

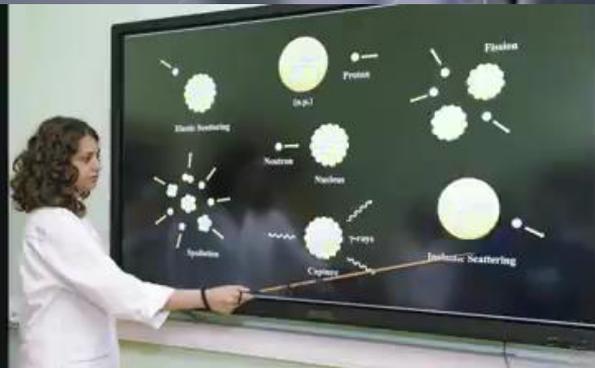
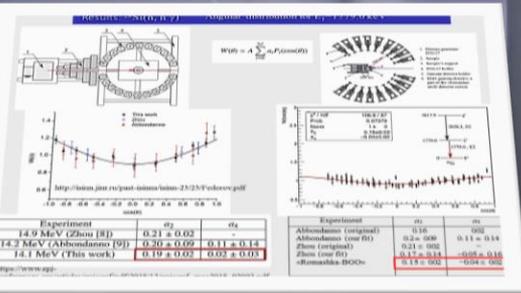
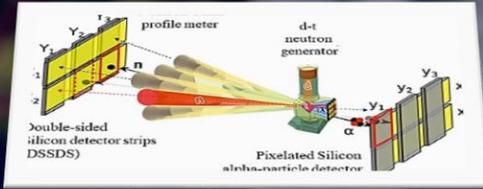
## Angular distribution of 1.368 MeV gamma-rays from inelastic scattering of 14.1 MeV neutrons on $^{24}\text{Mg}$

I.N. Ruskov for TANGRA collaboration

# TANGRA APPLICATIONS

# TANGRA SCIENCE & EDUCATION

# TANGRA TAGGED NEUTRONS & GAMMA RAYS

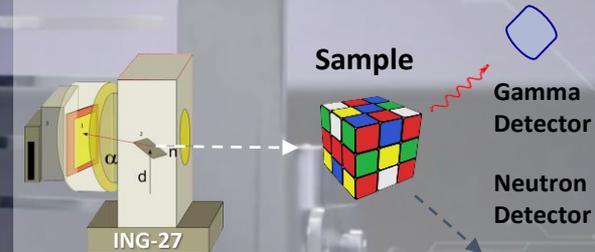


Basic and Applied Neutron-Nuclear Physics  
 Neutron induced Nuclear Reaction Characteristics  
 Nuclear Astrophysics (Fusion in Tokamak and Stars)  
 Neutron-Nuclear Reactions in Advance Reactors  
 Nuclear Forensics (Explosives, Drugs, Fissile Materials)  
 Art, Archeology, Mining (Diamonds, Coke)  
 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)  
 IGGP-ANAS (Baku, Azerbaijan)  
 DP-Banaras Hindu University (Varanasi, India)  
 SEPE, Xi'an Jiaotong University (China)  
 Alexandria University (Egypt)  
 University of Novi Sad (Serbia)  
 Ruđer Bošković Institute (Zagreb, Croatia)

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



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)



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 Former Project Vice-Leader: V.M. Bystritsky  
 Coordinator: I.N. Ruskov, [ivan.n.ruskov@gmail.com](mailto:ivan.n.ruskov@gmail.com)  
 Address: <http://flnph.jinr.ru/en/facilities/tangra-project>  
 Frank Laboratory of Neutron Physics (FLNP)  
 Joint Institute for Nuclear Research (JINR)  
 Joliot Curie str. 6, 141980 Dubna, Moscow region, Russia  
<https://www.facebook.com/Tangra-News-1705174506183427/>

## 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).

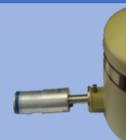
Number of NaI(Tl) detectors: 22  
 Size of NaI(Tl) crystals: hexagonal prism 78 x 90 x 200 mm  
 PMT type: Hamamatsu R1306  
 Gamma-ray Energy-resolution ~ 7.2 % @ 0.662 MeV  
 Gamma-ray Energy-resolution ~ 3.6 % @ 4.437 MeV  
 Gamma-ray Time-resolution ~ 3.8 ns @ 4.437 MeV



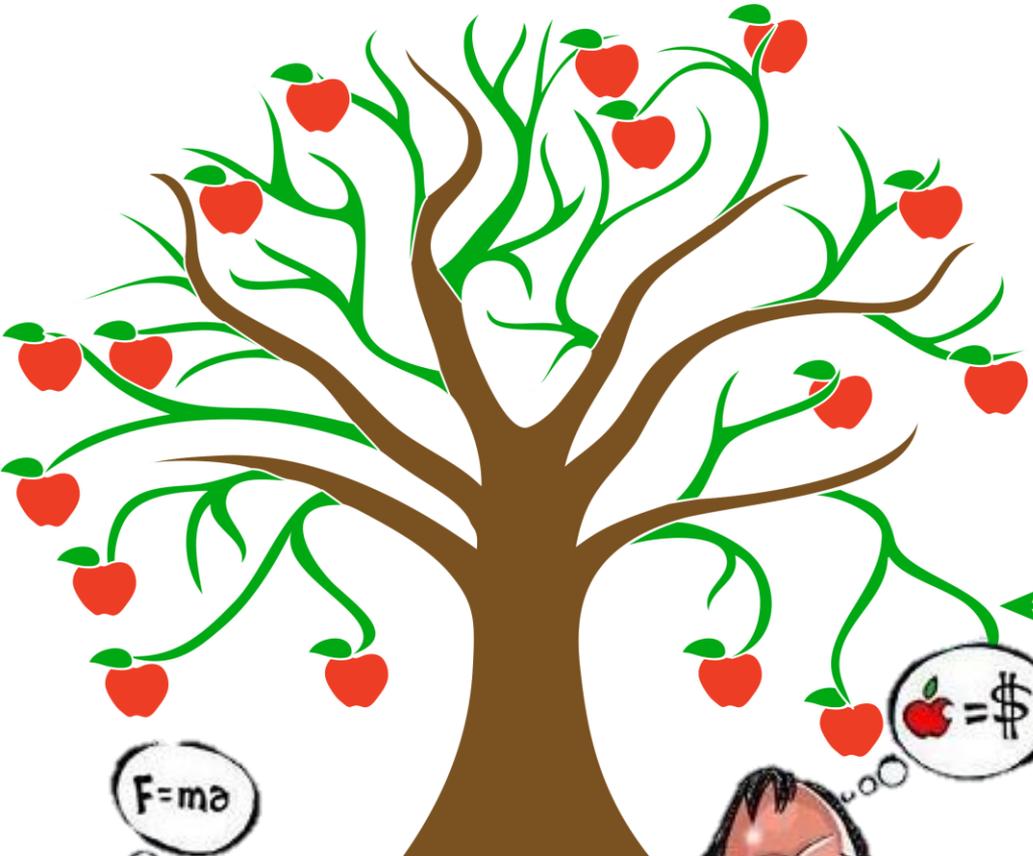
Number of BGO detectors: 18  
 Size of BGO crystals: cylinder  $\varnothing$  76 x 65 mm  
 PMT type: Hamamatsu R1307  
 Gamma-ray Energy-resolution ~ 10.4 % @ 0.662 MeV  
 Gamma-ray Energy-resolution ~ 4.0 % @ 4.437 MeV  
 Gamma-ray Time-resolution ~ 4.1 ns @ 4.437 MeV



Number of HPGe detectors: 1  
 Type: Ortec® GMX 30-83-PL-S,  $\varnothing$ 57.5 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 @ 4.437 MeV



# TANGRA: Neutron-Nuclear Research

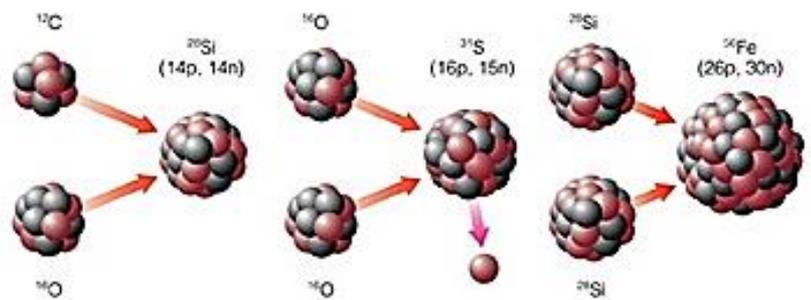
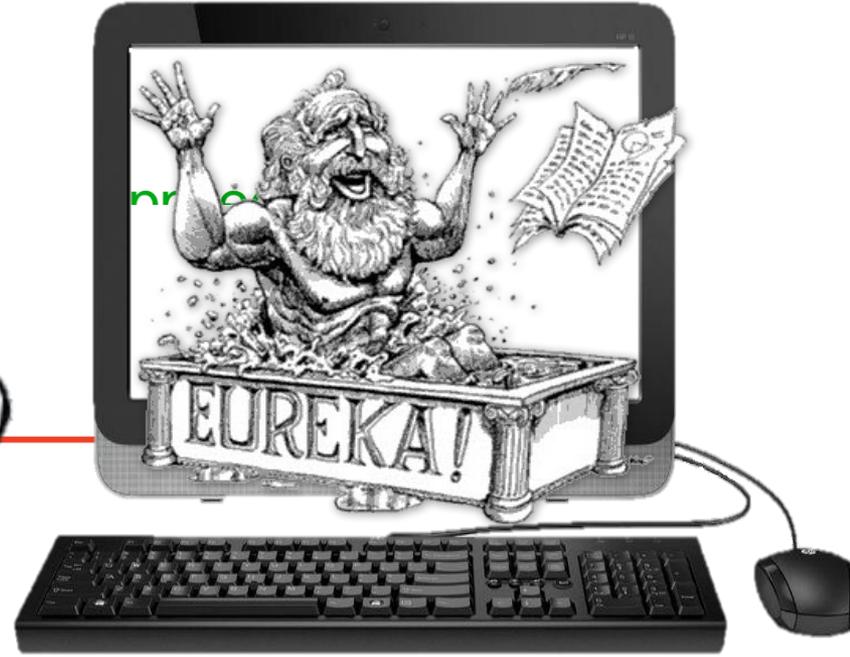
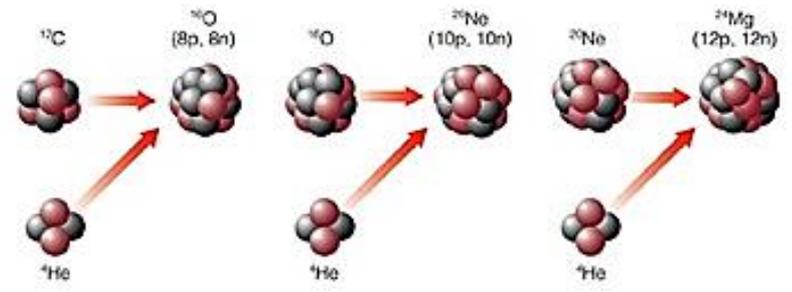


$F=ma$

**Fundamental**



**Applied**



# TANGRA: Inelastic neutron scattering



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ELSEVIER

Journal of Nuclear Energy (1954)

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



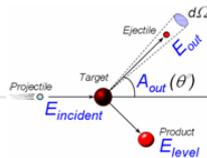
## Gamma-ray spectra excited by the inelastic scattering of fast neutrons by Mg, Al, Fe, Cu, Sn, and Sb ☆☆☆

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

Show more

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

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



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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.<sup>(1,2)</sup> 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 <sup>60</sup>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.

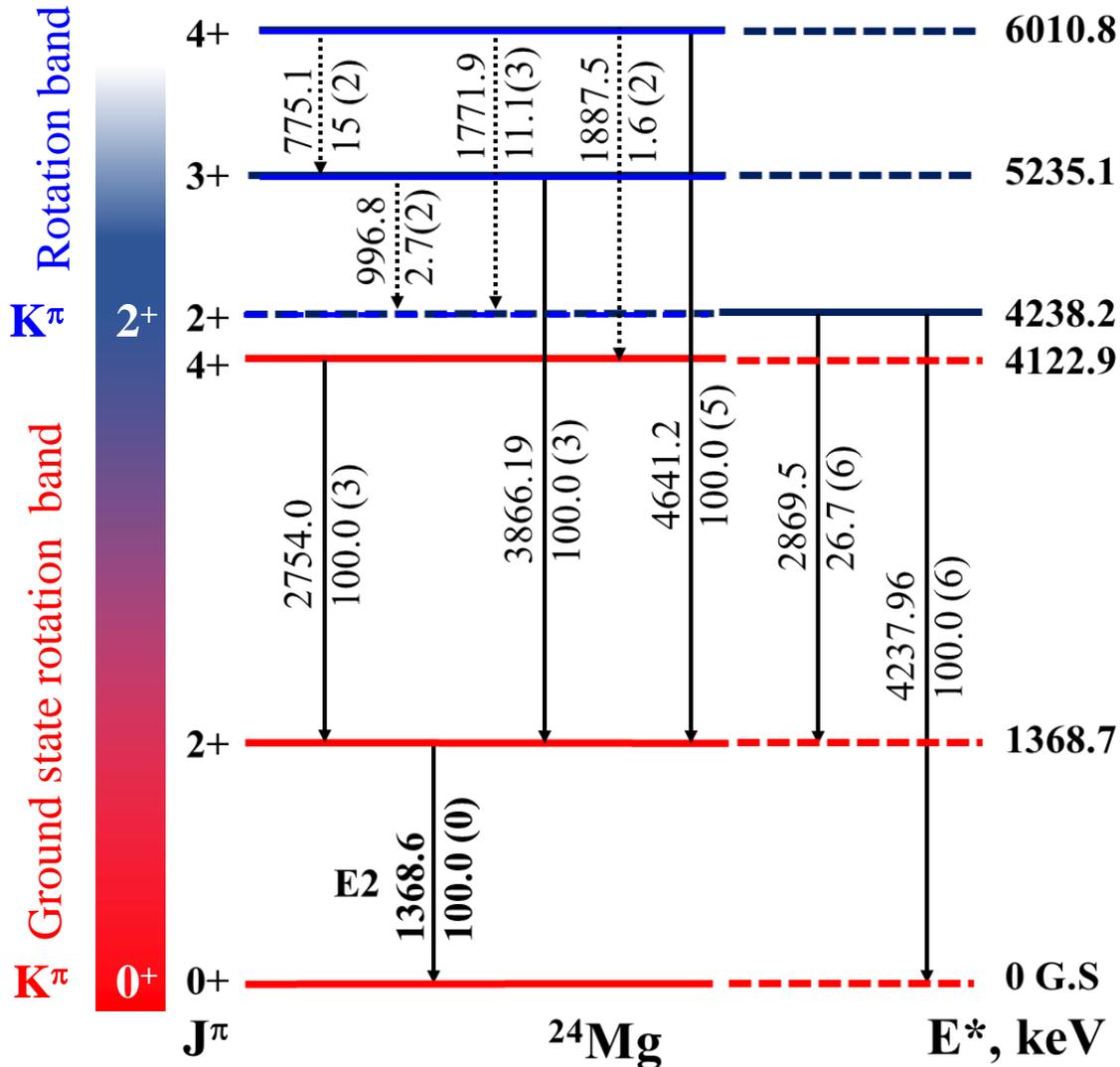
The practical value of these studies is due to the importance of inelastically scattered neutrons in the operation of fast neutron reactors.

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)

# TANGRA: Compound Nucleus and Direct Reaction Mechanism

## $^{24}\text{Mg}$ Level Diagram

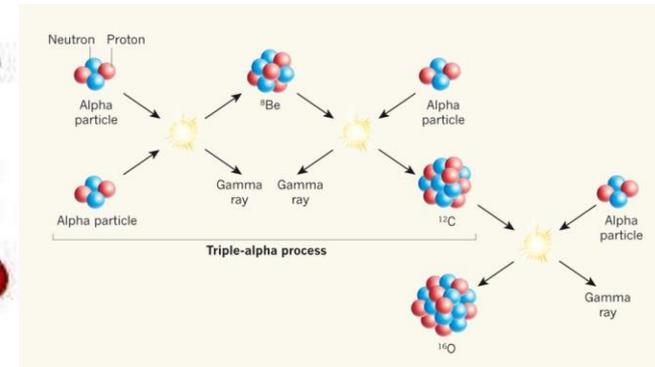
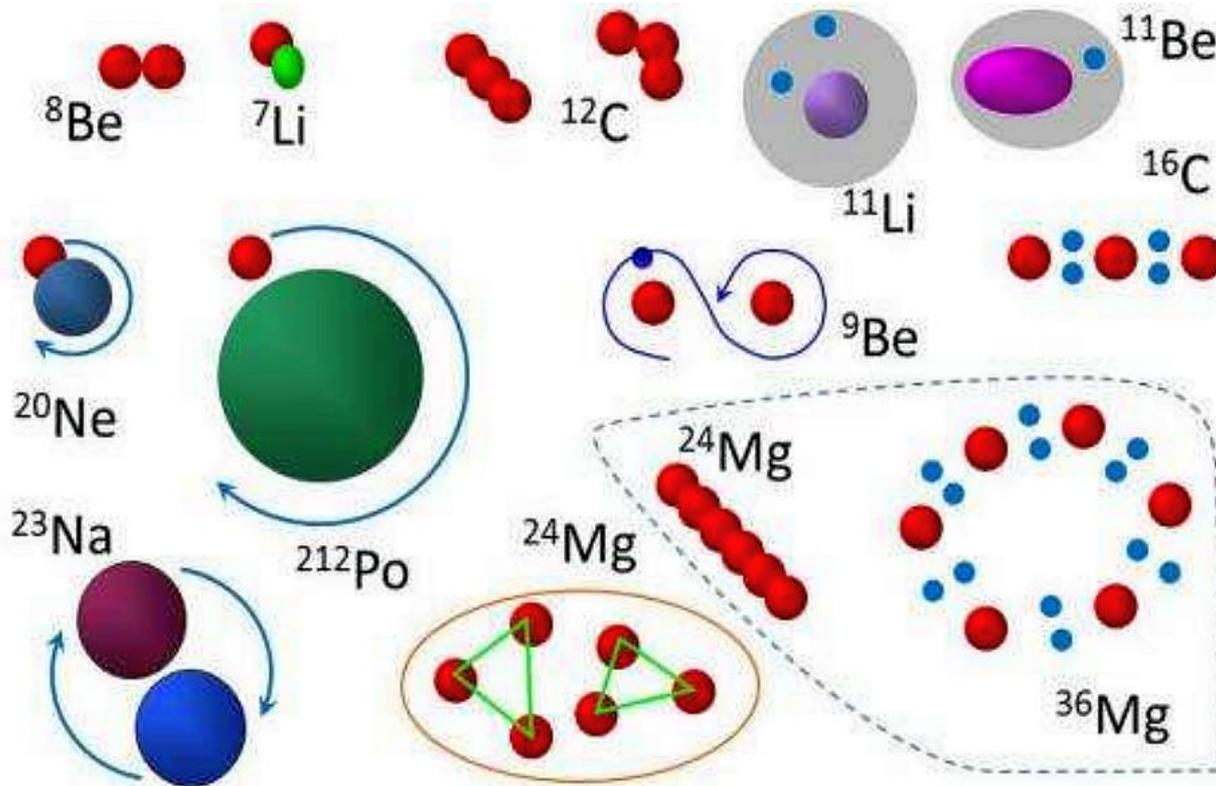


The measurement of **angular distributions of gamma rays** produced in the **inelastic scattering of neutrons** with nuclei is one of the important experimental means of studying **the nuclear level schemes**.

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.



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  $^{24}\text{Mg}$  can be viewed as two  $^{12}\text{C}$  nuclei in juxtaposition**. In a certain sense, therefore, **it is not too surprising that the low-lying levels of nuclei such as  $^{24}\text{Mg}$  can be modelled as two interacting  $^{12}\text{C}$  nuclei**.

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



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](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 23<sup>rd</sup> International Conference on Nuclear Engineering*



*Majuhari Messe, Chiba, Japan*

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

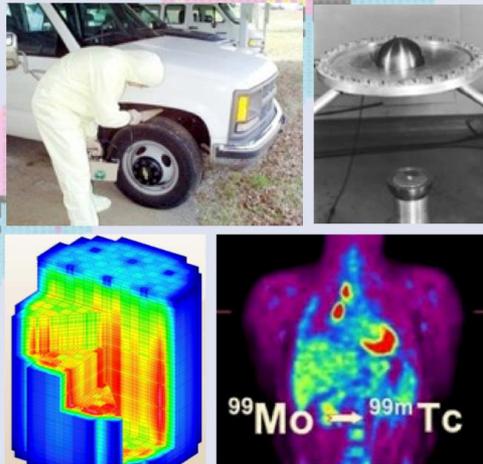
**May 19, 2015**

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

### Nuclear Data Needs and Capabilities for Applications

May 27-29, 2015

Lawrence Berkeley National Laboratory,  
Berkeley, CA USA



### 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  $\gamma$ -ray energy data and their corresponding total and partial radiative-capture ( $n,\gamma$ ) 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' $\gamma$ ) 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  $^{23}\text{Na}$** , 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	$(n, n'\gamma)$ $(n_{th}, \gamma)$ and $(n, n'\gamma)$ $(n, n'\gamma)$ $(n_{th}, \gamma)$	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)	$(n, n'\gamma)$ $(n_{th}, \gamma)$ $(n, n'\gamma)$ $(n_{th}, \gamma)$ 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	$(n_{th}, \gamma)$	specific capture $\gamma$ -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	$(n_{th}, \gamma)$ and $(n, n'\gamma)$ $(n_{th}, \gamma)$	specific capture (or inelastic) $\gamma$ -rays, e.g., 4.945 MeV $(n, \gamma)$ and 4.43 MeV $(n, n'\gamma)$ for C, 2.223 MeV for H, 5.420 MeV for S, etc.
NUCLEAR	$^{232}\text{Th}$ , $^{233}\text{U}$ , $^{235}\text{U}$ , $^{239}\text{Pu}$ , $^{240}\text{Pu}$	$(n_{th}, f)$ , $(n_f, f)$ , $(\gamma, f)$ secondary; $(n_{th}, \gamma)$ , $(n, n'\gamma)$	$n_p$ , $n_d$ , $\gamma_p$ , $\gamma_d$ ; total/coincidence; very high density

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

PRODUCED BY THE FOUNDATION FOR EDUCATION, SCIENCE AND TECHNOLOGY FOR NATIONAL SET WEEK 2003

## PERIODIC TABLE of the ELEMENTS



DEPARTMENT OF SCIENCE AND TECHNOLOGY

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IA 1 <b>H</b> Hydrogen 1 1.01	IIA 2 <b>He</b> Helium 2 4.00	III A 13 <b>B</b> Boron 5 10.81	IV A 14 <b>C</b> Carbon 6 12.01	V A 15 <b>N</b> Nitrogen 7 14.01	VI A 16 <b>O</b> Oxygen 8 16.00	VII A 17 <b>F</b> Fluorine 9 19.00
IIA 2 <b>Li</b> Lithium 3 6.94	IIIA 3 <b>Be</b> Beryllium 4 9.01	IIIA 3 <b>Mg</b> Magnesium 12 24.31	IIIA 3 <b>Al</b> Aluminium 13 26.98	IIIA 3 <b>Si</b> Silicon 14 28.09	IIIA 3 <b>P</b> Phosphorus 15 30.97	IIIA 3 <b>S</b> Sulphur 16 32.06
IIIA 3 <b>Ne</b> Neon 10 20.18	IIIA 3 <b>Na</b> Sodium 11 22.99	IIIA 3 <b>K</b> Potassium 19 39.10	IIIA 3 <b>Ca</b> Calcium 20 40.08	IIIA 3 <b>Sc</b> Scandium 21 44.96	IIIA 3 <b>Ti</b> Titanium 22 47.88	IIIA 3 <b>V</b> Vanadium 23 50.94
IIIA 3 <b>Ar</b> Argon 18 39.95	IIIA 3 <b>Kr</b> Krypton 34 83.80	IIIA 3 <b>Rb</b> Rubidium 37 85.47	IIIA 3 <b>Sr</b> Strontium 38 87.62	IIIA 3 <b>Y</b> Yttrium 39 88.91	IIIA 3 <b>Zr</b> Zirconium 40 91.22	IIIA 3 <b>Nb</b> Niobium 41 92.91
IIIA 3 <b>Xe</b> Xenon 54 131.29	IIIA 3 <b>Cs</b> Caesium 55 132.91	IIIA 3 <b>Ba</b> Barium 56 137.33	IIIA 3 <b>La</b> Lanthanum 57 138.91	IIIA 3 <b>Ce</b> Cerium 58 140.12	IIIA 3 <b>Pr</b> Praseodymium 59 140.90	IIIA 3 <b>Nd</b> Neodymium 60 144.24
IIIA 3 <b>Rn</b> Radon 86 (222)	IIIA 3 <b>Fr</b> Francium 87 (223)	IIIA 3 <b>Ra</b> Radium 88 (226)	IIIA 3 <b>Ac</b> Actinium 89 227.02	IIIA 3 <b>Th</b> Thorium 90 232.03	IIIA 3 <b>Pa</b> Protactinium 91 231.03	IIIA 3 <b>U</b> Uranium 92 238.02

**H** Hydrogen 1 1.01

At room temperature the element is:

- Gas
- Liquid
- Natural solid
- Man-made solid (synthetic)

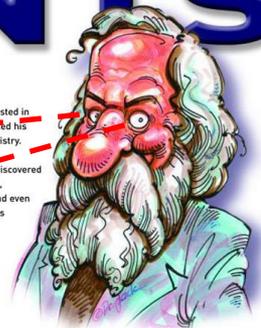
Symbol: H  
Element name: Hydrogen  
Atomic number: 1  
Atomic mass: 1.01

### DMITRI MENDELEYEV (1834 - 1907)

The Russian chemist, Dmitri Mendeleev, was the first to observe that if elements were listed in order of atomic mass, they showed regular (periodical) repeating properties. He predicted his discovery in a periodic table of elements, e.g. gaps as the backbone of modern chemistry.

The crowning achievement of Mendeleev's periodic table lay in his prophesy of A, undiscovered elements. In 1869, the year he published his periodic classification, the elements gallium, germanium and scandium were unknown. Mendeleev left spaces for them in his table and even predicted their atomic masses and other chemical properties. Six years later, gallium was discovered and his predictions were found to be accurate. Other discoveries followed and their chemical behaviour matched that predicted by Mendeleev.

This remarkable man, the youngest in a family of 17 children, has left the scientific community with a classification system so powerful that it became the cornerstone in chemistry teaching and the prediction of new elements ever since. In 1955, element 101 was named after him: Md, Mendeleevium.



### Diamonds, Explosive, Drugs

IIIA 13 <b>B</b> Boron 5 10.81	IV A 14 <b>C</b> Carbon 6 12.01	V A 15 <b>N</b> Nitrogen 7 14.01	VI A 16 <b>O</b> Oxygen 8 16.00	VII A 17 <b>F</b> Fluorine 9 19.00
IIIA 13 <b>Al</b> Aluminium 13 26.98	IV A 14 <b>Si</b> Silicon 14 28.09	V A 15 <b>P</b> Phosphorus 15 30.97	VI A 16 <b>S</b> Sulphur 16 32.06	VII A 17 <b>Cl</b> Chlorine 17 35.45
IIIA 13 <b>Ga</b> Gallium 31 69.72	IV A 14 <b>Ge</b> Germanium 32 72.61	V A 15 <b>As</b> Arsenic 33 74.92	VI A 16 <b>Se</b> Selenium 34 78.96	VII A 17 <b>Br</b> Bromine 35 79.90

### chemical warfare

IIIA 13 <b>In</b> Indium 49 114.82	IV A 14 <b>Sn</b> Tin 50 118.71	V A 15 <b>Sb</b> Antimony 51 121.76	VI A 16 <b>Te</b> Tellurium 52 127.60	VII A 17 <b>I</b> Iodine 53 126.90
IIIA 13 <b>Tl</b> Thallium 81 204.38	IV A 14 <b>Pb</b> Lead 82 207.20	V A 15 <b>Bi</b> Bismuth 83 208.98	VI A 16 <b>Po</b> Polonium 84 (209)	VII A 17 <b>At</b> Astatine 85 (210)

IIIB 3 <b>Sc</b> Scandium 21 44.96	IIIB 4 <b>Ti</b> Titanium 22 47.88	IIIB 5 <b>V</b> Vanadium 23 50.94	IIIB 6 <b>Cr</b> Chromium 24 52.00	IIIB 7 <b>Mn</b> Manganese 25 54.94	IIIB 8 <b>Fe</b> Iron 26 55.85	IIIB 9 <b>Co</b> Cobalt 27 58.93	IIIB 10 <b>Ni</b> Nickel 28 58.69	IIIB 11 <b>Cu</b> Copper 29 63.55	IIIB 12 <b>Zn</b> Zinc 30 65.39
IIIB 3 <b>Y</b> Yttrium 39 88.91	IIIB 4 <b>Zr</b> Zirconium 40 91.22	IIIB 5 <b>Nb</b> Niobium 41 92.91	IIIB 6 <b>Mo</b> Molybdenum 42 95.94	IIIB 7 <b>Tc</b> Technetium 43 (98)	IIIB 8 <b>Ru</b> Ruthenium 44 101.07	IIIB 9 <b>Rh</b> Rhodium 45 102.91	IIIB 10 <b>Pd</b> Palladium 46 106.42	IIIB 11 <b>Ag</b> Silver 47 107.87	IIIB 12 <b>Cd</b> Cadmium 48 112.41
IIIB 3 <b>La</b> Lanthanum 57 138.91	IIIB 4 <b>Ce</b> Cerium 58 140.12	IIIB 5 <b>Pr</b> Praseodymium 59 140.90	IIIB 6 <b>Nd</b> Neodymium 60 144.24	IIIB 7 <b>Pm</b> Promethium 61 (145)	IIIB 8 <b>Sm</b> Samarium 62 150.36	IIIB 9 <b>Eu</b> Europium 63 151.96	IIIB 10 <b>Gd</b> Gadolinium 64 157.25	IIIB 11 <b>Tb</b> Terbium 65 158.92	IIIB 12 <b>Dy</b> Dysprosium 66 162.50
IIIB 3 <b>Rf</b> Rutherfordium 104 (261)	IIIB 4 <b>Db</b> Dubnium 105 (262)	IIIB 5 <b>Sg</b> Seaborgium 106 (263)	IIIB 6 <b>Bh</b> Bohrium 107 (262)	IIIB 7 <b>Hs</b> Hassium 108 (265)	IIIB 8 <b>Mt</b> Meitnerium 109 (266)	IIIB 9 <b>La</b> Lanthanum 87 138.91	IIIB 10 <b>Ce</b> Cerium 88 140.12	IIIB 11 <b>Pr</b> Praseodymium 89 140.90	IIIB 12 <b>Nd</b> Neodymium 90 144.24
IIIB 3 <b>Ac</b> Actinium 89 227.02	IIIB 4 <b>Th</b> Thorium 90 232.03	IIIB 5 <b>Pa</b> Protactinium 91 231.03	IIIB 6 <b>U</b> Uranium 92 238.02	IIIB 7 <b>Np</b> Neptunium 93 237.04	IIIB 8 <b>Pu</b> Plutonium 94 244.06	IIIB 9 <b>Am</b> Americium 95 243.06	IIIB 10 <b>Cm</b> Curium 96 247.07	IIIB 11 <b>Bk</b> Berkelium 97 247.07	IIIB 12 <b>Cf</b> Californium 98 251.08
IIIB 3 <b>Es</b> Einsteinium 99 252.08	IIIB 4 <b>Fm</b> Fermium 100 257.10	IIIB 5 <b>Md</b> Mendelevium 101 258.10	IIIB 6 <b>No</b> Nobelium 102 259.10	IIIB 7 <b>Lr</b> Lawrencium 103 260.10	IIIB 8 <b>Ac</b> Actinium 89 227.02	IIIB 9 <b>Th</b> Thorium 90 232.03	IIIB 10 <b>Pa</b> Protactinium 91 231.03	IIIB 11 <b>U</b> Uranium 92 238.02	IIIB 12 <b>Np</b> Neptunium 93 237.04



**U Np Pu**  
S N M

# TANGRA: Magnesium

Stable isotopes:  $^{24}\text{Mg}$  (78.99%),  $^{25}\text{Mg}$  (10.00%) and  $^{26}\text{Mg}$  (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.

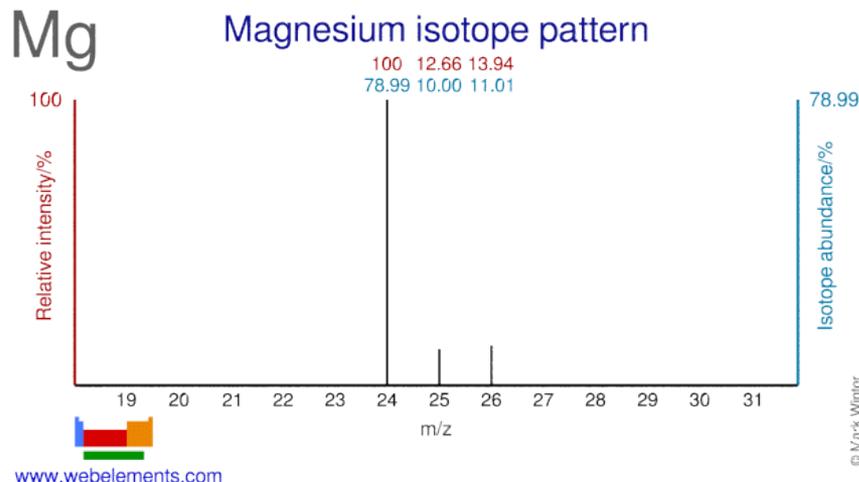
•The center of chlorophyll contains magnesium.

•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 ( $\text{MgCO}_3$ )

•Magnesium chloride ( $\text{MgCl}_2$ )

•Magnesium diboride ( $\text{MgB}_2$ )

•Magnesium fluoride ( $\text{MgF}_2$ )

•Magnesium hydroxide [ $\text{Mg}(\text{OH})_2$ ]

•Magnesium nitrate [ $\text{Mg}(\text{NO}_3)_2$ ]

•Magnesium oxide ( $\text{MgO}$ )

•Magnesium peroxide ( $\text{MgO}_2$ )

•Magnesium sulfate ( $\text{MgSO}_4$ )

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

# TANGRA: Magnesium for/in Life

Stable isotopes:  $^{24}\text{Mg}$  (78.99%),  $^{25}\text{Mg}$  (10.00%) and  $^{26}\text{Mg}$  (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.



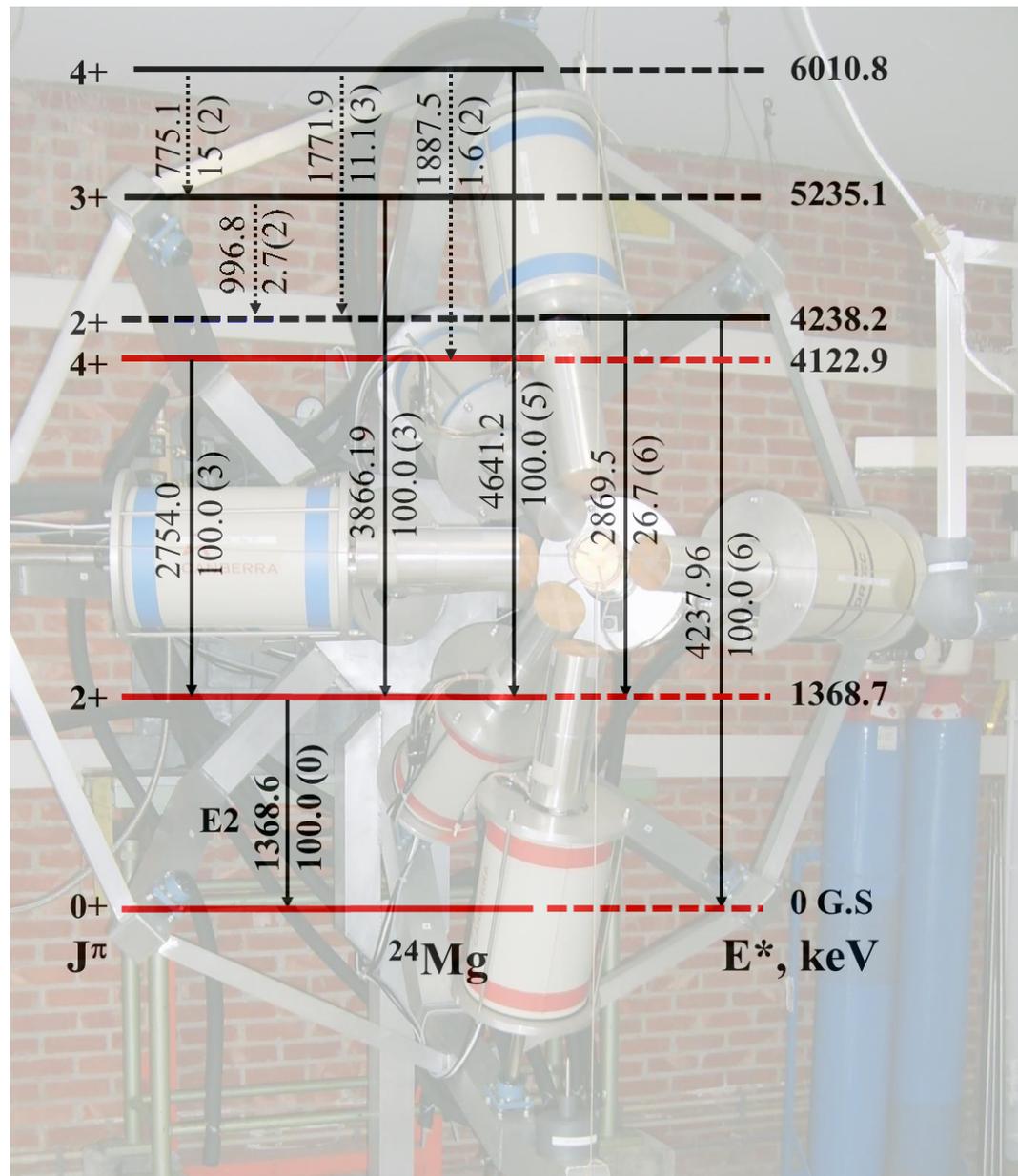
# TANGRA: n-INS on $^{24}\text{Mg}$ @ GELINA by GAINS

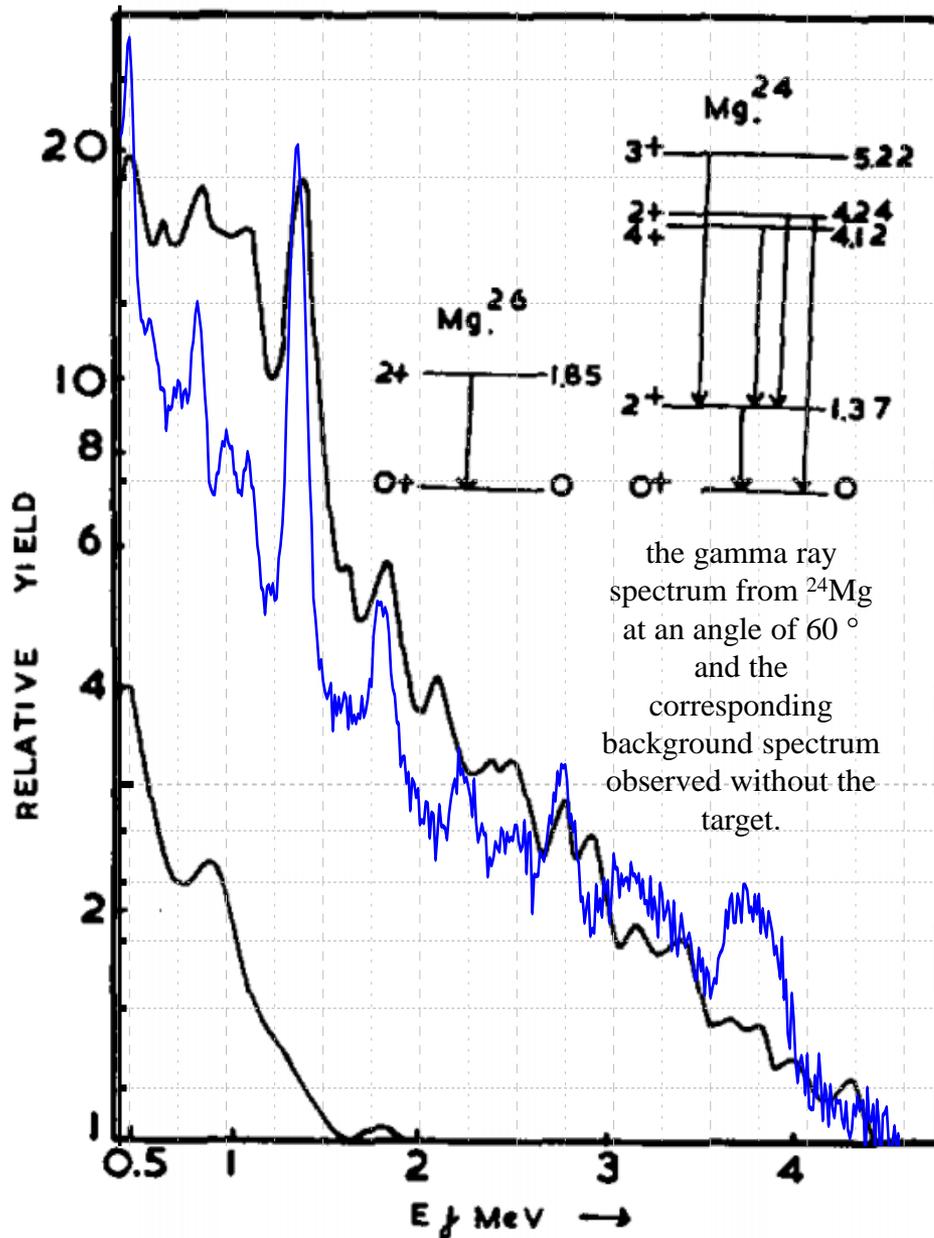
**Mg-alloy steel** is a structural material in the design of Gen-IV nuclear power reactor design

**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  $^{24}\text{Mg}$**

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





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

D.T. Stewart, P.W. Martin

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[https://doi.org/10.1016/0029-5582\(64\)90669-8](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  $\text{C}^{12}$  and for 1.37 MeV gamma rays from  $\text{Mg}^{24}$  have been determined.

The principal magnesium isotope,  $^{24}\text{Mg}$ , 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  $^{25}\text{Mg}$  and  $^{26}\text{Mg}$ , respectively, since the agreement of the energies with those of known levels in these isotopes is excellent.

$^{25}\text{Mg}$  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.

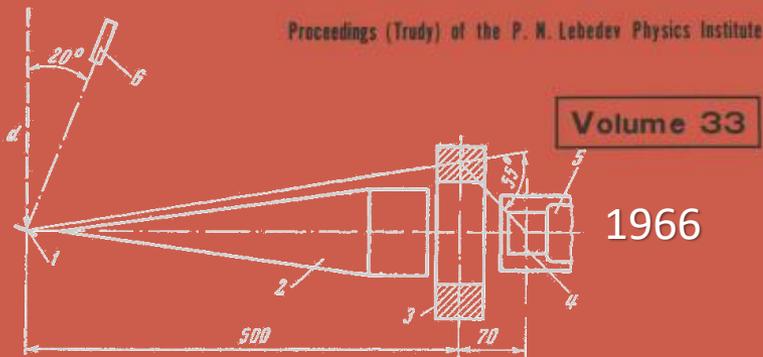


Fig. 16. Diagrammatic representation of the apparatus used in measurements on the cross section for inelastic scattering of neutrons by magnesium. 1) Neutron source; 2) lead shield; 3) specimen; 4) spectrometer scintillator; 5) photomultiplier; 6) proportional counter for  $\alpha$  particles.

## Studies of Nuclear Reactions

Edited by Academician D. V. Skobel'tsyn

## 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 $Mg^{24}$ , $Al^{27}$ , $Si^{28}$ , and $Fe^{56}$

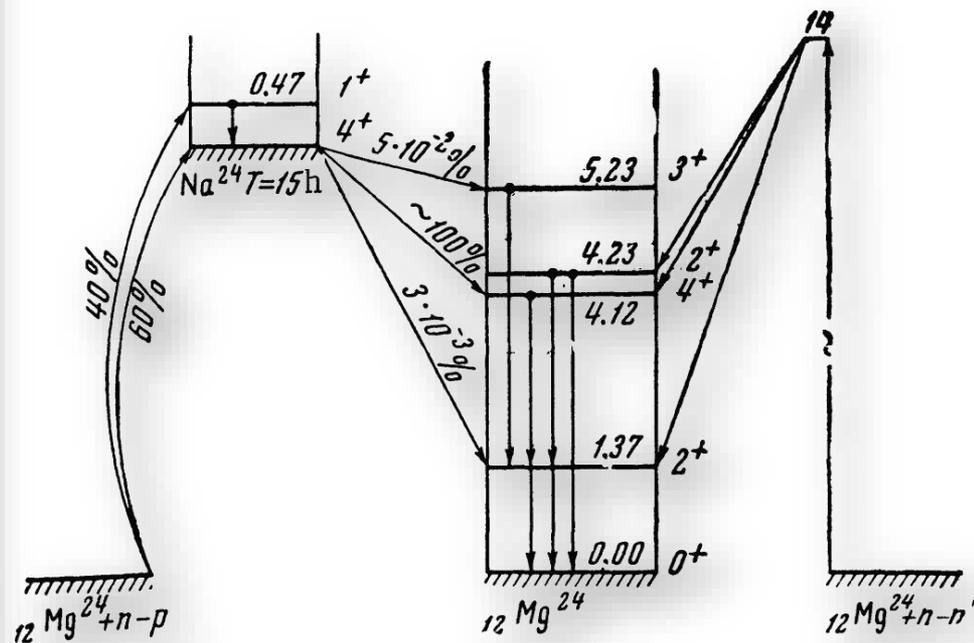


Fig. 15. Level and transition scheme for  $Mg^{24}$ .

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B.A. Benetskii, Yu. P. Betin, Ya. Gonzatko  
JETP, 1964, [Vol. 18](#), [No. 3](#), p. 640

[http://www.jetp.ac.ru/cgi-bin/dn/e\\_018\\_03\\_0640.pdf](http://www.jetp.ac.ru/cgi-bin/dn/e_018_03_0640.pdf)

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2. [Angular Correlation Between Gamma Rays and 14-MeV Neutrons Scattered Inelastically by Carbon](#)

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JETP, 1963, [Vol. 17](#), [No. 2](#), p. 309

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1. Inelastic Scattering of 14 MeV Neutrons on Mg<sup>24</sup>

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

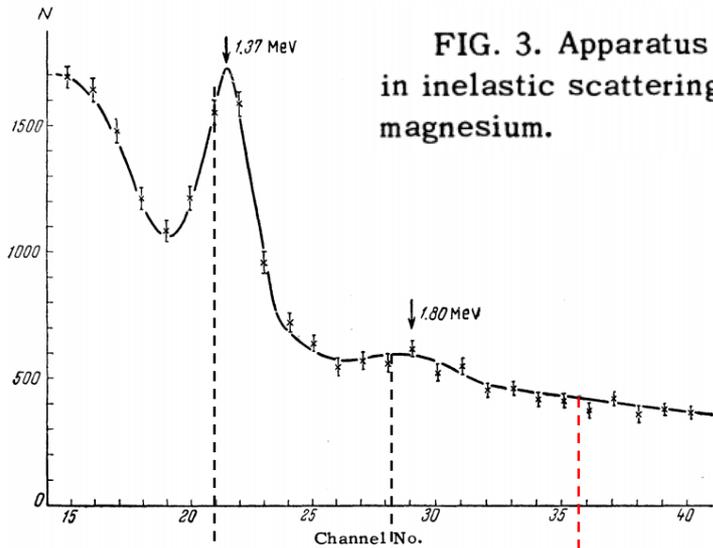


FIG. 3. Apparatus spectrum of  $\gamma$  quanta generated in inelastic scattering of 14-MeV neutrons by magnesium.

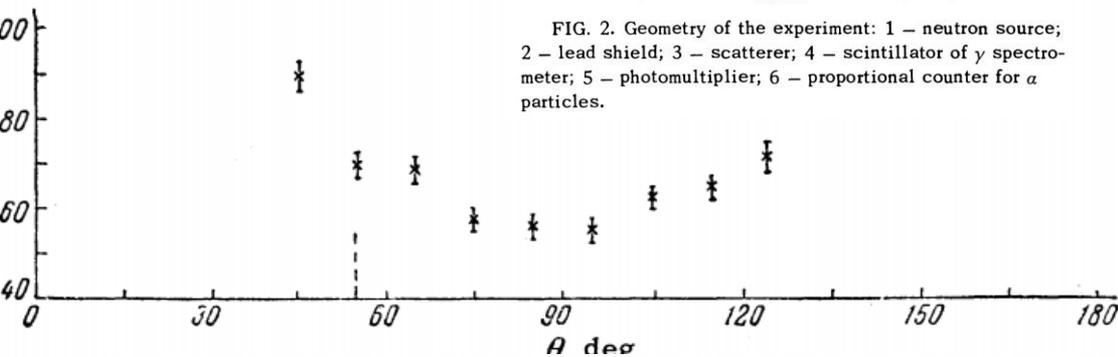
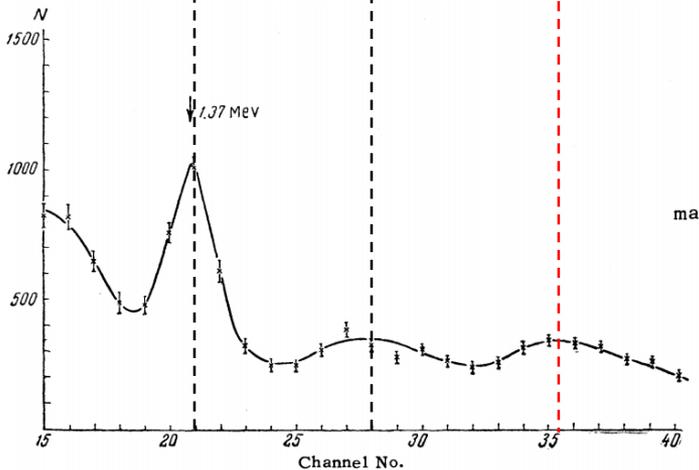


FIG. 5. Angular distribution of 1.37-MeV  $\gamma$  quanta generated by inelastic scattering of neutrons by magnesium.

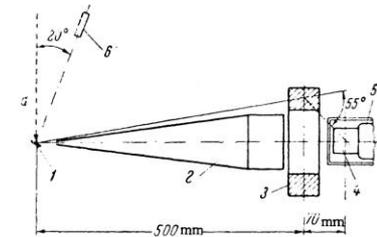
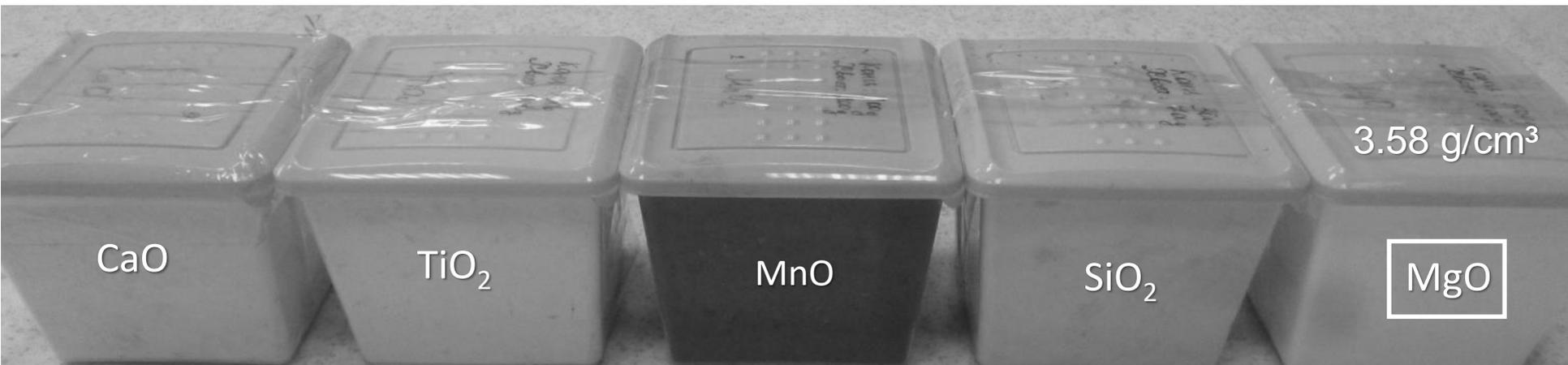
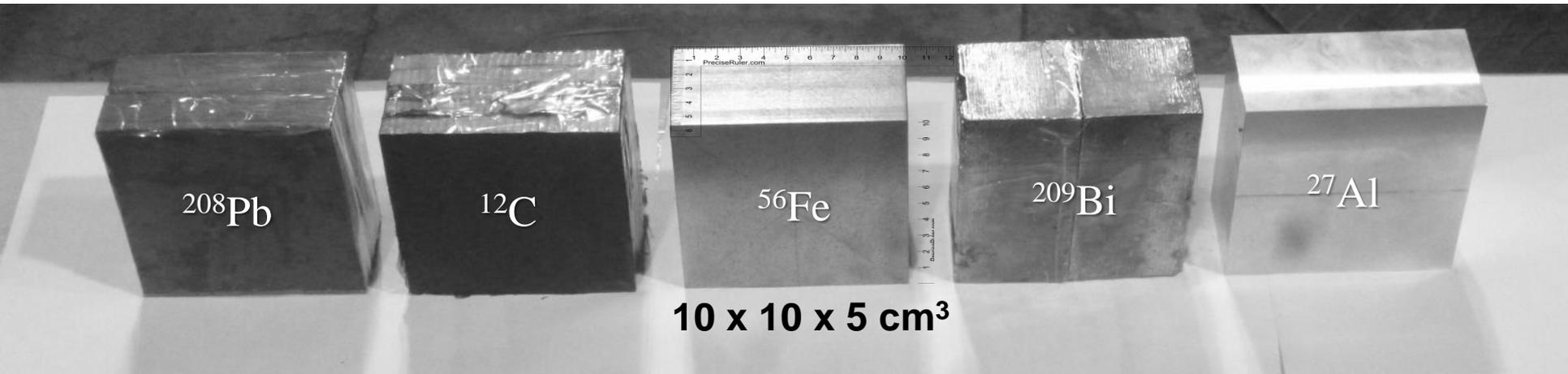


FIG. 2. Geometry of the experiment: 1 – neutron source; 2 – lead shield; 3 – scatterer; 4 – scintillator of  $\gamma$  spectrometer; 5 – photomultiplier; 6 – proportional counter for  $\alpha$  particles.

FIG. 4. Apparatus spectrum of  $\gamma$  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 <sup>-1</sup> )	
		Neutron	Particule α	Neutron	Particule α
t(d,n)α	17,6	14,1	3,5	5,13	1,31

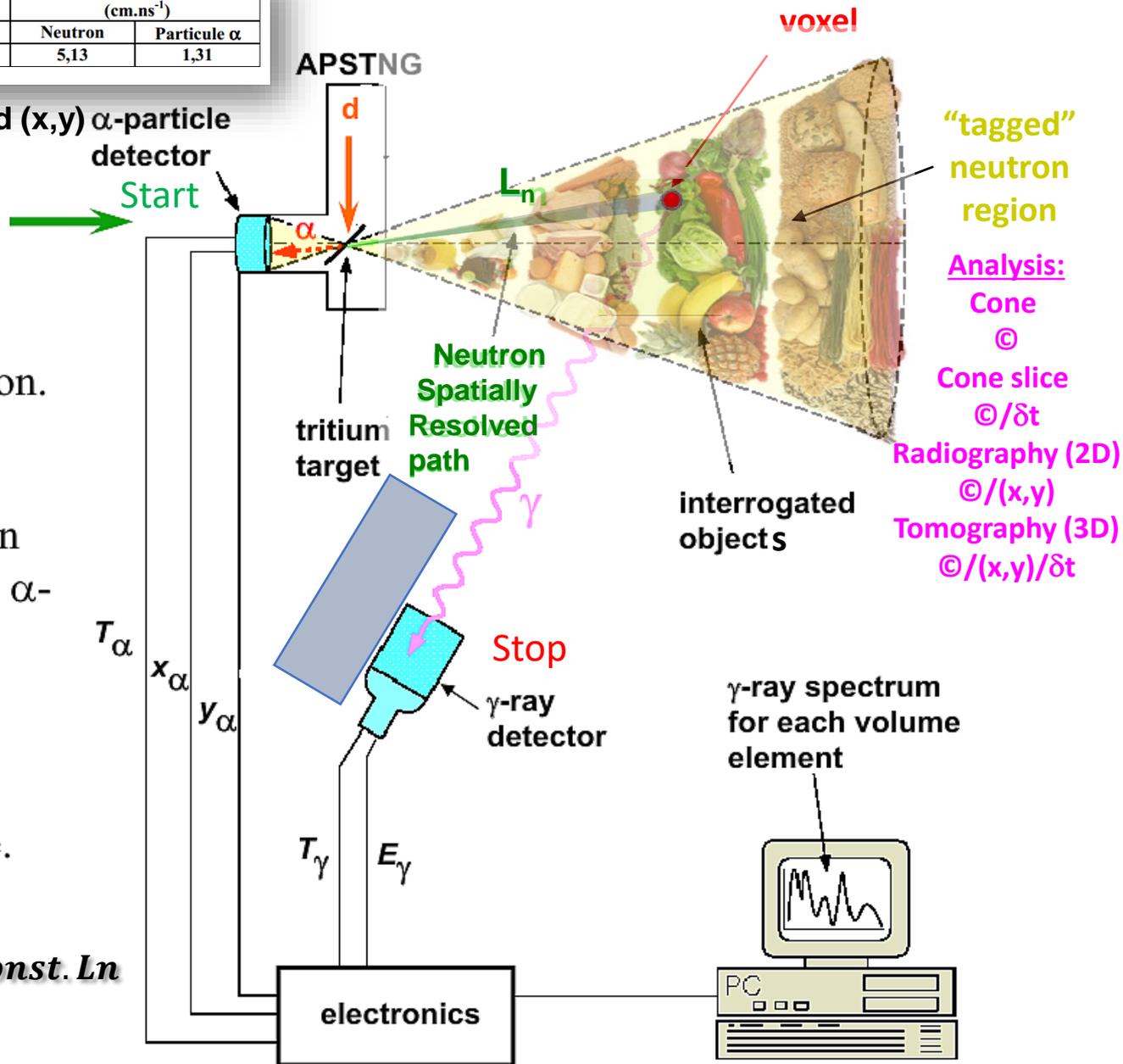
## Associated particle sealed tube neutron generator

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.

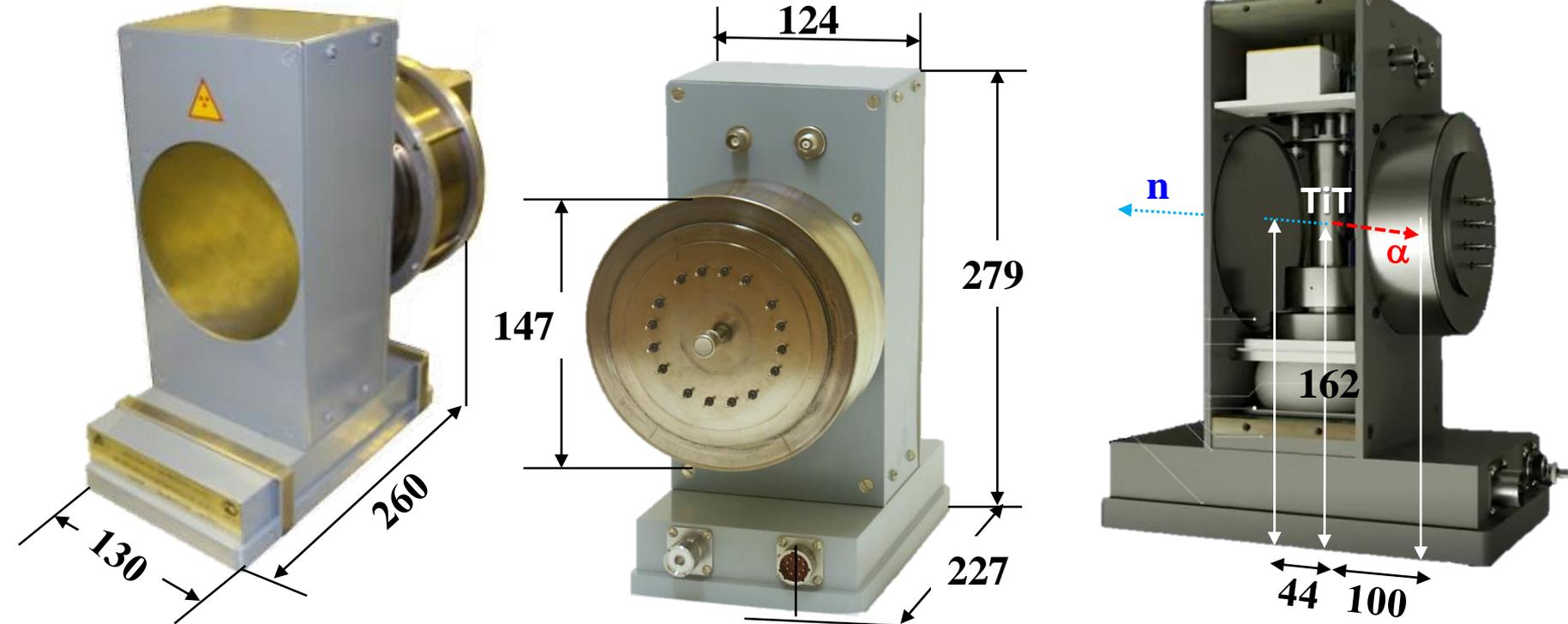
$$\Delta t = T_\gamma - T_\alpha = \sqrt{\frac{m_n}{2E_n}} \cdot L = \text{const.} \cdot Ln$$



# 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 :  $44.0 \pm 1.4$  mm  
TiT-to- $\alpha$ -detector distance:  $100 \pm 2$  mm  
Power supply voltage:  $200 \pm 5$  V  
Maw Power Supply Current:  $300 \pm 30$  mA  
Consumed Power:  $< 40$  W  
Continuous Mode: 14-MeV neutrons  
Initial Intensity:  $> 5.0 \times 10^7$  n/s/ $4\pi$   
Final Intensity:  $> 2.5 \times 10^7$  n/s/ $4\pi$   
Weight: ING-27:  $7.5 \pm 0.5$  kg ; Power Supply and Operation Unit:  $2.7 \pm 0.3$  kg

Double-side Si  $\alpha$ -particles detector  
Number of pixels: 64 (8x8 strips)  
Pixel area:  $6 \times 6$  mm<sup>2</sup>  
Distance between strips: 0.5 mm  
Voltage bias:  $-250$  V DC  
Dark current:  $< 8 \mu$ A  
n-tube life-time:  $> 800$  h  
< ING Duty time >: 18 months

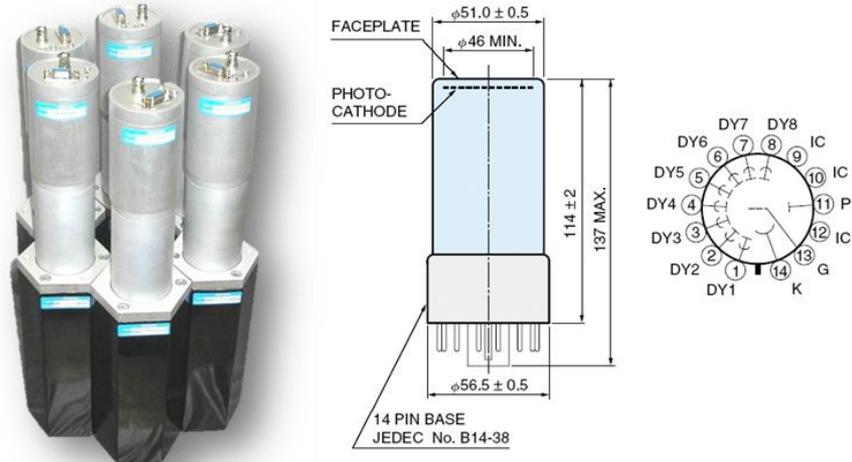
# TANGRA: Amcryst™ NaI(Tl) Gamma-ray Detector

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 $\lambda$	300nm
Max $\lambda$	650nm
Peak Sens.	420nm
Cathode Radiant Sensitivity	95mA/W
Window	Borosilicate
Cathode Type	Bialkali
Cathode Luminous Sensitivity	110 $\mu$ A/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

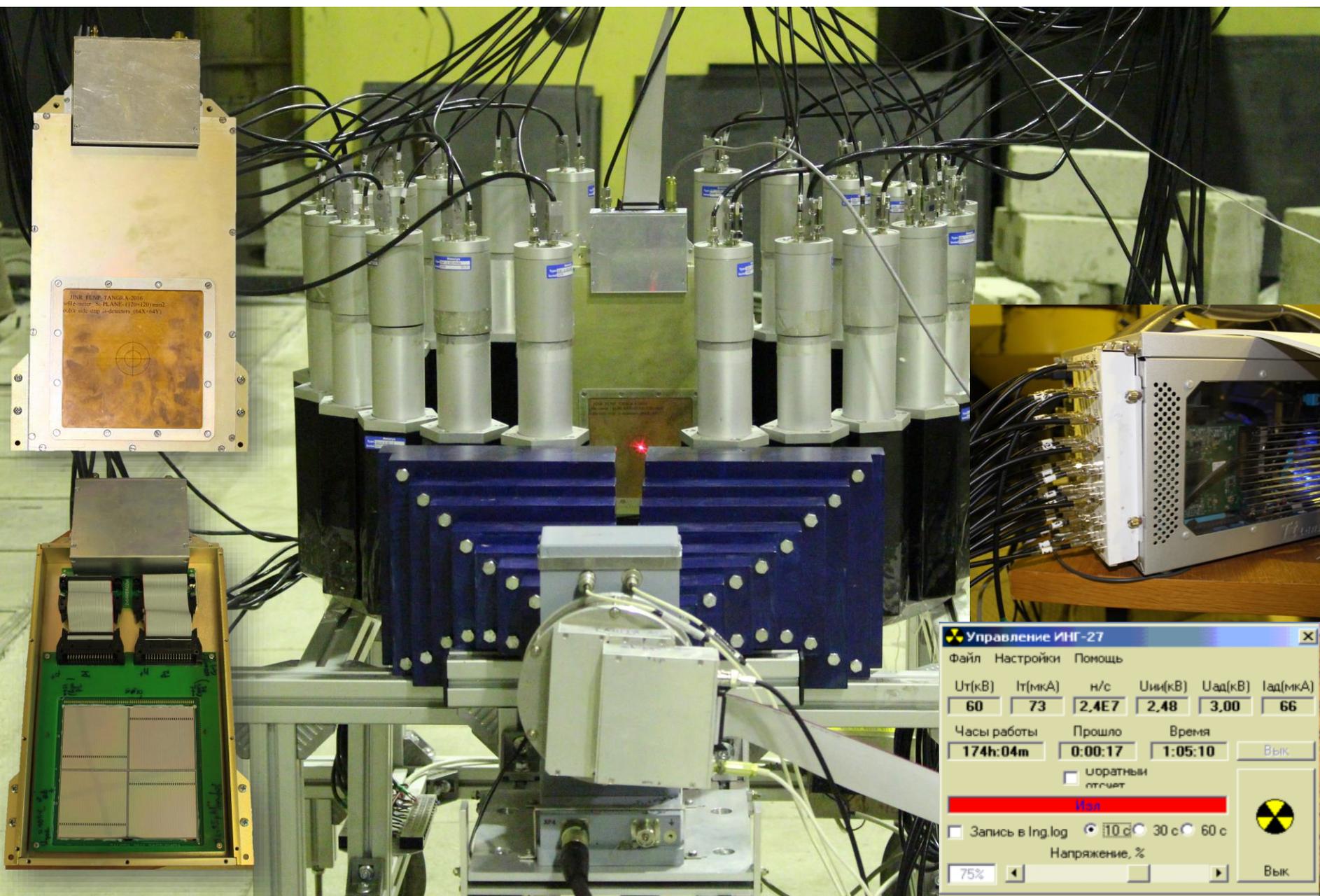
Properties	
Density [g/cm <sup>3</sup> ]	3.67
Melting point [K]	924
Thermal expansion coefficient [C <sup>-1</sup> ]	47.7 x 10 <sup>-6</sup>
Cleavage plane	<100>
Hardness (Mho)	2
Hygroscopic	yes
Wavelength of emission max. [nm]	415
Refractive index @ emission max	1.85
<u>Primary decay time [ns]</u>	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

<b>NaI(Tl)</b> 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



JMR ROM TANGRA-2010  
reflector: S-PLANE-(120x120)mm2  
public site: http://a-detectors.com/44/

**Управление ИНГ-27**

Файл Настройки Помощь

Uт(кВ)	Iт(мкА)	н/с	Uли(кВ)	Uад(кВ)	Iад(мкА)
60	73	2,4E7	2,48	3,00	66

Часы работы: 174h:04m    Прошло: 0:00:17    Время: 1:05:10   

Уоратный отсчет

Запись в log.log     10 с     30 с     60 с

Напряжение, %

## 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  $\sim 10^5$  events per second**

# TANGRA: ADCM Control Panel

ADCM Control Panel

File Setup Statistics Options Help

Reset

Run

Pause

T: 0:48:52.1

MB/s: 0.000

MB: 18.8

Decoder

OFF    Full

Offset    Shape

CPU 7%

Disk1 5%

Disk2 80%

Network Info

MAC 00235443CC0D

IP 192.168.0.101

Settings Histograms Decoder info

	E	Z/S	Inv	$\gamma$	$\alpha$	thr	f, kHz
0	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	111	1.195
1	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	111	1.180
3	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
4	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
5	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
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15	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
16	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
17	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
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23	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0

Window, ns

PW

MW

Lat

Cut, ns

L

R

$L \leq dT \leq R$

Fast scope

FFT    OffsetComp    Filter    Averaging



Decoding speed: 390.733 ev/s
ADC16-LTC Firmware ver 1.0.13836 S/N d75c, ver 1.0.13836 S/N e22a 40.4 °C, 37.9 °C

# TANGRA: ADCM Control Panel

ADCM Control Panel

File Setup Statistics Options Help

Reset

Run

Pause

T: 0:48:52.1  
MB/s: 0.000  
MB: 18.8

Decoder

OFF
 Full

Offset
 Shape

CPU 7%

Disk1 5%

Disk2 80%

Network Info

MAC 00235443CC0D  
IP 192.168.0.101

Settings

Histograms

Decoder info

	E	Z/S	Inv	$\gamma$	$\alpha$	thr	f, kHz
0	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	111	1.195
1	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	111	1.180
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18	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
19	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
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22	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0
23	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	111	0

Window, ns

PW -200

MW 500

Lat 300

Cut, ns

L -300

R 300

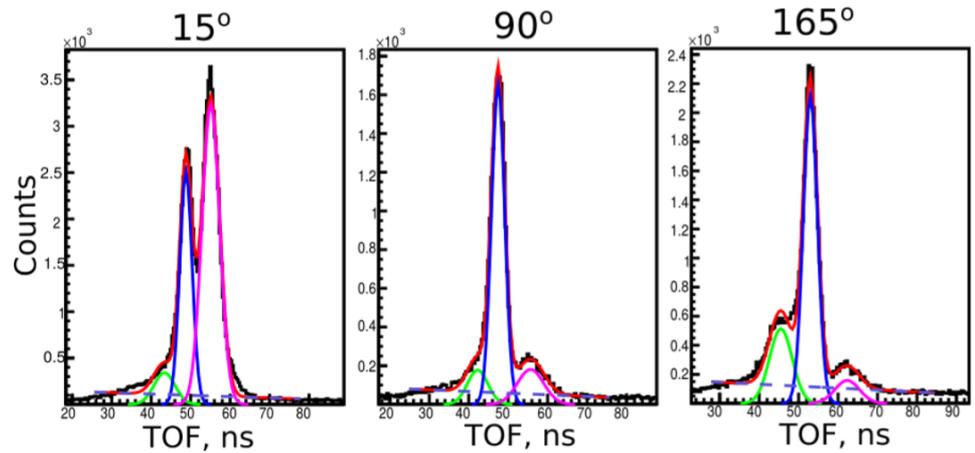
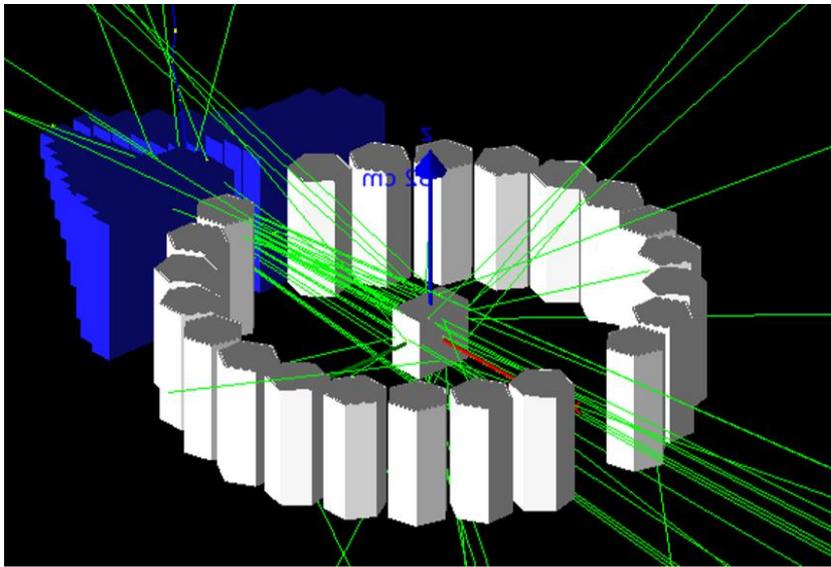
Fast scope

$L \leq dT \leq R$

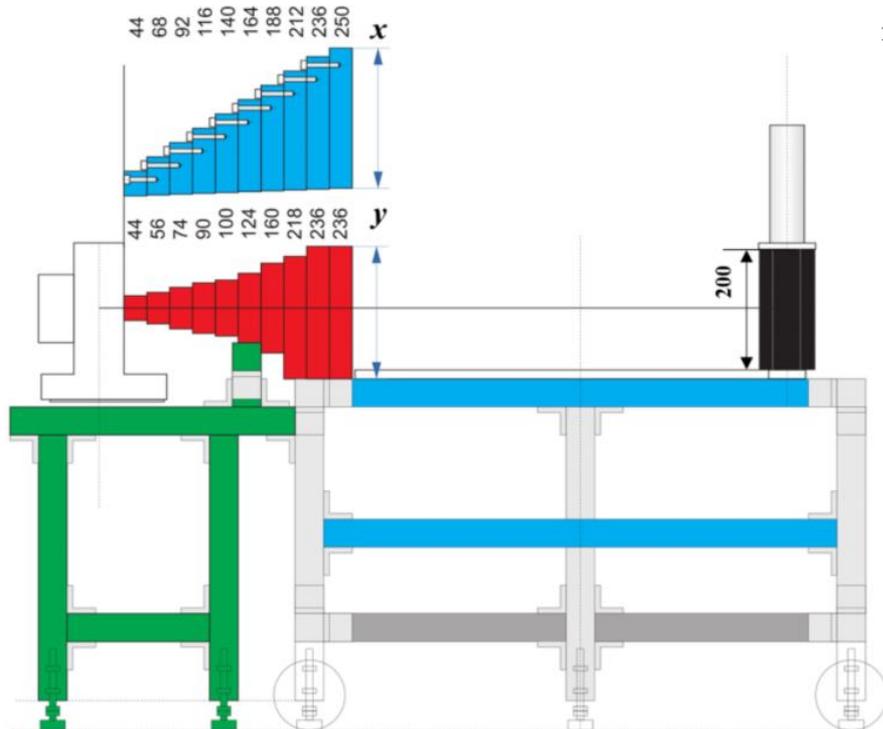
FFT
 OffsetComp
 Filter
 Averaging

Decoding speed: 390.733 ev/s
ADC16-LTC Firmware ver 1.0.13836 S/N d75c, ver 1.0.13836 S/N e22a 40.4 °C, 37.9 °C

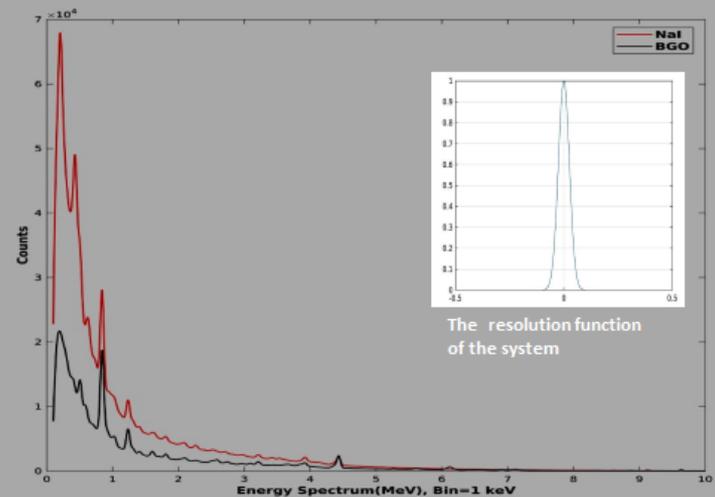
# TANGRA: Setup GEANT4 Simulations



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



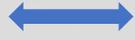
## The Energy Spectra of $\gamma$ -rays



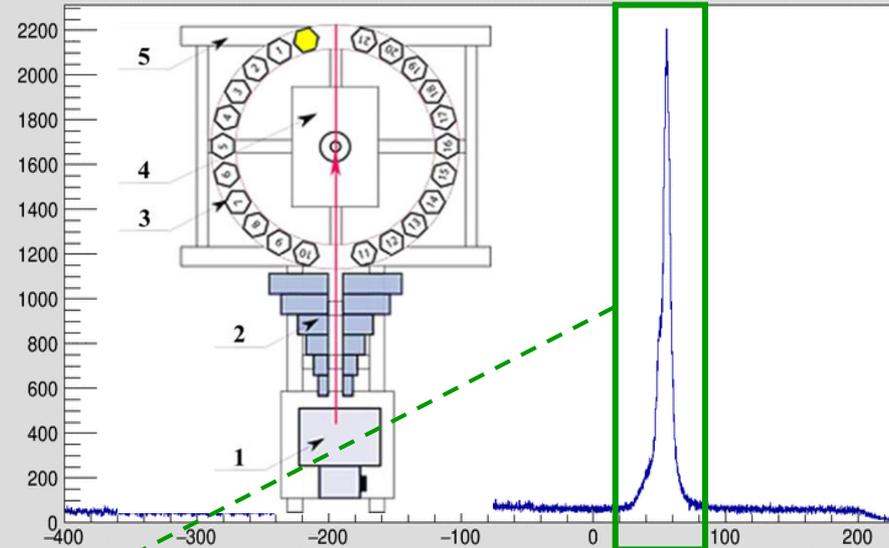
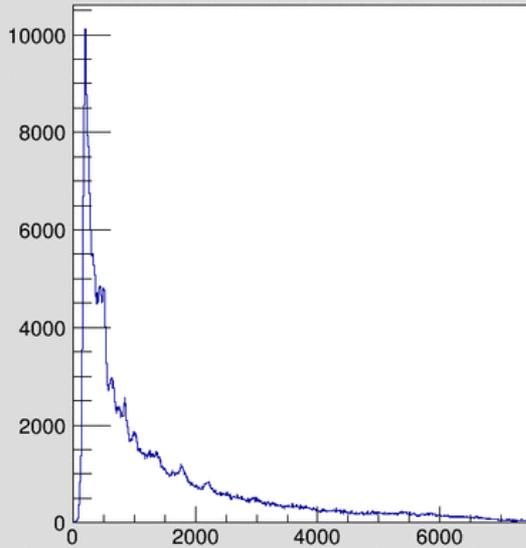
The resolution function of the system

# TANGRA: Experimental Data Analysis (Reduction)

Energy\_ch00 08:47:41

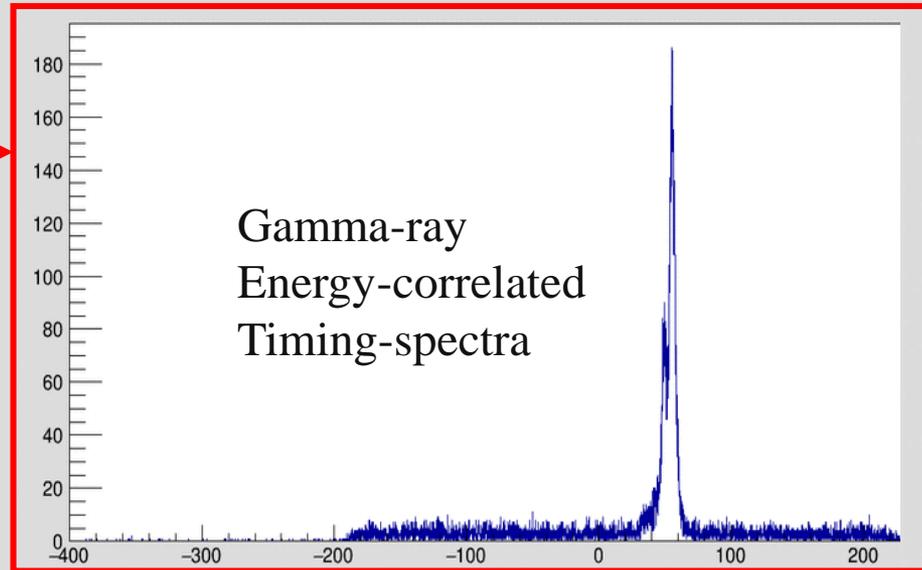
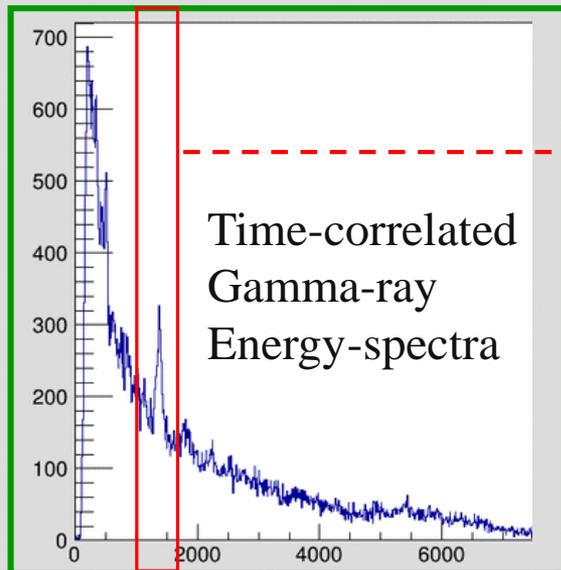


Time\_ch00 08:44:34 2019-04-02 run12\_Mg24.root/Time

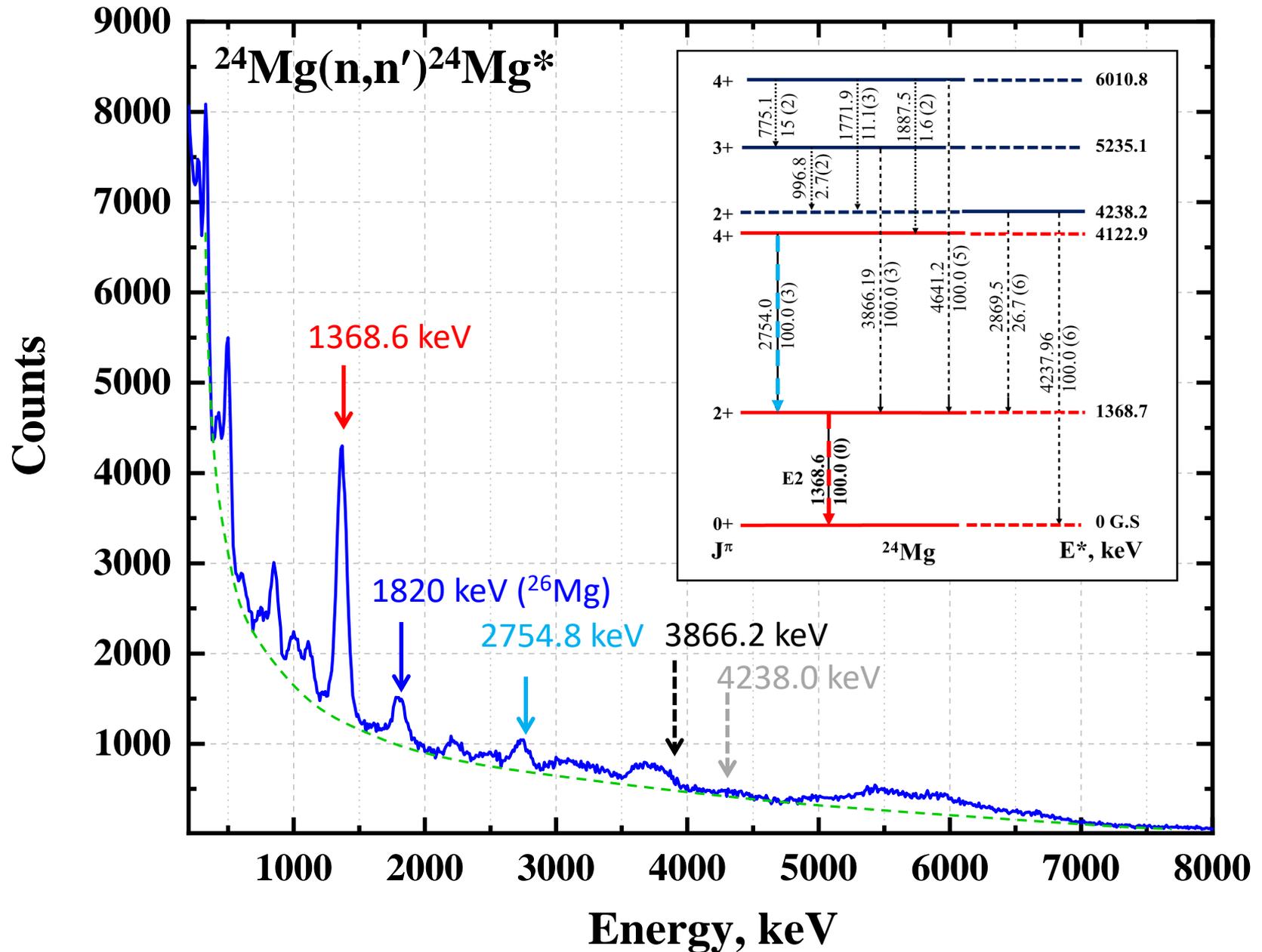


E\_t\_3sig\_ch00 08:47:41

Time\_e\_3sig\_ch00 08:47:41 2019-04-02 run12\_Mg24.root/Time\_e\_3

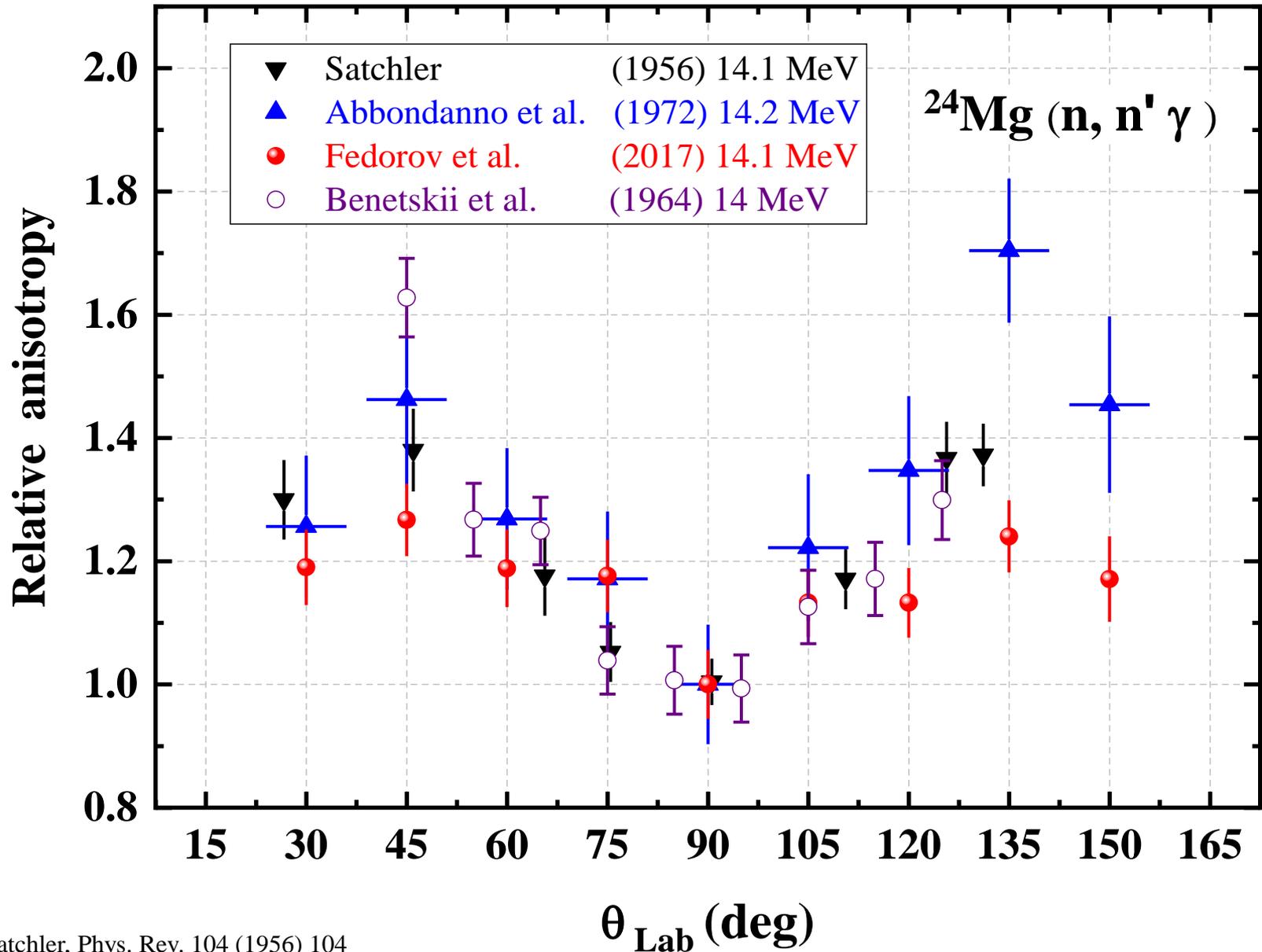


# TANGRA: Gamma-ray Energy Spectrum

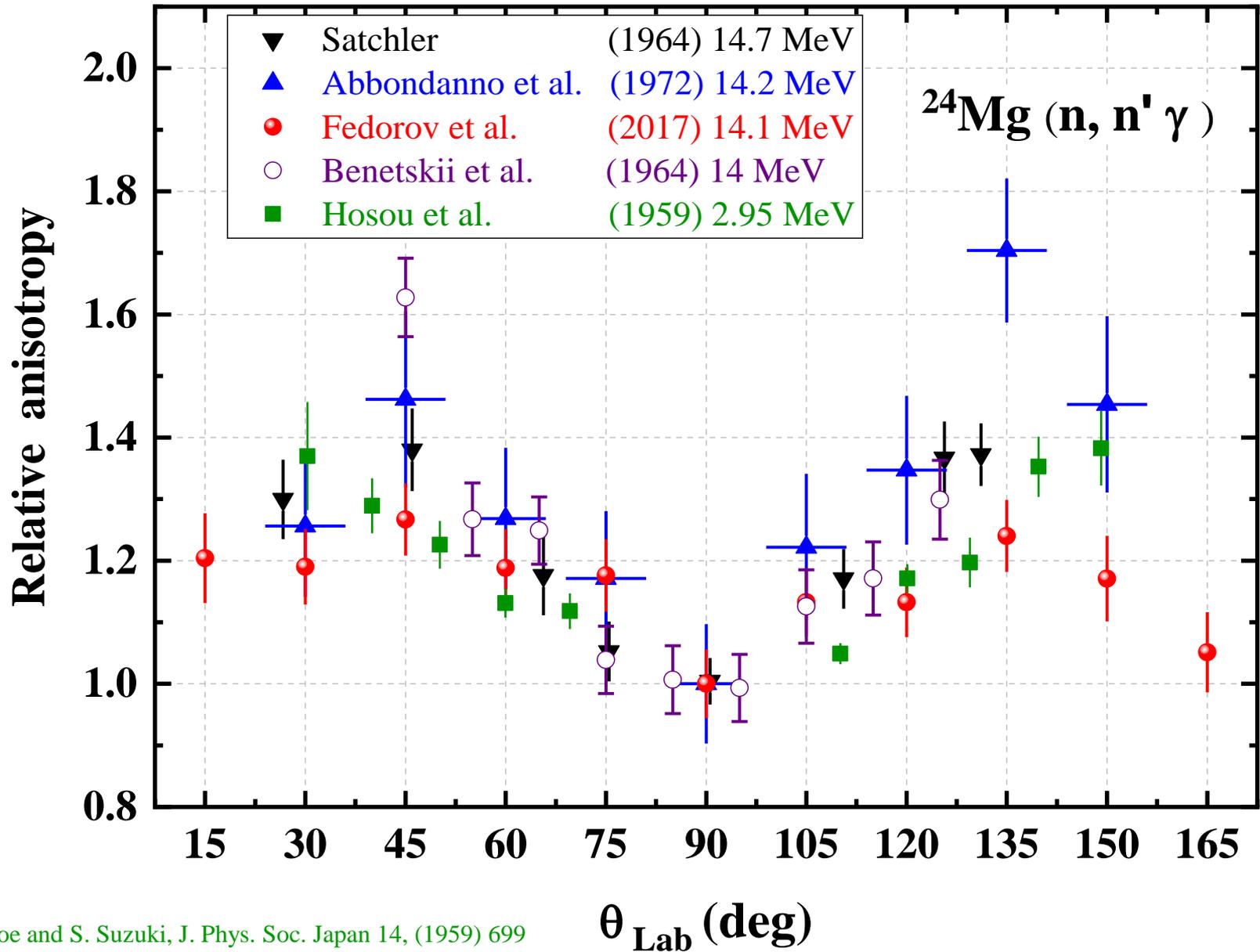


# TANGRA: Gamma-ray Angular Distributions

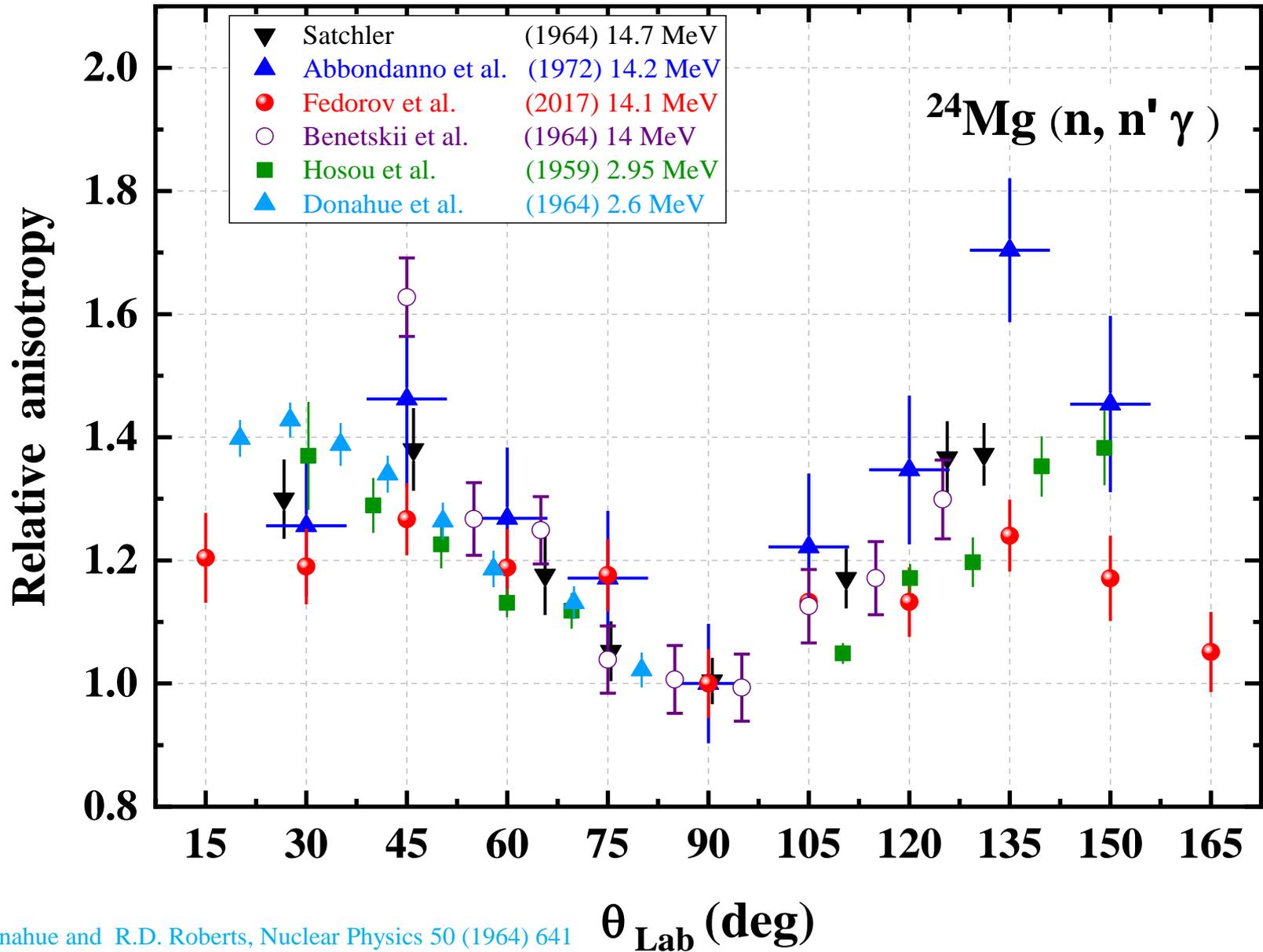
relative to the direction of the incident neutrons are symmetric around  $90^\circ$

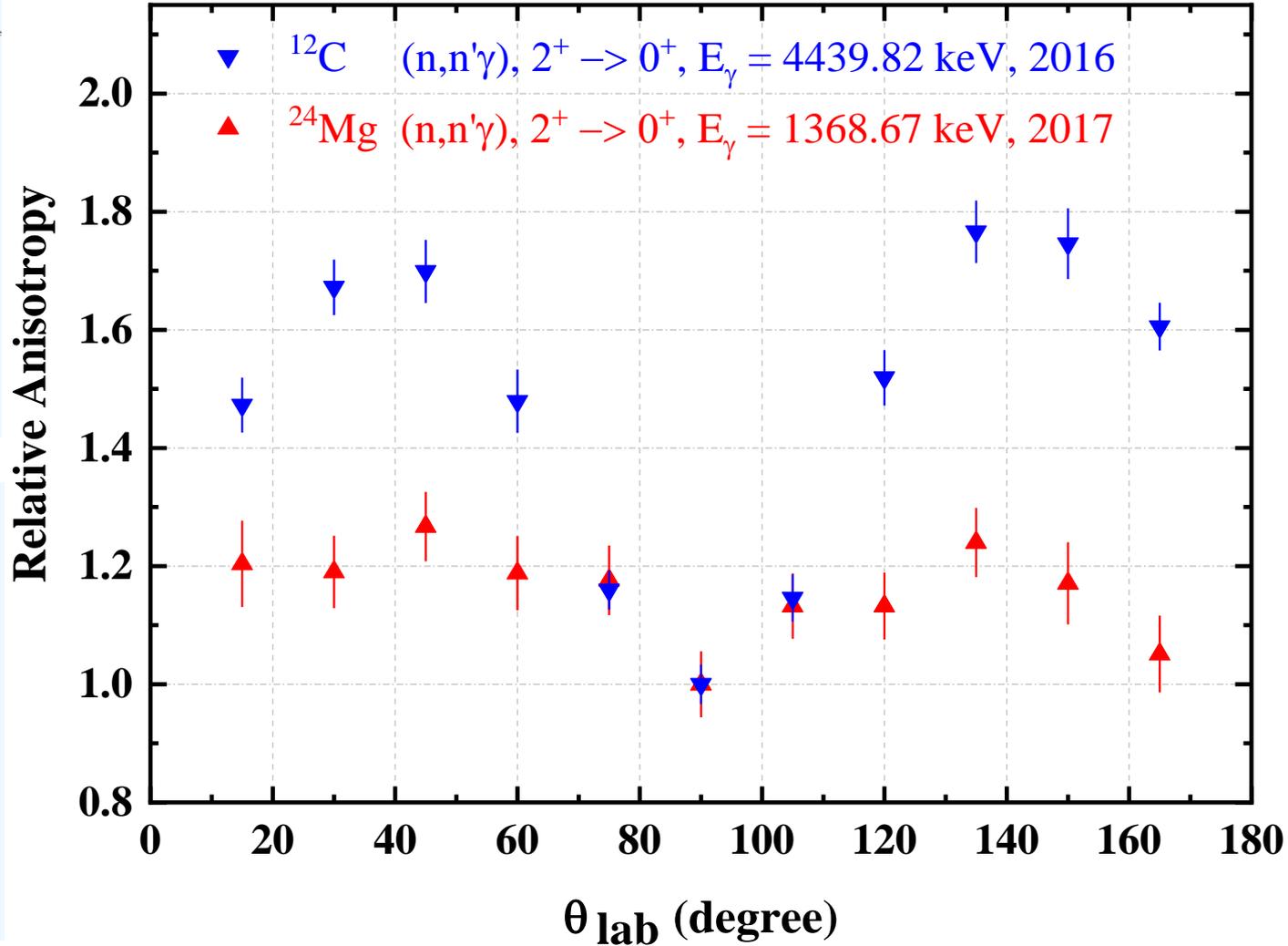
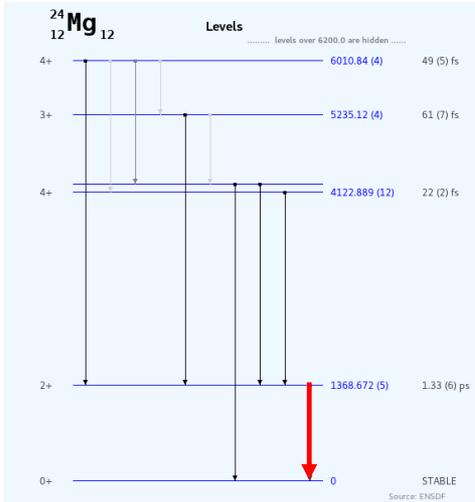
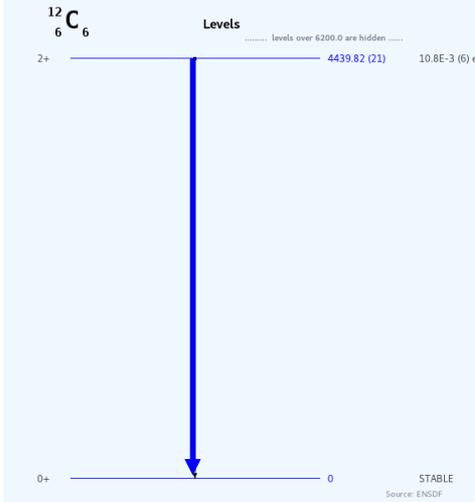


relative to the direction of the incident neutrons are symmetric around  $90^\circ$

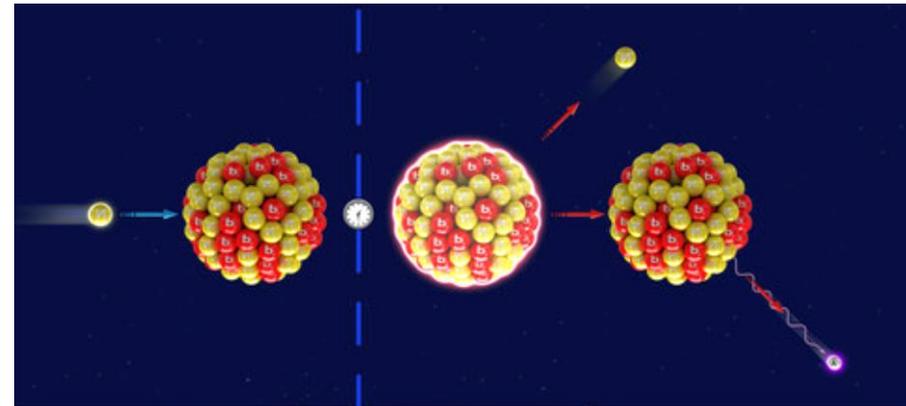
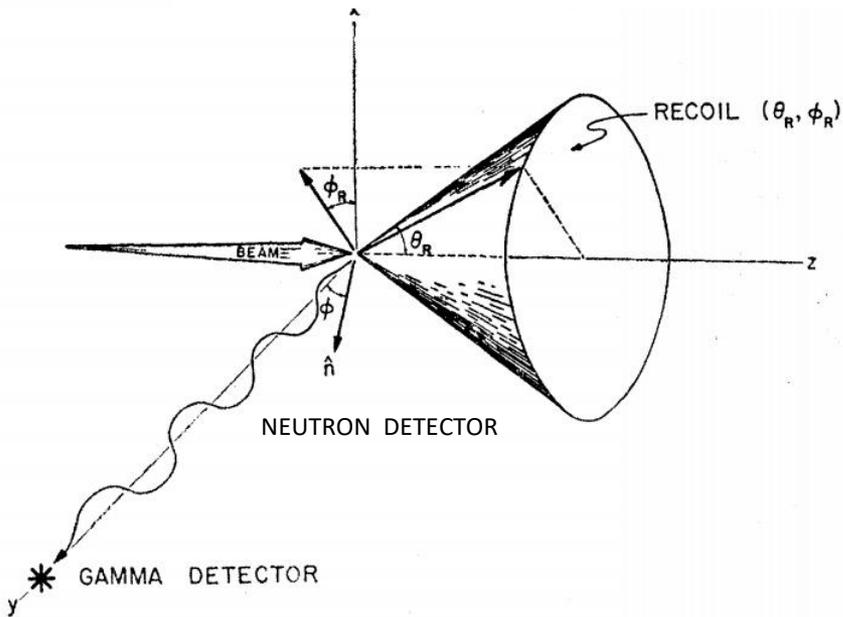
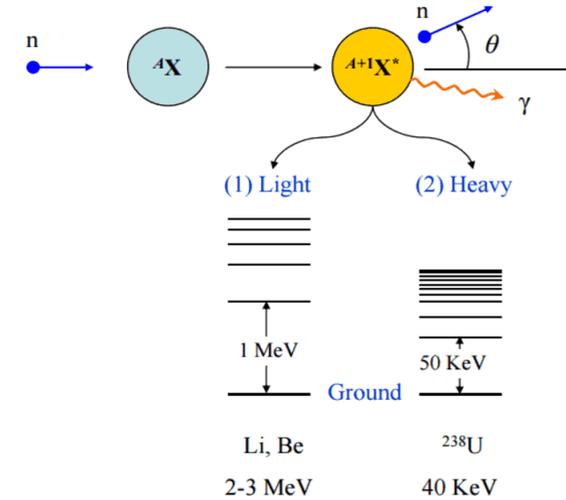
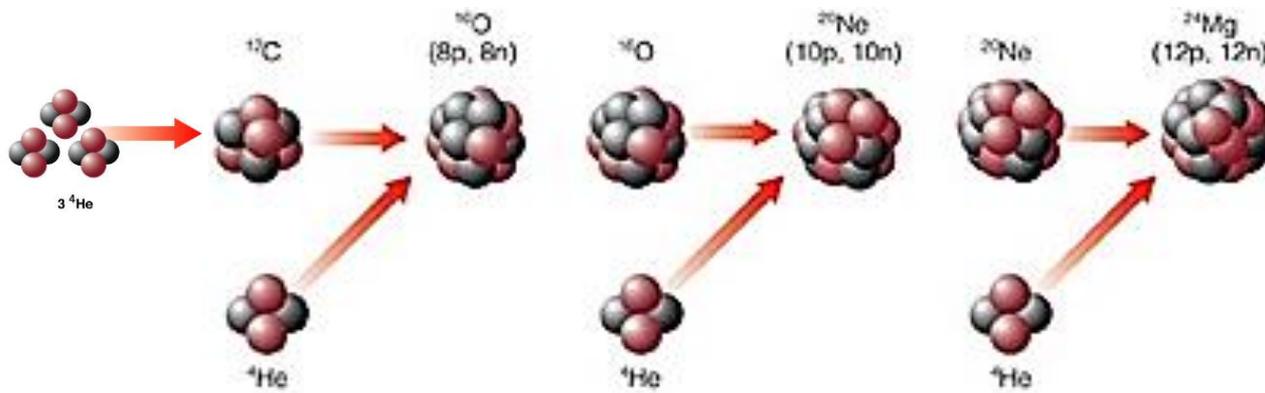
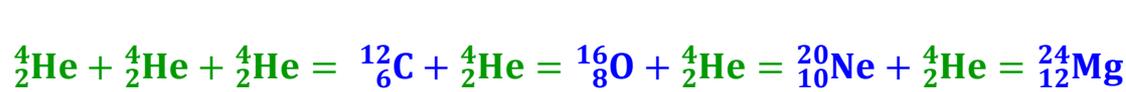


relative to the direction of the incident neutrons are symmetric around  $90^\circ$





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



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



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

#### 1. Inelastic Scattering of 14 MeV Neutrons on Mg<sup>24</sup>

B.A. Benetskii, Yu. P. Betin, Ya. Gonzatko  
JETP, 1964, Vol. 18, No. 3, p. 640

[http://www.jetp.ac.ru/cgi-bin/dn/e\\_018\\_03\\_0640.pdf](http://www.jetp.ac.ru/cgi-bin/dn/e_018_03_0640.pdf)

PDF (420.8K)

#### 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

[http://www.jetp.ac.ru/cgi-bin/dn/e\\_017\\_02\\_0309.pdf](http://www.jetp.ac.ru/cgi-bin/dn/e_017_02_0309.pdf)

PDF (675.7K)

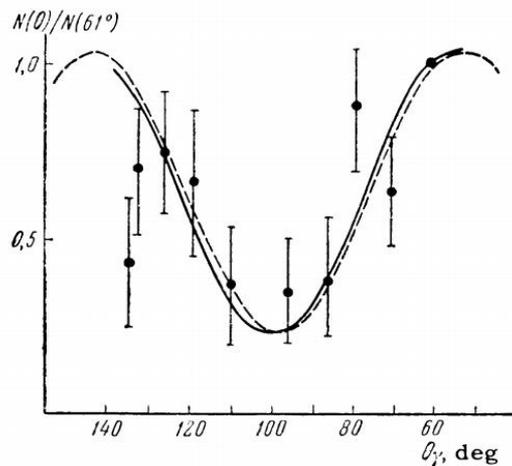


FIG. 4. Angular distribution of 4.4-MeV  $\gamma$ -rays in the reaction  $C^{12}(n, n')C^{12}$  for neutron scattering at the angle  $\vartheta_n = -24^\circ$ . The continuous curve represents the experimental formula (3.1); the dashed curve follows from the theory of direct interactions.<sup>[11]</sup>

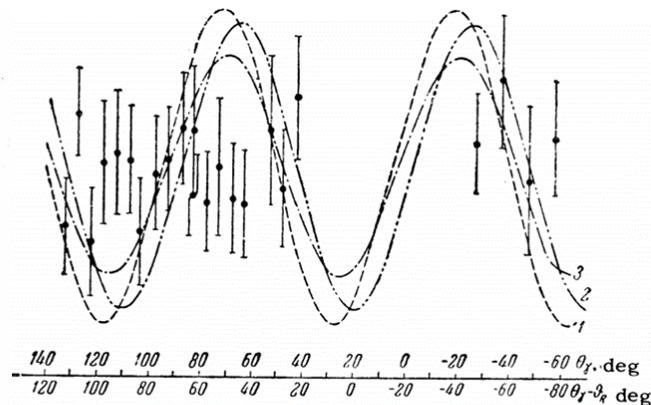
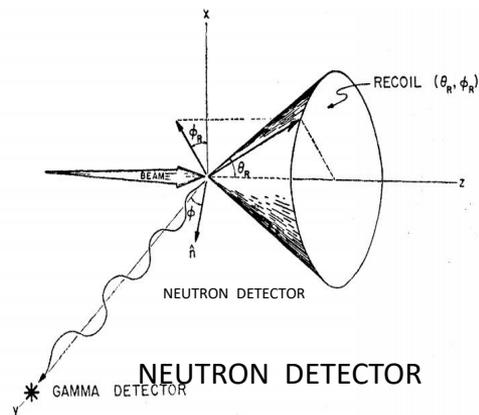
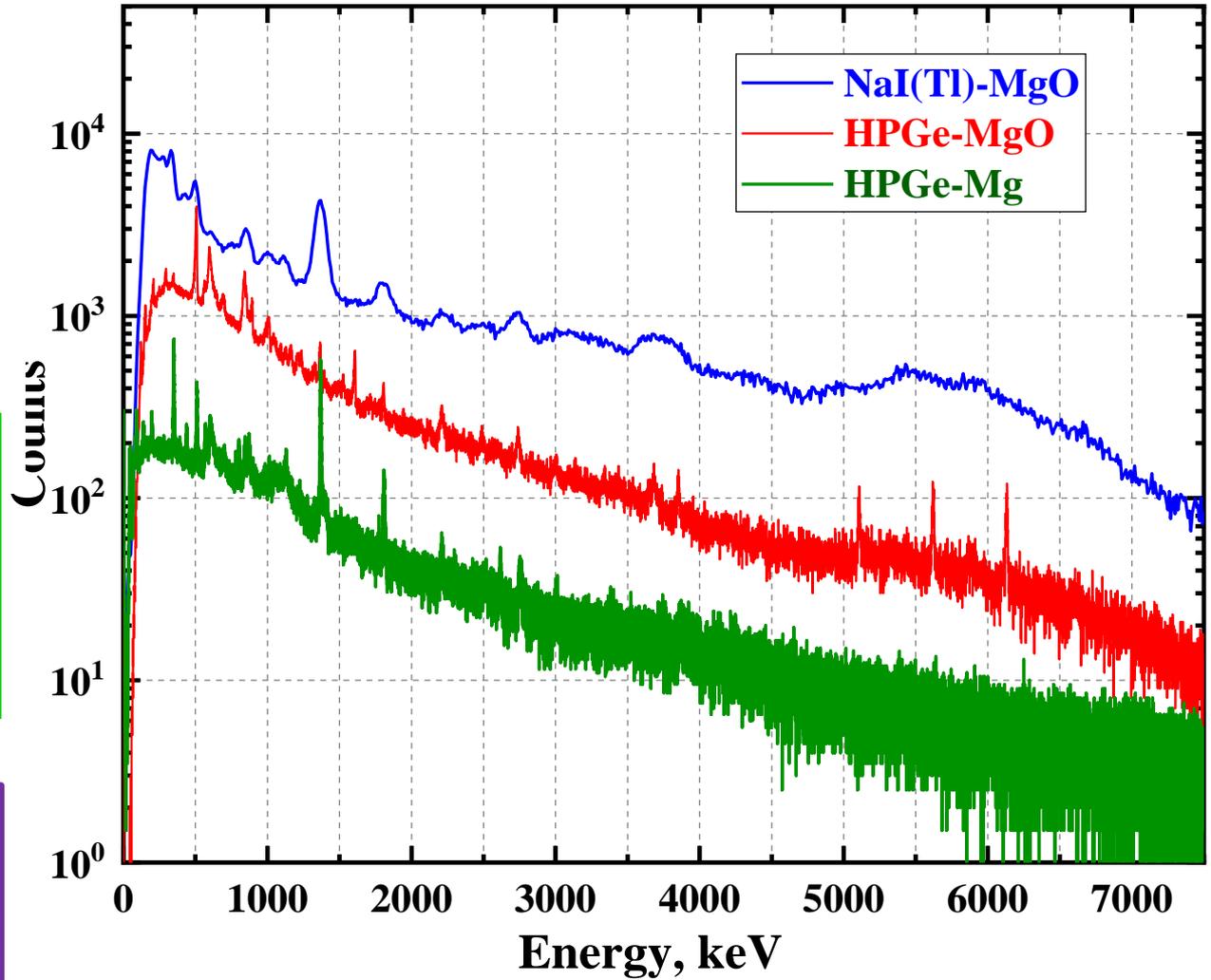
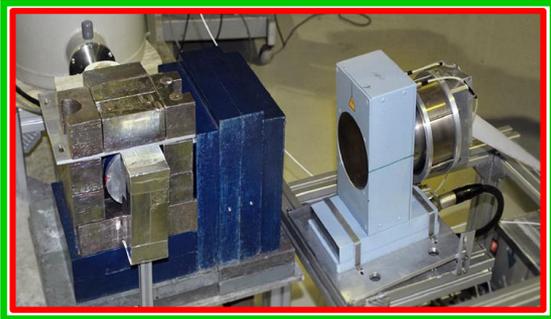


FIG. 6. Angular distribution of 4.4-MeV  $\gamma$ -rays in the reaction  $C^{12}(n, n')C^{12}$  for neutron scattering at the angle  $\vartheta_n = 135^\circ$ . Curve 1 – predicted by direct-interaction theory;<sup>[11]</sup> curves 2 and 3 –  $\gamma$ -ray distribution in the reaction  $C^{12}(p, p')\gamma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

# TANGRA: Comparison of NaI(Tl) and HPGe $\gamma$ -detector systems



Analyzed, to be added

# JINR

# TANGRA

# FLNP

## COLLABORATION

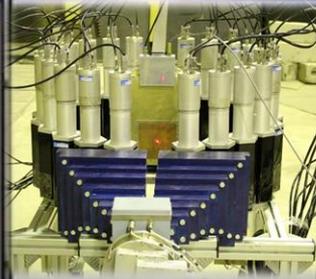
Linx Modular



ING-27 power sup.



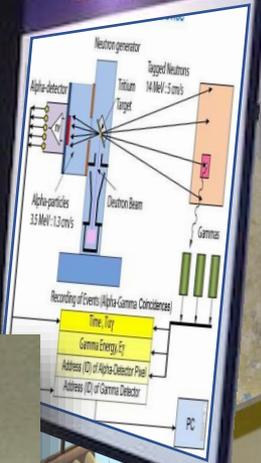
NaI(Tl) Romashka



PC ADCM 32 chan



Linx Modular



Everything is possible  
with a proper team

First observation of ground state  
dineutron decay 14Be

Experimental setup for the study of the ground state  
dineutron decay of  $^{14}\text{Be}$ . The setup includes a  
neutron generator, target, detectors, and a data acquisition  
system. The target is a  $^{14}\text{Be}$  nucleus, which decays into  
an alpha particle and a deuteron. The alpha particle is  
detected by an alpha detector, and the deuteron is  
detected by a gamma detector. The data acquisition  
system records the time, energy, and address of the  
detectors. The results show the first observation of  
ground state dineutron decay of  $^{14}\text{Be}$ .



Thank You Very Much  
For  
Your Attention

