

YIELDS OF CYCLOTRON-PRODUCED ISOTOPES

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The yields of all the isotopes that can be produced by the interaction of protons, deuterons and alpha particles of up to 36 MeV, with targets having atomic numbers between 20 and 92, have been calculated. For this purpose published empirically constructed excitation functions and range-energy data have been used. The results are presented in the form of thick target yields, as function of the incident energy, from which the desired yields for thick or even thin target can be directly read.

1 Introduction

Scientists around the world are spending a great deal of time and efforts in experimentally determining production cross sections and yields of isotopes in order to choose the best irradiation conditions, optimise production and to estimate the impurities which are also being produced simultaneously. On the other hand a great deal of theoretical and empirical data exists in the literature which can be used to calculate isotopic yields under any given irradiation conditions.

By making use of empirically estimated excitation functions of Large and Muenzel,¹ and the range energy tabulations of Williamson et al.,² we have calculated the isotope yields of all the isotopes that can be produced by the interaction of protons, deuterons and alpha particles of up to 36 MeV with targets whose atomic numbers are between 20 and 92. The reactions considered in the calculations are (p,xn), (d,xn), (d,p), (α ,xn), (α ,p) and (α ,np).

2 Method

The activity A produced in a target depends on incident particle flux F, cross section σ , half-life T, irradiation time t and the number N of target atoms per cm². If the target thickness is larger than the range of the projectile with energy E_p than this activity produced can be calculated with the following Eqn (1):

$$A = KF \left(1 - e^{-\frac{0.7t}{T}} \right) \int_0^{E_p} \sigma \left(\frac{dE}{dx} \right)^{-1} dE, \quad (1)$$

where K is a numerical constant and (dE/dx) the specific energy loss of the projectiles in the target. The value of K is given by: $K = fN_A/W$, where N_A is Avagadro's number, W the atomic weight of the target and f the abundance of the isotope in the target, taking part in the nuclear reaction.

The flux of the incoming particles $F = 6.25 \times I \times 10^{12}/z$, where z is the electronic charge of the projectile and I the beam intensity in microamperes. In order to calculate the produced activity 'A' from Eqn (1) the values of cross sections for nuclear reactions induced, by protons, deuterons and alpha particles at different energies, are extracted from Ref. (1). However, as the cross sections in the reference are given as functions of (E_p+Q) and not as functions of E_p, and are grouped for elements with Z=20-40, 40-60, 60-83 and greater than 90 respectively, values of $\sigma(E)$ had to be

extracted for each group of elements from the excitation functions. For this purpose the Q-values of all the nuclear reactions in each group were taken from the tables or computed for protons, deuterons, and alpha particles respectively, and their averages calculated. Then by using the average Q-value for each group of elements the cross sections were extracted for different energies of protons, deuterons and alpha particles of up to 36 MeV.

The values of (dE/dx) for each projectile at different energies were obtained from the tabulations in Ref. (2). For each group of elements that were combined for the excitation functions, the element around the middle was chosen for the values of (dE/dx) to be used in Eqn. (1). This means that the specific energy loss (dE/dx) values for Z = 20-40, 41-60, 61-83 and greater than 90 groups of elements were taken for elements with Z = 30, 50, 70, and 90 respectively.

Thick target yields for various groups of elements were calculated using Eqn. (1) for different incident energies of protons, deuterons and alphas. Two irradiation times, $t \gg T$, the half life of the isotope being produced (i.e. $t = 4T$ or greater) for saturation activity, and $t = T/10$ were used in Eqn. (1) to calculate the respective yields. The yields are presented in graphical forms from which production rates of any isotope in the above mentioned range can be directly read under given bombarding conditions.

3 Results and Discussion

Thick target yield curves for different projectiles are shown in fig. 1 for the two irradiation times, and are self-explanatory. The production yield of any desired isotope can be read directly from the curves either at saturation or for bombardment time amounting to one tenth of the half life of the isotope being produced. For any other irradiation time the activity can easily be calculated by taking the saturation activity from the yield curves and using Eqn. (1). The yield curves are also applicable for estimating the isotopic yields even when the target is thin or moderately, rather than infinitely, thick. This is done by taking the difference in the isotopic yield at the energies at which the incident particle beam enters and leaves the target.

The maximum error in the empirical cross sections as compared to those measured experimentally is generally expected to be less than a factor of 2. However, in the isotopic yield curves additional errors could creep in due to

the fact that we are taking the average of many Q-values in a group of target nuclides, for extracting the cross sections as function of the incident energy. However, preliminary comparison with measured yield has shown that the additional error would not significantly change the maximum error factor of 2.

4 Summary

Thick target yields for producing all isotopes, by the interaction of protons, deuterons and alpha particles of up to 36 MeV, with elements having $Z=20-92$, are calculated for different irradiation times and presented in easy-to-use graphical form. The maximum error in the isotopic yields is

generally expected to be less than a factor of 2. This data should be useful in selecting the most suitable nuclear reaction for producing a certain isotope, in optimising the irradiation conditions and giving an estimate of isotopic impurities which are being produced simultaneously.

References

1. J. Lange and H. Muenzel, *Report KFK-767 Karlsruhe* (1969)
2. C.F. Williamson, J.P. Boujot and J. Picard, *Rapport CEA-3042, Saclay* (1966)

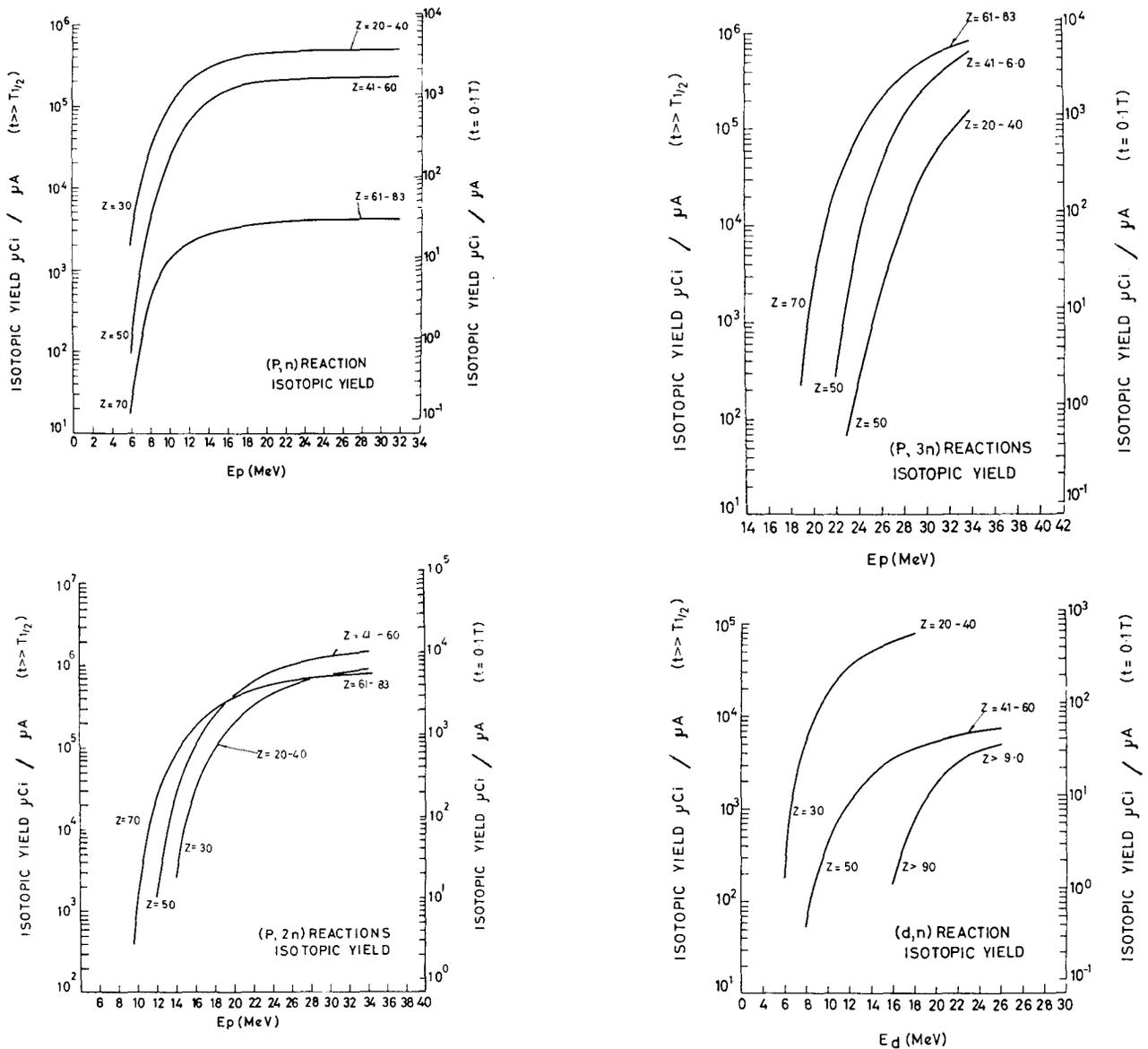


Fig. 1 Thick-target yields of isotopes.

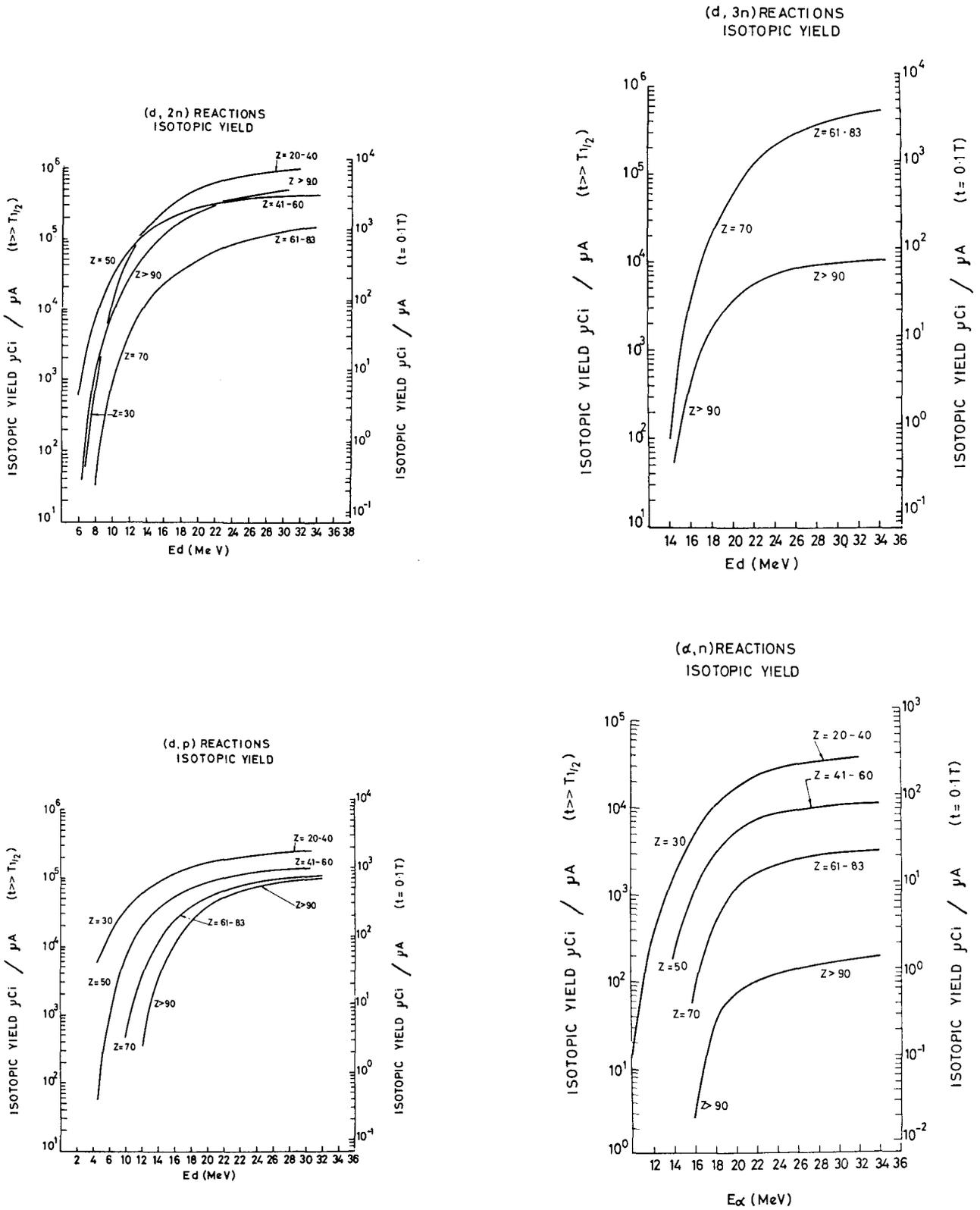


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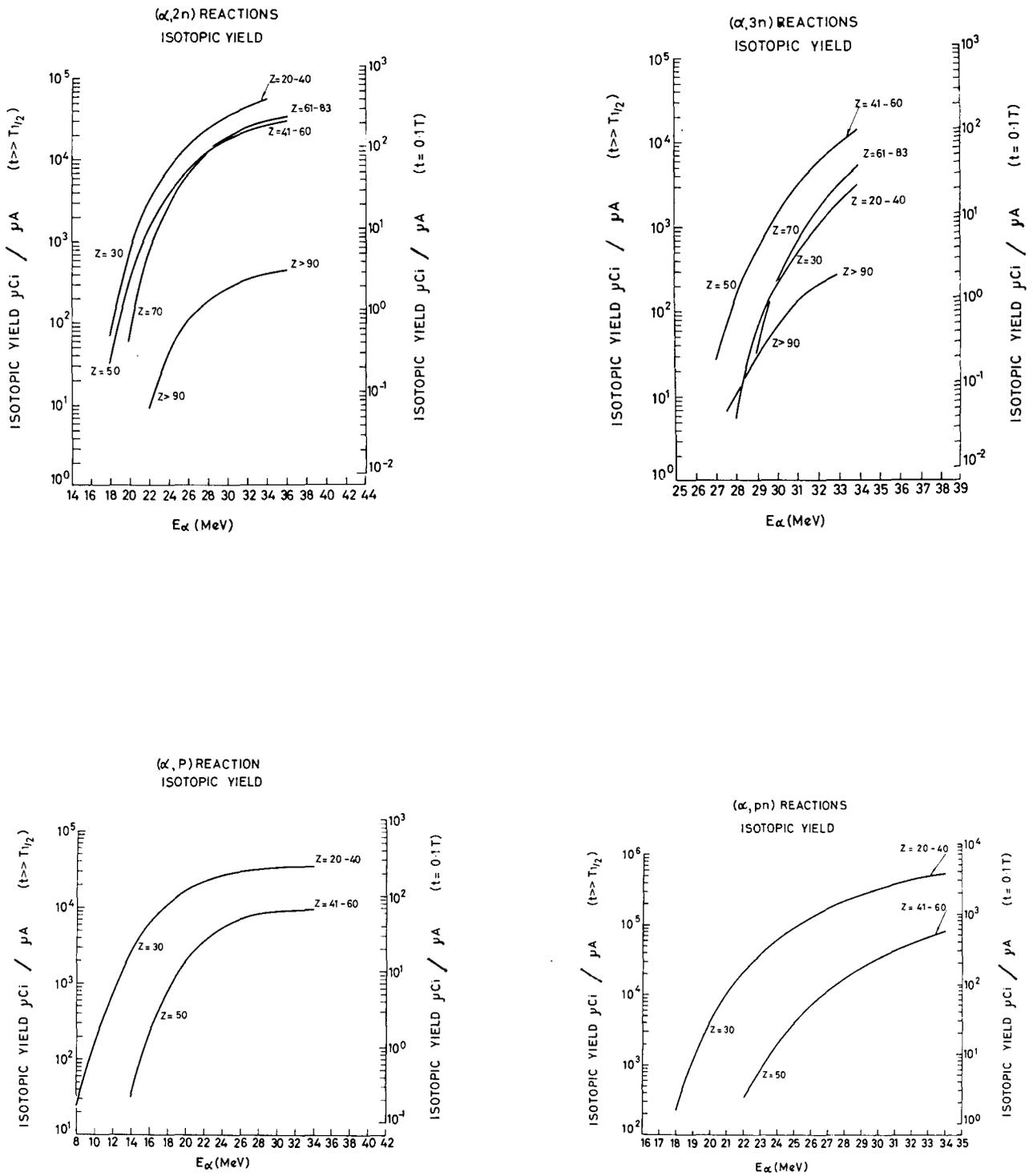


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