PROGRESS REPORT ON NUCLEAR DATA RESEARCH IN INSTITUTE FOR NUCLEAR RESEARCH (ATOMKI)

HUNGARY

for the period 1 January 2018-1 June 2021 Feb

Document for presenting ATOMKI activities at INDC Meeting (IAEA, 2021)

Nuclear Data Activities at the Institute for Nuclear Research, Hungarian Academy of Sciences (ATOMKI)

Summary

Related research fields

- nuclear reaction data for practical applications
- nuclear spectroscopy and nuclear structure (decay data, excited states, etc)
- nuclear reaction data for astrophysics

IAEA projects

- EXFOR
- Evaluation of cross sections for medical isotope production and CP beam monitoring
- Therapeutic radiopharmaceuticals labelled with new emerging radionuclides (^{67}Cu, ^{186}Re, ^{47}Sc)

- decay data evaluation

Data required

- Upgrade NUDAT
- Extend the list of evaluations on nuclear reactions for production of medical isotopes (PET, SPECT, therapy, CP monitor reactions)
- Upgrade of TENDL

2. Nuclear Data Activities of the ATOMKI Nuclear Reaction Data Group

F. Ditrói, K. Brezovcsik, F. Ditrói, A. Fenyvesi , Z. Kovács, F. Szelecsényi, Z. Szűcs, S. Takács, F.Tárkányi,

(Prepared by F. Tárkányi (2021 March 1)

Introduction

The research program: compilation, evaluation and application of low and medium energy charged particle induced nuclear reaction data in international collaborations (see bellow).

- Systematic experimental study of activation cross sections of proton, deuteron, ^{3}He and α-particle induced reactions for comparison with the results of modern theoretical codes to establish a more reliable experimental database and to prepare of a general use activation file up to 100 MeV protons and 50 MeV deuterons.
- Systematic investigation of nuclear data for production of radioisotopes candidate for use in diagnostic (SPECT and PET) and radiotherapy, not covered by international projects.
- Investigations of nuclear data of new candidate monitor reactions.

- Investigation of nuclear data for thin layer activation technique
- Testing theoretical nuclear reaction model codes

Experimental works and theoretical comparisons

The experiments are done in Debrecen and at cyclotrons of foreign laboratories in the frame of well established long term collaboration, in :

- Cyclotron Laboratory of the Vrije Universiteit Brussel (VUB, Brussels, Belgium)
- Division of Advanced Technology for Medical Imaging of the National Institute of Radiological Sciences (Chiba, Japan)
- Nishina Center for Accelerator-Based Science, RIKEN, Wako, Saitama 351-0198, Japan
- Radionuclide Production Laboratory of the iThemba Laboratory for Accelerator Based Sciences (Somerset West, South Africa).
- Centre de Ressources du Cyclotron, UCL, (Louvain-la-Neuve, Belgium)

In the experiments are also involved co-workers from other foreign institutes:

- Institute of Physics and Power Engineering (IPPE), Obninsk, Russia
- Institute of Nuclear Chemistry (FZ Jülich, Germany)
- Physics Department (Cyclotron Facility), (Nuclear Research Centre, Atomic Energy Authority, Cairo, Egypt)
- Nuclear Data Section, IAEA, Wien A-1400, Austria
- Faculty of Science, Hokkaido University, Sapporo 060-0810, Japan
- Nishina Center for Accelerator-Based Science, RIKEN, Wako 351-0198, Japan
- Graduate School of Biomedical Science and Engineering, Hokkaido University, Sapporo 060-8638, Japan
- Advanced Clinical Research Center, Fukushima Medical University, Fukushima 960-1295, Japan
- Radionuclide Production Group, iThemba LABS, P.O. Box 722, Somerset West, 7129, South Africa

Theoretical calculation of the measured data was done mostly in collaboration with scientist from Institute of Theoretical Physics, IPPE, Obninsk, Russia (ALICE-IPPE, TALYS, EMPIRE codes). We also use our own calculations using the EMPIRE code

Comparison is made in all cases with results from TENDL-2017and 2019 libraries (TALYS, Nuclear Research and Consultancy Group (NRG) Petten, The Netherlands))

Data compilations and evaluations

EXFOR compilations

Our responsibility to compile experimental data of charged particle induced nuclear reactions reported from Debrecen, Brussels and Jülich were compiled in EXFOR format.

In the last 3 years 32 new exfor entry were compiled and 11 entry were revised

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CRP and TC participations

- Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production (2012–2016)
- Therapeutic Radiopharmaceuticals Labelled with New Emerging Radionuclides (^{67}Cu, ^{186}Re, ^{47}Sc) (2016-2019)
- Alternative Radionuclide Production with a Cyclotron", IAEA (in print)

Staff

The staff partly connected to the experimental nuclear reaction data measurement practically did not changed (F. Tárkányi, S. Takács, F. Ditrói, A. Szelecsényi, Z. Kovács, Z. Szűcs, K. Brezovcsik, A. Fenyvesi). Out of them two (F. Tárkányi, S. Takács). Physicists are working also on data compilation and evaluation.

Nuclear data related publications in 2021-2018

Tárkányi F., Ditrói F., Takács S., Hermanne A., Ignatyuk A.V., Spahn, I., Spellerberg S.
I*nvestigation of activation cross-sections of deuteron induced reactions on ruthenium up to 50 MeV*
APPLIED RADIATION AND ISOTOPES 168 Paper: 109401 (2021)

Tárkányi F., Hermanne A. Ditrói F. Takács S. Ignatyuk A. V., Spahn I. Spellerberg S.
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IAEA TECDOC No. 1945 Wien, Ausztria : International Atomic Energy Agency (IAEA) (2021)

Tsoodol Z., Aikawa M., Ichinkhorloo D., Khishigjargal T., Norov E., Komori Y., Haba H., Takács S., Ditrói F., Szűcs Z.
Production cross sections of ^{45}Ti in the deuteron-induced reaction on ^{45}Sc up to 24 MeV
APPLIED RADIATION AND ISOTOPES 168 Paper: 109448 (2021)

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APPLIED RADIATION AND ISOTOPES 168 Paper: 109514 (2021)

Steyn G. F., van der Walt T.N., Szelecsényi F., Perrang C., Brümmer J.W., Vermeulen C., van der Meulen N.P., Motetshwane M.A., van Heerden M.R.
Large-scale production of ^{88}Y and ^{88}Zr/^{88}Y generators: A proof of concept study for a 70 MeV H − cyclotron
APPLIED RADIATION AND ISOTOPES 168 Paper: 109469 (2021)

Hermanne A., Tárkányi F., Takács S., Ditroi F., Ignatyuk A.
Deuteron induced reactions on tellurium: An alternative for production of ^{123}I?
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B-BEAM INTERACTIONS WITH MATERIALS AND ATOMS 466 pp. 20-30. (2020)

Hermanne A., Tárkányi F., Takács S., Ditrói F.
Additional excitation functions for radionuclides obtained by deuteron irradiation of Ta up to 50 MeV
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B-BEAM INTERACTIONS WITH MATERIALS AND ATOMS 481 pp. 82-90. , (2020)

Tárkányi F., Takács S., Ditrói F., Hermanne A., Adam-Rebeles R., Ignatyuk A. V.
Investigation of the deuteron induced nuclear reaction cross sections on lutetium up to 50 MeV: review of production routes for ^{177}Lu, ^{175}Hf and ^{172}Hf via charged particle activation
JOURNAL OF RADIOANALYTICAL AND NUCLEAR CHEMISTRY 324 : pp. 1405-1421. , 17 p. (2020)

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Experimental investigation and theoretical evaluation of proton induced nuclear reactions on nickel
APPLIED RADIATION AND ISOTOPES 159 p. 109094 (2020)

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Production cross sections of ^{169}Yb by the proton-induced reaction on ^{169}Tm
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Update of the IAEA Reference Cross Sections for Chargedparticle Monitor Reactions
In: International Conference on Nuclear Data for Science and Technology Conference Program and abstract book (2019) p. 211

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Measurement of activation cross sections of deuteron induced reactions on natIr in the 17–50 MeV energy range
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B-BEAM INTERACTIONS WITH MATERIALS AND ATOMS 458 pp. 105-117. , 13 p. (2019)

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Tárkányi, F. ; Ditrói, F. ; Takács, S. ; Hermanne, A. ; Ignatyuk, A. V.

Extension of experimental activation cross-sections database of deuteron induced nuclear reactions on manganese up to 50 MeV
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Nuclear Data Activities of the Atomki Nuclear Astrophysics Group

L. Csedreki, Z. Elekes, Zs. Fülöp, Gy. Gyürky, Z. Halász, G.G. Kiss, N.T. Szegedi, T. Szücs
(prepared by Gy. Gyürky, 12 March 2021)

The main task of the nuclear astrophysics group of Atomki is to measure charged particle induced reaction cross sections at low energies relevant for various astrophysical processes. Using the accelerators of Atomki, the following reaction cross sections have been measured (in the given center of mass energy ranges):

- $^{115}In(\alpha,\gamma)^{119}Sb$ 8.8 MeV – 15.6 MeV
- $^{115}In(\alpha,n)^{118}Sb$ 8.8 MeV – 15.6 MeV
- $^{121}Sb(\alpha,\gamma)^{125}I$ 9.7 MeV – 15.5 MeV
- $^{121}Sb(\alpha,n)^{124}I$ 9.7 MeV – 15.5 MeV
- $^{123}Sb(\alpha,n)^{125}I$ 9.7 MeV – 15.5 MeV
- $^{197}Au(\alpha,\gamma)^{201}Tl$ 13.7 MeV – 20 MeV
- $^{197}Au(\alpha,n)^{200}Tl$ 14 MeV – 20 MeV
- $^{197}Au(\alpha,2n)^{199}Tl$ 17.5 MeV – 20 MeV
- $^{191}Ir(\alpha,n)^{194}Au$ 13.5 MeV – 15.5 MeV
- $^{193}Ir(\alpha,n)^{196}Au$ 13.5 MeV – 16.5 MeV
- $^{193}Ir(\alpha,n)^{196m}Au$ 13.5 MeV – 16.5 MeV
- $^{96}Zr(\alpha,n)^{99}Mo$ 6.2 MeV – 12.5 MeV
- $^{3}He(\alpha,\gamma)^{7}Be$ 4.0 MeV – 4.4 MeV
- $^{14}N(p,\gamma)^{15}O$ resonance strengths at E_p = 278keV and 1058 keV

Precise decay half-lives have been measured for the isotopes ^{65}Ga, ^{95}Ru, ^{95}Tc, ^{95m}Tc, ^{125}Cs and ^{125}Xe.

Besides the above measurements carried out at Atomki, some members of the group are involved in experiments at foreign institutions. In the framework of the LUNA international collaboration (Gran Sasso, Italy), the low energy cross sections of the $d(p,\gamma)^3He$, $^6Li(p,\gamma)^7Be$, $^{22}Ne(p,\gamma)^{23}Na$, $^{18}O(p,\gamma)^{19}F$, $^{18}O(p,\alpha)^{15}N$ and $^{23}Na(p,\gamma)^{24}Mg$ reactions have been measured. At GSI, Germany, the cross section of the $^{124}Xe(p,\gamma)^{125}Cs$ reactions has been measured.

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Nuclear structure and decay data activities in the ATOMKI

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Introduction
Study of nuclear structure has been a long-standing research area in Atomki. Therefore, we have been producing new nuclear structure and decay data regularly. Since 2009 we also contribute to the mass-chain evaluation work for ENSDF and compilation work for XUNDL.
Since 2011 Atomki is an evaluation center, which is responsible for the A=101 – 105 mass chains.

Compilation and mass-chain evaluation
Two of us (Z. Elekes and J. Timár) participate part-time in the nuclear structure and decay data compilation and mass-chain evaluation work. At present besides the mass chains of our responsibility, we are still working on temporarily assigned mass chains, too.

During the past three years, we have

- been working on the revision of the A=101 mass chain for publication in Nuclear Data Sheets in collaboration with the Bucarest evaluation centre
- finished the A=105 mass chain evaluation and published it in Nuclear Data Sheets in collaboration with the Sofia evaluation centre

One of us (A. Algora) has been involved in the horizontal evaluation of beta-delayed neutron emission probanilities.

New experimental nuclear structure and decay data
Our research fields related to producing new nuclear structure and decay data are: study of exotic nuclei using radioactive beams, study of exotic shapes, excitation modes and decay of nuclei, as well as study of neutron skin and neutron halo in nuclei. We work on these topics in wide international collaborations using large scale facilities (RIKEN, GANIL, GSI, Gammasphere, Exogam, Jurogam). Our most important results in the past two years are published in the following papers:

Petrache, CM et al. "Evidence of chiral bands in even-even nuclei". *PHYSICAL REVIEW C* 97. (2018).

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