Second Advanced Workshop on Model Codes for Spallation Reactions

Saclay, February 8-11, 2010

Results of the de-excitation code ABLA07

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ABLA07

see proceedings of the "Joint ICTP-IAEA Advanced Workshop on Model Codes for Spallation Reactions,, held in Trieste, Italy, 4-8 January 2008

ABLA07

1. Emission of neutrons, LCP (Z=1, 2), IMF (Z>2) and γ is considered.

2.Particle decay widths based on Weisskopf-Ewing formalism, with:

- Energy dependent inverse cross sections based on nuclear potential
- Barriers for charged particles are calculated using the Bass potential
- Thermal expansion of the source is taken into account.
- Change of angular momentum due to particle emission is considered.
- 3. The fission decay width is described by including:
 - An analytical time-dependent approach to the solution of the Fokker-Planck equation,
 - The influence of the initial deformation on the fission decay width,
 - The double-humped structure in the fission barriers of actinides,
 - Symmetry classes in low-energy fission.
- 4. Particle emission on different stages, i.e. between ground state and saddle point, between the saddle and scission point, and from two separate fission fragments, of the fission process is calculated separately.
- 5. Kinetic-energy spectra from Maxwell-Boltzmann distribution
- 6. A stage of simultaneous break-up (MF) in the decay of hot excited systems is treated.

Neutron multiplicities

p(1200 MeV) + Fe – Neutron multiplicity distribution INCL45-ABLA07 ISABEL-ABLA07



p(1200 MeV) + Fe – Neutron multiplicity distribution

INCL45-ABLA07

INCL45-GEMINI++



p(1200 MeV) + Fe – Neutron multiplicity distribution

INCL45-ABLA07

ALL MODELS



p(1200 MeV) + Pb – Neutron multiplicity distribution INCL45-ABLA07 ISABEL-ABLA07



p(1200 MeV) + Pb – Neutron multiplicity distribution

INCL45-ABLA07

INCL45-GEMINI++



p(1200 MeV) + Pb – Neutron multiplicity distribution INCL45-ABLA07 ALL MODELS



p + Fe – Average neutron (2-20 MeV) multiplicity



p + Fe – Average neutron (20+ MeV) multiplicity



p + Pb – Average neutron (2-20 MeV) multiplicity



p + Pb – Average neutron (2-20 MeV) multiplicity



p + Pb – Average neutron (20+ MeV) multiplicity



Neutron multiplicity

Neutron spectra

p(63 MeV) + ²⁰⁸Pb – Neutron spectrum

INCL45-ABLA07 ISABEL-ABLA07 104 104 10³ 10³ 10² 10² ⁺⁺+} 10¹ 10¹ 10⁰ d²o/dΩdE (mb/sr/MeV) 10⁰ Ĥ₽**₽**₽ 10⁻¹ 10⁻¹ Ŧ Ŧ 10-2 10-2 I I 10⁻³ 10-3 10⁻⁴ 10-4 ncl45-abla07 isabel-abla07 24° (10¹) guertin et al. 35° (10⁰) (10*) guertin et al. 10⁻⁵ 10-5 (10) - 55° (10 tendency well reproduced, despite low 80° (10 120° (10 10-6 impinging energy ! 100 Neution energy (mev) ivenuon energy (ivleV)

n(65 MeV) + Fe – Neutron spectrum



p(256 MeV) + Pb – Neutron spectrum

INCL45-ABLA07 ISABEL-ABLA07 104 104 double differential cross section (mb/sr/MeV) 10³ 10³ 10² 10² 10¹ 10¹ $d^2\sigma/d\Omega dE~(mb/sr/MeV)$ 100 10⁰ 10⁻¹ 10⁻¹ 10⁻² 10-2 10-3 10-3 10⁻⁴ 10 meier et al. meier et al. (10)(10 60° 60⁶ (10)(10 (10)50 (10 10-5 10-3 0.5 10 100 500 0.5 1 10 100 500 Neutron energy (MeV) Neutron energy (MeV)

p(800 MeV) + Fe – Neutron spectrum



p(800 MeV) + Fe – Neutron spectrum



INCL45-ABLA07

p(800 MeV) + Pb – Neutron spectrum



p(800 MeV) + Pb - Neutron spectrum



INCL45-ABLA07

double differential cross section (mb/sr/MeV)

ISABEL-ABLA07

p(1200 MeV) + Fe – Neutron spectrum



p(1200 MeV) + Pb – Neutron spectrum



p(1600 MeV) + Fe – Neutron spectrum



p(1600 MeV) + Pb – Neutron spectrum



p(3000 MeV) + Fe – Neutron spectrum



p(3000 MeV) + Pb – Neutron spectrum



Neutrons

Neutron average multiplicity

Status: Good Improvement:?

Neutron multiplicity distribution

Status:

- INCL45+ any de-excitation and ISABEL+ any de-excitation: All models are too low at high neutron multiplicities (check E* coming from INC models?)

- p(1200 MeV) + Fe: strange shape (only with ABLA07); maybe break-up?
Improvement: Test break-up contribution. Test shape of spectra with modified initial E* distribution. Other?

Neutron double differential cross sections (starting from for $E_{neutron} = 256 \text{ MeV}$)

Status: Good

Improvement: INC models?

Proton spectra

p(62 MeV) + ⁵⁶Fe – Proton spectrum



p(62 MeV) + Bi – Proton spectrum

ISABEL-ABLA07

INCL45-ABLA07

104 10 double differential cross section (mb/sr/MeV) 10² 10² 100 100 10-2 10-2 10-4 10-4 d²σ/dΩdE (mb/sr/MeV) 10-6 10-6 isabel-abla07 incl45-abla0 15° (10) beitrand e 15° (10¹) bertrand e ···· 20° (10° HH 20° (10°) 10⁻⁸ 10-8 25° (101 ···· 25° (10⁻¹ 30° (1012 ·⊷ 30° (10⁻² нн 10⁻¹⁰ 10⁻¹⁰ 35° (10 ₩ 35° (10⁻³ HH 37° (10" 37° (10 40° (10 ·++ 40° (10⁻⁵ 10-12 10-12 ₩ 45° (10⁻⁶ 45° (10 HH 50° (10 50° (10 ---- 55° (10⁻⁸ 55° (10 10⁻¹⁴ 10-14 ₩ 60° (10⁻⁹ (10 60° ···· 70° (10⁻¹ 70° (10 10⁻¹⁶ 75° 75° (10⁻¹ (10 10-16 HH 90° (10⁻¹ 90° 10 1100 0 HH 110° (10" 10⁻¹⁸ 10-18 HH 120° (10" 120° 10 HH 135° (10" 135° 10 HH 160° (10 160° 10⁻²⁰ 10⁻²⁰ 10 10 100 100 Emitted particle energy (MeV) Emitted particle energy (MeV)

p(63 MeV) + ²⁰⁸Pb – Proton spectrum



p(175 MeV) + Ni – Proton spectrum

INCL45-ABLA07 ISABEL-ABLA07 104 10 incl45-abla07A ++ isabel-abla07A ++ 15° (10¹) fortsch et al. ++ 15° (10¹) fortsch et al. н 20° (10°) 20° (10°) н 10² 10² 25° (10⁻¹) 25° (10⁻¹) н -30° (10⁻² 30° (10⁻²) нн нн 35° (10⁻³ 35° (10⁻³) 10⁰ 10⁰ H 40° (10" 40° (10⁻⁴ ----45° (10⁻³ 45° (10⁻⁵) нн нн 10-2 50° (10° 50° (10°) 10-2 HH 1 H-1 55° (107 55° (10⁻⁷) **H** 60° (10⁻⁸ 60° (10⁻⁸ H-H **H** 65° (10"9 65° (10°) 10-4 10-4 --80° (10⁻¹⁰) 80° (10-10) d²σ/dΩdE (mb/sr/MeV) -90° (10⁻¹¹) 90° (10⁻¹¹) 144 10⁻⁶ 100° (10⁻¹²) 10-6 100° (10⁻¹²) ÷ 120° (10⁻¹³) 120° (10⁻¹³) нн 10-8 10-8 10⁻¹⁰ 10-10 10⁻¹² 10⁻¹² 10⁻¹⁴ 10⁻¹⁴ 10⁻¹⁶ 10⁻¹⁶ 10⁻¹⁸ 10-18 10 10 100 1000 100 1000 1 Emitted particle energy (MeV) Emitted particle energy (MeV)

double differential cross section (mb/sr/MeV)

p(175 MeV) + Ni – Proton spectrum



ISABEL-ABLA07


n(542 MeV) + Bi – Proton spectrum



p(800 MeV) + ²⁰⁸Pb – Proton spectrum



p(800 MeV) + ²⁰⁸Pb – Proton spectrum



p(1200 MeV) + Ta – Proton spectrum



p(1200 MeV) + Ta – Proton spectrum



p(1200 MeV) + Au – Proton spectrum



p(1200 MeV) + Au – Proton spectrum



p(2500 MeV) + Au – Proton spectrum



p(2500 MeV) + Au – Proton spectrum

INCL45-ABLA07 ISABEL-ABLA07 10³ 10³ incl45-abla07A ++ isabel-abla07A ++ double differential cross section (mb/sr/MeV) 30° (10¹) letourneau et al. 🛏 30° (10¹) letourneau et al. н 75° (10° 75° (10° ----105° (10⁻¹) 105° (10⁻¹) н н 10² 150° (10⁻²) 10² 150° (10⁻²) нн нн 10¹ 10¹ $d^2\sigma/d\Omega dE \ (mb/sr/MeV)$ 10⁰ 10⁰ 10⁻¹ 10⁻¹ 10⁻² 10-2 10⁻³ 10-3 10-4 10-4 10 100 1000 10 100 1000 3000 3000 Emitted particle energy (MeV) Emitted particle energy (MeV)

Deuteron spectra

p(62 MeV) + ⁵⁶Fe – Deuteron spectrum



p(62 MeV) + Bi – Deuteron spectrum

ISABEL-ABLA07 10³ 103 100 100 ₩^{₽₽₽}₽₽₩₩ 10-3 10-3 10-6 10-6 $d^2\sigma/d\Omega dE \ (mb/sr/MeV)$ incl45-abla07 isabel-abla07 15° (10¹) bertran 15° (10¹) bertrand ···· 20° (10° ···· 20° (10°) 10-9 10-9 - 25° (10⁻¹) ·⊷ 25° (10⁻¹) ++ 30° (10⁻²) → 30° (10⁻²) HH 35° (10⁻³ HH 35° (10⁻³ H 37° (10"4 37° (10" 10-12 10-12 ↔ 40° (10⁻⁵ ·++ 40° (10⁻³ ₩ 45° (10⁻⁶ HH 45° (10" H 50° (10-7) HH 50° (10" - 55° (10⁻⁸) ···· 55° (10⁻⁸ 10-15 10-15 ₩ 60° (10⁻⁹ ₩ 60° (10" ·-- 70° (10⁻¹⁰ ·-- 70° (10⁴⁰ ↔ 75° (10⁻¹¹) ·++ 75° (10¹¹ HH 90° (10¹² ·-- 90° (10⁻¹² 10⁻¹⁸ 10⁻¹⁸ HH 110° (1€⁻¹³ +++ 110° (10⁻¹³ ···· 120° (10⁻¹⁴ HH 135° (10⁻¹⁵ ↔ 135° (10⁻¹⁵ HH 160° (10-16 HH 160° (10-16

INCL45-ABLA07

10

Emitted particle energy (MeV)

double differential cross section (mb/sr/MeV)

10⁻²¹

emitted-particle energy (MeV)

100

10-21

10

Emitted particle energy (MeV)

100

p(63 MeV) + ²⁰⁸Pb – Deuteron spectrum

INCL45-ABLA07 ISABEL-ABLA07 10² 10² 10¹ 10¹ 10⁰ 10⁰ 10-1 10⁻¹ 10⁻² 10-2 10-3 10-3 10-4 d² o/dΩdE (mb/sr/MeV) 10-4 10-5 10-5 10-6 10-6 10-7 10-7 🛏 isabel-abla07 incl45-abla07 10-8 10-8 25° (10¹) guertin et al. 25° (10¹) guertin e ···· 35° (10° ···· 35° (10⁰ 10-9 - 45° (10⁻¹ 45° (10⁻¹ 10-9 HH 55° (10 ₩ 55° (10[°] 10⁻¹⁰ 65° (10⁻³ 10-10 65° (10°3 75° (10⁻⁴ 75° (10⁻⁴ HH 85° (10 10⁻¹¹ 85° (10 10-11 HH 95° (10⁻⁶ ↔ 95° (10° H 115° (10" + 115° (10 10⁻¹² 10-12 ••• 135° (10⁻⁸ HH 135° (10° HH 155° (10⁻⁹ HH 155° (10⁻⁹ 10⁻¹³ 10-13 10 10 100 100 Emitted particle energy (MeV) Emitted particle energy (MeV)

double differential cross section (mb/sr/MeV)

p(175 MeV) + Ni – Deuteron spectrum



n(542 MeV) + Bi – Deuteron spectrum



p(1200 MeV) + Ta – Deuteron spectrum



p(1200 MeV) + Au – Deuteron spectrum

INCL45-ABLA07

ISABEL-ABLA07



p(2500 MeV) + Au – Deuteron spectrum



p(2500 MeV) + Au – Deuteron spectrum

INCL45-ABLA07

10³ 10³ incl45-abla07A ++ isabel-abla07A ++ double differential cross section (mb/sr/MeV) 30° (10¹) letourneau et al. 30° (10¹) letourneau et al. 🛏 н 75° (10° 75° (10° н 105° (10⁻¹) 105° (10⁻¹) 10² 10² 150° (10⁻² 150° (10⁻²) нн нн 10¹ 10¹ ١R 10⁰ 10⁰ $d^2\sigma/d\Omega dE \ (mb/sr/MeV)$ 10⁻¹ 10⁻¹ 10-2 10-2 ALT 10-3 10-3 10-4 10-4 H#H 10-5 10-5 0.5 1 10 100 2500 0.5 1 10 100 1000 2500 1000 Emitted particle energy (MeV) Emitted particle energy (MeV)

emitted-particle energy (MeV)

ISABEL-ABLA07

Tritium spectra

p(62 MeV) + ⁵⁶Fe – Tritium spectrum



p(62 MeV) + Bi – Tritium spectrum

INCL45-ABLA07





p(63 MeV) + ²⁰⁸Pb – Tritium spectrum



p(175 MeV) + Ni – Tritium spectrum



n(542 MeV) + Bi – Tritium spectrum

INCL45-ABLA07





p(1200 MeV) + Ta – Tritium spectrum



p(1200 MeV) + Au – Tritium spectrum



p(2500 MeV) + Au – Tritium spectrum

INCL45-ABLA07

10³ 10³ incl45-abla07 ++ isabel-abla07 🕶 double differential cross section (mb/sr/MeV) 16° (10¹) bubak et al. 16° (10¹) bubak et al. ----10² 10² 20° (10⁰ 20° (10° 35° (10⁻¹ 35° (10⁻¹ 50° (10 50° (10 нн 10¹ 10¹ 65° (10" 65° (10)80° (10⁻ 80° (10" 100° (10⁻ 100° (10⁻⁵ 10⁰ 10⁰ H-1 10⁻¹ 10-1 d² o/dΩdE (mb/sr/MeV) 10-2 10-2 10-3 10-3 10-4 10-4 ÷н., 10-5 10-5 10-6 10-6 10-7 10-7 10-8 10-8 10⁻⁹ 10-9 10 100 10 100 1000 2000 1000 2000 Emitted particle energy (MeV) Emitted particle energy (MeV)

emitted-particle energy (MeV)

ISABEL-ABLA07

p(2500 MeV) + Au – Tritium spectrum



double differential cross section (mb/sr/MeV)

³He spectra

p(62 MeV) + Bi – ³He spectrum



ISABEL-ABLA07



p(62 MeV) + Bi – ³He spectrum

ISABEL-ABLA07

INCL45-ABLA07



p(63 MeV) + ²⁰⁸Pb – ³He spectrum

ISABEL-ABLA07

INCL45-ABLA07



p(175 MeV) + Ni – ³He spectrum



p(1200 MeV) + Ta – ³He spectrum

10² 10² incl45-abla07 ++ isabel-abla07 🕶 double differential cross section (mb/sr/MeV) 30° (10¹) herbach et al. 30° (10¹) herbach et al. 🛏 75° (10°) 75° (10°) н н 150° (10⁻¹) +++ 150° (10⁻¹) ++ 10¹ 10¹ 10⁰ 10⁰ $d^2\sigma/d\Omega dE \text{ (mb/sr/MeV)}$ 10⁻¹ 10⁻¹ 10-2 10-2 10-3 10-3 **Here** 10⁻⁴ 10-4 10-5 10-5 10 100 800 10 100 800 1 1 Emitted particle energy (MeV) Emitted particle energy (MeV)

emitted-particle energy (MeV)

ISABEL-ABLA07

INCL45-ABLA07

p(1200 MeV) + Au – ³He spectrum

ISABEL-ABLA07

10² 10² incl45-abla07 ++ isabel-abla07 🕶 double differential cross section (mb/sr/MeV) 16° (10¹) budzanowski et al. 16° (10¹) budzanowski et al. н ы 20° 20° (10° 10¹ 0.0 10¹ 35° (10° 35° (10)50° нн (10 10⁰ 10⁰ нн 10-1 10⁻¹ : Hale 10-2 10-2 $d^{2}\sigma/d\Omega dE~(mb/sr/MeV)$ 1112 10-3 10-3 10⁻⁴ 10-4 10-5 10-5 10-6 10-6 10-7 10-7 10-8 10-8 10-9 10⁻⁹ 10 100 10 800 800 100 Emitted particle energy (MeV) Emitted particle energy (MeV)

emitted-particle energy (MeV)

INCL45-ABLA07
p(2500 MeV) + Au – ³He spectrum



p(2500 MeV) + Au – ³He spectrum



⁴He spectra

p(62 MeV) + ⁵⁶Fe – ⁴He spectrum



p(62 MeV) + Bi – ⁴He spectrum

ISABEL-ABLA07

INCL45-ABLA07



$p(63 \text{ MeV}) + {}^{208}\text{Pb} - {}^{4}\text{He spectrum}$

INCL45-ABLA07 ISABEL-ABLA07 10² 10² 10⁰ 100 10-2 10-2 10-4 10-4 $d^2\sigma/d\Omega dE \,(mb/sr/MeV)$ 10-6 10-6 10-8 10-8 isabel-abla07 25° (10¹) gue -abla0 guertin et al. 0 guertin et 85° (10°) 45° (10⁻¹ 10-10 10-10 (10)(107 (10)85° (10 10⁻¹² 10⁻¹² 95° (10" 5° (10 135° (10 155° (10 10⁻¹⁴ 10-14 5 10 10 80 80 5 Emitted particle energy (MeV) Emitted particle energy (MeV)

double differential cross section (mb/sr/MeV)

p(160 MeV) + AI – ⁴He spectrum



p(160 MeV) + Au – ⁴He spectrum



Emitted particle energy (MeV)

Emitted particle energy (MeV)

4

200

emitted-particle energy (MeV)

double differential cross section (mb/sr/MeV)

p(175 MeV) + Ni – ⁴He spectrum



p(1200 MeV) + Ta – ⁴He spectrum

INCL45-ABLA07 ISABEL-ABLA07 10³ 10³ incl45-abla07 ++ isabel-abla07 🕶 double differential cross section (mb/sr/MeV) 30° (10¹) herbach et al. 🛏 30° (10¹) herbach et al. 75° (10°) 75° (10°) н н 150° (10⁻¹) ++ 150° (10⁻¹) ++ 10² 10² 10¹ 10¹ $d^2\sigma/d\Omega dE \text{ (mb/sr/MeV)}$ 10⁰ 10⁰ 10⁻¹ 10⁻¹ н 10⁻² 10-2 10-3 10-3 10-4 10-4 10 100 500 10 100 500 1 Emitted particle energy (MeV) Emitted particle energy (MeV)

p(1200 MeV) + Au – ⁴He spectrum



ISABEL-ABLA07



p(2500 MeV) + Au – ⁴He spectrum



p(2500 MeV) + Au – ⁴He spectrum



Light Charged Particles

LCP double differential cross sections (starting from $E_{proton} = 175 \text{ MeV}$)

Status

- Not so good with ISABEL + ABLA07
- Quite good with INCL45+ABLA07 for light target; not that good for heavy target
- Visible differences between INCL45 plus ABLA07 / SMM / GEMINI++
- But the spectra depend also on the INC (even in the low energy part of the spectrum) Improvement: Complicate!
- Concerning ABLA07:
- Tunneling through barrier (now taken into account only for calculating decay widths)
- Coulomb barriers (from Bass prescription) could be adjusted
- Apparently, in evaporation from deformed nuclei the emission could not be isotropic (to be demonstrated)

The empirical nuclear potential of R. Bass

$$-V_N(s) = \frac{C_1 \cdot C_2}{C_1 + C_2} \cdot \frac{1}{A \cdot \exp\left(\frac{s}{d_1}\right) + B \cdot \exp\left(\frac{s}{d_2}\right)}$$

$$A = 0.333 \text{ MeV}^{-1} \text{ fm},$$
 $B = 0.007 \text{ MeV}^{-1} \text{ fm},$ $d_1 = 3.5 \text{ fm},$ $d_2 = 0.65 \text{ fm}.$

$$C_{i} = R_{i} \cdot \left(1 - \frac{(0.9984 \text{fm})^{2}}{R_{i}^{2}}\right), \quad R_{1} = \left(1.28 \cdot A_{f}^{\frac{1}{3}} - 0.76 + \frac{0.8}{A_{f}^{\frac{1}{3}}}\right) \text{fm},$$
$$R_{2} = \left(1.28 \cdot A_{2}^{\frac{1}{3}} - 0.76 + \frac{0.8}{A_{2}^{\frac{1}{3}}} + d\right) \text{fm}, \quad d = \begin{cases} 3 \text{ fm}, & 1\text{H} \\ 0 \text{ fm}, & 2\text{H} \\ 0 \text{ fm}, & 3\text{H} \\ 0 \text{ fm}, & 3\text{He} \\ 1 \text{ fm}, & 4\text{He} \end{cases}$$

Coulomb potential

Residues

Fingerprints of the de-excitation process

1 GeV p + ²³⁸U INCL4.5, ISABEL + ABLA07





mass number A

$p(300 \text{ MeV}) + {}^{56}\text{Fe} - \text{final residues}$



charge number Z



$p(300 \text{ MeV}) + {}^{56}\text{Fe} - \text{final residues}$



ISABEL-ABLA07



cross section (mb)



mass number A



charge number Z

INCL45-ABLA07

ISABEL-ABLA07



INCL45-ABLA07

ISABEL-ABLA07





mass number A



charge number Z

cross section (mb)

INCL45-ABLA07

ISABEL-ABLA07



INCL45-ABLA07

ISABEL-ABLA07





mass number A



charge number Z

INCL45-ABLA07

ISABEL-ABLA07



INCL45-ABLA07

ISABEL-ABLA07



p(1000 MeV) + ²⁰⁸Pb – final residues



mass number A

mass number A

p(1000 MeV) + ²⁰⁸Pb – final residues

INCL45-ABLA07

ISABEL-ABLA07



p(1000 MeV) + ²⁰⁸Pb – final residues



mass number A

mass number A
p(1000 MeV) + ²⁰⁸Pb – final residues



mass number A

INCL45-ABLA07



ISABEL-ABLA07

250



cross section (mb)





charge number Z

INCL45-ABLA07



p(1000 MeV) + ²³⁸U – final residues

INCL45-ABLA07



p(1000 MeV) + ²³⁸U – final residues



 $p(1000 \text{ MeV}) + ^{238}\text{U} - \text{final residues}$

INCL45-ABLA07 ²³⁸U(p,x)Rb ²³⁸U(p,x)Sr ²³⁸U(p,x)Y ²³⁸U(p,x)Rb ²³⁸U(p,x)Sr ²³⁸U(p,x)Y 10² 10^{2} 10² 10² 102 (Z=38)gsi incl45_abla07 i (Z=38)gsi isabel₂abla07 нanii 10¹ 10^{1} 10^1 10¹ 10¹ n 10⁰ 10⁰ 10⁰ 10⁰ 10⁰ 10⁻¹ 10⁻¹ 10⁻¹ 10-1 10⁻¹ Ŧ 10⁻² 10⁻² 10-2 10-2 10-2 10-3 10-3 10-3 10-3 10-3 75 80 85 90 95 100 105 75 80 85 90 95 100 105 80 85 90 95 100 105 11 75 80 85 90 95 100 105 75 80 85 90 95 100 105 95 100 105 110 80 85 90 ²³⁸U(p,x)Zr ²³⁸U(p,x)Nb ²³⁸U(p,x)Mo ²³⁸U(p,x)Nb ²³⁸U(p,x)Mo ²³⁸U(p,x)Zr 10² 10^{2} 10² 102 10² 10^{1} 10^1 10¹ 10^{1} 10¹ 2 10⁰ 10⁰ 10⁰ 10⁰ 10⁰ þ ţ, 10⁻¹ 10⁻¹ 10⁻¹ 10⁻¹ 10⁻¹ 10⁻² 10⁻² 10-2 10-2 10-2 10-3 10-3 10-3 10⁻³ 10-3 95 100 105 110 100 105 110 115 100 105 110 11 80 90 85 90 95 85 90 95 80 85 90 95 100 105 110 85 95 100 105 110 115 95 100 105 110 115 85 90 85 90 ²³⁸U(p,x)Tc ²³⁸U(p,x)Ru ²³⁸U(p,x)Rh ²³⁸U(p,x)Ru ²³⁸U(p,x)Rh ²³⁸U(p,x)Tc 10² 10^{2} 10^{2} 102 10² 10¹ 10¹ 10^{1} 101 101 4 ¢ 100 10⁰ ÷0 -0 10⁰ 10⁰ 10⁰ ł ٦ 10⁻¹ 10⁻¹ 10-1 10⁻¹ 10⁻¹ 10-2 10-2 10-2 10-2 10-2 10-3 10-3 10-3 10-3 10⁻³ 95 100 105 110 115 120 95 100 105 110 115 120 90 95 100 105 110 115 12 95 100 105 110 115 120 95 100 105 110 115 120 95 100 105 110 115 120 90 90 90 90 90 mass number A

mass number A

INCL45-ABLA07



p(1000 MeV) + ²³⁸U – final residues



p(1000 MeV) + ²³⁸U – final residues



mass number A

p(1000 MeV) + ²³⁸U – final residues

INCL45-ABLA07 ISABEL-ABLA07 ²³⁸U(p,x)Ta ²³⁸U(p,x)Ta ²³⁸U(p,x)W ²³⁸U(p,x)Re ²³⁸U(p,x)W ²³⁸U(p,x)Re 10² 10² 10² 102 102 i⇔ (Z=74)gsi ➡ isabel-abla07 (Z=74)gsi ю incl45-abla07 10¹ 10^{1} 10¹ 10¹ 10¹ 0 10⁰ 10⁰ 10^{0} 10⁰ 100 10⁻¹ 10⁻¹ 10⁻¹ 10⁻¹ 10 10-2 10-2 10⁻² 10⁻² -2 10-2 10-3 10-3 10-3 10-3 10⁻³ 160 165 170 175 180 185 190 195 160 165 170 175 180 185 190 195 165 170 175 180 185 190 195 20 160 165 170 175 180 185 190 195 160 165 170 175 180 185 190 195 165 170 175 180 185 190 195 200 ²³⁸U(p,x)Ir ²³⁸U(p,x)Ir ²³⁸U(p,x)Pt ²³⁸U(p,x)Os ²³⁸U(p,x)Pt ²³⁸U(p,x)Os 10² 10^{2} 102 10² 10^{2} 10¹ 10^{1} 10¹ 10¹ 10¹ 0^1 10⁰ 10⁰ 10⁰ 10⁰ 10⁰ 0⁶ 10⁻¹ 10⁻¹ 10⁻¹ 10⁻¹ 10⁻¹ 10⁻² 10⁻² -2 10-2 10-2 10-2 10-3 10-3 10-3 -3 10-3 10⁻³ 165 170 175 180 185 190 195 200 170 175 180 185 190 195 200 205 170 175 180 185 190 195 200 20 165 170 175 180 185 190 195 200 170 175 180 185 190 195 200 205 170 175 180 185 190 195 200 205 ²³⁸U(p,x)Au ²³⁸U(p,x)Hg ²³⁸U(p,x)Tl ²³⁸U(p,x)Au ²³⁸U(p,x)Hg ²³⁸U(p,x)Tl 10^{2} 10² 10^{2} 10 102 10¹ 10^{1} 0 10¹ 10¹ 101 10⁰ 10⁰ 100 10⁰ 10⁰ o⁰ 10⁻¹ 10⁻¹ 10⁻¹ 10-1 10-1 4 10⁻² -2 10-2 10-2 10-2 10-2 ъ 10-3 10-3 10-3 10-3 10-3 175 180 185 190 195 200 205 210 180 185 190 195 200 205 21 175 180 185 190 195 200 205 175 180 185 190 195 200 205 210 180 185 190 195 200 205 210 175 180 185 190 195 200 205

mass number A

p(1000 MeV) + ²³⁸U – final residues

INCL45-ABLA07



²³⁸U(p,x)Pa ²³⁸U(p,x)U 10² 10² 10^{2} i≤i (Z=92)gsi incl45-abla07 H⊶ (Z=92)gsi H⊶ isabel-abla07 10^{1} 10^{1} 10^{1} 10^{0} 10⁰ 10⁰ 10⁻¹ 10⁻¹ 10⁻¹ 10⁻² 10-2 10⁻² 10⁻³ 10-3 10⁻³ 210 215 220 225 230 235 240 210 215 220 225 230 235 240 210 215 220 225 230 235 240 mass number A

ISABEL-ABLA07

INCL45-ABLA07



Residues

Status: Good

Improvement: Difficult to establish how to disentangle INC and de-excitation...

Concerning ABLA:

- 1) improve the description of even-odd (\rightarrow gamma decay strength)
- 2) improve structural effects (could be relevant for very light residues)

3) fission

Excitation functions

natFe(p,x)³He (cumulative)

INCL45-ABLA07



natPb(p,x)³He (cumulative)

INCL45-ABLA07



General conclusions

We (all here in this workshop) did a good job!

General tendencies and behaviors are well reproduced → we have understood the main physics behind!

Left to do: refinements...

Concerning ABLA07

Overall behavior satisfactorily, but there is still work to do

- neutron multiplicity distributions (INC or de-excitation?)

- LCP spectra: barriers, tunneling, break-up?

- Residues: even-odd effect, structural effects, fission

Strength of ABLA07: high physics content relatively low computing time (we want to keep this feature)

Thanks EU contribution (EUROTRANS)