III. RESULTS

A. Single Crystals

The second-order elastic constants measured for the two single-crystal samples are given in Table II along with the values determined for columbium by previous investigators.[24,25,27,28] The values for the present samples having no parentheses were determined directly from measured ultrasonic wave velocities and are estimated to be accurate to 0.2%, and the values in parentheses were calculated from them. It was considered necessary to determine these values for the present samples because of the rather large disagreement between previously reported values for columbium.

Table III lists all the calculated values of the slopes, and their estimated uncertainties for the three independent sets of measurements and the values of the TOEC calculated from them. As described before, sample 1 was run at a maximum uniaxial stress of 4800 psi, both before and after irradiation, and sample 2 at a maximum of 1600 psi. The hydrostatic pressure slopes in parentheses in column 3 were determined as the most probable values from the two samples before irradiation. The uncertainties shown for the TOEC were determined arithmetically as the maximum uncertainties based on the limits estimated for the slopes assuming no contribution from the uncertainties in the second-order elastic constants. In a few cases these uncertainties were increased above their arithmetic value because all of the relations could not be satisfied within the estimated uncertainties of the data.

The excellent agreement and internal consistency between the hydrostatic pressure slopes for the two samples justifies their emphasis in the calculations of the TOEC. Comparing the results of the three sets of measurements, differences in the values of the uniaxial stress slopes which are well outside the uncertainty limits are seen. However, there is no apparent trend between the sets of data, and the TOEC calculated from them agree within their uncertainty limits, so the differences in the slopes were ascribed to random errors brought about possibly by nonuniform stress distribution, interference caused by ultrasonic beam spreading in the small samples, or transducer bond characteristics changing with applied load. There are apparently no systematic differences which could be ascribed to dislocations.

The "best" values listed in the last column of Table III were then determined as the values which would best agree with all of the data. These values of the TOEC are considered the most representative of the two columbium single crystals studied. Their limits are estimated from the arithmetic limits calculated previously for the three sets of data.

[27] K. J. Carroll, J. Appl. Phys. 36, 3689 (1965).
[28] P. E. Armstrong, J. M. Dickenson, and H. L. Brown, Trans. Met. Soc. AIME 236, 1404 (1966).

TABLE V. The measured slopes of the stress dependences of the second-order elastic constants of polycrystalline columbium and the third-order elastic constants calculated from them. The relation numbers refer in order to the equations in Table IV of Ref. 26. The "best"-values slopes were calculated from the third-order elastic constants listed below them.

Relation No.	Sample A elongated $30\times75\ \mu$ grains	Sample B equiaxed 10 μ grains	
		Experimental	"Best" values
1'	$+6.20\pm0.25$	$+7.10\pm0.25$	$+7.098$
2'	$+0.273\pm0.04$	$+0.437\pm0.04$	$+0.450$
3'	$+1.51\pm1.0$	$+1.3\pm1.3$	$+0.758$
4'	-2.79 ± 0.46	-0.828 ± 0.07	-0.858
5'	$+4.72\pm0.30$	$+2.182\pm0.07$	$+2.156$
ν_1—10^{12} dyn/cm²	(see text)		-4.8 ± 1.2
ν_2—10^{12} dyn/cm²	$-4.01\ \pm0.3$		-3.70 ± 0.2
ν_3—10^{12} dyn/cm²	$+2.55\pm0.2$		$+0.75\pm0.05$

B. Polycrystalline Samples

The second-order elastic constants measured for the two polycrystalline samples are given in Table IV along with values calculated from the single-crystal constants using the VRH method[29] for comparison. Since the two elastic constants directly determined from the ultrasonic wave velocities, C_{11} and C_{44}, are accurate to about 0.2%, the differences between the two samples are considered to be real and to be caused by the difference in grain structure between the two samples. It is seen that the values determined for the sample having equiaxed 10 μ grains agree within 0.5% of the values calculated from the single-crystal elastic constants.

The TOEC results are shown in Table V. The effect of the grain texture in sample A can be seen by the very different values of the slopes, m_n', measured for the two samples. The internal consistency of the data for sample A is also very poor. The relation

$$m_2' - 2m_4' - m_5' = 0, \qquad (3)$$

which can be readily derived from Thurston and Brugger's equations, is very poorly satisfied by the data for that sample. The values of ν_2 and ν_3 were calculated by adjusting the values of the measured slopes m_2', m_4', and m_5' to satisfy Eq. (3) above, weighting the corrections in proportion to the estimated uncertainties in the measured slopes. However, using these values in relations 1' and 3' resulted in values of ν_1 of -7 ± 2 and $+17\pm9$, respectively. Other schemes for analyzing the data resulted in slightly better consistency but widely different values for the TOEC and therefore this set of data is considered to be meaningless.

The data for sample B shown in Table V were analyzed in the same manner as described above. For this sample Eq. (3) was very nearly satisfied by the data. The degree of internal consistency of the data may be

[29] R. Hill, Proc. Phys. Soc. Lond. 65, 350 (1952).