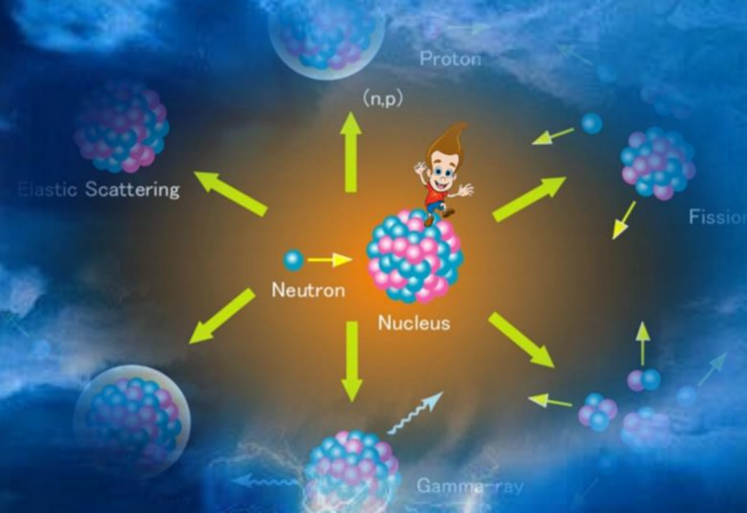
TANGRA

ISINN-27
27-th International Seminar on Interaction of Neutrons with Nuclei: «Fundamental Interactions & Neutrons, Nuclear Structure, Ultracold Neutrons, Related Topics»
June 10 – 14, 2019 | Dubna, Russia
isinn.jinr.ru

FLNP



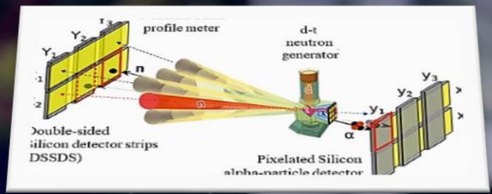
Angular distribution of 1.368 MeV gamma-rays from inelastic scattering of 14.1 MeV neutrons on ^{24}Mg

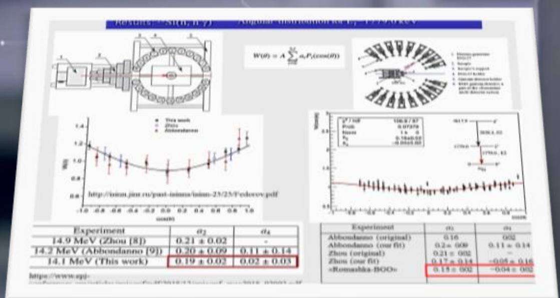
I.N. Ruskov for TANGRA collaboration

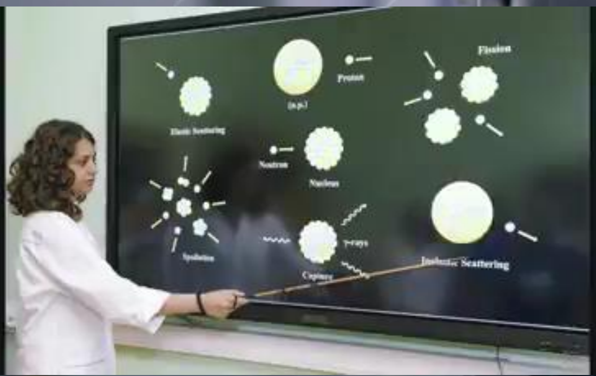
TANGRA
APPLICATIONS

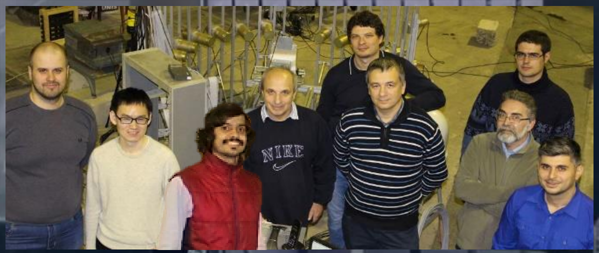
TANGRA
SCIENCE & EDUCATION

TANGRA
TAGGED NEUTRONS & GAMMA RAYS



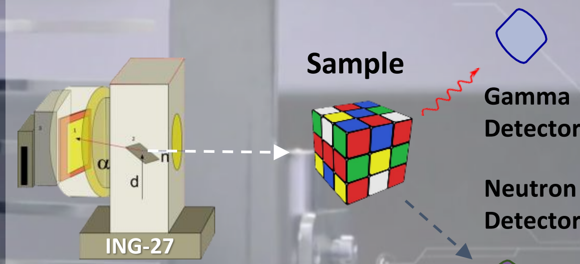






Design and development of the tagged neutron method for determination of the elemental structure of materials and nuclear reaction studies

$$d + t \rightarrow {}^{4}He\ (3.5\ MeV) + n\ (14.1\ MeV)$$



Measured Quantities:

- Time-of-flight (n-gamma separation, background rejection)
- Pulse shape (n-gamma separation)
- Angle of emission of the incident neutron and secondary particle (neutron or gamma)

Basic and Applied Neutron-Nuclear Physics

- Neutron induced Nuclear Reaction Characteristics
- Nuclear Astrophysics (Fusion in Tokamak and Stars
- Neutron-Nuclear Reactions in Advance Reactors
- Nuclear Forensics (Explosives, Drugs, Fissile Materials)
- Art, Archelogy , Mining (Diamonds, Coke)
- Nuclear Geophysics and Planetology (Water on Mars)
- Neutron Imaging, Radiography and Tomography
- Neutron-Nuclear Medicine (Cancer treatment)

JINR (FLNP, VBLHEP, DLNP, LRB), Dubna, Russia
VNIIA (Moscow, Russia)
Diamant LLC, Dubna, Russia
SINP-Moscow State University (Russia)
INRNE-BAS (Sofia, Bulgaria)
IC-ASM (Chisinau, Moldova)
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SEPE, Xi'an Jiaotong University (China)
Alexandria University (Egypt)
University of Novi Sad (Serbia)
Ruđer Bošković Institute (Zagreb, Croatia)

TANGRA Collaboration, tangra.collaboration @ mail.ru
Project Leader: Y.N. Kopatch, kopatch @ nf.jinr.ru
Former Project Vice-Leader: V.M. Bystritsky †
Coordinator: I.N. Ruskov, ivan.n.ruskov @ gmail.com
Address: http://flnph.jinr.ru/en/facilities/tangra-project
Frank Laboratory of Neutron Physics (FLNF)
Joint Institute for Nuclear Research (JINR)
Joliot Curie str. 6, 141980 Dubna, Moscow region, Russia
https://www.facebook.com/Tangra-News-1705174506183427/

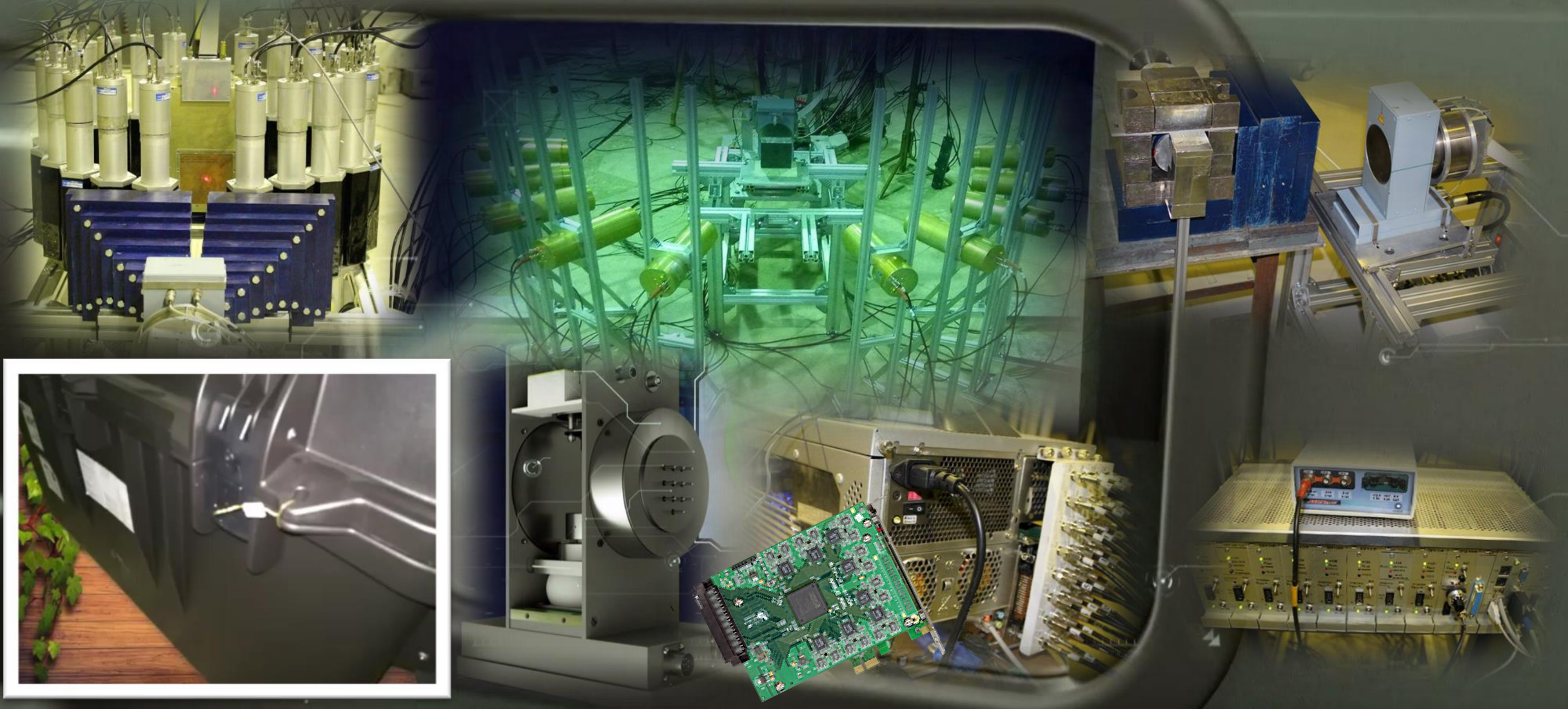
TANGRA SETUPS

Multidetector, multipurpose, multifunctional, mobile systems, to study the characteristics of the products from the nuclear reaction induced by 14 MeV tagged neutrons

NaI(Tl) Romashka

BGO Romasha

HPGe Romasha

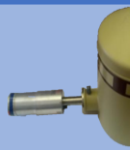


TANGRA Setups consist of a portable generator of "tagged" neutrons with an energy of 14.1 MeV, ING-27, with or without an iron shield-collimator, 2D fast neutron beam profilometer, arrays of neutron-gamma detectors in geometry of daisy-flower (Romashka, Romasha, HPGe), a computerized system for data acquisition and analysis (DAQ).

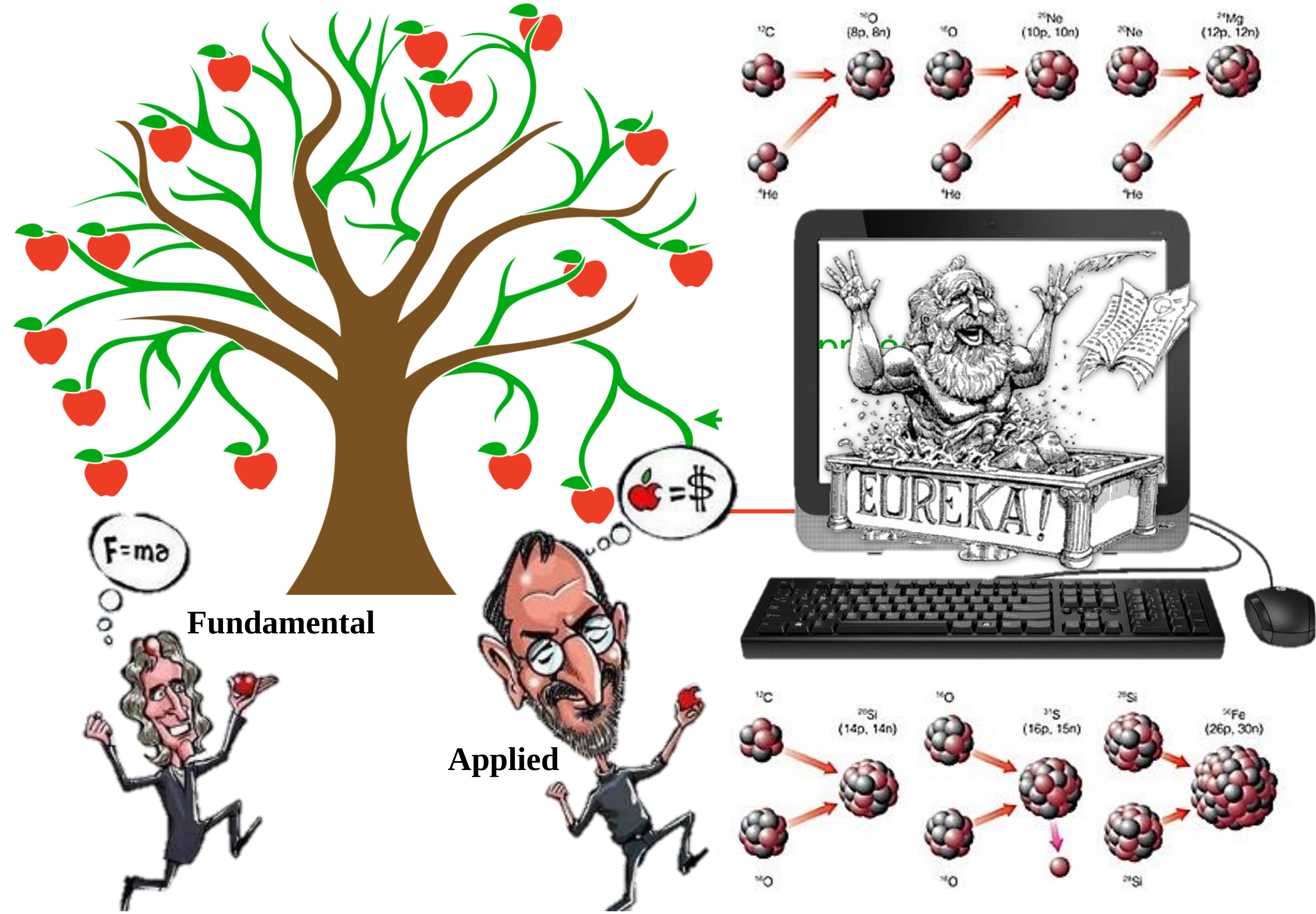
Number of NaI(Tl) detectors: 22
Size of NaI(Tl) crystals: hexagonal prism 78 x 90 x 200 mm
PMT type: Hamamatsu R1306
Gamma-ray Energy-resolution ~ 7.2 % @ 0.662 MeV
Gamma-ray Energy-resolution ~ 3.6 % @ 4.437 MeV
Gamma-ray Time-resolution ~ 3.8 ns @ 4.437 MeV

Number of BGO detectors: 18
Size of BGO crystals: cylinder $\varnothing$ 76 x 65 mm
PMT type: Hamamatsu R1307
Gamma-ray Energy-resolution ~ 10.4 % @ 0.662 MeV
Gamma-ray Energy-resolution ~ 4.0 % @ 4.437 MeV
Gamma-ray Time-resolution ~ 4.1 ns @ 4.437 MeV

Number of HPGe detectors: 1
Type: Ortec® GMX 30-83-PL-S, ϕ57.5 x 66.6 mm
Gamma-ray Energy-resolution ~ 3.4 % @ 0.662 MeV
Gamma-ray Energy-resolution ~ 0.3 % @ 4.437 MeV
Gamma-ray Time-resolution ~ 6.1 ns @ 4.4437MeV



TANGRA: Neutron-Nuclear Research



TANGRA: Inelastic neutron scattering

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ELSEVIER

Journal of Nuclear Energy (1954)

Volume 9, Issues 1–4, June 1959, Pages 120-127

Gamma-ray spectra excited by the inelastic scattering of fast neutrons by Mg, Al, Fe, Cu, Sn, and Sb ☆ ☆☆

Translated from *Atomnaya Energiya* **4**, 132 (1958).

I.F. Barchuk, M.V. Pasechnik, Iu.A. Tsibul'ko

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https://doi.org/10.1016/0891-3919(59)90148-9

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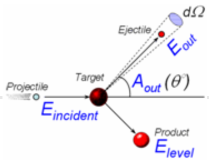


Abstract

The study of the inelastic scattering of fast neutrons is of considerable theoretical and practical importance. From the theoretical point of view such studies provide information about the levels of stable nuclei. The practical value of these studies is due to the importance of inelastically scattered neutrons in the operation of fast neutron reactors. A knowledge of the spectra of the inelastically scattered neutrons is essential to the provision of a sound theory of fast reactors. [1,2] In order to provide this information, the last 5–7 years has seen a considerable amount of work devoted to the development of fast neutron spectrometry and to the spectroscopy of the gamma-rays accompanying inelastic neutron scattering.

In this paper, we report measurements of the spectra of gamma-rays excited by the inelastic scattering of 2·8 MeV neutrons by Mg, Al, Fe, Cu, Sn, and Sb. A NaI(Tl) scintillation spectrometer was used in this work in conjunction with a photomultiplier, type FEU-1B, and a 50 channel pulse height analyser incorporating a magnetic drum memory device. For ^{60}Co gamma-rays, the resolution of the spectrometer was 6·5–7 per cent. Gamma-rays having the following energies (MeV)

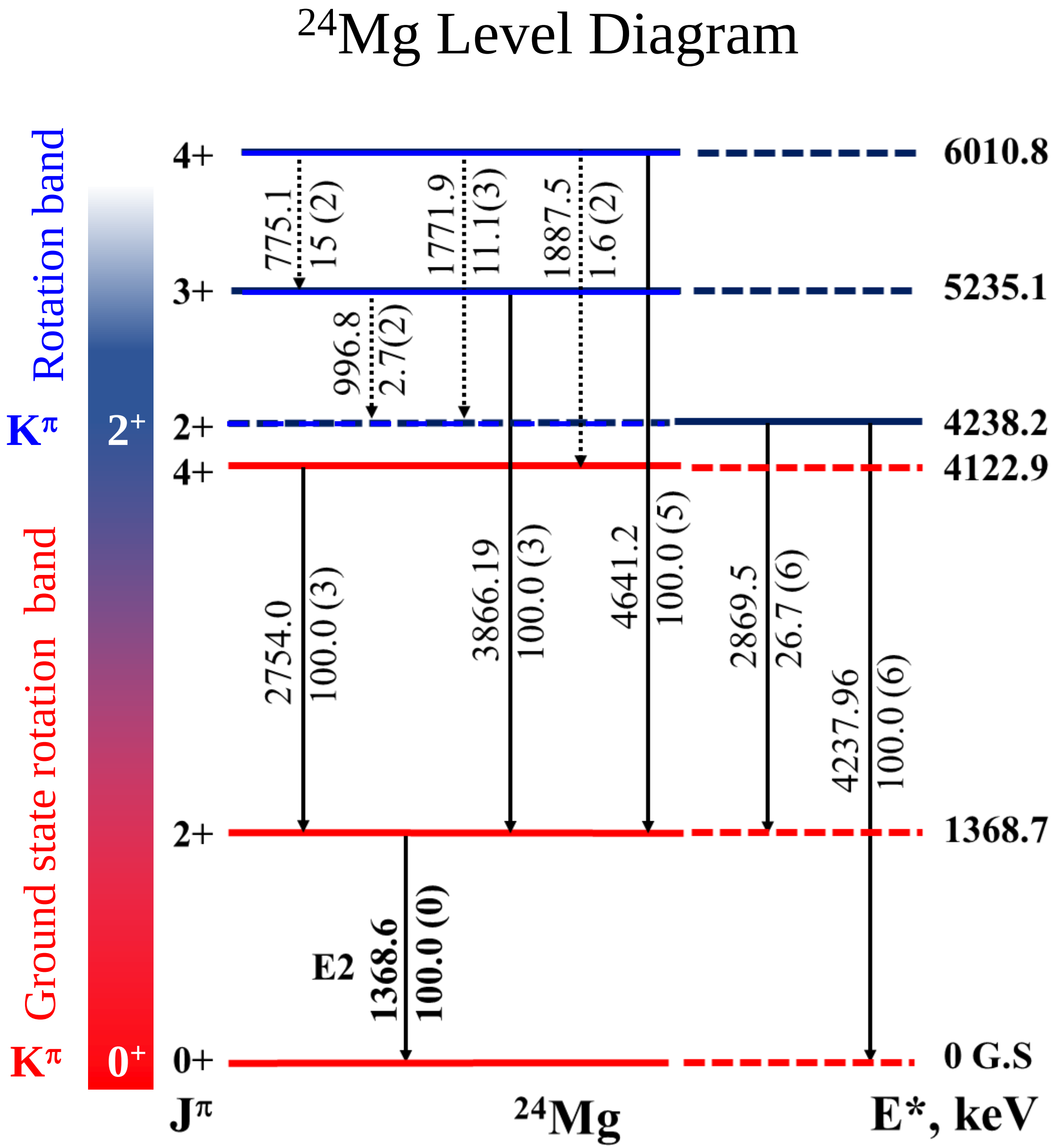
The study of the inelastic scattering of fast neutrons is of considerable theoretical and practical importance.

From the theoretical point of view such studies provide information about the levels of stable nuclei.

The practical value of these studies is due to the importance of inelastically scattered neutrons in the operation of fast neutron reactors.

A knowledge of the spectra of the inelastically scattered neutrons and gamma-rays is essential to the provision of a sound theory of fast reactors.

GOWTZEL G. et al., Proceedings of the First International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955. Vol. 5, p. 472. United Nations, New York (1956).
OKWNT D., AVERY R. and HUMMEL H. Proceedings of the First International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955. Vol. 5, p. 347. United Nations, New York (1956)



The measurement of **angular distributions of gamma rays** produced in the **inelastic scattering of neutrons** with nuclei is one of the important experimental means of studying **the nuclear level schemes**.

A **systematic study** over nuclei of different elements can lead to an insight into **the nuclear reaction mechanisms.**
A comparison of the experimental excitation functions and angular distributions with the Hauser-Feshbach and Satchler formalisms, **checks the validity of the statistical assumption in the compound nucleus formation**.

In this direction, the study of nucleon interactions with light nuclei is of great interest from early 60s till now.

TANGRA: Clusters in Nuclei

^{24}Mg is the classic cluster nucleus

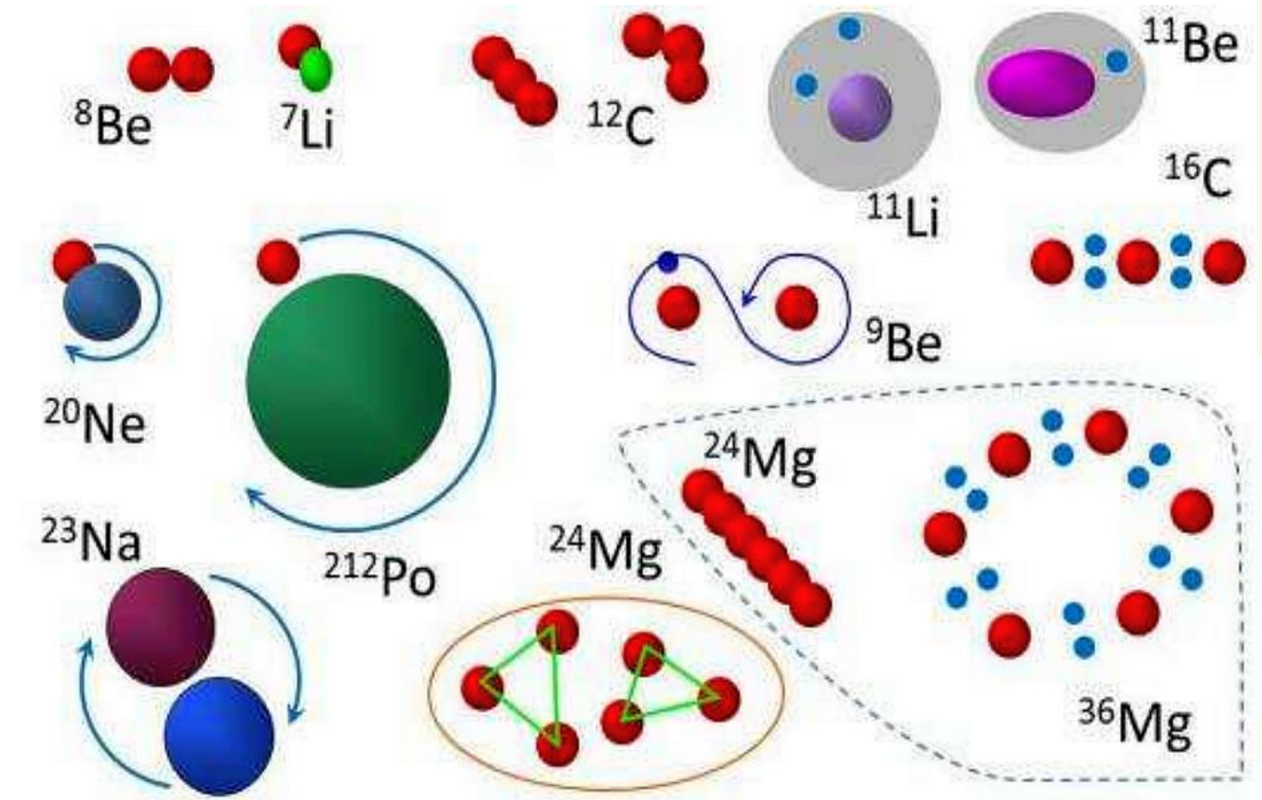
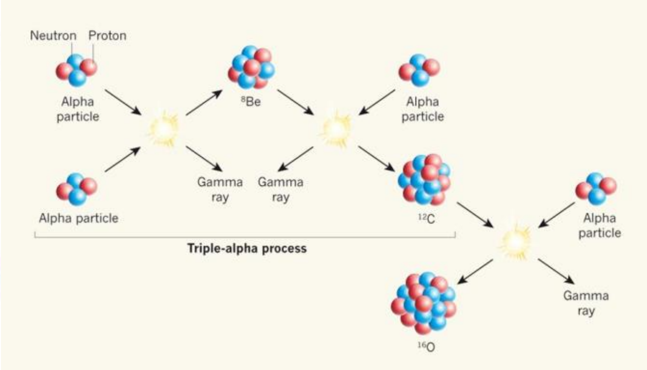
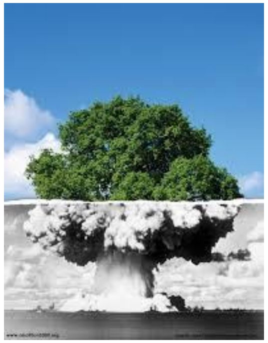


Fig. 1. Different types of nuclear clusters discussed in recent years [8, 15, 36, 37].





C. Beck, Recent Experimental Results on Nuclear Cluster Physics, 2016

https://arxiv.org/pdf/1608.03190.pdf

The calculations of Marsh and Rae using the Brink model show that the ground state of ^{24}Mg can be viewed as two ^{12}C nuclei in juxtaposition. In a certain sense, therefore, it is not too surprising that the low-lying levels of nuclei such as ^{24}Mg can be modelled as two interacting ^{12}C nuclei.

The internal energy levels and the electromagnetic transition strengths between them can be taken to be those for real, free ^{12}C nuclei.

D.M. Brink, in Proc. Int. School of Physics "Enrico Fermi", course XXXVI, Varenna, 1965, ed. C. Bloch (Academic Press, New York, 1966) p.247

S. Marsh and W.D.M. Rae, Phys. Lett. B153 (1985) 21

U.S. DEPARTMENT OF ENERGY | Nuclear Energy

https://www.gen-4.org/gif/upload/docs/application/pdf/2015-06/1-1-1_icone_23_jek_presentation_may_18_2015.pdf

International Perspective on the Future of Nuclear Power

The 23rd International Conference on Nuclear Engineering

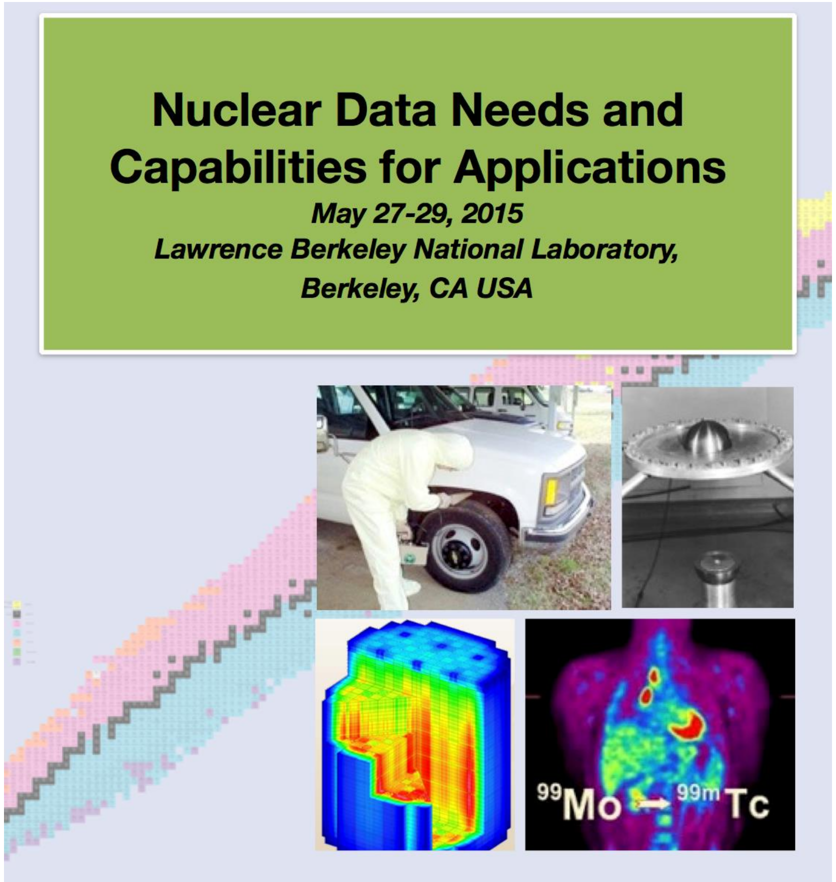
ICONE 23

Majuhari Messe, Chiba, Japan

John E. Kelly
Deputy Assistant Secretary for Nuclear Reactor Technologies
Office of Nuclear Energy
U.S. Department of Energy

May 19, 2015

Matrix A.1: National Security + Counter-Proliferation + Nuclear Energy



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Nuclides and Topic

H, Li, Be, B, N, O, Mg, Al, Si, Ti, V, Cr, Fe, Ni, Cu, Ga, Zr, Nb, Mo, Eu, Gd, Ta, W, Ir, Pt, Au, Pb, Po, Ra, Th, U, Np, Pu, Am:

Isotopes of these elements have been prioritized by Nonproliferation and Homeland Security funding agencies: Improved data and corresponding evaluations are required to meet the demands of several applications of societal interest, including: transport modeling of unknown assemblies, NDA to enable reliable accounting for SNM, detection of contraband substances and explosives, radiation shielding design and characterization, and institutionalizing a "Safeguards by Design" approach in the development of clean, cost-effective, proliferation-resistant nuclear reactor facilities, enrichment, fuel-fabrication and reprocessing plants. Systematic experimental campaigns based on this set isotopes will greatly facilitate this need, and are described in turn.

Precise γ-ray energy data and their corresponding total and partial radiative-capture (n,γ) cross sections, particularly for primary gamma rays, are needed for the EGAF library.
New measurements for separated isotopes are especially required from thermal incident neutron energies to 20 MeV.

These unique gamma-ray signatures are essential for ENDF to create complete and accurate libraries for nonproliferation applications predicated on credible high-fidelity data authentication.
The actinides for which there are no primaries in ENDF are a particular concern.

Matrix A.1: National Security + Counter-Proliferation + Nuclear Energy

Nuclides and Topic

(n,n′γ) and Cross Sections, Angular Distributions and Correlations:

Another recurring need was for accurate **modeling of neutron elastic and inelastic scattering**, not just on actinides, but also **on structural materials**. **Both the cross sections and outgoing angular distributions are needed.** These data are important in small systems in which neutron leakage plays an outsized role.

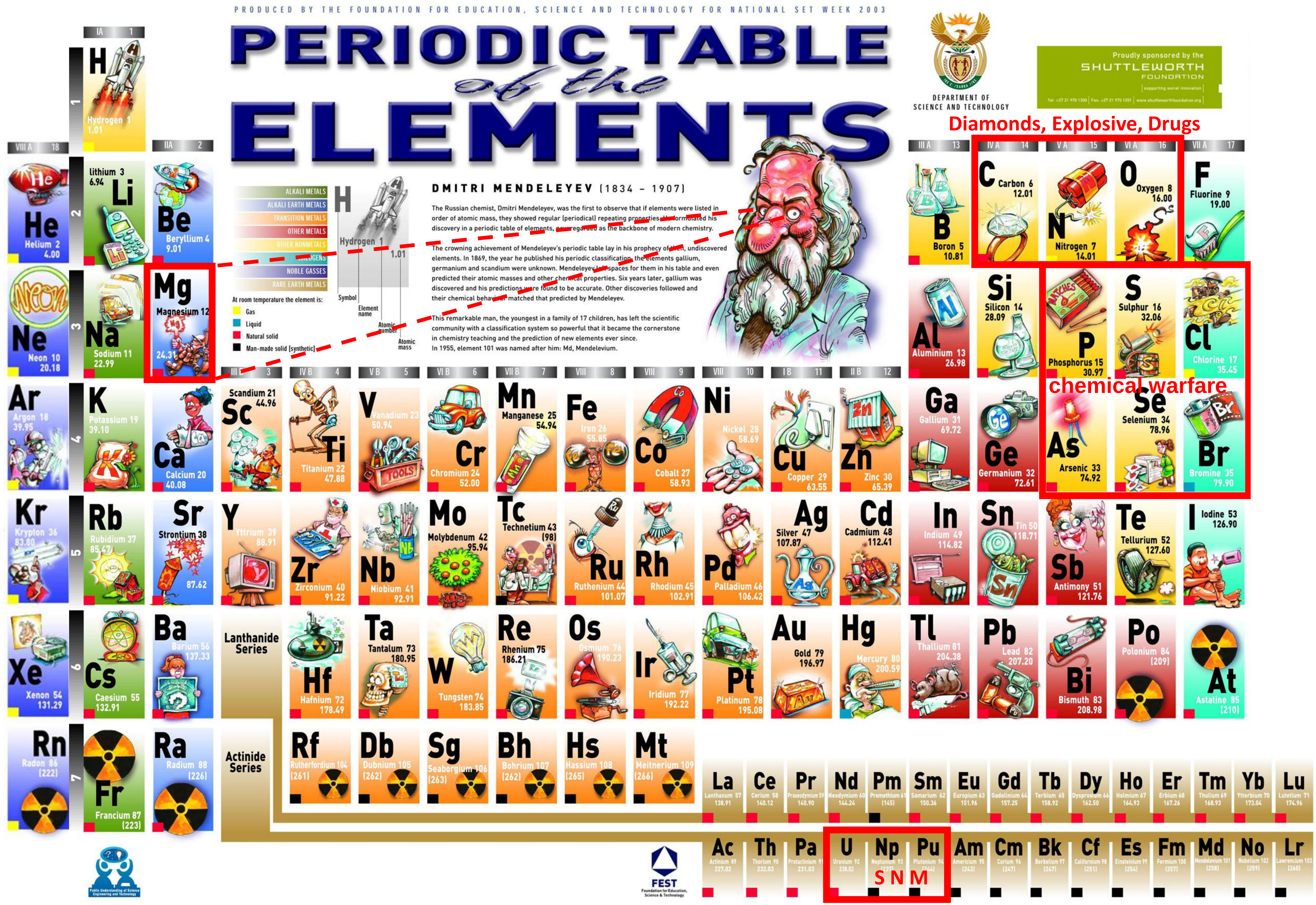
In studies of innovative materials as structural or fuel components, modern nuclear data evaluations and precision measurements of fast-neutron cross sections for structural materials and coolants are often missing or inadequate.

For example, inelastic scattering cross sections are required for important system-dependent structural materials, coolants, and inert fuel elements. (The elements involved include Na, **Mg**, Si, Fe, Mo, Zr, Pb, and Bi.) As a specific example, an accurate determination of the sodium void coefficient of an SFR (Sodium Fast Reactor) requires improvements in the inelastic scattering cross sections for ^{23}Na, as well as a complete covariance treatment. A careful reevaluation of uncertainties is definitely needed for materials associated with accident-tolerant fuels.

TANGRA: Key Elemental Features and Signatures

Material	Key Elemental Features	Usable Nuclear Reactions	Available Signatures
CONTRABAND Explosives	<u>Elemental Density (g/cc)</u> relatively high O relatively high N relatively low C relatively low H	 $(n, n'\gamma)$ (n_{th}, γ) and $(n, n'\gamma)$ $(n, n'\gamma)$ (n_{th}, γ)	 6.130 MeV 10.80, 5.11, 2.31, 1.64 MeV 4.43 MeV 2.223 MeV
Drugs (Cocaine/Heroin)	relatively high C relatively high H relatively low O low-medium Cl (for HCl-drugs)	$(n, n'\gamma)$ (n_{th}, γ) $(n, n'\gamma)$ (n_{th}, γ) and $(n, n'\gamma)$	as above as above as above 6.110 MeV and other strong lines for Cl
MINERALS Cement	Ca, Si, Fe, Al, Mg	(n_{th}, γ)	specific capture γ-rays, e.g., 6.420 MeV for Ca 4.934 MeV for Si 7.630/46 MeV for Fe, etc.
Coal	C (high concentration) H, S, Si, Al, Fe, Ca, K, Na, Ti	(n_{th}, γ) and $(n, n'\gamma)$ (n_{th}, γ)	specific capture (or inelastic) γ-rays, e.g., 4.945 MeV (n, γ) and 4.43 MeV $(n, n'\gamma)$ for C, 2.223 MeV for H, 5.420 MeV for S, etc.
NUCLEAR	^{232}Th, ^{233}U, ^{235}U, ^{239}Pu, ^{240}Pu	(n_{th}, f), (n_f, f), (γ, f) secondary; (n_{th}, γ), $(n, n'\gamma)$	n_p, n_d, γ_p, γ_d ; total/coincidence; very high density

TANGRA: Some elements of a big interest, at present!

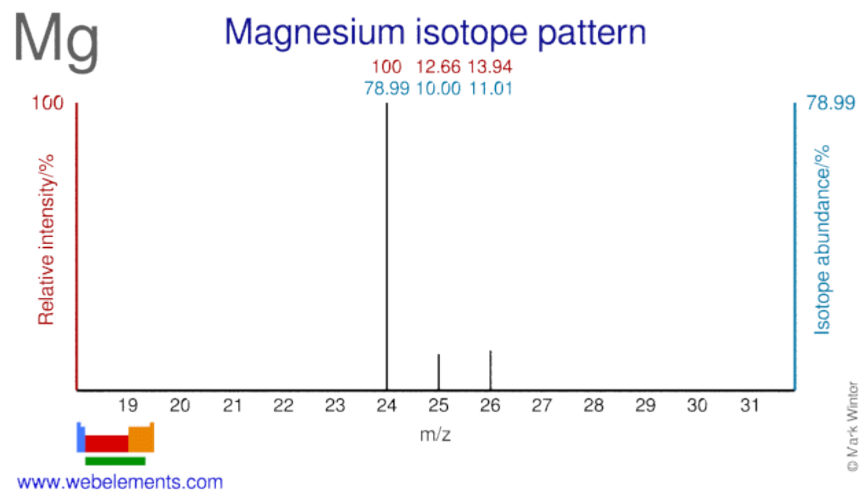


TANGRA: Magnesium

Stable isotopes: **^{24}Mg (78.99%),** ^{25}Mg (10.00%) and ^{26}Mg (11.01%)

•It is the 8th most common element in the earth's crust, but is the most commercially used element:
Photography flash products, Bombs, Signal flares, Medicines, Insulation, Paper, Fabrics, Cements, Ceramics, Cosmetics
•It is obtained from seawater.
•It is a very flammable metal.
•The center of chlorophyll contains magnesium.
•Pouring water on burning magnesium will increase the fire and can cause explosions.
•Magnesium oxide is the byproduct of burning magnesium and can cause respiratory problems like asthma or emphysema.

•Purity: 90-99.9% 99.9% ≥ 96.5%



- **Magnesium carbonate** ($MgCo_3$)
- **Magnesium chloride** ($MgCl_2$)
- **Magnesium diboride** (MgB_2)
- **Magnesium fluoride** (MgF_2)
- **Magnesium hydroxide** [$Mg(OH)_2$]
- **Magnesium nitrate** [$Mg(NO_3)_2$]
- **Magnesium oxide** (MgO)
- **Magnesium peroxide** (MgO_2)
- **Magnesium sulfate** ($MgSO_4$)

https://hobart.k12.in.us/ksms/PeriodicTable/magnesium.htm

TANGRA: Magnesium for/in Life

Stable isotopes: **^{24}Mg (78.99%),** ^{25}Mg (10.00%) and ^{26}Mg (11.01%)

In plants, magnesium is necessary for synthesis of chlorophyll and photosynthesis.

It is an essential mineral nutrient (i.e., element) for life and is present in every cell type in every organism.

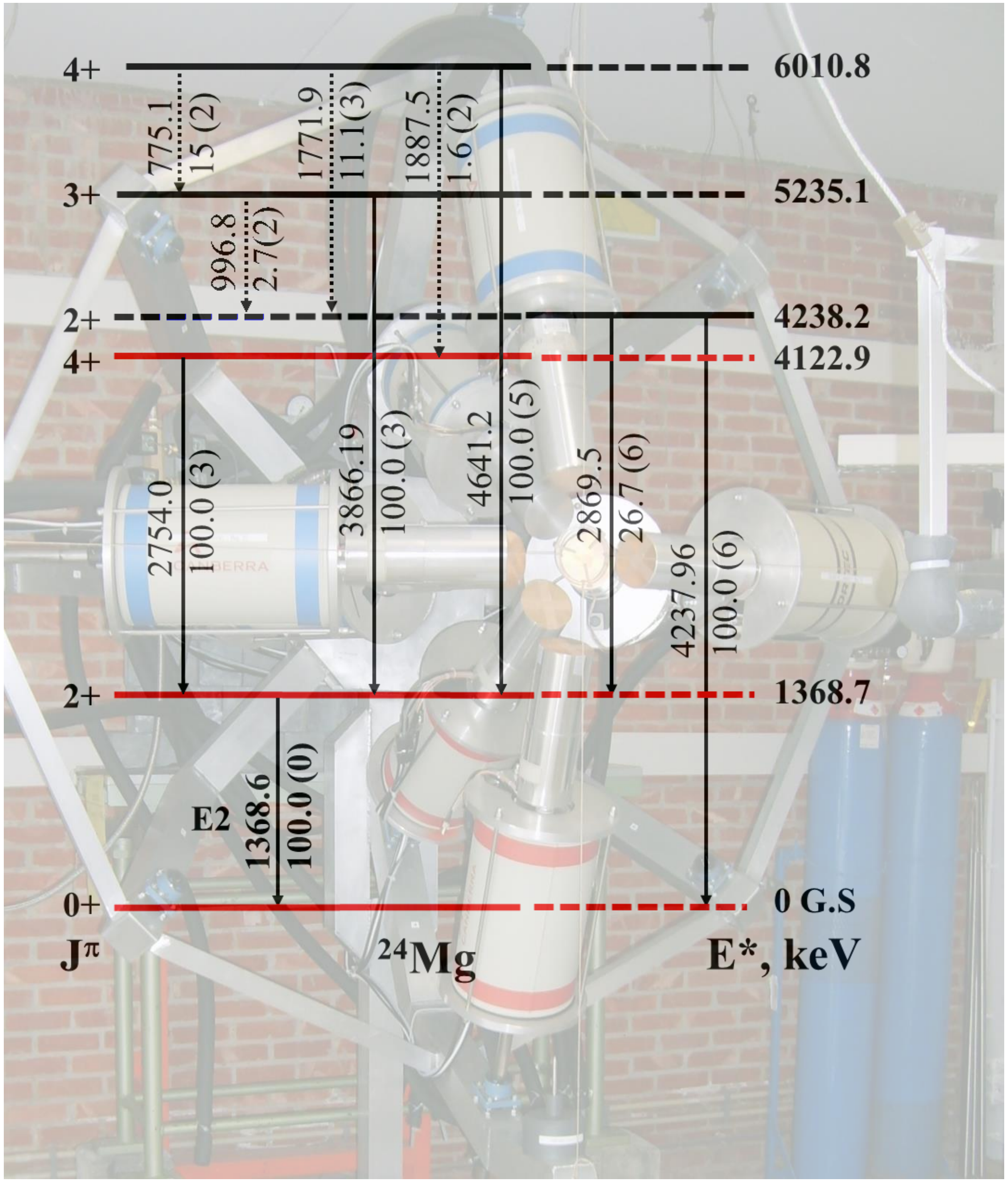
TANGRA: n-INS on ^{24}Mg @ GELINA by GAINS

Mg-alloy steel is a structural material in the design of Gen-IV nuclear power reactor design

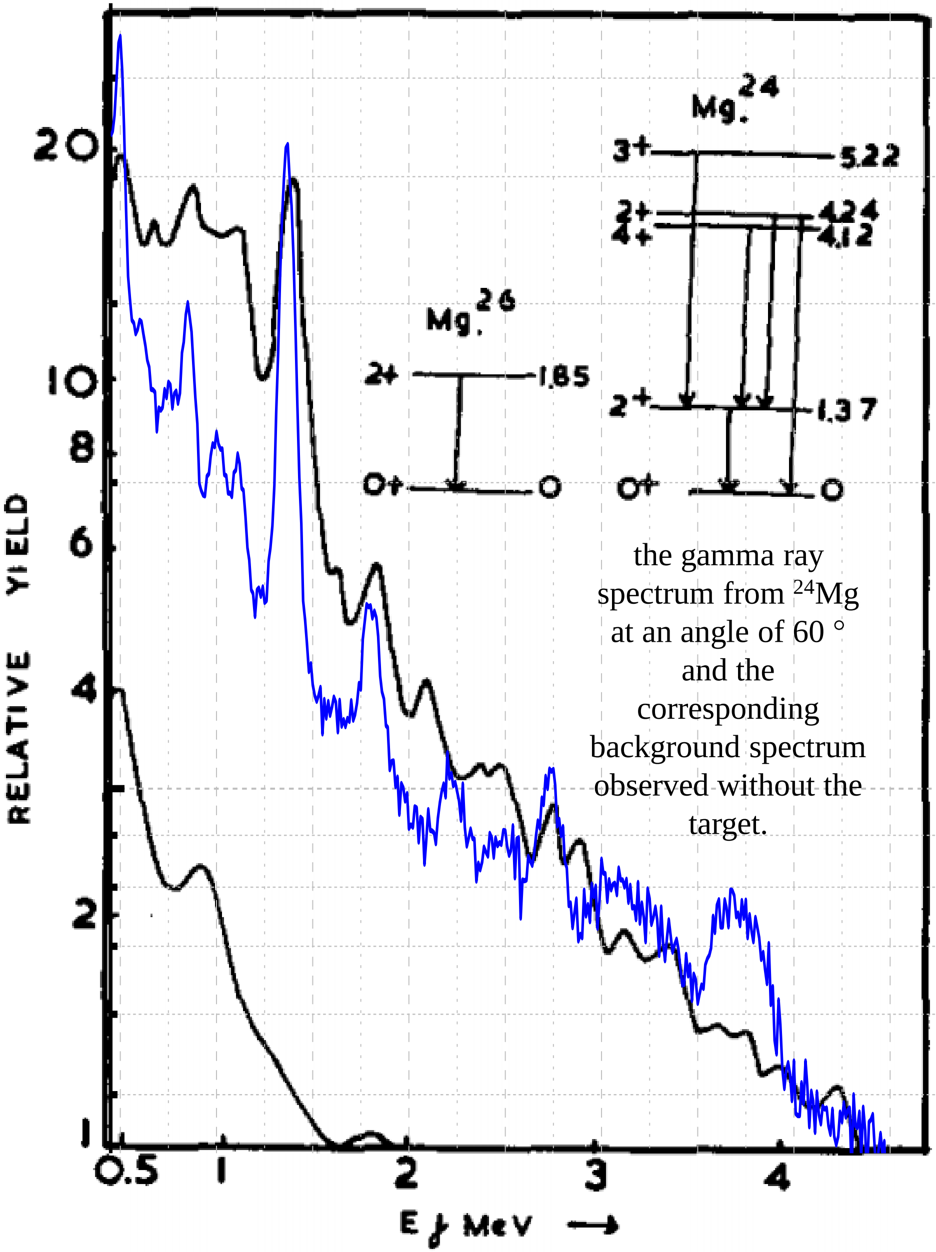
MgO-based inert matrix fuel for a minor actinide recycling in a fast reactor cycle

It is mandatory to have a good knowledge of the neutron-induced reactions on ^{24}Mg

A. Olacel, C. Borcea, P. Dessagne, M. Kerveno, A. Negret, and A. J. M. Plompen, **Neutron inelastic cross-section measurements for ^{24}Mg**, Phys. Rev. C 90, 034603 (2014)



TANGRA: Sci-papers of interest



the gamma ray spectrum from ^{24}Mg at an angle of 60 ° and the corresponding background spectrum observed without the target.

ELSEVIER

Nuclear Physics

Volume 60, Issue 2, November 1964, Pages 349-352

Gamma rays from the interaction of 14 MeV neutrons with C^{12} and Mg^{24}

D.T. Stewart, P.W. Martin

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https://doi.org/10.1016/0029-5582(64)90669-8

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Abstract

Gamma rays following the inelastic scattering of 14.1 MeV neutrons have been measured using the associated particle technique. Differential cross-sections for the production of 4.43 MeV gamma rays from C^{12} and for 1.37 MeV gamma rays from Mg^{24} have been determined.

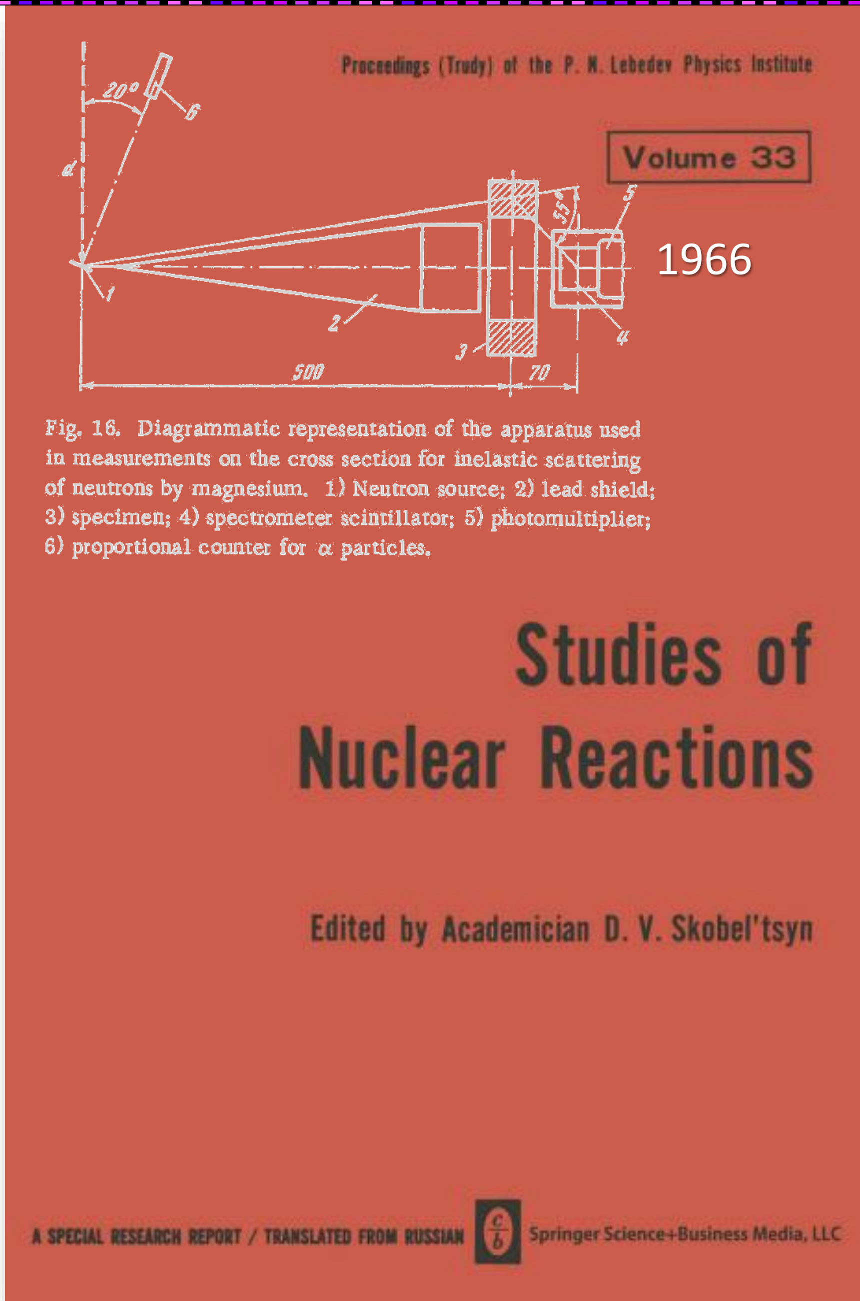
The principal magnesium isotope, ^{24}Mg, has a well-known level at 1.370 MeV.

The figure shows that this level is strongly excited by neutron inelastic scattering.

There are gamma-rays present of energy 1.62 MeV and 1.81 MeV.

These are very likely from ^{25}Mg and ^{26}Mg, respectively, since the agreement of the energies with those of known levels in these isotopes is excellent.

^{25}Mg is known to have lower-lying levels as well, but the high background from the Compton spectrum of the 1.37-Mev gamma ray and from neutron interactions in the crystal precluded these from being observed.



1966

A STUDY OF INELASTIC SCATTERING OF 14-MeV NEUTRONS BY LIGHT AND INTERMEDIATE NUCLEI

B. A. Benetskii

CHAPTER II Measurements of the Cross Section for Inelastic Scattering of 14-MeV Neutrons by Mg^{24} , Al^{21} , Si^{28} , and Fe^{56}

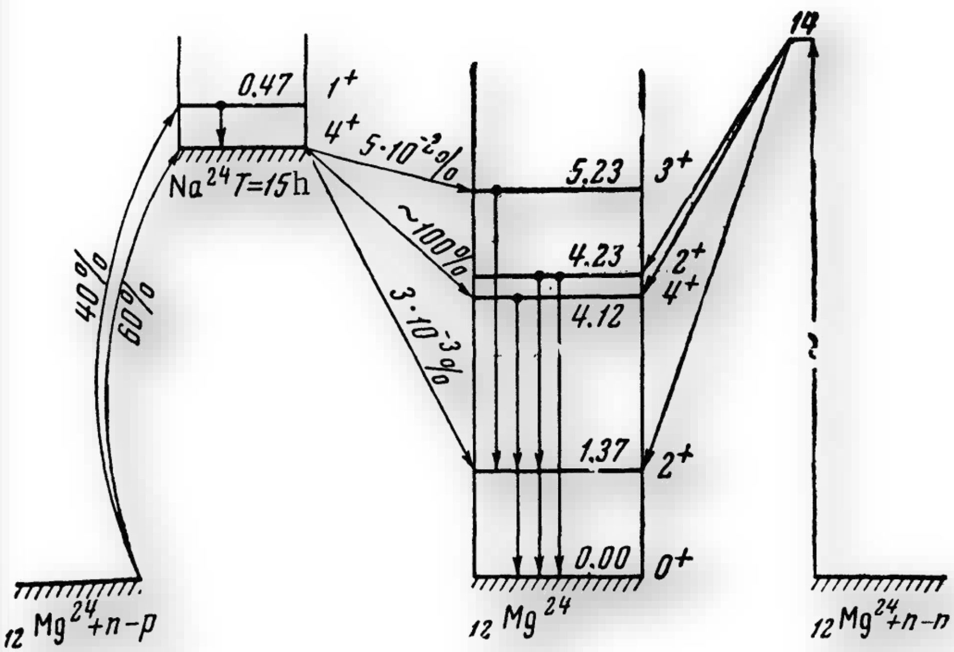


Fig. 15. Level and transition scheme for Mg^{24}.

Search publications with author "benetskii"
Found 2 record(s)

1. **Inelastic Scattering of 14 MeV Neutrons on Mg^{24}**
   B.A. Benetskii, Yu. P. Betin, Ya. Gonzatko
   JETP, 1964, Vol. 18, No. 3, p. 640
   PDF (420.8K)

http://www.jetp.ac.ru/cgi-bin/dn/e_018_03_0640.pdf

2. **Angular Correlation Between Gamma Rays and 14-MeV Neutrons Scattered Inelastically by Carbon**
   B.A. Benetskii, I.M. Frank
   JETP, 1963, Vol. 17, No. 2, p. 309
   PDF (675.7K)

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1. **Inelastic Scattering of 14 MeV Neutrons on Mg^{24}**
   B.A. Benetskii, Yu. P. Betin, Ya. Gonzatko
   JETP, 1964 г., Том 18, Вып. 3, стр. 640
   PDF (420.8K)

http://www.jetp.ac.ru/cgi-bin/dn/e_018_03_0640.pdf

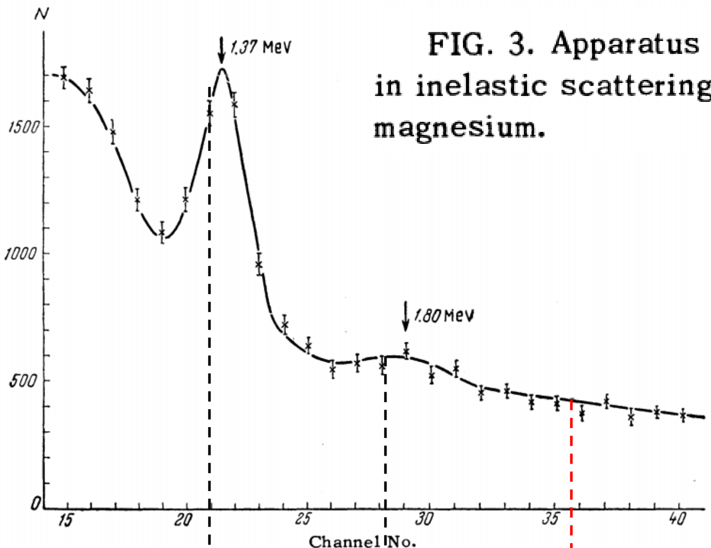

FIG. 3. Apparatus spectrum of γ quanta generated in inelastic scattering of 14-MeV neutrons by magnesium.

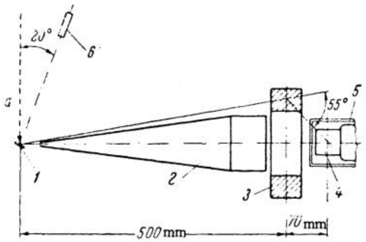

FIG. 2. Geometry of the experiment: 1 – neutron source; 2 – lead shield; 3 – scatterer; 4 – scintillator of γ spectrometer; 5 – photomultiplier; 6 – proportional counter for α particles.

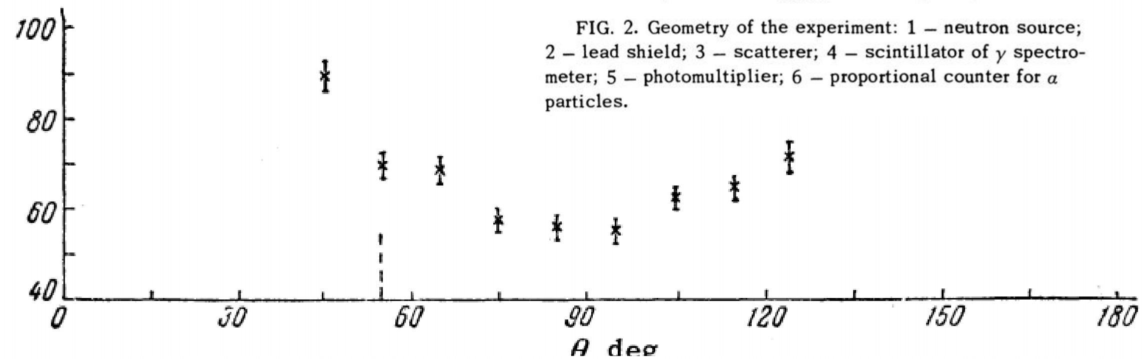

FIG. 5. Angular distribution of 1.37-MeV γ quanta generated by inelastic scattering of neutrons by magnesium.

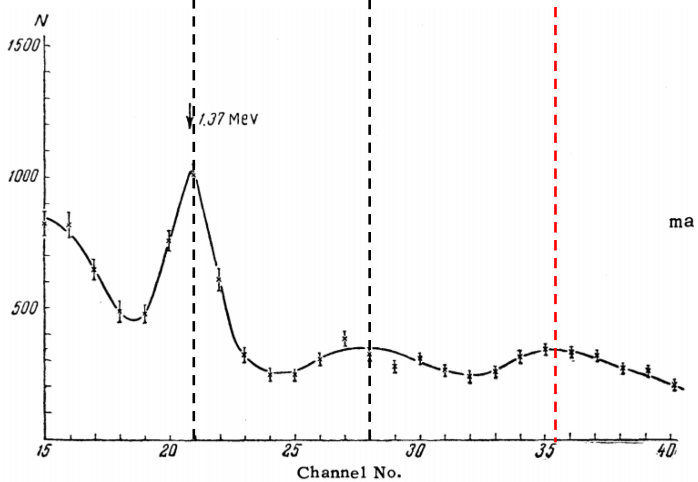

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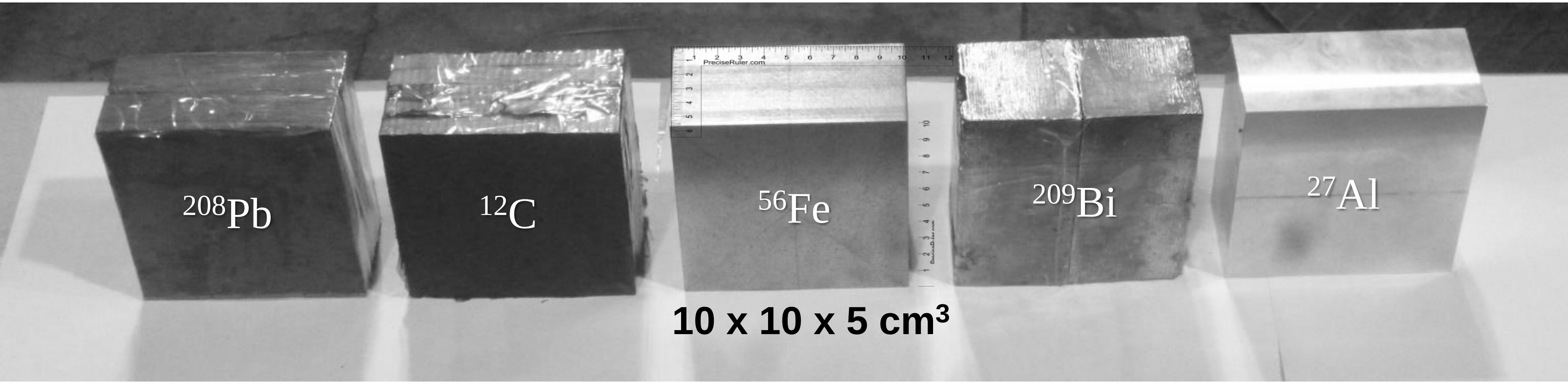
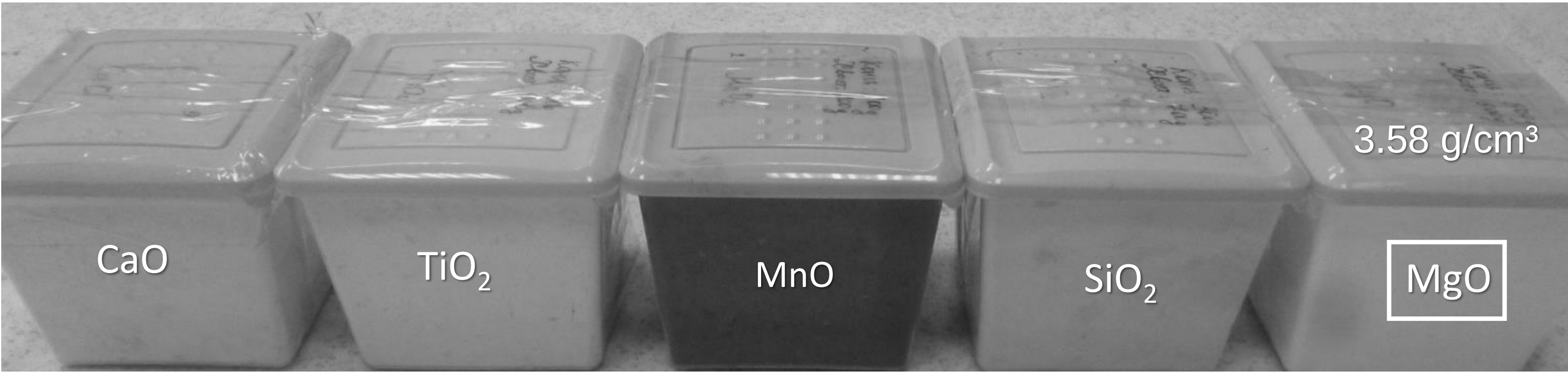
FIG. 4. Apparatus spectrum of γ quanta from a sample of magnesium activated with 14-MeV neutrons.

TANGRA: Samples under investigation





TANGRA: Time-correlated Associated Particle (Tagged Neutron) Method

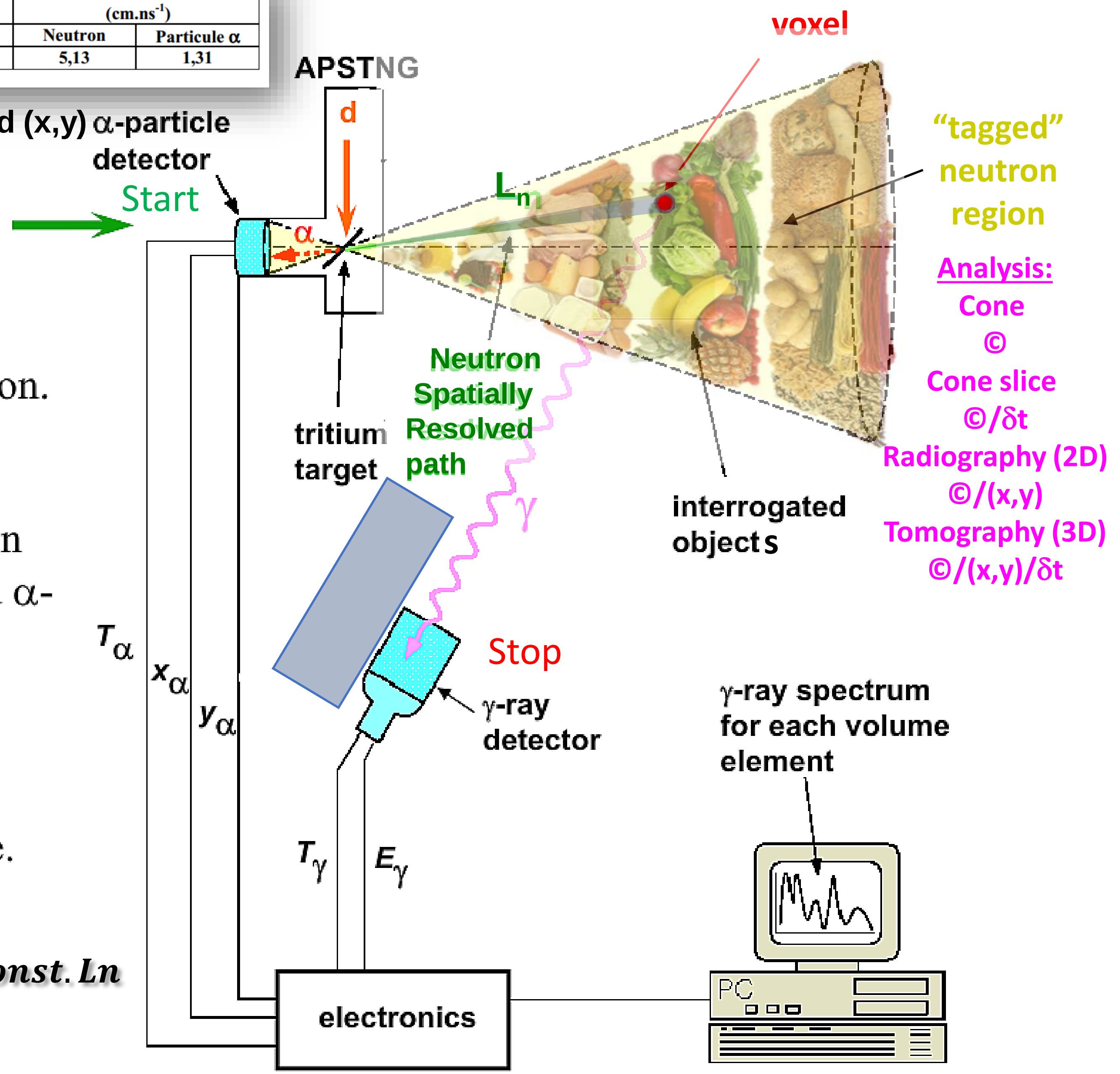
Réaction	Energie totale (MeV)	Energie cinétique (MeV)		Vitesse (cm.ns^{-1})	
		Neutron	Particule α	Neutron	Particule α
t(d,n)α	17,6	14,1	3,5	5,13	1,31

Associated particle sealed tube neutron generator utilising the T(d,n)α reaction.

The 14.1 MeV neutron is tagged in time and direction by detecting the associated α-particle released in the opposite direction.

... allows **ns-timed measurements** to be made.

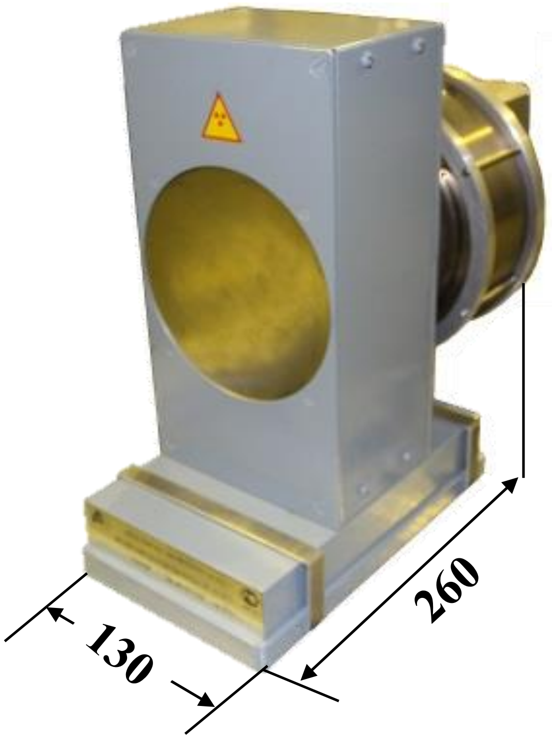
$$\Delta t = T_\gamma - T_\alpha = \sqrt{\frac{m_n}{2E_n}}.L = const.Ln$$

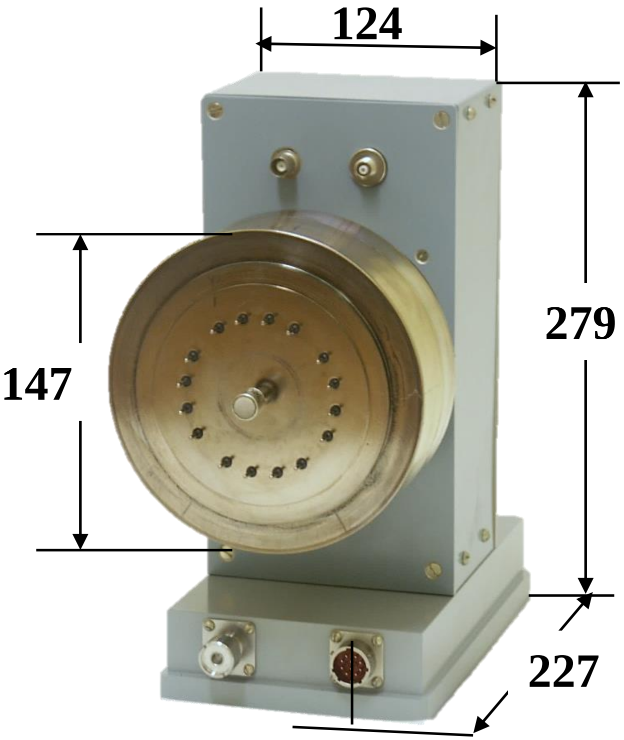


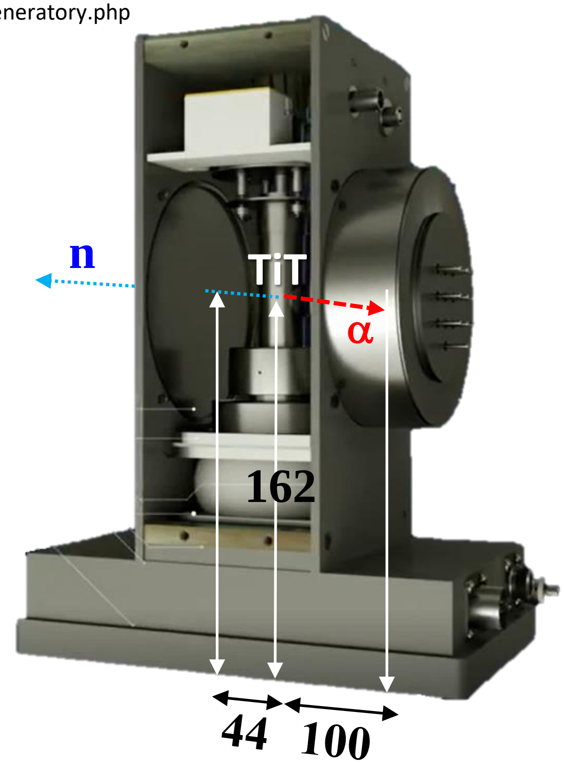
TANGRA: VNIIA™ ING-27 Neutron Generator

based on **sealed DT gas-filled tube**

http://www.vniia.ru/eng/production/neitronnie-generatory/neytronnye-generatory.php







TiT-to-front distance : 44.0 ± 1.4 mm
TiT-to-α–detector distance: 100 ± 2 mm
Power supply voltage: 200 ± 5 V
Maw Power Supply Current: 300 ± 30 mV
Consumed Power: < 40 W
Continuous Mode: 14-MeV neutrons
Initial Intensity: > 5.0 x 10^7 n/s/4π
Final Intensity: > 2.5 x 10^7 n/s/4π

Double-side Si α-particles detector

Number of pixels: 64 (8x8 strips)
Pixel area: 6x6 mm^2
Distance between strips: 0.5 mm
Voltage bias: –250V DC
Dark current: < 8μA
n-tube life-time: > 800 h
< ING Duty time >: 18 months

Weight: ING-27: 7.5 ± 0.5 kg ; Power Supply and Operation Unit: 2.7 ± 0.3 kg

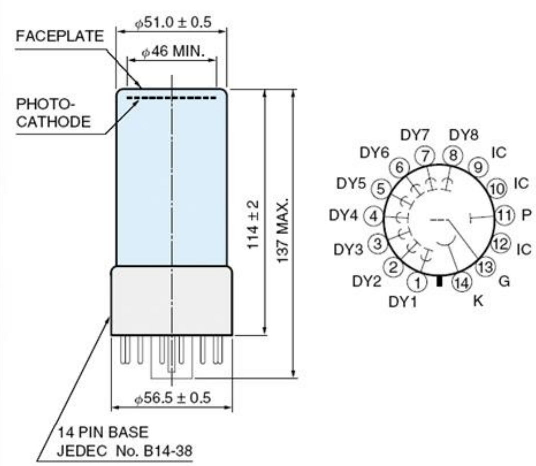
TANGRA: Amcrys™ NaI(Tl) Gamma-ray Detector

The large **NaI(Tl)** scintillators are used to detect gamma rays above 600 keV, which allows identifying most common elements such as **C, N, O, Si, Cl, Ca, Al, Fe, Cr, Ni, Cu, Zn, Pb,** etc. The high resolution LaBr3 scintillators are mainly used to detect gamma rays below 500 keV, in view to identify some of the chemical warfare elements that do not show clear gamma signatures at higher energy, such as arsenic, bromine, and iodine.

Part Number	R1306
Type	Head on
Size	51mm
ActiveDia/L	46mm
Min λ	300nm
Max λ	650nm
Peak Sens.	420nm
Cathode Radiant Sensitivity	95mA/W
Window	Borosilicate
Cathode Type	Bialkali
Cathode Luminous Sensitivity	110μA/lm
Cathode Blue Sensitivity Index	12
Red White Ratio	-
Anode Luminous Sensitivity	30A/lm
Gain	2.7E+05
Dark Current after 30 min.	2nA
Rise Time	7ns
Transit Time	60ns
Number of Dynodes	8
Applied Voltage	1000V

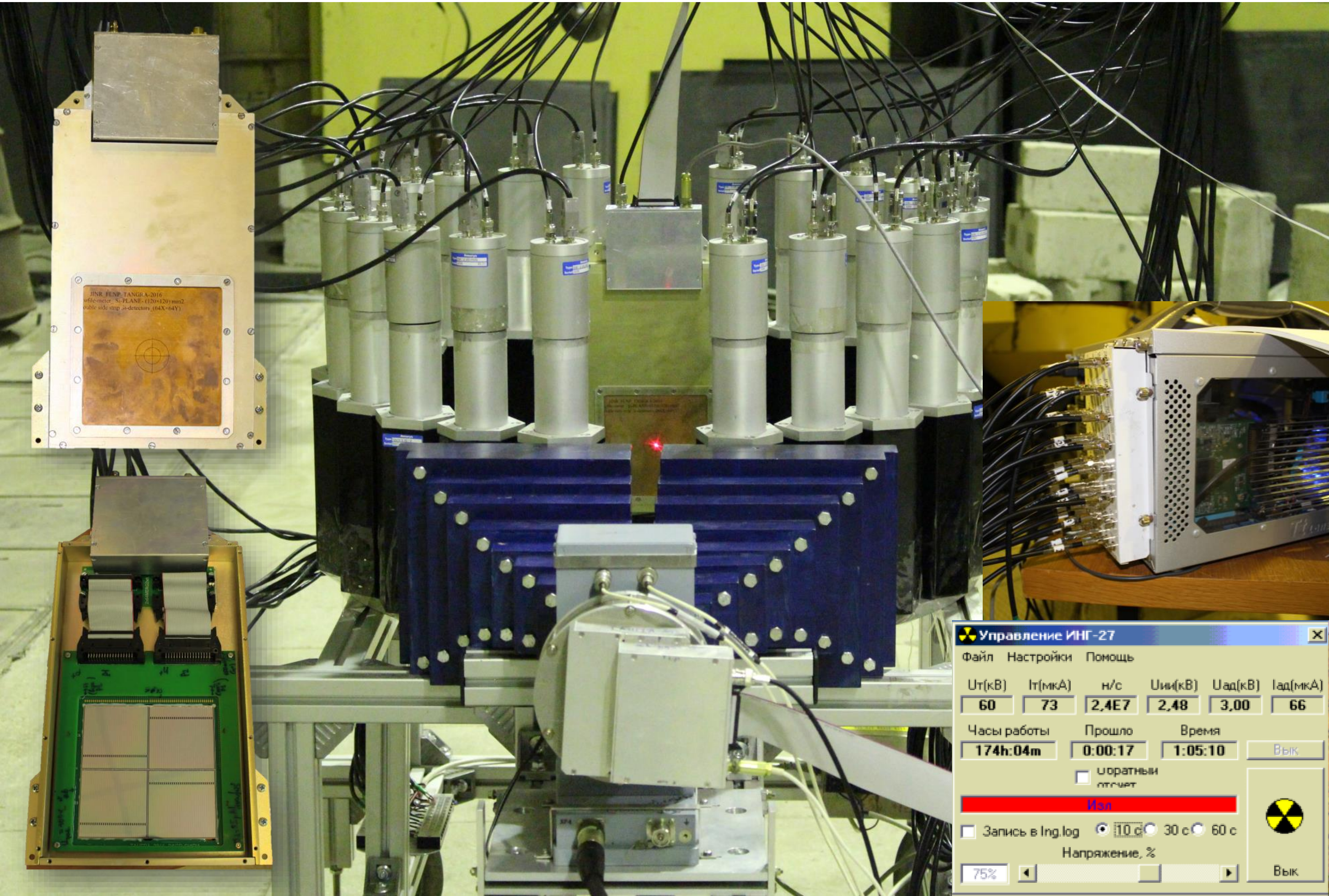
Properties	
Density [g/cm^3]	3.67
Melting point [K]	924
Thermal expansion coefficient [C^{-1}]	47.7 x 10^{-6}
Cleavage plane	<100>
Hardness (Mho)	2
Hygroscopic	yes
Wavelength of emission max. [nm]	415
Refractive index @ emission max	1.85
Primary decay time [ns]	250
Light yield [photons/keVγ	38
Temperature coefficient of light yield	-3%C^{-1}

NaI(Tl) mono crystal with a hexagonal cross section	Photomultiplier tube (PMT) Hamamatsu R1306
	
Crystal dimensions	90x78x200mm
Container	Aluminium
Electronics module type	EM/2.VD.HVG
Test gamma source	Cs-137
Average Energy resolution <FWHM> at 662keV	7.14 ± 0.06%



Time resolution ~3nsec

TANGRA: Romashka - 22 NaI(Tl) detectors



ADCM-16

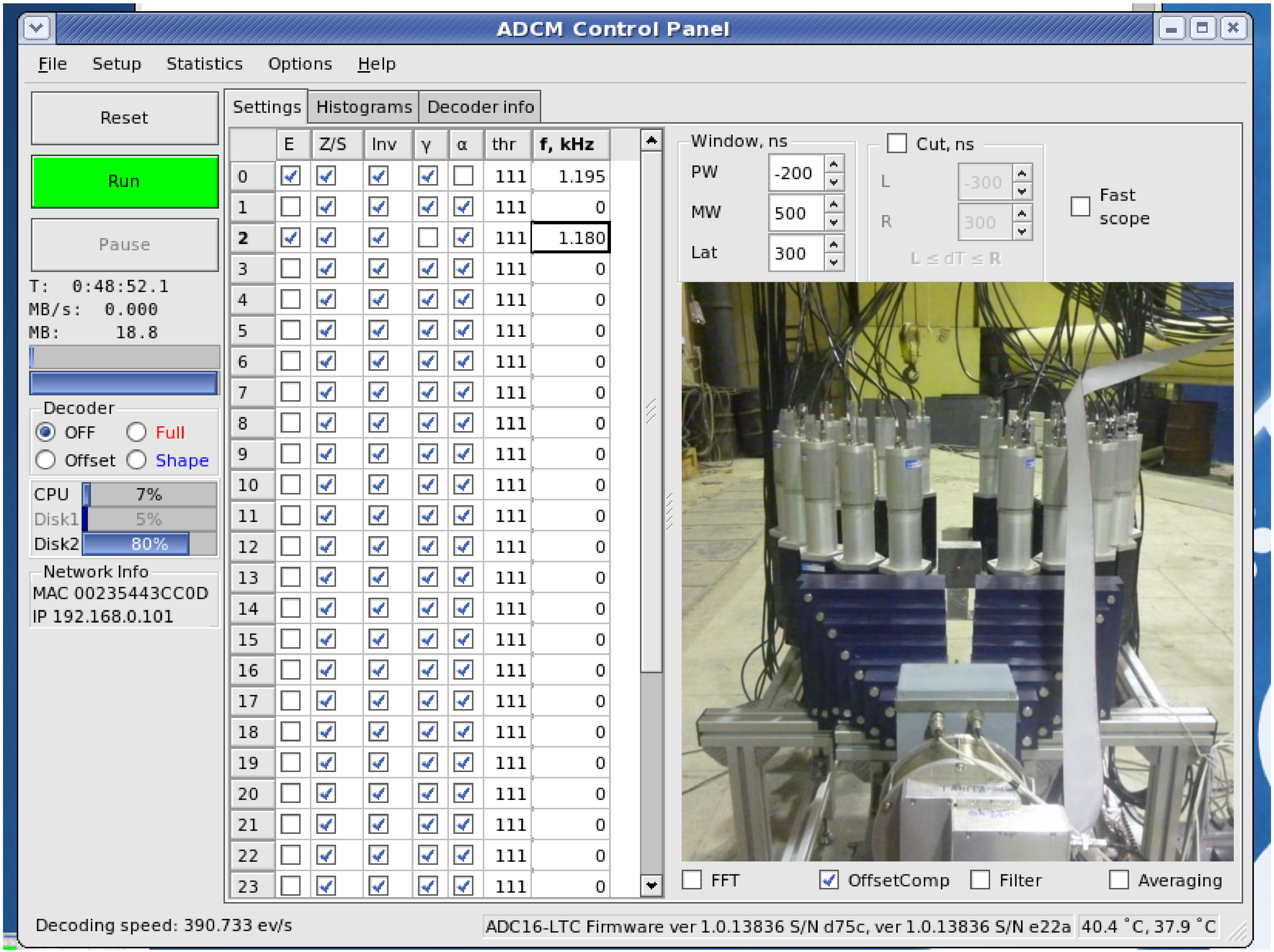
16/32/48-channel digitizers, in the form of one or several PCI-E cards.

Sampling frequency 100 MHz

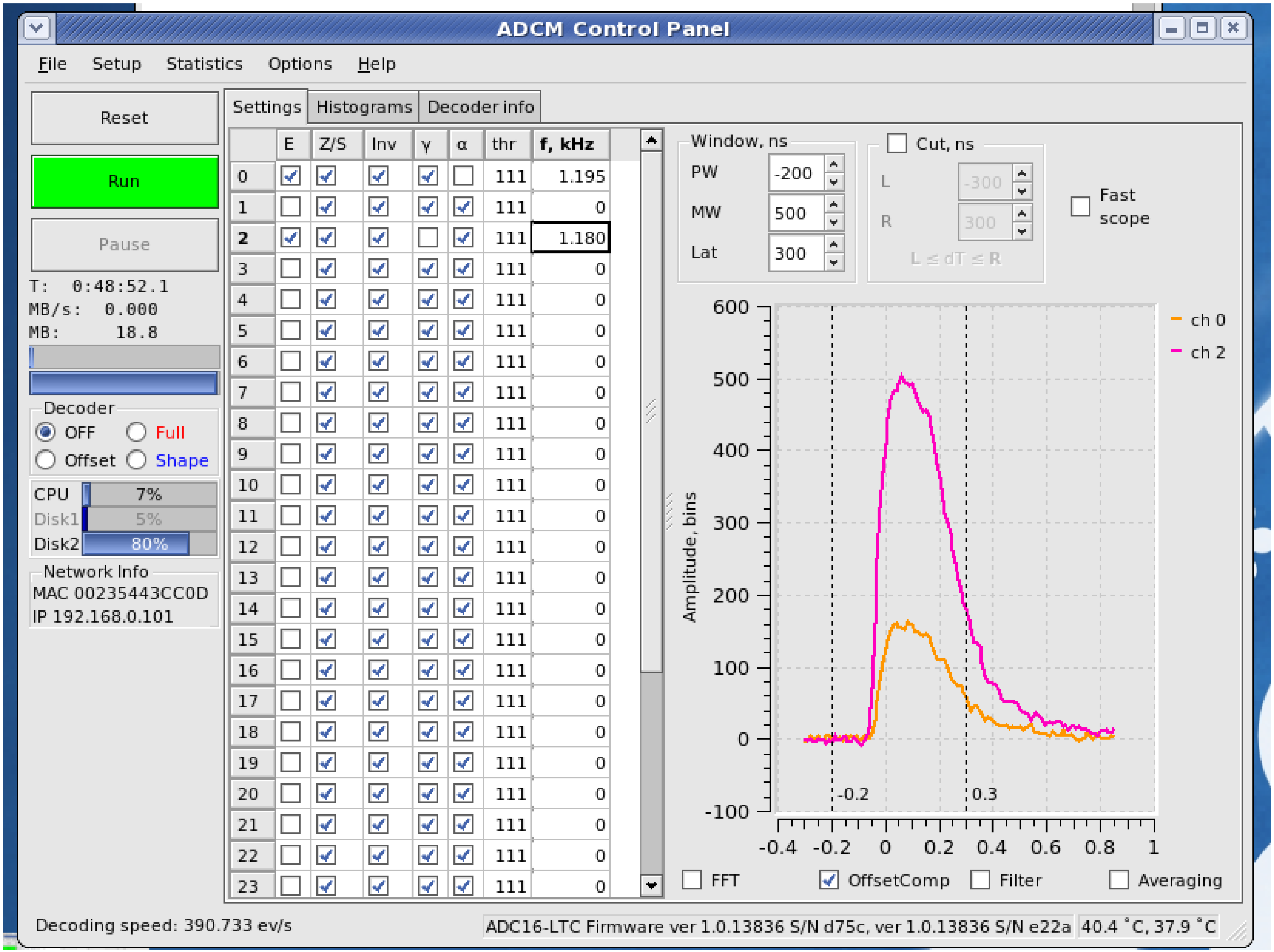
The digitized signals are transmitted via the PCI-E bus in the computer's memory, where all the data processing and storage takes place.

Maximum load of the system is ~ 10^5 events per second

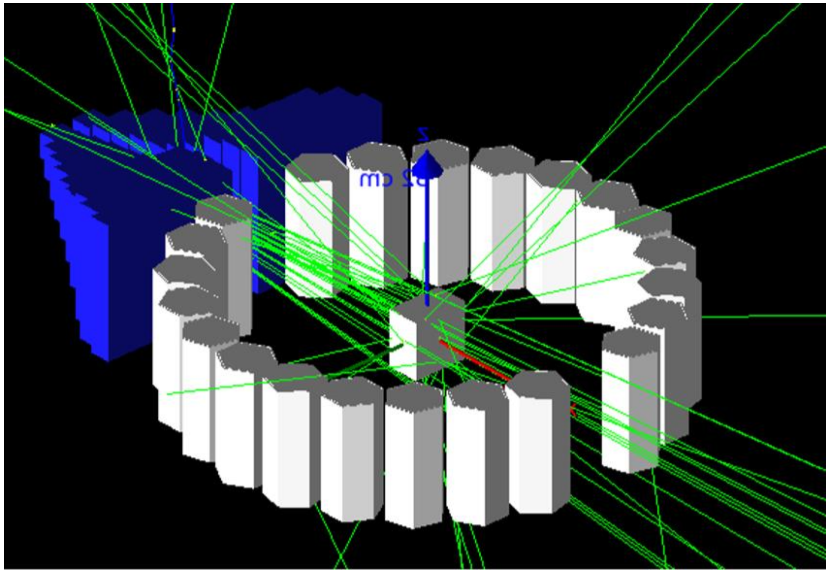
TANGRA: ADCM Control Panel

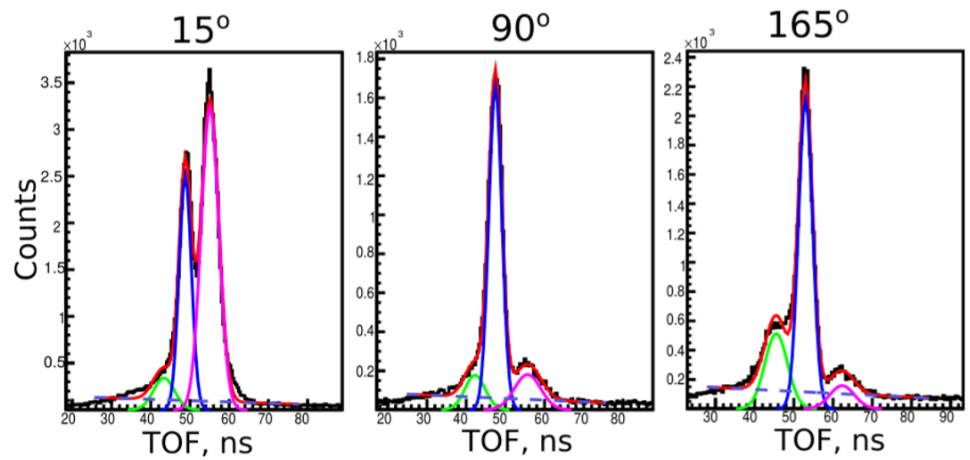


TANGRA: ADCM Control Panel

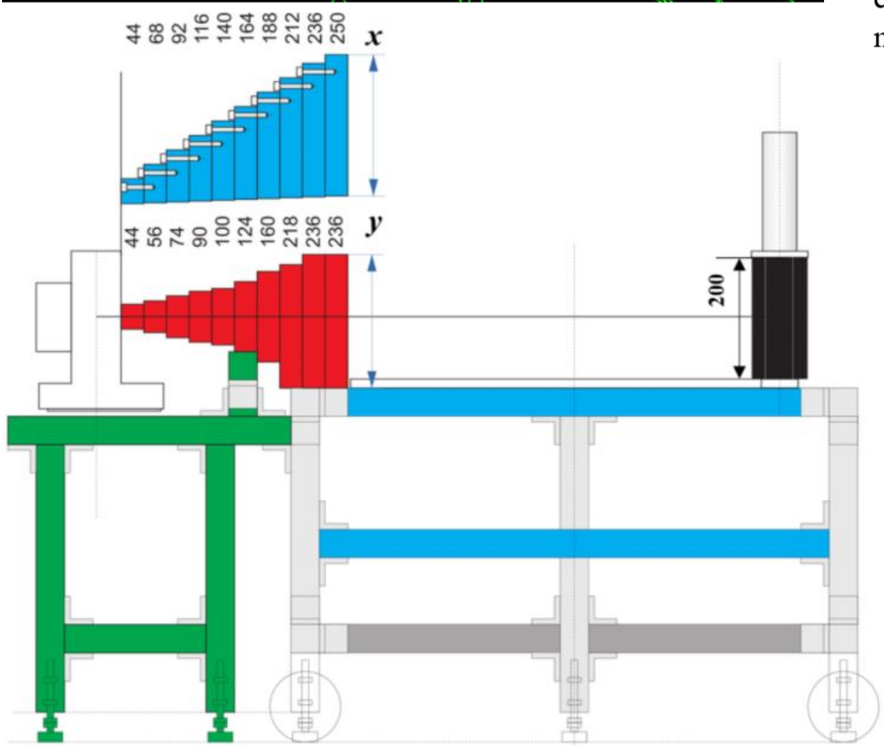


TANGRA: Setup GEANT4 Simulations

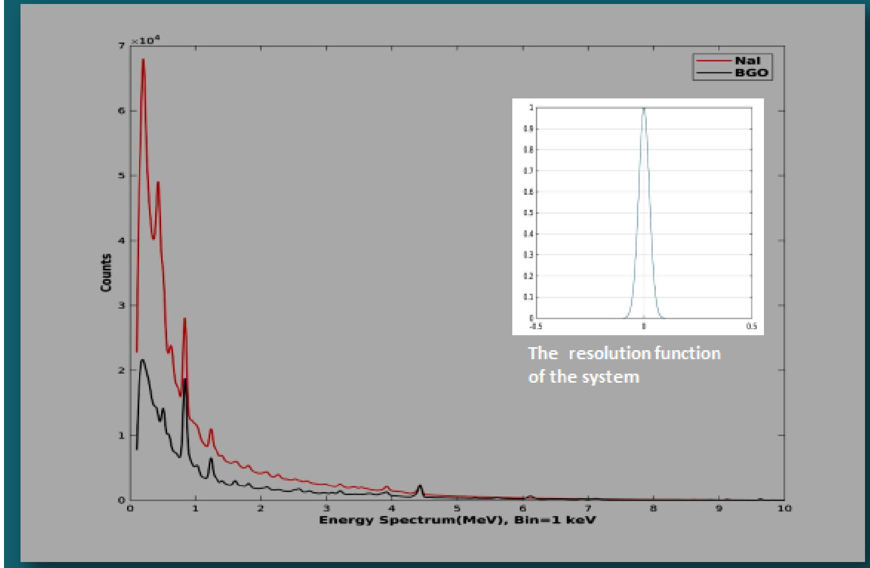




Green peak corresponds to γ-quanta emitted by inelastic scattering in collimator, **blue** peak – to γ-quanta emitted inside sample, **purple** peak – to neutrons which strikes the detector.

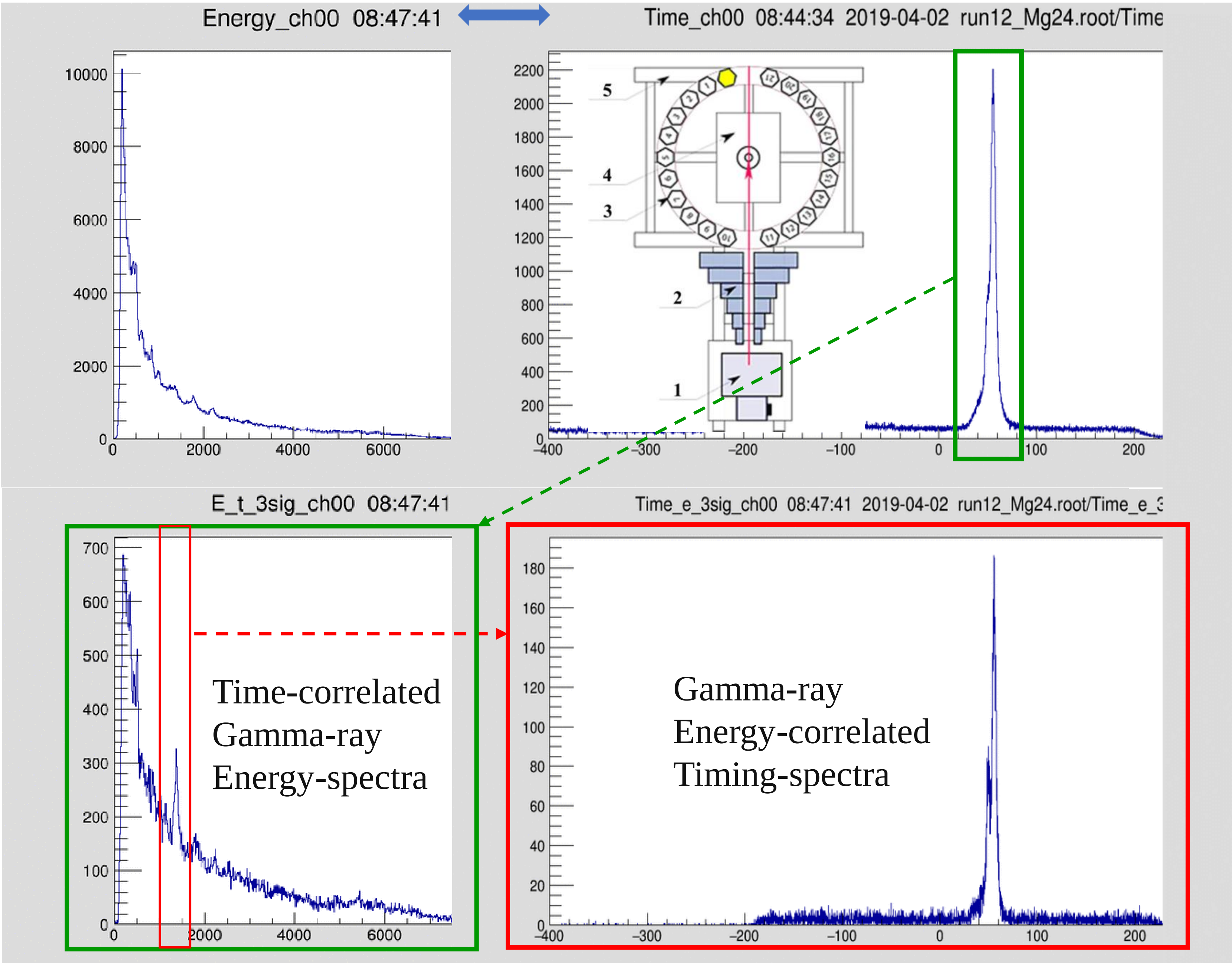


The Energy Spectra of γ-rays

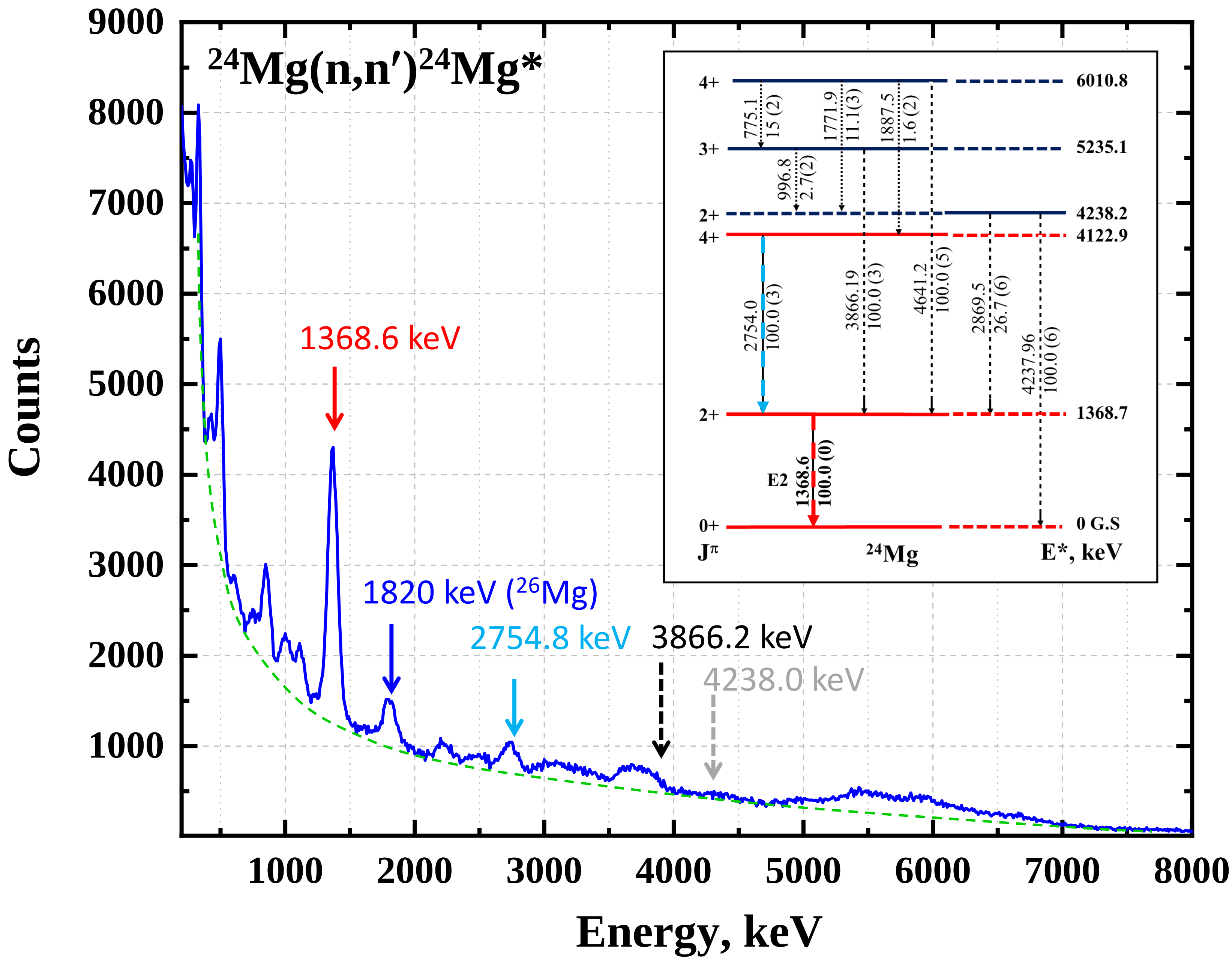


The resolution function of the system

TANGRA: Experimental Data Analysis (Reduction)

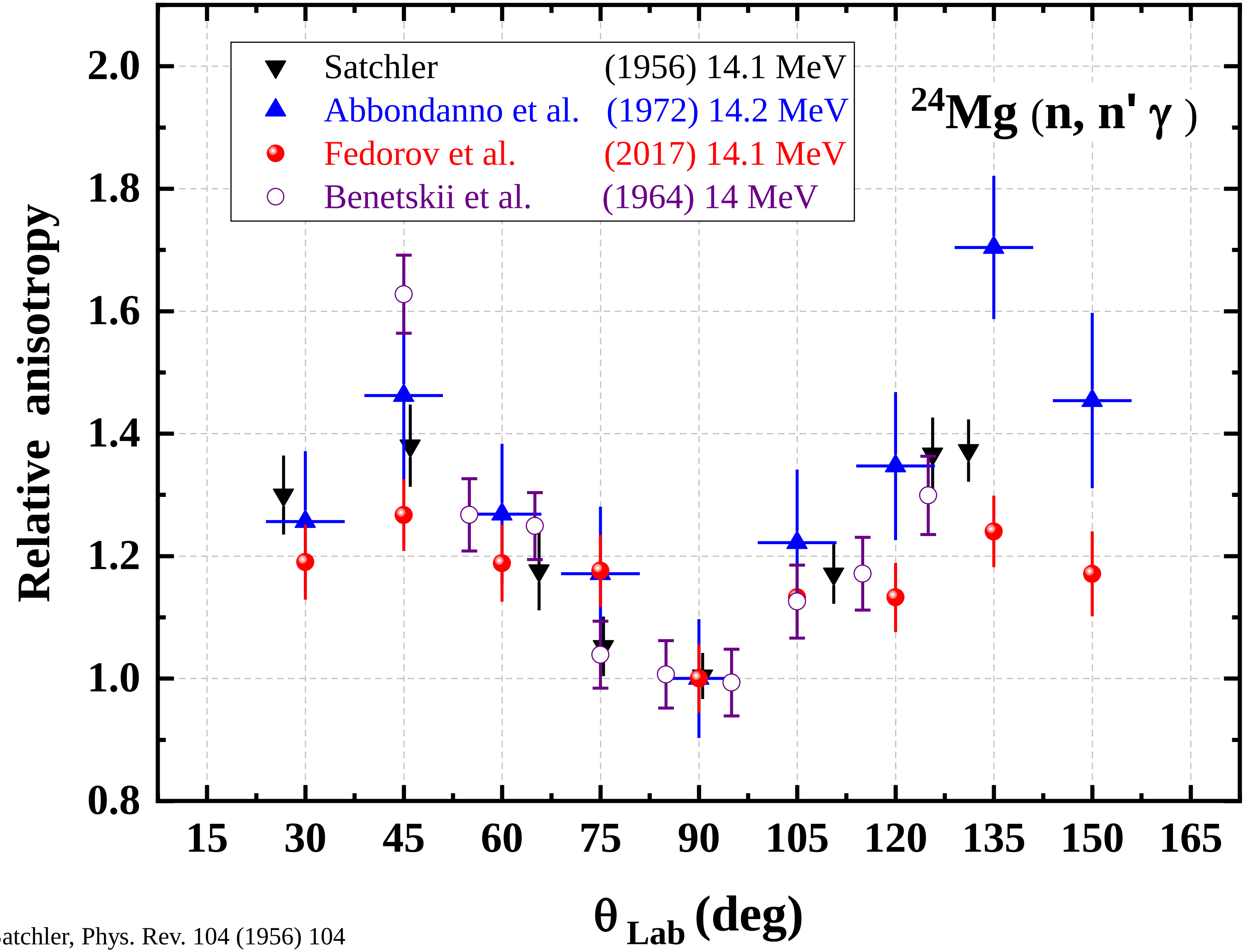


TANGRA: Gamma-ray Energy Spectrum

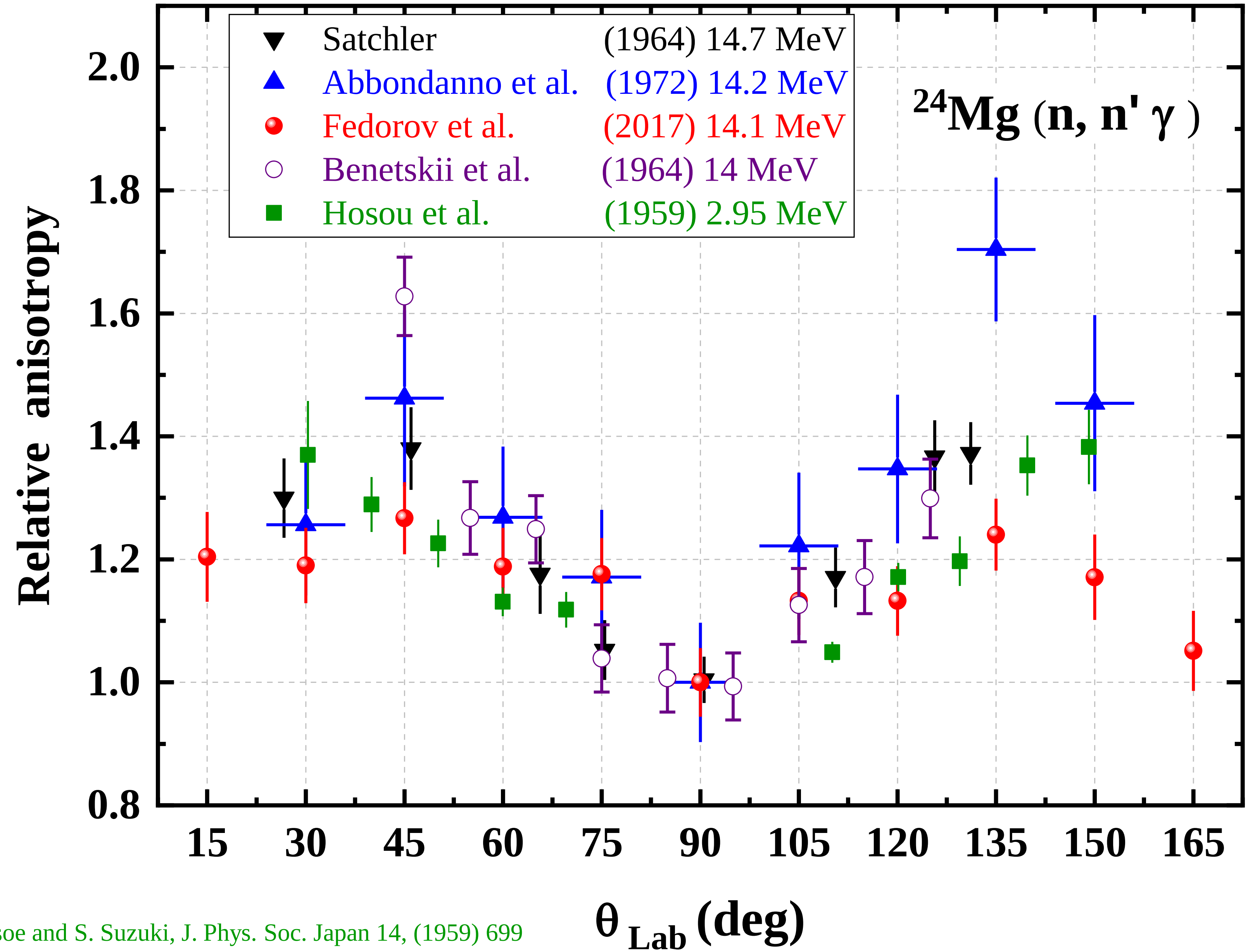


TANGRA: Gamma-ray Angular Distributions

relative to the direction of the incident neutrons **are symmetric around 90°**



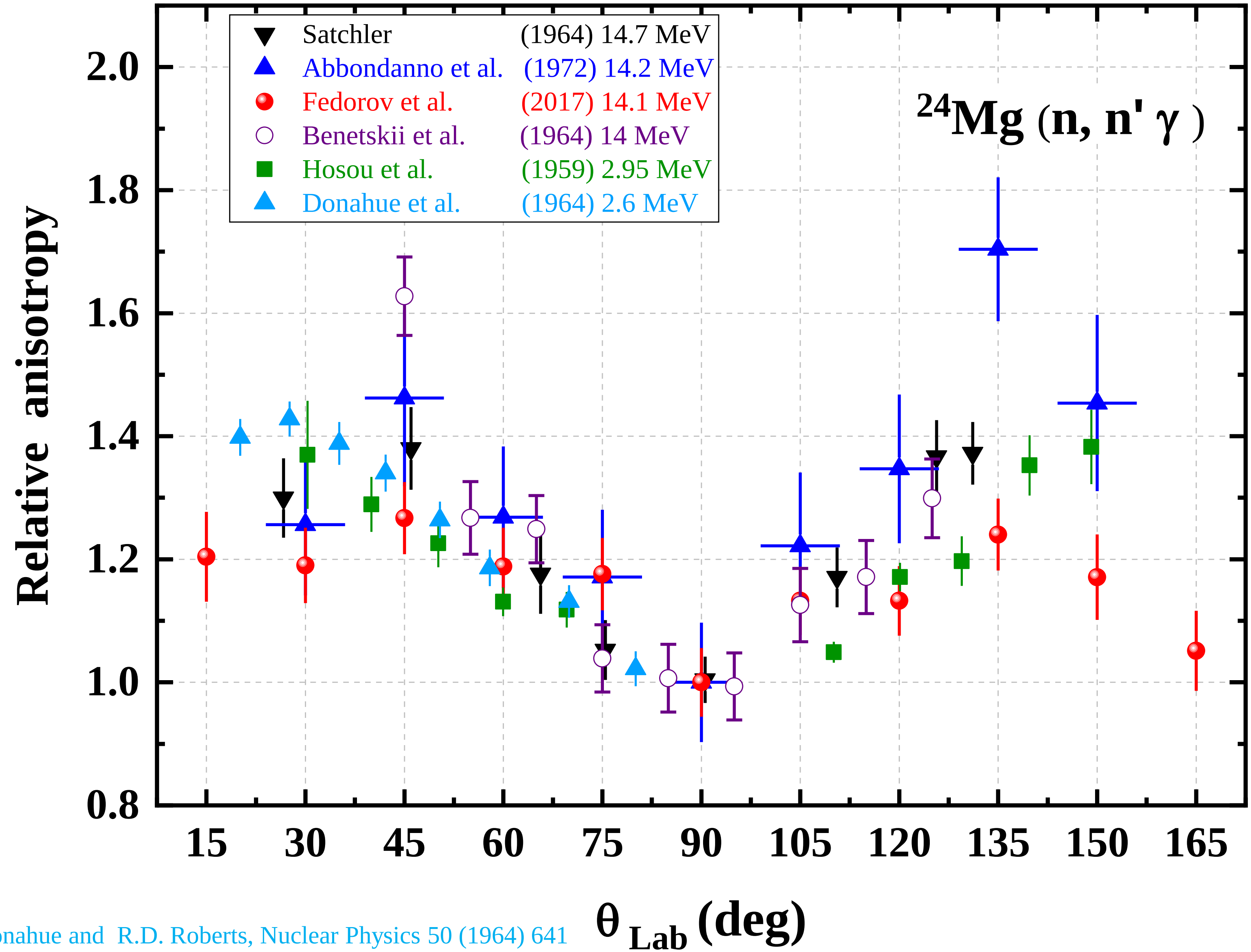
G. R. Satchler, Phys. Rev. 104 (1956) 104 relative to the direction of the incident neutrons **are symmetric around 90°**



M. Hosoe and S. Suzuki, J. Phys. Soc. Japan 14, (1959) 699

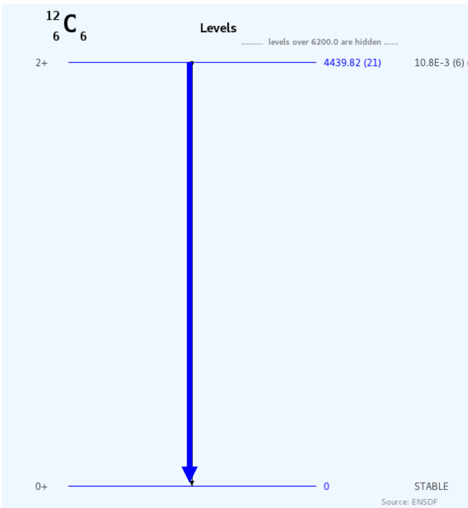
TANGRA: Gamma-ray Angular Distributions cont.

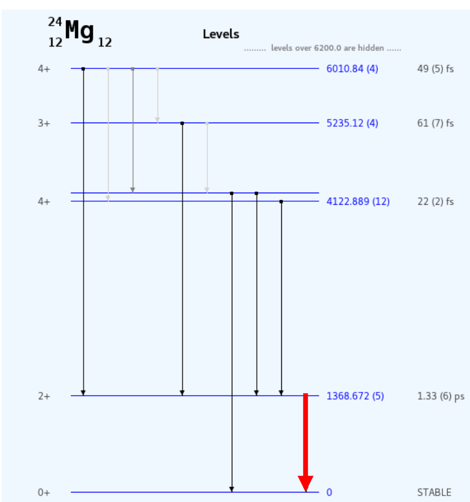
relative to the direction of the incident neutrons **are symmetric around 90°**

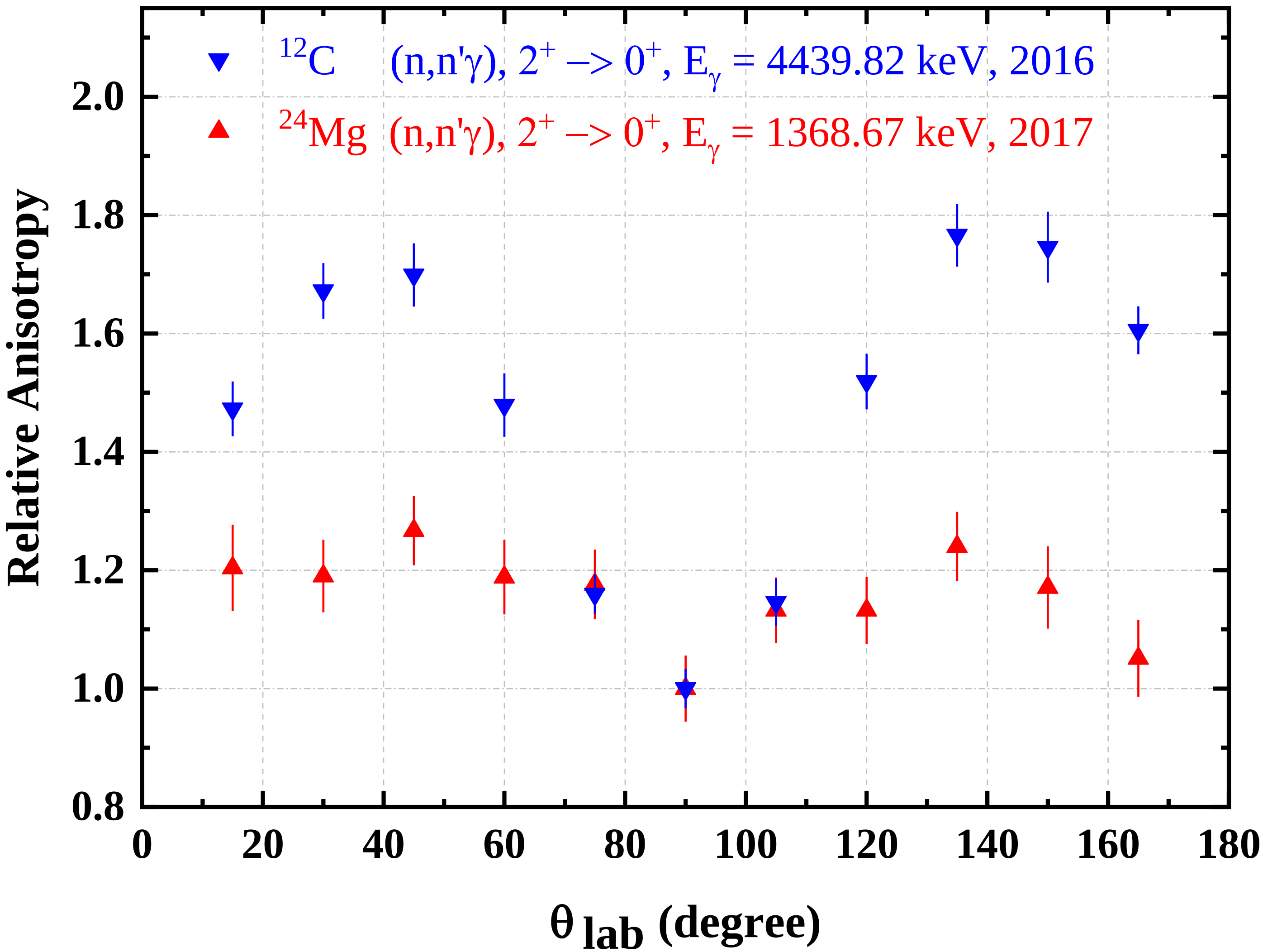


D.J. Donahue and R.D. Roberts, Nuclear Physics 50 (1964) 641

TANGRA: Gamma-ray Angular Distributions, cont.



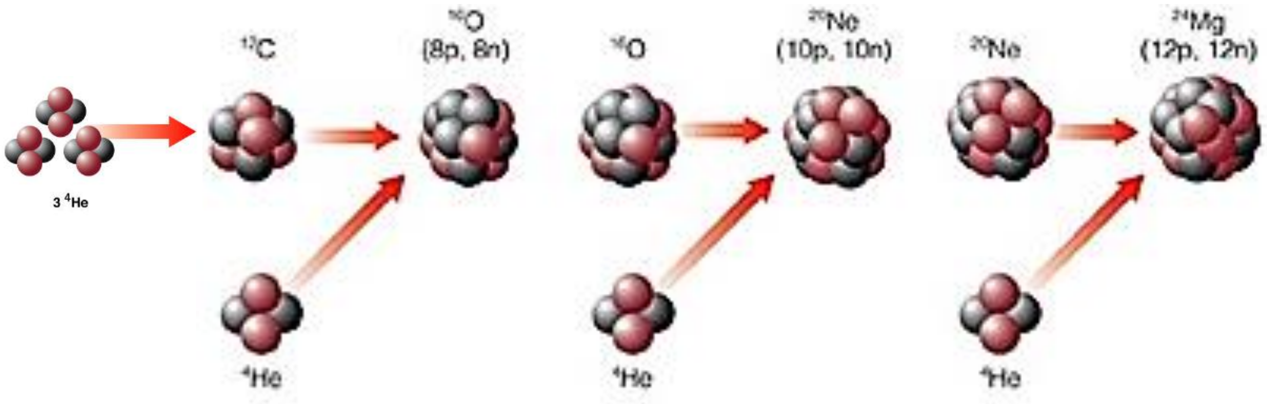


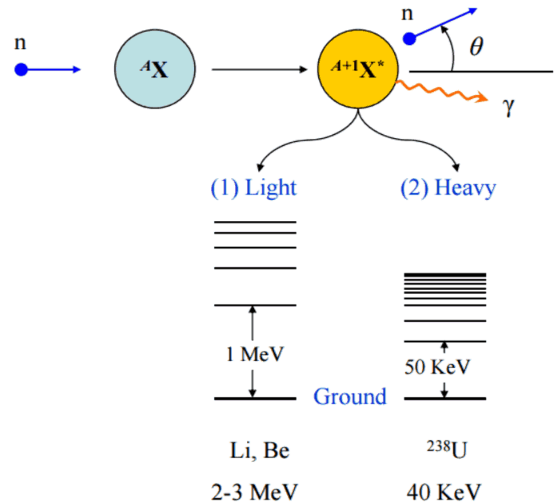


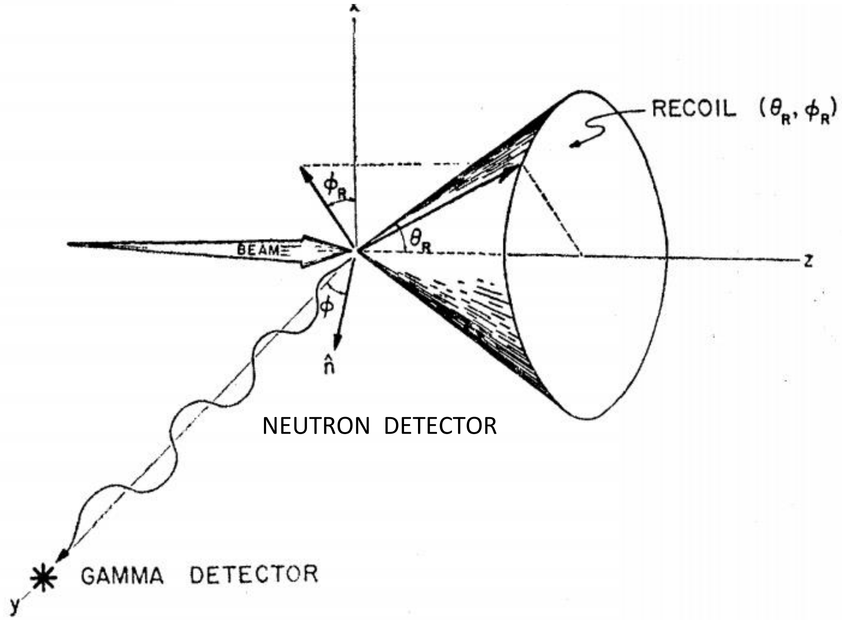
TANGRA: Angular Correlation of Gamma-rays from 14.1-MeV INS

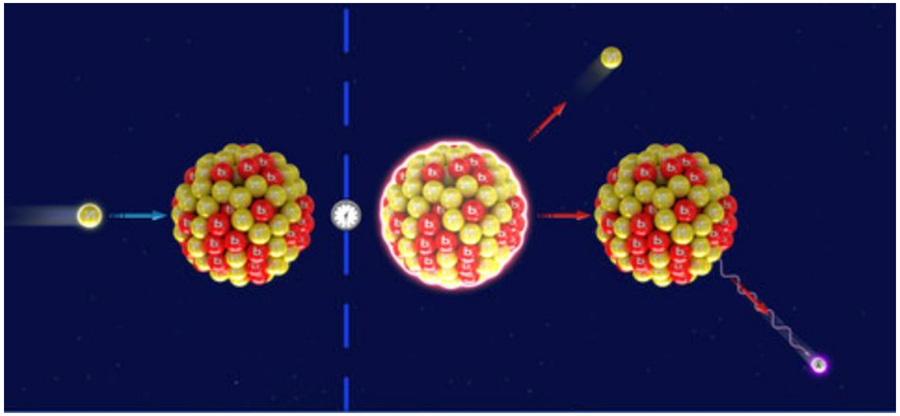
$^{4}_{2}He + ^{4}_{2}He + ^{4}_{2}He = ^{12}_{6}C + ^{4}_{2}He = ^{16}_{8}O + ^{4}_{2}He = ^{20}_{10}Ne + ^{4}_{2}He = ^{24}_{12}Mg$

$^{24}_{12}Mg(n, n')^{24}_{12}Mg^{*} \xrightarrow{\gamma} {}^{24}_{12}Mg$









$$W(\theta) \sim 1 + a_2 P_2(\cos\theta) + a_4 P_4(\cos\theta)$$

TANGRA: Outlook

Journal of Experimental and Theoretical Physics

Journal Issues
Golden Pages
About This journal
Aims and Scope
Editorial Board
Manuscript Submission
Guidelines for Authors
Manuscript Status
Contacts

Search publications with author "benetskii"
Found 2 record(s)

1. **Inelastic Scattering of 14 MeV Neutrons on Mg^{24}**
   B.A. Benetskii, Yu. P. Betin, Ya. Gonzatko
   JETP, 1964, Vol. 18, No. 3, p. 640
   PDF (420.8K)

http://www.jetp.ac.ru/cgi-bin/dn/e_018_03_0640.pdf

2. **Angular Correlation Between Gamma Rays and 14-MeV Neutrons Scattered Inelastically by Carbon**
   B.A. Benetskii, I.M. Frank
   JETP, 1963, Vol. 17, No. 2, p. 309
   PDF (675.7K)

http://www.jetp.ac.ru/cgi-bin/dn/e_017_02_0309.pdf

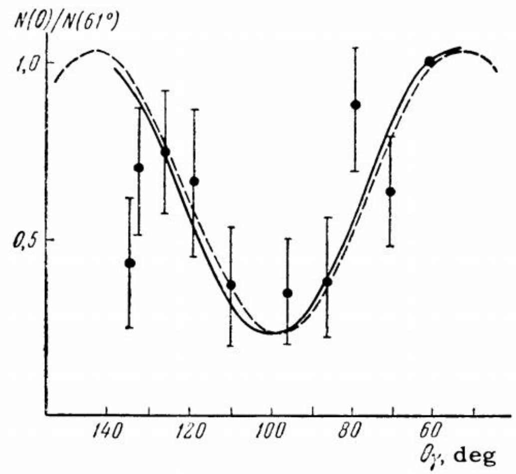
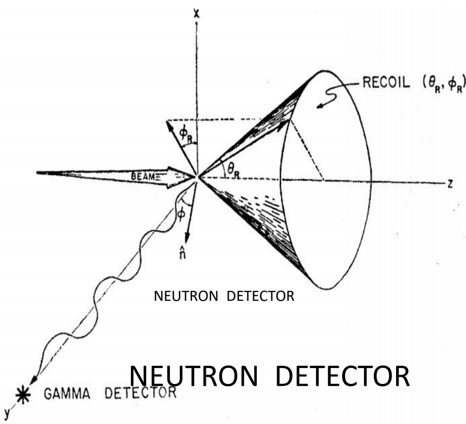


FIG. 4. Angular distribution of 4.4-MeV γ-rays in the reaction $C^{12}(n, n')C^{12}$ for neutron scattering at the angle $\vartheta_n = -24°$. The continuous curve represents the experimental formula (3.1); the dashed curve follows from the theory of direct interactions.[11]



NEUTRON DETECTOR

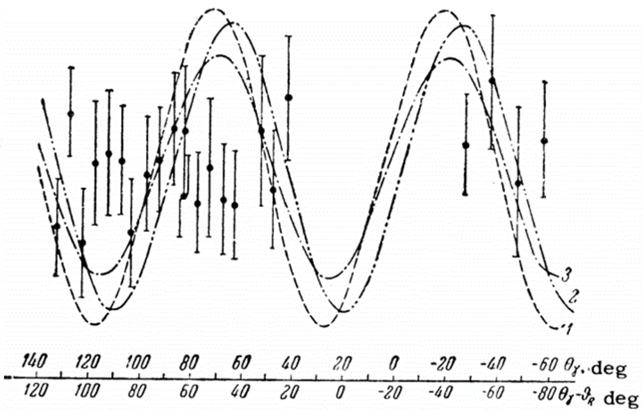
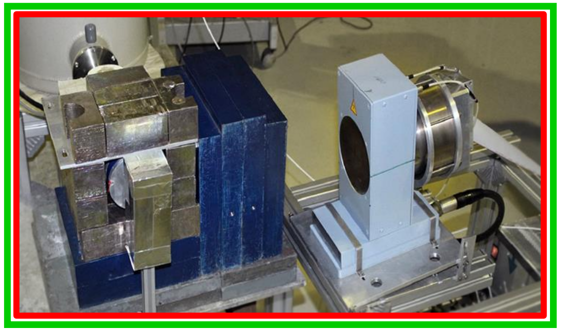
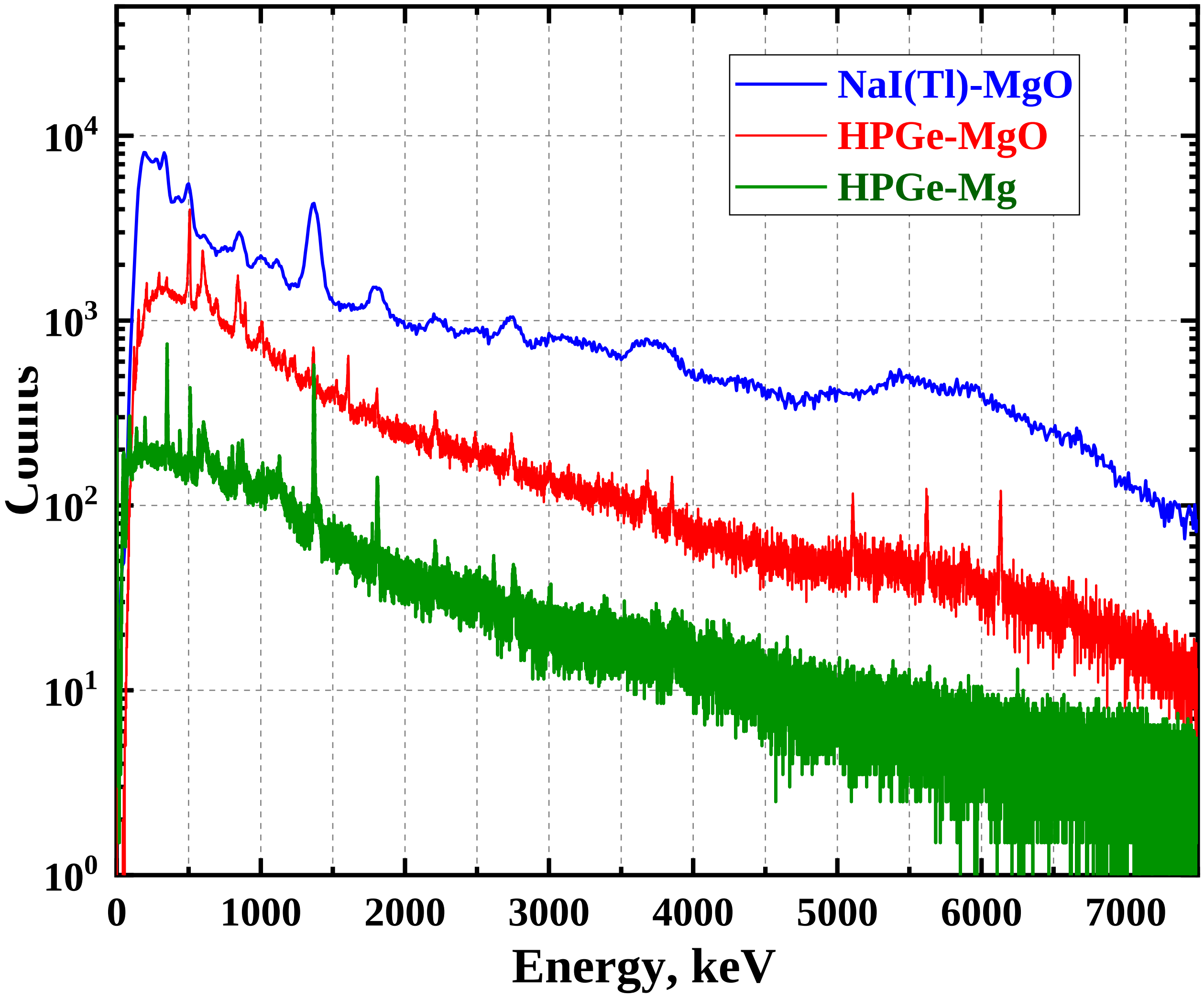


FIG. 6. Angular distribution of 4.4-MeV γ-rays in the reaction $C^{12}(n, n')C^{12}$ for neutron scattering at the angle $\vartheta_n = 135°$. Curve 1 – predicted by direct-interaction theory;[11] curves 2 and 3 – γ-ray distribution in the reaction $C^{12}(p, p'\gamma)C^{12}$ for $\vartheta_p = 150°$ and 110°,[11] respectively. γ-ray directions are measured from the direction ϑ_R of the recoil nucleus.

TANGRA: Comparison of NaI(Tl) and HPGe γ-detector systems





Analyzed, to be added


JINR
TANGRA
COLLABORATION
FLNP
ING-27 power sup.
NaI(Tl) Romashka
PC ADCM 32 chan
Everything is possible
with a proper team

Thank You Very Much For Your Attention