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LETTERS TO THE EDITORS

Elastic Constants of Polycrystalline Uranium[1]

In the preceding note Rothman and Fisher (*1*) discuss the calculation of the elastic constants of polycrystalline uranium from single crystal measurements (line 1 of Table I) and then proceed to compare the calculated moduli with a number of selected experimental values. The production of sufficiently large single crystals of α-uranium and Fisher and McSkimin's (*2*) study of them are both noteworthy achievements. However, I would like to take exception with the contention of Rothman and Fisher that the elastic properties of uranium strongly quenched from the β-phase are in any way characteristic of the polycrystalline metal.

It is well known, of course, that uranium in the as-cast, furnace cooled condition is extremely coarse-grained and that most mechanical treatments designed to reduce the grain size simultaneously introduce directional properties, so that the problem of obtaining and knowing when one has obtained isotropic samples is by no means an easy one. To a certain extent, sound velocity measurements using the free specimen resonance technique provide an indication of grain size and directionality. The first is seen as a scatter of velocities corresponding to successive harmonic resonance frequencies; the second is indicated by a difference in Poisson's ratio, σ, as obtained from the dispersion of the sound velocity with frequency, σ_{disp}, and as calculated from the measured longitudinal thin rod velocity, v_0, and the shear velocity, v_s. In our early work at Los Alamos (*3*) we used the resonance technique on a number of samples of different metallurgical history (cold swaged and annealed at 600°C, γ-extruded, and cast). Since all of the samples were quite coarse-grained, the sound velocities obtained from the various harmonic resonances scattered by $\pm 0.5\%$ from a smooth curve and no attempt was made to derive σ_{disp}. Lines 2 and 3 of Table I list the range of observed values and the best average values we proposed at that time.

The agreement with the calculated numbers of Rothman and Fisher (line 1) is surprisingly good, yet this work is not included in their comparison. Instead, they have selected one strongly quenched sample mentioned in my discussion of a paper by Reynolds (*4*). Reynolds used the pulse technique to observe longitudinal infinite medium velocities, v_L, and shear velocities. He corrected for anisotropy by measuring a cube along three orthogonal directions. His samples had been subject to a water quench from the β-phase. At the time of the discussion the details of the quenching procedure were classified because of its use in producing metal which would not undergo dimensional changes while in a reactor. Reynolds' results (line 4) were appreciably below our earlier data. The good agreement for other metals eliminated the likelihood of systematic experimental errors. Additional measurements (*5*) made at Los Alamos using both resonance and pulse techniques on cast and hot drawn samples confirmed the earlier work. Two cold-swaged and annealed samples were included for their pronounced directional properties. The results on several "impure" fine-grained samples (line 5) differed no more than could be ascribed to their difference in density. ("Impure" was a circumlocution for the then classified 1 and 2 at. % Nb alloys.) However, we were also able to see values even lower than Reynolds' on a sample of water-quenched uranium (line 6). We did not profess to know how microcracks or strains could produce such large differences in what is essentially a bulk property, and we certainly did not claim that this quenched specimen (which Rothman and Fisher have selected from among all the others) was in any way typical for uranium. Quite to the contrary, we speculated that "it might be possible to produce even larger differences by quenching thinner pieces (*5*)."

Some additional work was done during the summer of 1953 (*6*). This included two samples quenched from the β-phase (after $\frac{1}{2}$ hr at 725°C) and subsequently annealed 2 hr at 600°C (line 7) which had been sent to Dr. E. R. Jette by Dr. F. Foote; α-rolled samples, which, as expected, showed marked anisotropy; and a number of 2.5 and 5 at. % Mo alloys. It is interesting to note that annealing for 2 hr at 600°C removes the abnormality produced by the β-quench. Phenomenologically similar processes seem to occur in the Mo alloy where the cast and furnace-cooled sample (AC) is more or less normal (line 8), where the quenched (Q 700) sample has a very low velocity and modulus (line 9), and where the annealed sample (line 10) is again similar to the cast sample.

Rothman and Fisher also select some results obtained by Kammer, Vigness, and Cardinal (*7*) (line 11), who were furnished their specimens and partial information on metallurgical history and heat treatment by the New York Office of the AEC. Unfortunately, it is no longer possible to ascertain the complete history of those samples. One group is described as "heat treated at 720°C for 70 seconds," another as "heat treated at 600°C for $\frac{1}{2}$ hour" (line 12). Nothing is said about the subsequent rate of cooling and particularly whether the β heat treatment was followed by a "long" water quench or a "short" quench into the high α-region around 600°C. Both quenches are known to produce randomly oriented α-uranium, but the latter in effect anneals the metal as well, in which case there would be no discrepancy at all.

In conclusion, I would like to restate that there remains an unanswered question as to the nature of the changes produced in the quenched and unannealed specimens. Although the moduli are lowered, the ultimate tensile strength

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TABLE I

SOUND VELOCITIES AND ELASTIC CONSTANTS FOR URANIUM

Source	Description	Density	Cm/sec × 10^{-5}			Dynes/cm² × 10^{-11}		Psi × 10^{-6}		σ
			v_0	v_L	v_s	E	μ	E	μ	
1. Rothman and Fisher (*1*)	Calculation			3.40–3.49	2.06–2.15	19.5–21.0	8.06–8.80	28.3–30.5	11.69–12.77	0.1943–0.2087
2. Laquer *et al.* (*3*)	Observed range	18.94–18.98	3.25–3.32		2.08–2.10	20.1–20.9	8.20–8.35	29.2–30.3	11.9–12.1	0.22–0.25
3. Laquer *et al.* (*3*)	Average	18.96 ± 0.03	3.29 ± 0.02	(3.54)	2.095 ± 0.005	20.5 ± 0.2	8.34 ± 0.04	29.7	12.1	0.23 ± 0.02
4. Reynolds (*4*)	Q740	18.6	(3.07)	3.37 ± 0.02	1.94 ± 0.01	17.6	7.03	25.5	10.2	0.25
5. Laquer (*5*)	1–2% Nb, AC	18.85	3.21 ± 0.01	3.43 ± 0.02	2.04 ± 0.01	19.4	7.85	28.2	11.4	0.21 ± 0.01
6. Laquer (*5*)	Q725	18.9	(2.83)	3.18 ± 0.03	1.77 ± 0.04	15.1	5.92	22.0	8.6	0.275
7. Laquer and Levine (*6*)	HT725 (30 min), Q, A600	18.91	3.24	(3.46)	2.075	19.85	8.14	28.8	11.8	0.220
8. Laquer and Levine (*6*)	2.5% Mo, AC	18.70 ± 0.05	3.14 ± 0.01	—	—	18.4 ± 0.1	—	26.7	—	
9. Laquer and Levine (*6*)	2.5% Mo, Q700	18.59 ± 0.05	2.94 ± 0.01	—	—	16.1	—	23.3	—	
10. Laquer and Levine (*6*)	2.5% Mo, Q700, A500	18.70	3.16 ± 0.01	—	—	18.6	—	27.0	—	
11. Kammer *et al.* (*7*)	HT720 (70 sec)			3.35–3.44	2.10–2.12	19.3–20.1	8.22–8.48	28.0–29.2	11.9–12.3	0.178–0.194
12. Kammer *et al.* (*7*)	HT600 (30 min)			3.28	2.02–2.04	18.1–18.2	7.62–7.69	26.3–26.4	11.1–11.2	0.194–0.188

is increased (*8*) both in uranium and in the U-Mo alloy. This would seem to rule out microcracks and indicate metastable alloys, possibly with impurity atoms. Clearly, it would require extensive analytical and metallurgical work to test this hypothesis.

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Henry L. Laquer

University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

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Attenuation of 14-Mev Neutrons in Water and in 6-In. Lead and Water

Caswell *et al.* (*1*) have measured the fast neutron dose from a 14.1 Mev source in water employing a proportional counter dosimeter. As a heavy element (e.g., Pb or Bi) is sometimes used immediately after the source of fast neutrons to improve the neutron shielding properties of water, experimental distributions of fast (above 1 Mev) and resonance (1.46 ev) neutron flux in 6-in. Pb + water and pure water media have been obtained.

The experimental setup consisted of an aluminum tank (5 ft long, 3 ft wide, and 4 ft deep) filled with demineralized water as shown in Fig. 1. Neutrons of 14.1 Mev were obtained from the $H^3(d,n)He^4$ reaction. The deuteron beam was accelerated to 200 kev in a Cockroft-Walton type accelerator. The tritium target (2.5 cm in diameter) was kept under 2 ft of water in a tank, as shown in Fig. 1. For this an extension consisting of a thin aluminum tube, 3.8 cm in diameter, was joined to the main acceleration tube. The extension tube was insulated from water by wrapping a thin alkathene sheet around the tube. The target was cooled by circulating cold water in-between the alkathene sheet and the aluminum tube. All the measurements were made along the length (5 ft side) at 90° to the incident deuteron beam, the target being $1\frac{1}{2}$ ft from one end and $3\frac{1}{2}$ ft from the other. In order to check whether the dimensions of the experimental tank were large enough, additional tanks (6 in. wide) were kept on either side of the main tank. No change in the response of In detectors, irradiated at different distances, was noticed when the additional tanks were also present. For measurements in 6-in. Pb + H_2O medium, Pb bricks were piled up next to the target tube to form a wall of dimensions 6 in. thick by 3 ft wide and 4 ft high.

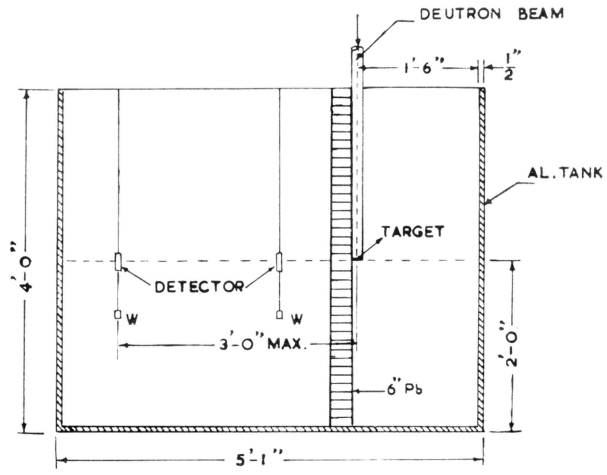

Fig. 1. Experimental setup for 6-in. Pb + H_2O medium. *W* refers to small iron weights used to keep the detectors straight.

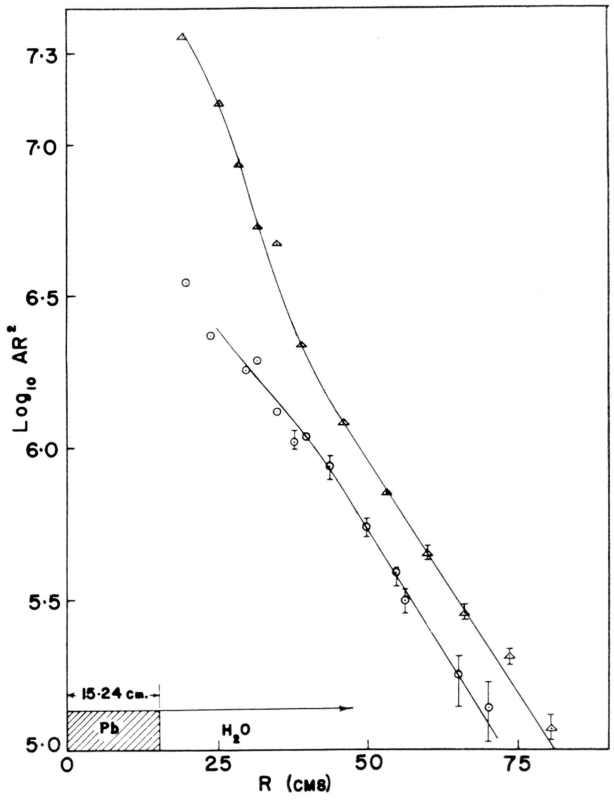

Fig. 2. Log AR^2 (in arbitary units) as a function of distance R (in cm) in 6-in. Pb + H_2O medium. △ Indium detector (1.46 ev). ○ Phosphorous detector (above 1 Mev).

Relative values of fast neutron flux were measured by irradiating phosphorous threshold detectors (above 1 Mev) and counting β-activity of the foils as described in an earlier paper (*2*). These foils were 2.5 cm × 2.5 cm in area