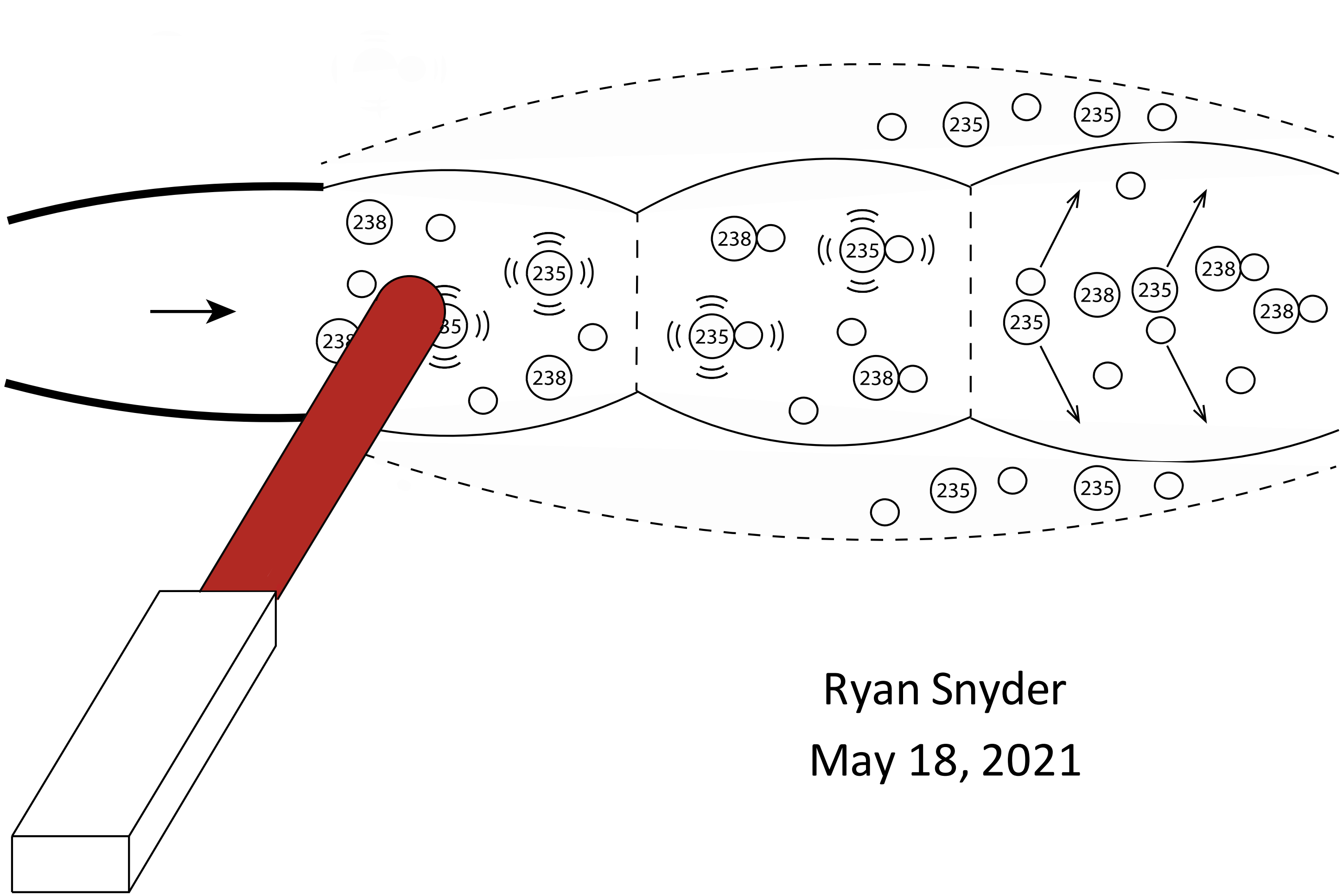
Proliferation Risks of Laser Enrichment of Uranium



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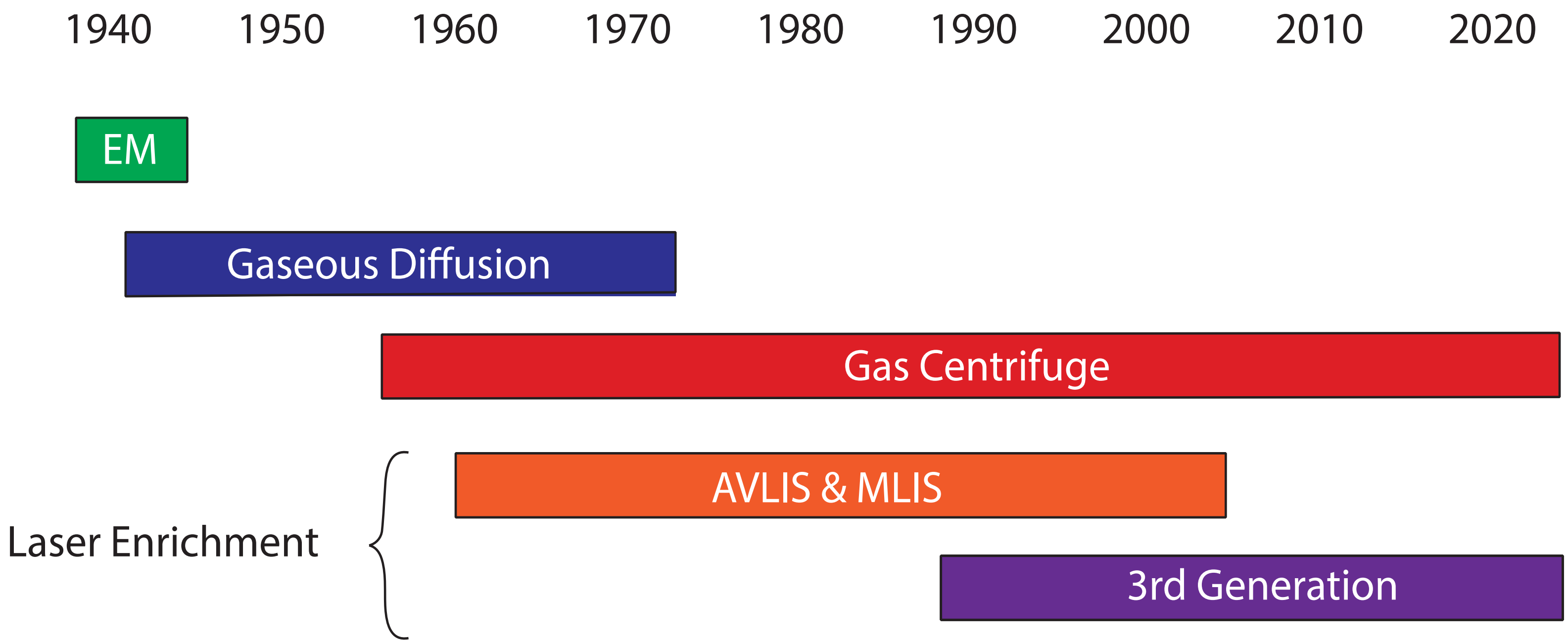
History of Uranium Enrichment



Previous enrichment technologies exploited the difference in mass between U-235 and U-238. Laser Isotope Separation exploits that U-235 and U-238 absorb different wavelengths of light.

3rd Generation laser enrichment relies on a separation concept called condensation repression (16 or 5.3 µm) by laser excitation (likely method for SILEX).

Enrichment technology spreads to others…

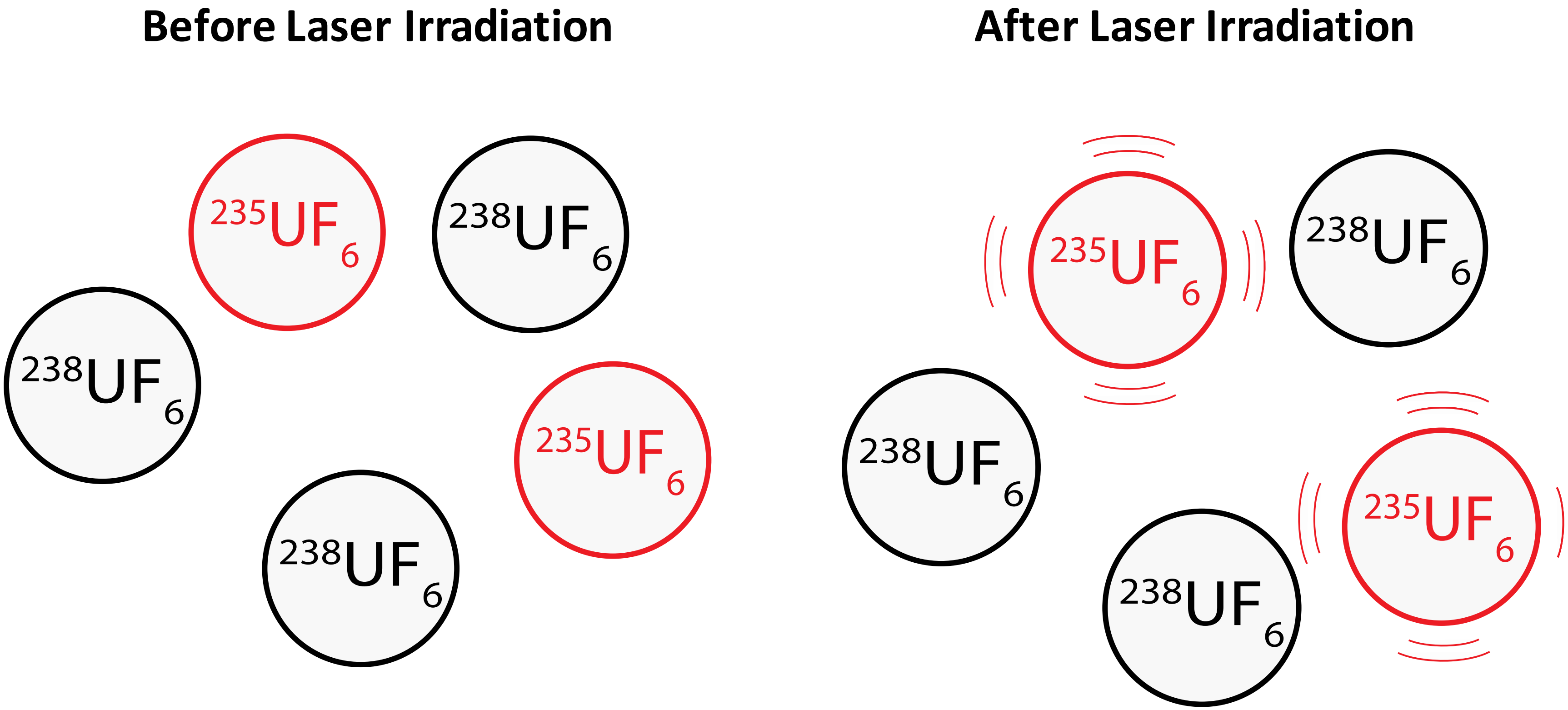
Gaseous Diffusion: USA, USSR, United Kingdom, France, China

Gas Centrifuge technology is now in use by 12 countries, others had R&D.

Large Plants	tSWU/yr	Small Plants	tSWU/yr
China	5900	Brazil	35
France	7500	India	15-30
Russia	29,000	Iran	5?
URENCO	19,000	Japan	75
		N. Korea	8?
		Pakistan	15-45
Total	$\sim 61,400$	Total	~ 153
Global demand	$< 55,000$		

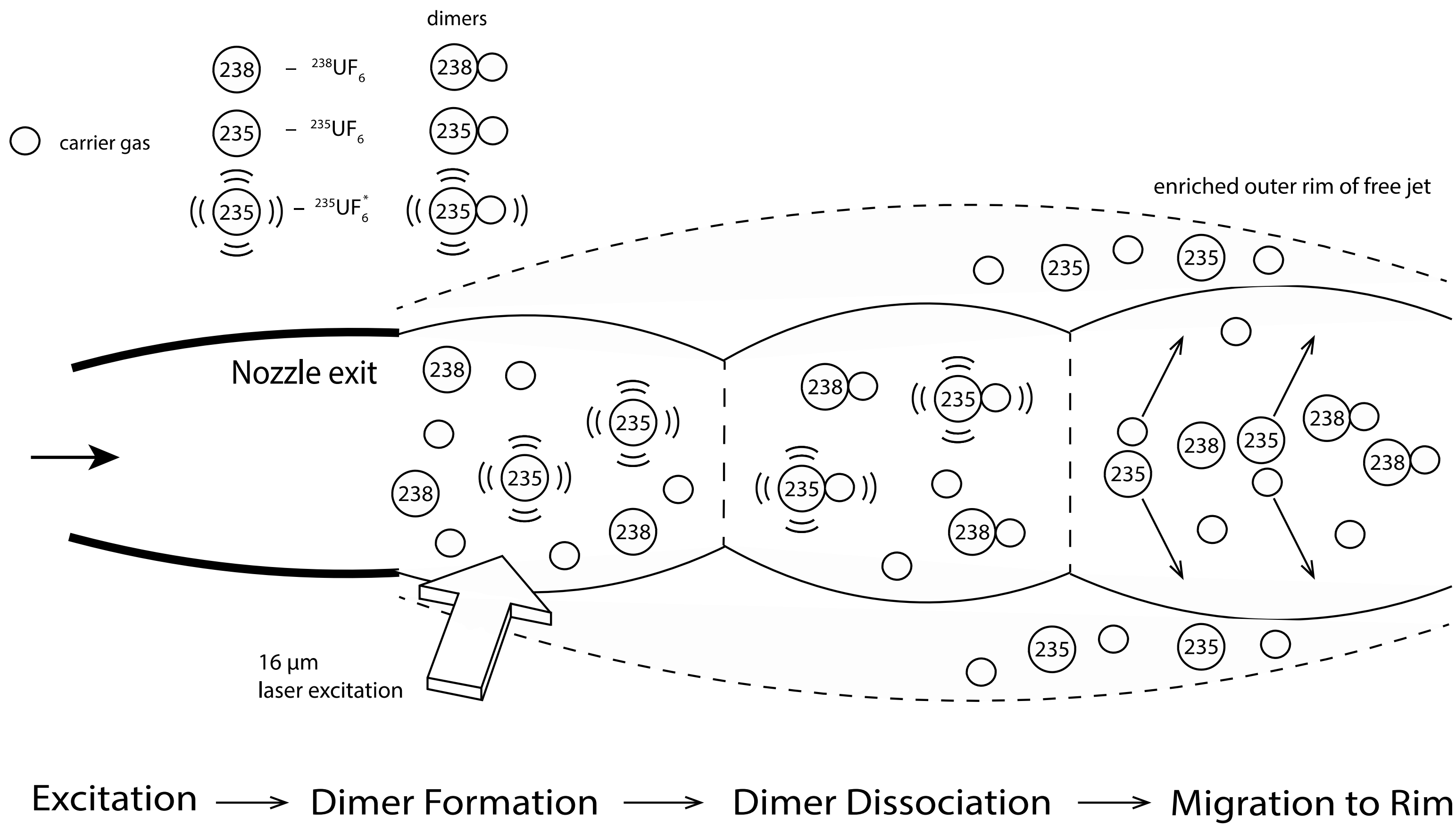
Source: fissilematerials.org

How Laser Isotope Separation Works



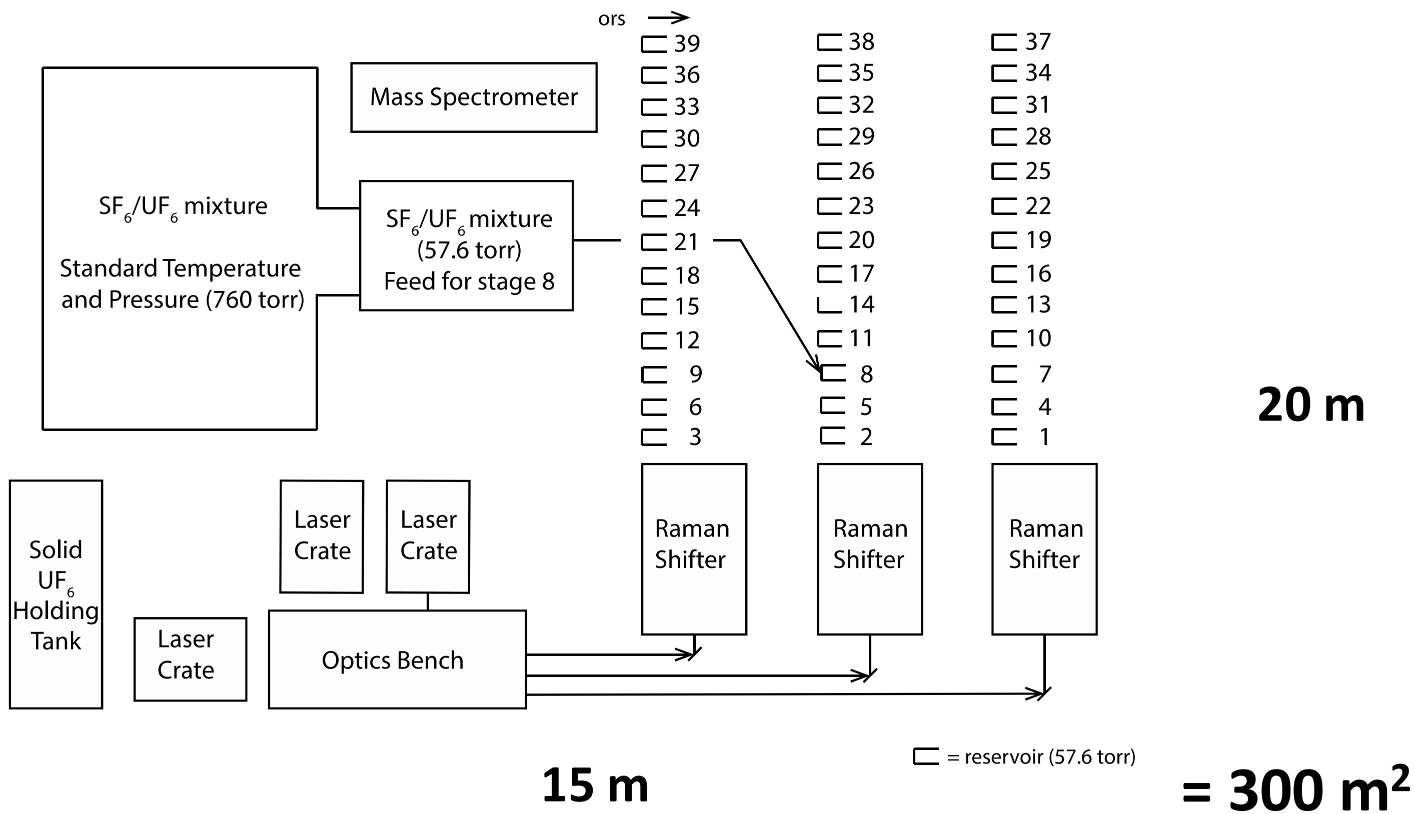
Natural uranium is 0.7% U-235.
Uranium enrichment aims to increase the concentration of U-235.
Weapon-grade uranium is typically 90% U-235.
With LIS, the goal is to use a laser to excite U-235 and leave U-238 alone.
Final step is to separate out the excited U-235.

How Does SILEX Separate Isotopes?



1. Recoil energy from broken dimer bond pushes $^{235}UF_6$ to the rim of the gas.
2. The pressure gradient between the expanding gas and the low pressure chamber allows for $^{235}UF_6$ to experience a greater acceleration than $^{238}UF_6$ +carrier gas.

Scaling Up from 0.7% to 90% HEU (9,000 SWU) for 1 SQ



This facility would produce 32.5 kg of HEU per year enriched to 90% in uranium-235. The IAEA defines one significant quantity (SQ) as 25 kg of uranium-235 included in HEU enriched to 20% or greater. For 90% HEU, 1 SQ = 27.8 kg.

An enrichment factor β greater than 2 would require less area and improve the energy efficiency. SILEX Systems claims β is 2–20.

For a 10 meter laser irradiation path: < 10 kWh/SWU (URENCO: 50 kWh/SWU)

Overinterpreting the GLE project in the US

- There is a danger of assuming that the success or failure of the GLE project accurately reflects the proliferation prospects of condensation repression technology.

- Of course, there are risks to having this technology commercialized:
  - Drive research interest around the world
  - Transfer of people, knowledge, and equipment through more channels that are difficult to monitor.

- Current status of GLE:
  - US Treasury Department recently approved merger (SILEX 75%, Cameco 25%) – entirely foreign controlled.
  - GLE might be able to eventually build a plant in Paducah, KY (enriching tails to natural levels)
  - Building a full enrichment plant in Wilmington, NC, looks less likely.

- SILEX Agreement between the United States and Australia was signed in 1999 and lasts until 2029.

- In the agreement, any technology developed in the United States may not be transferred to Australia
    - R&D is now done mostly in Australia

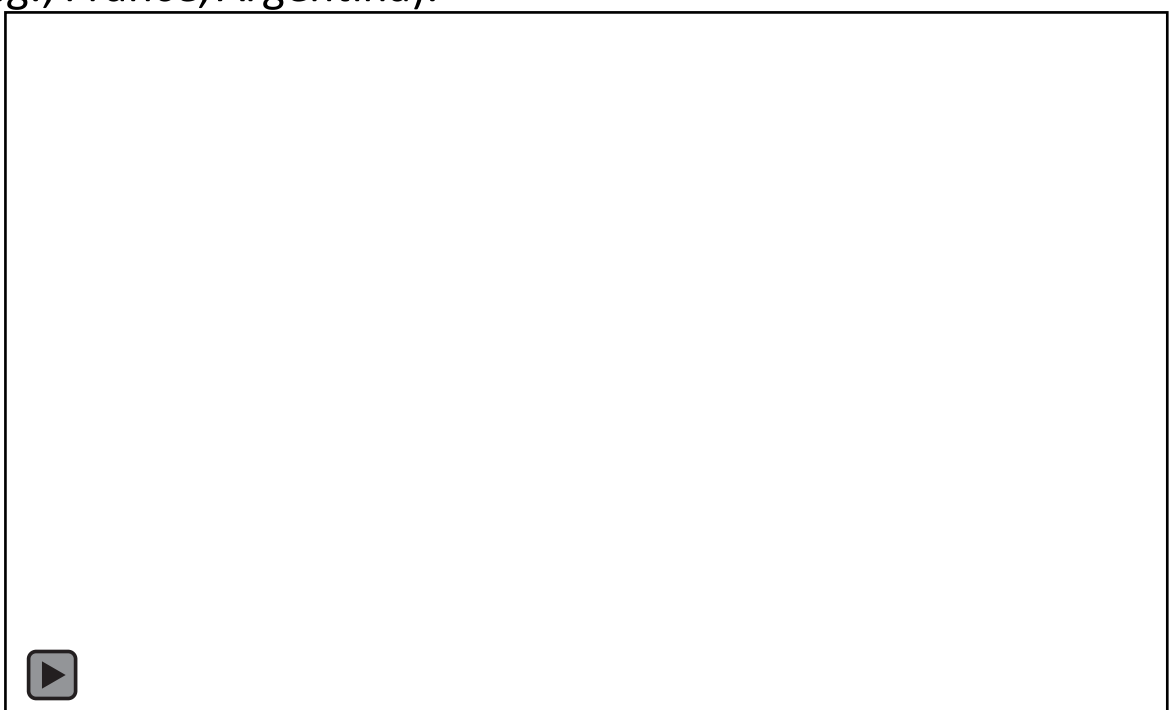
- But relevant R&D is done in many locations now.
    - Multiple laser systems
    - Condensation repression modeling and experiments with proxies for uranium
    - More evidence of thinking about industrial-scale production

- So my paper is fairly limited, and I would have focused on broader physics concepts that are now accessible by an increasing number of technologies.
    - Most of the relevant analysis about this technology is in the online technical supplement, not the main paper.

Quantum Cascade Lasers (QCLs)

- Power output is small and continuous (0.1–10 Watts), but arrangements could be imagined to allow for uranium enrichment by CR with multiple QCLs. Main use is identifying and quantifying chemicals. **(Not export controlled)**

- 16 μm lasers are on the market, but they are low power. Some countries are already developing these lasers for either detection or enrichment (e.g., France, Argentina).



Boron Neutron Capture Therapy

- Investigations into the use of condensation repression to produce boron-10 for cancer treatment (brain, head, and neck cancers)

- Basic science:
  - Guo, J., et al., "Laser Excitation of BCl_3 and consequential collision-induced reaction with carrier gases." *Chemical Physics Letters,* 2021.

- Modular design for industrial-scale production:
  - Lyakhov, K.A., "Some issues of industrial scale boron isotopes separation by the laser assisted retarded condensation (SILARC) method," *Separation and Purification Technology,* 2017.

- If any aspect of enriching uranium with condensation repression is challenging, it is probably extracting the enriched product and mastering the enrichment process to higher levels (i.e., challenges with gas processing between enrichment stages).

What Does this Mean? What is to be Done?

- Risks from commercialization (GLE project): transfer of people, knowledge, equipment to clandestine facilities

- Consider attractiveness for weapons production:

  - Smaller space required than most centrifuge designs (URENCO?)

  - More energy efficient (for imagined designs)

  - Laser expertise more widely available worldwide – more accessible?

  - New options for nuclear latency (laser development and condensation repression applications) – contrast with centrifuges

- Still important to improve safeguards, export controls, and monitoring, but the way this technology works and ongoing developments raise questions about the effectiveness of current efforts.

Other Relevant Reading

Ryan Snyder, “A Proliferation Assessment of Third Generation Laser Uranium Enrichment Technology,” *Science & Global Security,* 2016.

https://www.tandfonline.com/doi/full/10.1080/08929882.2016.1184528

Supplementary Material:

https://www.tandfonline.com/doi/suppl/10.1080/08929882.2016.1184528/suppl_file/gsgs_a_1184528_sm4908.pdf