Title

FISSION OF 232Th, 238U, 244Pu, 248Cm INDUCED BY Xe AND Kr IONS AT COULOMB BARRIER ENERGIES

Permalink

https://escholarship.org/uc/item/5225n00x

Author

Butler, P.A.

Publication Date

1977-03-01

Submitted to Physics Letters B

LBL-5854
Preprint c.1

FISSION OF ^{232}Th, ^{238}U, ^{244}Pu, ^{248}Cm INDUCED BY Xe AND Kr IONS AT COULOMB BARRIER ENERGIES

P. A. Butler, I. Y. Lee, J. O. Newton, Y. El-Masri,
M. M. Aleonard, P. Colombani, R. M. Diamond,
F. S. Stephens, R. W. Lougheed, and E. K. Hulet

March 1977

Prepared for the U. S. Energy Research and
Development Administration under Contract W-7405-ENG-48

DISCLAIMER

FISSION OF ^{232}Th, ^{238}U, ^{244}Pu, ^{248}Cm INDUCED BY Xe AND Kr IONS AT COULOMB BARRIER ENERGIES[*]

P. A. Butler
Laboratory for Nuclear Science
Massachusetts Institute of Technology, Cambridge, Mass. 02139

I. Y. Lee, J. O. Newton,[†] Y. El-Masri,[††] M. M. Aleonard[†††]
P. Colombani,[††††] R. M. Diamond and F. S. Stephens
Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

R. W. Lougheed and E. K. Hulet
Lawrence Livermore Laboratory
University of California
Livermore, California 94550

ABSTRACT

Excitation functions and angular distributions have been measured for the fission of ^{232}Th, ^{238}U, ^{244}Pu and ^{248}Cm induced by ^{86}Kr and ^{136}Xe ions at energies in the vicinity of the Coulomb barrier. No large differences as a function of either target or projectile were found. These results suggest that the main process occurring is not Coulomb fission.

---

[*] This work was done with support from the U.S. Energy Research and Development Administration.

[†] On leave from the Australian National University, Canberra, A.C.T. 2600 Australia

[††] On leave from Institut de Physique Corpusculaire, B-1348 Louvain-la-Neuve, Belgium

[†††] On leave from Centre d'Etudes Nucleaires de Bordeaux-Gradignan, Domaine du Haut-Vigneau, 33170 Gradignan, France

[††††] Present address, Institut de Physique Nucleaire, 91406 Orsay, France

The possibility of fission induced by the Coulomb field of ions with sufficiently high nuclear charge ($Z > 50$) has been of interest [1-3] for some time. The availability of such heavy-ion beams has recently permitted these ideas to be tested experimentally. We have reported measurements of excitation functions for ^{86}Kr(Z = 36) and ^{136}Xe(Z = 54) induced fission of ^{232}Th and ^{238}U which showed that fission of the heavy targets could be induced at incident energies below the Coulomb barrier [4]. These data did not show unambiguously that there was any pure Coulomb fission although there were some positive indications. The present work was undertaken in an attempt to resolve this question.

In order to distinguish Coulomb fission from that caused by nuclear processes, we have studied the dependence of the fission cross sections on projectile Z at incident energies below the Coulomb barrier, where pure Coulomb effects are expected to increase relative to nuclear processes as the energy decreases. We have also studied the dependence of the cross sections on the fission barrier, to which Coulomb-induced fission might be expected to be sensitive. In contrast, those nuclear processes which involve excitations comparable to or greater than the fission barrier, would be unlikely to be very sensitive to the barrier. In addition, we have measured angular distributions of the fission fragments. The angular distribution for Coulomb fission should peak at 90° to the beam axis for head-on collisions provided the fission takes place when the projectile is still very near the target [1,3]. On the other hand, fission following direct nuclear processes, such as transfer reactions or deep-inelastic scattering, is more likely to peak forward and backward along the recoil direction [5].

In this letter we report new measurements on the Kr and Xe induced fission of ^{232}Th and ^{238}U (barrier heights 6.0 and 5.8 MeV respectively [6]), and results for fission of ^{244}Pu (barrier height 5.4 MeV [6]) and ^{248}Cm. One might expect that the Coulomb fission cross section would depend quite strongly on both the fission barrier height and the detailed shape of the potential energy surface. The spontaneous fission half-lives are also sensitive to both of these quantities (though not in the same detailed way) and the wide spread of these half-lives in these nuclei (^{232}Th, $> 10^{21}$yr, ^{238}U, 7×10^{15}yr; ^{244}Pu, 3×10^{10}yr; and ^{248}Cm, 5×10^{6}yr) suggests that there might be appreciable differences in the probability for Coulomb fission.

The ^{136}Xe and ^{86}Kr beams were produced by the SuperHILAC at the Lawrence Berkeley Laboratory. Beam energies were measured by time-of-flight and, for the Kr runs, independently checked by magnetic analysis; the uncertainty was 0.5%. The rolled 2.0 mg/cm^2 ^{232}Th target was self-supporting: the 0.64 mg/cm^2 ^{238}U was evaporated on 0.5 mg/cm^2 Al. The 0.94 mg/cm^2 ^{248}Cm, in the form of CmF_3, was evaporated onto a 1.2 mg/cm^2 Al backing, and the 0.30 mg/cm^2 ^{244}Pu, in the form PuO_2, was electroplated on 1.2 mg/cm^2 Ni.

The detection system for the excitation function measurements is identical to that described before [4] and allows detection of coincident fission fragments in four 1.5 × 0.8 cm detectors (each subtending 70° in ϕ and about 10° in θ), in (triple) coincidence with the backscattered projectile detected in an annular counter. The average c.m. scattering angle was about 164°.

In order to determine the differential fission cross sections with respect to the backscattered projectile, $\frac{d\sigma}{d\Omega_p}$, which are shown in Fig. 1, we have assumed that the collision is nearly elastic, that the fission fragment mass distribution is asymmetric, and that the fragment angular distribution has the limiting form $\frac{d\sigma}{d\Omega_p} \propto \frac{1}{\sin\theta_f}$ in the c.m., where θ_f is measured from the direction of the recoiling heavy nucleus. The last assumption gives an upper limit to the cross section and is in rough accordance with the measurements over the limited range of angles used (Fig. 2). An assumption of isotropy for the angular distribution would change the efficiency by 30-40%. At the lowest beam energy for each target and each projectile, the values of the backscatter solid angle, target thickness, and accuracy of the beam charge collection were verified by comparing the measured elastic scattering rate with that expected from Rutherford scattering. It was estimated that the overall uncertainty in the measured cross sections from all sources, including the assumptions made, is about 50%. The relative uncertainty between the Kr and Xe excitation functions is better than 35%, whereas for the same projectile the uncertainty between runs at different bombarding energies and on different targets is no more than 20%. This last error is included together with the statistical errors in the values of $\frac{d\sigma}{d\Omega_p}$ shown in Fig. 1. Finally, the effective bombarding energy E_{eff} corresponding to the measured value of $\frac{d\sigma}{d\Omega_p}$ was determined in an iterative procedure, using the self-consistent relation:

$$\frac{d\sigma}{d\Omega_p}(E_{eff}) \text{ measured} = \int_{\text{target}} \frac{d\sigma}{d\Omega_p}(E)\, dE \Big/ \int_{\text{target}} dE$$

The fission-fragment angular distribution $\frac{d^2\sigma}{d\Omega_p d\Omega_f}$, was measured with a single counter with solid angle ∿ 0.05 sr, subtending about 5° in θ. By requiring a coincidence with a backscattered particle, only those heavy fissioning nuclei which recoiled at about 10° to the beam axis were selected. The recoil direction was further restricted to $\pm 45^\circ$ in ϕ by masking the annular backscatter counter. It was thus possible to measure the angular distribution as far forward as $\theta_f = 40^\circ$ (c.m.) without placing the fission counter closer than 20° (lab) to the beam axis. In the Xe runs, the angular distributions were normalized to the total number of elastically backscattered particles. For the high energy Kr + Cm run, this was not possible because of background from the spontaneous fission of Cm; in this case, the normalization was made using the total beam current integrated in each run. The values of $\frac{d^2\sigma}{d\Omega_p d\Omega_f}$ shown in Fig. 2 include an uncertainty of 20% which is inherent in the estimated relative values of the c.m. solid angle of the fission counter.

The excitation functions for each target shown in Fig. 1 are quite similar, and the variation for different targets is small. The large difference between the Xe and Kr excitation functions reported previously [4] is no longer apparent. This inconsistency is due mainly to an arithmetic error of 2% in the beam energy measurement in the previous Kr experiment. The previous data, corrected for this error and in addition a smaller normalization error, have been included in Fig. 1. Although the large difference between the Xe and Kr cross sections for ^{238}U has disappeared, nevertheless the Xe cross sections for ^{238}U, ^{244}Pu and ^{248}Cm remain ∿ 50% larger than those for Kr. The fission angular distribution measurements are shown in Fig. 2. They indicate $\frac{d^2\sigma}{d\Omega_p d\Omega_f}$ is larger at small θ_f than at $\theta_f = 90^\circ$, though the data for two of the systems are consistent with isotropic emission of the fission fragments.

The fission events discussed here do not appear to be due to pure Coulomb fission because there is no large variation with projectile, target or fission fragment angle. However we cannot exclude the presence of appreciable Coulomb fission since 1) the Xe cross sections are significantly higher than those for Kr for the U, Pu and Cm targets, 2) the dependence of the Coulomb fission process on the fission barrier is not reliably known, and 3) there is uncertainty as to the exact form of the angular distribution for both nuclear and pure Coulomb processes. It seems more likely that the observed events are due to a nuclear process such as transfer induced fission. In this case the lack of sensitivity to the fission barrier probably indicates that the process involves excitation energies comparable to or greater than the fission barrier.

REFERENCES

[1] L. Wilets, E. Guth, and J. S. Tenn, Phys. Rev. 156 (1967) 1349

[2] H. Holm and W. Greiner, Nucl. Phys. A195 (1972) 333

[3] K. Beyer and A. Winther, Phys. Lett. 30B (1969) 296

[4] P. Colombani, P. A. Butler, I. Y. Lee, D. Cline, R. M. Diamond, F. S. Stephens and D. Ward, Phys. Lett. 65B (1976) 39

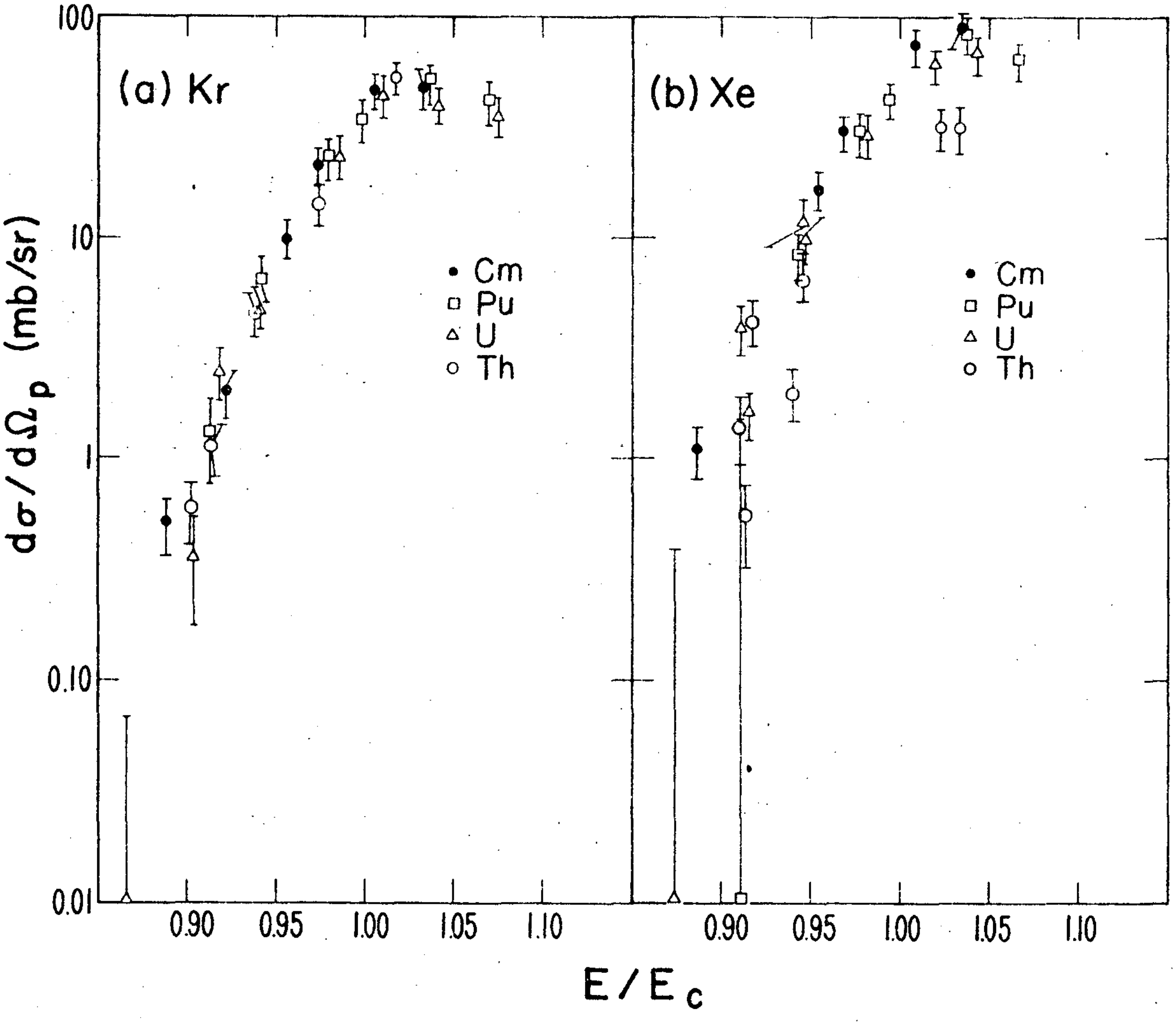
[5] J. R. Huizenga, J. P. Unik and B. D. Wilkins in *Proceedings of the Symposium on Physics and Chemistry of Fission*, (I.A.E.A., Vienna, 1965) Vol. I, p. 11

[6] R. Vandenbosch and J. R. Huizenga in *Nuclear Fission* (Academic Press, N.Y. 1973) p. 255.

FIGURE CAPTIONS

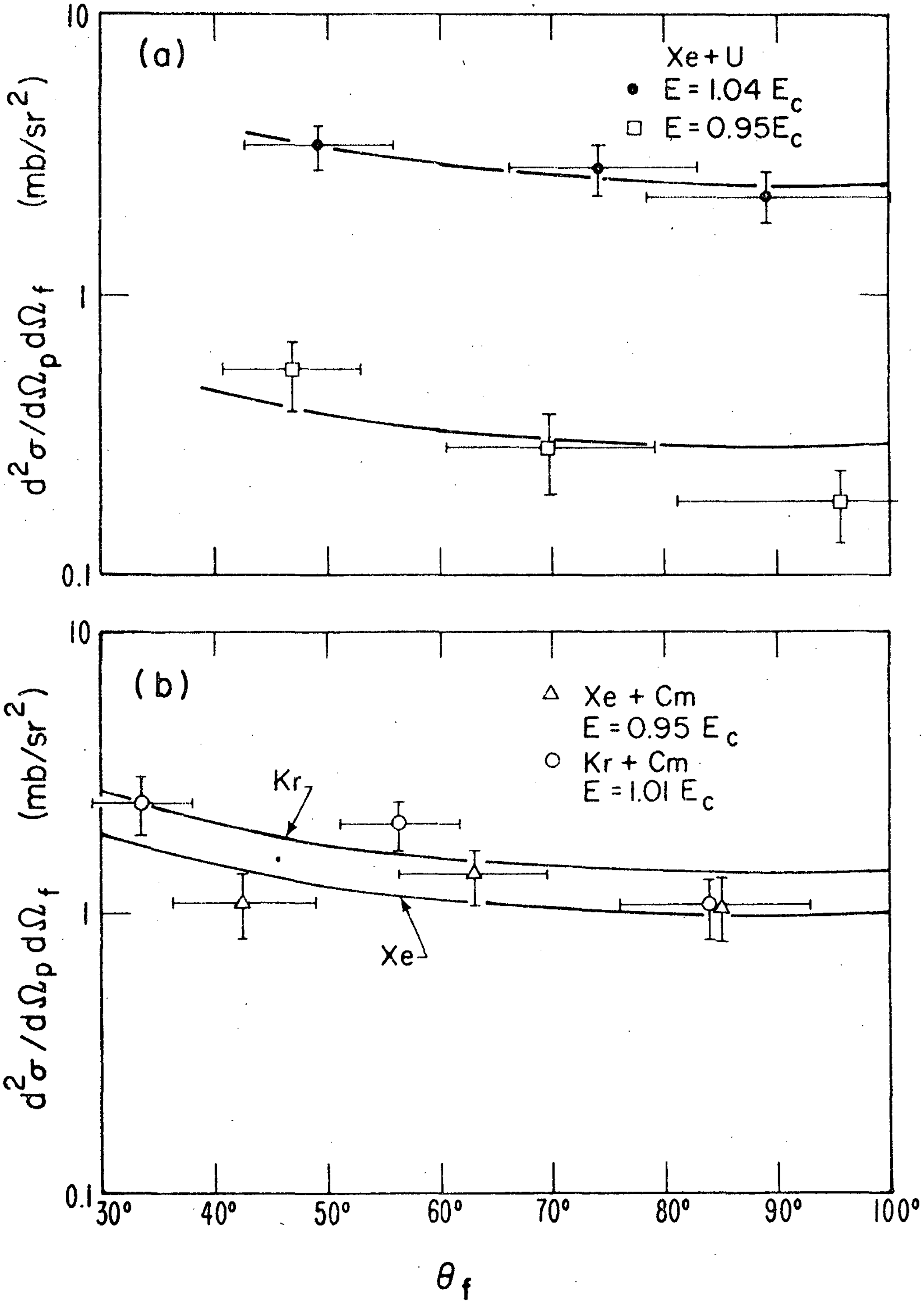
Fig. 1 Differential cross sections with respect to the backscattered projectile $\frac{d\sigma}{d\Omega_p}$ (in c.m.) at $\theta_p = 164^\circ$ (c.m.) for a) ^{86}Kr and b) ^{136}Xe induced fission of ^{232}Th, ^{238}U, ^{244}Pu, ^{248}Cm as a function of bombarding energy. The incident energy E is expressed as a fraction of the Coulomb barrier E_c evaluated using an interaction radius $R = 1.16\ (A_1^{1/3} + A_2^{1/3} + 2)$ fm.

Fig. 2 Fission fragment angular distributions $\frac{d^2\sigma}{d\Omega_p d\Omega_f}$ at $\theta_p = 160^\circ$ (c.m.) for a) ^{136}Xe + ^{238}U ($E = 1.04\ E_c$ and $E = 0.95\ E_c$); and b) ^{136}Xe + ^{248}Cm ($E = 0.95\ E_c$) and ^{86}Kr + ^{248}Cm ($E = 1.01\ E_c$). The horizontal bars reflect the range of θ_f seen in the fission detector caused by its finite solid angle. The best fit for a $1/\sin\theta$ distribution is indicated by the solid lines.


(a) Kr
(b) Xe
● Cm
□ Pu
△ U
○ Th
dσ/dΩ_p (mb/sr)
100
10
1
0.10
0.01
0.90
0.95
1.00
1.05
1.10
E/E_c

XBL 7612-11145 A

Fig. 1



XBL 7612-11146

Fig. 2

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720