Forensic Signatures from Laser-Induced Resonance Ionization

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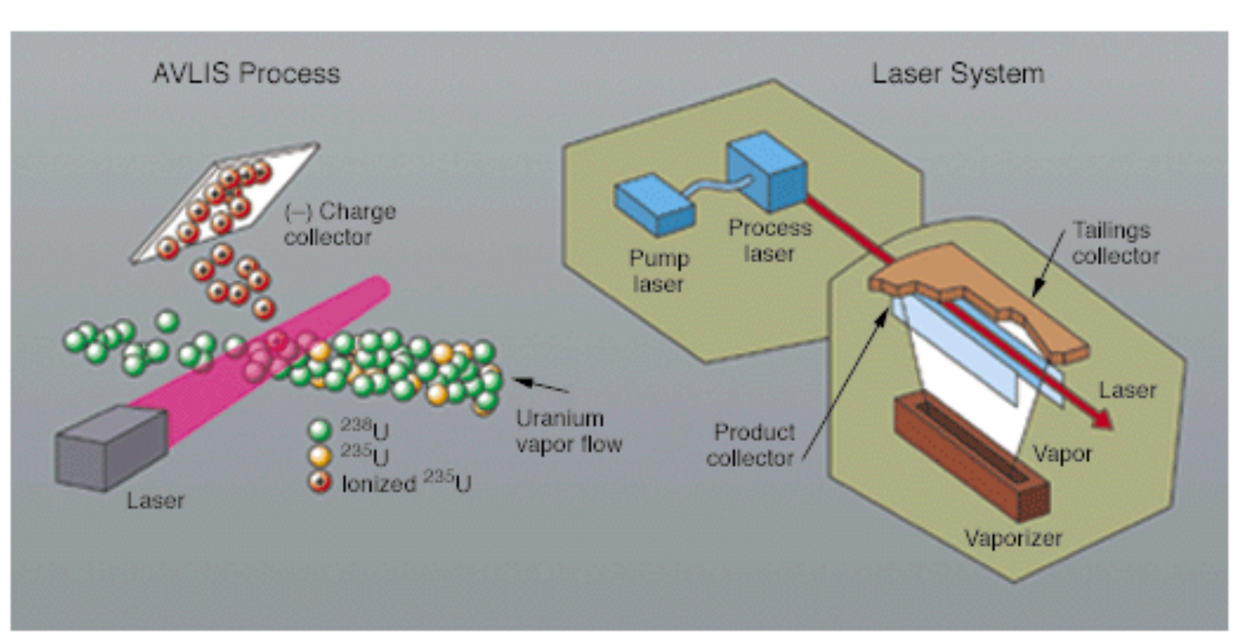
Introduction and Motivation

- Atomic vapor laser isotope separation, or AVLIS, is one possible method of uranium enrichment.
- AVLIS works by vaporizing natural uranium and passing a tuned laser through the vapor, which selectively ionizes ^{235}U.
- The ionized ^{235}U can then be collected on a negatively charged collector plate.
- AVLIS is a promising enrichment method but also presents a proliferation risk.
- We hope to develop signatures that demonstrate when AVLIS is being used, as well as inspection methods for AVLIS facilities.

Mission Relevance

- Developing valid signatures for AVLIS will allow for the monitoring of this uranium enrichment pathway.
- Per the NNSA mission statement, “Developing and maintaining the technical means to monitor whether the terms of a nuclear arms control treaty or other international agreement are fulfilled is a critical factor in ensuring that such agreements are successful.”
- In order to ensure these agreements are successful, nonproliferation organizations must have the ability to monitor laser enrichment plants as well as conventional enrichment plants.



In the laser system used for the LIS uranium enrichment process (right), electrons from the ^{235}U atoms are separated (left), leaving positively charged ^{235}U ions that can be easily collected for use.

Technical Approach

- Two important parameters in the design of an AVLIS device are η, the fraction of ^{235}U photoionized and collected, and φ, the fraction of vapor combined at feed assay with the product.
- These parameters can be determined without analyzing the machine’s design, simply by sampling the product and tails.
- The isotopic composition of natural uranium is approximately 99.27% ^{238}U, 0.72% ^{235}U, and 0.0054% ^{234}U. In the following work, including graphs, we assume a feed of natural uranium.

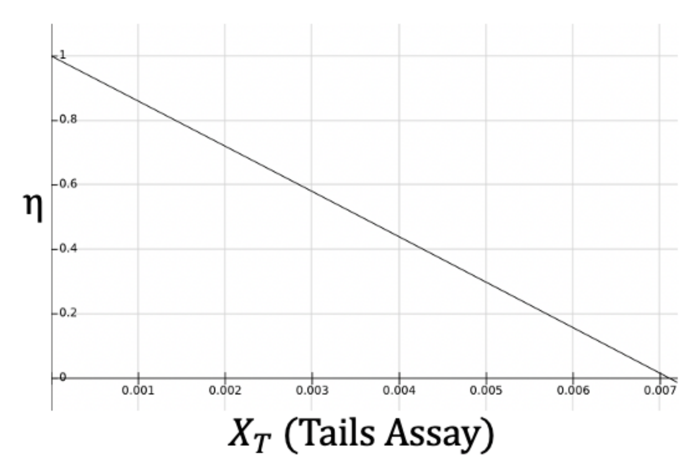
$$X_p = X_f \frac{\varphi + \eta(1-\varphi)}{\varphi + \eta X_f(1-\varphi)}$$

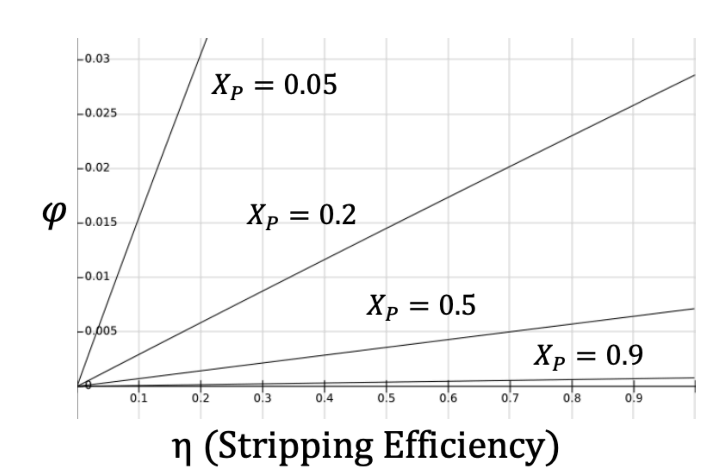
$$\eta = \frac{X_F - X_T}{X_F(1-X_T)}$$

$$\varphi = \frac{X_F(1-X_P)}{X_P - X_F + \eta X_F(1-X_P)}\eta$$

η = stripping efficiency
φ = nonselective pickup
X = assay
P = product
F = feed
T = tails

Results





- It can be determined whether any given sample of enriched uranium originates from a centrifuge or AVLIS facility.
- As a mass-based process, centrifuge enrichment enriches ^{234}U as well as ^{235}U.
- In contrast, AVLIS can be highly selective for 235U in particular, which results in depletion of both 238U and 234U.
- $X_{P,234} = \frac{\varphi X_{F,234}}{\varphi + \eta X_{F,235}(1-\varphi)} = X_{F,234}\frac{1-X_P}{1-X_F}$
- As shown in the graph of φ above, φ is generally quite low, and this results in a substantially decreased ^{234}U product assay.

Conclusion

- The ability to determine machine parameters purely through analysis of product and tails will be of use to facilities inspectors.
- Furthermore, giving the product assay of ^{234}U in terms of the feed assays should allow for an accurate determination of the original feed assays. These can be compared to known feed assays from different sources. Small-scale variations in ^{234}U/^{238}U ratios between sources may be used to determine the origin of the feed material.
- Currently, this work focuses on AVLIS-enriched uranium directly after production; future work will consist of modeling the expected isotopic composition over time to determine likely ^{234}U percentages in AVLIS-enriched uranium as a function of time.
- We also plan to extend this work to plutonium AVLIS.

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