RECOIL RANGES OF NUCLEI PRODUCED IN PROTON INDUCED REACTIONS

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The integral recoil ranges of the radioactive nuclei produced following the bombardment of ^{58}Ni and ^{62}Ni targets with 80, 136 and 164 MeV protons have been measured. The method[1] consists of comparing the radioactivity of the product nuclei remaining in 3 mg/cm^2 thick self-supporting target foils with those recoiling into 2 mg/cm^2 thick Kapton catchers. The knowledge of the thickness of the target and its uniformity is essential for accurate range measurements and was determined by the energy loss method using α-particles from a ^{241}Am source.

For more than fifteen product nuclei the recoil ranges were determined and their values

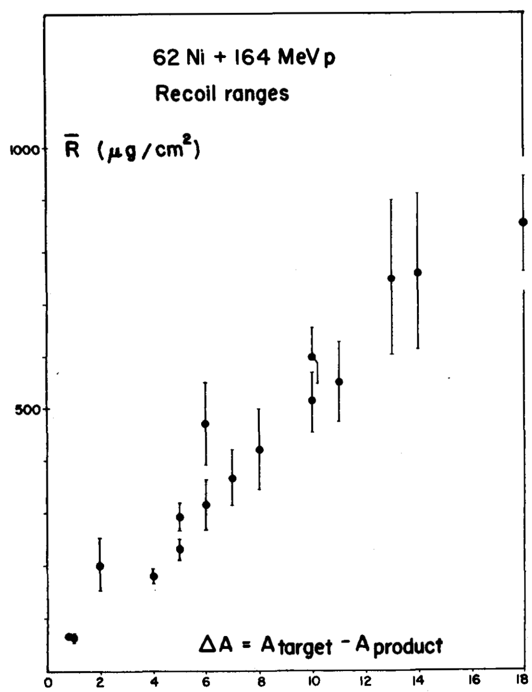

Figure 1. Integral recoil ranges vs. $\Delta A = A_{target} - A_{product}$ for ^{62}Ni at 164 MeV bombarding energy.

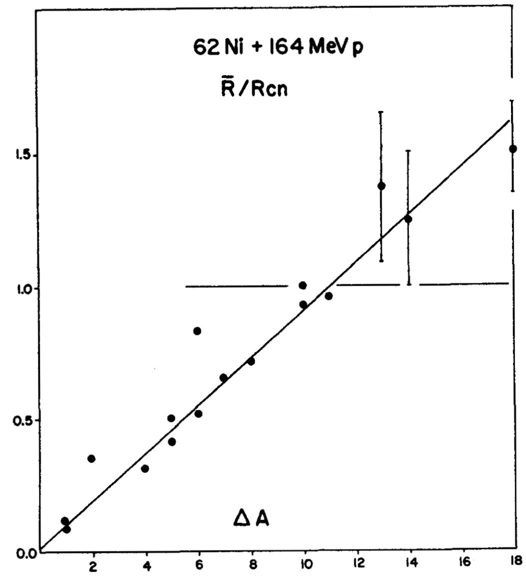

Figure 2. Ratio of measured ranges to ranges expected for the full momentum transfer of the bombarding particle to the target nucleus. To calculate R_{CN} the recoiling energy is determined from the relation $E^R_{CN} = E_b A_b A_R / (A_R + A_T)^2$ and is converted to range using ref. 2 range-energy tables. Particle evaporation and straggling of the recoil nuclei (ref.5) is neglected in computation of R_{CN}.

are presented in Figure 1 as a function of mass removal $\Delta A = A_{target} - A_{product}$ for ^{62}Ni target at 164 MeV proton energy. Similar results are found for ^{58}Ni target.

It is instructive to express the observed ranges for each nucleus as a fraction of the range[1,2] the nucleus would have (referred to as R_{CN} hereafter) if it were produced after the full momentum transfer of the bombarding particle to the target nucleus. (See Figure 2). For simplicity the R_{CN} were calculated for each case assuming that the evaporated particles do not carry out any momentum. The evaporation of nucleons tends to increase the measured ranges if the range is not proportional to the energy[1,3,4]. These changes will not affect the discussion presented below.

The nucleon-nucleus interaction is visualized as proceeding through a phase of pre-equilibrium nucleon emission followed by nucleon evaporation. The pre-equilibrium nucleons can carry away energy over a broad range and thus would correspondingly determine the recoil energies (and as a consequence the ranges of the product nuclei) more stringently than the evaporation nucleons. The linear dependence of $\bar{R}$ or $\bar{R}/R_{CN}$ with ΔA implies that a progressively smaller fraction of the incident energy is carried out by pre-equilibrium nucleons as more nucleons, ΔA, are removed. The extremely small ranges of nuclei near the target mass imply that these nuclei are produced primarily following pre-equilibrium emission. The nuclei with $\Delta A \sim 10$ for which $\bar{R}/R_{CN}$ has the value close to unity, must have been produced primarily as a consequence of evaporation from the compound system which has lost little energy in the pre-equilibrium phase. Final nuclei with $\Delta A \geq 13$ have ranges which are considerably greater than the corresponding R_{CN}. To understand the observed ranges for these cases one must assume not only that no fast nucleons were emitted but also that two or more alpha particles were involved in the evaporation chain.

Attempts are underway to explain the observed variation of R with ΔA quantitatively.

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