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# Alpha-particle induced excitation function studies upto 120 MeV

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**Abstract** : Alpha particle induced reactions show much less satisfactory results for preequilibrium decay compared with reactions induced by protons of energy up to ~ 200 MeV on target elements covering the entire Perodic Table. Recent studies of the reactions induced by alpha particles of up to 180 MeV on targets of light, medium and heavy nuclei indicate disappointing agreement between experiment and calculations based on hybrid models, the quasifree scattering model, and the modified exciton model. Studies of the interaction of energetic alpha particles with complex nuclei have shown that different mechanisms (inelastic scattering, binary fragmentation, dissolution of the alpha particle into four nucleons in the nuclear field, and interaction of the alpha particle with individual nucleons of the target nucleus) may be partly responsible for the experimently observed results.

A careful and systematic experimental study of the excitation function of typical nuclear reactions with alpha particle beam energy up to 120 MeV has been undertaken. Stacked foil activation technique has been employed for this purpose. Excitation functions for more than twelve reactions of the type ($\alpha$, $xnypz\alpha$) for the target elements vanadium and niobium will be reported.

**Keyword** : Alpha-particle induced reactions, excitation function, vanadium and niobium targets

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## 1. Introduction

The present investigation is part of a survey of $^4$He ion induced reactions with ions of upto 120 MeV on vanadium and niobium targets, using foil stack activation technique and high resolution gamma ray spectroscopy method. The highly excited nuclear system produced by the projectile bombardment decays first by emitting a number of fast nucleons at the pre-equilibrium stage and later on by evaporating low energy nucleons at the equilibrium stage. The pre-equilibrium models [1–3] introduced to describe the equilibrium process of an excited nuclear system and the subsequent emission of particles have become a very promising tool for the analysis and interpretation of nuclear reactions of energy greater than a few of tens of MeV. Predictions from these models as to excitation function and energy spectra of emitted particles compared well with the exsiting experimental data. This has prompted a continued interest in these models to predict cross sections for a number of practical purposes and to test the adequacy of underlying physics. The present work involves the experimental measurement of the excitation function for the reactions $^{51}V(\alpha, \alpha\ 2pn)^{48}Sc$, $^{51}V(\alpha, \alpha\ 3n)^{48}V$, $^{51}V(\alpha, p6n)^{48}Cr$, $^{51}V(\alpha, 2\alpha 3n)^{44m}Sc$, $^{51}V(\alpha, p3n)^{51}Cr$, $^{93}Nb(\alpha, \alpha\ p4n)^{88}Zr$, $^{93}Nb(\alpha, \alpha\ p3n)^{89}Zr$, $^{93}Nb(\alpha, \alpha\ p6n)^{86}Zr$, $^{93}Nb(\alpha, \alpha\ 3n)^{90}Nb$, $^{93}Nb(\alpha, 2\alpha 3n)^{86g}Y$ more precisely than earlier reported results, where the catcher foil activity was not taken into account.

## 2. Experimental method and discussion

Natural vanadium and niobium foils of thickness 15 mg/cm$^2$ and 22 mg/cm$^2$ were used as targets in this work while aluminium foil of varying thickness served as energy degraders. The beam energy associated with each target unit is calculated by range energy data points of Williamson *et al.* To avoid the error in the particle straggling and account for the equilibrium and pre-equilibrium (PE) components the measurements were taken up in steps of 40–80 MeV and 75–120 MeV respectively. The flux monitor reaction used were $^{27}Al(\alpha_1, \alpha 2pn)^{24}Na$ and $^{27}Al(\alpha, 2\alpha n)^{22}Na$. Experiments were performed at Indiana University Cyclotron Facility, USA. The decay characteristics of the residual nuclei investigated for alpha particle induced reactions on $^{51}V$ and $^{93}Nb$ are given in Table 1.

**Table 1.** Decay characteristics of radiation observed for $\alpha$-induced reactions on $^{51}V$ and $^{93}Nb$.

| Reaction | $Q$ values (MeV) | Half life | $E_\gamma$(MeV) | Intensity ($I_\gamma$) |
|---|---|---|---|---|
| $^{51}V(\alpha,\alpha 2pn)^{48}Sc$ | −30.35 | 44.05h | 1037 | .97 |
| $^{51}V(\alpha,\alpha 3n)^{48}V$ | −31.94 | 15.97d | 1312 | .97 |
| $^{51}V(\alpha, p6n)^{48}Cr$ | −36 8 | 21.56h | 308 | .99 |
| $^{51}V(\alpha, 2\alpha 3n)^{44m}Sc$ | −41.3 | 2.44d | 271 | .86 |
| $^{51}V(\alpha, p3n)^{51}Cr$ | −29.83 | 27.97d | 320 | .1 |
| $^{93}Nb(\alpha,\alpha p4n)^{88}Zr$ | −43.16 | 83.40d | 393 | .97 |
| $^{93}Nb(\alpha,\alpha p3n)^{89}Zr$ | −33.85 | 78.40h | 909 | .99 |
| $^{93}Nb(\alpha,\alpha p6n)^{86}Zr$ | −65.16 | 16.50h | 243 | .96 |
| $^{93}Nb(\alpha,2\alpha 3n)^{86g}Y$ | −34.16 | 14.74h | 1077 | .82 |
| $^{93}Nb(\alpha,\alpha 3n)^{90}Nb$ | −28.95 | 14.60h | 1129 | .93 |
| Monitor | | | | |
| $^{27}Al(\alpha,\alpha 2pn)^{24}Na$ | −31.40 | 15.05h | 1369 | 1 |
| $^{27}Al(\alpha, 2\alpha n)^{22}Na$ | −22.5 | 2.6h | 1275 | 1 |

**Table 2.** Experimental cross section for the $\alpha$-induced reaction with Vanadium and Niobium

| E (MeV) | Cross section for the product (mb) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $^{44m}Sc$ | $^{48}Cr$ | $^{48}V$ | $^{48}Sc$ | $^{51}Cr$ | $^{89}Zr$ | $^{86}Zr$ | $^{86g}Y$ | $^{88}Zr$ | $^{90}Nb$ |
| 112.7 | 14.05 ± 1.4 | .73 ± .07 | 106.61 ± 10 | 5.73 ± .57 | 69 95 ± 7 | 179 11 ± 11 | 10 08 ± 0 56 | 63 99 ± 6 | 482 ± 31 | 208 04 ± 19 |
| 107.3 | 12.95 ± 1.3 | .66 ± .07 | 102.96 ± 10 | 5.36 ± .53 | 132 ± 13 | 147 23 ± 9 | 3 67 ± .24 | 34.77 ± 3.0 | 482 ± 25 | 278 54 ± 19 |
| 101.8 | 12.73 ± 1.3 | .52 + .05 | 24.62 ± 9 | 5.36 ± .53 | 143 ± 14 | 125 63 ± 8 | 1.33 ± 1 3 | 19 89 ± 1.9 | 295 ± 19 | 257.92 ± 16 |
| 96.4 | 13.18 ± 1.3 | .32 ± .03 | 83.75 ± 8 | 4.76 ± .47 | 146 93 ± 14 | 127 94 ± 8 | 0 57 ± 11 | 18 13 ± 1.6 | 193 ± 12 | 214 99 ± 14 |
| 91.2 | 12.87 ± 1.3 | .25 ± .02 | 74.27 ± 7 | 4.58 ± .45 | 155 29 ± 15 | 140 22 ± 9 | – | 17 54 ± 1.6 | 112 ± 7 | 143 69 ± 9 |
| 86.1 | 15.43 ± 1.5 | – | 55.02 ± 5 | 4.69 ± 46 | 181.5 ± 18 | 161 30 ± 10 | – | 16.57 ± 1.6 | 66.5 ± 42 | 90.52 ± 6 |
| 81.0 | 12.08 ± 1.2 | – | 71 96 ± 7 | 4 44 ± .44 | 192 5 ± 19 | 173 22 ± 11 | – | 13 03 ± 1.3 | 41.6 ± 2 8 | 68 09 ± 4 |
| 75.9 | 8.04 ± .8 | – | 84.32 ± 8 | 4.62 ± .46 | 229 9 ± 22 | 178.6 ± 11 | – | 25 47 ± 2.5 | 29.4 ± 1 9 | 65.99 ± 4 |
| 75.0 | 3.39 ± .3 | – | 99.52 ± 9 | 4.37 ± .44 | 274.48 ± 27 | 145.6 ± 9 | – | 9 70 ± .9 | 35.0 ± 2 | 82 05 ± 5 |
| 70.6 | 5.06 ± .5 | – | 77.33 ± 7.7 | 3.95 ± 4 | 197.63 ± 19 | 113 02 ± 7 | – | 6 84 ± .66 | 20.0 ± 1 2 | 93.32 ± 6 |
| 69.2 | 1.20 ± .12 | – | 94 76 ± 9 | 3.45 ± .34 | 248.57 ± 34 | 107 2 ± 7 | – | – | 25.0 ± 2 | 118.2 ± 8 |
| 64.4 | 0.14 ± .014 | – | 99 87 ± 10 | 2.28 ± .23 | 354 4 ± 34 | 35 2 ± 2.0 | – | – | – | 144.6 ± 9 |
| 63.2 | – | – | 67 35 ± 6 | – | 389 4 ± 38 | 32.5 ± 2 | – | – | 15 0 ± 1 | 117 8 ± 7 |
| 57.2 | – | – | 18.91 ± 2 | – | 321.2 ± 32 | 2.8 ± 2 | – | – | 4 6 ± 3 | 54.5 ± 3 |
| 51.6 | – | – | 1 25 ± 12 | – | 116 11 ± 11 | – | – | – | 0 47 ± 03 | 8 6 ± 6 |
| 46.2 | – | – | – | – | 14 3 ± 1 4 | – | – | – | – | 8.1 ± 5 |
| 40.2 | – | – | – | – | – | – | – | – | – | – |

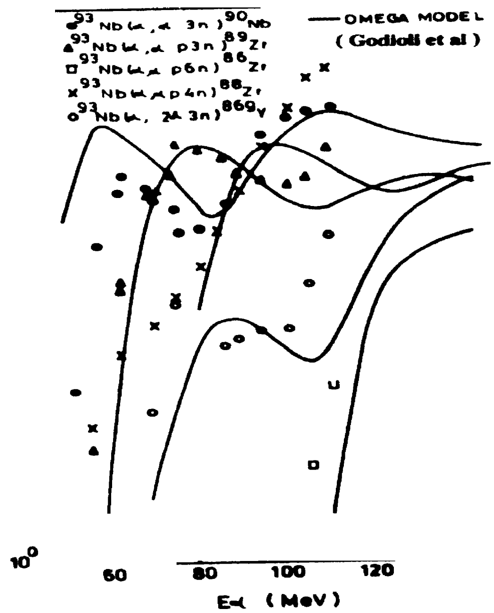


Figure 1. Excitation function of $^{93}$Nb reactions.

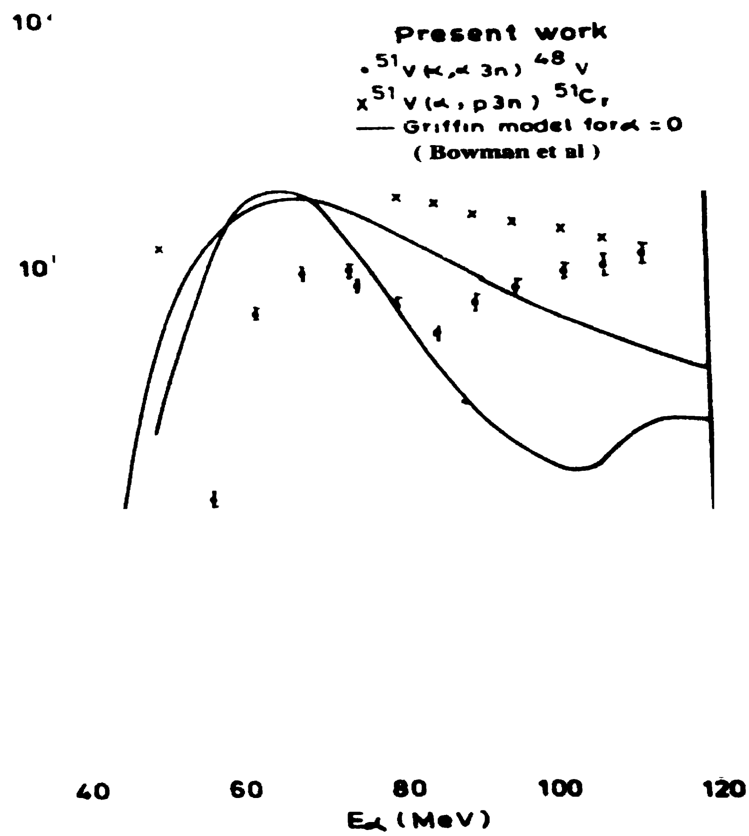


**Figure 2.** Excitation function of $^{51}$V reactions.

In Table 2 the experimental cross section are presented along with absolute error. The absolute error consists of detector efficiency (2%), monitor cross section (6–10%), including the statistical and other errors, the overall projected error in our measurement is between 6–12%.

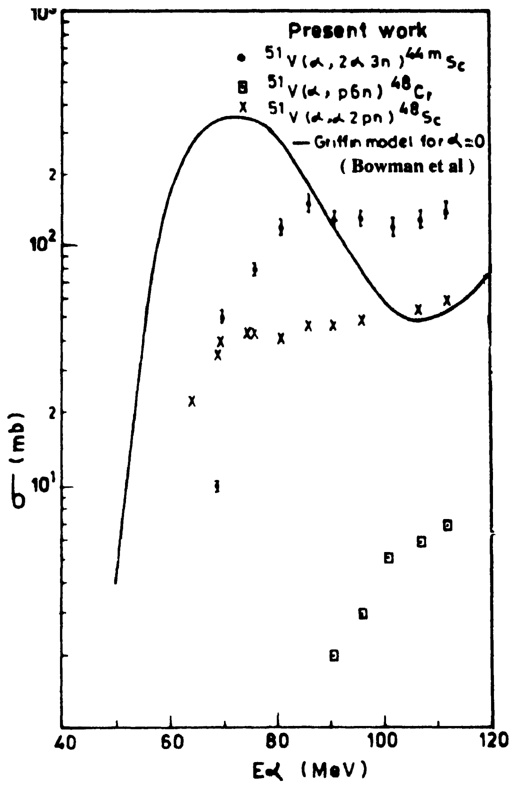


**Figure 3.** Excitation function of $^{51}V$ reactions

Excitation function of the reactions of ($\alpha$, $xnypz\alpha$) type for $^{51}V$ were measured by Bowman *et al* [5]. The uncertainties in the measurement of Bowman *et al* were quoted 20–35% whereas the uncertainties in the present measurement are 6–12%. In case of Niobium reactions which were previously measured by Gadioli *et al* [6] and Ernst *et al* [7] there are differences between their results beyond the limit of error. Therefore we have remeasured the reaction cross sections with an uncertainity of 6–12% and finer energy steps of 3–5 MeV. Figures 1, 2 and 3 show the comparison of experimental results (present work) together with theoretical predictions based on the Hybrid Model and the Modified Exciton Model developed by Gadioli *et al* [6]. Theoretical calculations for comparison with the present experimentally measured excitation function is further planned.

**References**

[1] J J Griffin *Phys. Rev. Lett.* **17** 478 (1966)

[2] G D Harp, J M Miller and J M Bern *Phys. Rev.* **165** 1766 (1968)

[3] M Blann *Ann. Rev. Nucl. Sci* **25** 123 (1975)

[4] L Chaturvedi *et al Nucl Phys Symp India* **32B** 288 (1985)

[5] W W Bowman and M Blann *Nucl Phys* **A131** 513 (1969)

[6] E Gadioli, Gadioli-Erba, J J E Hogan and B V Jacak *Phys Rev* **C29** 76 (1984)

[7] J Ernst, R Iboski, H Klampfl and H Mackher *Z Phys* **A308** 301 (1982)