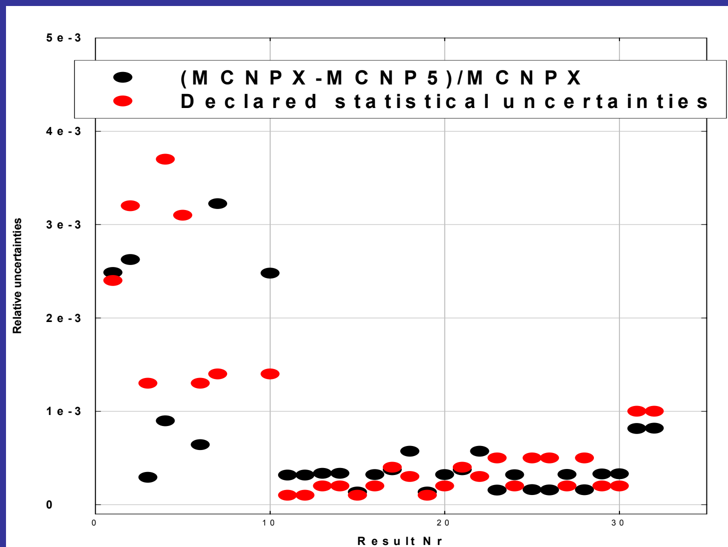
Realistic model : relative $f(1 - \delta)$



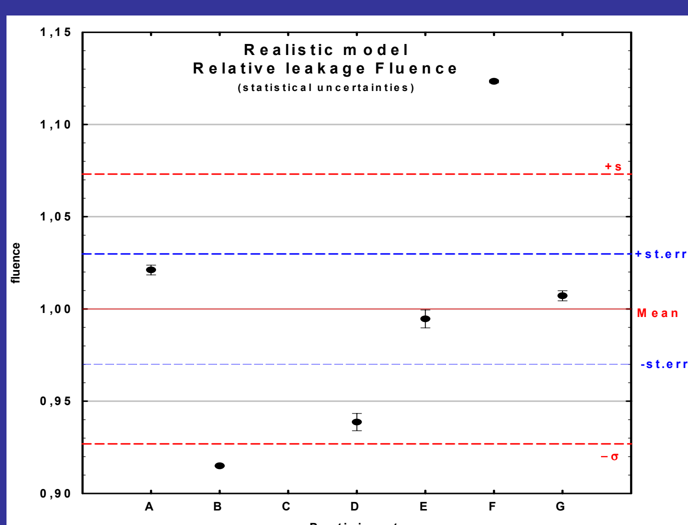
Realistic model: $f(1 - \delta)$

- **Comments:**
- **Deviations of results with respect to the mean value 0.425 are <± 0.3%**
- **Assigned statistical uncertainties are much lower**
- **Proposal:**
  - **- Source modelling**
  - **- Selected XS**
  - **- Tally mult. FM**
  - **- Different code versions ?**

Realistic model



Realistic model : relative leakage fluence

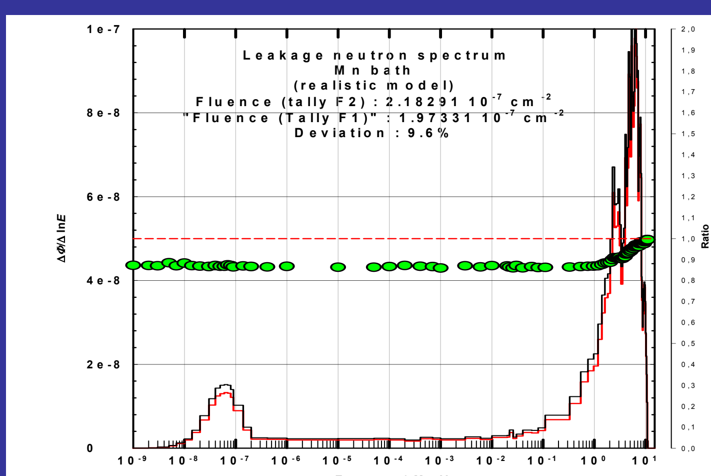


Realistic model : leakage fluence

- **Same comment as for the simplified model**
- **Deviations with respect to the mean value up to about 12% with small statistical uncertainties**
- **Among other reasons:**
- **Consequence of the confusion between Tally F1 (neutron current) and Tally F2 (neutron fluence)**

Realistic model : leakage fluence

tallies F1 and F2



Uncertainties evaluation

Based on the investigation of the Influence of :

- **Addition of air and concrete floor and walls**
- **Density of the solution : ±0.5%**
- **Density of the radioactive material: ± 20%**
- **Source positioning : ± 10mm**
- **Spherical tank radius : ± 5 mm**
- **Neutron cross-sections (Mn, H ,O,S, ….) available : ENDFB-V; ENDFB-VI.6; ENDFB-VI.8; ENDFB-VII.0 …**

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Uncertainties evaluation

- **3 participants : detailed procedure and results enabling to reach the uncertainty assigned to** $f(1-\delta)$
- **1 participant : provided values of uncertainties**
- **Similar techniques:**

  - calculation of the fraction changes of each element of the list of calculations due to uncertain-ties assigned to selected input file parameters (PERT card or separate runs)

  - quadratic summation of those 'elementary' fraction changes

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Uncertainties evaluation

- [δ] = [O] + [L] + [S] ~ 0.050
- Capture fraction changes are generally small, sometimes not significant: air+concrete, source position, …
- Although numerical values presented by participants are often different with large uncertainties, the influence on the overall uncertainty is limited
- Information not available to explain the differences (code input file,use of 'PERT+FM', techniques for combining uncertainties, etc …)

Uncertainties evaluation

- Different modes of uncertainty estimation on cross-sections:
  - either a priori values
  - or overestimation by comparison with results derived from old libraries

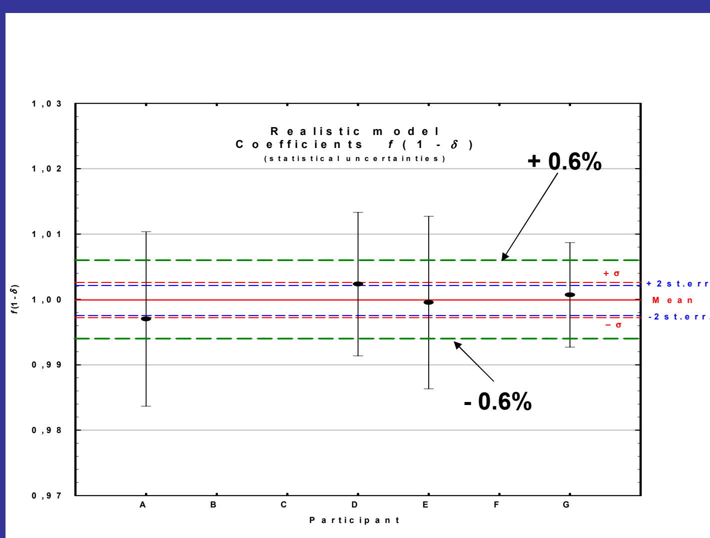
  → need for a 'unified' procedure

  - current procedure is CPU-time consuming

Uncertainties results (provisional)

- Overall uncertainties assigned to $f\,(1 - \delta)$:
- Participant A : ± 1.33%   including ENDFB-V (oxygen)
- «   D : ± 1.1 %
- «   E : ± 1.32%
- «   G : ± 0.80% including ENDFB-V (oxygen)
  ± 0.40% including ENDFB-VI (oxygen)
- Mean value $f\,(1 - \delta)$ = 0.425 $\sigma_{f\,(1 - \delta)}$ = 0.6%

Uncertainty results (provisional)



Some conclusions about P5

- **For both models, capture fractions and *f (1 - δ)* results are quite consistent (in vacuum)**
- **Several participants have dealt with the evaluation of the uncertainty assigned to the final result, but some uncertainty budgets need to be clarified,**
- **Simple exercise to distinguish between neutron current and fluence!**
- **Brings a better knowledge of the Mn bath facility (modelling of the source) and uncertainty assessment**
- **The investigation of the influence of cross-sections should be extended to recent libraries (ENDFB-VII)**

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Tentative experimental validation of manganese bath calculations

• Measurement of the neutron leakage fluence

• Rate of production of ^{56}Mn (deduced from ^{56}Mn equilibrium activity and reference source emission flux)

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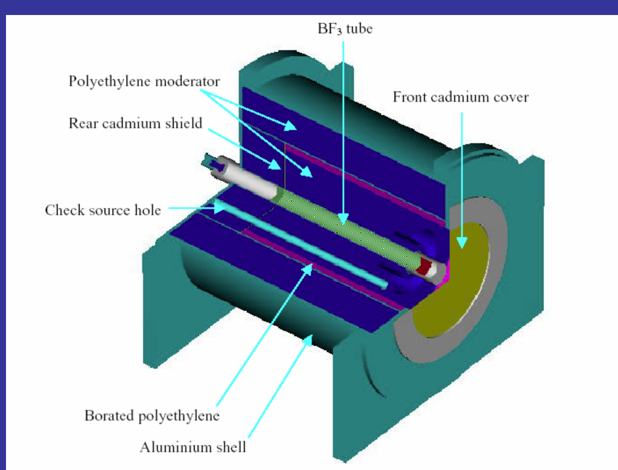
Experimental problems

- Absolute neutron measurement is (very) difficult:
  - non-ionizing particle,
    indirect measurement via nuclear reactions
  - diffusion in the room

- Difficulties to find a standard source of known flux
  (the reference measurement method is the manganese bath !)

- ^{32}P and ^{35}S are difficult to measure (pure beta emitters and low production rate)

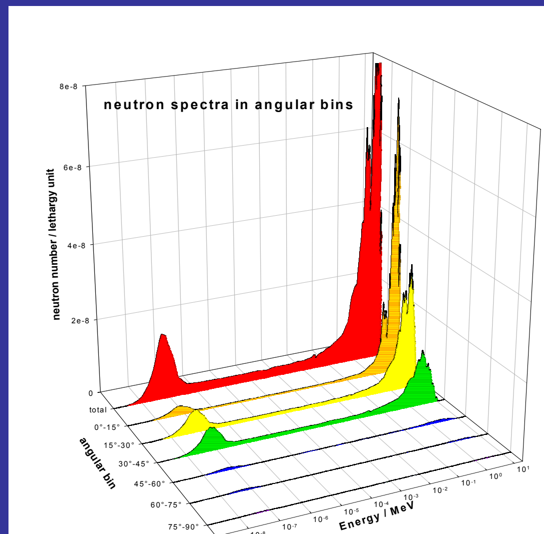
Leakage measurements (de Pangher long counter)



Leakage measurements

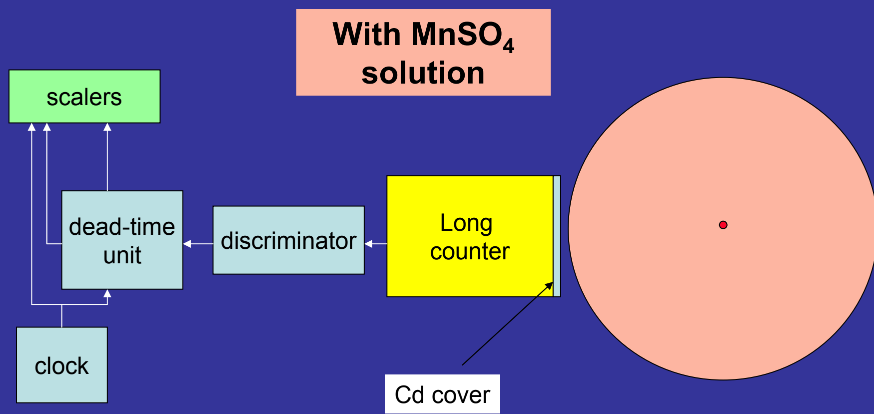
•Idea: most of the neutrons escaping from the Mn bath are fast neutrons

•Comparison of calculated leakage fluence with relative fluence measurement with or without Mn bath in the same measurement geometry



Neutron leakage (relative measurement) AmBe source

Neutron leakage (relative measurement)
AmBe source



Count rate ratio (with and without Mn bath)
AmBe source

Experimental	Count rate ratio	Std uncertainty
With Cd cover	0.01239	0.00042
Without Cd cover	0.01465	0.00041

Calculated	ratio	Std uncertainty
Flux ratio	0.0126	0.0014
Fluence ratio	0.0128	0.0014
Fluence ratio without thermal	0.0106	0.0014

Agreement within standard uncertainties (but ≈ 10 %)

^{56}Mn measurement

•Reference source : X3 source from international comparison

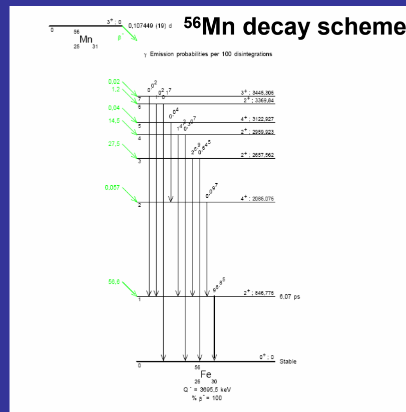
•Measurement using 4π β–γ coincidence system (absolute measurement method)

  •Cerenkov and Ge detector

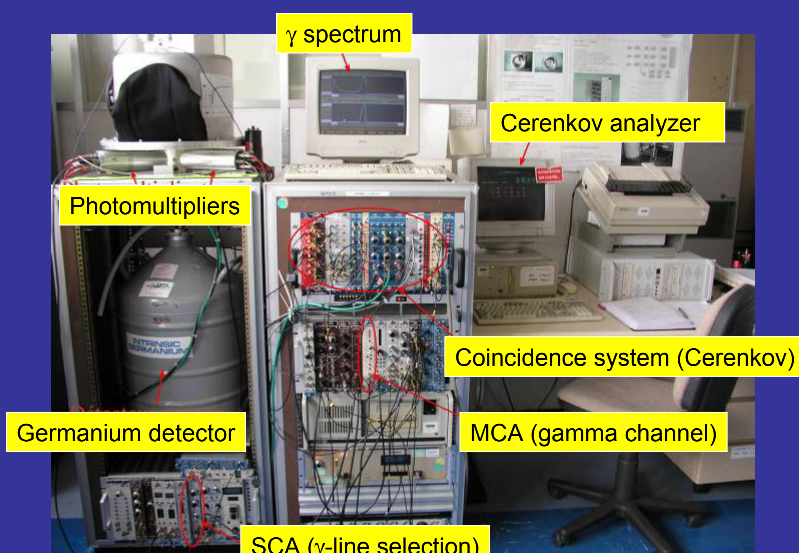
•Measurement procedure:

  •saturation of the bath
  •sampling in 20 ml glass vial
  •measurement of-line on a specific 4πβ(LS)-γ counter

•Normalization for P5 description



Experimental system



Experimental results

$\Phi_{reference}$ (from intercomparison): 2.425 10^6 s^{-1} @ 21/10/2004

$A_{measured}$: 1.87 10^6 Bq ± 1.2 % @ 21/10/2004

→ *f(1-δ)*= 0.422 ± 1.2 % …

… to be compared with calculated *f(1-d)*= 0.425 ± 0.6 %

Conclusions

Tentative comparison of calculated results with:

- Relative neutron fluence measurement with and without Mn bath
- Saturation ^{56}Mn activity and reference source

Reasonable agreement between calculated and experimental results but large experimental uncertainties

These experimental results are OK to confirm the order of magnitude of calculated results… but cannot be used as reference solution for P5