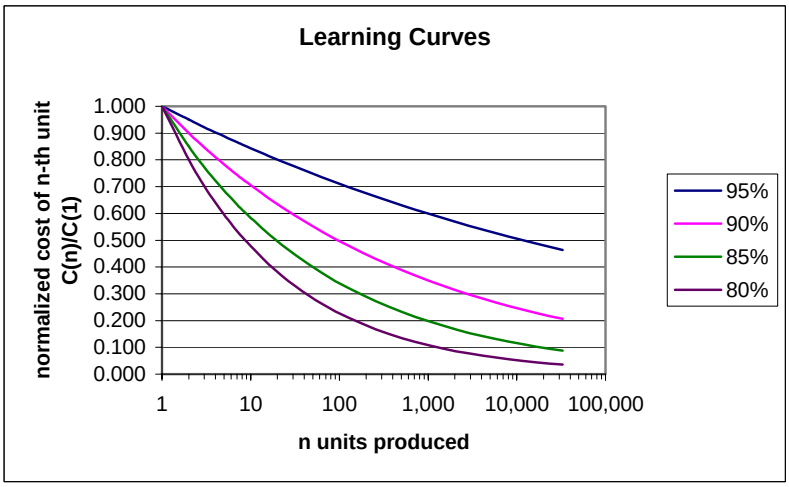
**Learning Curves:** A Learning Curve is an industrial tool or formula for the expected reduction of unit costs for large quantity production of components. Learning curves draw from historic building experience to determine expected reductions in labor and materials costs. Expected reductions can be gauged from the labor and materials content of the manufactured item, plus the number of doublings of the initial production run. Estimators will apply learning curves under guidance from management.

Cost estimates need to reflect the observed characteristic that costs will vary in proportion to the quantity produced. Quantity discounts on commodities or on commercially available components is one aspect. The amortization of fixed set-up or tooling costs over the production run for a forging or casting application is another. The most widely accepted cost-estimating tool for adjusting cost to volume is the learning curve. This assumes that repetitive production costs will decrease due to learning by the manufacturing staff - by increasing yields, increasing operation throughput, improved tooling, substituting equipment for labor, eliminating unnecessary steps, and process improvement and substitution.

Example: Learning curves result in a fixed percentage decline in unit costs with each doubling of cumulative volume. A 70% learning curve (doubling of volume drops costs by 30%) is considered very aggressive; a 95% curve (doubling of volume drops costs by 5%) is considered very conservative. Labor-intensive operations normally have curves in the 80%-85% range; machine-intensive operations have curves in the 90%-95% range. If a learning curve, or cost estimates for different quantities are available for a given item, use that information. If such information is not available, use the 80%-85% and 90%-95% general guidelines for labor- and machine-intensive elements.

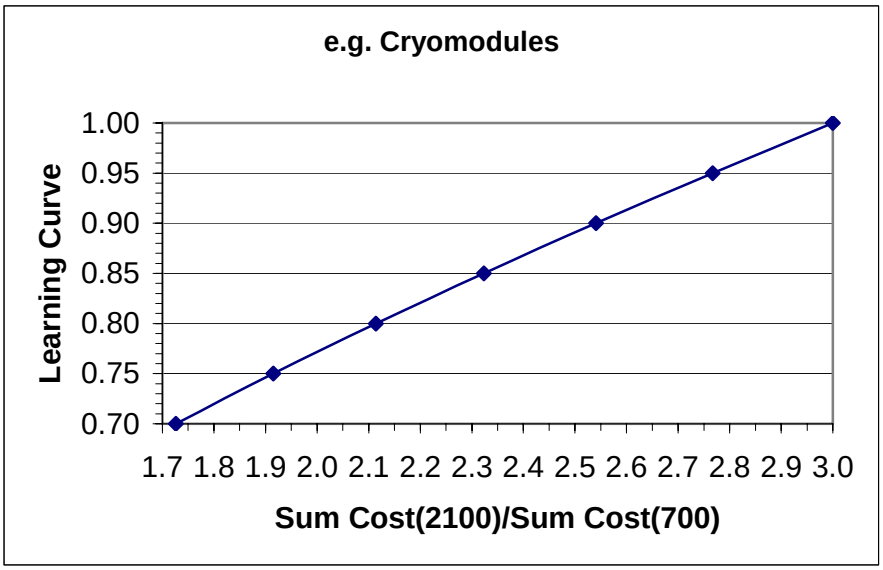
Ray Larsen's example for a 90% learning curve is that the cost of the 2$^{nd}$ item is 90% the cost of the 1$^{st}$ item, 4$^{th}$ is 90% cost of 2$^{nd}$, and 2N$^{th}$ item is 90% the cost of the N$^{th}$ item.

In this case, the cost for the N-th item is $C_N = C_1 N^{\alpha}$
where $C_1$ is the cost of the first unit and $\alpha$ = log(Learning Curve in %)/log(2)
So, for example, for 90% Learning Curve $\alpha = -0.152$ and $C_{64} = 0.531 * C_1$




compiled by PHG - 21april06

If you get the Learning Curve percentage from a vendor or an industrial study directly, then use that value. We have asked for industrial studies on producing the full complement of RF units for the ILC, and also for 1/3 of the units, as if they would be distributed equally across the three regions. So we are expecting two cost estimates for two quantities of cryomodules: 2100 for the whole complement, and 700 for the 1/3 quantity. One can then form the ratio of Sum Cost (2100)/Sum Cost (700) and compare this to a curve generated by summing the unit costs for a set of learning curves to find the average learning curve for the cryomodules, as from the plot below. Note that there is a slight difference whether one uses a summation or an integral, which is in the noise (less than 1% difference) for these quantities for Learning Curves > 70%. Getting the learning curve from this two-point data will allow cost estimating extrapolation for other divisions of responsibility across regions or across multiple vendors within a given region.

lc_cryomodules.xls
phg - 24april06

| | cost(2100)/cost(700) | |
|---|---|---|
| LC | sum | integral |
| 1.00 | 3.000 | 3.000 |
| 0.95 | 2.767 | 2.766 |
| 0.90 | 2.541 | 2.539 |
| 0.85 | 2.323 | 2.319 |
| 0.80 | 2.114 | 2.106 |
| 0.75 | 1.915 | 1.902 |
| 0.70 | 1.726 | 1.705 |