cases, the measured ionization potentials agree with the spectroscopic values within 0.1 volt, and the ionization probability curves obtained were straight lines for energies less than 2 ev above the ionization potentials. Figure 2 gives a comparison of the ionization probability curve for argon obtained by this method with that obtained by the conventional method. Runs 1 and 2 show a typical curve under the influence of thermal energy spread in the electrons, contact potentials, and the ion-draw-out field. Run 3 shows a curve in which the thermal energy spread has been narrowed to within 0.1 ev and the contact potential between the filament and the electrodes has been eliminated. The slight "tailing" in curve 3 is attributed to the inhomogeneity in electron energy introduced by the ion-draw-out field. In run 4 all these effects have been eliminated, yielding a straight-line ionization probability curve going to zero at a value which agrees closely with the spectroscopic value of the ionization potential.

In conclusion, the authors wish to express their appreciation to Dr. T. Holstein for his contributions to the method described.

[1] See, for example, J. J. Mitchell and F. F. Coleman, J. Chem. Phys. 17, 44–55 (1949).

Nuclear Structure in Fission

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MASS spectrometric investigations of the relative abundances of fission product species from uranium fission have been made by Thode and co-workers[1] and Inghram and co-workers.[2] This type of measurement is capable of high precision and, with appropriate normalization, permits the establishment of fission yields to a much higher degree of accuracy than the present radiochemical techniques.

The early results of Thode *et al.* on Kr and Xe abundances in fission indicated abnormally high yields at masses 133 and 134 and, perhaps, in the region 83–86 as well. One would, of course, expect some fine structure in the yield-mass curve as a result of known delayed neutron effects, but these, at most, are of the order of $\sim$0.5 percent in fission yield and cannot account for the magnitude of Thode's results. Recent radiochemical studies on Te and I fission yields have also indicated a high yield at mass 134.[3]

A proposal to account for the observed anomalies which was made by one of us,[4] based on the boiling-off of an extra neutron from the fission fragments containing 51 or 83 neutrons, appeared to be qualitatively successful. This hypothesis, however, predicts a low yield at mass 137 which has been shown not to be the case.[5] The discrepancy between observation and prediction here led Thode to propose a possible preference for an 82-neutron configuration in the fission act in addition to a neutron boil-off effect following fission. It should be noted that an extension of the neutron boil-off hypothesis to fission fragments containing three and five neutrons in excess of a closed shell would account for the observed "normal" yield of mass 137. Fission yield determinations of masses complementary to the mass region 133–137 should establish whether the fine structure observed is the result of a preferential mode of fission or of phenomena following fission. Such studies are now in progress at this laboratory.

In the present work some interesting effects have been noted in the isotopic abundances of Mo and Zr produced in the fission of uranium. These data, together with normalized data on fission Xe and Kr (Thode) and Nd (Inghram), are presented in Fig. 1 where they are compared with the smooth radiochemical fission yield-mass curve.

Since the results obtained from these investigations are relative abundances, the data of one element must be fitted to those of another in some, as yet arbitrary, manner. For the present we have normalized the Xe data to the radiochemical yield-mass curve at mass 131 (=2.8 percent). Since the ratio of total Xe to Kr was

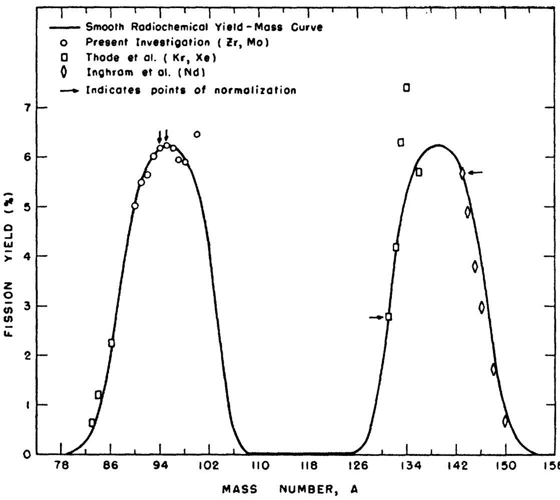

FIG. 1. Comparison of smooth radiochemical U^{235} fission yield data with mass spectrometric data.

obtained in Thode's work, this also fixes the Kr yields. Likewise, the Nd data were normalized to the radiochemical curve at mass 143 (=5.7 percent), Zr was normalized at mass 94=6.20 percent and Mo at 95=6.25 percent. Experiments are in progress to establish absolute abundances of Zr, Mo, and Ru in fission and thus obviate some of the difficulties of normalizing the relative abundance data.

It should be noted, however, that whatever normalization is employed, the present data for Mo indicate an abnormally high yield in the mass region 98–100. The anomalies in the mass 133–136 region are also quite evident on this linear plot. The original Kr^{86} and Xe^{136} data have been corrected for known delayed neutron emission. Thus, the data are corrected for the significant changes known to take place after fission. If a value of 2.5 for the number of neutrons per fission is taken for U^{235}, the data may be plotted as in Fig. 2, with the heavy group reflected over the light group such that the masses of complementary fission products sum to 233.5. In such a "folded" curve the coincidence of the anomalies at masses 98–100 *vs* 133–136 becomes obvious. Although neutron boil-off effects may be operating in the 133–137 mass region (the region in which 82 neutrons are present), there does not appear to be any reasonable basis for this effect in the region of mass 100. The high yield at Mo^{100}, then, suggests a preference for this mass in the fission act, perhaps as the complement of a preferred 82-neutron shell in the heavy fragment.

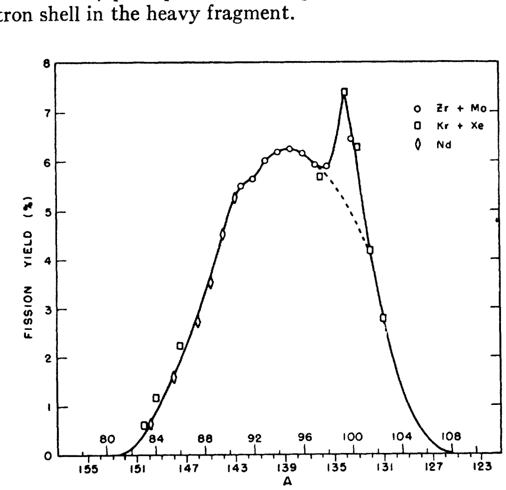

FIG. 2. Mass spectrometric yield-mass curve in U^{235} fission.

In addition to an enhanced yield resulting from some preferential mode of fission, delayed neutron and neutron boil-off effects from the fragments after fission could affect the yields in the 133–136 region further. Evidence supported the latter effects is provided by the abnormally low yield of Xe^{136} (and of I^{136} determined radiochemically[6]). However, the existence of a short-lived isomeric state could account for the observed result in the case of I^{136} and perhaps faulty normalization in the case of Xe^{136}.

A treatment of beta-decay systematics by Suess[7] indicates that the observed energies of Zr^{93} and Zr^{95} are much lower than expected. This may be an indication of a shell at 40 protons. Recent mass measurements by Duckworth and Preston[8] also indicate extra stability for a 40-proton configuration. If this is true, the high yields near mass 100 may also be the result of a preference in fission for a 40-proton configuration. In any event, it appears that the only reasonable explanation for the anomalous yield at Mo^{100} is a nuclear structure preference in the fission act.

The data also indicate a dip in the curve at mass 92 which is unexplained at present. Since low binding of closed shell plus 3 and 5 neutrons seems probable from published data on neutron binding energies,[9] boil-off of the 55th neutron (at Rb^{92}) is perhaps prominent here.

Further investigations are in progress with a view toward establishing as complete a fission yield-mass curve as possible by mass spectrometric measurements of the isotopic abundances of fission produced elements as well as accurate radiochemical determinations. Similar studies on U^{233} and Pu^{239} fission products are planned to observe the effects of change in mass and nuclear charge of the fissile nucleus on the observations reported here.

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Evidence for Production of Hole Traps in Germanium by Fast Neutron Bombardment

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In Si[1] both acceptors or electron traps and donors or hole traps, presumably associated with lattice vacancies and interstitials, respectively, are introduced near the middle of the forbidden band by nucleon bombardment. Consequently, the Fermi level ζ of N-type Si is depressed and that of P-type Si is elevated by bombardment toward a limiting or saturation value $\zeta_{\rm limit}$ causing a corresponding decrease in the conductivity of both N- and P-type Si. Heretofore, experiments on both N- and P-type Ge[2] indicate that bombardment causes an increase in P-type character with an accompanying depression of ζ toward the top of the filled band. This behavior may be interpreted as being the result of the introduction of acceptors only. However, in view of the close similarity of the electronic and crystal structure of Ge and Si, one would expect donors to be introduced into Ge as well.

James and Lehman[3] have investigated the situation in which both acceptors and hole traps (donors) are introduced in equal numbers below the middle of the filled band and find that $\zeta_{\rm limit}$ lies half way between the two introduced levels. Thus the ζ of originally N-type or high to moderate resistivity P-type Ge will be depressed toward $\zeta_{\rm limit}$ by bombardment while low resistivity P-type Ge with a ζ value below $\zeta_{\rm limit}$ will show an elevation of ζ corresponding to a decrease in conductivity.

The conductivity of 5 low resistivity P-type Ge single crystals[4]

Table I. Bombardment data for low resistivity P-type Ge.

Sample	n_h^0	$dn_h/d(nvt)_{\rm fast}$	T_e
1	7.0×10^{17} cm^{-3}	-5.0	32°C
2	1.01×10^{19}	-5.0	37
3	1.3×10^{19}	-2.2	48
4	1.5×10^{19}	-2.9	48

($n_h>7\times10^{17}$ cm^{-3}) was followed during fast neutron bombardment in the Oak Ridge pile. The initial rate of change in carrier concentration per incident neutron $dn_h/d(nvt)_{\rm fast}$, the original hole concentration n_h^0, and the exposure temperature for these samples sre listed in Table I. All samples showed a decrease in conductivity with bombardment and a gradual approach to a limiting value as predicted by the model.

The limiting value of the hole concentration, above which a decrease in hole concentration with bombardment is expected, is given by

$$(n_h)_{\rm limit}=2(2\pi m_h^* kT/h^2)^{3/2}\exp(-\zeta_{\rm limit}/kT], \qquad (1)$$

where $\zeta_{\rm limit}$ is measured from the top of the filled band. Consequently, it should be possible to choose Ge samples with appropriate hole concentrations which on bombardment would show a decrease in carrier concentration at low temperatures and an increase at high temperatures within a convenient temperature range. Several samples with hole concentrations of $\sim10^{16}$ cm^{-3} were bombarded at -78°C, and the conductivity was followed at that and at ambient temperature (55°C) after the dry ice was sublimed. A typical conductivity *vs* integrated fast neutron flux $(nvt)_{\rm fast}$ curve is shown in Fig. 1. The values of $dn_h/d(nvt)_{\rm fast}$ for both temperatures and the original hole concentrations for these samples are listed in Table II. In every case the slope is negative at

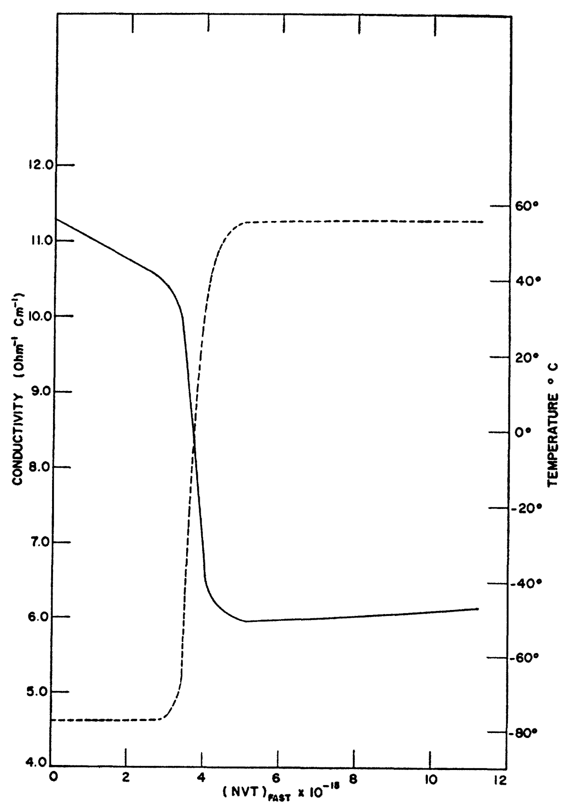

Fig. 1. Conductivity *vs* integrated fast neutron flux for P-type Ge ($n_h^0\sim4\times10^{16}$) exposed successively at -78°C and 55°C. The dashed curve is temperature.