reduced approximately 3:1. The second will be based on the maximum extrusion ratio possible with a stationary mandrel, assumed to be 4:1 from Figure 30. The third example will be based on the use of a floating mandrel which adds extra pressure to the end of the tube. As previously discussed, this additional force is limited to the yield strength of the starting tube. Assuming the yield strength to be 135,000 psi for Ti-6Al-4V, the maximum reduction ratio achievable for a floating mandrel was estimated to be 8:1. This reduction requires a total billet-end pressure of 385,000 psi and was determined by extrapolating the plot of pressure versus reduction ratio on Figure 30. In the last two examples, the extrusion ratio cited are estimated to be the maximum possible within the 250,000 psi fluid pressure capacity of the present tooling.

The conversion cost of hydrostatic tube extrusions was estimated in the following manner. Since experimentally no die wear was observed from the hydrostatic extrusion of a properly lubricated Ti-6Al-4V titanium alloy tube, die and mandrel costs were estimated conservatively on a life of 25 extrusions each. It was assumed, using relatively unsophiticated tooling, that the mandrel manipulation might be time consuming and, therefore, a production rate of only 12 billets per hour was used to determine the press cost per extrusion. The final cost per extrusion and the breakdown of this cost are shown:

(1) Die costs: \$100/die ÷ 25 extrusions/die	= \$4.00/tube
(2) Mandrel costs: \$30/mandrel ÷ 25 extrusions/mandrel	= \$1.20/tube
(3) Seals, fluids, and lubricants	= \$0.50/tube
(4) Press cost: \$46.96/hr ÷ 12 tubes/hr	= \$3.91/tube
Total Tube Conversion Cost	\$9.61/tube

The conversion cost per unit length of tube produced by hydrostatic extrusion is a direct function of the length of tube produced per extrusion, which in turn depends on both the extrusion ratio and initial starting billet length. The relationships and resultant conversion costs are shown on Table XXXIX. To assist in establishing trends, containers capable of accommodating 3- and 6-foot-long tube blanks were assumed. The cost per extrusion of \$10.11 for starting lengths 4 to 6 feet was determined by doubling the cost of hydrostatic tooling (from \$30,000 to \$60,000) and keeping all other costs factors constant. The cost of pressure vessels generally vary linearly with length.

Two sources were used to obtain cost figures for comparison with hydrostatic extrusion. The first source was a published price list for standard Grade 2 titanium tube (commercially pure titanium). For the second source, oral quotations for Ti-6Al-4V tubing were obtained. Selected sizes of tubes representing reductions of 3:1, 4:1, and 8:1 were analyzed for both materials and are shown on Table XL. The dimensions of Tubes A, C, and D were chosen as typical sizes which could be made by both hydrostatic techniques and conventional processing. Dimensions for Tube B were selected to approximate the tube size produced in this program. The conversion costs for producing tubes by conventional techniques were estimated from selling prices and were determined as follows:

$$\frac{\left(\text{Cost of the finished tube, dollars/ft} \times \text{Amount of finished tube produced per foot of starting tube, ft}\right) - \text{Cost of the starting tube per foot, dollars}}{\text{Amount of finished tube produced per foot of starting tube, ft}} = \text{Conversion cost, dollars/ft}$$

The amount of finished tube produced per foot of starting tube was assumed equal to the reduction ratio.

TABLE XXXIX. ESTIMATED CONVERSION COSTS FOR PRODUCING Ti-6Al-4V TITANIUM ALLOY TUBING BY HYDROSTATIC EXTRUSION TECHNIQUES

Extrusion Ratio	Starting Length, ft	Finished Length, ft	Cost/Extrusion, dollars	Conversion Cost, dollars/ft
3:1	1	3	9.61	3.20
	2	6	9.61	1.60
	3	9	9.61	1.06
	4	12	10.11(a)	0.84
	5	15	10.11(a)	0.67
	6	18	10.11(a)	0.56
4:1	1	4	9.61	2.40
	2	8	9.61	1.20
	3	12	9.61	0.80
	4	16	10.11(a)	0.63
	5	20	10.11(a)	0.51
	6	24	10.11(a)	0.42
8:1	1	8	9.61	1.20
	2	16	9.61	0.60
	3	24	9.61	0.40
	4	32	10.11(a)	0.31
	5	40	10.11(a)	0.25
	6	48	10.11(a)	0.21

(a) This value was obtained by doubling the container length and cost and assuming all other costs factors remained constant.

A comparison of data in Tables XXXIX and XL, indicates that hydrostatic extrusion of Ti-6Al-4V titanium alloy tubes appears to offer cost advantages over conventional processing at the smallest reductions and shortest lengths considered. It should be emphasized that the figures for the hydrostatic extrusions are conversion costs only, whereas those conversion costs for conventionally produced tubes, as shown in Table XL reflect the influence of selling prices. The figures used for the cost of conventionally processed Ti-6Al-4V tubes are current and do not reflect potential cost reductions as the production becomes a production item. However, it can be shown that, even if substantial cost reductions are achieved in the conventional process, the hydrostatic extrusion process remains attractive. For example, considering Tube A in Table XL, the current selling price for the starting and finished tube sizes are $40.00 per pound and $150.00 per pound, respectively. (See footnotes b and c.) If it is assumed the starting cost of Ti-6Al-4V alloy tubing is $10.00/lb and the final cost is $20.00/lb, the conversion cost of Tube A is calculated to be $2.26/ft. However, the cost of producing the same size tubing by the hydrostatic extrusion process is estimated to be as low as $0.56/ft depending on the length produced (see Table XXXIX). The cost advantages of hydrostatic extrusion should be accentuated if very thin walled tubing was considered, since these items are particularly difficult to produce using conventional techniques. For example, Tube B, produced experimentally on this contract, could not be purchased commercially on fixed-price basis.

It is also of interest to point out that the analysis shows that under certain conditions, the hydrostatic extrusion technique could convert unalloyed titanium tubing at or below the estimated cost of conventionally produced unalloyed tubing. Generally, to