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ACCELERATION OF FISSION FRAGMENTS*

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November 1969

Fission fragments produced by the isotope ^{252}Cf were accelerated to energies of ~ 200 MeV using an MP Van de Graaff accelerator. The fragment energy spectra were measured as a function of accelerator voltage. Some information was obtained on the average charges of the fragments. Estimates are given of the energies which could be attained by fragments if much higher acceleration voltages are used.

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The purpose of this letter is to present the results of experiments in which fission fragments were accelerated from an average energy of ~ 80 MeV up to an average energy of ~ 200 MeV.

These experiments were undertaken to investigate a possible means of circumventing the present difficulties associated with the acceleration of heavy ions. The difficulty is that present accelerators are not able to accelerate ions of mass much greater than argon to energies sufficient to

penetrate the Coulomb barrier of uranium (the value of B_c for the reaction $^{238}U + {}^{140}Xe$ is about 725 MeV).

If such energetic heavy ions were available, an exciting new region of nuclear reactions would become accessible. It should then be possible for example to find out whether compound nucleus products are formed, to determine the conditions for such reactions, and investigate reaction dynamics. One might even test certain predictions of the liquid drop theories as applied to heavy-ion reactions. It should be noted that large negative Q values in the new region which is made accessible by heavier projectiles may make it possible to study new kinds of reaction products which could be formed at relatively low excitation energies.

The availability of energetic ions much heavier than argon would also present new possibilities in the search for superheavy elements. Some of these possibilities are discussed by several authors[1,2,3,4] in connection with their calculations concerning special stability associated with Z = 114 and N = 184. These calculations indicate that a major difficulty in producing observable superheavy nuclei by nuclear reactions involving presently available projectiles is that the products tend to be extremely neutron deficient. The half lives are expected to increase by factors of 10^2 to 10^3 as the result of the addition of each neutron.

The use of fission fragments as projectiles may have certain advantages over conventional ions in attempting to solve some of the problems mentioned above. The fragments have high initial charges ($\bar{q} \sim 20$) and energies of the order of 80 MeV to begin with and they have a greater neutron richness than is available from any other projectile. Further, since the probable reac-

tions leading to a stable superheavy element nucleus have not been specifically isolated, the extensive range of projectile masses and energies arriving at the target might even be an advantage.

A preliminary experiment was performed at the MP accelerator at High Voltage Engineering Corporation in Burlington, Massachusetts. A source of 6 μg of ^{252}Cf was placed at the high voltage terminal. A schematic drawing of the setup is shown in Fig. 1. The fragments were emitted from a source of ~ 3 mm diameter prepared by R. Latimer of the Lawrence Radiation Laboratory in Berkeley. In order to prevent contamination of the accelerator the source was covered by several protective layers; first by a coating of 200 $\mu g/cm^2$ of aluminum, then a 100 $\mu g/cm^2$ nickel foil and finally ~ 3 cm downstream there was a 10 $\mu g/cm^2$ carbon foil. Both thin foils were held on a 92% transparent electromesh and lasted without breaking throughout repeated careful evacuations of the system. The mean energy loss in the protective covers was about 13 MeV.

The fragments passed through a 1 in. diameter tube placed inside a 15 in. long quadrupole magnet (a doublet made of permanent magnets) which was designed to focus a source placed ~ 2 in. from the end of the magnet into a parallel beam. Another electromesh was placed before the entrance to the first accelerating tube to prevent any sparks from entering the source holder. At the midsection of the acceleration column there was a removable thin carbon foil to strip the fragments of additional electrons after partial acceleration. Another quadrupole lens, this one an electromagnet, was used at the high energy end of the accelerator to focus the fragments onto a 4.5 cm^2 surface barrier detector. The distance from the source to the de-

tector was ~ 17 meters.

When the high voltage in the accelerator was first turned on there was some "dark current" composed probably of hydrocarbons and other outgassing products which impinged on the solid-state detector. However, this was reduced significantly as the accelerator was "conditioned." Further significant reduction in the dark current was observed when the thin carbon foils were put into the beam.

The fragments were accelerated as was expected; the energy spectra as a function of terminal voltage are shown in Fig. 2 in which the channel numbers correspond rather closely to units of MeV. The maximum voltage on the terminal in our experiments was 6 MV.

Because of their larger initial charges, the energies of the heavy fragments increase more rapidly than the energies of the light fragments. At a voltage of 2 MV there is still a difference as indicated by the shoulder on the spectrum. At 4 MV the two groups are indistinguishable. At 6 MV the average energy of the fragments was about 200 MeV and the width of the energy distribution (FWHM) was ~ 45 MeV. As the acceleration voltage increased the widths of the two energy distributions of californium fragments increased as would be expected on the basis of a distribution in the charge states of the fragments.

An accurate determination of the energy spectra depends on an accurate calibration of channel number versus energy. Therefore some knowledge of the pulse-height response of solid-state detectors to heavy ions is necessary. As a basis for this calibration we used the well known energy spectrum obtained from a ^{252}Cf standard source located in front of our detector.

The energies obtained on the basis of the following two assumptions were then compared: 1) A linear response of the detector was assumed and the average energies of the light and heavy peaks were taken to be those given by Fraser et al.[5] 2) The "Schmitt calibration procedure" which prescribes a mass dependent pulse-height response was assumed.[6]

The mean values of the energy spectra are shown in Fig. 3. Some ambiguity due to the uncertainty in exact positions of the light and heavy peaks occurs in the Schmitt calibration and is indicated by the small bars. It can be seen that there is a discrepancy of over 10 MeV between the two calibration methods at an energy of ~ 200 MeV. Therefore we have obtained two different values for the overall average charge state of the fragments: $\bar{q}$ = 19.2 is obtained by the Fraser[5] calibration and 21.0 is obtained using the Schmitt[6] calibration. Information about the mean charge of the light and heavy fragments separately was obtained from the data taken at a voltage of 2 MV where the two peaks could still be resolved. These results also depend on the choice of a calibration procedure and are 17.5 to 18.8 for the light fragments and 20.8 to 23.0 for the heavy ones.

The mean charges of the heavy fragments are in agreement with the values obtained from the data of experiments performed at High Voltage Engineering Corporation by Grodzins et al.[7] and Moak et al.[8] Comparisons of the mean charge state were made at the same ion velocities (appropriate corrections were made for the 13 amu difference between stable ^{127}I and fission fragment ^{140}I). For the light fragments the above reference would predict a mean charge of 21.0; whereas, our experimental value is 18 ± 1. This difference may be due to the effect of selection by the focussing magnet at the

source.

The intensity of the beam of fragments at the end of the 17-meter acceleration path is shown as a function of terminal voltage in the upper part of Fig. 3. The observed increase in intensity as a function of voltage exceeds the expected increase due to electrostatic focussing of a perfectly aligned system. Increased electrostatic focussing tends to reduce the effect of errors in alignment. These results show that the system was not well aligned to begin with and indicate that additional intensity could have been obtained. The source emitted 5×10^8 fragments/min into 4π solid angle and at 6 MV we obtained 2.25×10^3 fragments/min. The transmission factor, therefore, was 4.5×10^{-6} as compared with a geometrical transmission of 1.3×10^{-7}.

The insertion of a carbon foil reduced the intensity from 2.25×10^3/min to about 1.5×10^3/min. We are unable to determine whether this is due only to the scattering by the foil or whether it is due to an effect on the acceptance angle.

The source used in this experiment also emits 10^{10} α/min and 2×10^9 fast n/min. It was mounted and taken out of position without any difficulties and no contamination at the entrance of the acceleration tubes could be detected after its removal from the high-voltage terminal. (The upper limit of contamination was less than 10 alpha disintegrations per minute per square foot of surface.)

The method of acceleration discussed here could be incorporated with the Hilab project[9] which combines a TU and an MP accelerator. The source could be placed at the high-voltage terminal of the TU. On the basis of our

results on the mean charge state and results of other groups, we can calculate the final energy. Assuming the addition of a carbon stripping foil at any available location where it helps to increase the energy we would obtain 880 MeV for the light fragments and 900 MeV for the heavy ones with an energy spread of ~ 160 MeV (FWHM). These values are calculated on the basis of the conservative terminal voltages of 16 MV on the TU and 10 MV on the MP. At the end of the TU alone with terminal voltage of 16 MV the energies would be 526 and 516 MeV for the light fragments and heavy fragments respectively. With a voltage of 20 MV on the TU the energies would be 620 and 640 MeV for light and heavy fragments respectively. Thus at the end of the TU only the light fragments could be used to induce nuclear reactions in uranium.

The transmission of a system which starts with a 10 mg ^{252}Cf source and has a quadrupole magnet in every bellows between the acceleration tubes could be as large as 10^{-5} according to calculations by A. Garren. The beam would then be 8×10^{6} fragments/min. Included in this estimate a factor of 30 or so is due to variation in magnetic rigidity and scattering losses due to the strippers. The low transmission is due in part to the large area source that must be used. The source thickness cannot exceed 1-2 mg/cm^2; otherwise, the energies and charges of the fragments would be decreased too much. With a transmission of 10^{-5} the beam intensity is small in comparison with those obtained with more conventional particles. Whether useful experiments can be done depends primarily on the reaction cross sections which can range from 10^{-24} cm^2 down to $< 10^{-34}$ cm^2. However, for the purposes of orientation let us assume that the cross section for fission in the reaction $^{238}U + {}^{140}Xe$ is about 1 barn. The fractional yield for a single interesting

product might be of the order 10^{-3}. Then using a target of thickness 2 mg/cm^2 and assuming that 10% of the fragments are useful in producing something of interest we obtain 4×10^{-3} events per min (~ 60 per day). Such numbers are small but not unheard of in heavy element research.

In conclusion we have demonstrated that the acceleration of fission fragments takes place as expected. The operation was carried out safely with a moderately strong ^{252}Cf spontaneous fission source. On the basis of our results it seems clear that the fragments can be accelerated to energies sufficient to overcome the Coulomb barrier of uranium. The most important difficulty which might be encountered unless some improved method of focussing the fragments is found is that the particle flux might be rather small.

We are grateful to Dr. A. Garren for his calculations of the optimum conditions for focussing of fission fragments. The help of James Haley with the ^{252}Cf source and with the experiments was indispensable. We also wish to express our gratitude to Peter Rose, Jacques Shaw and Wernher Scheer of the High Voltage Engineering Corporation for help with planning and carrying out the experiments. We are indebted to William Pope for assistance in the construction and assembly of the quadrupole magnets and with the equipment in which the source was mounted.

FOOTNOTES AND REFERENCES

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†On leave from the Weizmann Institute of Science, Rehovoth, Israel.

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FIGURE CAPTIONS

Fig. 1. Experimental arrangement. The californium source holder with its protective foils is shown in detail in the insert.

Fig. 2. Spectra of the fragments for several terminal voltages. The standard source shown in the upper part is not covered with any protective foils. 1 channel $\approx$ 1 MeV. $\bar{N}$ is the mean value of the distribution in channel numbers.

Fig. 3. (a) Intensity as a function of terminal voltage.

(b) The mean energy as a function of the terminal voltage for two calibration procedures as explained in the text.

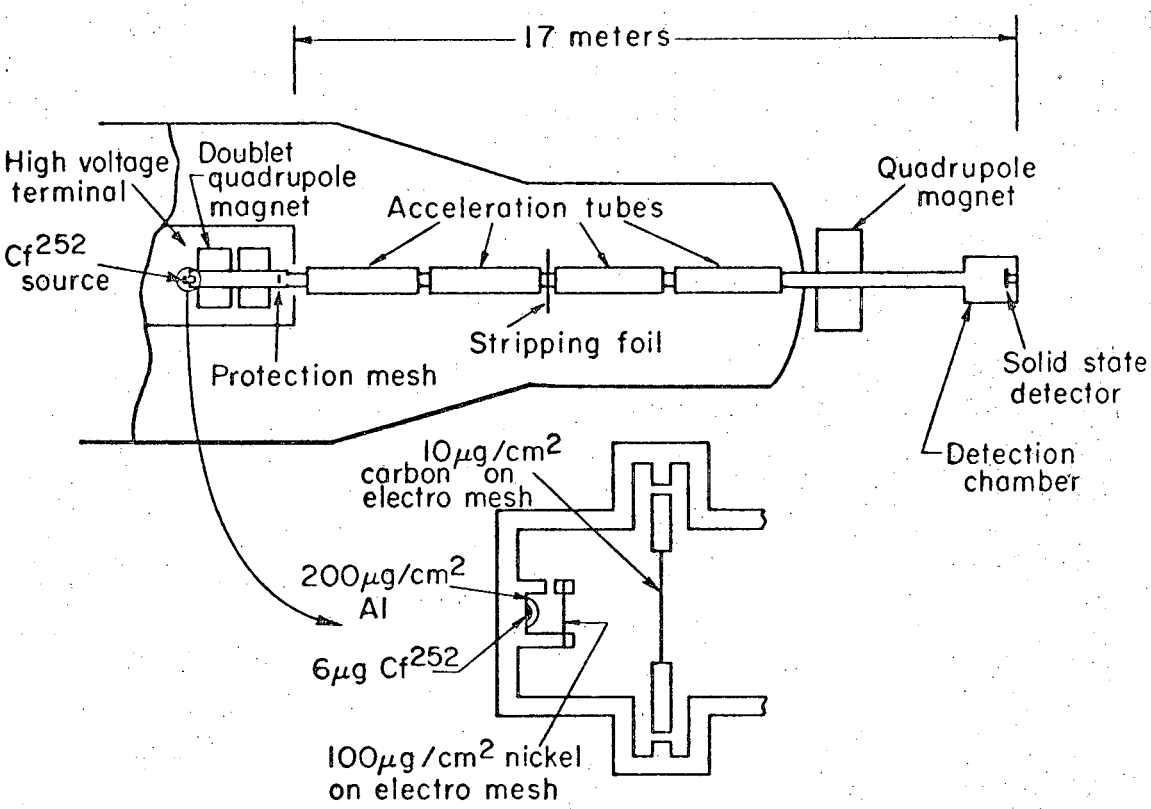
17 meters
High voltage terminal
Doublet quadrupole magnet
Acceleration tubes
Quadrupole magnet
Cf252 source
Stripping foil
Protection mesh
Solid state detector
Detection chamber
10μg/cm2 carbon on electro mesh
200μg/cm2 Al
6μg Cf252
100μg/cm2 nickel on electro mesh
XBL6911-6259

Fig. 1

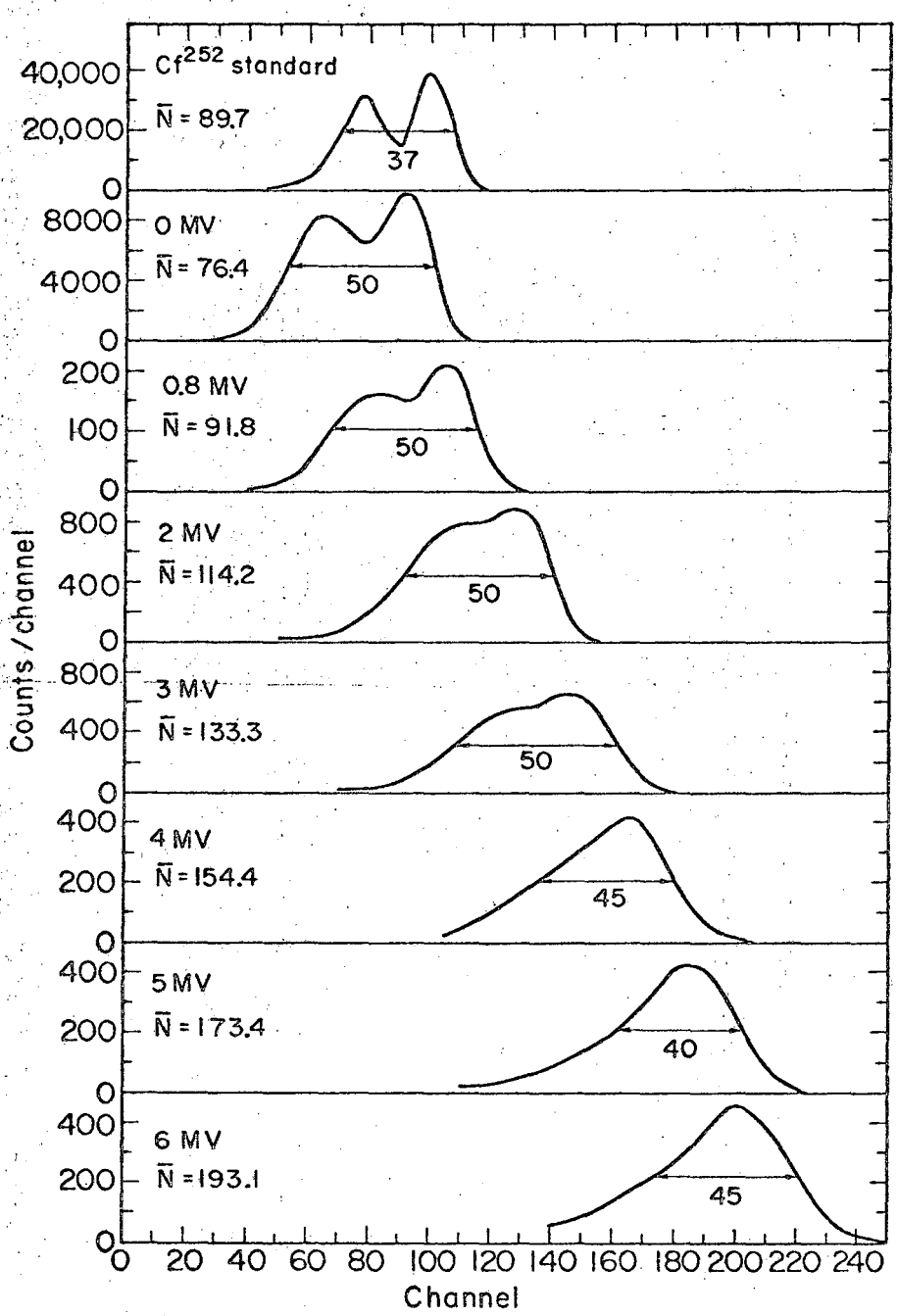
Cf252 standard
N̄ = 89.7
37
0 MV
N̄ = 76.4
50
0.8 MV
N̄ = 91.8
50
2 MV
N̄ = 114.2
50
3 MV
N̄ = 133.3
50
4 MV
N̄ = 154.4
45
5 MV
N̄ = 173.4
40
6 MV
N̄ = 193.1
45
Counts / channel
Channel
XBL6911 - 6260

Fig. 2

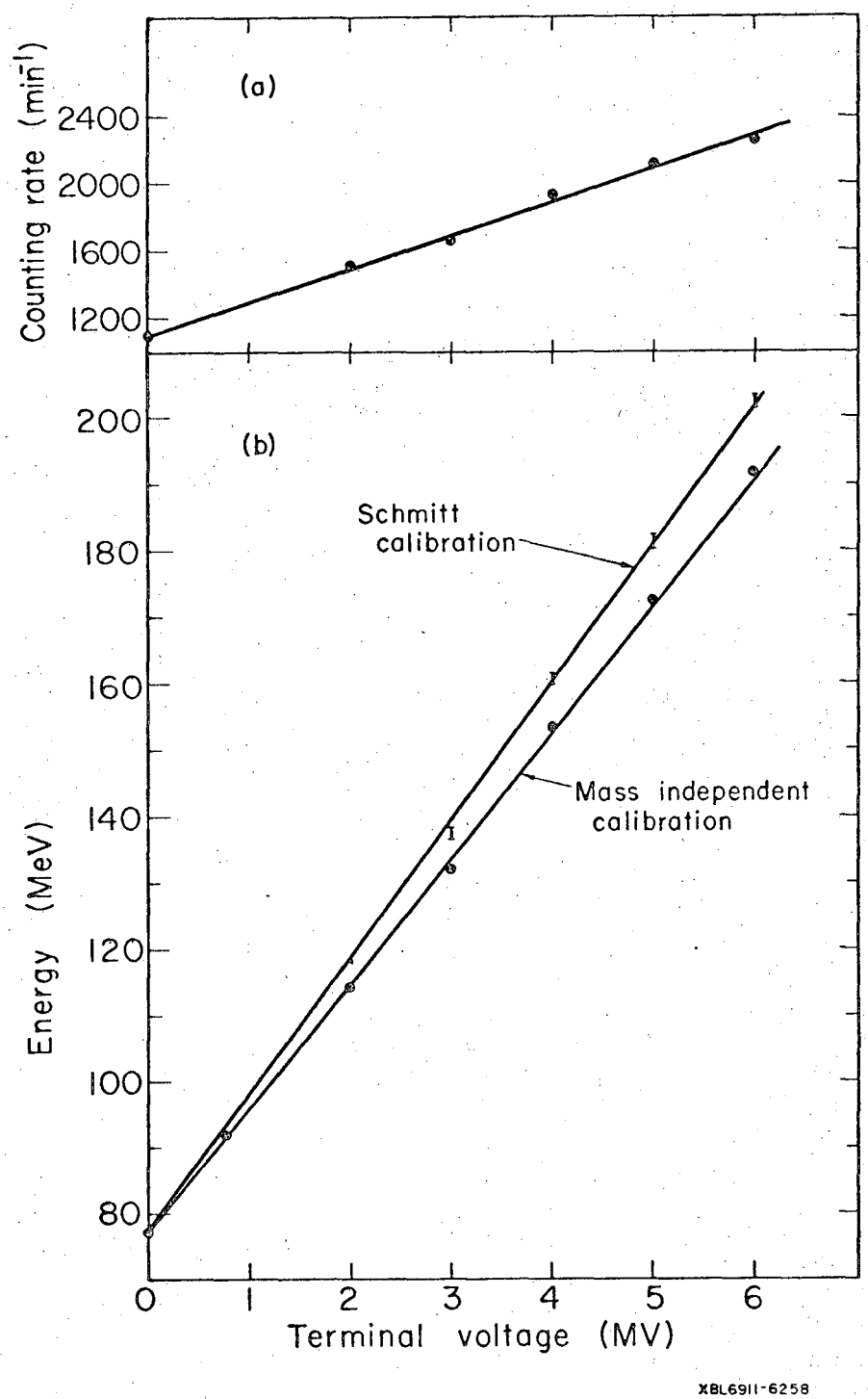
(a)
Counting rate (min⁻¹)
2400
2000
1600
1200
(b)
Schmitt calibration
Mass independent calibration
Energy (MeV)
200
180
160
140
120
100
80
0
1
2
3
4
5
6
Terminal voltage (MV)
XBL6911-6258

Fig. 3

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