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Proposals to the Physics III Committee CERN

from

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I. RECOIL MOMENTA OF PRODUCT NUCLEI FROM INTERACTION OF 25 GeV PROTONS WITH URANIUM

The very complex situation that arises when high energy protons interact with heavy nuclei has been mainly discussed in terms of two different processes, fission and spallation. In the first of these, the energy deposited in the targets leads to emission of a few nucleons and fission of the residual nucleus. The energy deposited in the target ranges from near zero to about 300 MeV.

Spallation is characterized by a fast cascade followed by the emission of a large number of nucleons and other light particles in numbers ranging from a few, up to at least 100.

The observation of light products up to $A \approx 30$ which have a forward peaked angular distribution and with high kinetic energies in the forward direction has lead to discussion of a third process, that of fragmentation. This process is assumed to be a direct emission from the target of a rather large fragment. A demonstration of this process at only 5.6 GeV is given by Poskanzer et al.[1].

While these experiments observed the light fragments, we propose in a gross manner to study the properties of the nuclei which presumably are left residuals from this kind of reaction. In this context it may be worth noting that the possible presence of clusters - especially alpha clusters - in nuclei very recently is receiving increased attention, see e.g. 2). One may in this spirit think also of other light fragments as preformed clusters.

Measurements of cross sections[3,4] and average kinetic energies[5,6] of reaction products have been measured earlier and show two distinct groups of products in this mass region. (See figs. 1 and 2). Neutron-deficient products are found to have much lower average kinetic energies and smaller average forward momenta in the laboratory system than neutron rich products of the same mass. Average kinetic energies and momenta clearly identify the neutron rich products as fission products.

The neutron-deficient products do not show the same average kinetic energies and forward momenta as the fission product and neither do they agree with the expectations for spallation products. Different empirical extrapolations[7,8,9] of spallation product properties all lead to the same results: The average kinetic energies are predicted to be lower and the forward momenta higher than what is actually observed.

In the first part of our experiment we have measured differential ranges of some of these products in 90^o to the beam[10]. These show that the neutron deficient products contain a significant contribution from fission. (See examples in figs. 3-5). The average properties are thus not specific for a certain process. If we attempt to subtract the fission contribution, we arrive at average momenta at 90^o which are more like the momenta expected from spallation[7,8,9]. However, without knowing the forward and backward momenta, it is impossible to make any suggestion about the mechanism. If the contribution from fission in the forward and backward directions are equally important as in 90^o, it seems probable that the non-fission products actually on the average move backward in the lab. -system, giving a rather strong indication that sizeable fragments are emitted forward.

As the total cross section for the presumable fragmentation products at 25 GeV may be of the order of 30 per cent of the total inelastic cross section, it seems to us that better knowledge of this process also should be of considerable interest for astrophysics if it is one of the major processes occuring at these energies in the universe.

Proposed experiment

Measurements of differential ranges in very thin plastic foils of selected products from uranium + 24-26 GeV protons. Target is about 30 μg/cm^2 uranium on 0.025 mm Be foil (= 4.6 mg/cm^2). Catchers are made of 0.35 mg/cm^2 polyetheneterephtalate (Mylar or Hostaphan) foils in stacks of about 15, placed in 24±12^o and 156±12^o to the beam. A normalizing catcher is placed in 90±12^o.

The target assembly is constructed by the PS target group (we are indebted to Mr. Steinbach and Mr. Van Rooy). One test run is done and was very successful. It will be very slightly modified with the aim of reducing pumping time which is presently about one hour before it can be introduced into the PS-vacuum.

We intend to study 10-15 products that give typical momentum distributions for fission, spallation and presumable fragmentation in the mass range 87 to 173. Five irradiations, including one reserve, of one hour each will be needed, and including mounting, pumping and demounting of the target from the PS, a total PS-time of up to a max of 12.5 hours may be needed during spring and summer this year.

The ISOLDE group has kindly agreed to let us borrow γ-ray measuring equipment at least before ISOLDE will restart in late summer. Short-lived nuclei will therefore be measured by their specific γ-rays at CERN and the longer lived products will be measured in Oslo.

II. PRODUCTION OF ^{24}Na AT INTERMEDIATE AND LOW PROTON ENERGIES

At high energies, the production of light nuclei like ^{24}Na from heavy targets has shown a rather pronounced forward peaking in the lab-system. The origin of the word fragmentation stems from this. We have studied the cross section for $U(p,X)^{24}Na$ at present from 15-170 MeV and the excitation function (See fig. 6) shows some structure at very low energies, indicating that other mechanisms than the proposed rough high energy fragmentation must be of importance. Evaporation or extremely asymmetric fission are suggested as well as triple fission. The possibility of preformed clusters in nuclei has also to be taken into account and the observed structure in the excitation function may indicate some kind of resonance energy for the process of releasing this cluster.

In order to resolve the excitation function for protons on uranium into two components at low energies (50-450 MeV), a few measurements in the region 170-600 MeV are needed. We therefore propose 8 irradiations of which 6 should be 1 h internal irradiations of thin uranium foils with C- or Be-catchers. Two may be performed in the external beam in any position except after the ISOLDE target when this is in the beam.

III. MEASUREMENTS OF AVERAGE ENERGIES, FORWARD MOMENTA AND ANISOTROPIES OF SPECIFIC FISSION PRODUCTS FROM FISSION OF LEAD INDUCED BY 600 MeV PROTONS

The model of a complex nuclear reaction in heavy nuclei as a nucleon cascade followed by nucleon evaporation and/or fission may be coupled to the liquid drop model of fission to give a complete description of high energy fission. Product cross section distributions, kinetic energies of fission fragments, anisotropies of fission fragments and intrinsic angular momenta of fission fragments may be calculated, when the models are properly used. For nuclei in the lead region the liquid drop theory of fission is seen to work well[16].

By using ISOLDE and radiochemical techniques we have well determined the cross section distributions as function of mass and charge of the fission products[17].

Until now we have only had access to cascade calculations at 380 MeV of recent date[18]. By estimating the difference between 380 MeV and 600 MeV using older cascade calculations[19], we can estimate what products are most probable after the nucleonic cascade. Comparing these with the measured most probable products after fission by using approximate results from evaporation calculations and predicted properties of fission products from the liquid drop model[16], we have calculated the deposition energies in cascades leading to fission. A few recoil measurements at 450 MeV are available in the literature[20], and our simple calculations reproduce the results from these measurements remarkably well[17].

We plan to perform cascade calculations at 600 MeV, combined with proper evaporation calculations with angular momentum included[21] and with fission as one decay mode. When using the liquid drop model predictions for the properties of fission fragments, we will finally be in a position to tell how well our models are capable of reproducing the experimental results.

Proposed experiment

Thick target thick catcher experiments at 600 MeV. Recoils collected parallel and perpendicularly to the proton beam will give information on average kinetic energies, cascade deposition energies and anisotropies of specific fission products.

We plan to do the measurements in Oslo. Four irradiations of 1-2 hours duration in the internal SC beam will be needed and two very long irradiations are wanted externally in a parasitic mode anywhere in the proton beam except behind the ISOLDE target when this is in the beam. Total target thickness will be about 120 mg/cm^2.

We want to perform and finish this experiment during 1975.

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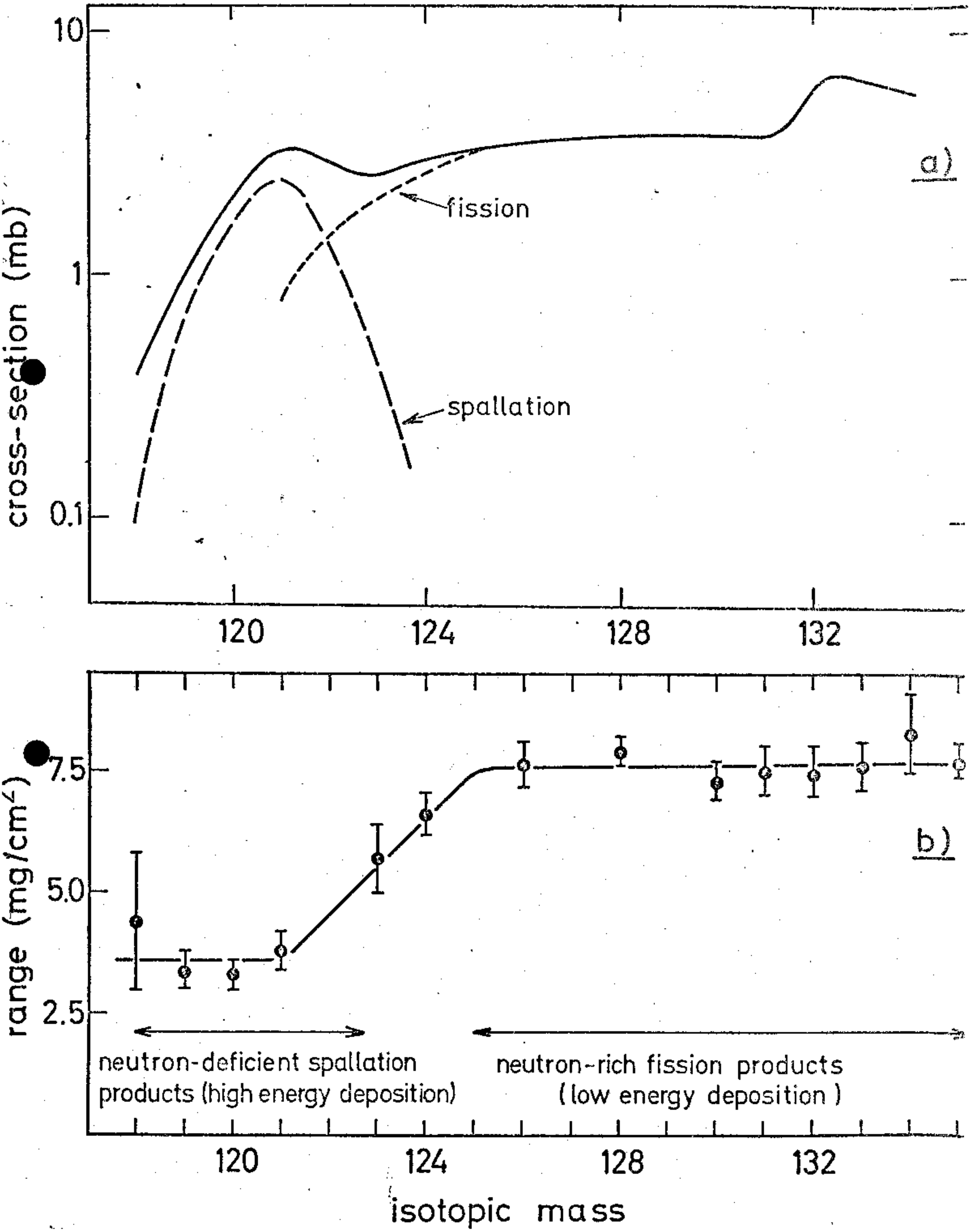
FIGURES

1. Cross section[3] (a) and average recoil reanges in uranium[5] (b) for iodine isotopes produced by uranium irradiated with 18.2 GeV protons. The term spallation is here used only to stress the non-fission character of the process.

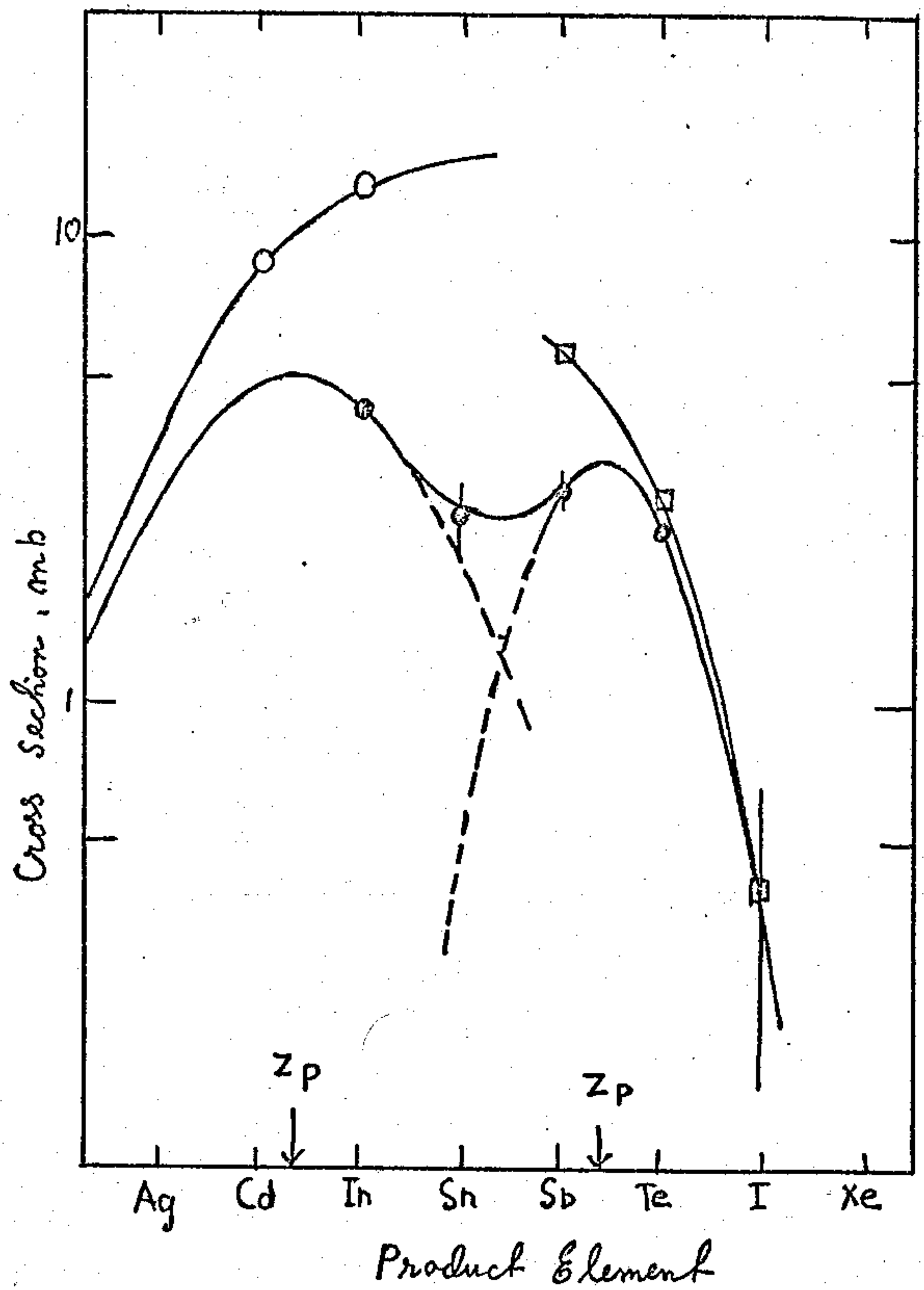
2. Charge dispersion curve for A = 117 from uranium irradiated with 18.2 GeV protons

3-5. Momentum spectra in 90^o for a typical neutron rich product ^{99}Mo, a typical neutron deficient product ^{111}In and a product which does not contain a fission contribution ^{173}Hf. Arrows indicate average momenta. (Ref. 10).

6. Excitation function for production of ^{24}Na from uranium.
   $E_p \lesssim 170$ MeV: The Oslo group.
   $E_p \gtrsim 340$ MeV: Refs. 11 - 15.

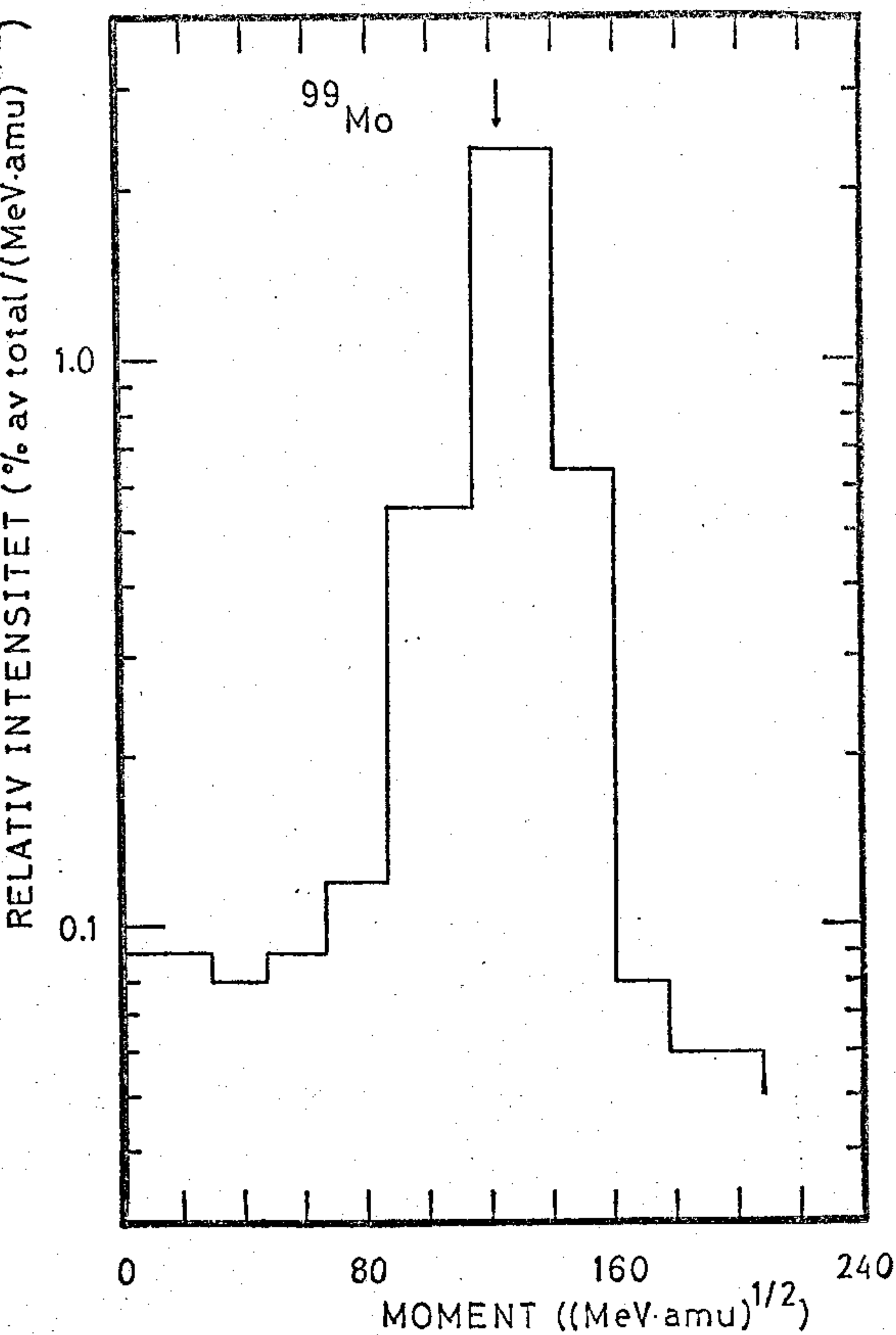


10
1
0.1
cross-section (mb)
fission
spallation
a)
120
124
128
132
7.5
5.0
2.5
range (mg/cm²)
b)
neutron-deficient spallation products (high energy deposition)
neutron-rich fission products (low energy deposition)
120
124
128
132
isotopic mass



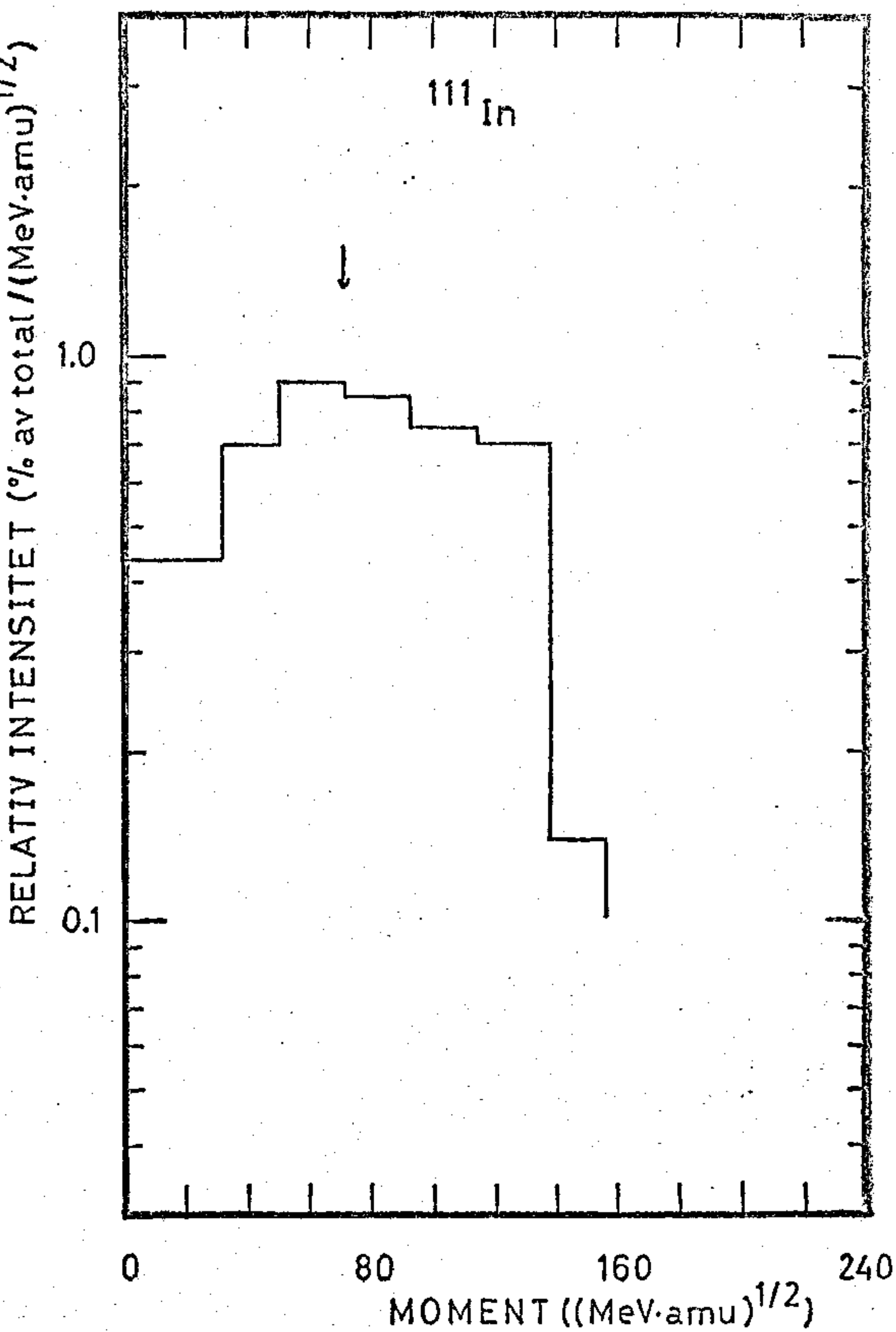
Cross Section, mb
10
1
Zp
Zp
Ag
Cd
In
Sn
Sb
Te
I
Xe
Product Element

Figure 2



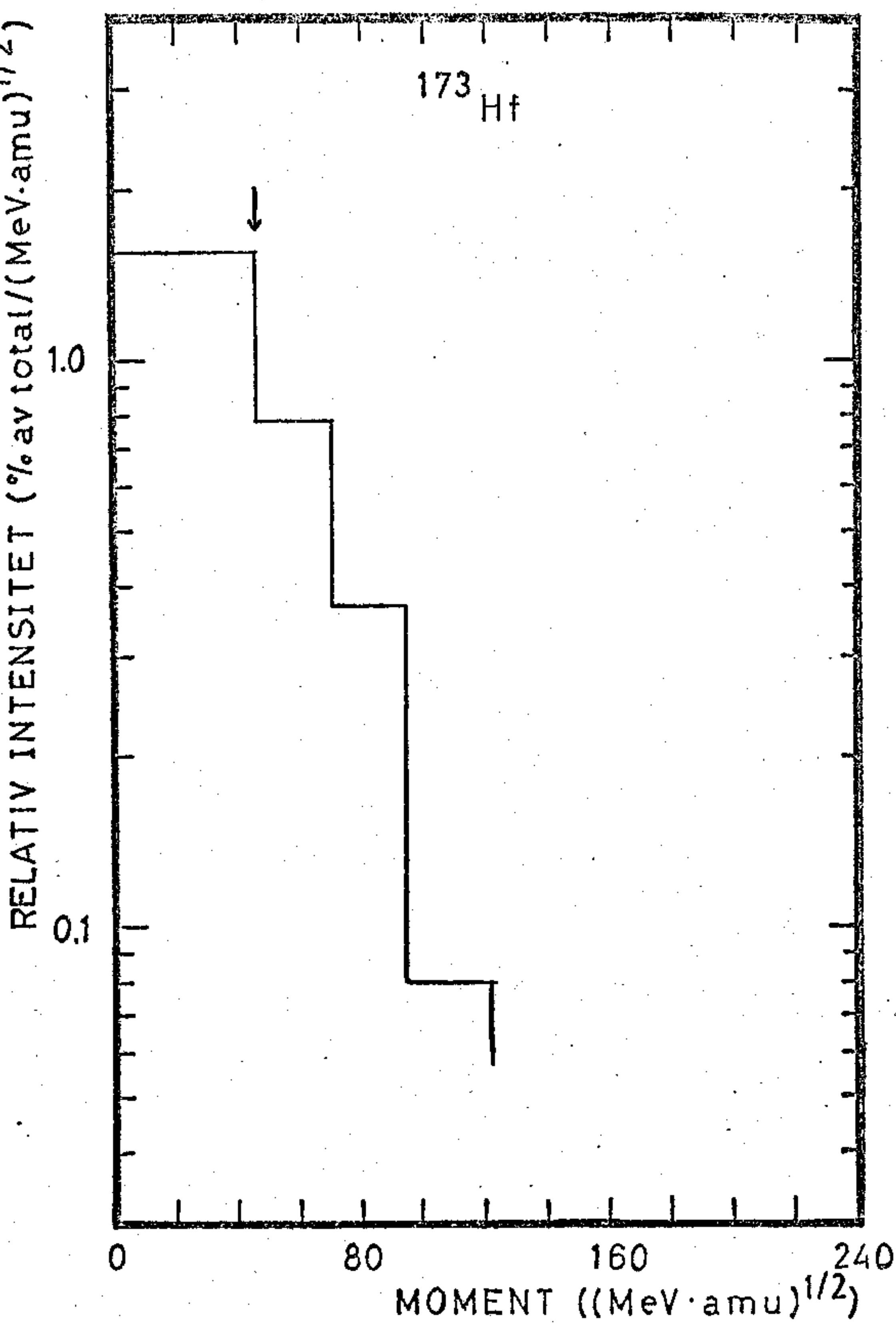
99Mo
1.0
0.1
RELATIV INTENSITET (% av total / (MeV·amu)1/2)
0
80
160
240
MOMENT ((MeV·amu)1/2)

Figure 3



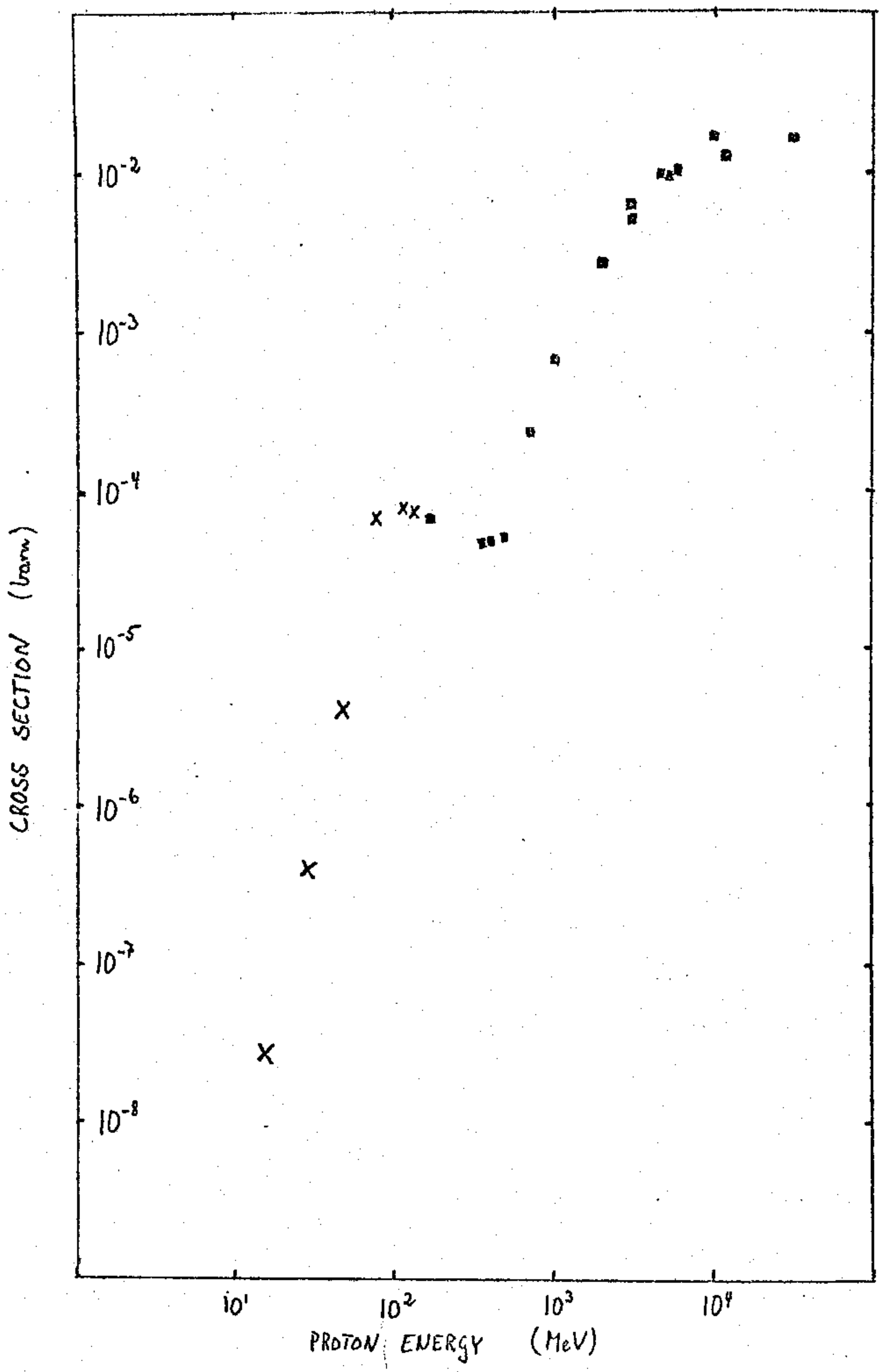
111In
1.0
0.1
RELATIV INTENSITET (% av total /(MeV·amu)1/2)
0
80
160
240
MOMENT ((MeV·amu)1/2)

Figure 4



173Hf
RELATIV INTENSITET (% av total/(MeV·amu)1/2)
1.0
0.1
0
80
160
240
MOMENT ((MeV·amu)1/2)

Figure 5


CROSS SECTION (barn)
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^1
10^2
10^3
10^4
PROTON ENERGY (MeV)
Figure 5