ENRICHMENT TAILS ASSAYS AND URANIUM SUPPLY: A DYNAMIC RELATIONSHIP

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At present, utility fuel buyers order uranium, conversion, and enrichment services according to optimization criteria based on relative prices for EUP inputs. Enrichment decisions are constrained only by enrichment contract requirements that limit the tails assays nominated to a certain range without surcharges. At present, given a uranium price of $33.75/kg U as UF6, and roughly $105/SWU, the economic optimum tails assay is about 0.35%.

Recent articles in the trade press suggest that upward movement in uranium price could result in utilities nominating lower tails assays and substituting SWU for uranium. Some utilities have even taken this to mean that there is a cap on uranium prices.

The purpose of this memo is to evaluate the magnitude of this substitution possibility at various uranium price levels, and with attention to SWU prices.

Optimal Tails

The economic optimum tails is usually determined by consulting standard industry tables or charts, where the optimal tails is plotted against the ratio of uranium price ($/kg U as UF6) to the price of SWU ($/kg-SWU). We have recomputed this chart, as shown in Figure 1. At current prices, the ratio is about 0.32, which corresponds to an optimal tails

Figure 1
Optimal Tails as a Function of Ratio of Uranium and SWU Prices

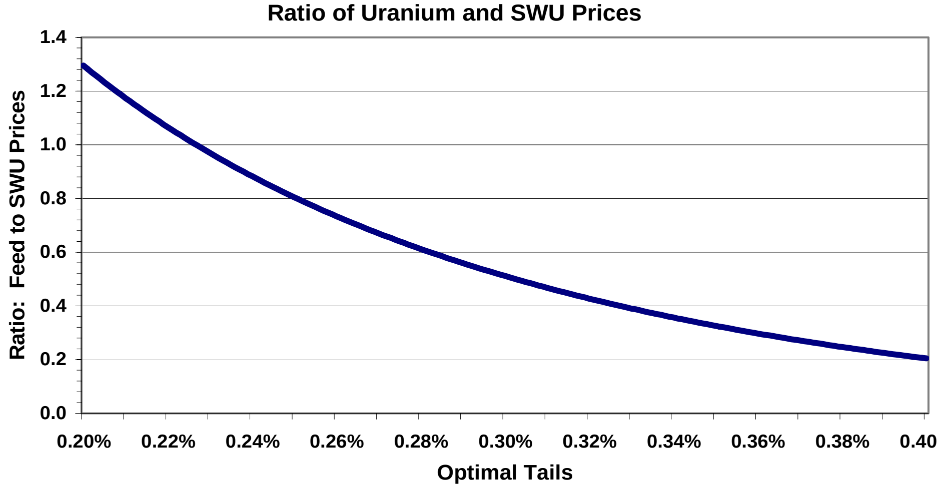

Figure 1 above assumes 4.5% enriched product. Ratio is $/Kg U as UF_6 to $/Kg SWU. Tails assay is weight-percent U-235.

of about 0.35%. This is at the limit of, or above, flexibilities under enrichment contracts. Note that if uranium prices rise, and SWU prices remain steady, the optimal tails declines and demand for uranium should decline. If uranium prices fall, simple economics would suggest that tails assay would rise, increasing uranium demand for a given reactor fuel requirement. However, under the terms of most enrichment contracts, this is not possible without payment of surcharges, in part because the enricher must dispose of more tails at higher tails assays. In effect, the enrichment price rises as tails assay increases.

As a result of enrichment contract terms, the economic pressures are thus asymmetric: as long as enrichment prices remain steady, uranium price rises are somewhat self limiting as utilities increasingly nominate lower tails assays and thus reduce demand for uranium.

However, the magnitude of this effect is limited, as we shall now see. The cap on uranium prices rises quite rapidly as one attempts to extract more uranium from tails.

Supply from Tails

The reduction in uranium demand caused by reducing tails assay is equivalent to stripping tails to make additional uranium. That is, if the optimal tails is 0.35% at present and tails assays nominated by utilities are reduced to 0.34%, the reduction in uranium demand is equivalent to increasing uranium supply by a certain amount. It is as if an enrichment plant acts like a uranium mine.

This way of approaching the problem is very convenient since it allows us to calculate a "supply curve" for uranium obtained from stripping tails (or, the equivalent, reducing tails assays in enrichment). A supply curve shows the amount of uranium made available at various costs by purchasing enrichment services instead of uranium. This supply curve may then be compared directly with supply curves for primary supply from new mines. If supply from a new mine or supply source is lower than the cost of uranium derived from reducing tails assay, utilities should prefer to buy from the new primary source rather than "obtaining" uranium by reducing tails assay in enrichment.

A supply curve typically rises as the volume of production increases, since incremental units of production at the margin become more expensive to produce. For example, in a mining project, the design level of production may be relatively inexpensive to produce but expanding production may involve mining lower grade ores. For a farm, increasing output may require that more water or fertilizer be used or that less productive land be utilized.

In the case of using enrichment services to "extract" uranium, increasing amounts of energy must be used to overcome entropy to separate diminishing numbers of U-235 atoms from a sea of U-238. Extracting incremental volumes of U-235, in the form of natural uranium, become increasingly difficult and expensive as the relative proportion of U-235 declines. As a result, the incremental cost of taking uranium from tails rises quite rapidly.

In our calculations we assume a world utilization of uranium of 63,200 tonnes U at a tails assay of 0.35%. We then examine how much uranium would be saved by enriching at

0.34%, and the cost of doing so. We then calculate what it would cost to remove the uranium between 0.34% and 0.33% tails assay, and so on. A fixed enrichment cost of $105/SWU is assumed. As noted, saving uranium by enriching at lower tails is precisely equivalent to stripping it from residual tails as an alternative source of supply. Figure 2 shows the results of this calculation.

Figure 2
Cost of Extracting Additional Uranium
as Tails Assay Declines

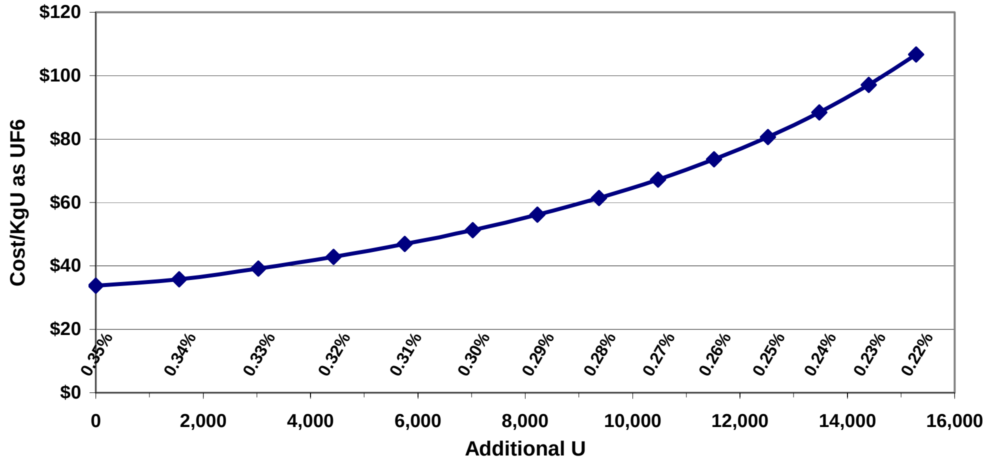

Figure 2 above assumes 4.5% enriched product. Figure 2 also assumes initial world requirements of 63,200 tU at 0.35% tails assay. The cost of SWU to extract additional uranium is assumed to be $105/SWU.

As Figure 2 illustrates, the first kilograms of uranium saved by lowering tails assay are relatively inexpensive. About 1550 tonnes may be saved by lowering the average tails assay to 0.34%, at a cost of $35.76/kg U. However, the next 1,470 tonnes extracted between 0.34% and 0.33% costs $39.17/kg U to "extract." The curve then rises rapidly, as increasing amounts of separative work must be used to extract decreasing volumes of uranium. In stripping from 0.25% to 0.24%, for example, only 960 tonnes of uranium are produced, at a unit cost of $88.47/kg U.

The reason for the rapid increase in cost is that as tails assays are reduced, increasing amounts of separative work are needed to extract each kilogram of uranium—the increasing difficulty of recovering declining numbers of U-235 atoms noted above. Figure 3 shows this effect by calculating the number of SWU needed to extract a kilogram of uranium at each level of tails assay.

Figure 3
SWU Required to Extract Additional Uranium as Tails Assay Decreases

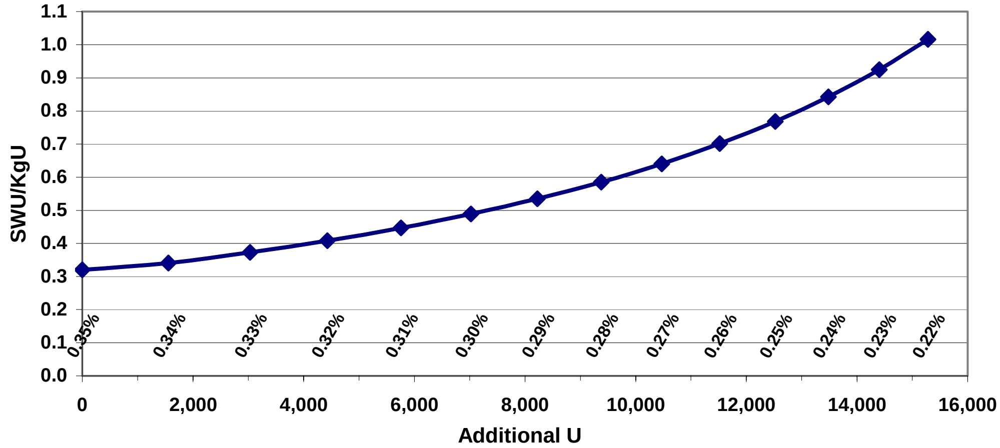

Figure 3 above assumes initial world requirements of 63,200 tU at 0.35% tails assay. 4.5% enriched product is assumed.

To extract uranium in reducing tails assay from 0.35% to 0.34% U-235, only about 0.34 SWU is required per kilogram of natural uranium saved (or produced). However between 0.23% and 0.22%, more than one SWU is needed per kilogram of natural uranium saved or produced.

At some point, it becomes cheaper to mine uranium from even relatively high cost environments, rather than use additional enrichment services to extract the same amount of uranium. For example, if there is an arbitrarily large amount of primary uranium production possible at or below $50/kg U (as UF6), then Figure 2 indicates that enrichment tails assay would never decline below 0.30%, at which point about 7,000 tonnes U would be saved by the reduction in tails assay from 0.35% to 0.30%.

In effect, supply from tails competes at the margin with primary supply according to the supply curve in Figure 2. In compiling a world supply curve, one would construct a similar curve composed of supply from various sources arrayed according to increasing cost. The lowest cost mines would be at the left, along with small amounts available from very modest tails stripping. Higher cost production, from mines or tails, would be added as one went to the right. The net effect of tails stripping, or operating at lower tails assay, is to move the world supply curve out to the right: there would be somewhat more supply available at each price level than would be estimated from mining projects alone.

Each tranch of supply from tails effectively competes with primary production at comparable cost. For example, the supply from tails available between 0.31% and 0.30% tails assay might compete with ISL production in the U.S. The volume from tails between 0.31% and 0.30%, about 1,300 tonnes, is roughly comparable to a single ISL operation.

Effect of Enrichment Pricing

In the preceding analysis, we have assumed that supply of enrichment services is totally elastic: additional supplies are available at a constant price (assumed to be $105/SWU). In reality, and like uranium, increased supply is likely to be increasingly expensive. Indeed, the lack of supply of SWU from inventory, and continued dependence on gaseous diffusion to meet demand, suggests that enrichment needed to reduce tails assays could be significantly more expensive than assumed.

The volume of SWU needed to reduce average tails assays at various levels of uranium “production” from tails rapidly becomes large. Reducing average tails assay for world supply from 0.35% to 0.30% would require an additional 2.9 million SWU annually. Lowering tails assay from 0.35% to 0.25% would require an expansion of world production by an additional 6.4 million SWU. Such increased demand would undoubtedly lead to increases in SWU prices and thus increased costs for exploiting tails assay reductions to increase uranium supply.

As a result, the unit cost of increasing uranium supply by reducing tails assay would increase more rapidly than shown in Figure 2. From Figure 3, we see that nearly one-half SWU is required to extract an additional kilogram of uranium by reducing tails assay from 0.31% to 0.30%. At $105/SWU, this is about $50/kg U. However, if SWU prices rise to $140/SWU due to increased demand to reduce tails assay or for other reasons, the cost of extracting additional uranium increases to $70/kg U.

To find the point of economic optimization, one must combine supply curves for uranium and SWU. Because it is very difficult to construct both enrichment and uranium production facilities, there is considerable uncertainty about the precise optimization point. The actual outcome is likely to depend on unpredictable events. However, what this paper shows is that the maximum variation due to economically feasible changes in tails assay is on the order of 10% for both uranium and SWU (perhaps 7,000 tonnes additional uranium at a cost of about 3 million SWU).

Higher Tails Assay

If, in fact, there were a shortfall in enrichment supply, and thus much higher prices for SWU, it might make sense to raise tails assays and consume more uranium, even if there were surcharges to be paid. Indeed, surcharges under existing contracts with low embedded prices might result in a net price lower than the price for new enrichment supply.

It is thus interesting to see how much uranium demand might increase if higher tails assays were chosen, and the savings in SWU achieved. Figure 4 shows the results of this calculation, along with the data in Figure 3. The horizontal axis shows the additional amount of uranium used (negative numbers) at higher tails assays, relative to the amount used at 0.35% standard current assay. For example, at 0.40% tails assay, utilities would use about 9,300 tonnes more uranium (relative to the base volume of about 63,200).

Figure 4
SWU Saved (Used) By Using (Freeing Up) Uranium
By Adjusting Tails Assay

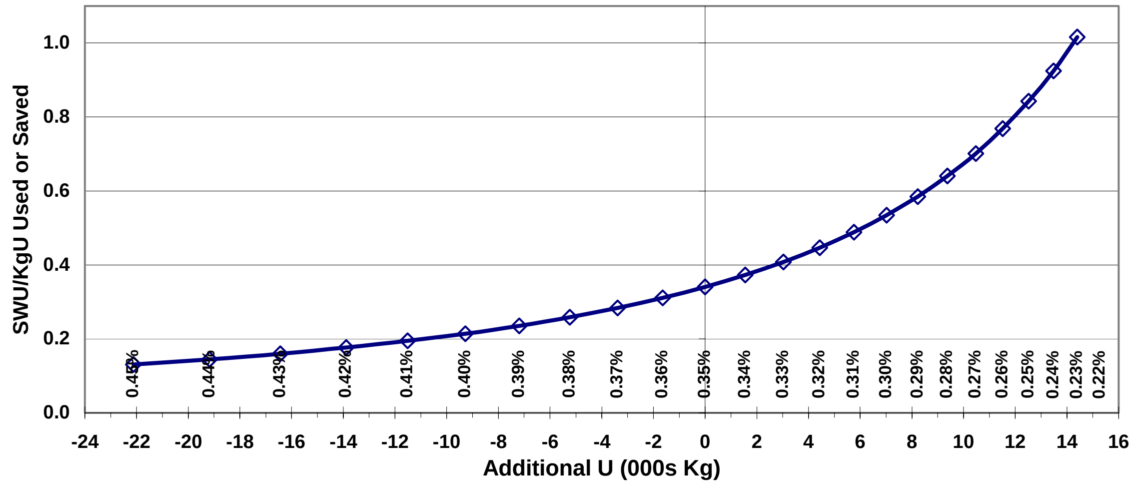

Figure 4 above assumes 4.5% enriched product.

The vertical axis shows the ratio of SWU required per kilogram of additional uranium used or saved in making EUP. For example, at 0.40% tails, 0.20 SWU are saved per kilogram U used, relative to the base case. Thus, if uranium cost $35/kgU, one would be justified in using more uranium by enriching at 0.40% tails assay only if SWU prices rose to about five times this amount, or about $165/SWU.

As indicated in Figure 4, the ratio of SWU to uranium saved (or used) is relatively low at higher tails assays, and the curve is relatively flat. While this means that SWU price would have to rise significantly from current levels to justify using more uranium, it also means that even small reductions in uranium price could result in considerably more uranium being used when SWU prices are high.

Enrichment Market Imperfections

The analysis above assumes current market prices for uranium and SWU. However, under some circumstances, the cost of enrichment may be lower. For example, embedded prices in existing enrichment contracts may be lower than current market prices. Or enrichment services may be available from Russia for tails stripping at prices lower than market levels because Russia is effectively excluded from many western markets.

Embedded prices in existing SWU contracts are lower than current market prices, a result of cut-throat competition in the 1990s. If the average price being paid is, say $95/SWU, and if utilities have flexibility to take additional SWU at this price (a matter that varies with contract), then nominated tails assays may be lower in such cases. At $95/SWU and $33.75/kgU, the optimal tails assay is 0.34%. If all SWU supply were at this price level, uranium demand would be lower by about 1,550 tonnes per year than our base case above. Of course, prices for uranium in existing contracts may also be lower than current market levels (e.g., because of a discount), leading utilities to nominate higher tails assays.

As embedded enrichment contract prices are replaced by higher long-term prices, tails assays will tend to move back up. This trend may be countered by rising uranium prices, which favor lower tails assays. As a result, the current level of tails assays in western enrichment operations may be relatively stable.

Russian SWU supply currently plays an important, but probably temporary, role in western enrichment activities, with European enrichers sending tails to Russia to be stripped and made into natural or enriched product.[1] The primary benefit to European enrichers is probably not the value of the product received back but, rather, the avoidance of paying for tails disposition.

Production of one kilogram of EUP uses about 6 SWU but produces about 10 kg of tails (assuming 0.35% tails assay). If tails disposition costs $3/kg (a USEC estimate), the accrued disposition cost would be about $30/kg EUP, or about $5/SWU. Stripping these 10 kg of tails from 0.35% to only 0.31% would produce one kilogram of natural uranium. At $60 per Russian SWU, the cost to the western enricher would be about $23.40/kg natural uranium. The ultimate savings on tails disposition would be larger. The precise terms of these arrangements are not publicly known.

While western enrichers appear to have entered into tails upgrading deals with Russia to avoid tails disposition liabilities, and perhaps make small amounts of money on upgraded material, Russia appears to need clean western tails to make blend-stock for HEU. The latter appears to set the volume of tails upgrading deals Russia may be willing to enter into. Otherwise, both Tenex and Russian enrichment plant officials appear to regard tails upgrading as not very good business.

[1] As a practical matter, the natural or enriched uranium shipped back to Europe may be derived from displaced HEU feed that has been returned to Russia. Isotopic analysis would settle this matter.