Evaluation of Cross-Sections for *n* and *p* Induced Reactions on W Producing Hazardous Radionuclides in the Energy Range up to 3 GeV

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Objectives

- to perform cross-section evaluation for reactions on tungsten producing of hazardous radionuclides at intermediate and high energies
- to make a first step for the preparation of nuclear model codes and processing tools obtaining activation data file for tungsten isotopes at energies up to 3 GeV

p+W and n+W interactions

The main contributors to the hazard (D.Ene, Sweden)

No	nuclide	$T_{1/2}$(s)	H1(%)
1	W187	8.539E+04	17.63
2	Gd148	2.354E+09	14.14
3	Re186g	3.263E+05	12.04
4	Ta182g	9.887E+06	7.85
5	Hf172	5.900E+07	7.79
6	W-185g	6.489E+06	5.97
7	Re188	6.121E+04	5.16
8	Hf178m1	4.000E+00	4.68
9	Hf179m1	1.867E+01	2.66

Problems

- uncertainty of nuclear model predictions in GeV region

- yield of isomers

- yield of light and heavy clusters, Z > 2

- agreement with low and high energy simulations using different codes

examples: MCNPX calculations, available evaluated data

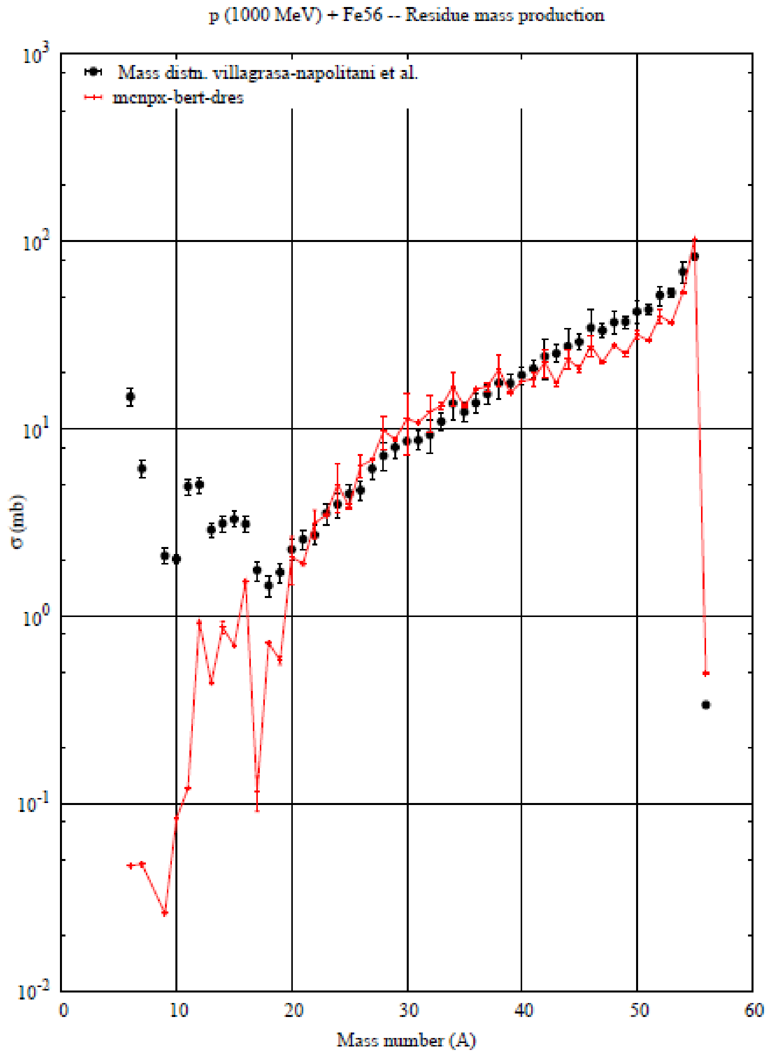
- experimental data for cumulative yields and natural tungsten

Evaluated data: JENDL-HE (up to 3 GeV)

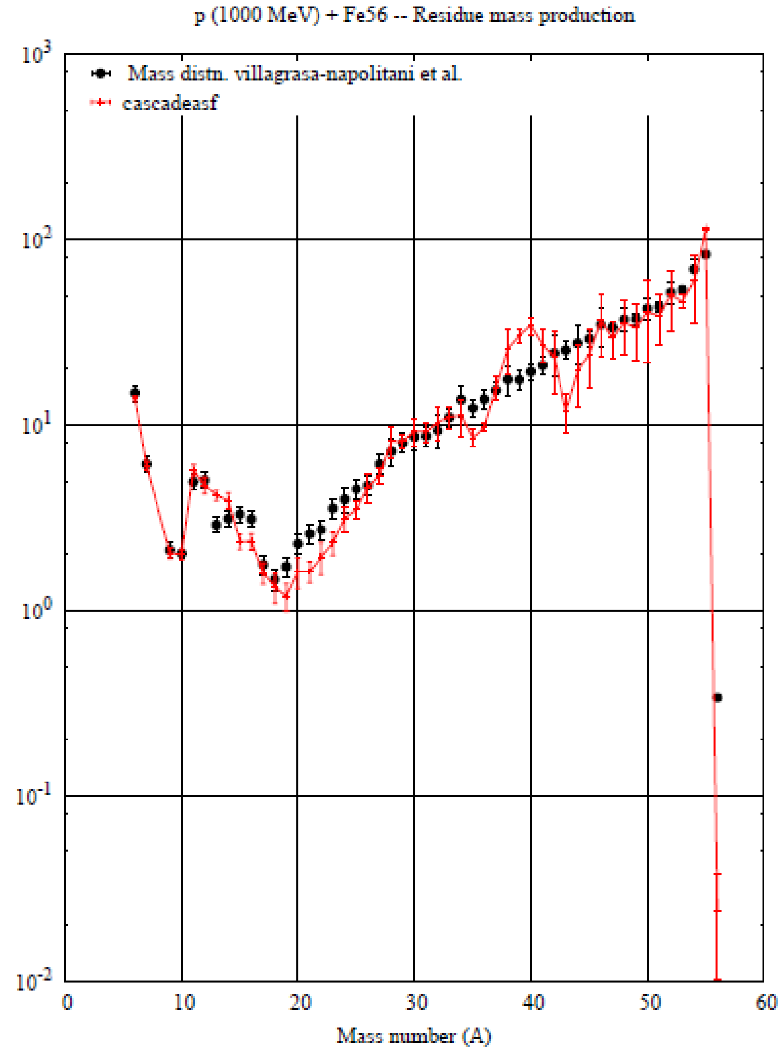
isomers, calculations above 150 MeV

Codes: MCNPX models Weisskopf-Ewing

Bertini-Dresner, MCNPX



CASCADE (KIT)



Solutions

Intranuclear cascade model + Hauser-Feshbach model

CASCADE (KIT,JINR) **+ TALYS**

Simulation of light and heavy cluster emission

Expected improvement of accuracy

CASCADE/ASF KIT, 2005

IAEA Intercomparison of spallation models , 2009

A.Stankovskiy (SCK CEN): CASCADEX: 2008

High energy model (MC) +evaporation model (deterministic): 2000, 2001

S.Yavshits, O.Grudzevich

Code implementation

Computing time due to Hauser-Feshbach and high energy of projectiles

i) basic calculations

ii) MC calculations for covariances

Combination of advanced and well justified approaches

- reduced uncertainty of modeling

- yields of nuclei in metastable states

- unified approach for whole energy range under consideration

Possible improvement

"hybrid" transition between PE model (TALYS) to INC (CASCADE) at 100-200 MeV

Alternative approaches

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ALICE/ASH

comparison with TALYS for $Z > 50$ for (p,x) reaction up to 150 MeV

Hybrid Monte Carlo (HMS) – Hauser-Feshbach model (TALYS)

JEFF Meeting December 2010

Independent origins of knowledge about considered reactions

Measured yields for p+W reactions

EXFOR: about 3700 (Z_R,A_R,E_0) points

independent (,IND,SIG)

cumulative (,CUM,SIG)

undefined by EXFOR compilers or by authors

Kelley, 2005 (74-W-0(P,X) ELEM/MASS,,SIG). C1225006

Statistical error only

O0768189, (74-W-0(P,X)73-TA-172,IND,SIG)

Disagreement between some measurements E.Porras (2000) and R.Michel (2002) (74-W-0(P,X)73-TA-182,CUM,SIG)

Duplications

R.Michel (2002) O1099053 and M.Miah (2002) O1100011

Incorrect compilation

Bonardi (2011) O1884 „W-0“ is shown instead of W-186

Difference with common cross-sections evaluations

Cumulative yields

about 50 % of measurements

cumulative and/or individual data for precursors

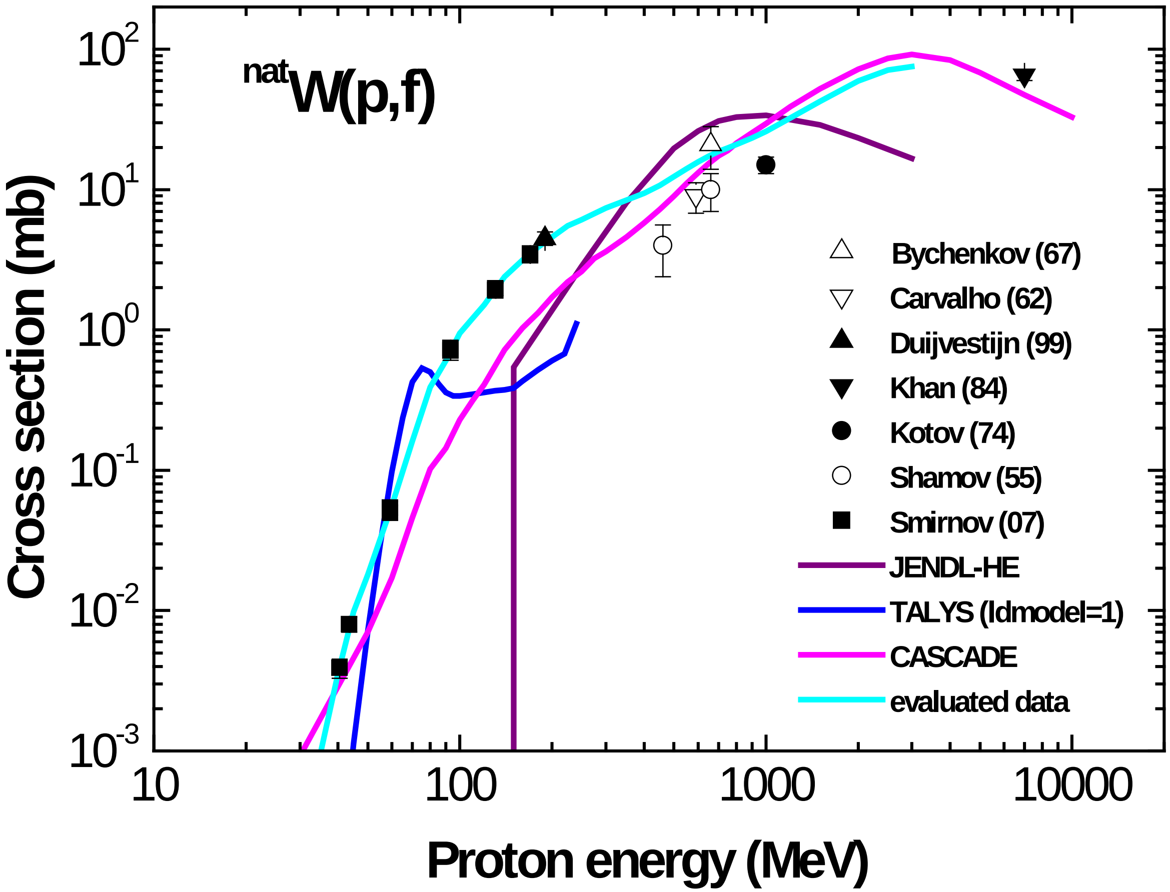
Data for natural mixture of isotopes of W

about 68 % of measurements

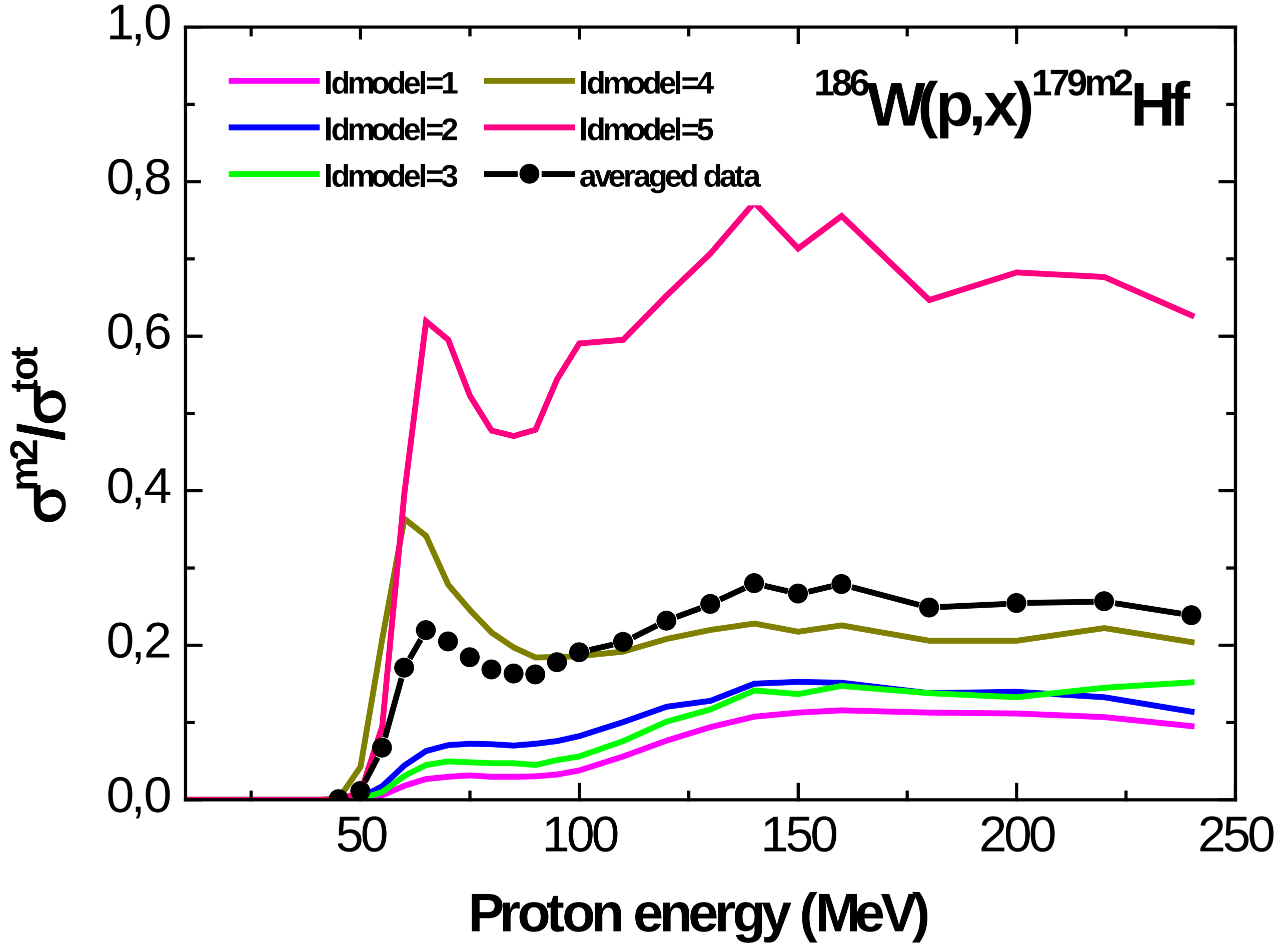
Positive influence on the quality of final data

Steps of evaluation

Correction of model parameters



Calculations using different models



Covariance information

CASCADE (KIT): INC+EQ

Evaluation of uncertainties: MC method of D.L.Smith

Parameters: a, δ, a_0, E_d, σ for n-n , n-π

$p_0=\{p_{01},\ldots.p_{0M}\}$, $\Delta p_0=\{\Delta p_{01,},\ldots..,\Delta p_{0M}\}$

Covariance matrix after K histories

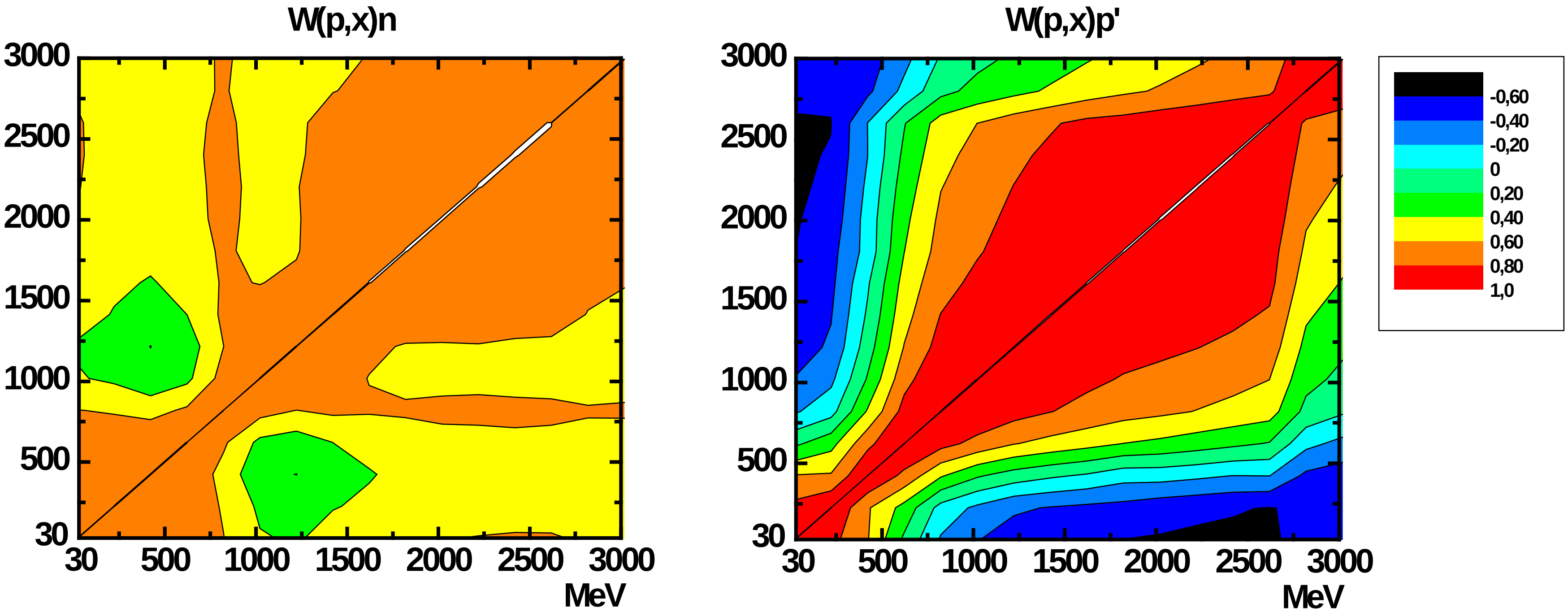
$$V_{i,j} = (1/K) \sum_{k=1,K}^{K} (\sigma_{ki} - \sigma_{0i})(\sigma_{kj} - \sigma_{0j})$$ for i,j=1,N (energy)

The time of computation K x N_{MC}

K : 10,000 – 100,000

Example

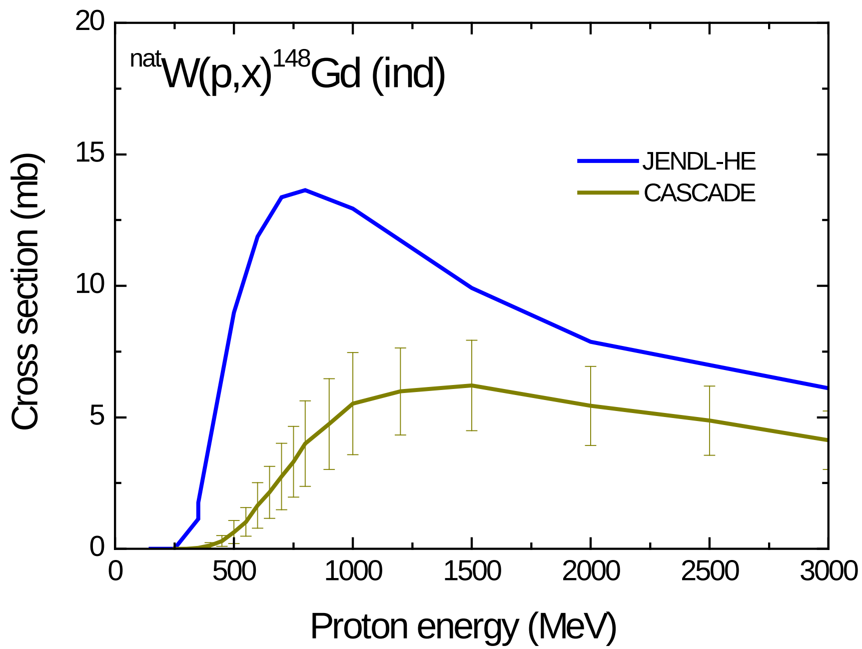
Correlation matrices for W(p,x)n and W(p,x)p cross-section



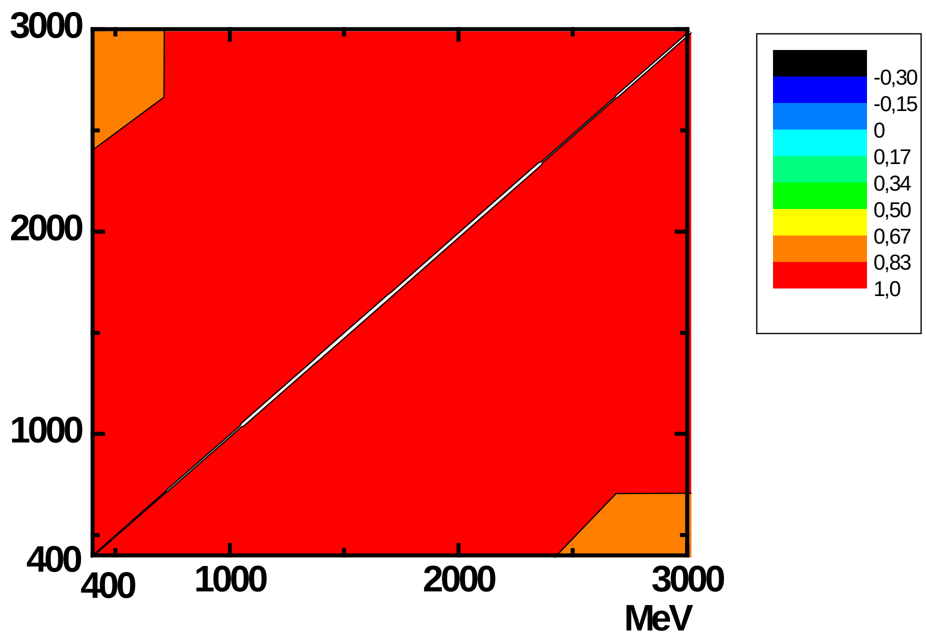
W(p,x)^{148}Gd

Nuclide	Average contribution to cumulative yield
Gd148	21. %
Tb148g	14. %
Tb148m	14. %
Dy148	26. %
Ho148g	0.52 %
Ho148m	0.52 %
Ho148m2	0.52 %
Ho152g	2.3 %
Ho152m	2.01 %
Er152	16. %
Yb156	1.9 %
Lu160	2.0 %

W(p,x)^{148}Gd

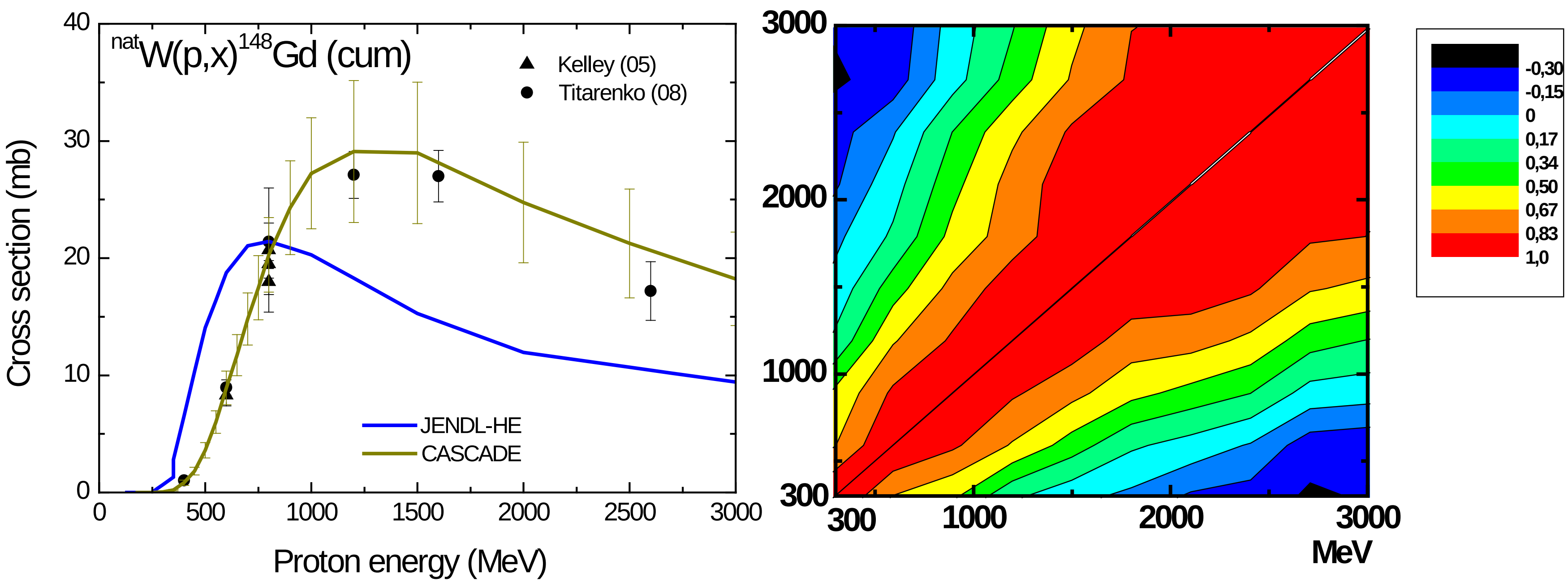


natW(p,x)148Gd (ind)
JENDL-HE
CASCADE
Cross section (mb)
Proton energy (MeV)
0
5
10
15
20
0
500
1000
1500
2000
2500
3000



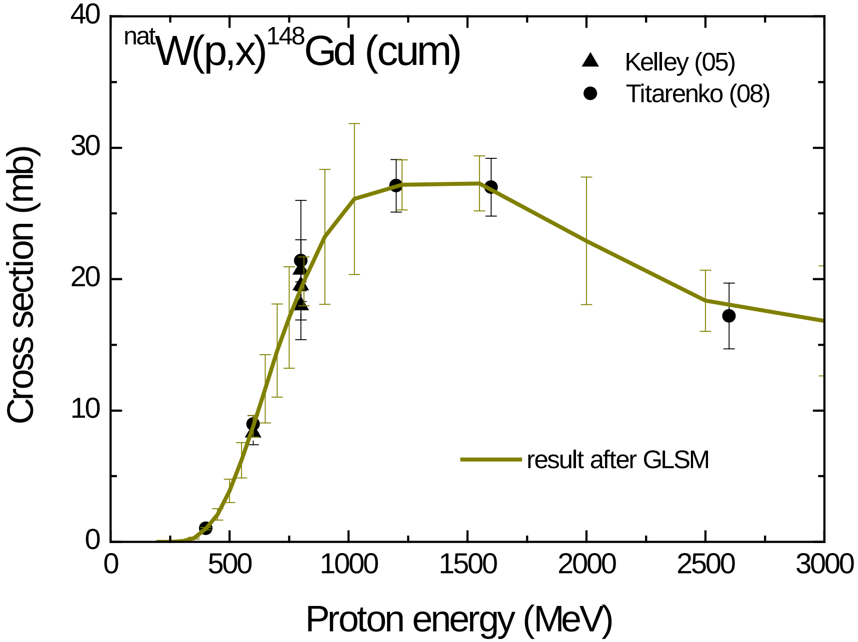
3000
2000
1000
400
400
1000
2000
3000
MeV
-0,30
-0,15
0
0,17
0,34
0,50
0,67
0,83
1,0

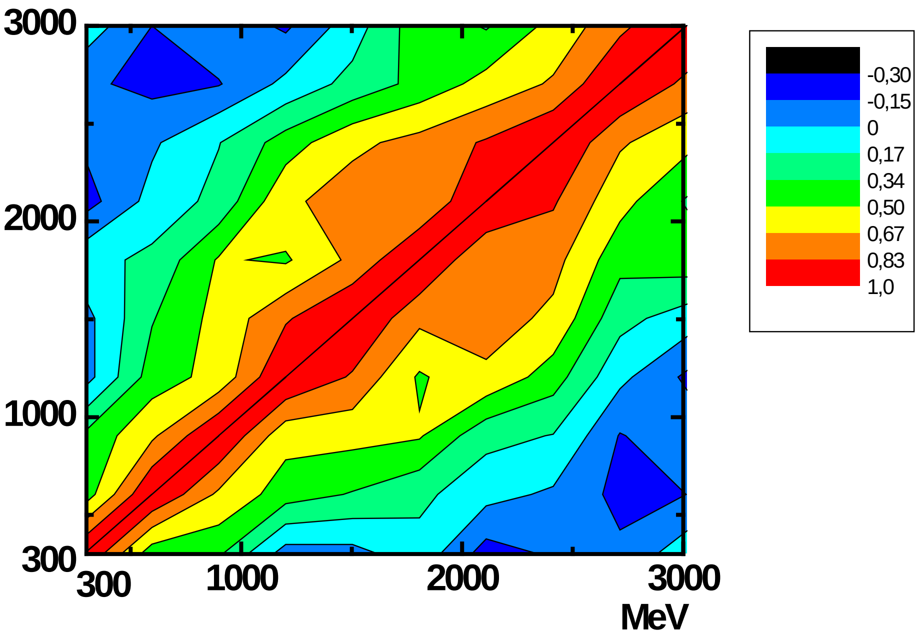
W(p,x)^{148}Gd (cumulative)



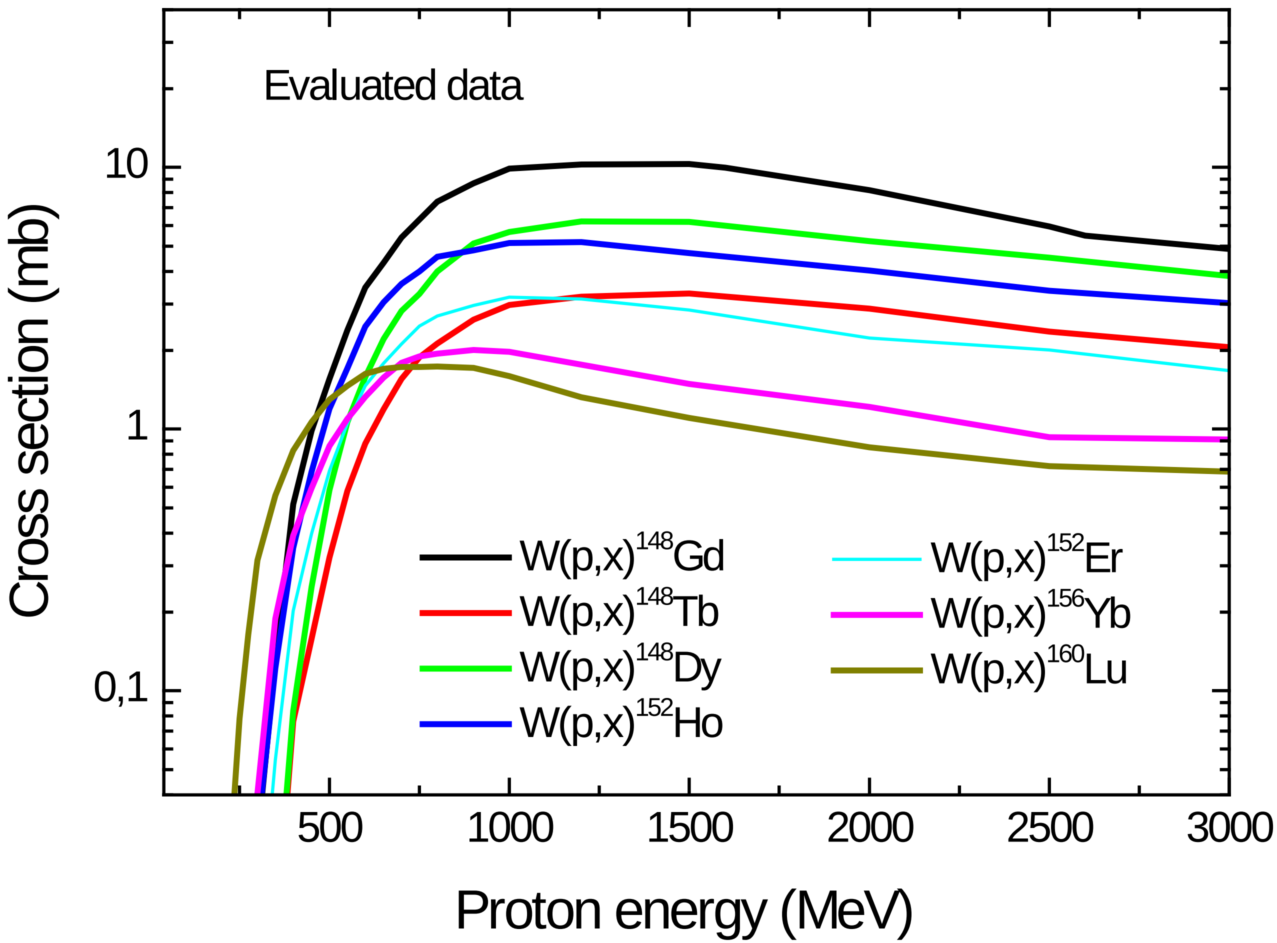
JENDL-HE: Yield of Gd148 is twice underestimated

Evaluated cross-section





W(p,x)^{148}Gd


Evaluated data
Cross section (mb)
10
1
0,1
500
1000
1500
2000
2500
3000
Proton energy (MeV)
W(p,x)148Gd
W(p,x)148Tb
W(p,x)148Dy
W(p,x)152Ho
W(p,x)152Er
W(p,x)156Yb
W(p,x)160Lu

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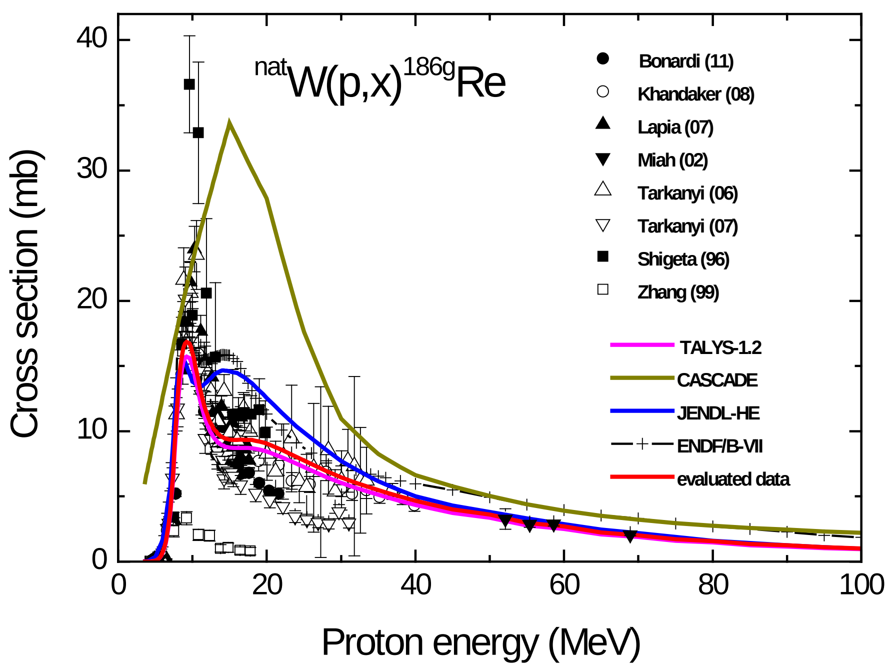
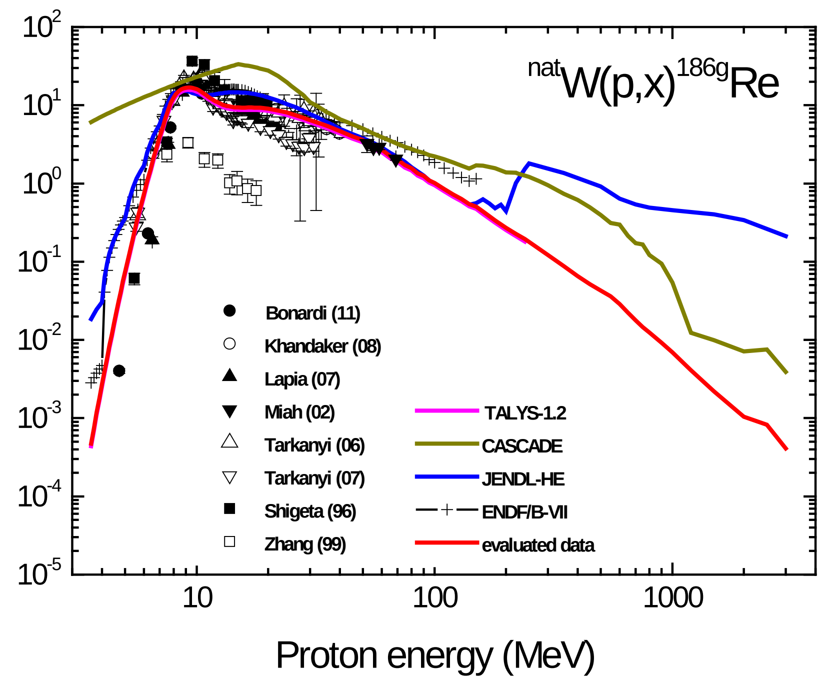
W(p,x)^{186g}Re





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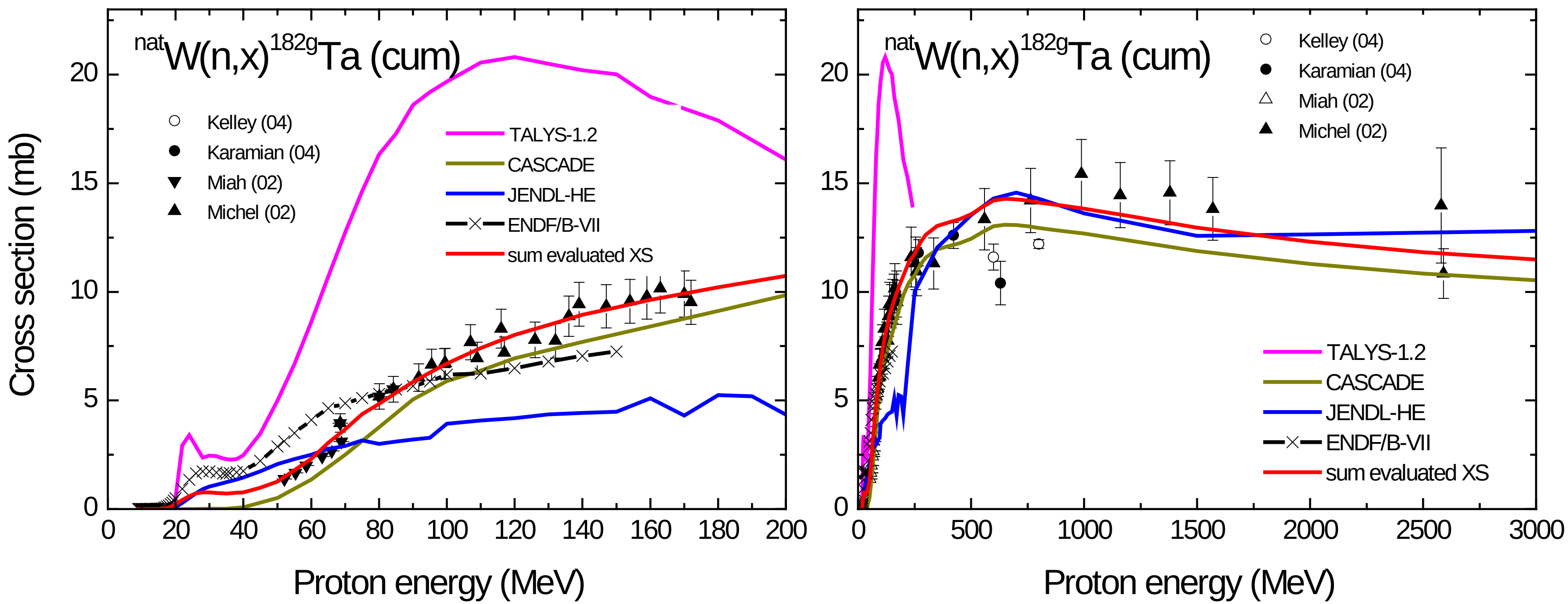
W(p,x)^{182g}Ta



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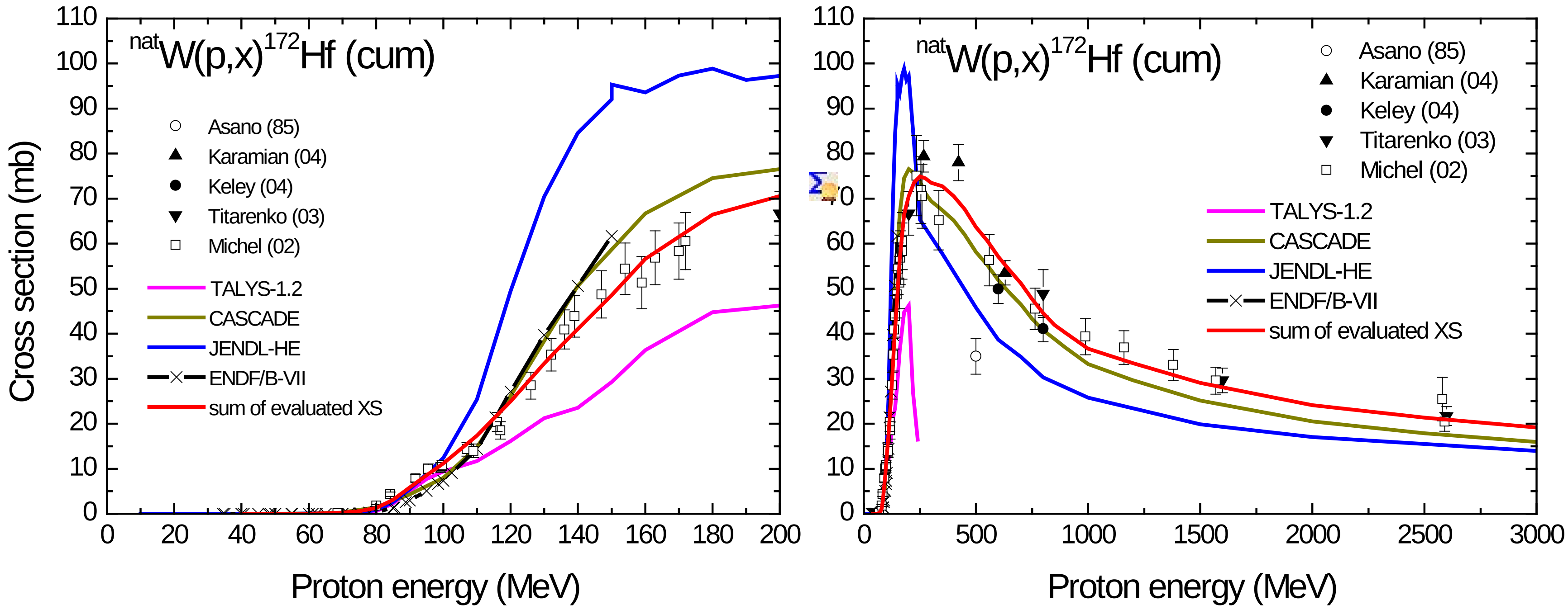
W(p,x)^{172}Hf



natW(p,x)172Hf (cum)
Asano (85)
Karamian (04)
Keley (04)
Titarenko (03)
Michel (02)
TALYS-1.2
CASCADE
JENDL-HE
ENDF/B-VII
sum of evaluated XS
Cross section (mb)
Proton energy (MeV)
natW(p,x)172Hf (cum)
Proton energy (MeV)

Conclusion

Cross-sections for reactions resulting to hazardous nuclides by the nucleon irradiation of tungsten were evaluated using advanced nuclear models and experimental data at energies up to 3 GeV

The first step is made to prepare the evaluation tools for high energy applications