IFIN-HH participation at the n_TOF CERN COLLABORATION (I)
THE n_TOF FACILITY CERN
### n_TOF basic parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>proton beam momentum</td>
<td>20 GeV/c</td>
</tr>
<tr>
<td>intensity (dedicated mode)</td>
<td>$7 \times 10^{12}$ protons/pulse</td>
</tr>
<tr>
<td>repetition frequency</td>
<td>1 pulse/2.4s</td>
</tr>
<tr>
<td>pulse width</td>
<td>6 ns (rms)</td>
</tr>
<tr>
<td>$n/p$</td>
<td>300</td>
</tr>
<tr>
<td>lead target dimensions</td>
<td>80x80x60 cm$^3$</td>
</tr>
<tr>
<td>cooling &amp; moderation material</td>
<td>H$_2$O</td>
</tr>
<tr>
<td>moderator thickness in the exit face</td>
<td>5 cm</td>
</tr>
<tr>
<td>neutron beam dimension in EAR-1 (capture mode)</td>
<td>2 cm (FWHM)</td>
</tr>
</tbody>
</table>
ENERGY DISTRIBUTION OF NEUTRONS

- n_TOF beam characteristics:
  Neutron intensity and resolution in the full energy range

Energy resolution @ 187.5 m (collimator for capture mode)

<table>
<thead>
<tr>
<th>Neutron Energy</th>
<th>p-beam pulse width FWHM [cm]</th>
<th>moderation FWHM [cm]</th>
<th>$\Delta E/E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 eV</td>
<td>0.0</td>
<td>3.0</td>
<td>3.0E-04</td>
</tr>
<tr>
<td>10 eV</td>
<td>0.1</td>
<td>3.0</td>
<td>3.2E-04</td>
</tr>
<tr>
<td>100 eV</td>
<td>0.2</td>
<td>3.3</td>
<td>3.5E-04</td>
</tr>
<tr>
<td>1 keV</td>
<td>0.6</td>
<td>5.1</td>
<td>5.5E-04</td>
</tr>
<tr>
<td>10 keV</td>
<td>2.0</td>
<td>7.9</td>
<td>8.7E-04</td>
</tr>
<tr>
<td>30 keV</td>
<td>3.4</td>
<td>10.2</td>
<td>1.1E-03</td>
</tr>
<tr>
<td>100 keV</td>
<td>6.2</td>
<td>18.0</td>
<td>2.0E-03</td>
</tr>
<tr>
<td>1 MeV</td>
<td>19.5</td>
<td>34.1</td>
<td>4.2E-03</td>
</tr>
<tr>
<td>10 MeV</td>
<td>61.7</td>
<td>16.9</td>
<td>6.8E-03</td>
</tr>
<tr>
<td>100 MeV</td>
<td>195.0</td>
<td>14.5</td>
<td>2.1E-02</td>
</tr>
</tbody>
</table>
Objectives of the activity at n_TOF

1. Cross sections relevant for Nuclear Astrophysics

2. Measurements of neutron cross sections relevant for Nuclear Waste Transmutation and related Nuclear Technologies (*)

3. Neutrons as probes for fundamental Nuclear Physics
Experimental Set-Up

-Pb Target

Detection systems:
- Compensate Ion Chamber (CIC)
- Gaseous detectors MICROMEGAS
- DE-E Telescopes (silicon or scintillators)
- PPAC detectors
- C6D6 Detectors
- TAC (40 BaF2 crystals)
The IFIN-HH research team working on analysis of activation cross sections for nuclear fusion projects has met particular question marks in relation to the capture cross section measurements already proposed for the n_TOF-Ph2.

The IFIN-HH research team will be involved in the cross section measurements for reactions contributing to the $^{232}$Th/$^{233}$U nuclear fuel cycle.

New Information on the basic mechanism of nuclear fission can be obtained by mixing accurate experimental data with new theories that take into account the nuclear structure of the nuclear system during the whole disintegration process.
Publications

The IFIN team joined the n_TOF collaboration for the 2010 campaign. The publications realized last year:

ARTICLES


PROCEEDINGS


New information on the basic mechanisms of nuclear fission can be obtained by mixing accurate experimental data with new theories that take into account the nuclear structure of the nuclear system during the whole disintegration process.

WHY?

Because a lack of consistency exists in the actual evaluation of fission data. Several problems will be mentioned.

1. The cross section is simulated by using a set of values for the heights of the barriers and the level density. But two different sets of such values can give the same cross section.

2. The variation of the level densities during the fission is subject to many phenomenological corrections, some of them in the aim of fitting the data.

3. Some physical ingredients (as the heights of the barriers) are obtained from experimental data and their experimental systematic is used afterward to predict the cross section of unmeasured nuclei. So it is considered that the structure (that change dramatically from one nucleus to another) plays a minor role.

4. The fine structure is considered as being due to the existence of the triple barrier. But, the minimums of this triple barrier are located in very different regions of the configuration space and it is difficult to believe that the fission trajectory is a zigzag one. The inertia increases dramatically in the inflexion points and the process is very improbable.

5. The variation of the inertia is neglected.

6. The low energy transition states do not intersect. In reality the levels are rearranged.

7. The population of the transition states is considered essentially unity. It is false hypothesis that contradicts the quantum mechanics.
The very high resolution of the n-TOF beam provides a unique opportunity to address some open questions concerning the structure of vibrational resonances. Theoretical investigations concerning the distribution of vibrational resonances at the fission threshold energies can be also performed emphasizing the role-played by the microscopic dynamical single-particle effects. This kind of effects already explained the fine structure behavior evidenced in the thorium anomaly phenomenon. Also, these investigations are realized from a microscopic point of view and offer a complete characterization of each resonance, including the knowledge of the spin and parity. So, fragment distributions at resonance can be obtained. These studies provide completely new information on the basic mechanism of nuclear fission. However, the new explanation needs further experimental support and reliable experimental data. Also, the actual evaluations can be improved by taking into account the new mechanisms in the phenomenological models. The possibility offered by the model to assign spins and parities to resonances that exist in the intermediary structure will suggest a way to reconstruct the fission-fragment angular distribution for the experimental activity. Yields of fission fragments can be also estimated.
Objective 2013: Dissipation and configuration mixing in fission from microscopic equations of motion.

Activity 1. Dissipation in fission processes

Activity 2. Configuration mixing in fission processes.

Up to now the dissipation in fission was treated within statistical models, with macroscopic approaches. For the first time the dissipation and the configuration mixing in fission is explained with full quantum mechanical approach. For this purpose, generalized equations of motion are deduced. The time dependent pairing equations (that are similar to the time dependent Hartree-Fock-Bogoliubov equations) are particular case of our new set of equations. The results agree with the experimental findings.
FIG. 1. Ideal avoided crossing regions between two adiabatic single particle levels $\epsilon_i$ and $\epsilon_j$ characterized by the same good quantum numbers. Three possible transitions between configurations in an avoided crossing region in the superfluid model are displayed: (a) The configuration remains unchanged after the passage through the avoided crossing region; (b) A pair is broken; (c) A pair is created.

The postulated interaction

$$H'(t) = \sum_{i,j\neq i}^{n} \epsilon_{ij}(t) \left[ \alpha_i(0) \alpha_j(0) \prod_{k\neq i,j} \alpha_k(0) \alpha_k^+(i,j) 
+ \alpha_i^+(0) \alpha_j^+(0) \prod_{k\neq i,j} \alpha_k(i,j) \alpha_k^+(0) \right],$$
The time dependent pairing equations for configuration mixing emerges from the minimization of the following functional

$$\delta\mathcal{L} = \delta \left\langle \varphi \left| H + H' - \lambda \left( N_2\hat{N}_1 - N_1\hat{N}_2 \right) - i\hbar \frac{\partial}{\partial t} \right| \varphi \right\rangle.$$ 

The trial many body wave function is a superposition of seniority zero and seniority two wave functions

$$|\varphi(t)\rangle = \left[ c_0 \prod_k \left( u_{k(0)}(t) + v_{k(0)}(t) a_k^+ a_k^\dagger \right) 
+ \sum_{j,l\neq j} c_{jl}(t) a_j^+ a_l^\dagger \prod_{k\neq j,l} \left( u_{k(jl)}(t) - v_{k(jl)}(t) a_k^+ a_k^\dagger \right) \right] |0\rangle.$$
FIG. 5. Proton single particle level scheme. The levels with spin projection $\Omega=3/2$ that give the lower energy configuration for the unpaired fragments is plotted with a full line. The Fermi energy of the compound nucleus is displayed with a thick dashed line. Four avoided level crossing regions were identified for $R \approx 9.1$, 14.7, 16 and 20 fm.
RESULTS
YIELD DISTRIBUTION AT VERY LOW EXCITATION ENERGIES FOR TWO FISSION PARTITIONS
THE EXPERIMENTAL DATA ARE EXPLAINED

SELECTED REFERENCES FOR INGREDIENTS OF THE MODEL:
Phys. Rev. C 78, 044618 (2008);
Phys. Lett. B 680, 316 (2009);
Phys. Rev. C 83, 054608 (2011);
Phys. Lett. B 717, 252 (2012);
arxiv 1309.7132 (2013)

FIG. 8. Full line: dependence of even even yield in arbitrary units $Y_0$ as function of the final excitation $E_x^*$ of the fission fragments. Dashed line: dependence of the odd-odd yields $Y_2$ as function of the excitation energy. The panel (a) corresponds to the cranking model, the panel (b) is obtained with the non-adiabatic cranking approach and the panel (c) with the Gaussian overlap approximation.
Objective 2014: Fragment distribution in low energy fission

The distributions of fission fragments will be determined and compared with experimental data.

Activity 1: Model for the determination of nuclear fragment distributions at low energies/30.07.2014

The model used in the determination of distributions will be presented.


The mass distribution will be determined and compared with experimental data.