the die, it was mechanically attached to a copper wire by twisting the latter around the beryllium wire point. The copper wire was then wrapped round the coiling reel which applied the draw stress. This technique does, however, cause some time delay between threading the hot die and loading in the container.

Method of Coiling. The coiling technique used was the free vertical coil described in Figure 36. Most of the coils used were in the order of 6 feet long and presented no problem in loading in the container. However, when 60 feet coils were to be loaded, a warm-wrapping technique was required to prevent excessive tangling during loading and paying out. In this technique, wire is wrapped on to a hollow steel tube which is heated to about 600 F. In this way, the wire is given a permanent set so that it remains in a tight coil and single coils in excess of 100 feet can be contained in the pressure chamber bore without difficulty.

Wire Lubrication. Although PTFE proved best, several wire lubricants were evaluated and the techniques of application of these lubricants was necessarily different from those used on large-diameter billets. Essentially, the techniques were of a tactual nature due to the small-gage wire and its inherent brittleness. The wire was coiled before the lubricant was applied. Pre-coiling did not present any problems because the PTFE coating was applied by spraying and because it was easier to handle a coil of wire in the subsequent baking operation at 750 F.

Stem and Die Seals. Various stem and die seal arrangements were evaluated because in the HYDRAW of beryllium wire, it was necessary to hold at a set pressure level for several minutes while draw load and draw speed were varied. During this time, it was felt that distortion and deterioration of the O-ring materials might cause problems. Even so, the best arrangement was a PTFE + rubber O-ring in spite of the fact that rubber O-ring became hard after exposure to the high temperature and pressure conditions.

Die Design and Construction. The dies used initially were similar to those used in standard wire-drawing practice for diameters of 0.020 inch and less. The usual practice is to mount a diamond die in a sintered compound supported by a steel case. This construction held up to fluid pressures of 250,000 psi at 80 F, but at 500 F, the sintered compound softened and the diamond blew out under pressure due to lack of adequate support. Even at 80 F, the high pressure caused the sintered mount to loosen from the steel case, however, an epoxy cement was sufficient to prevent fluid leaks.

The thermal-softening problem encountered with diamond dies necessitated the use of carbide dies. Support of the carbide insert or nib is readily achieved and problems of leaking were not encountered. However, carbide dies below about 0.005-inch diameter apparently are not available. Thus, in future work at these small wire sizes, diamond dies with special support will be required.

Handling of the Wire and Hot Die During Loading. Special care was required during loading the hot die, wire guide, and wire coil in the container. To improve accessibility to the area beneath the container when it was in the raised position, the tie rods supporting the container were lengthened by nearly 3 inches. A wide pulley beneath the container was used so that the fine beryllium wire would not get entangled around the bearings in the yoke during wire threading.

In a production operation designed around the HYDRAW concept it is envisaged that these handling problems could be avoided.

HYDRAW of Beryllium Wire of Ingot Origin

Trials were initially conducted at room temperature to determine the properties of the cold-worked extrusion-drawn wire. The aim was to reduce the nominal 0.020-inch-diameter wire by 60 percent in area. In all trials conducted at this reduction, the pressure requirements were beyond the pressure capacity of the tooling. In the trials, a fluid pressure of 200,000 psi plus a draw stress of up to 20,000 psi was found to be inadequate for the 60 percent reduction, whereas 200,000 psi was required to extrude a 1-3/4-inch-diameter billet at a reduction of 75 percent. While it was believed that die angles smaller than those specified (the diamond dies used had a flared or trumpet shaped entry instead of a straight 45 degree entry) contributed to the high pressures needed, preliminary trials with soft copper wire and experience with other materials indicated that there is a "size effect" in extrusion. That is, the energy per unit volume required to reduce a billet or wire a given amount increases as the starting diameter decreases. This is believed to be associated with the greater surface-area to volume-ratio for a given reduction as the starting size decreases.

Thus, a trial (No. 1020) at the modest reduction of about 25 percent was successful in producing 5 feet of wire to 0.0165-inch diameter. The conditions were the same as those in Table XXXIII except that the trial was conducted at 80 F and the fluid was castor oil. The die was tungsten carbide. In spite of the low reduction in area, the pressures required were relatively high. The fluid pressure of 116,000 psi and draw stress of 2,350 psi gave a P+D requirement of 118,350 psi.

After only a short length of 0.0165-inch-diameter wire was produced, the wire broke on bending through 90 degrees round a 3-inch-diameter pulley. The remaining coil of wire in the container continued to extrude at 114,000 psi for a short period. In subsequent handling of the extruded product, the wire was found to be extremely brittle (which perhaps explains why it broke initially on bending around the pulley). The wire surface was examined stereoscopically at low power and was found to contain short, periodic, circumferential cracks.

In view of the results at the low reduction of 25 percent, consideration was given to warm extrusion-drawing at a higher reduction. This was considered especially promising since in two earlier trials, electrical resistance heating techniques had produced a short length of sound wire at a 60 percent reduction (Trials 1017 and 1018) and also, since in the extrusion of large beryllium rounds at a 75 percent reduction, fluid pressures were reduced from 200,000 to 133,000 by raising the temperature to 500 F.

The data obtained in producing beryllium wire by HYDRAW at a 60 percent reduction and at fluid temperatures between 500 and 550 F are given in Table XXXIII. It is seen that in three trials, wire was produced under controlled exit conditions and considerable lengths of wire were produced. The P'+D levels in obtaining this wire were