# СЕКЦИЯ 4. РАДИОТЕХНИКА, МЕХАТРОНИКА, ТЕХНИЧЕСКИЕ И ПРОГРАММНЫЕ СРЕДСТВА АВТОМАТИЗАЦИИ И ТЕЛЕКОММУНИКАЦИЙ

UDC 621.384.6:621.039.31

## AN INVESTIGATION OF PRODUCTS OF (*n*, *f*), (*n*, γ) AND (γ, *f*), (γ, *xn*, *p*) REACTIONS ON SAMPLES OF URANIUM AND BISMUTH USING THE PHASOTRON AND LINAC-200 ACCELERATORS AT JINR: EXPERIMENTS AND CALCULATIONS

**S. I. Tyutyunnikov, V. I. Stegailov, V. V. Kobets, B. S. Yuldashev, N. G. Shakun, S. V. Rozov, A. G. Letov, F. A. Rasulova, I. A. Kryachko**

*Joint Institute for Nuclear Research, Dubna, Russian Federation*

**A. A. Smirnov**

*Institute in Physical and Technical Problems, Dubna, Russian Federation*

**T. N. Tran**

*Joint Institute for Nuclear Research, Dubna, Russian Federation*
*Institute of Physics, Vietnam Academy of Science and Technology, Hanoi*

*The paper presents the results of physical experiments with $^{238}$U and $^{209}$Bi samples at the Nuclotron, Phasotron and LINAC-200 accelerators of the Joint Institute for Nuclear Research, with the results processed using the FLUKA, GEANT4 and MCNP programs.*

**Keywords:** particle accelerator, Nuclotron, Phasotron, LINAC-200, complex of the proton and electron accelerators, secondary neutron radiation, proton beam, fission curve.

Studies of deeply inelastic nuclear processes and their theoretical description are the main tasks of the “Energy + Transmutation” collaboration [1, 2]. Experiments were carried out at JINR accelerators: Nuclotron, Phasotron and LINAC-200 (fig. 1).

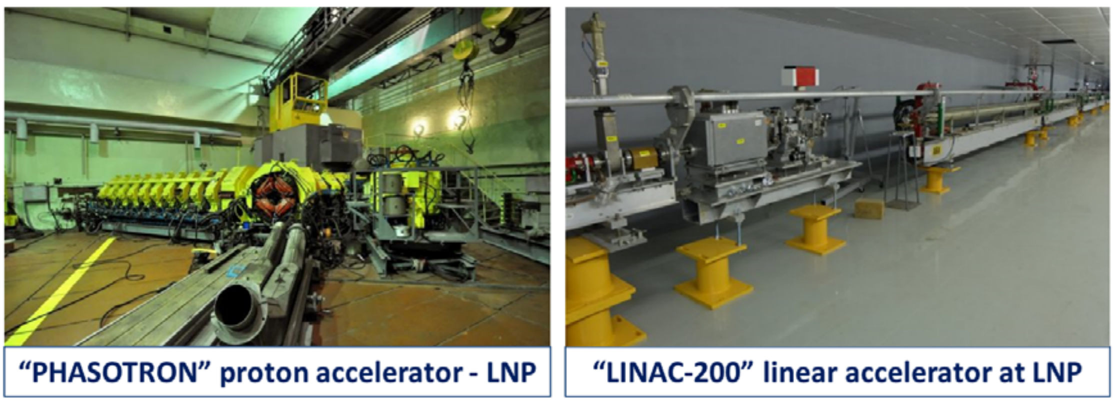


*Fig. 1*. The complexes of the proton and electron accelerators used in the experiments

In the course of the experiments, the (*n*, *f*), (*n*, γ) and (γ, *f*), (γ, *xn*, *p*) reactions were investigated. The $^{238}$U and $^{209}$Bi samples were used in the experiments. In the process of modeling experimental results with help of FLUKA, GEANT4 and MCNP programs, we investigated:

– the distribution of neutrons emitted from a lead target by energies and positions on a proton beam;

– the distribution of secondary bremsstrahlung radiation (and secondary neutron radiation) on an electron beam was obtained using Pb or $^{209}$Bi converters;

– the quantitative results of (*n*, *f*) fission reaction productson proton beams in the $^{238}$U samples;

– the quantitative results of (γ, *xn*) photonuclear reaction products on electron beams in the $^{238}$U and $^{209}$Bi samples;

– the fission product mass yield curve shown in fig. 2 was obtained as a result of the (*n*, *f*) fission reactionson the proton beam with $E$ = 660 MeV of the Phasotron accelerator. A foil of $^{238}$U with a thickness of 0.1 mm was irradiated in the neutron field from the lead converter. The measurements were implemented conducted with the help of HPGe detectors in the measuring complexes of LNP and LHEP at JINR. The processing of the spectra and the determining the yields of the nuclei were done using the programs DEIMOS, MAESTRO, Origin and GAMMA;

– the spread of the yield of nuclei on the fission curve indicates the need for careful consideration of the decay processes of nuclei arising during fission, especially their isomeric states. The yield of isomers could affect the analyzed results.

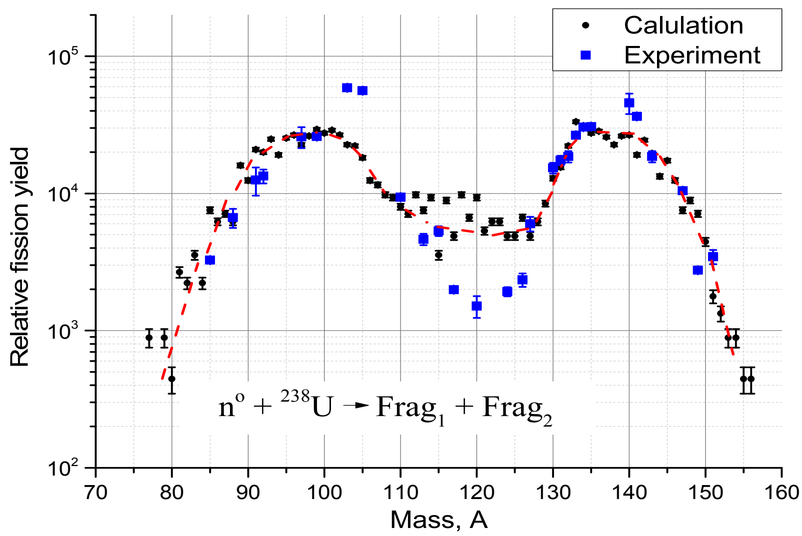


*Fig. 2.* The fission reaction products of the $^{238}$U
in the neutron field, $E_p$ = 660 MeV

One of the main tasks of our work is to take into account the channels of decay and isomer yields in fission processes of uranium nuclei in the neutron field of a lead converter on the beam and electron beams.

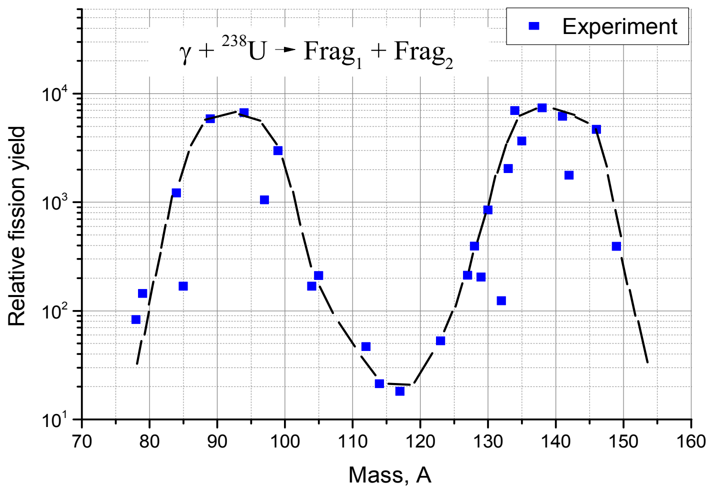


*Fig. 3*. Thefission reaction products of the $^{238}$U
in the bremstrahlung field, $E_{e-}$ = 140 MeV

Fig. 3 shows the fission curve of the uranium nuclei in the field of bremsstrahlung radiation generated by irradiating a lead convertor with the electron beam with $E$ = 140 MeV. In the field where theuranium samples were placed, the measurement and processing of the spectra were carried out similarly to the experiments on the proton beam. Comparison of the results obtained in photonuclear reactions and ($n$, $f$) fission reactions is of undoubted scientific interest.In experiments on electron beams, a $^{209}$Bi target was used as a test monitor [3]. The production of $^{239}$Np nuclei and neutron capture were investigated in the process of studying the chain:$^{238}$U ($n$, $\gamma$) $^{239}$U (23.54 m) $\beta^{-}\rightarrow^{239}$Np (2.36 d) $\beta^{-}\rightarrow^{239}$Pu (24110 y).

References

1. S. I. Tyutyunnikov,V. I. Stegailov [et al.] // NUCLEUS-2021. St-Petersburg, 130 (2021).
2. S. I. Tyutyunnikov [et al.] // Nuclear Science and Technologies, Almaty, 157 (2021).
3. S. S. Belyshev [et al.] // Eur. Phys. J. A 51, 67 (2015).

УДК 62-83:621.313.333

# ОБЩАЯ ДИНАМИКА МАШИН А. А. АНДРОНОВА КАК ОСНОВА НЕЛИНЕЙНОЙ ЭЛЕКТРОМЕХАНИКИ

**Д. В. Комнатный**

*Учреждение образования «Гомельский государственный технический университет имени П. О. Сухого», Республика Беларусь*

*Рассмотрена проблема построения нелинейной электромеханики как теории электрических машин, основанной на нелинейной теории динамических систем. Предложено в русле идей академика А. А. Андронова анализировать фазовое пространство уравнений электрических машин, выявить аналогии с механическими системами. Приведены примеры фазовых пространств динамики генератора постоянного тока с самовозбуждением, синхронного генератора, асинхронного двигателя, ускорителя элементарных частиц. Показана универсальность предлагаемого подхода, его соответствие современным направлениям развития науки.*

**Ключевые слова:** нелинейная электромеханика, нелинейная теория динамических систем, грубые системы, фазовое пространство, предельный цикл, механическая аналогия, электрические машины.