The mechanism of $^6$Li induced reactions on $^{54}$Fe and $^{56}$Fe targets is presently being studied by in-beam and off-line gamma counting techniques. Figure 1 presents the distribution of the cross sections determined mainly in-beam for 84 MeV bombarding energy on a $^{56}$Fe target. These cross sections are obtained by summing the absolute intensities of gamma transitions leading to the ground state (or low excited states in some cases) as measured in 90° close geometry. The experimental technique is analogous to that described in Reference 1. The absolute gamma ray intensities are believed to be accurate to about ±30%. The relative intensities have much smaller errors for strong or medium intensity and well-resolved peaks. Measurements have also been made at 55, 65, 77, 91 and 99 MeV lithium bombarding energy with $^{56}$Fe targets.

In the case of nuclei which are produced with cross sections higher than about 20 mb, not only the most intense ground state transitions are observed, but also whole cascades have been identified in some cases up to states having spins $I - I_{\text{ground}} = 8\%$. The observed reaction cross section is distributed among 30 final products but a large fraction of it is concentrated on products lying close to the target. Although this behavior is to be expected in this mass region for $^6$Li induced reactions of 60-100 MeV from the pure evaporation picture$^2$) we present later additional measurements which show that direct reactions contribute substantially to the total reaction cross section.

Figure 1. Distribution of the cross section on final products in the reaction $^6$Li + $^{56}$Fe at 84 MeV bombarding energy. Quoted cross sections for $^{55}$Co and $^{56}$Mn were obtained by the radioactivity measurements, other ones were determined in-beam.
The in-beam observed cross sections amount to 1020 mb at 84 MeV bombarding energy and account only for 55% of the reaction cross section estimated in terms of the optical model\(^2\). For nuclei close to the target the cross sections determined off-line for the radioactive products are 1.8 times higher than observed in-beam (mean value for \(^{58}\)Co, \(^{57}\)Co, \(^{56}\)Co and \(^{54}\)Mn). This difference cannot be accounted for by systematic errors in the absolute cross section determination and indicates that in the interaction of \(^6\)Li with \(^{56}\)Fe the reaction products are often formed in their ground states or multiple low spin, highly excited states.

In order to gather more information on the reaction mechanism, the measurements of the recoil ranges of the reaction products have been undertaken. Those measurements are still in progress but the information obtained till now has proven to be very helpful in the analysis of the reaction mechanism.

The integral recoil ranges have been measured at 55, 65 and 84 MeV \(^6\)Li bombarding energies using 4 mg/cm\(^2\) \(^{54}\)Fe and \(^{56}\)Fe targets and 2 mg/cm\(^2\) kapton catchers. The differential ranges were measured at 84 MeV using a 0.4 mg/cm\(^2\) \(^{56}\)Fe target followed by five 0.2 mg/cm\(^2\) Al catchers and one 2 mg/cm\(^2\) styrene catcher. The analysis of the experimental data follows closely the previous works in this field\(^3\).

For both targets studied one observes a clear correlation between the measured ranges and the position in the nuclear chart of the final product with respect to the target. The product nuclei lying close to the target in general exhibit much shorter ranges than those lying far from it. This correlation seems to be more pronounced for lower bombarding energies.

The distributions of ranges for cobalt and manganese isotopes is exhibited in Figure 2. Table 1 summarizes the preliminary range data for all measured products at 84 MeV bombarding energy for \(^{56}\)Fe targets.

Relatively small recoil ranges and a broad or flat distribution of the differential ranges for product nuclei lying close to the target as well as the differences in the in-beam and radioactivity determined cross sections imply that direct transfer of one or a few nucleons contributes substantially to the production of these nuclei. In particular

![Figure 2. Distributions of ranges for \(^6\)Li + \(^{56}\)Fe reaction products at 84 MeV bombarding energy.](image-url)
Table 1. Summary of the recoil range data for the reaction $^{6}\text{Li} + ^{56}\text{Fe}$ at 84 MeV bombarding energy

<table>
<thead>
<tr>
<th>Reaction Product</th>
<th>$R_\text{Ro}$ Integral Range in Fe (a) mg/cm$^2$</th>
<th>$R_\text{Ro}$ Average Range in Al (b) mg/cm$^2$</th>
<th>$R_\text{m}$ Median Range in Al (b) mg/cm$^2$</th>
<th>$\rho$ Straggling Parameter</th>
<th>$R_\text{Ro}/R_\text{CN}$ (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{57}\text{Ni}$</td>
<td>$1.0 \pm 0.1$</td>
<td>$0.636$</td>
<td>$0.630$</td>
<td>$0.46$</td>
<td>$0.75$</td>
</tr>
<tr>
<td>$^{56}\text{Ni}$</td>
<td>$1.2 \pm 0.4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{58}\text{Co}$</td>
<td>$0.8 \pm 0.1$</td>
<td>$0.653$</td>
<td>$0.650$</td>
<td>$0.40$</td>
<td>$0.79$</td>
</tr>
<tr>
<td>$^{57}\text{Co}$</td>
<td>$0.8 \pm 0.1$</td>
<td>$0.595$</td>
<td>$0.60$</td>
<td></td>
<td>$0.73$</td>
</tr>
<tr>
<td>$^{56}\text{Co}$</td>
<td>$0.7 \pm 0.1$</td>
<td>$0.511$</td>
<td>$0.47$</td>
<td></td>
<td>$0.64$</td>
</tr>
<tr>
<td>$^{55}\text{Co}$</td>
<td>$0.7 \pm 0.1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{53}\text{Fe}$</td>
<td>$1.2 \pm 0.1$</td>
<td>$0.514$</td>
<td>$0.46$</td>
<td></td>
<td>$0.60$</td>
</tr>
<tr>
<td>$^{56}\text{Mn}$</td>
<td>$0.7 \pm 0.1$</td>
<td>$0.724$</td>
<td>$0.710$</td>
<td>$0.62$</td>
<td>$0.88$</td>
</tr>
<tr>
<td>$^{54}\text{Mn}$</td>
<td>$0.9 \pm 0.1$</td>
<td>$0.702$</td>
<td>$0.680$</td>
<td>$0.70$</td>
<td>$0.88$</td>
</tr>
<tr>
<td>$^{52}\text{Mn}$</td>
<td>$0.9 \pm 0.1$</td>
<td>$0.762$</td>
<td>$0.750$</td>
<td>$0.52$</td>
<td>$0.95$</td>
</tr>
<tr>
<td>$^{51}\text{Cr}$</td>
<td>$1.1 \pm 0.1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{49}\text{Cr}$</td>
<td>$1.1 \pm 0.4$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a) Quoted errors include the counting statistic and estimated target thickness error

b) See Reference 7 for definition.

c) Influence of particle evaporation and straggling on the computed $R_\text{CN}$ is not taken into account. $R_\text{CN}$ is calculated from Reference 4 data.

The occurrence of the ($^6\text{Li}$, $^7\text{Be}$) reaction was unambiguously identified by detecting the $^7\text{Be}$ activity in a thick Fe target. In this experiment a 10 mg/cm$^2$ natural Fe target backed by a 250 mg/cm$^2$ thick target prepared from the same material was irradiated by 84 MeV $^6\text{Li}$ beam. The $^7\text{Be}$ activity was detected only in the thicker foil, indicating that energetic $^7\text{Be}$ nuclei were formed and emitted in a forward direction in this reaction. A lower limit (since $^7\text{Be}^*$ left in particle-unstable states would be missed by this method) of the energy averaged (from 84 MeV to Coulomb barrier) cross section for the reaction ($^6\text{Li}$,$^7\text{Be}$) is determined in this experiment to be equal to 4.5 mb. At 84 MeV for all reaction products (even those exhibiting the symmetric differential range distribution) the measured range in Al is smaller than that expected if the full bombarding particle momentum were transferred to the compound system. This fact indicates that a pre-equilibrium particle emission
after the absorption of the entire $^6$Li particle by
the target nucleus may be of some importance. The
reaction products which show symmetric range dis-
tribution have straggling parameter $\rho$ much higher
than was observed in reactions induced by heavier
ions in this mass region $^5$). This may be indicating$^6$)
that alpha particle emission plays a significantly
larger role in $^6$Li induced reactions.

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