Analysis of the Isotopic Composition of Uranium Enriched by AVLIS

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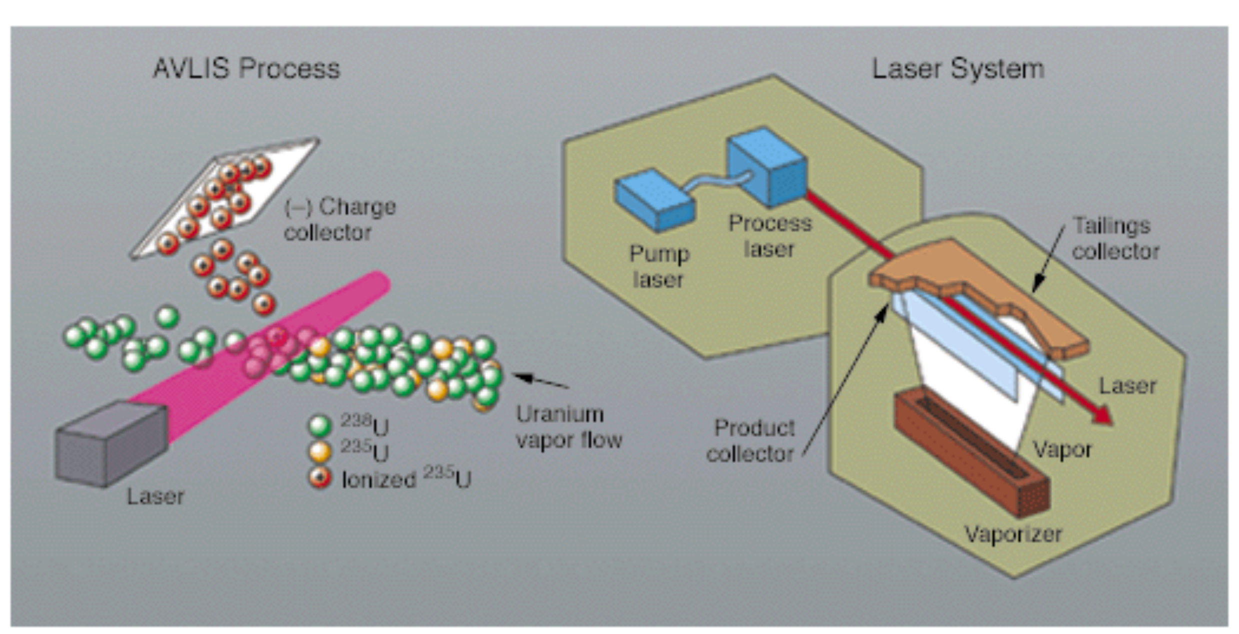
Introduction and Motivation

- 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 with a magnetic field.
- In theory, AVLIS plants are smaller and consume less energy than centrifuge plants that produce similar amounts of fissile material. This would make them more difficult to detect through conventional means. [1][2]
- We hope to develop signatures that demonstrate when AVLIS is being used.

Mission Relevance

- Developing valid signatures for AVLIS will allow for the detection of a possible 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 for 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

- A laser must be tuned to the ionization frequency of ^{235}U with an accuracy of one part in 10^5. At this point, the laser has essentially perfect selectivity, ionizing only ^{235}U atoms which pass through the beam. [3]
- The uranium vapor streams through the laser. All the ionized ^{235}U condenses onto a collector plate, along with some of the natural uranium that does not pass through the laser. The system is designed such that this condensate is 5% ^{235}U. [3]
- The isotopic composition of natural uranium is approximately 99.28% ^{238}U, 0.71% ^{235}U, and 0.0054% ^{234}U. [4] To find the expected composition of the final product, we solve the following simple system of equations, where u_e is the percentage of the final product from the enriched stream and u_n is the percentage from the unenriched vapor:

$$u_e + u_n = 1$$
$$1.0(u_e) + 0.0071(u_n) = 0.05$$

- Multiplying u_n by 0.0054% gives the expected proportion of ^{234}U to be approximately 0.0052%, slightly lower than the amount found in unenriched uranium.
- In contrast, uranium enriched by gas centrifuge or diffusion undergoes enrichment in ^{234}U to significantly higher levels, since these mass-based processes select for lighter isotopes.

Results

- A spectroscopic analysis of an enriched uranium sample can determine whether the sample was enriched through AVLIS or centrifuge based on the percentage of the sample composed of ^{234}U. A measurement of approximately 0.0052% ^{234}U, or slightly lower than naturally occurring, indicates the use of AVLIS, while any amount substantially higher than 0.0054% indicates the use of centrifuge enrichment.

Expected Impact

- This work will allow researchers to analyze a sample of enriched uranium and determine whether it was enriched through AVLIS.
- Further work will hopefully allow researchers to determine the sample’s provenance more precisely. Analysis of differing designs may reveal slight differences in isotopic composition that can be used to deduce the exact variant of AVLIS used to enrich the sample.

MTV Impact

- MTV has given us the opportunity to connect with AVLIS researchers at Lawrence Livermore National Lab (LLNL), who will bring a wealth of expertise to this project.
- During the summer of 2020, this project will continue in collaboration with LLNL researchers thanks to an MTV-funded internship.
- The effort will be led by Chris Carson, who began work on AVLIS at LLNL in 1988 and has decades of experience in nonproliferation work.

Conclusion

- As has been previously noted, this analysis of AVLIS, though only in its preliminary stages, will aid the NNSA in its nonproliferation efforts by providing novel means by which the provenance of enriched uranium may be ascertained.
- The extension to analysis of different AVLIS configurations planned for this summer will result in a refined model capable of determining a uranium sample’s origin with enhanced precision.

References

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- [3] USNRC Technical Training Center: Uranium Enrichment Process Module 3.
- [4] PubChem, National Institutes of Health. Uranium. https://pubchem.ncbi.nlm.nih.gov/element/Uranium#section=Isotopes

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