



<http://nrv.jinr.ru>

NRV web knowledge base: scientific and educational applications

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- *What is “Knowledge base”*
- *Scientific application*
- *Educational potential*

Supported by:

- **JINR**
- **JINR-SAR cooperation program**

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What is Web Knowledge base?

Typical situation with scientific codes

Input

Output

```
1001100130010000 209Pb(1H,2H)208Pb Elab=4180.00 MeV
91.000 0.000 2.000
35 1
0.1000-39.9000 1.5000 1.5000 0.0000 0.0000 0.0000 0.0000
4180.000209.0000 82.0000 1.0000 1.0000 7.2341 1.0000 0.0000 9.0000 0.0000
1.0000 -54.0000 7.3291 0.6470 0.0000 0.0000 0.0000 0.0000 0.0000
1.0000
-2.0000
-1.711920
1.0000
1.0000
-2.0000
-3.9360
-1.0000
1.0000
-2.2246
-10.0000
0.0000
9
```

File Edit Options Help

DUCKS-DISTORTED WAVES USING ORADO - PC - UNIX-VERSION 01/Aug /1999
Elapsed time = 0.00

CONTROL INTEGERS
1 2 3 4 5 6 7 8 9 A B C D E F G H I J K RUN IDENTIFICATION 2010/12/21 2.40.57
1 0 0 1 1 0 0 1 3 0 0 1 0 0 0 0 0 0 0 209Pb(1H,2H)208Pb Elab=4180.00 MeV

ANGLE DATA THETA= 181.0000 THETA= 0.0000 DTHE1= 1.0000 A-ANG= 0.0000 B-ANG= 0.0000

OCARD SET 3 DATA LMAX = 35 NLTR = 1
SCALE FACTORS= 1.0000

OCARD SET 4 DATA DRF = 0.1000 RMAX = -39.9000 ACCURACY SETTINGS, 1.500 1.500 0.000 0.000 0.000 0.000

PARTICLE DATA
PARTICLE 1
INPUT DATA ELAB = 4180.0000 RCD = 7.2341 AC = 1.0000 2*STR= 9.0000 Plab = MeV/c
HASSP= 209.0000 HASSI= 1.0000 Q = 0.0000
ZP = 82.0000 ZT = 1.0000 PNLDC= 0.0000

DERIVED DATA ECH = 19.9000 RC = 7.2341 RHO = 7.0428 P_cn = 192.1088 MeV/c
K = 0.9000 ETA = 2.8876 DR = 0.1000

POTENTIAL PARAMETERS
NX=1 VOLUME W-S U RL = 34.0000 RRL = 7.3291 A RL = 0.6470 R RL = 7.3291 USOR = 0.0000
U IH = 0.0000 RIH = 0.0000 A IH = 0.0000 R IH = 0.0000 USOI = 0.0000 POWR = 0.0000
NX=1 VOLUME W-S U RL = 0.0000 RRL = 0.0000 A RL = 0.0000 R RL = 0.0000 USOR = 0.0000
U IH = -1.4220 RIH = 7.3291 A IH = 0.6470 R IH = 7.3291 USOI = 0.0000 POWR = 0.0000
NX=2 SURFACE W-S U RL = 0.0000 RRL = 0.0000 A RL = 0.0000 R RL = 0.0000 USOR = 0.0000
U IH = 40.0000 RIH = 7.4062 A IH = 0.6270 R IH = 7.4062 USOI = 0.0000 POWR = 0.0000

PARTICLE 2
INPUT DATA ELAB = 1910.2505 RCD = 6.1135 AC = 1.0000 2*STR= 0.0000 Plab = MeV/c
HASSP= 208.0000 HASSI= 2.0000 Q = -1.7119
ZP = 82.0000 ZT = 1.0000 PNLDC= 0.0000

DERIVED DATA ECH = 18.1929 RC = 7.7825 RHO = 10.1144 P_cn = 259.1151 MeV/c
K = 1.3101 ETA = 4.2610 DR = 0.1000

POTENTIAL PARAMETERS
NX=1 VOLUME W-S U RL = -95.8010 RRL = 5.4081 A RL = 0.7940 R RL = 6.8138 USOR = 0.0000

- 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!

The screenshot displays the 'TRANSFER REACTION (DWBA) : O18 + Ni58' software interface. It is divided into several sections:

- Available variants:** A list of nuclear reactions including O18 + Ni58, Ca40 + Ca48, H1 + Li9, Ti50 + Zr90, Gd160 + W186, Xe136 + Bi209, and Ca52 + U238.
- Projectile:** Set to O18 with spin 0.
- Target:** Set to Ni58 with spin 0.
- Energy:** Set to 25.00 MeV, with options for lab, cm, or E/A.
- Transferred particle:** Set to 1 n.
- Q value:** Set to -13.42 MeV.
- Stripping:** Options for pick-up or stripping.
- Ejectile:** Set to O19 with spin 1/2.
- Recoil nucleus:** Section for calculating recoil nucleus parameters.
- Entrance channel:** Includes OM parameters (Proximity, W.S. Surface) and bound state parameters (e.g., $e_{sep} = -15.64$ MeV, $r_o = 1.200$ fm).
- Exit channel:** Includes OM parameters and bound state parameters (e.g., $r_o = 1.000$, $V_o = -23.9$ MeV).
- Graphical Plots:** Several plots showing potential energy curves (V(r)) and other reaction-related data as a function of distance (r).
- Buttons:** 'Exit', 'Calculate', 'View and Change', and 'Adjust the depth and View'.

Solution: Do the same working in **Internet Browsers**

The NRV web knowledge base is a unique interactive research system:

- Allows to run complicated computational codes
- Works in internet browser supporting Java
- Has graphical interface for preparation of input parameters and analysis of output results
- Combines computational codes with experimental databases on properties of nuclei and nuclear reactions
- Contains detailed description of models

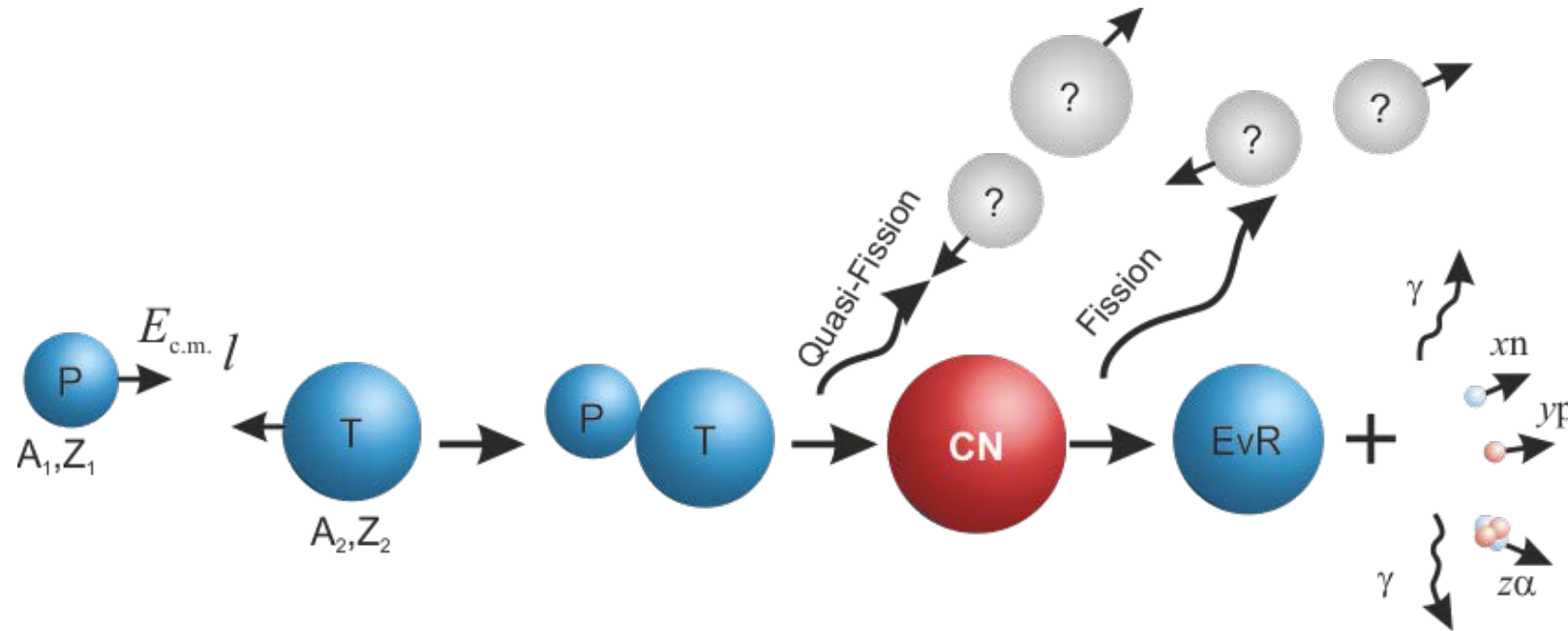
The screenshot shows the main interface of the NRV web knowledge base. It features a top navigation bar with categories like Nuclear Properties, Nuclear Models, Nuclear Decays, and Nuclear Reactions. Below this, there are several sub-sections with icons and text, including 'Getting Started', 'Warning: sections marked by this icon...', and various model descriptions like 'Liquid Drop Model' and 'Two-Center Shell Model'. The page is densely packed with information and interactive elements.

This screenshot displays the 'Near-barrier fusion reactions of atomic nuclei' interface. It includes a 'Model' section with 'Empirical' and 'Channel Coupling' options. The 'Input data' section shows parameters for a reaction between ^{16}O and ^{154}Sm , such as projectile energy, target radius, and Coulomb barrier. There are several plots: a 'Potential Energy' plot showing the interaction potential $V(r)$ and a 'Fusion Cross Section' plot showing σ_{fus} as a function of center-of-mass energy E_{cm} . The interface is designed for detailed parameter adjustment and calculation.

This screenshot shows the 'NRV: Fusion (Channel coupling)' interface. It features a plot of the nuclear potential $\psi^{(k)}(r, \xi) = \sum_n \psi_n(r) \Theta_n(\xi)$ and a graph of the fusion cross section σ_{fus} versus E_{cm} . The interface is titled 'Fusion of $^{16}\text{O} + ^{154}\text{Sm}$ ' and includes a button to 'Calculate evaporation residue cross section'. It provides a detailed view of the fusion process parameters and results.

This screenshot displays the 'NRV: Evaporation residue cross section' interface. It includes a plot of the evaporation residue cross section σ_{ER} versus E_{cm} . The interface is titled 'Evaporation residue cross section for the reaction $^{16}\text{O} + ^{154}\text{Sm}$ '. It features a 'Simulation' section with various parameters and a 'Calculate' button. The plot shows the cross section as a function of center-of-mass energy, with multiple curves representing different simulation runs.

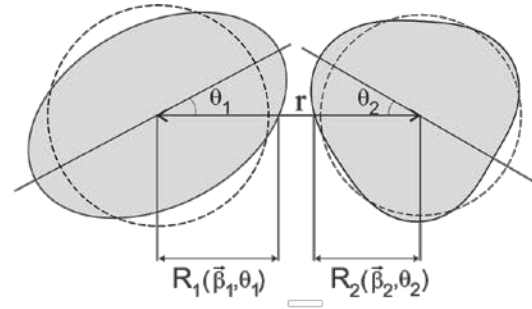
Scientific application: Synthesis of SH nuclei in fusion reactions



Cross section of SH elements production in fusion reactions with the emission of particles:

$$\sigma_{\text{EvR}}^{xn, yp, z\alpha}(E) = \underbrace{\frac{\pi \hbar^2}{2\mu E} \sum_{\ell=0}^{\infty} (2\ell+1) \cdot P_{\text{capt}}(E, \ell)}_{\text{Capture cross section (QCC and ECC model)}} \cdot \underbrace{P_{\text{CN}}(E^*, \ell)}_{\text{CN formation probability for SH systems}} \cdot \underbrace{P_{xn, yp, z\alpha}(E^*, \ell)}_{\text{Survival probability}}$$

Fusion: Quantum channel-coupling model



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

$$\tilde{R} = R_0 / \left[1 + \frac{3}{4\pi} \sum_{\lambda} \beta_{\lambda}^2 + \dots \right]^{1/3}$$

$$V_{12}(r; \vec{\beta}_1, \theta_1, \vec{\beta}_2, \theta_2) = V_C(r; \vec{\beta}_1, \theta_1, \vec{\beta}_2, \theta_2) + V_N(r; \vec{\beta}_1, \theta_1, \vec{\beta}_2, \theta_2) + \frac{1}{2} \sum_{i=1}^2 \sum_{\lambda} C_{i\lambda} \cdot \beta_{i\lambda}^2$$

$$H = -\frac{\hbar^2 \nabla_r^2}{2\mu} + V_C(r; \vec{\beta}_1, \theta_1, \vec{\beta}_2, \theta_2) + V_N(r; \vec{\beta}_1, \theta_1, \vec{\beta}_2, \theta_2) + \sum_{i=1,2} \frac{\hbar^2 \hat{I}_i^2}{2J_i} + \sum_{i=1,2} \sum_{\lambda \geq 2} \left(-\frac{1}{2d_{i\lambda}} \frac{\partial^2}{\partial s_{i\lambda}^2} + \frac{1}{2} c_{i\lambda} s_{i\lambda}^2 \right)$$

$$H\Psi = E\Psi$$

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

$$H_{\text{int}} \phi_{\nu}(\vec{\alpha}) = \varepsilon_{\nu} \phi_{\nu}(\vec{\alpha})$$

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

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

boundary conditions

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

$$y_{l,\nu}'(r < R_{\text{fus}}) \sim -i k_{l,\nu} y_{l,\nu}(r)$$

flux in channel ν

$$j_{l,\nu} = -i \frac{\hbar}{2\mu} \left(y_{l,\nu} \frac{dy_{l,\nu}^*}{dr} - y_{l,\nu}^* \frac{dy_{l,\nu}}{dr} \right) \Big|_{r \leq R_{\text{fus}}}$$

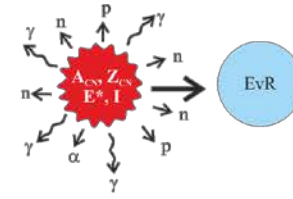
$$T_l(E) = \sum_{\nu} j_{l,\nu} / j_0$$

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

CCFULL code (Hagino, Rowley, Kruppa)

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

Decay of excited nuclei (Statistical model)



✓ Level Density

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

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

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

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

✓ Decay Widths

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

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

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

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

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

decay probabilities

✓ Multifold integration method

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

x-fold integration for survival probability in xn channel

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

Nuclear Models: Fusion-fission-surviving

Firefox NRV NUCLEAR REACTIONS VIDEO Project



Supported by
Russian Foundation for Basic Research

Nuclear Reactions Video

Low Energy Nuclear Knowledge Base

Nuclear Properties	Nuclear Models	Nuclear Decays	Nuclear Reactions	
Nuclear Map	Shell Model	Alpha - decay	Elastic scattering Classical Semiclassical Optical Model Phase analysis	Experimental Data $d\sigma/d\Omega$
<p>Check your Browser Settings Java applets blocked?</p> <p> Warning! NRV extensively uses Java. Your browser must support Java Virtual Machine</p>	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) Semiclassical approach (GRAZING code) 3-body classical model Two-nucleon transfer Massive transfer	
		Decay of excited nuclei	Fragmentation EPAX v3 Break-up (DWBA) Semiclassical model	LISE v3
			Fusion Empirical model Channel Coupling Langevin equations	Experimental Data $\sigma_{fus}(E)$
			Driving potentials Synthesis of SHE (movie)	
			Evaporation residues Monte-Carlo	Experimental Data $\sigma_{XR}(E)$
			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	

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.

NRV: Evaporation residues - Windows

File View Redraw

Evaporation residue cross section for the reaction $^{16}\text{O} + ^{160}\text{Nd}$

Reaction: $^{16}\text{O} + ^{150}\text{Nd}$ $50 \text{ MeV} \leq E_{\text{cr}}$

use empirical formula for the CN format (otherwise $P_{\text{CN}}=1$)

Experimental data:

Level-density parameter:

$$\alpha = \tilde{a} \left[1 + \delta E \frac{1 - \exp(-\gamma E)}{E} \right], \quad \tilde{a}$$

α [0.073] β [0.095] γ [0.081]

Moment of inertia:

$$J_{\perp} = [0.5] J_{\text{rigid body}}$$

Collective enhancement of level density

$K_{\text{coll}} = K_{\text{rot}}(E) \cdot \varphi(\beta_2) + E_{\text{vib}}(E) \cdot (1 - \varphi(\beta_2))$ [2]

$K_{\text{coll}} = K_{\text{rot}}(E)$ (deformed nuclei case)

$K_{\text{coll}} = K_{\text{vib}}(E)$ (spherical nuclei case)

Deformation dependence of collective level density:

$$\varphi(\beta_2) = \left[1 + \exp\left(\frac{\beta_2^0 - |\beta_2|}{\Delta\beta_2}\right) \right]^{-1}$$

Energy dependence of collective level density

$$K_{\text{rot(vib)}}(E) = \frac{K_{\text{rot(vib)}} - 1}{1 + \exp\left[\frac{(E - E_{\alpha})}{\Delta}\right]}$$

$K_{\text{rot}} = [1] \cdot \frac{J_{\perp} T}{\hbar^2}$

$K_{\text{vib}} = \exp(0.0555 A^{2/3} T^{4/3})$ [3]

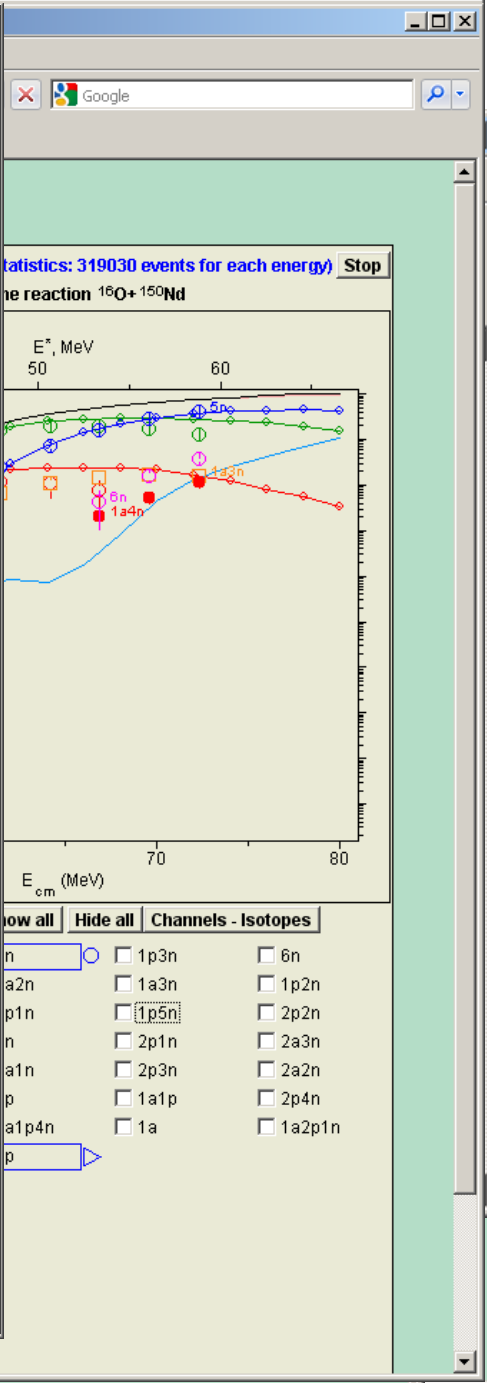
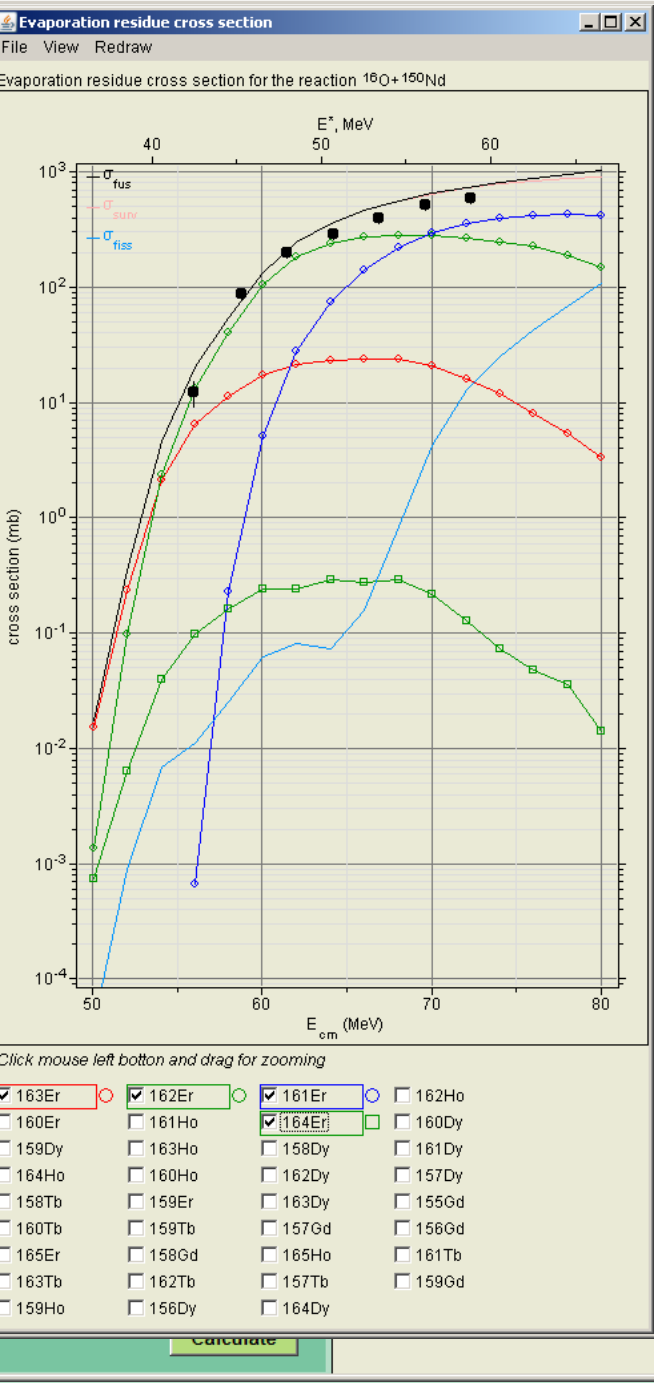
$K_{\text{vib}} = [25] \beta_{\text{eff}}^2 \frac{J_{\perp} T}{\hbar^2}$ [4]

$\beta_{\text{eff}} = [0.022] + [0.003] \Delta N + [0.005]$

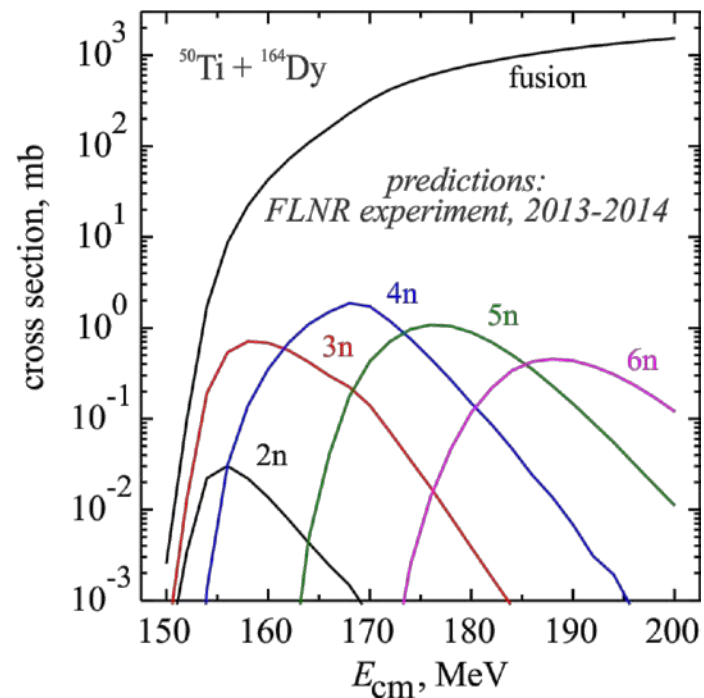
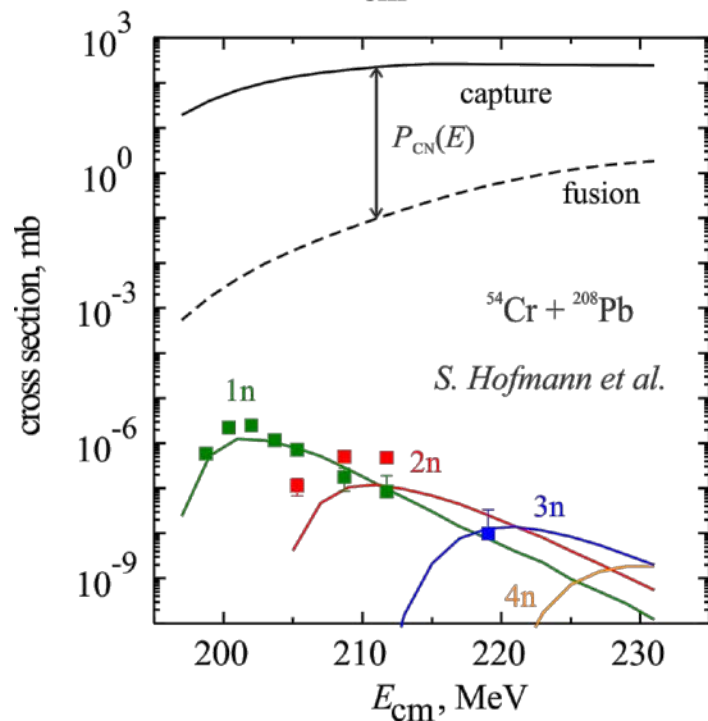
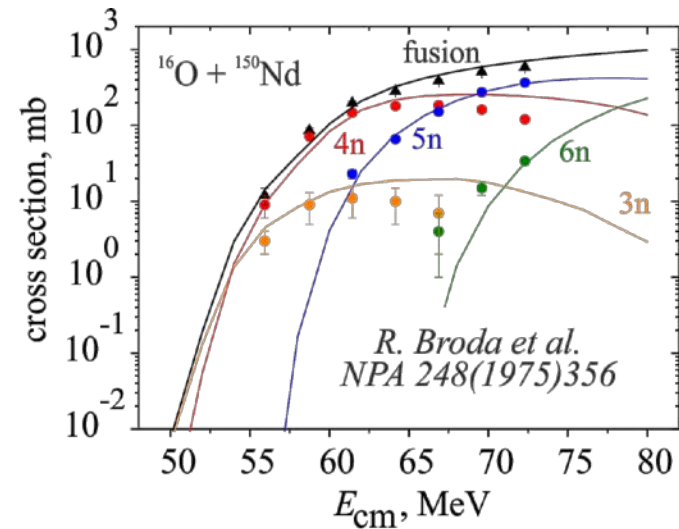
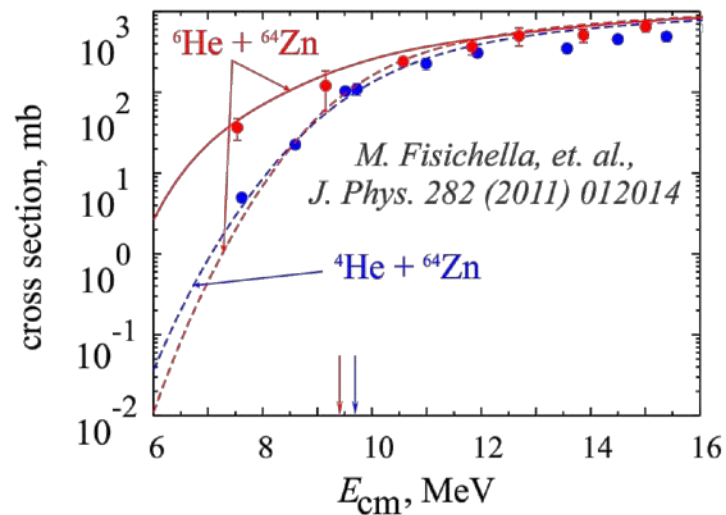
ΔN (ΔZ) are the absolute values of the above or below nearest shell closure

Monte-Carlo simulation (all possible channels)

Multifold integration (1n-4n channels)



Tool for analysis and prediction

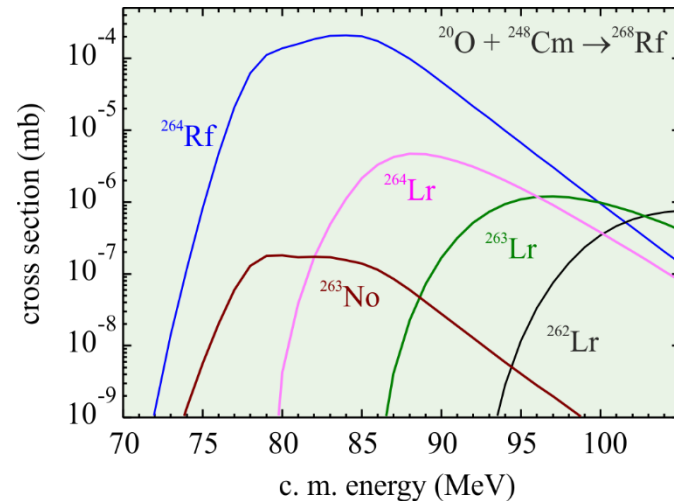
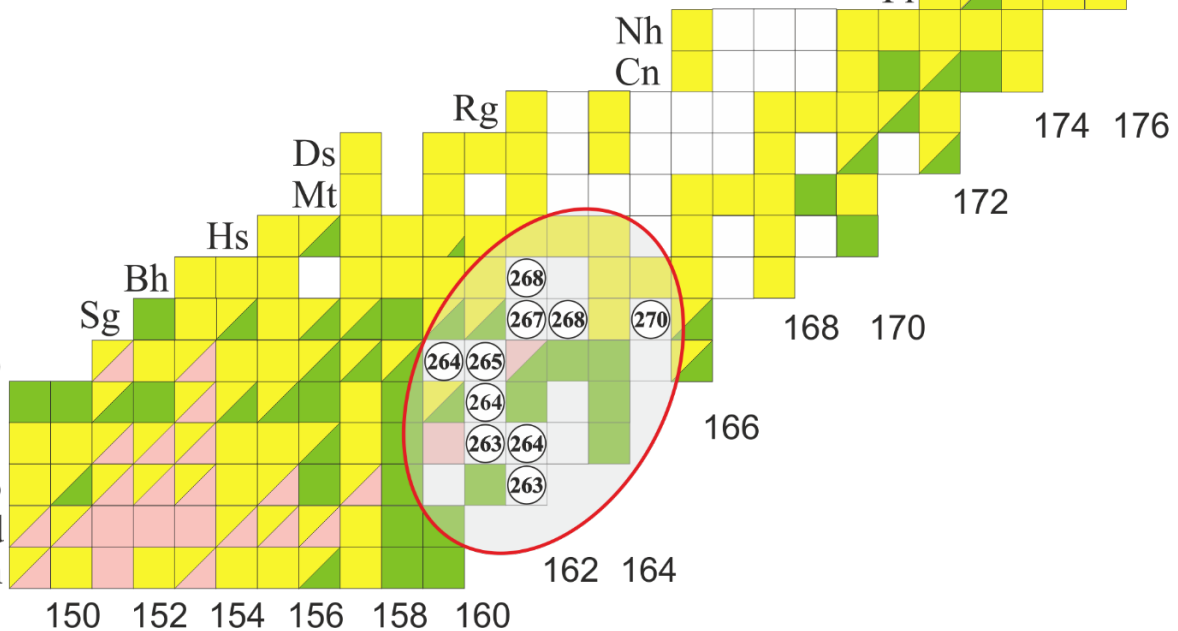
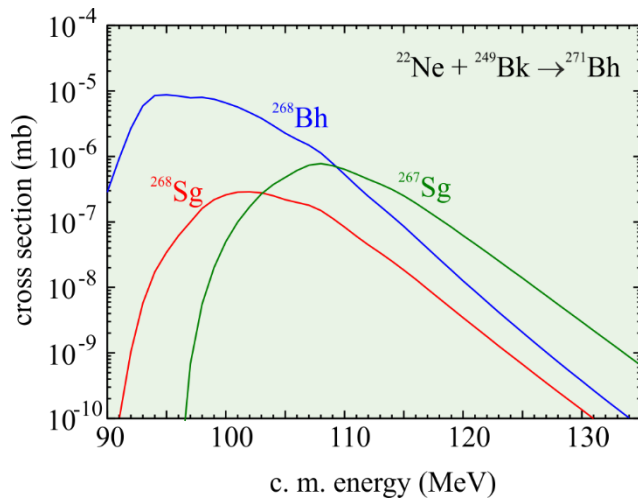
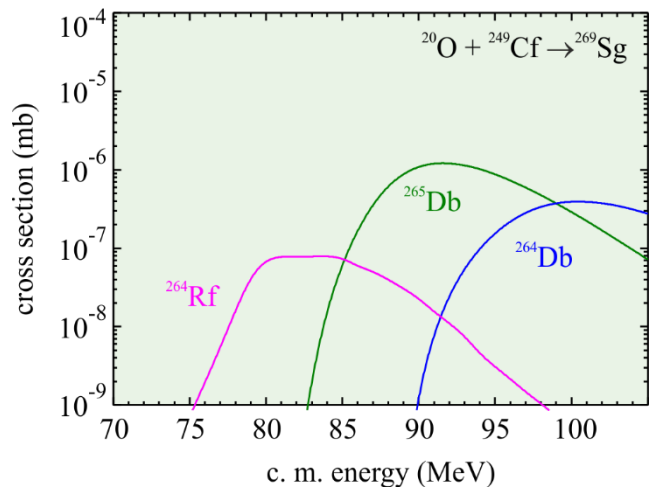
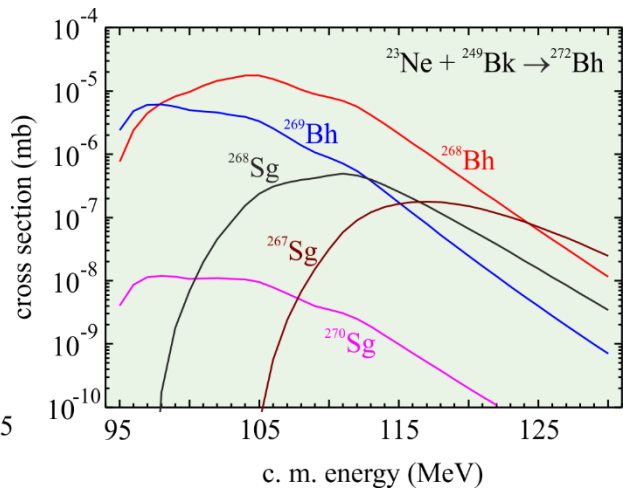
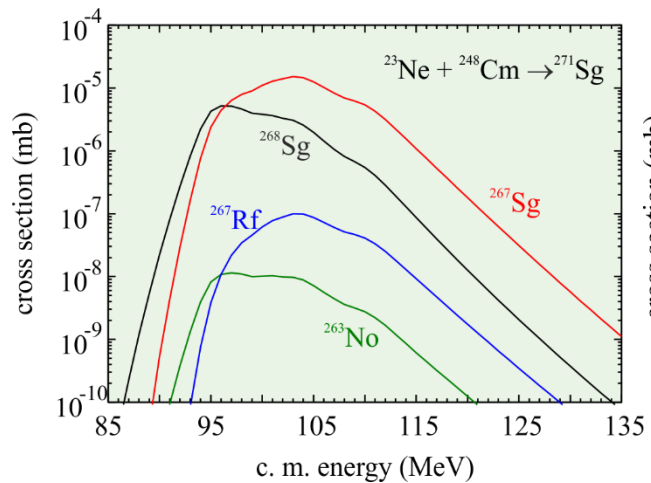


Tool for prediction: New isotopes with $Z = 102 - 107$

Projectile + target systems were chosen for which $\sigma_{ER} > 1$ pb

Projectile
 $^{22}\text{Ne}, ^{23}\text{Ne}, ^{20}\text{O}$

Targets
 $^{248}\text{Cm}, ^{249}\text{Cf}, ^{249}\text{Bk}$



Statistics of use of the Knowledge base



<http://nrv.jinr.ru>

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	36 000
2015	96 000	36 000
2016	115 000	60 000
2017	165 000 / year ~450 / day 1 every 3 minutes!	170 000 / year ~460 / day 1 every 3 minutes!

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

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

Educational potential of the NRV system

Background:

many-years experience of the NRV use for education in Dubna University and UC JINR Summer Student Programme.

Purpose:

development of practical courses on nuclear physics based on the NRV

Collaboration:

common project with UNISA (Prof. M.L. Lekala) started 2016



Unique on-line research instrument
Everyone, Everywhere, Free

<http://nrv.jinr.ru>

The NRV Team:



Prof. V. Zagrebaev
The project founder
(1950-2015)



Dr. A. Karpov
Today's project leaders



Dr. A. Denikin



A. Alekseev
Web programmer



V. Rachkov



M. Naumenko



Prof. V. Samarin



V.V. Saiko



Prof. M.L. Lekala
UNISA



Students...