THE EMISSION OF K-X-RAYS IN SLOW NEUTRON FISSION
OF ^{233}U, ^{235}U, AND ^{239}Pu*

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Present techniques admit the possibility of studying the character of fission fragments with spectroscopic identification of pairs of fragments. The simultaneous measurement of the masses and atomic numbers of fission fragments has been demonstrated in studies of the fission of ^{252}Cf (1). The atomic number is determined by detection of a characteristic x-ray, most often a K-x-ray, emitted by one of the fragments. These x-rays arise from atomic electron vacancies produced by internal conversion in the deexcitation of the fragments (2). Not surprisingly, there is considerable structure in yield as a function of the masses of the fragments (1) and of their atomic numbers (3).

The work reported in this letter sought to determine the feasibility of studies of slow neutron induced fission by multi-parameter measurements which include K-x-ray identification of atomic number. Such measurements require an appreciable yield of K-x-rays from the fragments, but, more importantly, this method of identification must not introduce an unknown bias in the selection. It is clear that the structure in yields implies that a considerable bias is introduced by requiring the emission of a

K-x-ray, but the degree to which this bias depends on features of
the fission process, other than the Z and A distributions of the
fragments, is not known. Eismont and Yurgenson (4) have discussed
the rationale for a universal dependence of x-ray emission
probability on the Z and A of the secondary (post-neutron-
emission) fragments. They measured the K-x-ray yields in the
fission of ^{235}U and found results which are incompatible with an
extrapolation, based on a universal dependence, from published
values for K-x-ray yields in ^{252}Cf fission. However, the poor
agreement among reported K-x-ray yields in neutron-induced fission
(see Table I) prevents a clear conclusion regarding such a
universal dependence.

Experimental Methods

We have employed an experimental arrangement similar to that
previously used for ^{252}Cf (2,3) in order to facilitate direct
comparisons between the results for the different fissioning
systems. Targets of fissionable material were placed in a colli-
mated beam of neutrons (8×10^6 n cm^{-2} sec^{-1}, Cd ratio for Au of 28).
Each target consisted of about 0.5 mg of material spread over an
area of 1 cm^2 on a backing of Al foil (7 mg cm^{-2}). Fission frag-
ments were detected in a surface-barrier semiconductor detector,
which was placed 1 cm from the target. X-rays were detected in a
thin NaI(Tl) detector placed on the opposite side of the target
and at a distance of 7 cm from the target (solid angle of x-ray
detector about 1.3% of 4π). Fragments were selected by a single
channel analyzer with a lower level set above pulses corresponding
to twice the energy of the α particles emitted by the target.
(This criterion prevented contamination of the fission K-x-ray
spectrum with L-x-rays which are emitted following α decay of the
target.) Coincidences between the two detectors were selected by

a time overlap circuit with a total resolving time of 0.4 micro-
seconds. Valid events were recorded in a coincidence-gated
multichannel analyzer, which processed the signals from the
NaI(Tl) detector.

Net K-x-ray distributions were obtained both by graphically
estimating the height of the continuum produced by neutrons and
γ rays, and by subtracting the spectrum obtained through a graded
Cu-Al absorber. (The absorber removes some of the γ rays which
contribute to the continuum, and the correction is slightly
insufficient.) Although these corrections amount to less than
40% of the net x-ray contributions from either the light or the
heavy group of fission fragments, they are rather uncertain and
are the major source of error in the final yields.

The x-ray detection efficiencies were determined with a set
of x-ray standards consisting of radioactive samples which decay
by electron capture. Efficiency corrections were made in two
ways. First, the efficiency versus x-ray energy was assumed to
imply a corresponding scale of efficiency versus channel number.
This efficiency scale was applied directly to the net counts per
channel, and these corrected counts were summed to give light and
heavy group yields. This method introduces errors due to the
curvature of efficiency versus energy over an energy range related
to the resolution of the detector. Such errors are small because
the extremes in efficiency differ by less than 30%. Second, trial
yields, as a function of Z, were multiplied by the efficiency
versus Z, and these results were compared with the net x-ray
spectrum. Final yields were obtained by summing suitable trial
functions. The two methods gave essentially the same results.

Results

Our results are summarized in Table I, which includes other

TABLE I

Yields of K-X-Rays from Light and Heavy Fragments

		Yields per fission in %		
Target	Group	Measured	Predicted	Other values
^{233}U	light	$11^{+}_{-}2$	12	--
^{235}U	"	$13^{+}_{-}2$	14	$10^{+}_{-}3$ (5a), 8 (5b), $17^{+}_{-}2$ (5c), $12^{+}_{-}3$ (5d), $18^{+}_{-}4$ (4), $8^{+}_{-}1$ (5e).
^{239}Pu	"	$18^{+}_{-}3$	18	$15^{+}_{-}2$ (5c).
^{233}U	heavy	$19^{+}_{-}3$	19	--
^{235}U	"	$21^{+}_{-}3$	20	$42^{+}_{-}12$ (5a), 12 (5b), $43^{+}_{-}4$ (5c), $20^{+}_{-}5$ (5d), $34^{+}_{-}7$ (4), $30^{+}_{-}2$ (5e).
^{239}Pu	"	$21^{+}_{-}3$	19	$26^{+}_{-}3$ (5c).

values reported for K-x-ray yields. Although the same time
intervals were not used in the several studies, the differences
are negligible in terms of the errors in the measurements and the
known time dependence of K-x-ray emission in the fission of
^{252}Cf (2). Measurements for time intervals of about 1 nanosecond
give significantly lower yields and have been omitted from the
summary. The predicted yields given in the table were obtained by
assuming a mass dependence of emission probabilities and applying
this dependence to the experimental mass distributions (6) for the
three fissioning systems. This mass dependence was based on the
results of Kapoor, Bowman, and Thompson (1) and an extrapolation
to masses below A=95 with a dependence proportional to that given
by Reisdorf (7) for a 1 nanosecond interval following fission
of ^{235}U.

The good agreement between our results and the predicted
yields supports the hypothesis that K-x-ray emission is largely
independent of details of the fission process. This support is
strongest in terms of the relative yields and their relation to

shifts in the mass yield distributions. A better measure of the

trends in x-ray emission could be obtained by the use of a high-

resolution detector, such as that used by Watson, Bowman, and

Thompson (3). Preparations are being made for such a measurement.

Acknowledgments

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