Khlopin Radium Institute ISTC projects for transmutation

#2524 “Development of nuclear data library for nucleon-induced reactions on heavy nuclei in wide energy region”

#2524 “Development of nuclear data library for nucleon-induced reactions on heavy nuclei in wide energy region”

Status and perspectives

- Completion – April 31, 2007
- Funding – USA

- Collaborators:
- K.L.Peddicord, Texas A&M University, USA
- V.Pronyaev IAEA NDS
- G.Kim, Kyungpook National University, Korea
- C.Broeders, FZK, Germany

Project goals

- Theoretical nuclear data library for ADS
- *Targets: heavy nuclei from Pb to Cm*
- *Projectile energy region: 20 MeV – 1 GeV for proton and neutron induced reactions*

  below 20 MeV – linking with ENDF/B-6, BROND
- *Complete transport files in ENDF-6 format*

Status

- New code for description of main characteristics of nucleon-induced reactions *MCFx* *has been developed*

- The code is based on the reliable and time-proved models of nuclear reactions and nuclear structure to fix the set of model parameters as it could be possible
  - Optical model – new global optical model potential KRI200 for Pb-Bi and actinides up to 1 GeV
  - Intranuclear cascade model – last version of elementary cross-sections table used
  - Model of multiple preequilibrium emission – new version developed
  - Statistical model for fission and particle evaporation – detailed HF calculations, fission barrier library (error ~ 0,3-0,4 MeV), new model for atomic mass calculations

Status (II)

- Large volume of calculations has been performed and comparison of results with available experimental data was carried out

- The standard models used in the code were modified to raise the quality and reliability of calculations

Publications:

- ND2004, Santa Fe, USA,
- Fission2005, Cadarache, France,
- NEUDOS10, Uppsala, Sweden, 2006,
- Problems of atomic science and technology (in Russian) 2006,
- ISINN-14, Dubna, Russia, 2006
- ND2007, Nice, France – to be published

Code generates nuclear data for transport files

- Elastic and inelastic cross-sections
- Energy-angle distributions of elastic scattering – *optical model ECIS*

- Energy-angle distributions and multiplicities of secondary particles

  3 sources: intranuclear cascade, preequilibrium emission, evaporation

– *Dubna version of cascade model*
– *model MCP*
- *modified STAPRE code*

- Fission cross-section

Complete ENDF-6 formatted transport files of neutron- and proton-induced nuclear data up to 1 GeV for 208Pb target

Contents

- MF=1 General information
- MT=451 Description data and dictionary
- MT=452 Number of neutron per fission
- No data on prompt and delayed neutron

- MF=2 Resonance parameters – no data

MF=3 Cross sections

MT=1 Total cross sections – OM calculations

MT=2 Elastic scattering cross sections - OM calculations

MT=5 Interaction cross sections = total-elastic-fission

MT=18 Total fission cross sections – MCFx calculations

- MF=6 Products (neutrons and protons) energy-angle distributions instead of MF=4,5

- recommended by ENDF-102 **“when so many reaction channels are opened that it is difficult to provide separate reactions”**

- MT=2 Elastic scattering - OM calculations
- Discrete two-body scattering (LAW=2)
- $p(\mu, E) = \int dE' f(\mu, E, E')$ *f* are presented

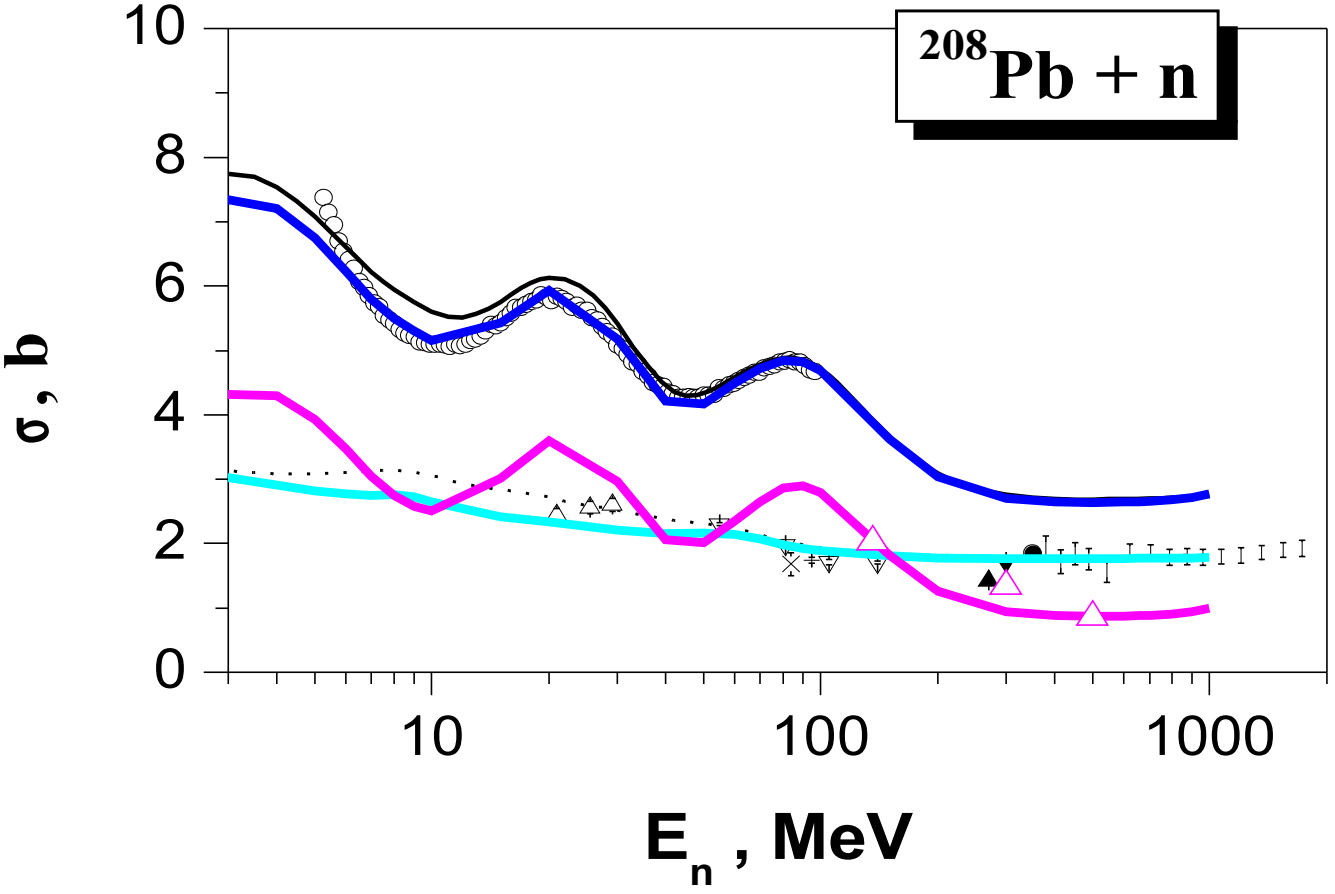
MT=6 Neutron and proton distributions

Multiplicity as a function of projectile energy

- $f_0(E,E')$ - integral of angular distribution and (MCFx), $r(E,E')$ - coefficients of Kalbach-Mann systematics of angular distributions
- nonequilibrium fraction of cross sections

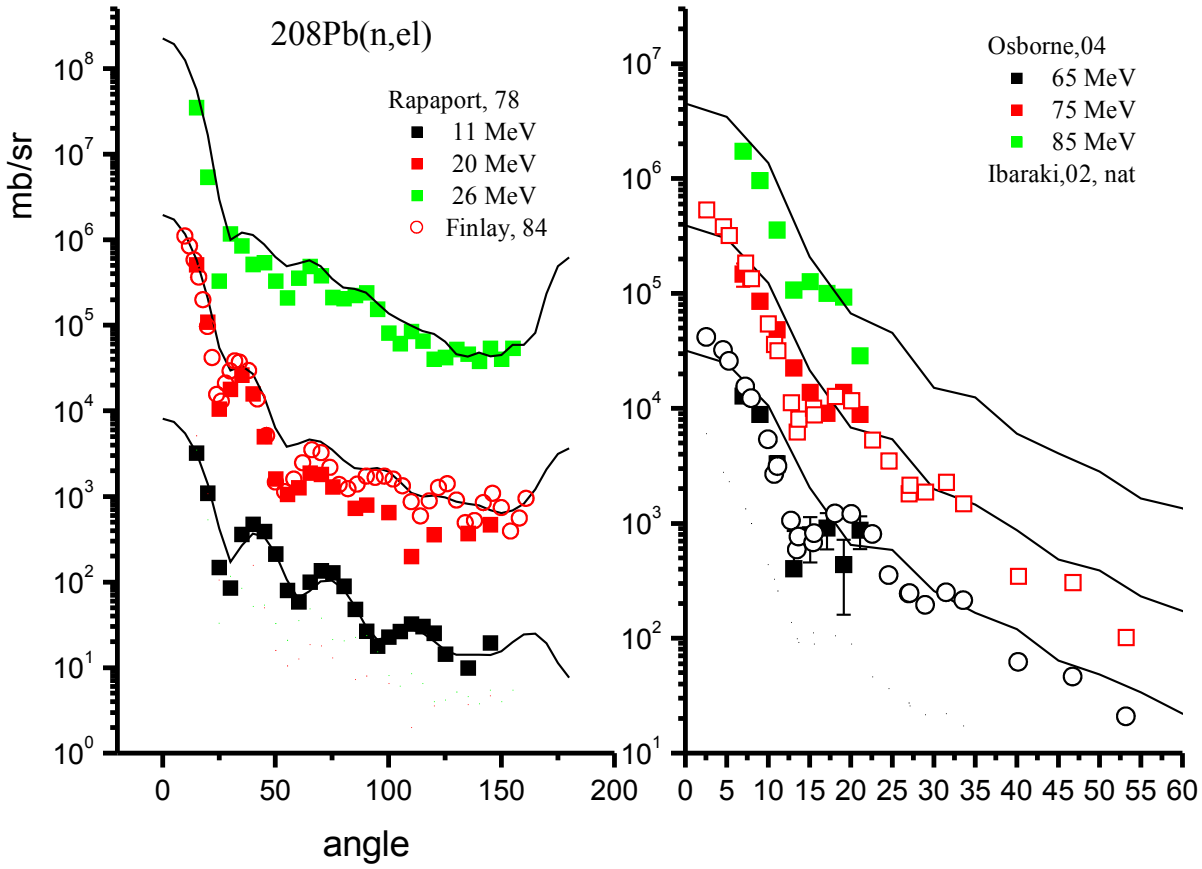
^{208}Pb+n

ECIS calculations with developed optical model potential

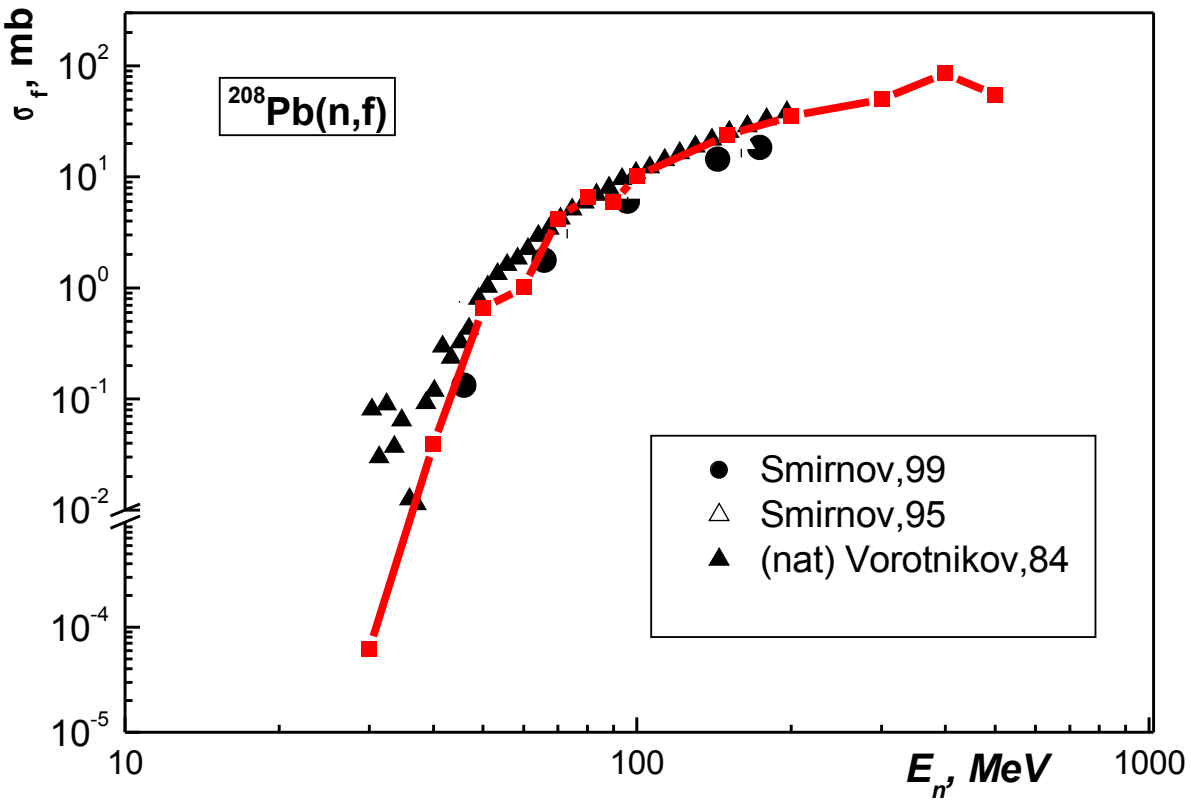


^{208}Pb+n

ECIS calculations with developed optical model potential

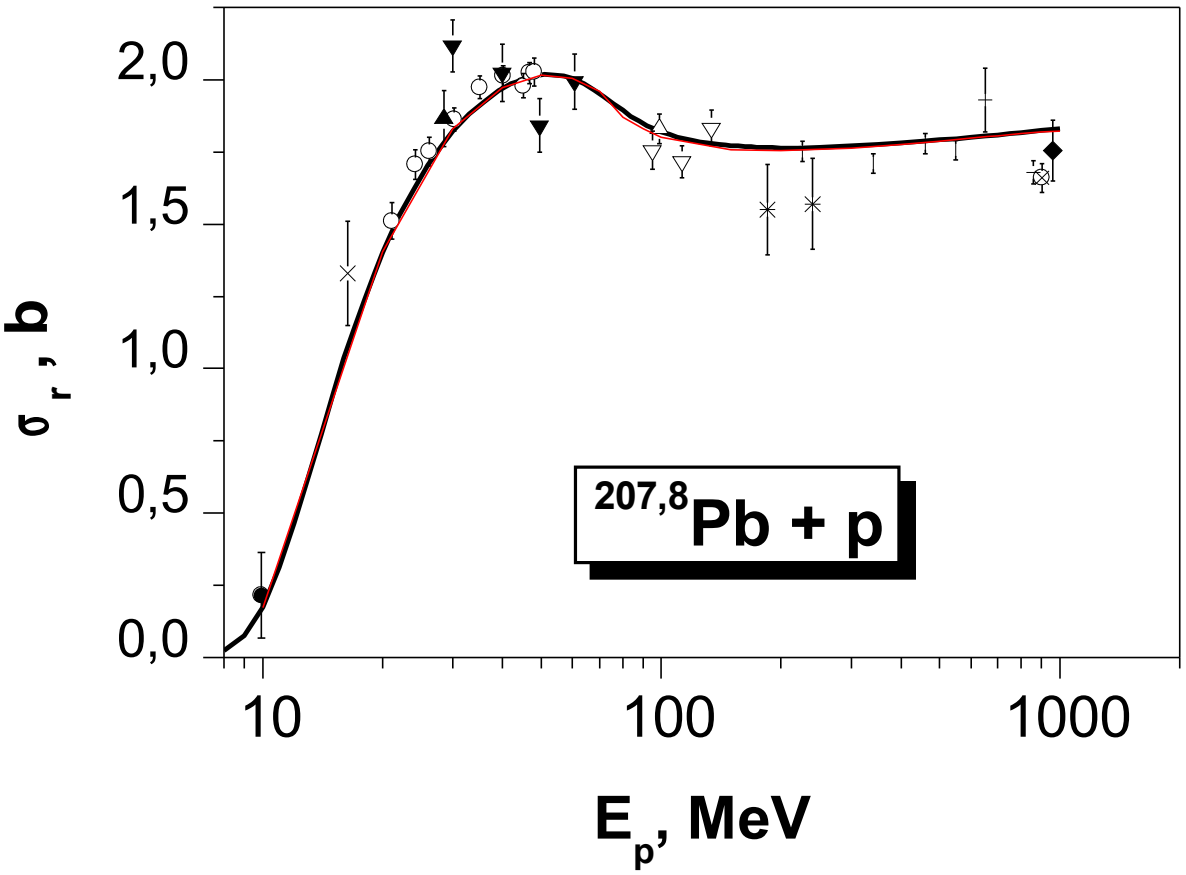


Fission cross-section



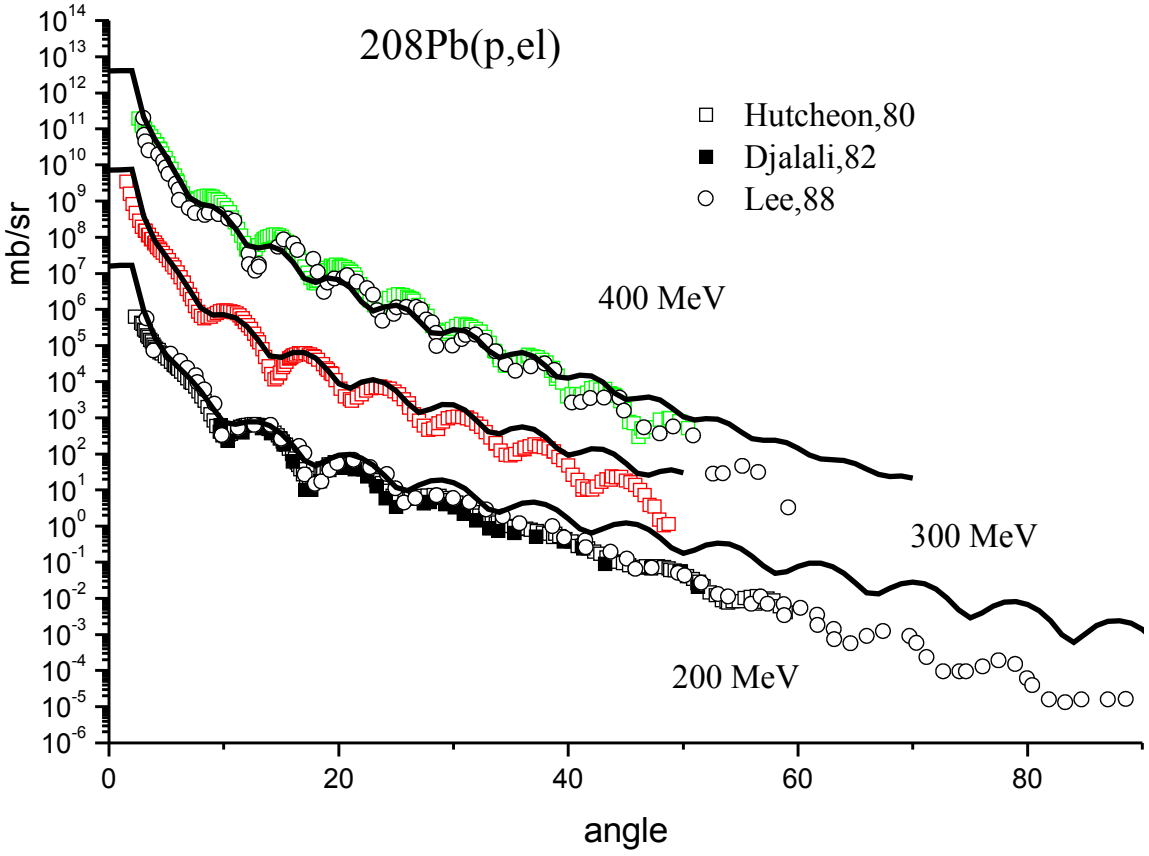
^{208}Pb+p

ECIS calculations with developed optical model potential

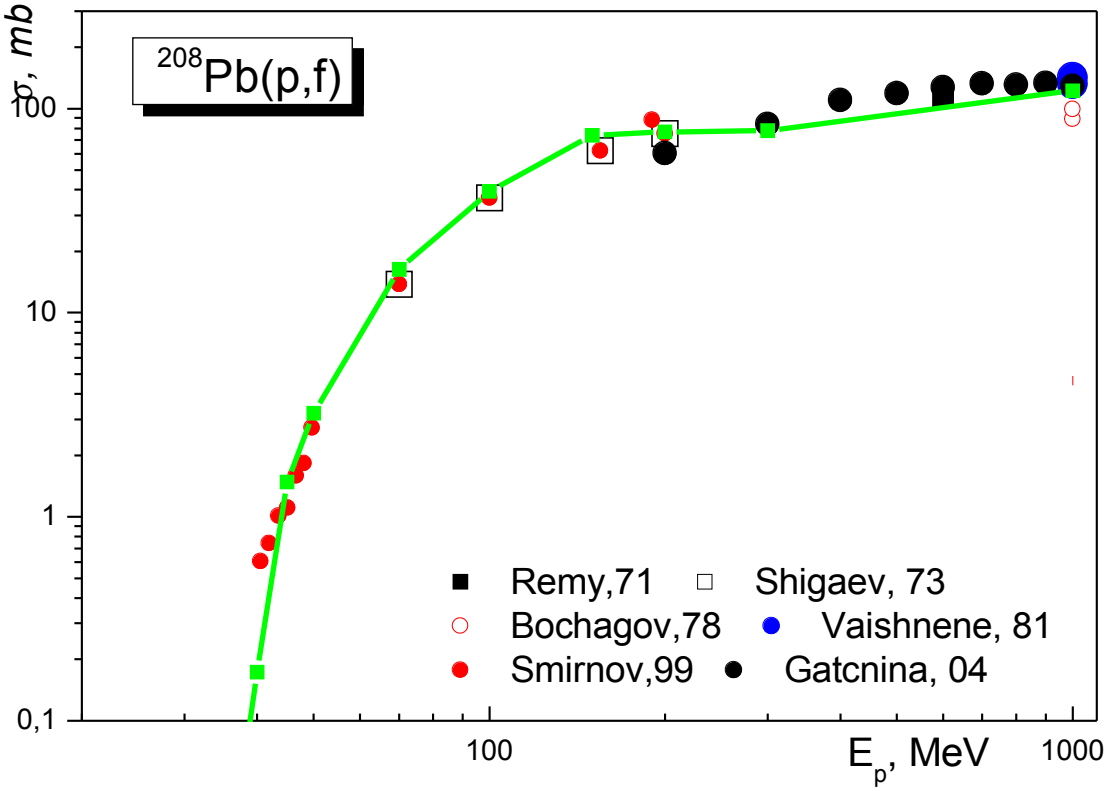


^{208}Pb+p

ECIS calculations with developed optical model potential



Fission cross-section



KRI-TF library

- ^{208}Pb + n(p) – done

in progress

^{209}Bi + n(p)

^{235}U + n(p) ^{238}U + n(p) ^{232}Th + n(p)

^{241}Am + n(p) ^{239}Pu + n(p) ^{237}Np + n(p)

Perspectives

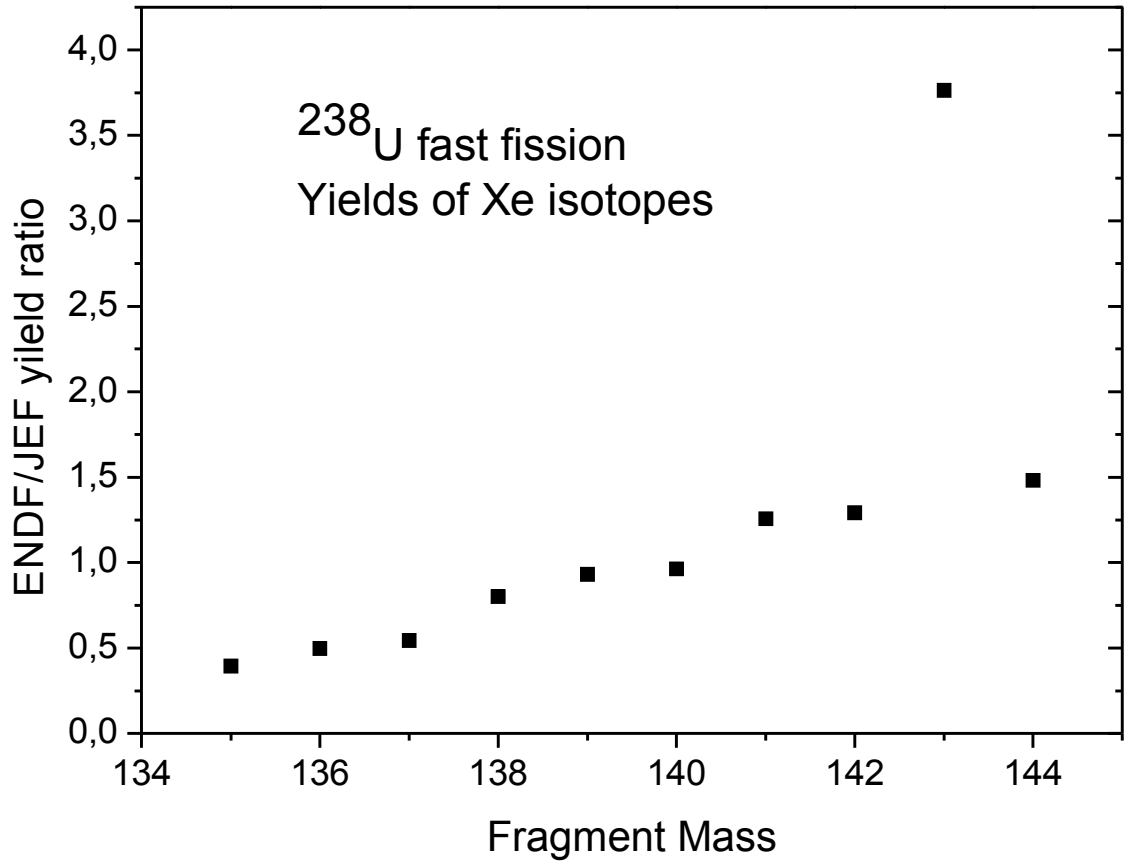
- Extension of list of isotopes in the library
- Release of the code
- Fission fragment library for nucleon-induced fission on heavy nuclei for energies > 1 MeV

IAEA TECDOC 1168 2000

S-spontaneous
T-thermal
F-fast (~1 MeV)
H-high (14 MeV)

Fissioning	ENBF/B-VI				UKFY2/3		(JEF-2)		CENDL		
nucleus	S	T	F	H	S	T	F	H	T	F	H
^{227}Th		X									
^{229}Th		X									
^{232}Th			X	X			X	X		X	
^{231}Pa			X								
^{232}U		X									
^{233}U		X	X	X		X	X	X	X		
^{234}U			X	X			X				
^{235}U		X	X	X		X	X	X	X	X	X
^{236}U			X	X			X				
^{237}U			X								
^{238}U			X	X			X	X		X	X
^{237}Np	X	X	X	X		X	X				
^{238}Np			X			X	X				
^{238}Pu			X			X	X				
^{239}Pu		X	X	X		X	X		X	X	
^{240}Pu		X	X	X			X				
^{241}Pu		X	X			X	X		X		
^{242}Pu		X	X	X			X				
^{241}Am		X	X	X		X	X				
^{242m}Am		X				X	X				
^{243} Am			X			X	X				
^{242}Cm			X		X						
^{243}Cm		X	X			X	X				
^{244}Cm	X		X		X	X	X				
^{245}Cm		X				X	X				
^{246}Cm	X		X								
^{248}Cm	X		X								
^{249}Cf		X									
^{250}Cf	X										
^{251}Cf		X									
^{252}Cf	X				X						
^{253}Es	X										
^{254}Es		X									
^{254}Fm	X										
^{255}Fm		X									
^{256}Fm	X										

FY ratio: ENDF/B-VI to JEF2.2 for Xe isotopes in fast fission of 238U



E > 14 MeV

- n-induced fission:

  Zoller C.M. Doctoral thesises TH Darmstadt, 1995

^{238}U+n, E_n from threshold to 450 MeV

p-induced fission

Tewes52 Tewes, Phys. Rev. 88, 860 (1952) p+232Th: 8.0, 9.3, 13.3, 17.8, 21.1 MeV
Hicks55 Hicks, Phys. Rev. 100, 1286 (1955) p+natU: 75.0, 100.0, 170.0, 250.0, 340.0 MeV
Steve58 Stevenson, Phys. Rev. 111, 886 (1958) p+238U: 10.0, 32.0, 70.0, 100.0, 150.0, 200.0, 250.0, 300.0, 340.0 MeV
Hageb64 Hagebo, J. Inorg. Nucl. Chem. 26, 1639 (1964) p+natU: 170.0 MeV
Pappa66 Pappas, J. Inorg. Nucl. Chem. 28, 1769 (1966) p+natU: 170.0 MeV
Croal69 Croall, Nucl. Phys. A125, 402 (1969) p+232Th: 13.0, 20.0, 27.0, 35.0, 40.0, 45.0, 53.0 MeV
Baba71 Baba, Nucl. Phys. A175, 177 (1971) p+238U: 13.0, 15.7, 18.1, 21.8, 25.0, 30.0, 35.0, 40.0, 44.9, 50.1, 55.0 MeV
Kandil76 Kandil, J. Inorg. Nucl. Chem. 38, 37 (1976) p+238U: 13.0, 14.0, 15.0, 16.0 MeV
Galin77 Galinier, J. Inorg. Nucl. Chem. 39, 1497 (1977) p+238U: 20.0, 25.0, 30.0, 35.0, 40.0, 45.0, 50.0, 55.0, 60.0, 65.0, 70.0, 77.0, 85.0 MeV
Kudo82 Kudo, Phys. Rev. C25, 3011 (1982) p+232Th: 8.6, 9.9, 11.9, 13.0, 13.9, 14.8, 16.0, 17.0, 18.4, 20.2, 21.9 MeV
Winkel84 Winkelmann, Phys. Rev C30, 934 (1984) p+242Pu: 15.1 MeV
Ohtsu89 Ohtsuki, Phys. Rev. C40, 2144 (1989) p+233U: 9.8, 11.2, 13.9, 15.5 MeV
p+235U: 10.2, 12.0, 13.6, 15.6, 18.0 MeV
p+236U: 10.2, 12.1, 14.0, 15.6 MeV
p+237Np: 10.2, 11.9, 13.2, 14.2, 15.5, 17.5, 19.5, 20.5, 21.6, 22.5, 23.6, 24.6, 25.5, 26.5, 27.5, 28.8, 31.7 MeV
p+239Pu: 11.2, 12.2, 13.9, 15.5 MeV
p+242Pu: 12.0, 18.0 MeV
p+244Pu: 11.7, 13.1, 15.6, 18.0 MeV
p+241Am: 10.0, 12.0, 14.0, 15.0, 16.0 MeV
p+243Am: 10.4, 12.0, 14.0, 15.6 MeV
Baba96 Baba, Z. Phys. A 356, 61 (1996) p+238U: 14.8, 17.9 MeV
Aysto97 Aysto, Proc, Int. Conf. on Fission and Properties of p+238U: 20.0, 60.0 MeV
Kudo98 Kudo, Phys. Rev. C57, 178 (1998) p+238U: 24.0 MeV

E > 14 MeV

- Lack of data leads to inability of empirical approaches used in the main libraries
- Two new underway ISTC projects #3192, #3363 for FY measurements up to 200 MeV

- Urgent need in reliable physical model for FY description

→ New ISTC project (in the ISTC - February-March)

Duration – 30 months

Estimated total cost of the project (US $) 169650

Collaborators:
A.Nichols, IAEA NDS
F.Goenenwein, Tubingen University, Germany

COMPLETE NUCLEAR DATA LIBRARY ON NUCLEON-INDUCED FISSION YIELDS FOR APPLICATIONS IN WIDE ENERGY REGION

- The systematic calculations for the proton-induced reaction up to 1 GeV and neutron-induced reactions up to 500 MeV on nuclei from Pb to Cf will be performed;
- The nuclear data files on absolute values of independent and cumulative (after neutron emission) fission product yields in the ground and isomeric states, ternary fission yields and chain yields will be formed in the ENDF-6 format.