A study of pre-equilibrium emission in some proton induced reactions: Measurement of cross-sections

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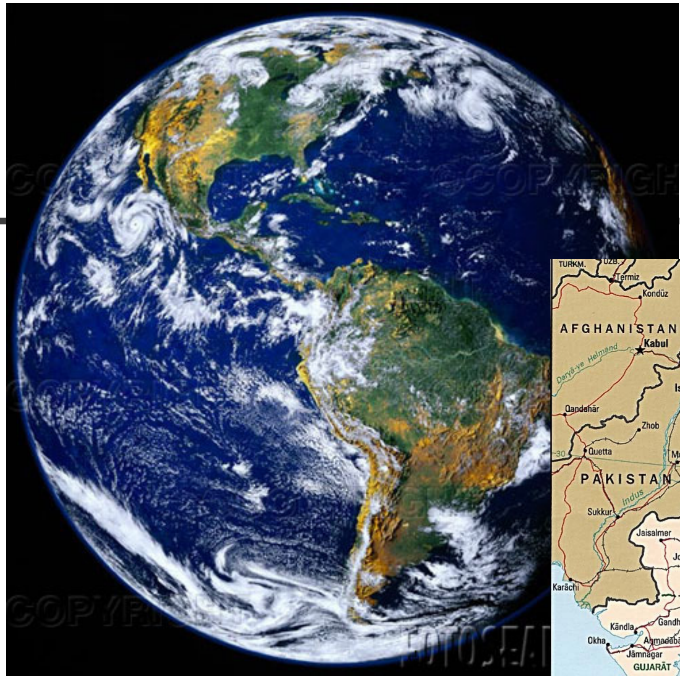


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AFGHANISTAN
PAKISTAN
CHINA
NEPAL
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Arabian Sea
Bay of Bengal
INDIAN OCEAN

A.M. University

M. Azad Lib.

Faculty builds.

Plan of talk……….

- Introduction….
- Experimental details….
- Results and discussion….

A M University, Aligarh, INDIA

Experimental Nuclear Physics

Discovery of neutrons - 1932

nuclear structure and reaction mechanism

cross-sections measured

Cock-croft Walton accelerator-1960

An indigenous machine

(n,p) reactions

Prof. H.S. Hans
Prof. R.Prasad
Prof. C.S. Khurana
Prof. I.M. Govil
&
others

A major turning point in the study of basic science and technology

Development of nuclear reactors → Estimate of nuclear reaction cross-sections

Reactor design cross-section data ↔ Accurate measurements are needed

Cross-section data

Proton & alpha
induced reactions

Wide range of
energy and target nuclei

Reliable data base
to test the
capability of codes

Accelerator Driv... ...itical reactors

Enlarged th...
research b...
neutrons and ga...

...cles

A programme of measurement and analysis of excitation functions for a large number of reactions induced by protons and α-particles has been undertaken.

cross-section data → Spallation neutron source for ADS system.

Work done using……

- Proton and
- Alpha-particle beams

Variable Energy Cyclotron Centre (VECC), Kolkata, INDIA

Reaction cross-sections measurements

Activation technique

Unique decay mode-specific way of its identification and measurement.

- Several activities of different reactions may be produced in an irradiated sample.
- Cross-sections for several reactions can, therefore, be measured in the same irradiation.
- In activation technique - the analysis some times becomes complicated due to interfering reactions.
- Simple and accurate.

Several types of reactions are possible with energetic protons or alpha-particles

- Since, enough energy may be imparted to the particle to penetrate the Coulomb barrier while leaving the nucleus.

- Generally speaking, higher the energy of the incident particle the larger is the number of reactions possible.

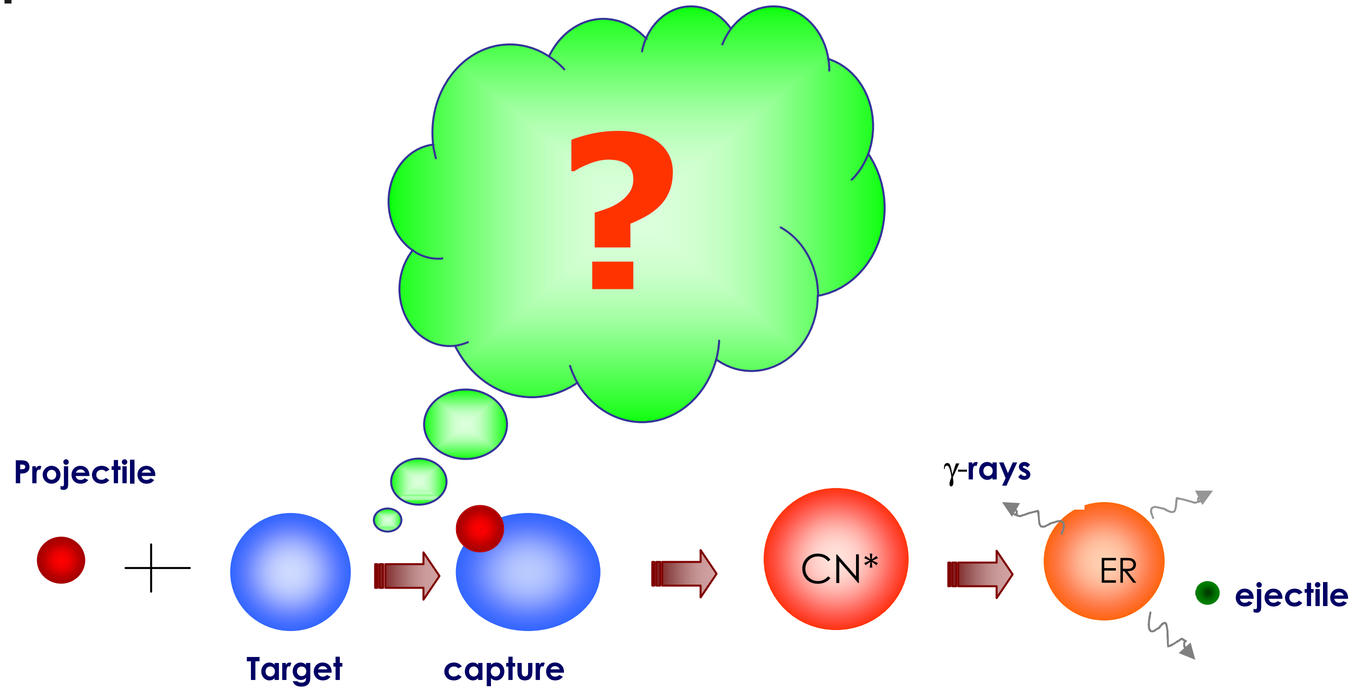
At still higher energies "Spallation" occurs i.e., several particles are split off from the target nucleus.

- The "Spallation" process may be used to create more and more neutrons, which may cause fission of the heavier elements.

- This is basically the concept, which may be used in the accelerator driven sub-critical reactors to generate energy.

(Carlo Rubbia; Yacin Kadi; ………….)

In a typical nuclear reaction……….!



EFs for all possible reactions – Difficult to measure

- Measured cross-section - Validity of nuclear reaction models.

- The compound nucleus model was successfully verified.

- However, at higher energies - the experimental data were, in general, not in agreement with the theoretical calculations done using statistical models.

- Pre-equilibrium emission

Characteristics of PE-emission

- Forward peaked angular distribution of emitted particles

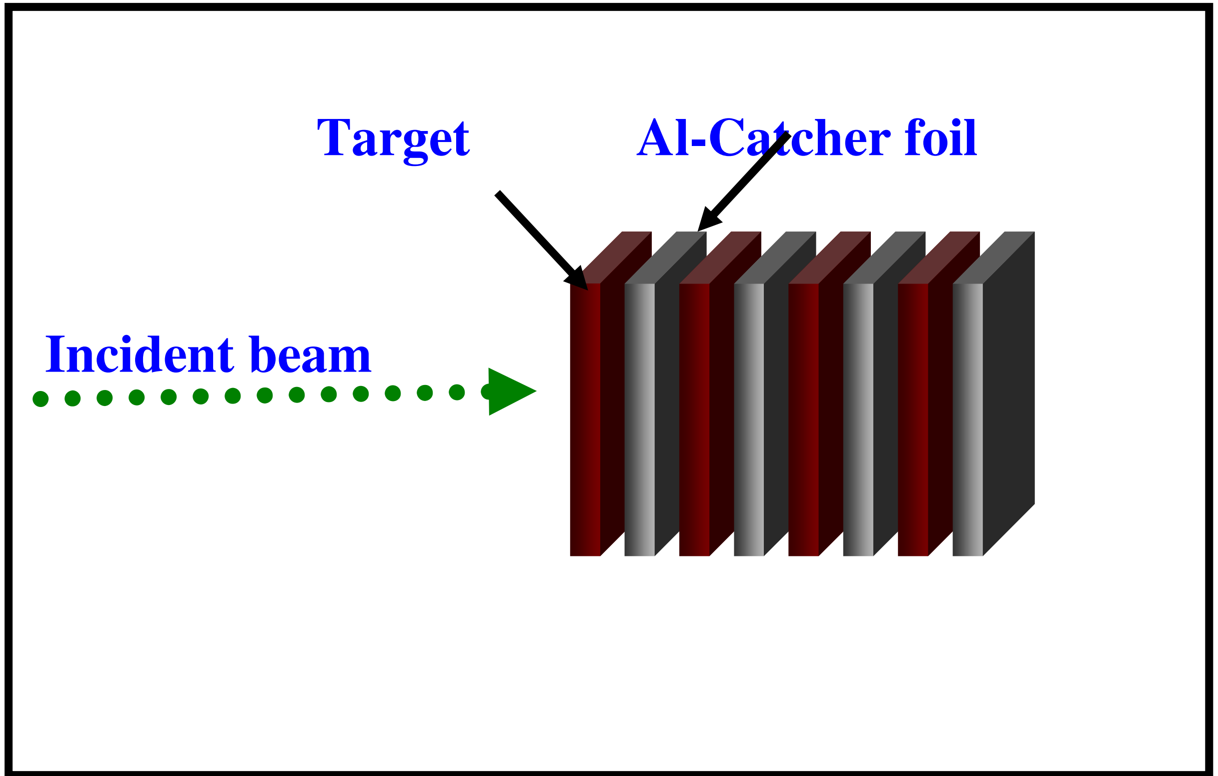
- Emission of large number of high energy particles than predicted by CN model

- Slowly descending tails of the EFs,

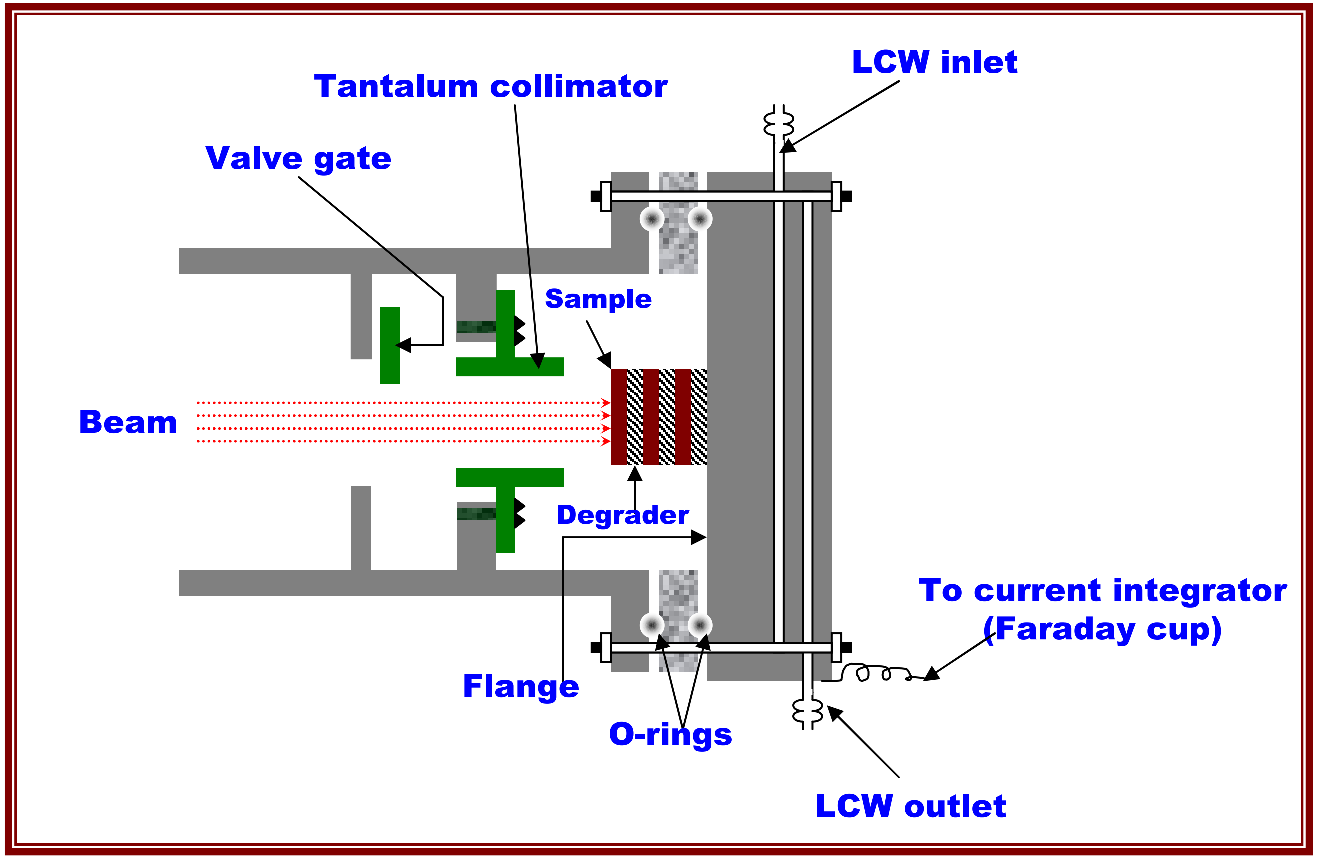
The measured EFs, may contain interesting information on the mechanism of equilibration process and may give a description of the evolution of the reaction.

Stacked foil activation technique

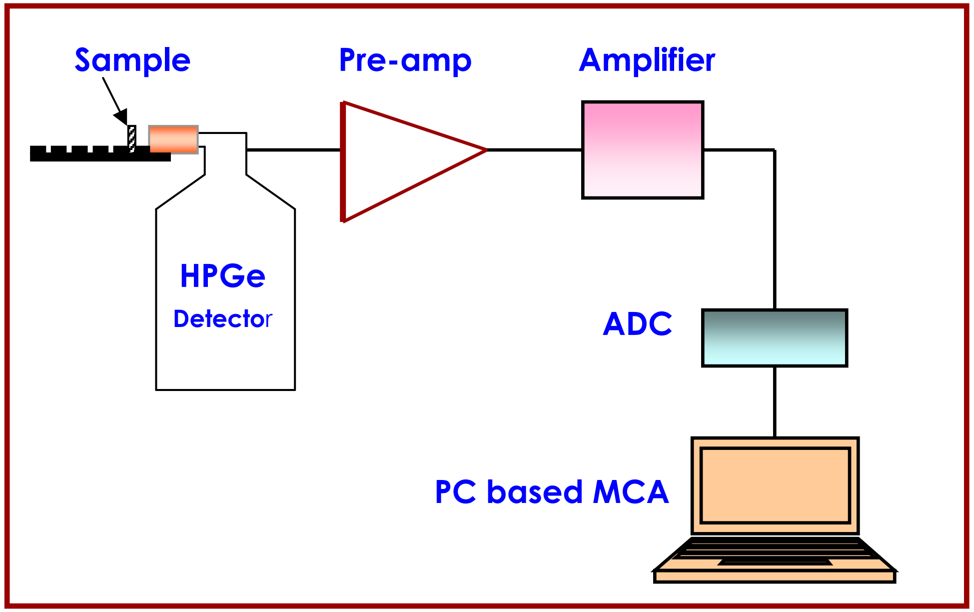
Irradiation



A typical experimental setup used for irradiation at VECC, Kolkata, INDIA



A typical block diagram of γ-ray spectrometer



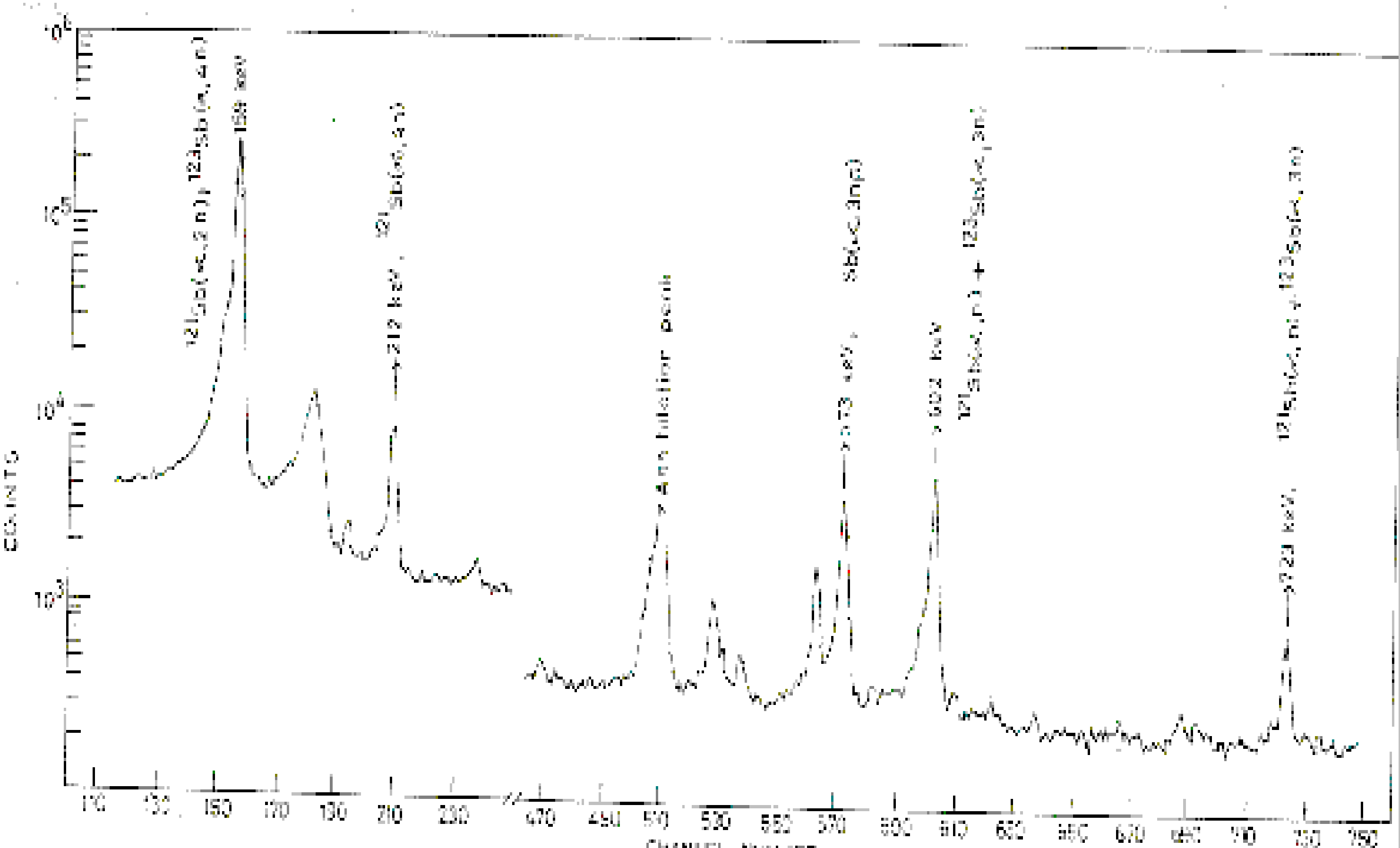


Fig. 5. Observed γ-ray spectrum from $^{121,123}Sb$ irradiated by ≈45 MeV α-particles.

Some of the reactions for which EFs have been measured

^{51}V(p,n)^{51}Cr	^{58}Ni(p,α)^{55}Co	^{60}Ni(p,n)^{60}Cu	^{60}Ni(p,γ)^{61}Cu	^{60}Ni(p,n)^{61}Cu
^{62}Ni(p,2n)^{61}Cu	^{63}Cu(p,n)^{63}Zn	^{63}Cu(p,2n)^{62}Zn	^{65}Cu(p,n)^{65}Zn	^{89}Y(p,n)^{89m,g}Zr
^{93}Nb(p,n)^{93m}Mo	^{113}In(p,n)^{113}Sn	^{115}In(p,3n)^{113}Sn	^{121}Sb(p,n)^{121}Sn	^{121}Sb(p,np)^{120}Sb
^{123}Sb(p,n)^{123m}Sn	^{123}Sb(p,np)^{122}Sb	^{130}Te(p,n)^{130}I	^{197}Au(p,n)^{197m,g}Hg	^{197}Au(p,np)^{196}Au

^{55}Mn(α,n)^{58}Co	^{55}Mn(α,2n)^{57}Co	^{55}Mn(α,3n)^{56}Co	^{55}Mn(α,4n)^{55}Co	^{55}Mn(α,nα)^{54}Mn
^{55}Mn(α,3n,2p)^{54}Mn	^{55}Mn(α,3nα)^{52}Mn	^{121}Sb(α,n)^{124}I	^{123}Sb(α,3n)^{124}I	^{121}Sb(α,2n)^{123}I
^{123}Sb(α,4n)^{123}I	^{121}Sb(α,4n)^{121}I	^{121}Sb(α,3np)^{121}	^{129}Sb(α,n)^{126}I	^{128}Te(α,np)^{130}I
^{130}Te(α,np)^{132}I	^{130}Te(α,np)^{132m}I	^{165}Ho(α,n)^{168}Tm	^{165}Ho(α,2n)^{167}Tm	^{165}Ho(α,3n)^{166}Tm
^{165}Ho(α,4n)^{165}Tm	^{197}Au(α,n)^{200}Tl	^{197}Au(α,2n)^{199}Tl	^{197}Au(α,3n)^{198g}Tl	^{197}Au(α,4n)^{197}Tl
^{209}Bi(α,3n)^{210}At	^{209}Bi(α,4n)^{209}At	^{209}Bi(α,5n)^{208}At	^{59}Co(α,2n)^{61}Cu	^{59}Co(α,nα)^{58}Co
^{63}Cu(α,n)^{66}Ga	^{63}Cu(α,2n)^{67}Ga	^{63}Cu(α,np)^{65}Zn	^{63}Cu(α,2nα)^{61}Ga	^{65}Cu(α,n)^{68}Ga
^{65}Cu(α,2n)^{65}Ga	^{65}Cu(α,3n)^{66}Ga	^{93}Nb(α,n)^{96}Tc	^{93}Nb(α,2n)^{95m}Tc	^{93}Nb(α,3n)^{94g,m}Tc
^{121}Sb(α,n)^{124}I	^{121}Sb(α,2n)^{123}I	^{123}Sb(α,n)^{126}I	^{123}Sb(α,3n)^{124}I	^{197}Au(α,n)^{200}Tl
^{197}Au(α,2n)^{199}Tl	^{197}Au(α,3n)^{198}Tl	^{58}Ni(α,n)^{61}Zn	^{58}Ni(α,p)^{61}Cu	^{58}Ni(α,pn)^{60}Cu
^{58}Ni(α,αn)^{57}Ni	^{60}Ni(α,p)^{69}Zn	^{60}Ni(α,2n)^{62}Zn	^{60}Ni(α,p2n)^{61}Cu	^{61}Ni(α,2n)^{63}Zn
^{61}Ni(α,3n)^{62}Zn	^{62}Ni(α,3n)^{69}Zn	^{141}Pr(α,n)^{144}Pm	^{141}Pr(α,2n)^{149}Pm	

Analysis

Hauser-Feshbach → CN

Exciton model → PE

Important parameters of the code…

⇨Level Density parameter 'a'

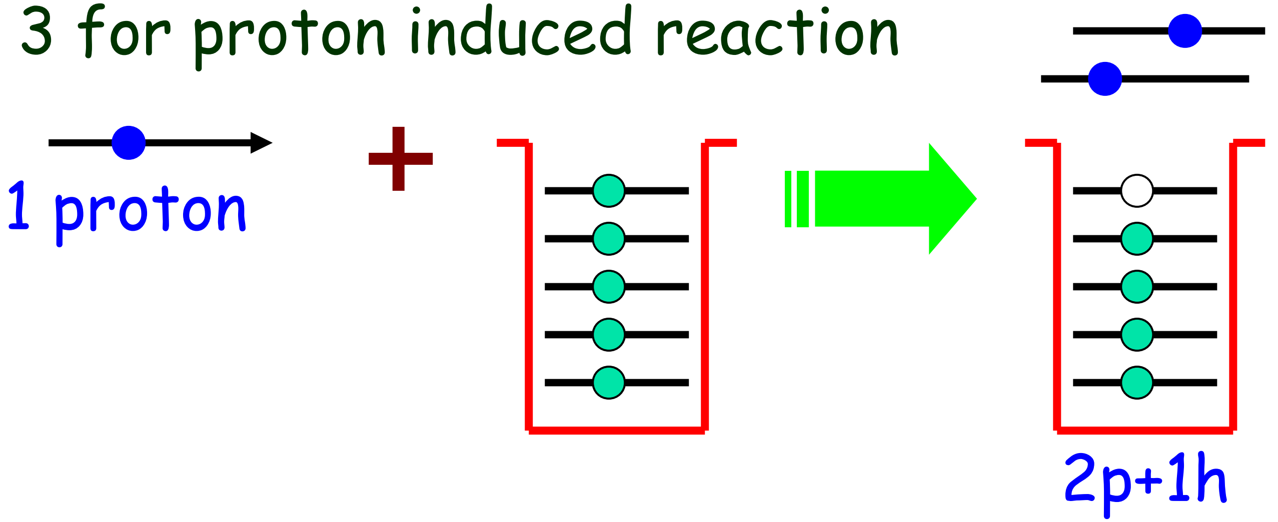
[Dilg et. al. Nucl. Phys. A217(1973)269]

⇨Initial Exciton Number $n_0=(n_p+n_h)$

$n_0=3$; for proton induced reactions

⇨Strength parameter F_M, of the square of two body residual interaction matrix element

$N_0 = 3$ for proton induced reaction

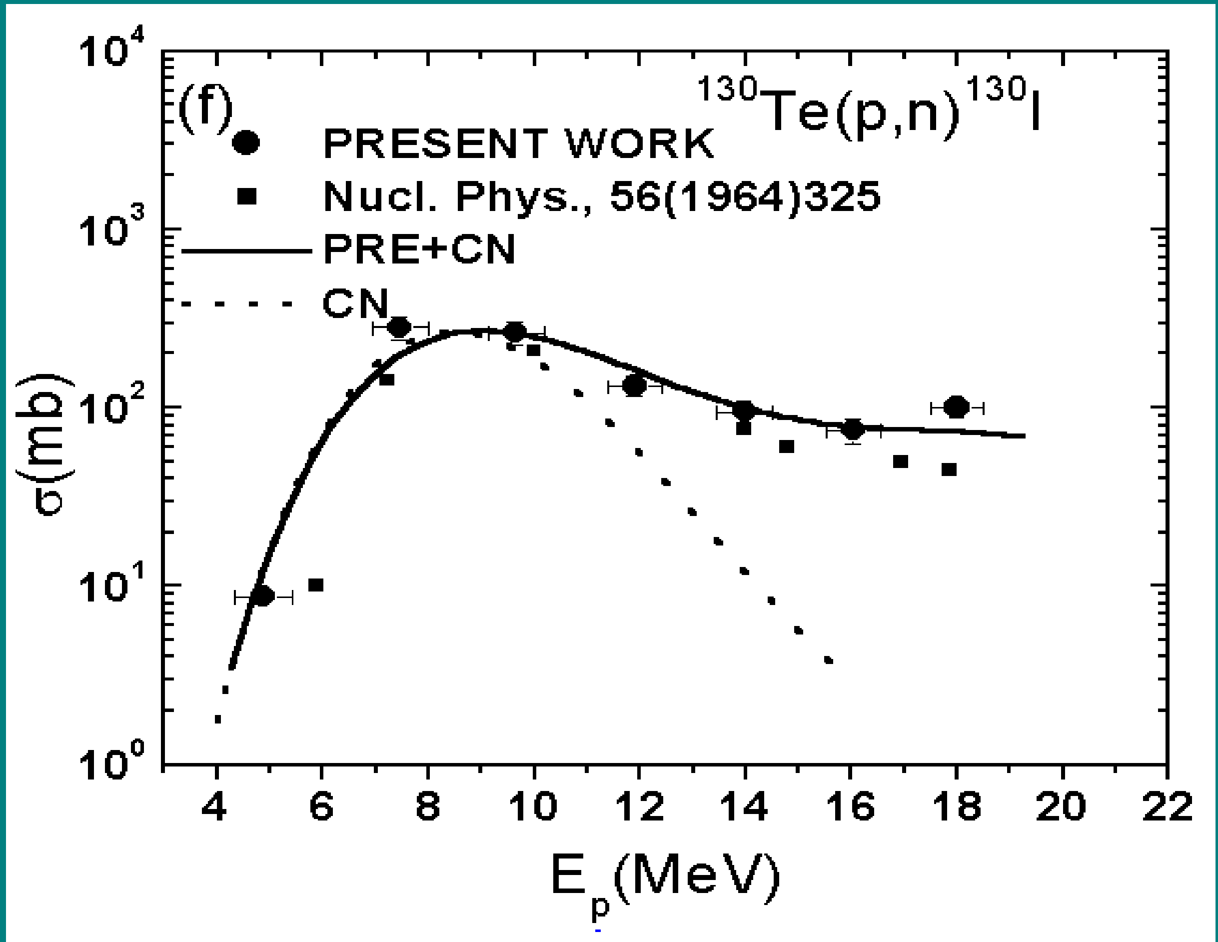


$$|M|^2 = F_M A^{-3} U^{-1}$$

[C. Kalbach-Cline Nucl. Phys. A 210(1973)590]

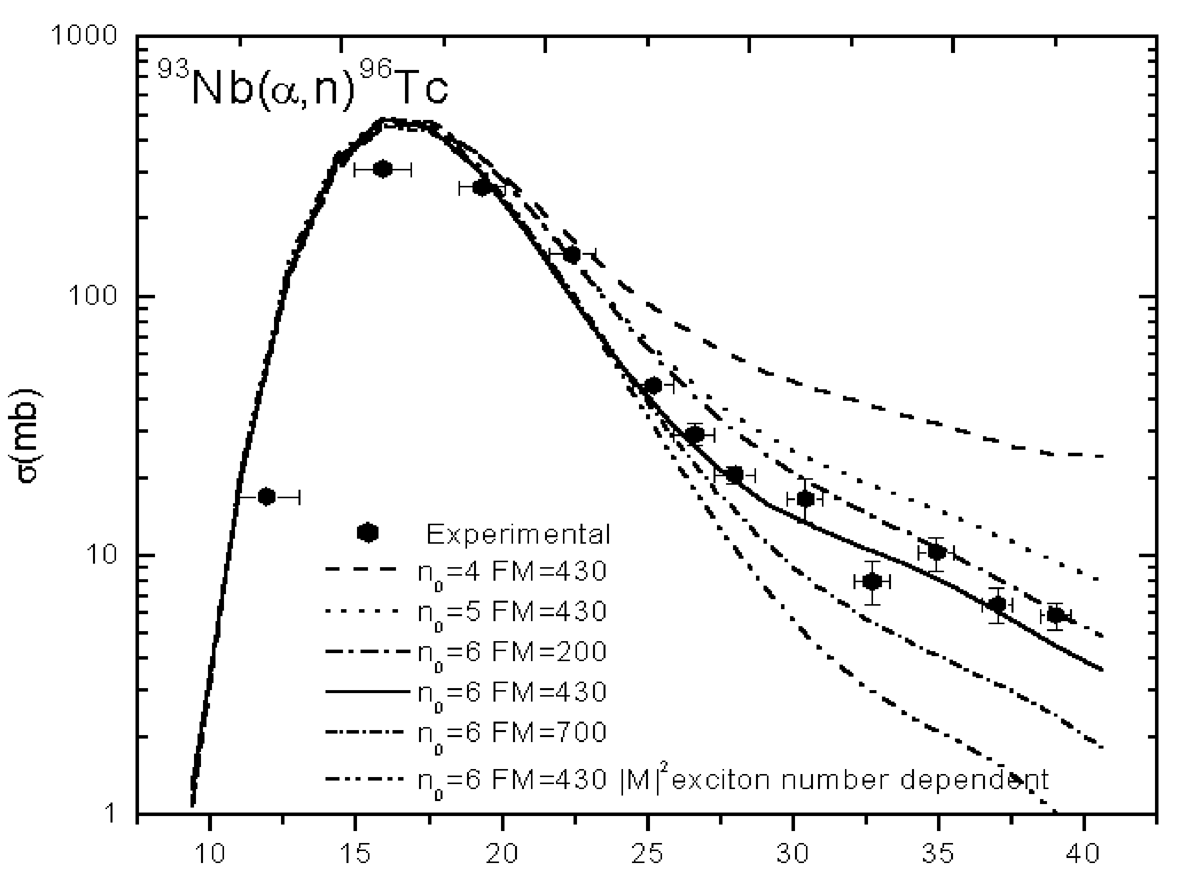
In the present work F_M=430 MeV^3 gives satisfactory reproduction of the experimental data

EFs………



(f)
^{130}Te(p,n)^{130}I
PRESENT WORK
Nucl. Phys., 56(1964)325
PRE+CN
CN
σ(mb)
E$_p$(MeV)

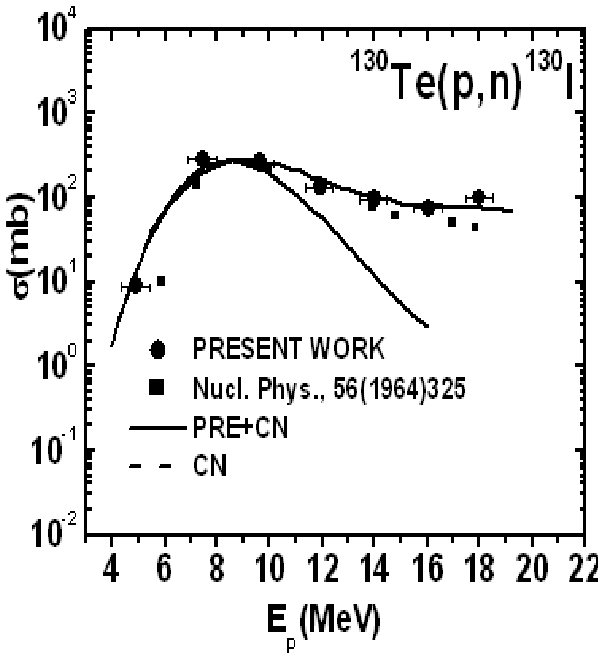
EFs……

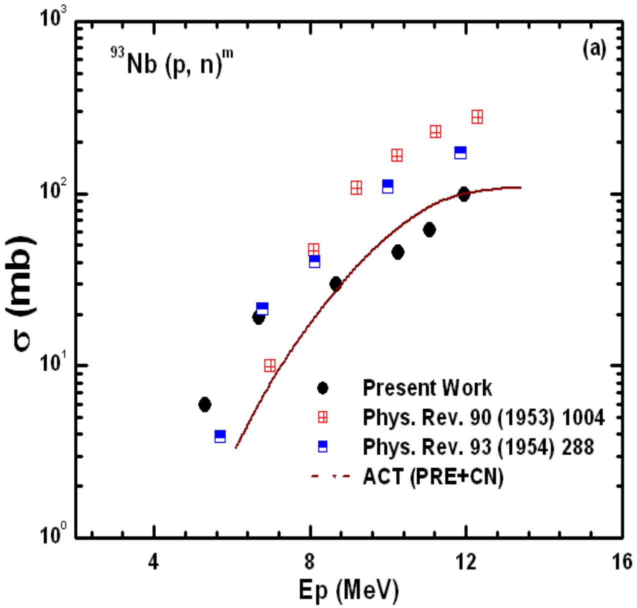


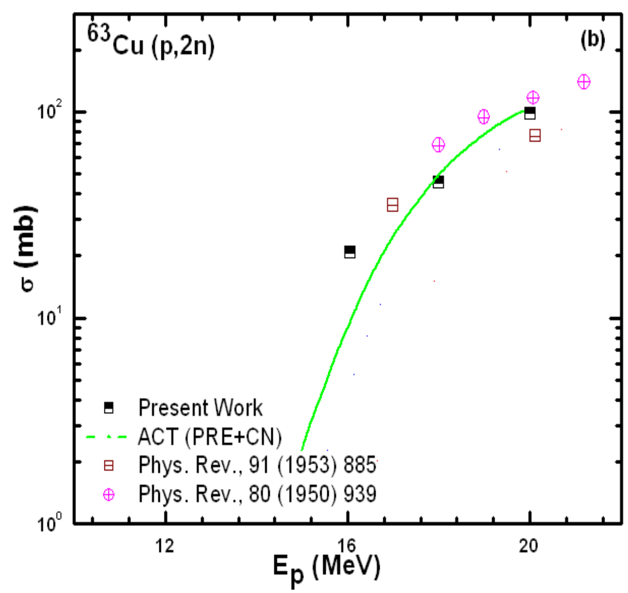
$^{93}Nb(\alpha,n)^{96}Tc$
1000
100
10
1
σ(mb)
Experimental
n_0=4 FM=430
n_0=5 FM=430
n_0=6 FM=200
n_0=6 FM=430
n_0=6 FM=700
n_0=6 FM=430 $|M|^2$exciton number dependent
10
15
20
25
30
35
40
Energy

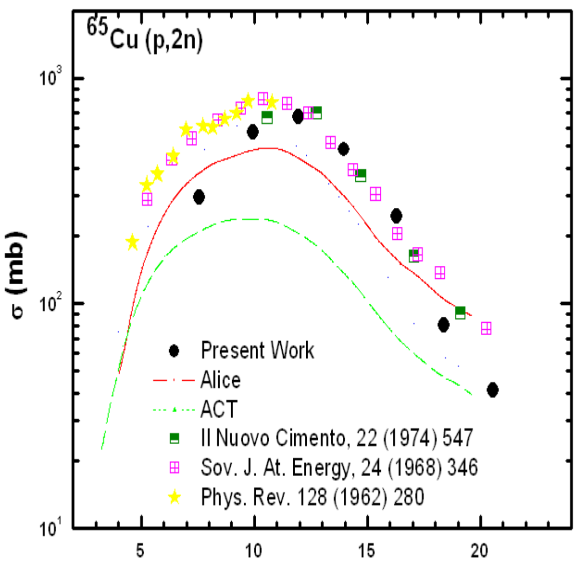
Fig. 8

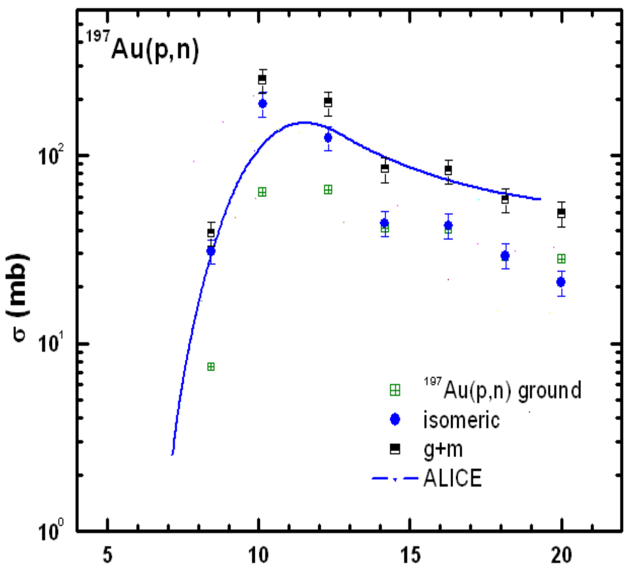
SOME TYPICAL EXCITATION FUNCTIONS……

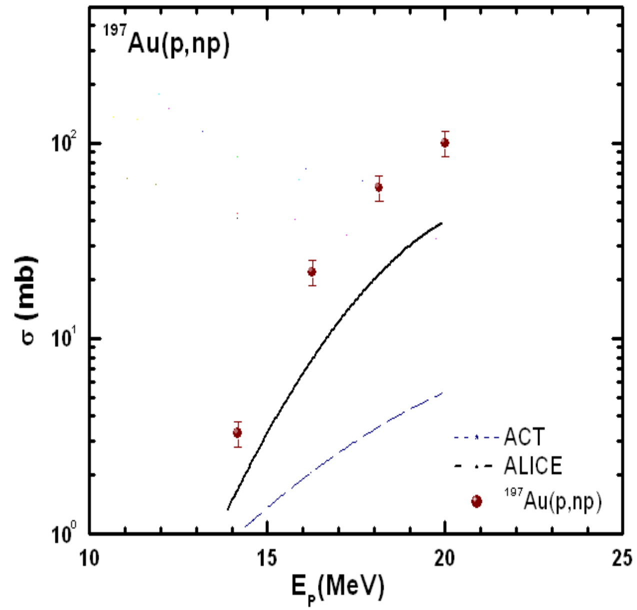












PHYSICAL REVIEW C VOLUME 52, NUMBER 6 DECEMBER 1995

Semiclassical and quantum mechanical analysis of the excitation function for the $^{130}Te(p,n)^{130}I$ reaction

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(Received 19 December 1994)

We report excitation function for the reaction $^{130}Te(p,n)^{130}I$ in the energy range $\approx 4-18$ MeV. The measurements were done employing stacked foil activation technique and enriched isotope. To the best of our knowledge this excitation function has been reported for the first time. The theoretical analysis of the excitation function has been done employing both the semiclassical as well as quantum mechanical descriptions of the preequilibrium emission. In general, theoretical calculations agree well with the experimental data.

PACS number(s): 25.40.Kv, 27.60.+j

I. INTRODUCTION

Preequilibrium (PE) emission, as a reaction mechanism at moderate excitation energies, has attracted considerable attention from both the experimental as well as the theoretical viewpoints [1]. Initially, semiclassical models [2–6] were successfully used to describe the experimental data on PE emission. Recently, however, the stress has been laid on the systematic study of trends with a view to finding a consistent set of input parameters that can describe the large amount of experimental data. Lately, totally quantum mechanical (QM) theories for PE emission have also been developed and have been used to analyze mostly the data on nucleon-induced reactions [7–11].

In the present work the excitation function for the reaction $^{130}Te(p,n)^{130}I$ has been measured using the stacked foil activation technique. The analysis has been performed within the framework of both the semiclassical and QM models. The computer codes ALICE/LIVERMORE-82 [12] and ACT [13] have been used for the semiclassical treatment while the code EXIFON [14] has been employed for the QM calculations involving the multistep compound (MSC) and the multistep direct (MSD) formulations [7]. The details of the measurements are presented in Sec. II and the analysis of the data is discussed in Sec. III.

II. EXPERIMENTAL DETAILS

In the present measurements the stacked foil activation technique [15] has been employed. An enriched isotope (61%) of tellurium (mass number=130) was used for preparing the samples, which were made by vacuum evaporation, of 1.1 mg/cm^2 thickness on aluminum backing of 6.75 mg/cm^2. The square pieces of targets of size 1.2×1.2 cm^2 were used as samples in the stack. Each target was mounted individually on a conducting metal frame for heat dissipation. A stack for irradiation was made by taking seven targets with Al foils of suitable thickness as degraders, in between, to have the desired energy at each target. The stack was irradiated by an unresolved diffused proton beam with an energy uncertainty of 0.5 MeV at the Variable Energy Cyclotron Centre (VECC), Calcutta, India. A tantalum collimator was used just before the sample stack to restrict the size of the beam to 8 mm diameter. The incident energies on the first and last foils were ≈ 18 and ≈ 4.87 MeV, respectively. The charge accumulated in the Faraday cup during the irradiation was measured using an ORTEC current integrater device. Further details of the experiment and the measurements are described elsewhere [16].

The γ counting of the irradiated samples was carried out using conventional Ge(Li) γ-ray spectroscopy. The detector was calibrated using various standard γ sources including a ^{152}Eu source of known strength which was also used for determining the geometry-dependent detector efficiency for γ rays of different energies and at different source-detector distances. A typical efficiency curve at a source-detector distance of 6.4 cm is shown in Fig. 1. The γ rays of energies 418.0, 536.1, 668.56, 739.48, and 1157.49 keV emitted by ^{130}I produced in the reaction $^{130}Te(p,n)$ were identified. In

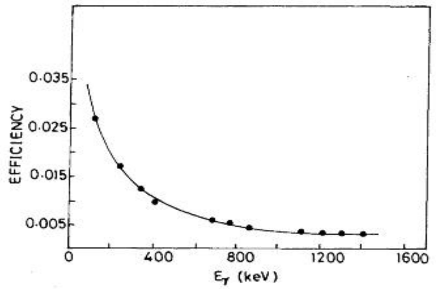

FIG. 1. Geometry-dependent efficiency of Ge(Li) detector at a source detector distance of 6.4 cm.

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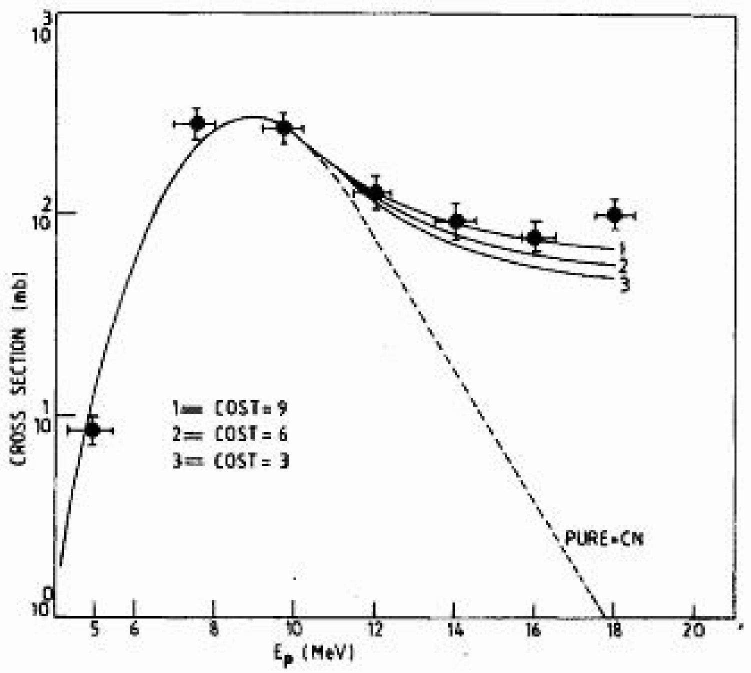
Phys. Rev. *C* 52 (1995) 03174



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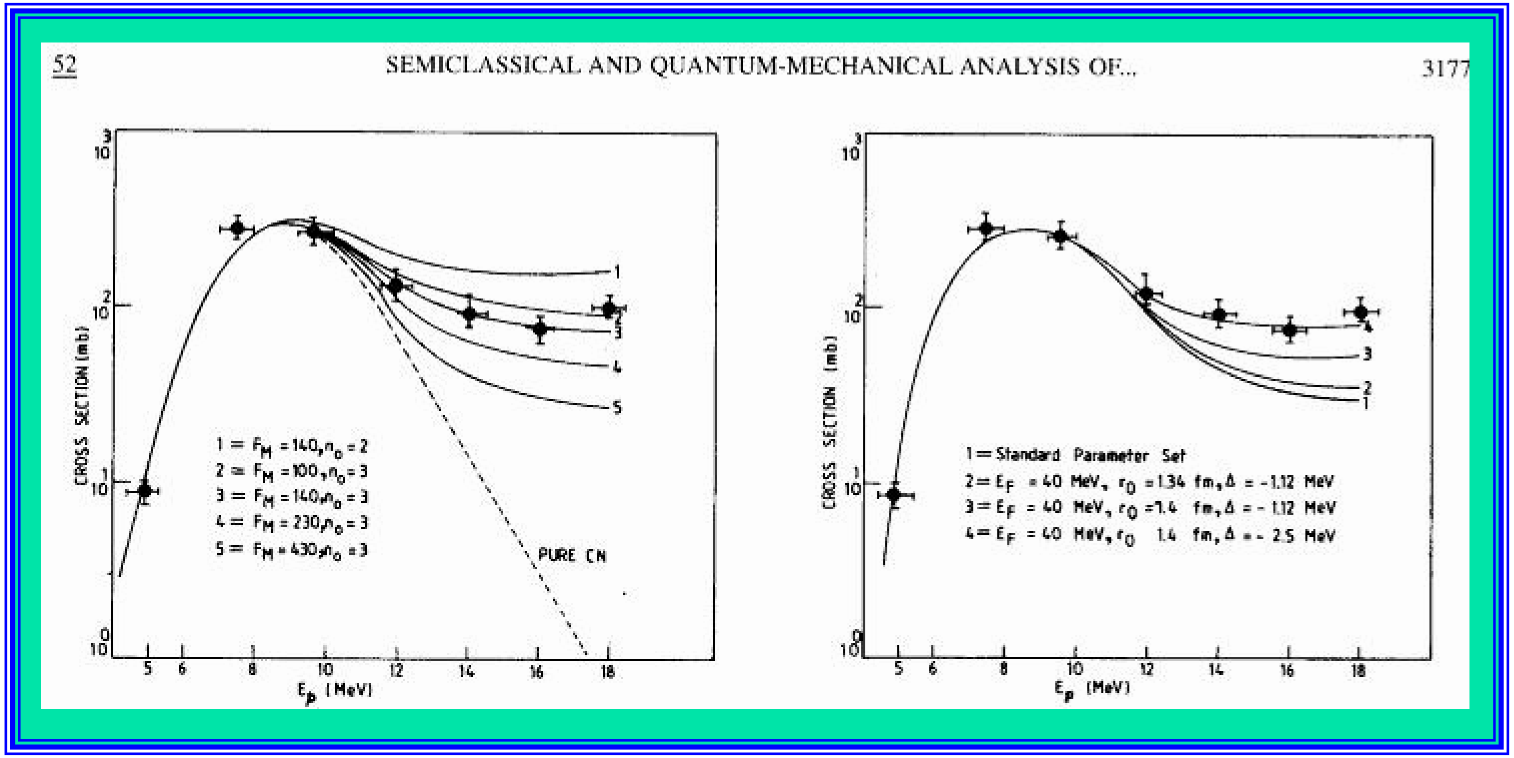

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Measurement and analysis of cross sections for (p,n) reactions in ^{51}V and ^{113}In

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Abstract

Excitation functions (EFs) for the reactions $^{51}V(p,n)^{51}Cr$ up to 15 MeV and $^{113}In(p,n)^{113}Sn$ up to 20 MeV from threshold have been measured employing the stacked foil activation technique. To the best of our knowledge EF for the reaction $^{113}In(p,n)^{113}Sn$ has been reported for the first time. The theoretical analysis of the EFs has been done employing both the semi-classical as well as quantum mechanical codes which include compound nucleus and pre-equilibrium (PE) emission into consideration. In general, theoretical calculations agree well with the experimental data. Effect of various free parameters used in the calculations have also been discussed. A significant contribution of pre-equilibrium component has been observed at these energies.

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1. Introduction

More and more experimental nuclear reactions cross-section data are needed to determine the optimum irradiation condition for the production yield of various radioisotopes. More recently, these reaction cross-sections are also in demand in order to know the transmutation probabilities for the proposed accelerator driven systems (Rubbia et al., 1995) (sub-critical reactors) popularly known as energy amplifiers. Though several investigations are available in the literature for the determination of reaction cross-sections related to the production of radio-nuclides, there are large discrepancies in the cross-sections measured for the same reaction by different authors. Further, there are large uncertainties in the measured cross-sections due to the use of low-resolution detectors. Moreover, the details of errors and their evaluation are not discussed in general. Recent experiments have clearly indicated that in statistical nuclear reactions, at moderate excitation energies, particles are emitted prior to the establishment of thermodynamic equilibrium of the compound nucleus (CN). This process is generally known as pre-equilibrium (PE) emission. Signatures of PE emission are often found in the high energy tails of the excitation functions. The PE emission mechanism has attracted considerable attention from both the experimental and theoretical view points (Gadioli and Hodgson, 1992). Semi-classical models (Blann, 1971; Ernst et al., 1987) have been successfully used to describe the experimental data on PE emission. Recently, quantum mechanical (QM) theories have also been used to analyse the experimental data mostly on nucleon induced reactions (Feshbach et al., 1980; Tamura and Udgawa, 1978; Udgawa and Low, 1983; Gudima et al., 1983; Bonetti et al., 1991). The stress has been, however, laid on the systematic study of input parameters that can describe the large amount of experimental data.

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Conclusions

- Cross-section for several proton and alpha induced reactions have been measured in a wide energy range.
- PE-emission is important at these energies.

- As such, while the cross-section value for some unmeasured reaction is required, it may be obtained by considering PE-emission also into account.
- Pre-equlibrium fraction is found to depend sensitively on excitation energy and atomic mass number.

Publications

1. *"Large pre-equilibrium contribution in α+Ni interactions at ≈ 8-40MeV":* Abhishek Yadav, Pushpendra P. Singh, M. M. Musthafa, Manoj Kumar Sharma, Devendra P. Singh, Unnati, **B. P. Singh**, and R. Prasad. **PHYSICAL REVIEW C 78, 044606 (2008).**
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4. *"Measurement and analysis of cross-sections for (p,n) reactions in ^{51}V and ^{113}In":* M. M. Musthafa, Manoj Kumar Sharma, ***B.P. Singh*** *and R. Prasad,* ***Applied Radiation Isotopes 62(2005) 419-428.***
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Continue

8. "*Semi-classical and quantum mechanical analysis of the excitation functions for ^{130}Te (p,n)^{130}I reactions*": M.M. Musthafa, **B.P. Singh**, M.G.V. Sankaracharyulu, H.D. Bhardwaj and R. Prasad, **Physical Review C52 (1995) 3174.**
9. "*Measurement and analysis of excitation functions for the reactions ^{165}Ho (α,xn) (x=1-3) in the energy range ≈10-40 MeV*": ***B. P. Singh*** *and R. Prasad,* ***Physica Scripta 51(1995) 440****.*
10. *"Equilibrium and pre-equilibrium emission in some alpha induced reactions on enriched isotopes $^{128,130}Te$ at moderate excitation energies*": ***B. P. Singh****, M.G.V. Sankaracharyulu, M. Afzal Ansari, H.D. Bhardwaj and R. Prasad,* ***Physical Review C47 (1993) 2055****.*
11. *"Measurement and analysis of excitation functions for alpha induced reactions in Bismuth*": ***B. P. Singh****, M.G.V. Sankaracharyulu, M.A. Ansari, H.D. Bhardwaj and R.Prasad* ***International Journal of Modern Physics E1 (1992) 823.***
12. *"Exciton model analysis of alpha-induced reactions on manganese*": ***B. P. Singh****, H.D. Bhardwaj and R. Prasad.* ***Il Nuovo Cimento 104A (1991) 475.***
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14. *"A study of pre-equilibrium emission in alpha induced reaction on $^{121,123}Sb$*": ***B.P. Singh****, H.D. Bhardwaj and R. Prasad.* ***Canadian Journal of Physics 69(1991) 1376.***

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Thanks...!