http://nrv.jinr.ru

Web knowledge base on low-energy nuclear physics

Alexander Karpov, JINR, Dubna

- What is "Knowledge base"
- Fusion-Fission-Evaporation analysis

JINR-SAR cooperation
JINR-ARE cooperation

NUCLEUS-2015, Peterhof, 03.06.15

Nuclear Data Resources in the Internet

NACRE

National Nuclear Data Center

NNDC

BROOKHAVEN NATIONAL LABORATORY

EMPIRE

Nuclear Reaction Model Code

Version 2.19 (Lodi)

AMDC

Atomic Mass Data Center

LUNDS UNIVERSITET

Janis 3

Triangle Universities Nuclear Laboratory — TUNL — Duke, UNC, NCSU

Energy Levels of Light Nuclei, A = 3 - 20

Nuclear Data Evaluation Project

NUCLEAR DATA VIEWER

los alamos

The Isotop Explorer

AEN NEA — Agence pour l'énergie nucléaire — Nuclear Energy Agency

IAEA.org — International Atomic Energy Agency

JAEA NDC — Nuclear Data Center — Japan Atomic Energy Agency

γ-Ray Spectra
Radium Institute,
St.-Petersburg

CDFE
MSU, Moscow

Reaction Data Database
Durham, UK

Nuclear Data Resources in the Internet

- NNDC http://www.nndc.bnl.gov/index.jsp
- CDFE http://cdfe.sinp.msu.ru/index.en.html
- The Isotopes Project (LBNL) http://ie.lbl.gov/
- TUNL http://www.tunl.duke.edu/nucldata/
- NN-Online http://nn-online.org/
- NEA Data bank http://www.oecd-nea.org/dbprog/
- NACRE http://pntpm.ulb.ac.be/Nacre/
- NDC JAEA http://wwwndc.jaea.go.jp/

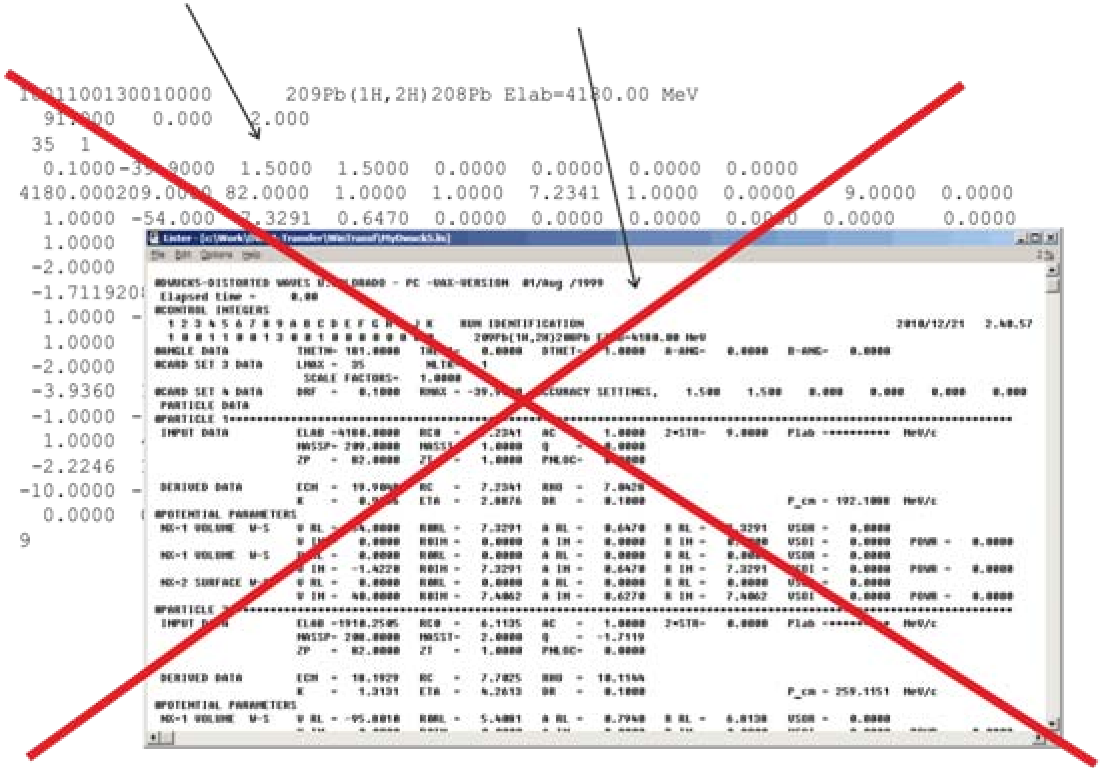
Computer Codes for Nuclear Data

- **TALYS** – software for the simulation of nuclear reactions http://www.talys.eu/
- **EMPIRE** – modular system of nuclear reaction codes for advanced modeling of nuclear reactions using various theoretical models http://www.nndc.bnl.gov/empire219/
- **NEA Data Bank Computer Program Services** http://www.oecd-nea.org/dbprog/
- **LISE++** – a tool for calculating the transmission and yields of fragments produced and collected in a spectrometer (more details in the next talk) http://lise.nscl.msu.edu/lise.html
- **FRESCO**, **CCFULL**, **GRAZING**, **EPAX**, **DWUCK**, **PACE**, and many **others**

What is Web Knowledge base?

Typical situation with scientific codes

Input Output



- meaning of parameters?
- preparation of inputs?
- processing of outputs?
- no graphics
- OS dependent
- difficult to update

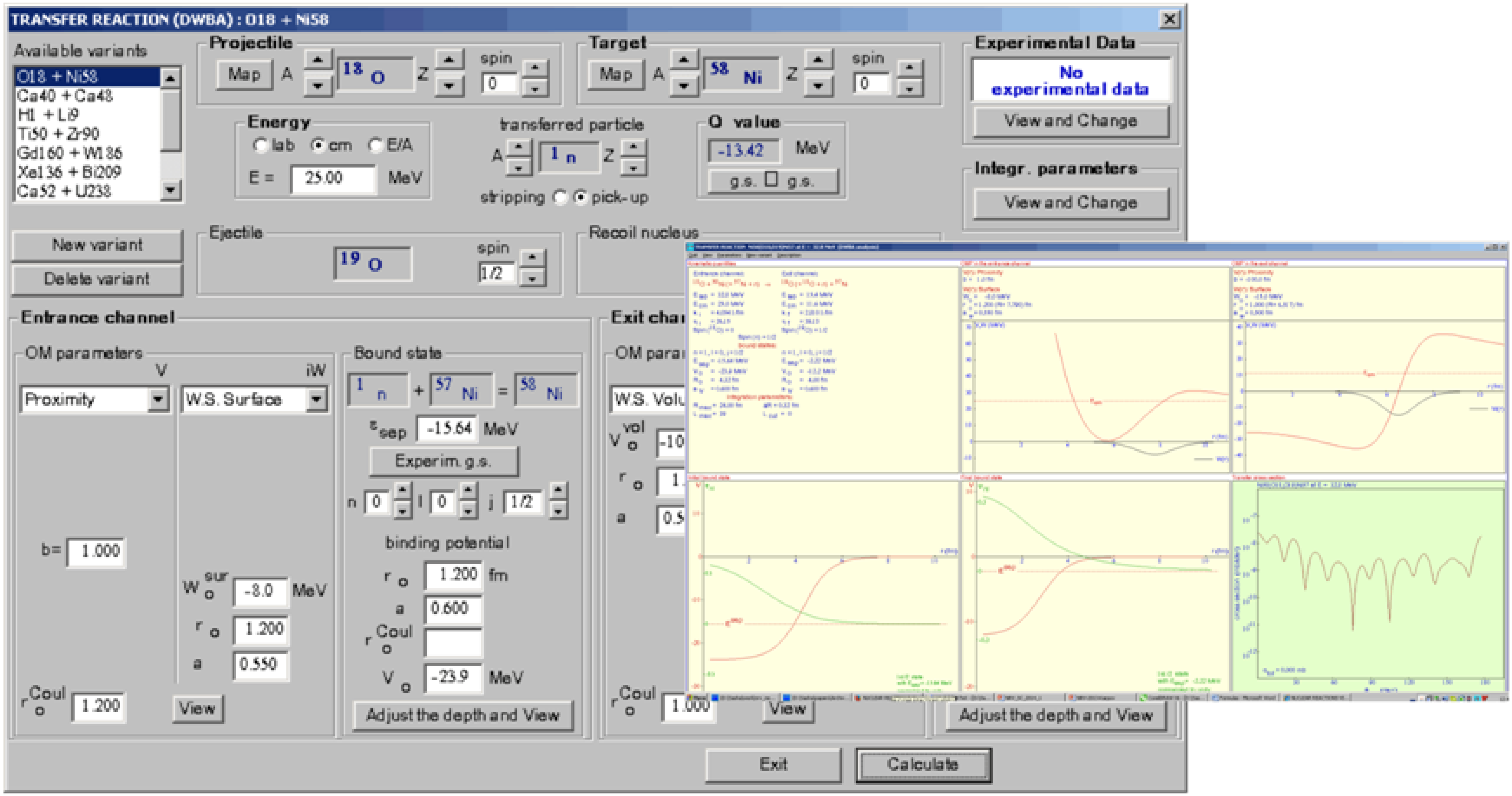
Solution: Interactive interface for codes with Graphics

What is Web Knowledge base?

First, it was done for Windows!

(*25 years ago by V. Zagrebaev and A. Kozhin*)

But, what about Linux, MacOS, Android, etc.?.. Does not work!



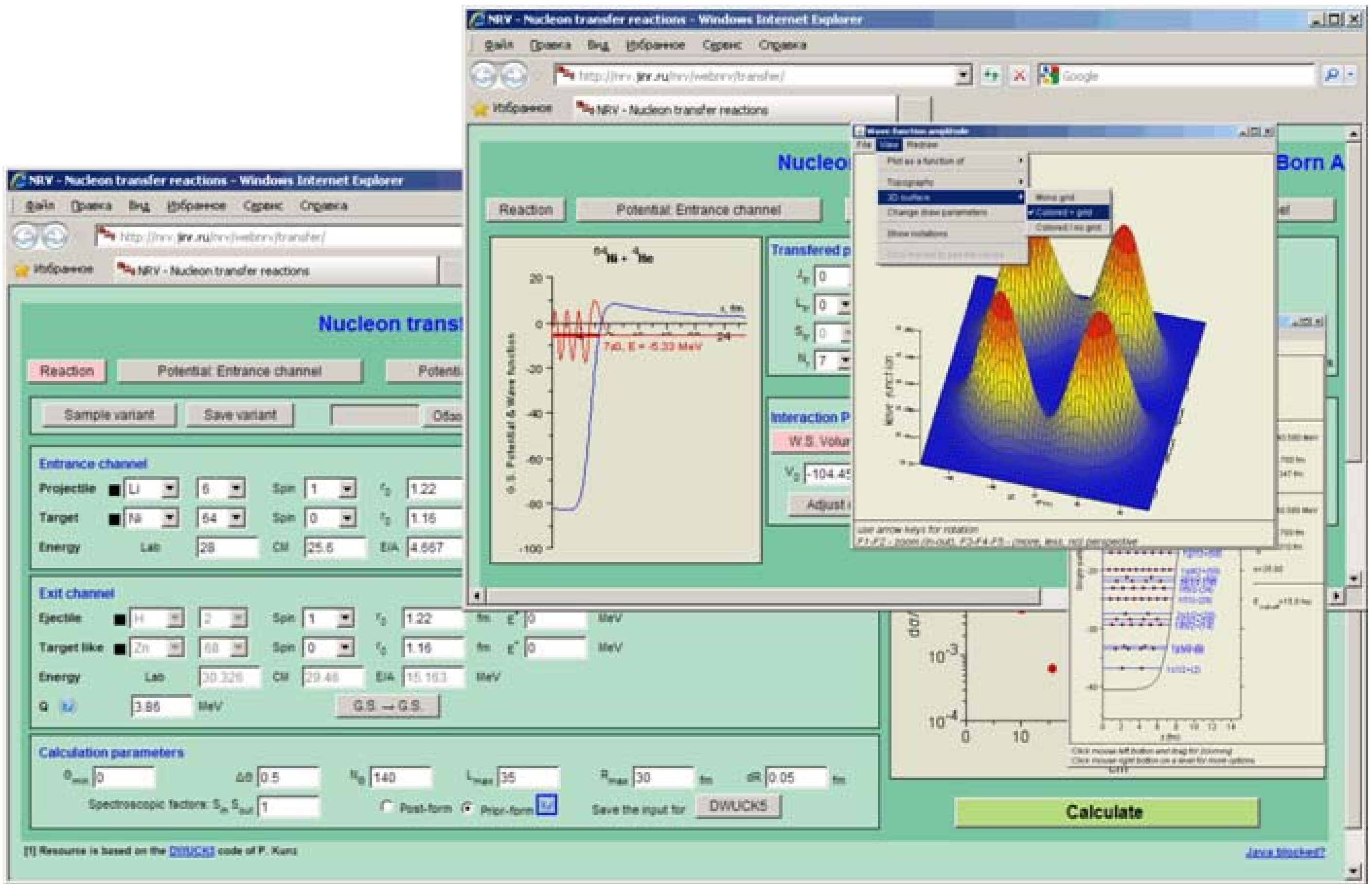
Solution: Do the same working in Internet Browsers

http://nrv.jinr.ru

The Web Knowledge base is unique interactive research system:

1. Allowing to run complicated computational codes
2. Working in any Internet browser
3. Having graphical interface of preparation inputs and analysis of outputs

Done!



For the first time it becomes possible to study complicated nuclear dynamics just in the Internet!

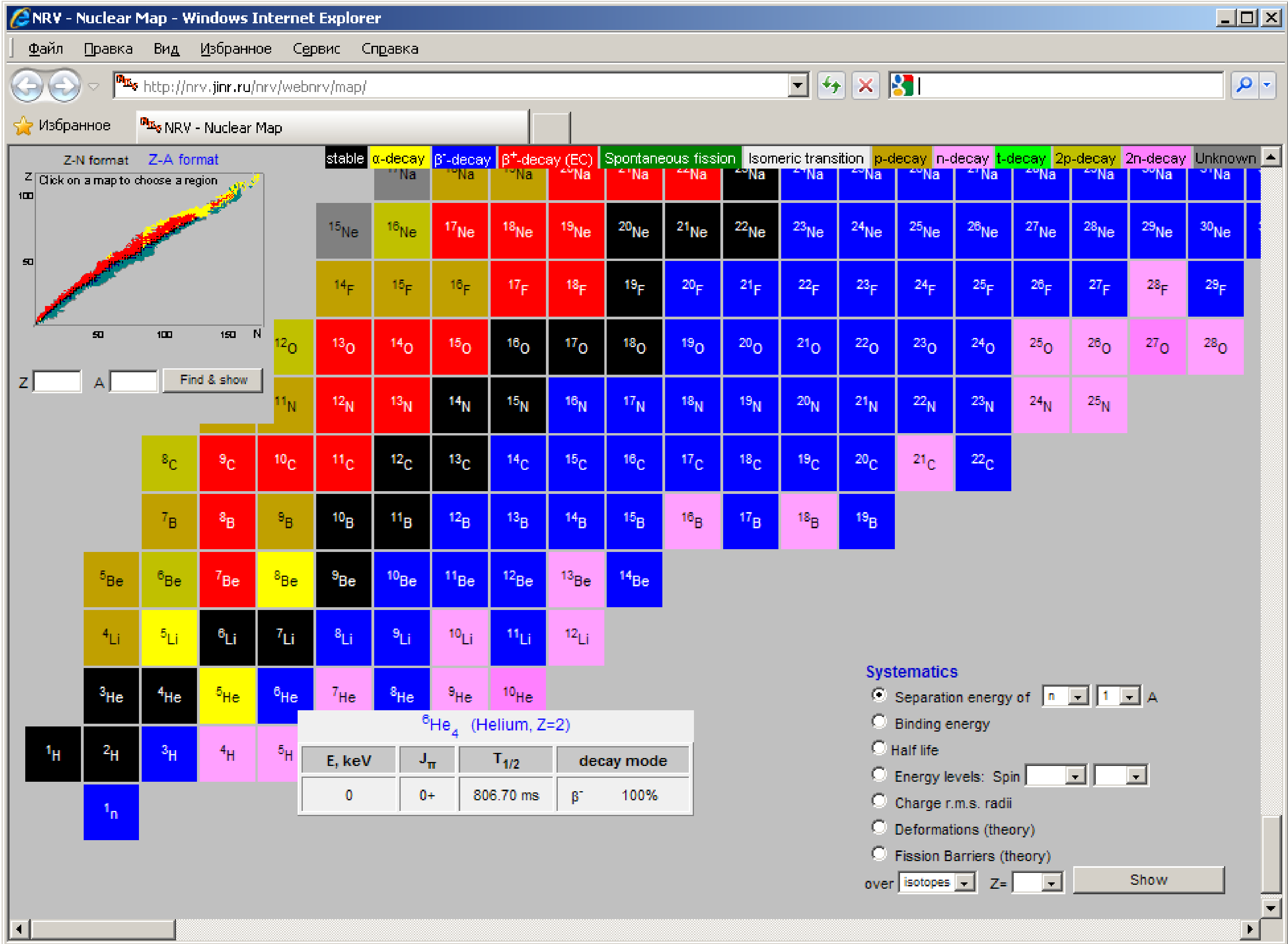
http://nrv.jinr.ru

Have an Internet browser?
May try!

requires Java

NRV. Main menu

Databases: Nuclear Map



Nuclear Models: Fusion-fission-surviving

Firefox

NUCLEAR REACTIONS VIDEO Project

Nuclear Reactions Video

Low Energy Nuclear Knowledge Base

Supported by
Russian Foundation for Basic Research

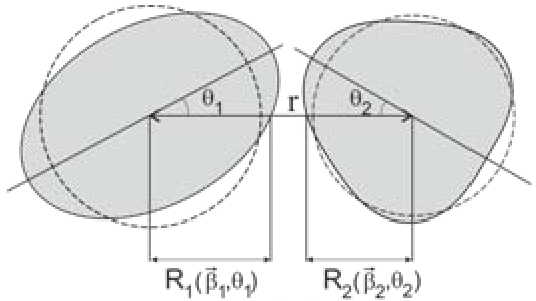
Nuclear Properties	Nuclear Models	Nuclear Decays	Nuclear Reactions	
Nuclear Map	Shell Model	Alpha - decay	**Elastic scattering** Classical Semiclassical Optical Model **Phase analysis**	Experimental Data $d\sigma/d\Omega$
	Liquid Drop Model	Beta - decay	**Inelastic Scattering** Coulomb excitation Direct process (DWBA) Channel coupling Deep inelastic collision	
	Two-Center Shell Model	Fission	**Transfer reactions:** **Direct process (DWBA)** **Semicalssical approach (GRAZING code)** 3-body classical model Two-nucleon transfer Massive transfer	
		Decay of excited nuclei	**Fragmentation** **EPAX v.3** Break-up (DWBA) Semiclassical model	LISE++
			Fusion Empirical model Channel Coupling Langevin equations	Experimental Data $\sigma_{fus}(E)$
			Driving potentials	
			Synthesis of SHE (movie)	
			Evaporation residues Monte-Carlo	Experimental Data $\sigma_{xn}(E)$
			Radiative capture Potential model	Experimental Data NACRE NACRE-II
			Pre-equilibrium LP formation 4-body classical model Semiclassical model Moving sources	
			Kinematics: 2-body / / 3-body / / Q-values Detector loading	

Check your **Browser Settings**
Java applets blocked?

Warning! NRV extensively uses Java. Your browser must support **Java Virtual Machine**

All resources of the NRV Knowledge Base are free to use.
We, nevertheless, need a support of our project by official establishment for further development of it. New models of nuclear dynamics and much more experimental data on nuclear reactions have to be included.
If you get useful results, **please, quote the NRV** in your papers and talks.
In a case of elastic scattering, for example, appropriate reference could be V.I. Zagrebaev et al., OM code of NRV, **http://nrv.jinr.ru/nrv/**, and so on.

Fusion: Quantum channel-coupling model



$$R(\vec\beta,\theta)=\tilde R\cdot\left(1+\sum_{\lambda\geq 2}\beta_\lambda Y_{\lambda 0}(\theta,0)\right)$$

$$\tilde R = Ro/[1+\frac{3}{4\pi}\sum_\lambda \beta_\lambda^2+\ldots]^{1/3}$$

$$V_{12}(r;\vec\beta_1,\theta_1,\vec\beta_2,\theta_2)=V_C(r;\vec\beta_1,\theta_1,\vec\beta_2,\theta_2)+V_N(r;\vec\beta_1,\theta_1,\vec\beta_2,\theta_2)+\frac{1}{2}\sum_{i=1}^{2}\sum_\lambda C_{i\lambda}\cdot\beta_{i\lambda}^2$$

$$H=-\frac{\hbar^2\nabla_r^2}{2\mu}+V_C(r;\vec\beta_1,\theta_1,\vec\beta_2,\theta_2)+V_N(r;\vec\beta_1,\theta_1,\vec\beta_2,\theta_2)+\sum_{i=1,2}\frac{\hbar^2\hat I_i^2}{2J_i}+\sum_{i=1,2}\sum_{\lambda\geq 2}\left(-\frac{1}{2d_{i\lambda}}\frac{\partial^2}{\partial s_{i\lambda}^2}+\frac{1}{2}c_{i\lambda}s_{i\lambda}^2\right)$$

$$H\Psi=E\Psi$$

$$H_{\rm int}\varphi_\nu(\vec\alpha)=\varepsilon_\nu\varphi_\nu(\vec\alpha)$$

$$\Psi_{\vec k}(r,\vartheta,\vec\alpha)=\frac{1}{kr}\sum_{l=0}^{\infty}i^l e^{i\sigma_l}(2l+1)\chi_l(r,\vec\alpha)P_l(\cos\vartheta)\,,$$

$$\chi_l(r,\vec\alpha)=\sum_\nu y_{l,\nu}(r)\cdot\varphi_\nu(\vec\alpha)$$

$$y''_{l,\nu}-\frac{l(l+1)}{r^2}+\frac{2\mu}{\hbar^2}\left[E-\varepsilon_\nu-V_{\nu\nu}(r)\right]y_{l,\nu}-\sum_{\mu\neq\nu}\frac{2\mu}{\hbar^2}V_{\nu\mu}(r)y_{l,\mu}=0$$

boundary conditions

$$y_{l,\nu}(r\to\infty)=\frac{i}{2}\left[h_l^{(-)}(\eta_\nu,k_\nu r)\cdot\delta_{\nu 0}-\left(\frac{k_0}{k_\nu}\right)^{1/2}S_{\nu 0}^l\cdot h_l^{(+)}(\eta_\nu,k_\nu r)\right]$$

$$y'_{l,\nu}(r<R_{\rm fus})\sim -ik_{l,\nu}y_{l,\nu}(r)$$

flux in channel ν

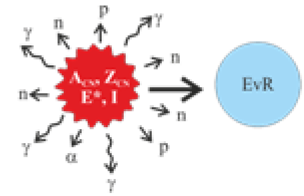
$$j_{l,\nu}=-i\frac{\hbar}{2\mu}\left(y_{l,\nu}\frac{dy^*_{l,\nu}}{dr}-y^*_{l,\nu}\frac{dy_{l,\nu}}{dr}\right)\Big|_{r\leq R_{\rm fus}}\qquad T_l(E)=\sum_\nu j_{l,\nu}/j_0$$

$$\sigma_{\rm fus}(E)=\frac{\pi}{k_0^2}\sum_{l=0}^{\infty}(2l+1)\cdot T_l(E)$$

CCFULL code (Hagino, Rowley, Kruppa)

NRV-codes: Fusion-CC (*Samarin, Zagrebaev*)

Decay of excited nuclei (Statistical model)



✔ Level Density

$$\rho(Z,A,U,I)=\rho_{\rm int}(Z,A,U,I)\cdot K_{coll}(Z,A,U)$$

$$\rho_{\rm int}(Z,A,U,I)=\frac{(2I+1)\sqrt{a}}{24\left(U-\Delta-\dfrac{\hbar^2 I(I+1)}{2J_\perp}\right)^2}\left(\frac{\hbar^2}{J_\perp}\right)^{3/2}\exp\left[2\sqrt{a\left(U-\Delta-\dfrac{\hbar^2 I(I+1)}{2J_\perp}\right)}\right]$$

$$a=\tilde{a}\left[1+\delta U\,\frac{1-\exp(-\gamma_D U)}{U}\right]$$

$$U=E^*-\Delta$$

✔ Decay Widths

$$\Gamma_{A\to B+a}(E^*,I)=\frac{1}{2\pi\rho_A(E^*,I)}\int_0^{E^*-B_a}\sum_{l,j}T_{lj}(e_a)\sum_{I'=|I-j|}^{I'=|I+j|}\rho_B(E^*-B_a-e_a,I')\,de_a \qquad (a=n,p,\alpha)$$

$$\Gamma_\gamma^L(E^*,I)=\frac{1}{2\pi\rho_A(E^*,I)}\int_0^{E^*}f_L(e_\gamma)\sum_{I'=|I-L|}^{I'=|I+L|}e_\gamma^{2L+1}\rho_A(E^*-e_\gamma,I')\,de_\gamma$$

$$\Gamma_{fiss}(E^*,I)=\frac{K_{\rm Kramers}(\text{friction})}{2\pi\rho_A(E^*,I)}\int_0^{E^*}T_{fiss}(e)\rho_A^{saddle}(E^*-e,I)\,de$$

T_{lj} - transmission coefficient for a particle emission

f_L - strength function of γ-quanta emission

T_{fiss} - transmission coefficient for fission

✔ Monte Carlo method

$$P_x=\frac{\Gamma_x}{\Gamma_{tot}} \qquad P_f=\frac{\Gamma_f}{\Gamma_{tot}} \qquad \Gamma_{tot}=\sum_{i=n,p,\alpha,\gamma,f}\Gamma_i \qquad E^*(n)=E^*(n-1)-B_x-E_{particle} \qquad E^*>\min(B_a,B_f)$$

decay probabilities

✔ Multifold integration method

$$P_{xn}=\int_0^{E_0^*-B_n(1)}\frac{\Gamma_n}{\Gamma_{tot}}(E_0^*,I_0)\cdot W_n(E_0^*,e_1)de_1\int_0^{E_1^*-B_n(2)}\frac{\Gamma_n}{\Gamma_{tot}}(E_1^*,I_1)\cdot W_n(E_1^*,e_2)de_2\ldots$$

x-fold integration for survival probability in xn channel

$$\int_0^{E_{x-1}^*-B_n(x)}\frac{\Gamma_n}{\Gamma_{tot}}(E_{x-1}^*,I_{x-1})\cdot W_n(E_{x-1}^*,e_x)\cdot\prod_{i=1}^{N}\frac{\Gamma_\gamma}{\Gamma_{tot}}(E_i^*,I_i)\cdot de_x$$

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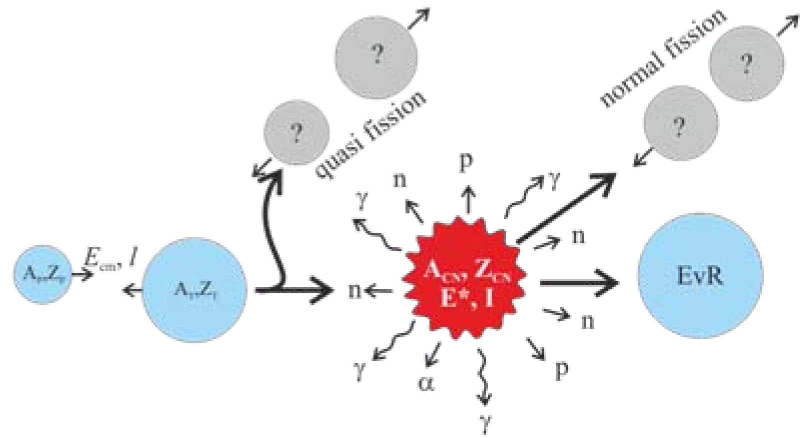
Fusion + Surviving

$$\sigma_{\text{fiss}} = \sigma_{\text{fus}} - \sum_{X,Y,Z} \sigma_{XnYpZ\alpha}$$



$$\sigma_{XnYpZ\alpha}(E) = \underbrace{\frac{\pi\hbar}{2\mu E}\sum_{l=0}^{\infty}(2l+1)T_l(E)}\underbrace{P_{CN}(E,l)}\underbrace{P_{XnYpZ\alpha}(E,l)}$$

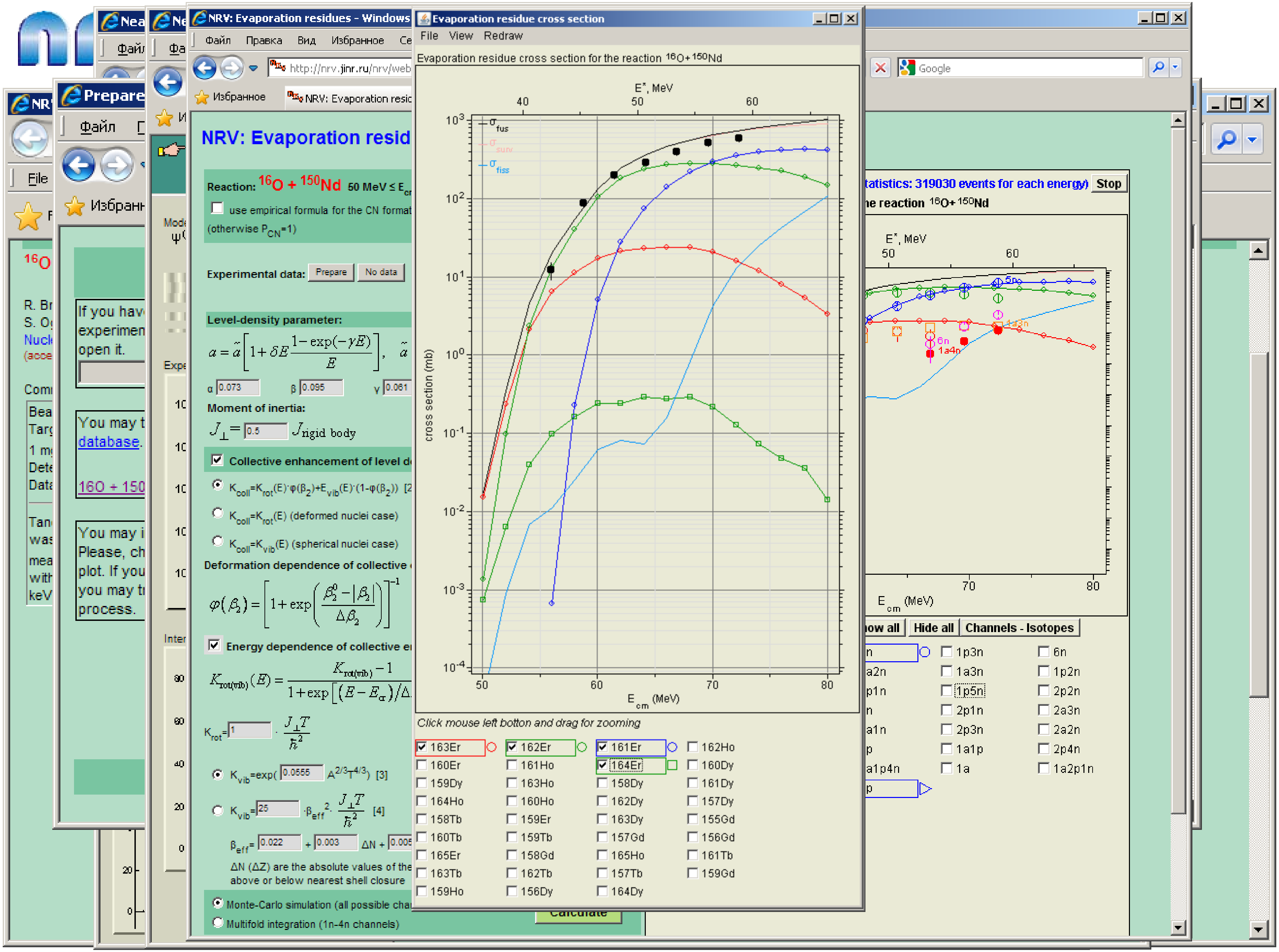
fusion cross section
(ECC or QCC)

survival probability
(statistical model)

CN formation probability for SH systems
(phenomenological relation for cold fusion reactions)

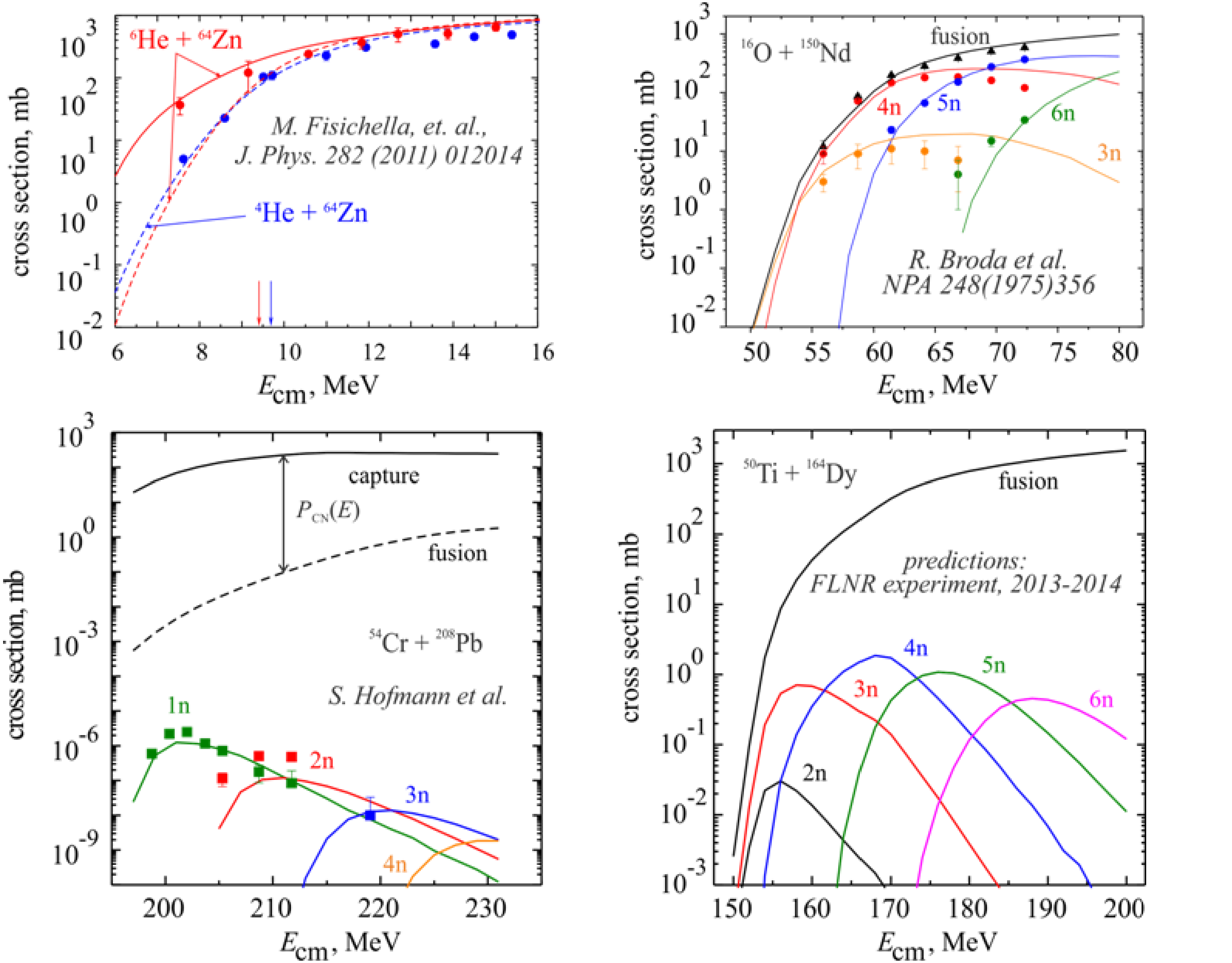
Experimental data for the Fusion Cross Sections (>1500 excitation functions)

Experimental data for the Evaporation Residue Cross Sections (~750 excitation functions)



NRV: Evaporation residues - Windows
Evaporation residue cross section
File View Redraw
Evaporation residue cross section for the reaction 16O+150Nd
E*, MeV
cross section (mb)
E cm (MeV)
σ fus
σ surv
σ fiss
Click mouse left botton and drag for zooming
163Er 162Er 161Er 162Ho
160Er 161Ho 164Er 160Dy
159Dy 163Ho 158Dy 161Dy
164Ho 160Ho 162Dy 157Dy
158Tb 159Er 163Dy 155Gd
160Tb 159Tb 157Gd 156Gd
165Er 158Gd 165Ho 161Tb
163Tb 162Tb 157Tb 159Gd
159Ho 156Dy 164Dy
NRV: Evaporation resid
Reaction: 16O + 150Nd 50 MeV ≤ E
use empirical formula for the CN format
(otherwise P CN=1)
Experimental data: Prepare No data
Level-density parameter:
α 0.073 β 0.095 γ 0.061
Moment of inertia:
Collective enhancement of level d
K coll=K rot(E)·φ(β2)+E vib(E)·(1-φ(β2))
K coll=K rot(E) (deformed nuclei case)
K coll=K vib(E) (spherical nuclei case)
Deformation dependence of collective
Energy dependence of collective e
ΔN (ΔZ) are the absolute values of the
above or below nearest shell closure
Monte-Carlo simulation (all possible cha
Multifold integration (1n-4n channels)
Calculate
tatistics: 319030 events for each energy) Stop
he reaction 16O+150Nd
Show all Hide all Channels - Isotopes
1p3n 6n
1a3n 1p2n
1p5n 2p2n
2p1n 2a3n
2p3n 2a2n
1a1p 2p4n
1a 1a2p1n
http://nrv.jinr.ru/nrv/web
Google
Файл Правка Вид Избранное
NRV: Evaporation resid
Prepare
If you hav experimen open it.
You may t database.
16O + 150
You may i Please, ch plot. If you you may tr process.

Tool for analysis and prediction



PRESENT possibilities of fusion-evaporation codes

a) Statistical code alone

•*Level densities (energy dependence)*
•*Decay widths (neutron, proton, alpha, gamma, fission)*
•*Survival probabilities (Monte-Carlo and Multifold integration)*

b) Fusion codes alone

•*Fusion cross section*
•*Barrier distribution*
•*Partial fusion cross section*

c) Combination of Fusion and Decay codes

•*Fission cross section*
•*Total survival cross section*
•*Evaporation cross sections for any possible channel*
•*Isotopic evaporation cross sections*
•*Account for CN formation probability (for cold fusion)*
•*Fission-fragment mass-charge distributions*

SOON-COMING (1-2 years) possibilities of fusion-evaporation codes

Combination of Fusion and Decay codes

- *Account for fission transient effects (fission delay time)*

- *Average multiplicities of pre- (from CN) and post- (from fragments) scission evaporated particles*

- *Energy spectra of evaporated particles (survived events, before and after scission of fissioning nuclei)*

Statistics of use of the Knowledge base

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Year	**Nuclear data** Nr. of searches	**Computational codes** Nr. of runs
2011	17 000	20 000
2012	36 000	21 000
2013	197 000	32 000
2014	199 000 per year ~540 per day 1 every 160 sec!	36 000 per year ~100 per day 1 every 15 min!

The most intensively using countries except Russia (*according to feedbacks and journal citations*):

USA, Germany, France, China, India, Italy, Poland

Prof. V. Zagrebaev
Head of the project

nrv http://nrv.jinr.ru

Unique research instrument in Internet

Everyone, Everywhere, Free

The Team

Dr. A. Karpov

Dr. A. Denikin

A. Alekseev
Web programmer

V. Rachkov

Prof. V. Samarin

M. Naumenko

Students…

NRV WEB KNOWLEDGE BASE ON LOW ENERGY NUCLEAR PHYSICS

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The NRV web knowledge base on low-energy nuclear physics [1] was developed at FLNR, JINR to allow quick access to the up-to-date experimental data on nuclear structure and cross sections of nuclear reactions as well as analysis of the data and modeling of the processes of nuclear dynamics within well-established physical approaches.

There are several unique advantages of the NRV web knowledge base compared to other nuclear databases.

As a rule, the nuclear databases supply users with ordinary text information. Thus, to obtain even the simplest systematics the user must manually prepare a separate file with all the necessary data and then use a separate graphical package to plot it. The NRV web knowledge base contains special programs for graphic representation of the data, their comparative analysis and obtaining systematics of all kinds either over a group of nuclei or the whole nuclear map.

Our databases on experimental cross sections of nuclear reactions allow quick processing, easy graphical comparison and analysis of the data within different theoretical models. All this is performed just in a window of the web browser without downloading and installation of any additional computational or graphical software. The computational programs for modeling low-energy nuclear dynamics are the significant part of the NRV web knowledge base.

Other advantages include simplicity of use, the interactive graphical interface allowing to adjust the parameters of theoretical models, detailed descriptions, graphical representation of the results, easy access via the Internet, etc.

The NRV web knowledge base contains most of the available experimental data on properties of nuclei as well as data on the cross sections of different nuclear reactions including fusion, evaporation and elastic scattering.

The available codes include the nuclear map, the shell model, the optical model, the CC model, the DWBA approach, reaction kinematics, etc.

The NRV web knowledge base is now widely used not only for scientific purposes, but also as a valuable tool in the education process in the field of nuclear physics [2].

This work was supported by grant 15-07-07673-a of the Russian Foundation for Basic Research (RFBR).

1. NRV web knowledge base on low-energy nuclear physics. http://nrv.jinr.ru/
2. A.S.Denikin *et al.* // Proc. of Conf. "Scientific services in Internet". 2008. P.393.