STATUS REPORT ON NUCLEAR DATA ACTIVITY COMPILATION (1999-2002)

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1. List of the co-authors

2. Experimental works
- 2.1. Excitation functions relevant to the production of diagnostic radioisotopes
  - 2.1.1. Positron emitters
  - 2.1.2. Gamma-emitters
- 2.2. Excitation functions relevant to the production of therapeutic radioisotopes
- 2.3. Excitation functions of monitor reactions
- 2.4. Excitation functions for TLA technique
- 2.5. Isomeric ratios

3. Data compilation and evaluation
- 3.1. EXFOR compilations
- 3.2. Charged particle cross-section database for medical radioisotope production: diagnostic radioisotopes
- 3.3. Cross-section database for production of ^{103}Pd from Rh, ^{123,124}I from Te, ^{201}Tl from Tl
- 3.4. Charged particle cross-section database for thin layer activation technique

4. Methodology for measurements and application of nuclear data for practical purposes
- 4.1. Methodical investigations for nuclear data measurement
- 4.2. Investigations in application of nuclear data

5. References 1999-2002

6. References submitted

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2. Experimental works

Cross sections for production of different residual radionuclei induced by low and medium energy light ion beams are important for a variety of applications and of research studies. The experimental data is the basis for applications demanding accurate data and for model calculations to test the capability of the models and to adjust the optimal parameters. During the last years we have continued the systematic measurement of excitation functions of charged particle reactions for many different applications.
These experiments were done at the MGC 20E cyclotron and VdG-5 accelerator in Debrecen and at cyclotrons of foreign laboratories in the frame of well established long term collaboration, in :

- the Institute of Nuclear Chemistry (FZ Jülich, Germany)
- the Cyclotron Laboratory of the Free University of Brussels (VUB, Brussels, Belgium)
- the Cyclotron Radioisotope Center of the Tohoku University (CYRIC, Sendai, Japan)
- the Cyclotron Laboratory of the Abo Akademi (Turku, Finland)
- the Division of Advanced Technology for Medical Imaging of the National Institute of Radiological Sciences (Chiba, Japan)
- the Radionuclide Production Laboratory of the National Accelerator Centre (Faure, South Africa)

The theoretical calculation of the measured data was done in collaboration with scientists from

- Institute of Theoretical Physics, IPPE, Obninsk, Russia
- Lawrence Livermore National Laboratory, Livermore, USA
- China Institute of Atomic Energy, Beijing, China

Bellow we have collected the results published in the period covered. Several other excitation functions of light charged particle induced nuclear reactions on Fe, Cu, Kr, Nb, Mo, Zr, Pd, Te, Ta, Pt and Bi have been also measured and are in evaluation stage.

2.1. Excitation functions relevant to the production of diagnostic radioisotopes

In the field of the production of diagnostic radioisotopes the nuclear reaction data are mostly used to optimise the production circumstances (high yield, minimal impurity level, low cost). The data for the production of major positron and gamma emitters requires validation and additional measurements in selected energy regions. The cross-section database for the newly introduced positron and gamma emitters is very poor. In many cases basic data are missing.

For production of diagnostic radioisotopes used in nuclear medicine during the covered period the following investigations were done.

2.1.1. Positron emitters

- Measurement of the excitation function of $^{18}O(p,n)^{18}F$ reaction in the energy range 3-35 MeV

- Investigation of the production possibility of ^{60,61,62}Cu radioisotopes by alpha induced reactions on cobalt for PET
- Cross section measurements on gas targets relevant to the production of the positron emitting radionuclides ^{14}0 and ^{76}Br
- Remeasurement of the excitation function of ^{nat}Rb(p,xn)^{82,83}Sr up to 70 MeV

2.1.2. Gamma-emitters

- Excitation functions of the ^{68}Zn(p,2n)^{67}Ga and ^{nat}Zn(p,xn)^{67}Ga reactions for production ^{67}Ga
- Cross sections of deuteron induced nuclear reactions on ^{nat}Mo and ^{100}Mo(90%) up to 50 MeV for production of ^{99m}Tc and ^{99}Mo
- Excitation function of the ^{122}Te(d,n)^{123}I nuclear reaction for production of ^{123}I
- Cross section data for production of ^{81}Rb via the ^{80}Kr(d,n) reaction
- Proton induced reactions on ^{nat}Mo: new cross sections for production of ^{99m}Tc and ^{99}Mo isotopes

2.2. Excitation functions relevant to the production of therapeutic radioisotopes

Therapeutic radioisotopes are playing an emerging role in nuclear medicine. There is a long list on radioisotopes either routinely used or undergoing research investigations. Due to the long half-life the production requires high flux reactors and high intensity accelerators. The knowledge of production data is essential to optimise the production circumstances under complicated circumstances. The database in the field of the neutron-induced reactions is more or less acceptable. In the field of charged particle reactions the situation is more complex. Here in most of the cases either no experimental data are available or only contradicting data sets were published, except a few well-measured reactions. During last years we have intensified our investigations on the measurements of nuclear data related to this field.

- Activation cross section of the ^{186}W(d,2n)^{186}Re reaction for production of ^{186}Re
- Production cross section of ^{103}Pd and characterisation of contaminants in the deuteron irradiation of ^{103}Rh
- Excitation functions of proton induced nuclear reactions on^{103}Rh. Production of ^{103}Pd up to 28 MeV

2.3. Excitation functions of monitor reactions

The importance of the monitor reactions is well known in the field of neutron and charged particle induced reactions. They are broadly used both in irradiations for practical applications and for basic research. We extended the list of the charged particle monitor reactions. We have tried to validate the existing database for series of reactions with integral measurements. We made dedicated irradiations under identical circumstances to produce consistent data sets and to make intercomparison of the different monitor reactions. The main published results:

- Monitoring of alpha-beam properties by the $^{nat}Ti(\alpha,x)^{51}Cr$ reaction.
- Investigation of ^{3}He-induced reactions on natural Ti for nuclear analytical studies and beam monitoring.
- Experimental study of excitation functions for some reactions induced by deuterons (10-50 MeV) on natural Fe and Ti.
- New data on the $^{nat}Cu(\alpha, X)^{66}Ga$, $^{nat}Cu(\alpha, X)^{67}Ga$ and $^{nat}Cu(\alpha, X)^{65}Zn$ monitor reactions.
- Deuteron monitor reactions on Al, Ti, Fe, Ni and Cu.
- Alpha beam monitoring via ^{nat}Cu+alpha processes in the energy range from 40 to 60 MeV.
- New cross-sections and intercomparison of proton monitor reactions on Ti, Ni and Cu.
- Proton beam monitoring on Cu via $^{nat}Cu(p,x)^{58}Co$ reaction in medium energy range.

2.4. Excitation functions for TLA technique

The thin layer activation technique is an important field of application of the charged particle reactions. It is used to follow quantitatively the wear, the corrosion or the erosion process by detection of the loss of the radioactive material during the investigated industrial or biological process. The nuclear data are inevitable important to optimise the activation and to follow wear process. The investigated tools are constructed mostly from metals. Some reactions, therefore, are common with the monitor reactions, considering that the targets for monitor are also metal due to the required physical properties.

- Alpha particles up to 42 MeV on ^{nat}Ti forTLA.
- Investigation of deuteron induced nuclear reactions on niobium.
- Investigation of ^{3}He-induced reactions on natural Ti for TLA.
- Excitation functions for reactions induced by deuterons (10-50 MeV) on natural Fe and Ti.
- TLA with alpha particles on Cu.
- Nuclear data for the $^{nat}Ti(p,x)^{48}V$ nuclear process.
- New data and evaluation of ^{3}He induced nuclear reaction on Cu.

2.4. Isomeric ratios

The investigation of the formation of isomeric pairs has special interest in basic studies of the mechanism of the nuclear reactions and of the nuclear structure. In the ongoing experiments significant information have been collected on the population of isomeric states, but the data evaluation and the model calculation are still in progress. The isomeric ratios have been measured for the following reactions:

Nb(α,xn)Tc
Mo(p,xn)Tc
Mo(d,xn)Tc
Kr(p,xn)Rb
Kr(d,xn)Rb
Pd(p,xn)Ag

Pt(p,x)Au
Pt(d,x)Au
W(p,x)Re
W(d,x)Re
Ta(α,xn)Re

3. Data compilation and evaluation

3.1. EXFOR compilations

In the frame of collaboration of the Nuclear Reaction Data Centers the following compilation were made with assistance of the IAEA NDS:

- 97 “short” entrees for CRP on medical radioisotopes
- 35 entrees mostly from ATOMKI and FZ Jülich

3.2. Charged particle cross-section database for medical radioisotope production: diagnostic radioisotopes

Medical application of nuclear technology is very important for every country. A project was started at 1996 with co-ordination of the IAEA to produce recommended cross-section data base for charged particle induced reactions relevant to production of radioisotopes used for medical diagnostic and for related reactions to monitor beam parameters. The database contains 86 reactions. In the reported period, two members ATOMKI group have been participated in the following work:

- Finalisation of the database.
- Preparation of the TECDOC.
- Preparation of the Web page.
- Updating and corrections.

3.3 Cross-section database for production of ^{103}Pd from Rh, ^{123,124}I from Te, ^{201}Tl from Tl

In the production process of medical radioisotopes the so called "targetry" plays very important role. For standardisation of high intensity solid targets a co-ordinated project was initiated by the IAEA: "Standardised High Current Targets for Production of Diagnostic and Therapeutic Radionuclides". The project deals with all aspects of the production of ^{103}Pd, ^{123,124}I and ^{201}Tl radioisotopes by using Rh, Te and Tl targets including yields, radionuclidic purities, and radiation dose from the targets and from the backings. The production requires reliable cross section database for the main and the unwanted parallel reactions taking place on realistic target composition. Compilation and evaluation have been started for the participating stable isotopes of targets and for the backing materials:

- About 40 proton and deuteron induced reactions on isotopes of Te.
- 2 reactions on Rh.
- 3 reactions on Tl.
- Reactions on Pt, Ir, Cu, Rh.

3.4. Charged particle cross-section database for thin layer activation technique

To deduce depth-activity curves either new measurement has to be done on the investigated material or knowledge of the nuclear reaction data and of the elemental composition are required. The detailed measurements are very time consuming; therefore in most cases it is more fruitful to obtain the activity distribution with calculation and to perform checking and validation only at few points with more simple experiments. Unfortunately presently no evaluated cross section database exists for thin layer activation studies. In an earlier co-ordinated project a preliminary cross-section database was reported for TLA applications. In the database the reported calibration functions and integral yields are based on direct measurements and mostly on excitation functions obtained in the literature. We have found large disagreement in several cases between our recently measured integral yields and the data sets reported in the mentioned database. Therefore for practical use in the ATOMKI an independent database for TLA is under development by using evaluated cross section data. Presently it contains p, d, ^{3}He and alpha-particle induced reactions up to 30-40 MeV on the following elements:

Al, Ti, Fe, Ni, Cu, Zn, Zr, Nb, Mo, Rh, Pd, Cd, W, Ta, Pt

4. Methodology for measurements and application of nuclear data for practical purposes

At the Cyclotron Department in the ATOMKI the nuclear data measurement and the data evaluation is performed only in part time. The members of the department have an every day task in the field of routine radioisotope production for medical and other purposes, in irradiations for wear measurement and for charged particle activation analysis. In connection with the nuclear data measurements and with the application it was necessary to perform several methodical investigations:

4.1. Methodical investigations for nuclear data measurement

- Gas density reduction by using gas targets.
- Measurement of energy averaged cross section and integral yields by using thin targets.
- Determination of charged particle beam energy/intensity uncertainties at a multi-target irradiation.

4.2. Investigations in application of nuclear data

- Applications of small energy cyclotrons for thin layer activation technique.
- The use of cross section data for monitoring charged particle beam parameters.
- Accelerators used for routine production of PET radioisotopes.
- Determination of activation curves on the basis of excitation functions.

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