# Nuclear Constants for NAA and their Relation to Differential Cross Sections

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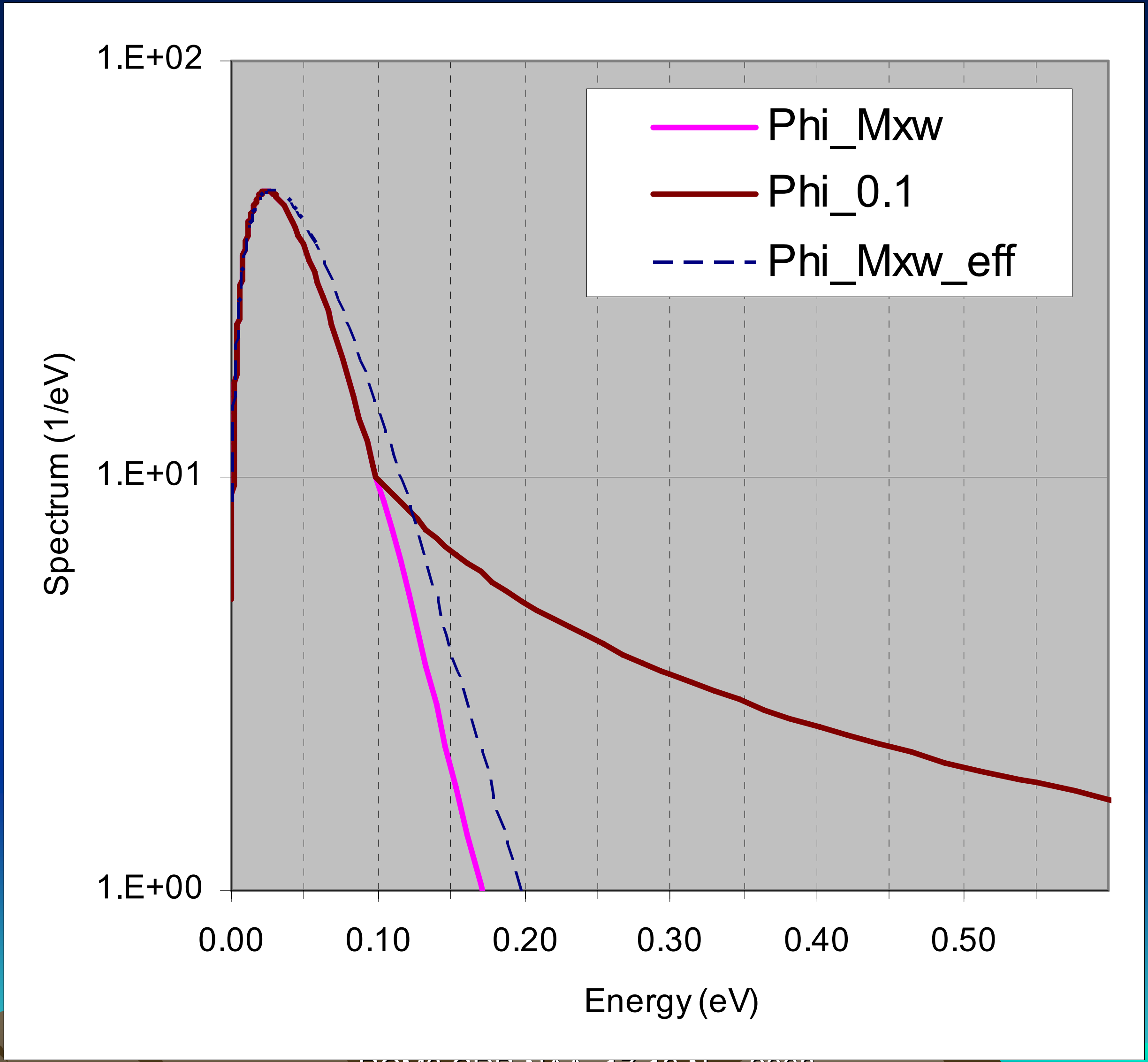
# Scope

- Definitions of constants
- Neutron self-shielding
- Spectrum characterisation
- Nuclear data updating strategy

# Definitions of Constants

- Paper in preparation (still!)
- Influence of 1/E spectrum on thermal constants
- Cadmium method to determine resonance integrals

# The 1/E spectrum contribution



# The 1/E spectrum contribution

$\Phi = v_T \int n(v)\, dv$; consider $E<0.55$ eV

For $E_{th}=0.1$, $v_T/v_0=1.148$

➔Effective spectrum temperature changes significantly (depends on $E_{th}$)

Why does $k_0$ method still work?

- The difference is transferred to an effective f-factor, which is measured

$\varphi_f \ \sigma_0 \left[ f \ g \ G_t + \left( Q \ G_f + H \ h \right) \right]$

# The 1/E spectrum contribution

A= $\varphi_f \ \sigma_0 \left[ f \ g \ G_t + \left( Q \ G_f + H \ h \right) \right]$

Generalised g-factor

$$g = \frac{\int_0^{E_{cd}} \sigma(E) \ \varphi(E) \ dE}{\sigma_0 \ \frac{\sqrt{\pi}}{2} \int_0^{E_{cd}} \varphi(E) \ dE} = \frac{2}{\sqrt{\pi}} \frac{\sigma_{th}}{\sigma_0}$$

# Cadmium method for resonance integrals

Instead of applying the cadmium ratio method, measure the ratio of sub-cadmium reaction rates relative to a standard (irradiated simultaneously)

Advantage: no reliance on “same irradiation conditions”, spectral perturbations, etc.

Disadvantage: introduction of dependence on gamma emission probabilities

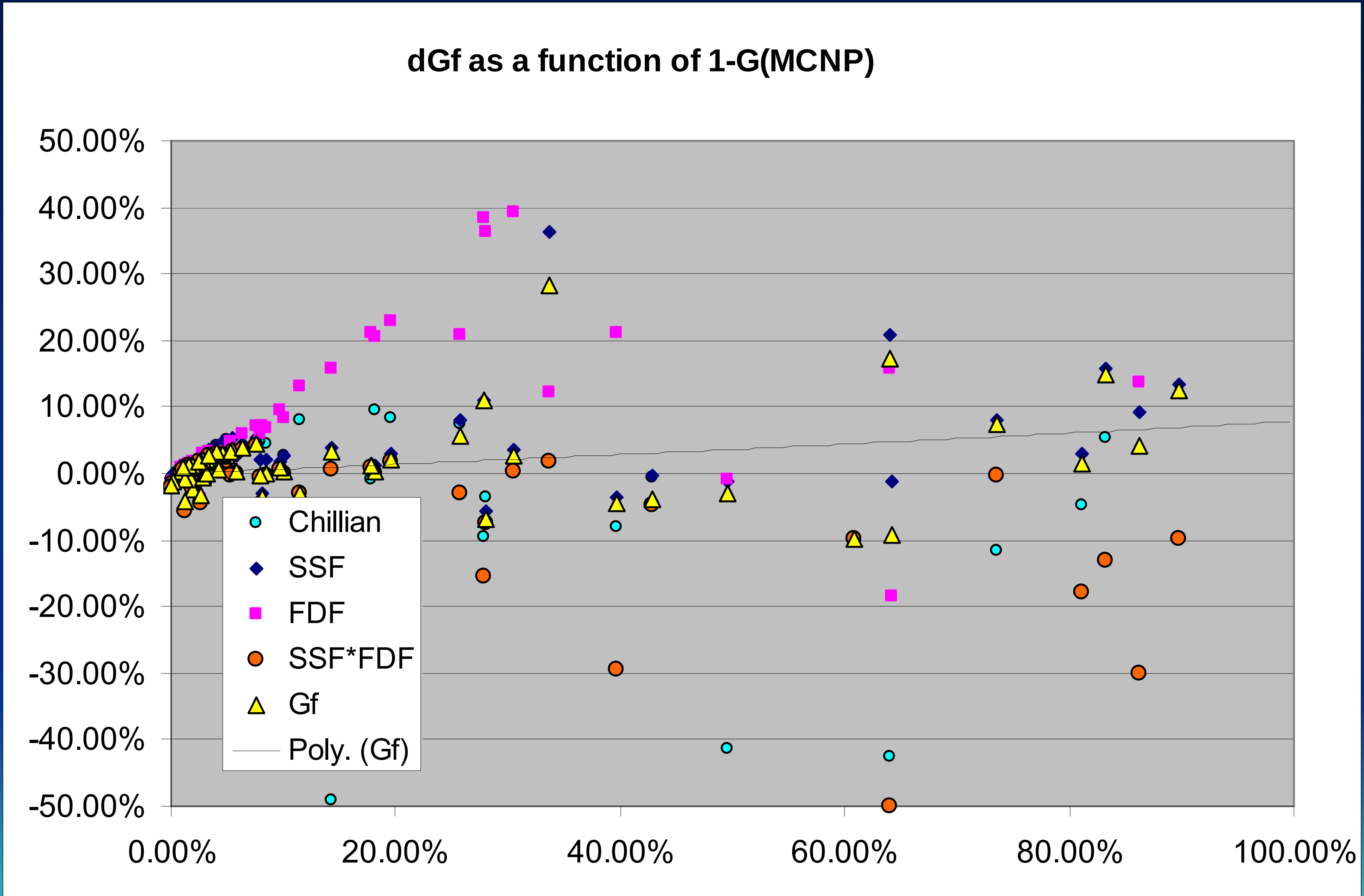
Simultaneous use of both methods may be used as a cross-check of consistency.

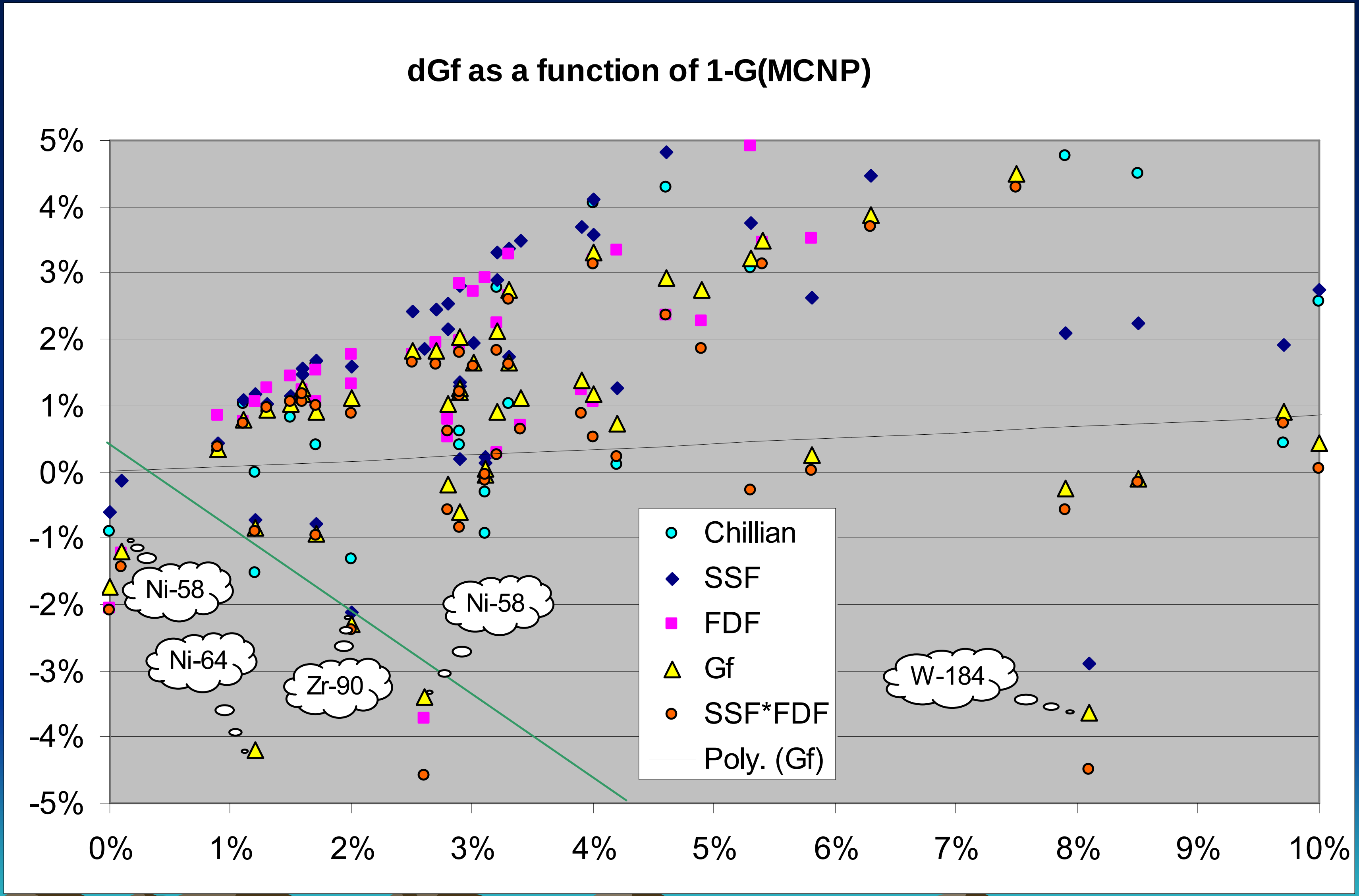
# Neutron self-shielding factors

- Paper published by Chillian et al
- MATSSF – interpolation of rigorously-calculated epithermal self-shielding factors
- Monte Carlo simulation → flux depression is important (alloys)

# Neutron self-shielding factors

- For single isotopes the MATSSF method works well, compared to MC simulation
- Considering the crudeness and simplicity, the method of Chillian is not so bad.
- Unfortunately there is more to it: multi-isotope matrices give rise to flux depression, which influences self-shielding significantly


dGf as a function of 1-G(MCNP)
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
-10.00%
-20.00%
-30.00%
-40.00%
-50.00%
0.00%
20.00%
40.00%
60.00%
80.00%
100.00%
Chillian
SSF
FDF
SSF*FDF
Gf
Poly. (Gf)



dGf as a function of 1-G(MCNP)
5%
4%
3%
2%
1%
0%
-1%
-2%
-3%
-4%
-5%
0%
1%
2%
3%
4%
5%
6%
7%
8%
9%
10%
Chillian
SSF
FDF
Gf
SSF*FDF
Poly. (Gf)
Ni-58
Ni-58
Ni-64
Zr-90
W-184

# Spectrum Characterisation

- TRIGA IJS
- Nigerian reactor
- Collaboration with CEA

Main difficulty: reliable differential cross sections of monitor reactions

# Nuclear Data Updating Strategy

Suggestion (ref. M. Blaauw):

- Do not update by data type but by nuclide

Review all data for one nuclide rather than one data type for all nuclides to avoid introducing inconsistencies

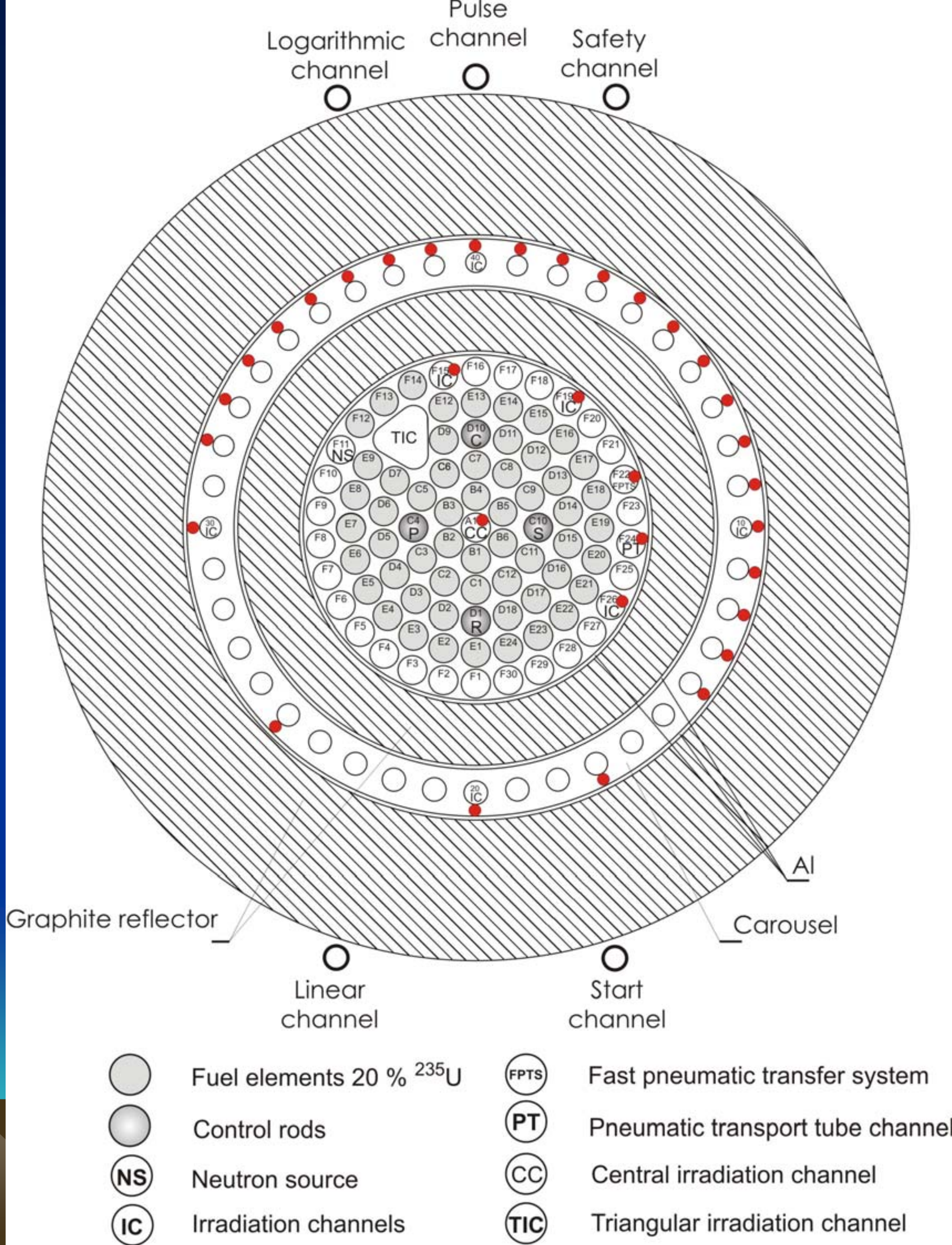
# CRP Outputs

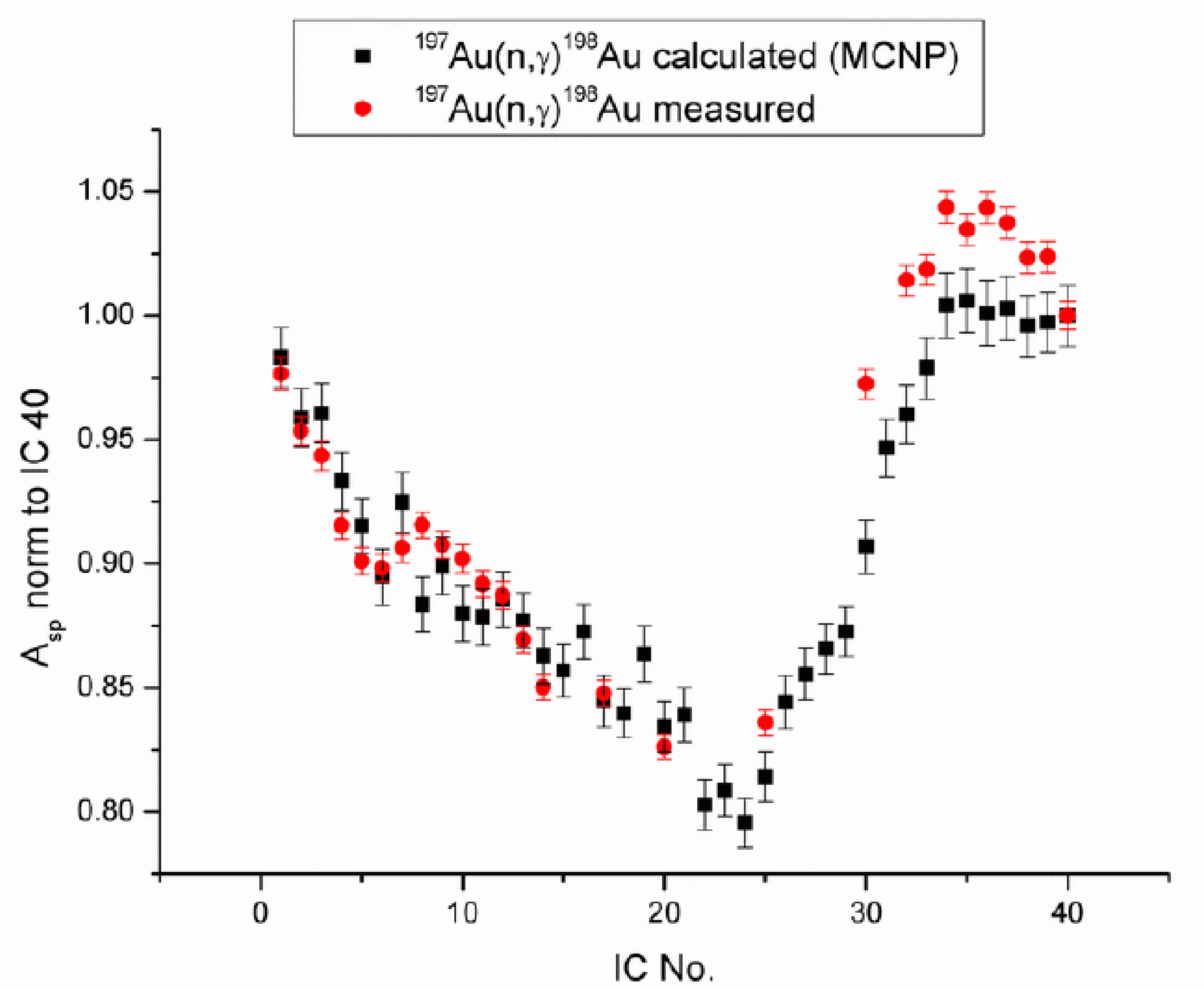
Contributions:

- MATSSF for self-shielding calculations
- GRUPINT for spectrum analysis
- Starter “activation” library
- Document with rigorous and self-consistent definitions of constants

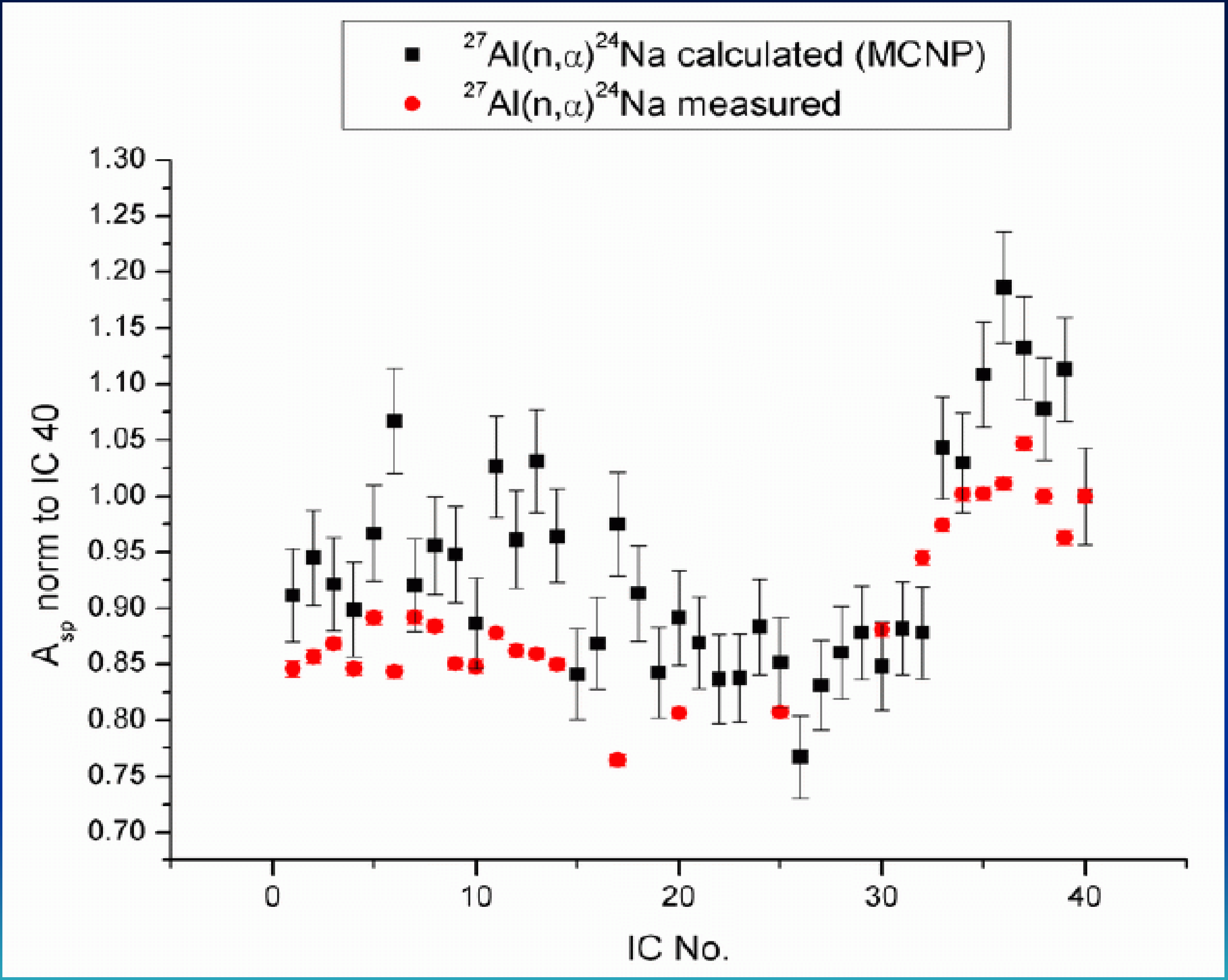
# Neutron spectrum

- Detailed Monte Carlo model developed.
- Al-Au(0.1%) foils irradiated in 33 channels (6 in the core, 27 in the reflector)
- $^{197}Au(n,\gamma)^{197}Au$ (thermal flux monitor) and $^{27}Al(n,\alpha)^{23}Na$ (fast flux monitor) activities measured.
- Calculated and measured values compared.


Pulse channel
Logarithmic channel
Safety channel
TIC
Al
Graphite reflector
Carousel
Linear channel
Start channel
Fuel elements 20 % $^{235}$U
Control rods
Neutron source
Irradiation channels
Fast pneumatic transfer system
Pneumatic transport tube channel
Central irradiation channel
Triangular irradiation channel



$^{197}Au(n,\gamma)^{198}Au$ calculated (MCNP)
$^{197}Au(n,\gamma)^{198}Au$ measured
$A_{sp}$ norm to IC 40
1.05
1.00
0.95
0.90
0.85
0.80
0
10
20
30
40
IC No.



$^{27}Al(n,\alpha)^{24}Na$ calculated (MCNP)
$^{27}Al(n,\alpha)^{24}Na$ measured
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
$A_{sp}$ norm to IC 40
0
10
20
30
40
IC No.

# Neutron spectrum (cont.)

- Computational model validated by flux distribution measurements.
- Spectrum parameterised by analytic function, modulated by the fine structure of the calculated spectrum.
- Multi-monitor irradiation in 4 selected channels.
- Parameters adjusted to match measured activities.

# Neutron spectrum (cont.)

$$\psi_t = C_t\, E\left[e^{-E/kT} + C_{t1}e^{-E/kT_1} + C_{t2}e^{-E/kT_2}\right]$$

$$\psi_e = E^{-\left[1+\alpha_0+\alpha_1 \log E+\alpha_2(\log E)^2\right]}$$

$$\psi_f = C_f e^{-E/W}\sinh\left(\sqrt{EW_b}\right)\cdot\frac{1}{E^m} \quad or$$

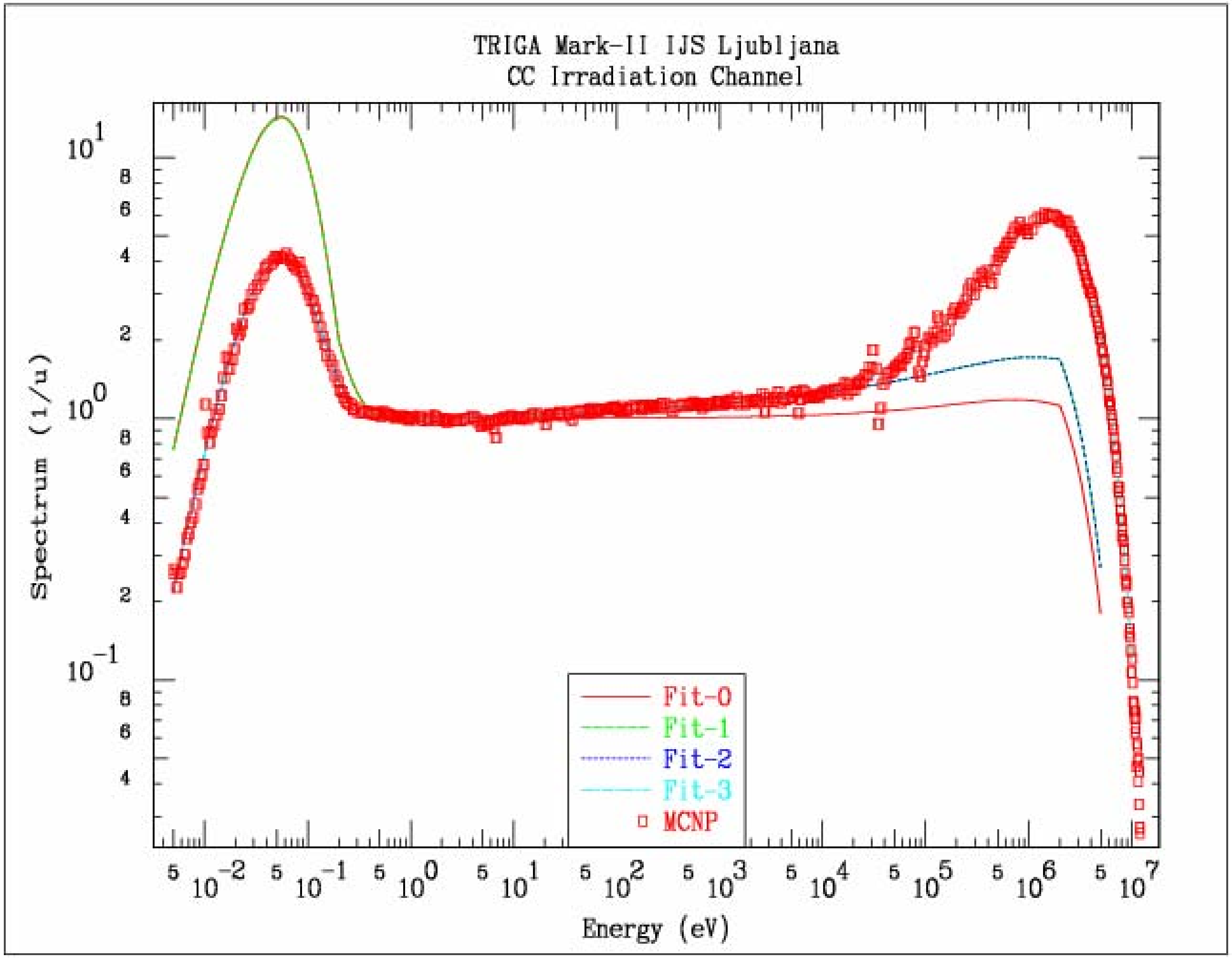
$$C_f\sqrt{E}\; e^{-E/E_T}\cdot\frac{1}{E^{m_0+m_1E}}$$

$$\psi = K_t\,\psi_t + K_e\,\psi_e + K_f\psi_f$$

*Ke* = 1 for *Et* < *E* < *Ef*
0 otherwise

*Kt* = 1 + *Ot* - *Ke*

*Kf* = 1 + *Of* - *Ke*


TRIGA Mark-II IJS Ljubljana
CC Irradiation Channel
Spectrum (1/u)
Energy (eV)
Fit-0
Fit-1
Fit-2
Fit-3
MCNP

# Neutron spectrum (cont.)

Results:

- Selected reaction rate ratios were considered.
- Some reactions excluded – cross sections not reliable enough.

Basis:

- Use computed spectrum on fine group structure.
- Calculate reaction rates by multiplying flux with cross-sections from IRDF-2002.
- Consider epithermal self-shielding.

# CC

| Target | Product | Ratio | Target | Product | Ratio | Dif.[%] | Unc.[%] |
|---|---|---|---|---|---|---|---|
| 79-Au-197g | 79-Au-198 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 947.79 | -15.5* | ( 3.4) |
| 13-Al- 27g | 12-Mg- 27 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 1.629E-2 | -13.8* | ( 2.9) |
| 13-Al- 27g | 11-Na- 24 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 3.175E-3 | -12.5* | ( 2.9) |
| 13-Al- 27g | 12-Mg- 27 | Tot/Tot | 79-Au-197g | 79-Au-198 | 1.718E-5 | 1.9 | ( 3.1) |
| 13-Al- 27g | 11-Na- 24 | Tot/Tot | 79-Au-197g | 79-Au-198 | 3.350E-6 | 3.5 | ( 3.2) |
| 79-Au-197g | 79-Au-198 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 2780 | -2.5 | ( 3.2) |
| 40-Zr- 96g | 40-Zr- 97 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 6.3610 | -0.3 | ( 2.5) |
| 40-Zr- 90g | 40-Zr- 89 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 1.520E-3 | -0.2 | ( 3.2) |
| 79-Au-197g | 79-Au-198 | Tot/Tot | 40-Zr- 96g | 40-Zr- 97 | 437.03 | -2.2 | ( 3.2) |
| 40-Zr- 90g | 40-Zr- 89 | Tot/Tot | 40-Zr- 96g | 40-Zr- 97 | 2.390E-4 | 0.1 | ( 3.0) |
| 30-Zn- 64g | 30-Zn- 65 | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 9.6714 | 2.2 | ( 2.2) |
| 30-Zn- 70g | 30-Zn- 71m | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 0.1022 | -52.8* | ( 1.3) |
| 30-Zn- 64g | 29-Cu- 64 | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 0.3832 | -16.4* | ( 1.0) |
| 28-Ni- 64g | 28-Ni- 65 | Tot/Tot | 79-Au-197g | 79-Au-198 | 7.114E-3 | 16.5* | ( 1.2) |
| 25-Mn- 55g | 25-Mn- 56 | Tot/Tot | 79-Au-197g | 79-Au-198 | 6.471E-2 | 22.8* | ( 0.2) |
| 42-Mo- 98g | 42-Mo- 99 | Tot/Tot | 79-Au-197g | 79-Au-198 | 3.785E-3 | 2.1* | ( 2.2) |
| 42-Mo-100g | 42-Mo-101 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.564E-3 | -14.0* | ( 2.5) |
| 74-W -186g | 74-W -187 | Tot/Tot | 79-Au-197g | 79-Au-198 | 0.3288 | -11.1* | ( 2.3) |
| 28-Ni- 58g | 27-Co- 58 | Tot/Tot | 79-Au-197g | 79-Au-198 | 4.598E-4 | -1.1 | ( 2.2) |
| 42-Mo- 92g | 41-Nb- 92 | Tot/Tot | 79-Au-197g | 79-Au-198 | 4.694E-5 | -4.9* | ( 2.5) |
| 28-Ni- 58g | 27-Co- 58 | Tot/Tot | 28-Ni- 64g | 28-Ni- 65 | 6.464E-2 | -15.1* | ( 1.4) |
| 42-Mo- 92g | 41-Nb- 92 | Tot/Tot | 42-Mo- 98g | 42-Mo- 99 | 1.240E-2 | -6.8* | ( 4.3) |

# FPTS

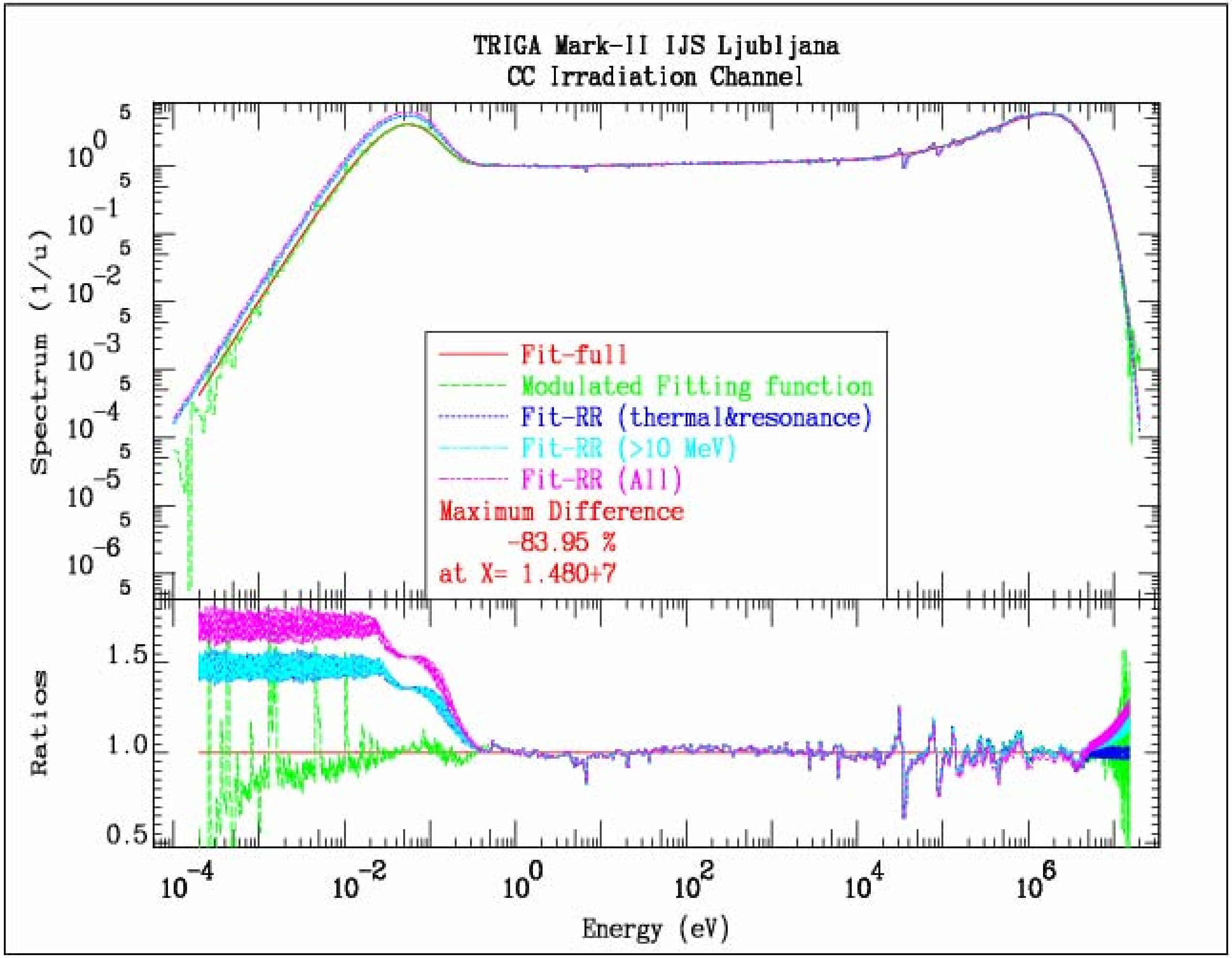
| Target | Product | Ratio | Target | Product | Ratio | Dif.[%] | Unc.[%] |
|---|---|---|---|---|---|---|---|
| 79-Au-197g | 79-Au-198 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 680.89 | -8.7* | ( 3.5) |
| 13-Al- 27g | 12-Mg- 27 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 5.898E-3 | -7.5* | ( 3.0) |
| 13-Al- 27g | 11-Na- 24 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 1.188E-3 | -9.6* | ( 3.1) |
| 13-Al- 27g | 12-Mg- 27 | Tot/Tot | 79-Au-197g | 79-Au-198 | 8.662E-6 | 1.2 | ( 3.3) |
| 13-Al- 27g | 11-Na- 24 | Tot/Tot | 79-Au-197g | 79-Au-198 | 1.745E-6 | -1.1 | ( 3.3) |
| 79-Au-197g | 79-Au-198 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 2600 | 3.1 | ( 3.3) |
| 40-Zr- 96g | 40-Zr- 97 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 3.6928 | 0.8 | ( 2.6) |
| 40-Zr- 90g | 40-Zr- 89 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 8.125E-4 | 0.6 | ( 5.7) |
| 79-Au-197g | 79-Au-198 | Tot/Tot | 40-Zr- 96g | 40-Zr- 97 | 704.09 | 2.3 | ( 3.1) |
| 40-Zr- 90g | 40-Zr- 89 | Tot/Tot | 40-Zr- 96g | 40-Zr- 97 | 2.200E-4 | -0.2 | ( 5.6) |
| 30-Zn- 64g | 30-Zn- 65 | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 10.13 | 2.3 | ( 2.2) |
| 30-Zn- 70g | 30-Zn- 71m | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 0.1086 | -17.8* | ( 2.3) |
| 30-Zn- 64g | 29-Cu- 64 | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 0.1542 | -13.6* | ( 1.7) |
| 28-Ni- 64g | 28-Ni- 65 | Tot/Tot | 79-Au-197g | 79-Au-198 | 9.856E-3 | 5.4* | ( 1.5) |
| 25-Mn- 55g | 25-Mn- 56 | Tot/Tot | 79-Au-197g | 79-Au-198 | 8.818E-2 | 15.8* | ( 0.3) |
| 42-Mo- 98g | 42-Mo- 99 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.710E-3 | 6.0* | ( 2.7) |
| 42-Mo-100g | 42-Mo-101 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.187E-3 | 5.1* | ( 5.8) |
| 74-W -186g | 74-W -187 | Tot/Tot | 79-Au-197g | 79-Au-198 | 0.3415 | -12.7* | ( 3.8) |
| 28-Ni- 58g | 27-Co- 58 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.263E-4 | 0.2 | ( 2.5) |
| 42-Mo- 92g | 41-Nb- 92 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.320E-5 | 49.8* | ( 9.1) |
| 28-Ni- 58g | 27-Co- 58 | Tot/Tot | 28-Ni- 64g | 28-Ni- 65 | 2.296E-2 | -5.0* | ( 1.4) |
| 42-Mo- 92g | 41-Nb- 92 | Tot/Tot | 42-Mo- 98g | 42-Mo- 99 | 8.561E-3 | 41.3* | ( 9.1) |

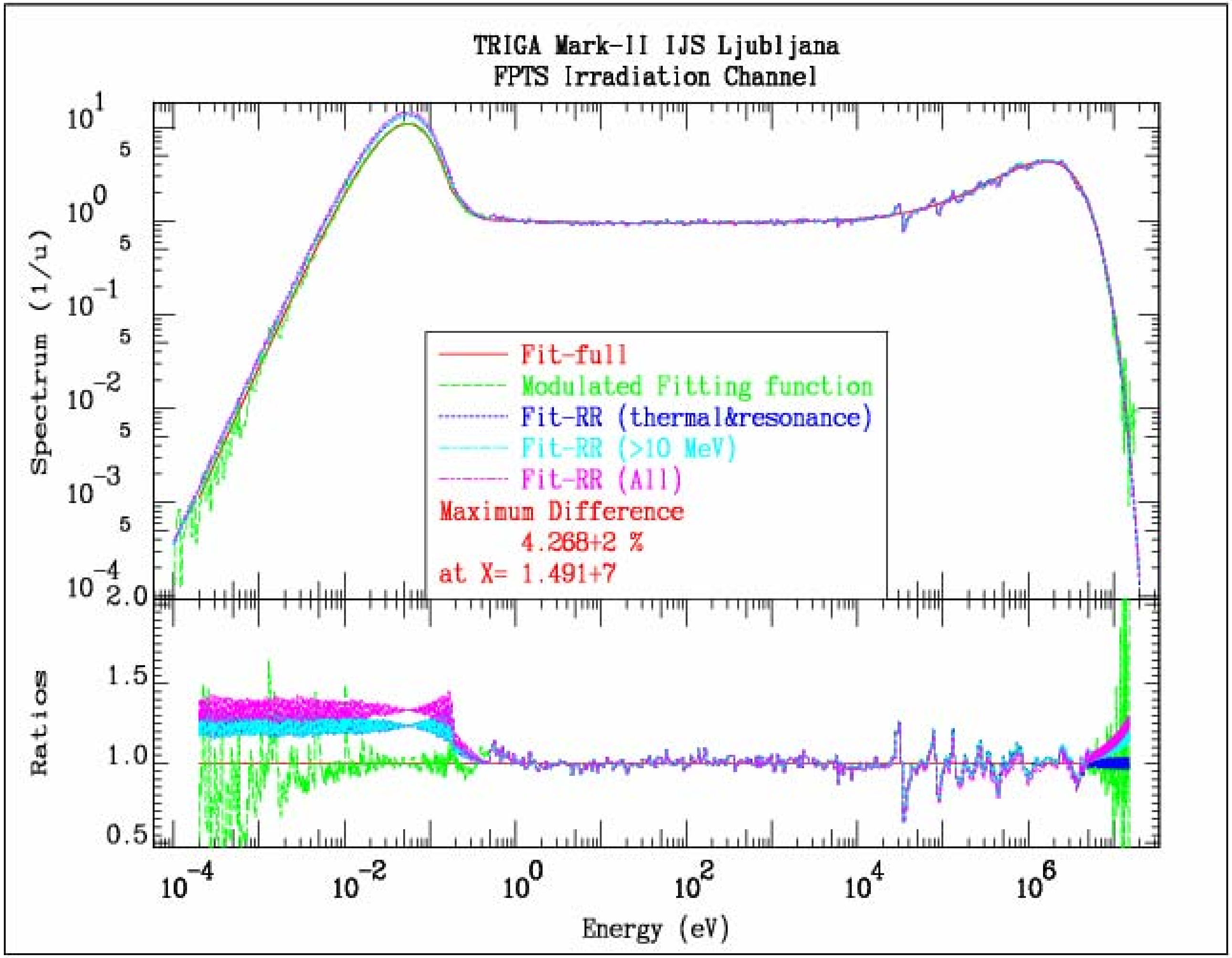
# PT

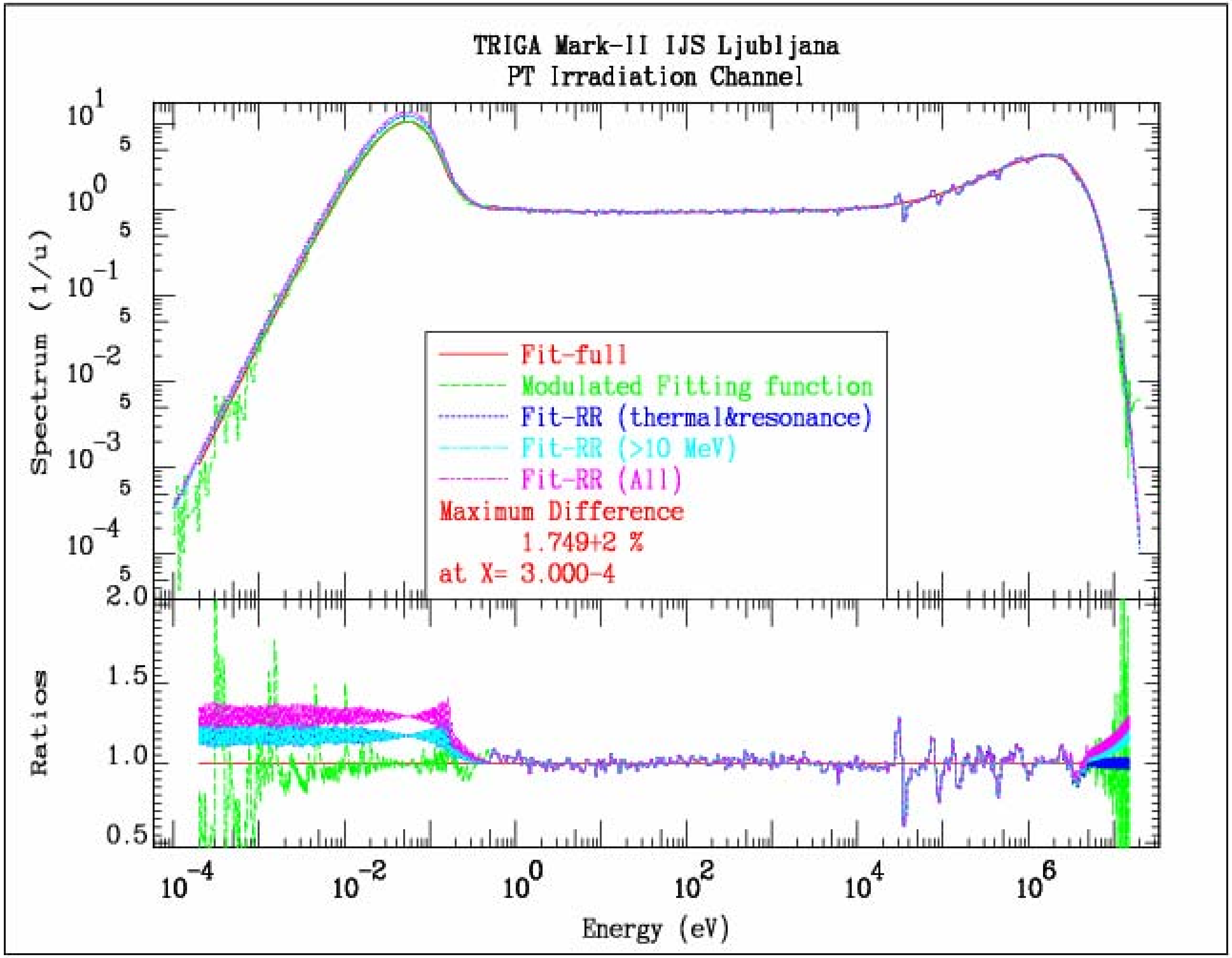
| Target | Product | Ratio | Target | Product | Ratio | Dif.[%] | Unc.[%] |
|---|---|---|---|---|---|---|---|
| 79-Au-197g | 79-Au-198 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 695.88 | -6.2* | ( 3.5) |
| 13-Al- 27g | 12-Mg- 27 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 6.356E-3 | -6.2* | ( 3.0) |
| 13-Al- 27g | 11-Na- 24 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 1.280E-3 | -4.9* | ( 3.1) |
| 13-Al- 27g | 12-Mg- 27 | Tot/Tot | 79-Au-197g | 79-Au-198 | 9.133E-6 | 0.1 | ( 3.3) |
| 13-Al- 27g | 11-Na- 24 | Tot/Tot | 79-Au-197g | 79-Au-198 | 1.840E-6 | 1.3 | ( 3.3) |
| 79-Au-197g | 79-Au-198 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 2623 | 4.6 | ( 3.3) |
| 40-Zr- 96g | 40-Zr- 97 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 3.7522 | 0.8 | ( 2.6) |
| 40-Zr- 90g | 40-Zr- 89 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 8.558E-4 | -0.3 | ( 5.7) |
| 79-Au-197g | 79-Au-198 | Tot/Tot | 40-Zr- 96g | 40-Zr- 97 | 699.18 | 3.8 | ( 3.1) |
| 40-Zr- 90g | 40-Zr- 89 | Tot/Tot | 40-Zr- 96g | 40-Zr- 97 | 2.281E-4 | -1.1 | ( 5.6) |
| 30-Zn- 64g | 30-Zn- 65 | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 10.08 | 0.5 | ( 2.2) |
| 30-Zn- 70g | 30-Zn- 71m | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 0.1081 | -14.5* | ( 2.3) |
| 30-Zn- 64g | 29-Cu- 64 | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 0.1651 | -8.7* | ( 1.7) |
| 28-Ni- 64g | 28-Ni- 65 | Tot/Tot | 79-Au-197g | 79-Au-198 | 9.650E-3 | 1.7* | ( 1.5) |
| 25-Mn- 55g | 25-Mn- 56 | Tot/Tot | 79-Au-197g | 79-Au-198 | 8.636E-2 | 9.8* | ( 0.2) |
| 42-Mo- 98g | 42-Mo- 99 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.718E-3 | 3.4* | ( 2.6) |
| 42-Mo-100g | 42-Mo-101 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.228E-3 | 3.8* | ( 3.8) |
| 74-W -186g | 74-W -187 | Tot/Tot | 79-Au-197g | 79-Au-198 | 0.3402 | -12.2* | ( 3.7) |
| 28-Ni- 58g | 27-Co- 58 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.387E-4 | 0.0 | ( 2.4) |
| 42-Mo- 92g | 41-Nb- 92 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.447E-5 | 51.3* | ( 7.1) |
| 28-Ni- 58g | 27-Co- 58 | Tot/Tot | 28-Ni- 64g | 28-Ni- 65 | 2.473E-2 | -1.7* | ( 1.4) |
| 42-Mo- 92g | 41-Nb- 92 | Tot/Tot | 42-Mo- 98g | 42-Mo- 99 | 9.003E-3 | 46.3* | ( 7.1) |

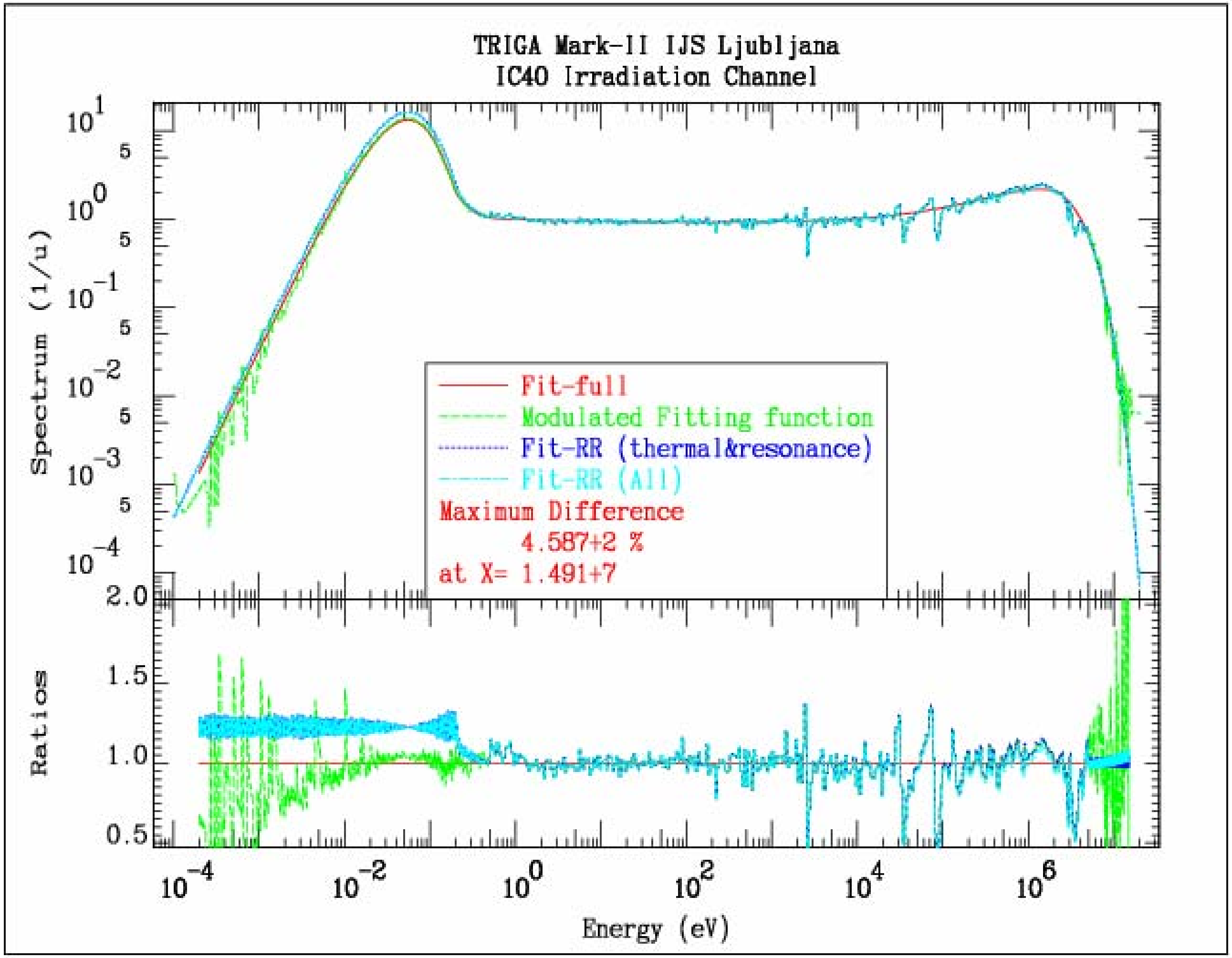
# IC40

| Target | Product | Ratio | Target | Product | Ratio | Dif.[%] | Unc.[%] |
|---|---|---|---|---|---|---|---|
| 79-Au-197g | 79-Au-198 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 652.67 | -5.3* | ( 3.5) |
| 13-Al- 27g | 12-Mg- 27 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 2.110E-3 | -9.4* | ( 3.6) |
| 13-Al- 27g | 11-Na- 24 | Tot/Tot | 13-Al- 27g | 13-Al- 28 | 4.221E-4 | 0.7* | ( 4.3) |
| 13-Al- 27g | 12-Mg- 27 | Tot/Tot | 79-Au-197g | 79-Au-198 | 3.233E-6 | -4.4 | ( 3.9) |
| 13-Al- 27g | 11-Na- 24 | Tot/Tot | 79-Au-197g | 79-Au-198 | 6.468E-7 | 6.3 | ( 4.5) |
| 79-Au-197g | 79-Au-198 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 2624 | 4.0 | ( 3.5) |
| 40-Zr- 96g | 40-Zr- 97 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 3.1672 | 0.9 | ( 2.9) |
| 40-Zr- 90g | 40-Zr- 89 | Tot/Tot | 40-Zr- 94g | 40-Zr- 95 | 3.090E-4 | -2.0 | ( 11.0) |
| 79-Au-197g | 79-Au-198 | Tot/Tot | 40-Zr- 96g | 40-Zr- 97 | 828.50 | 3.1 | ( 3.2) |
| 40-Zr- 90g | 40-Zr- 89 | Tot/Tot | 40-Zr- 96g | 40-Zr- 97 | 9.757E-5 | -2.8 | ( 10.0) |
| 30-Zn- 64g | 30-Zn- 65 | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 10.23 | 4.3 | ( 2.5) |
| 30-Zn- 70g | 30-Zn- 71m | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 0.1106 | -16.5* | ( 4.4) |
| 30-Zn- 64g | 29-Cu- 64 | Tot/Tot | 30-Zn- 68g | 30-Zn- 69m | 5.543E-2 | -6.5* | ( 8.3) |
| 28-Ni- 64g | 28-Ni- 65 | Tot/Tot | 79-Au-197g | 79-Au-198 | 1.027E-2 | -0.7* | ( 1.4) |
| 25-Mn- 55g | 25-Mn- 56 | Tot/Tot | 79-Au-197g | 79-Au-198 | 9.179E-2 | 11.1* | ( 0.2) |
| 42-Mo- 98g | 42-Mo- 99 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.487E-3 | 9.0* | ( 3.2) |
| 42-Mo-100g | 42-Mo-101 | Tot/Tot | 79-Au-197g | 79-Au-198 | 2.185E-3 | -8.8* | ( 3.3) |
| 74-W -186g | 74-W -187 | Tot/Tot | 79-Au-197g | 79-Au-198 | 0.3450 | -11.1* | ( 3.8) |
| 28-Ni- 58g | 27-Co- 58 | Tot/Tot | 79-Au-197g | 79-Au-198 | 8.439E-5 | 0.6 | ( 3.1) |
| 42-Mo- 92g | 41-Nb- 92 | Tot/Tot | 79-Au-197g | 79-Au-198 | 8.665E-6 | -12.0* | (100.0) |
| 28-Ni- 58g | 27-Co- 58 | Tot/Tot | 28-Ni- 64g | 28-Ni- 65 | 8.217E-3 | -37.5* | ( 1.7) |
| 42-Mo- 92g | 41-Nb- 92 | Tot/Tot | 42-Mo- 98g | 42-Mo- 99 | 3.484E-3 | -19.2* | (100.0) |


TRIGA Mark-II IJS Ljubljana
CC Irradiation Channel
Spectrum (1/u)
Ratios
Energy (eV)
Fit-full
Modulated Fitting function
Fit-RR (thermal&resonance)
Fit-RR (>10 MeV)
Fit-RR (All)
Maximum Difference
-83.95 %
at X= 1.480+7


TRIGA Mark-II IJS Ljubljana
FPTS Irradiation Channel
Spectrum (1/u)
Ratios
Energy (eV)
Fit-full
Modulated Fitting function
Fit-RR (thermal&resonance)
Fit-RR (>10 MeV)
Fit-RR (All)
Maximum Difference
4.268+2 %
at X= 1.491+7


TRIGA Mark-II IJS Ljubljana
PT Irradiation Channel
Spectrum (1/u)
Ratios
Energy (eV)
Fit-full
Modulated Fitting function
Fit-RR (thermal&resonance)
Fit-RR (>10 MeV)
Fit-RR (All)
Maximum Difference
1.749+2 %
at X= 3.000-4


TRIGA Mark-II IJS Ljubljana
IC40 Irradiation Channel
Spectrum (1/u)
Ratios
Energy (eV)
Fit-full
Modulated Fitting function
Fit-RR (thermal&resonance)
Fit-RR (All)
Maximum Difference
4.587+2 %
at X= 1.491+7

# Conclusions

Results:

- Method seems to work.
- Generally, adjusted spectrum reproduces well the measured reaction rates.
- Calculated thermal spectrum lower than measured by gold activation, particularly in the core centre.

Question:

- Do we trust the results?

# Conclusions (cont.)

Weaknesses:

- Threshold cross sections abundant and well-known, resonance cross sections are not.
- Thermal spectrum in present analysis based on Au and Zr.

Further work :

- Include $^{232}Th$, $^{238}U$ and $^{58}Fe$
- Add measurements under Cd cover

# Summary

- Rigorous definitions of constants for NAA from differential cross sections.
- Spectrum calculation using validated computational model.
- Parameterisation of the calculated spectrum.
- Adjustment of parameters to match measured monitor activities.
- Spectrum can be used to validate/adjust cross sections of other nuclides.