RESEARCH ACTIVITIES BASED ON SMALL ACCELERATORS IN VIETNAM

Nguyen Van Do, Tran Duc Thiep
Department of Nuclear Physics , National Institute of Physics
P.O.Box 429 Boho, Hanoi 10000 Vietnam

Abstract

Neutron generator (NA-3C) and Electron Accelerator (Microtron MT-17) have been put into operation since 1974 and 1982 in the Institute of Physics , Hanoi. The neutron generator produces 14 MeV neutrons with total yield of 10^{10} n/s . The Microtron accelerator produces both fission neutrons and bremsstrahlung with maximum energy of 15 MeV . These facilities have been exploited in both fundamental and applied nuclear physics research. The main research activities were focused on the fields of nuclear data, nuclear reactions and fissions as well as nuclear analytical methods. In this report we present some results obtained during the recent years and discuss about the main interests in our future work and the possibilities of regional collaboration .

1 INTRODUCTION

Up to now , there are two small accelerators in Vietnam . They are located in the Institute of Physics of the National Centre for Natural Science and Technology of Vietnam .

The Neutron generator (made in Hungary) operates with an accelerating voltage of 120 kV and produces 14 MeV neutrons via the $^3T(D,n)^4He$ reaction with yield of about 10^{10} n/s .

The Microtron MT-17 (made in Dubna, Russian) is possible to accelerate electron beam of up to 18 μA and produces both bremsstrahlung photons with maximum end point energy of 15 MeV and fission neutrons with total out put of about 10^{11} n/s . The bremsstrahlung photons are produced in channel 56^o by bombarding electron beam into a tungsten (W) target :

e^- ----> W ----> bremsstrahlung

and the fission neutrons are produced in channel 0^o with the aid of two converters : tungsten and uranium (U) :

e^----->W---->bremsstrahlung----> U----> fission neutrons

Neutrons and bremsstrahlung photons from NA-3C and MT-17 facilities have been used since many years. In the experimental studies the activation techniques in combination with gamma spectrometric methods were used . The single gamma spectrometer consists of a high purity germanium (HPGe) detector and a multichannel pulse - height analyzer interfaced to a PC for data processing. The total and photo peaks efficiencies of the detector were determined experimentally by use of the single line gamma standard sources with diameter of 20 mm [1] . The gamma-gamma coincidence spectrometer consists of HPGe-NaI(Tl) detectors and coincidence unit (built up in our laboratory) and other electronic modules. The resolving time of the system is 0.1 μs [2] .

Based on available radiation sources and measuring equipments we have focused our research activities into the following directions : nuclear data , nuclear reactions and fissions as well as nuclear analytical methods . In this report we will summarize some our results obtained during the last years.

2 RESEARCH ACTIVITIES

2.1 Study of nuclear data

2.1.1 Measurement of 14 MeV neutron reaction cross sections [3,4,5,6,7]

As we know, Nuclear data are of considerable importance for testing nuclear models and for practical applications , especially in fusion reactor technology.

In Vietnam, we have carried out measurements of 14 MeV neutron induced reaction cross-sections since 1980. Based on available experimental conditions a conventional activation method was used. The advantages of the activation method are : simplicity, high sensitivity and it is possible to distinguish between (n,x) and (n,n'x) process since they lead to different activation products .

The nuclear reaction cross-sections can be determined using the well-known activation equation . In practice , sample and standard (with well-known cross section value of the reference reactions) having disk-shaped with a diameter of 20 mm were irradiated and their activities measured under identical conditions. From the ratio of the counted activities it is easy to calculate the cross section of the investigated reaction . In order to improve the accuracy of the experimental results the following necessary corrections have been made :

Corrections for the time variation of the neutron flux during the irradiation.

Corrections for the measured activities, namely for random pile-up, for full energy peak efficiency , for branching ratio, for self-absorption , for cascade coincidence and dead-time.

Corrections for interference reactions.

In the framework of a coordinated Research Programme on " Measurement and analysis of neutron activation cross sections around 14 MeV " supported by the International Atomic Energy Agency, measurements of (n,p), (n,n'p) and (n,α) cross sections induced by 14 MeV neutrons on Cr and Ti isotopes were carried out . Some typical cross sections measured with our neutron generator are given in table 1.

2.1.2 Evaluation of Nuclear data by systematic [8,9]

Sometimes the nuclear data needed are not directly determined by measurements due to specific experimental difficulties . So, beside experimental measurement it is necessary to evaluate nuclear data by theoretical calculations or nuclear sytematics . In our case, reaction cross sections induced by 14 - 15 MeV neutrons have been analyzed on the basis of available data taken from the literature using the multiple regression technique . The dependence of (n,p) and (n,2n) reaction cross sections on some nuclear parameters was investigated. For the (n,p) reactions the following empirical formula was proposed :

$$Lg(\sigma_{n,p}) = a_o + a_1N + a_2Z + a_3(N\text{-}Z)/A^{1/3} + a_4B_n + a_5B_p$$

Where N and Z are neutron and proton numbers, (N-Z)/A is asymmetry factor and A=N+Z, B_n and B_p are neutron and proton binding energies . a_i (i=0,1,2,...5) are fitted parameters . For the (n,2n) reactions , threshold parameter (E_f) was also taken into account [8].

In order to check the validity of the proposed formulas the (n,p) reaction cross sections of 247 isotopes were calculated . The data obtained by using Levkovski's [10], Eder's [11] and our formula are compared with those of measurement [12]. The differences between the experimental values and those of other authors are calculated . These deviations are collected into 20 groups with intervals of 5% . The comparison shows that in 52% of all cases our formula gives the best approximation. Eder and Levkovski obtained the best approximation in 26% and 22% of the cases; respectively . The distribution of the deviations between experimental and calculated values can be seen in Fig.1.

2.1.3 Measurements of isomeric cross section ratios [13,14]

Isomeric ratios R furnish valuable information about the energy level structure of nuclei and the nuclear reaction mechanism involved.

The isomeric cross section ratio was defined usually as the ratio of the cross section for the production of a metastable state (σ_m) relative to that of ground state (σ_g) , namely R=σ_m/σ_g . In some work it is also defined as the ratio of high to low spin state yield production. In case of bremsstrahlung irradiation, due to the energy spectrum is continuous , isomeric cross section ratio can be interpreted as follow :

$$R = \int_{E_{th}}^{E_{\max}} N\phi(E)\sigma_m(E)dE \,/ \int_{E_{th}}^{E_{\max}} N\phi(E)\sigma_g(E)dE$$

Where N is the number of target nuclei, ϕ(E) is the incident bremsstrahlung flux, E_{max} is the maximum bremsstrahlung energy, E_{th} is the threshold energy, σ_m and σ_g are the cross sections for the metastable and the ground states, respectively. Some typical isomeric yield ratios determined via (n,2n) reactions (induced by 14 MeV neutrons) and (γ,n) reactions (induced by bremsstrahlung with maximum end point energy of 15 MeV) are listed in table 2.

2.2 Nuclear fission studies [15,16,17,18,19,20,21]

The fission process occupied a unique place in the development of nuclear physics. It represents the most dramatic rearrangement of nuclear matter.

We started our studies with photofission . It is a powerful tool for the investigation of the fission process due to the well-known properties of the electromagnetic interactions .

Our studies were focused on the mass and charge distributions . Measurement of mass and charge distributions of fission products helps in understanding the delicate interplay between the macroscopic aspects of nuclear matter and the quantal effects of a finite number of fermions and provides an invaluable testing ground for many body theories of large amplitude collective nuclear motion.

Mass distribution are obtained from measurements of cumulative yields of fission products . Charge distributions are obtained from primary or independent yields of individual fission products . In the measurements the direct gamma spectrometric method was used. By using this method , from one irradiation the yields of many mass chains among which there are many yields from short - lived nuclides can be measured simultaneously. Furthermore, the samples were counted several times and more than one gamma line were used in yields determinations wherever possible .

Due to the complexity of the measured gamma spectra in order to get accurate energy and intensity of the gamma peaks , good spectrum analysis programmes and deep experiences are needed . After correcting the measured intensities of the gamma peaks for detector efficiencies , the decay curves are analyzed . Photofission products are identified based on their half-lives and gamma ray energies. Chain yields are determined from a number of the chains that give measurable activities .

In practice , fission of ^{238}U and ^{232}Th induced by bremsstrahlung from MT-17 accelerator has been investigated. Thorium samples of 15 mg/cm^2 pure thorium and Uranium sample of 18 mg/cm^2 U_3O_8 enriched to 99.6% prepared on 0.5 mm thick pure aluminum disk with a diameter of 20 mm were irradiated. The electron beam current was 15 μA with a stability better than 5% . The gross gamma spectra of irradiated samples were measured using high energy resolution gamma spectrometers. For low energy region , from 3 keV to about 1000 keV a thin planar HPGe detector with a resolution of 165 eV /FWHM/ at 5.9 keV and in the region from 60 keV to about 2500 keV a 63 cm^3 HPGe detector with a resolution of 2.1 keV at 1332 keV of ^{60}Co were used. The measuring time was varied depending on the half-lives of the products of interest .

Up to now , in photofission of ^{238}U , 19 independent yields and 62 cumulative yields of fission products were determined by measuring some hundreds gamma lines . These fission products are the members of 33 chains in the mass number region from 78 to 151 . The fine structures in the mass regions 133-135 and 140-142 were observed. The mass distribution curve can be seen in Fig.2. In addition, the independent yields of three isomeric pairs ^{128m,g}Sb, ^{132m,g}I, and ^{135m,g}Xe were also obtained . The charge distribution for the mass chains 95 ; 97; 99; 128; 130; 131; 132; 134; 135; 138; 140 and 141 were determined. The fractional yield data are consistent with a Gaussian curve :

$$Y_i = (\pi c)^{-1/2} \exp[-(Z-Z_p)^2/C]$$

where Y_i is the fractional independent yields of a chain number having atomic number Z and Z_p is the most probable charge and C is the width parameter of the distribution . The value of C obtained from a weighted average of the several chains is 0.94 ± 0.08 .

In case of ^{232} Th , 7 independent yields , 34 cumulative yields and 28 mass chains in the mass number region from 88 to 149 were obtained.

Beside experimental work , the mass distributions of fission fragments for a wide range of nuclides from ^{232}Th to ^{258}Fm were computed using the modified statistical theory .

2.3 Application and development of activation analysis method

Activation analysis is one of the widely used analytical methods because it is sensitive, nondestructive and a large number of elements in the samples can be determined simultaneously .

In our laboratory for irradiations the 14 MeV neutrons as well as fission neutrons and bremsstrahlung radiations were used. In most cases , neutrons and photons are considered to be complementary each with its strengths and weaknesses. A lot of the proposed analytical procedures have been successfully used for routine analysis of various kinds of sample.

2.3.1 14 MeV neutron activation analysis [22,23,24,25]

14 MeV neutron activation analysis method has been used for the determination of the elements having large reaction cross sections and short half-lives such as aluminum , silicon and iron (in bauxite), nitrogen (in Soya beans and rice) and fluorine (in fluorite ores). In the analysis , the following nuclear reactions were used :

^{27}Al(n,p)^{27}Mg (σ=81 mb,$T_{1/2}$ = 9.5 min ; E_γ = 0.84 MeV)
^{28}Si(n,p)^{28}Al (σ=235 mb,$T_{1/2}$= 2.31 min ; E_γ=1.78 MeV)
^{56}Fe(n,p)^{56}Mn(σ=103mb,$T_{1/2}$=154.56min;E_γ= 0.85 MeV)
^{14}N(n,2n)^{13}N (σ=5.70 mb,$T_{1/2}$=9.96 min; E_γ=0.51 MeV)
^{19}F(n,p)^{19}O(σ=14.3 mb,$T_{1/2}$ =0.48 min; E_γ= 0.136 MeV)

2.3.2 Thermal neutron activation analysis [26]

Fission neutrons from MT-17 accelerator can be slowed down to the thermal level by use of paraffin moderator. Thermal neutron activation analysis is very sensitive method for a large number of elements such as Mn, In, Au, U and Dy ... Under typical conditions, the sensitivity of the analysis of gold in geological samples based on ^{197}Au(n,γ)^{198}Au nuclear reaction ($T_{1/2}$ = 2.7 d, E_γ = 411.8 keV) is about 0.1 ppm.

2.3.3 Photon activation analysis [27,28,29,30]

In photon activation analysis , the principal photonuclear reaction used is (γ,n). Other reactions that are useful , albeit less often are (γ,p) and (γ,γ‘). The sensitivity of the analysis is about 10 to 0.1 ppm for a large number of elements . Specially , this method is successfully used in routine activation analysis of Sn, W and Au in geological samples using the following photonuclear reactions :

^{124}Sn(γ,n)^{123m}Sn ($T_{1/2}$ = 39.5 min ; E_γ = 159 keV)
^{186}W(γ,n)^{185m}W ($T_{1/2}$ = 1.6 min ; E_γ = 174 keV)
^{197}Au(γ,n)^{196}Au ($T_{1/2}$ = 6.18 d ; E_γ = 355.7 keV)

Usually, in the analysis relative method was used . However , in specific conditions the following modified classical methods such as cumulative method, internal standard method and standard addition method have also been applied. Furthermore, in order to improve the sensitivity of the analysis mixed photon - neutron activation method was applied . In this case , the radioactive products $^{A+1}$X are formed from both the ^{A}X (n,γ) and $^{A+2}$X(γ,n) reactions . For Cd and Sn the sensitivity of the analysis using ^{115}Cd (formed via ^{114}Cd(n,γ)^{115}Cd and ^{116}Cd(γ,n)^{115}Cd reactions) and ^{123m}Sn (formed via ^{122}Sn(n,γ)^{123m}Sn and ^{124}Sn(γ,n)^{123m}Sn reactions) isotopes were improved by factors of 2 and 10 , respectively.

In order to improve the accuracy of the analysis , counting losses and fine interferences corrections have also been taken into account.

3 CONCLUSION

Neutron generator NA-3C and Microtron accelerator MT-17 are the first accelerators put into operation in Vietnam. These facilities are comparatively inexpensive, easy to install and operate. Therefore they are rather suitable for the developing countries like Vietnam in the beginning period of nuclear physics research.

The main limitations of our facilities are low intensities and their energies can not be changed . However, in practice these difficulties should be overcome by selection of the best experimental procedures and more attentions have been paid for data processing and all necessary corrections.

Although our accelerators are relatively modest, but with experienced researchers they have effectively been exploited for different fields of experimental nuclear physics research as well as for training young physicists.

Under the conditions of lack in experimental facilities and limited availability of funds, in order to improve the research capabilities we have focused our attentions for the improvement of measuring equipments and look for some collaborations where we should use advanced facilities . We think in developing countries it is difficult to do nuclear physics research without collaborations . Therefore , we hope that KEK will become one of the centres like CERN in ASIA where physicists from Asia-Pacific region will be able to use advanced experimental facilities .

4 REFERENCES

[1] Nguyen Van Do, Nguyen Duy Thang, Nguyen Khac Thi : Communications in Physics, Vol.4, No.4 (1994)182-185

[2] Nguyen Van Do, Nguyen Khac Thi, Pham Duc Khue, Le Hong Khiem, Nguyen Duy Thang : Communications in Physics , Vol.5, No.4(1996)14-19

[3] Hoang Dac Luc, Phan Nhu Ngoc, Nguyen Van Do, Ly Ba Bach :

- Proceeding of the International Symposium on Fast Neutrons in Science and Technology, Chiang Mai, Thai Lan, 4-8 February(1985)163-166.
- INDC(VN)-4/GI, July 1985.

[4] Hoang Dac Luc, Phan Nhu Ngoc, Nguyen Van Do, Ly Ba Bach : INDC(VN)-5/G1, September 1986 .

[5] Ly Ba Bach, Nguyen Van Do, Phan Nhu Ngoc : Scientific Communications of the National Centre for Scientific Research of Vietnam , No.1(1987)24-28.

[6] Ly Ba Bach, Phan Nhu Ngoc, Nguyen Van Do : Progress in Scientific Research, National Centre for Scientific research of Vietnam , No.2(1988)5-12.

[7] Ly Ba Bach : Ph.D. Thesis, Hanoi 1993.

[8] Le Hong Khiem, Nguyen Van Do, Pham Duc Khue, Ly Ba Bach : J.Radioanal. Nucl.Chem., Letters ,Vol.212, No.3(1996)197-208 .

[9] Le Hong Khiem, Nguyen Van Do, Pham Duc Khue: J.Radioanal. Nucl.Chem., Letters, Vol. 231, No.1,2(1998)

[10] V.N. Levkovski, Sov : J.Nuclear Physics, 18/4(1973)705

[11] G.Eder, G.Winkler, P.Hille : Z.Physik, 253(1972)335

[12] Cross Sections of Neutron Induced Threshold Reactions . Handbook, Energoizdat, 1982

[13] Hoang Dac Luc, Tran Duc Thiep, Truong Thi An, Phan An : Bulgaria J.Phys. 14(1987)152-156.

[14] Tran Duc Thiep, Nguyen Van Do, Nguyen Tuan Khai, Truong Thi An, Nguyen Ngoc Son : Communications in Physics, Vol.6, No.3(1996)29-32.

[15] Tran Duc Thiep, Nguyen Van Do, Nguyen Ngoc Son, Truong Thi An, Nguyen Tuan Khai : Communications in Physics, Vol.5, No.1(1995) 2-12

[16] Nguyen Van Do,Nguyen Ngoc Son : Communications in Physics , Vol.5, No.1(1995)22-29.

[17] Nguyen Ngoc Son, Nguyen Van Do, Tran Duc Thiep, Truong Thi An, Nguyen Tuan Khai : Proceeding of the First Vietnam National Conference on Nuclear Physics and Technique, Hanoi 14-15 May(1996), 99-101.

[18] Nguyen Van Do, Tran Duc Thiep, Nguyen Tuan Khai, Nguyen Ngoc Son, Truong Thi An : Communications in Physics, Vol.5, No.1(1996)27-32.

[19] Nguyen Van Do, Tran Duc Thiep, Nguyen Tuan Khai, Truong Thi An, Nguyen Ngoc Son : Communications in Physics, Vol.6, No.2(1996)1-4 .

[20] Nguyen Ngoc Son : Ph.D. Thesis, Hanoi 1996 .

[21] Thierens, H. etal : Phys. Rev. C14(1976)1058

[22] Nguyen Van Do, Nguyen Tat To : Reprint of the Institute of Geophysics, No.2(1980)45-51

[23] Hoang Dac Luc, Truong Thi An, Nguyen Van Do: Scientific Communications of the National Centre for Scientific Research of Vietnam, No.1(1984)24-28 .

[24] Dao Nhat Thien : Diploma Thesis, Hanoi 1988.

[25] Nguyen Van Do : Communications in Physics, Vol.2, No.3(1992)17-20.

[26] Nguyen Van Do, Tran Duc Thiep, Truong Thi An, Ly Ba Bach, N. T. Khai, D. N. Thien, Tr. V. Vuong: Communications in Physics , Vol.2, No.3(1992)65-69

[27] Nguyen Van Do, Tran Duc Thiep, Truong Thi An, Tran Minh Duc, Han Ngoc Cuong : J. Radioanal. Nucl. Chem. Letters,Vol.107, No.1(1988)29-37 .

[28] Nguyen Van Do : J. Radioanal. Nucl. Chem. Letters, Vol.107, No.1(1988)39-47.

[29] Nguyen Van Do, Tran Duc Thiep, Truong Thi An : Bulgarian Academy of Science, Communications of the Department of Chemistry. Vol.20, No.3(1987)401-406.

[30] Nguyen Van Do, etal : J. Geology, Geological Survey of Vietnam , Vol.A, No.(212-213) 9-12/1992, P.63-67.

Table1: Some typical reaction cross sections induced with 14 MeV neutrons

Nuclear reaction	Cross-section (mb) This work	Cross-section (mb) References
$^{52}Cr(n,p)^{52}V$	81.5±6.2	80±6; 94±10
$^{53}Cr(n,p)^{53}V$	45.7±3.1	48±7; 40±7
$^{54}Cr(n,p)^{54}V$	14±2	18±3; 15±4
$^{53}Cr(n,n'p)^{52}Cr$	14±3	12±3; 7.3±0.6
$^{54}Cr(n,n'p)^{53}V$	6.5±1.5	3±0.8; 1.53±0.14
$^{46}Ti(n,p)^{46m}Sc$	56±4	55.0±2.2; 48±8
$^{47}Ti(n,p)^{47}Sc$	103±10	169.5±6.9; 116±14
$^{48}Ti(n,p)^{48}Sc$	60±4	71.7±2.6; 53±6
$^{50}Ti(n,p)^{50}Sc$	17±4	15.4±0.6; 12±2
$^{24}Mg(n,p)^{24}Na$	173.5±8.46	181±8; 179±5
$^{90}Zr(n,p)^{90m}Y$	11.9±0.8	8±1; 9± 0.8
$^{64}Zn(n,2n)^{63}Zn$	179±15	200±23; 175±30
$^{100}Mo(n,2n)^{99}Mo$	1489±86	1418±175; 1420±150
$^{90}Zr(n,2n)^{89m}Zr$	131±7	143.4 ±7.8; 130±12
$^{90}Zr(n,2n)^{89}Zr$	796±53	763±10; 832±4
$^{87}Rb(n,2n)^{86m}Rb$	515±51	547±57; 559±17
$^{87}Rb(n,2n)^{86g}Rb$	875±105	821±82; 789±67
$^{87}Rb(n,2n)^{86}Rb$	1390±117	1395±139; 1307±107
$^{54}Cr(n,\alpha)^{51}Ti$	12.5±1.5	10.63±0.46; 15.0±1.6

Table 2 : Some typical isomeric yield ratios determined via (n,2n) and (γ,n) reactions :

Nuclear reaction	Isomeric yield ratios	
	Induced by 14 MeV neutron	Induced by 15 MeV bremsstrhlung
$^{142}Nd(n,2n)^{141m,g}Nd$	0.46 ± 0.04	
$^{142}Nd(\gamma,n)^{141m,g}Nd$		0.022 ± 0.002
$^{144}Sm(n,2n)^{143m,g}Sm$	0.70 ± 0.06	
$^{144}Sm(\gamma,n)^{143m,g}Sm$		0.031 ± 0.003
$^{110}Pd(n,2n)^{109m,g}Pd$	0.41 ± 0.03	
$^{110}Pd(\gamma,n)^{109m,g}Nd$		0.060 ± 0.005

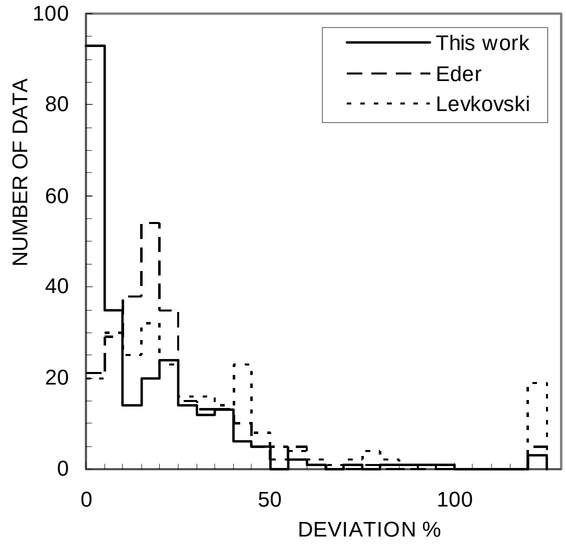

Fig.1 : Distribution of the relative difference between experimental and theoretical cross sections .

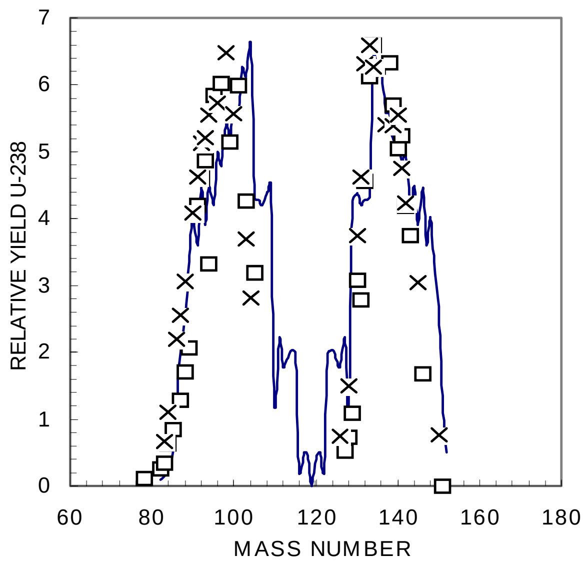

Fig.2 : Mass-yied curve for photofission of ^{238}U (• calculation; □ this work; x taken from ref.[21])