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International symposium on present status and future perspective
for reducing radioactive wastes ~ aiming for zero-release ~

Laser Isotope separation

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Isotopes

- Atoms with the same chemical character but different masses

  ^{235}U, ^{238}U, ..

- Strongly related with nuclear reactions

  Fission, nuclear spallation, neutron capture

- Abundant in spent nuclear fuel

  U, Pu, MA, FP

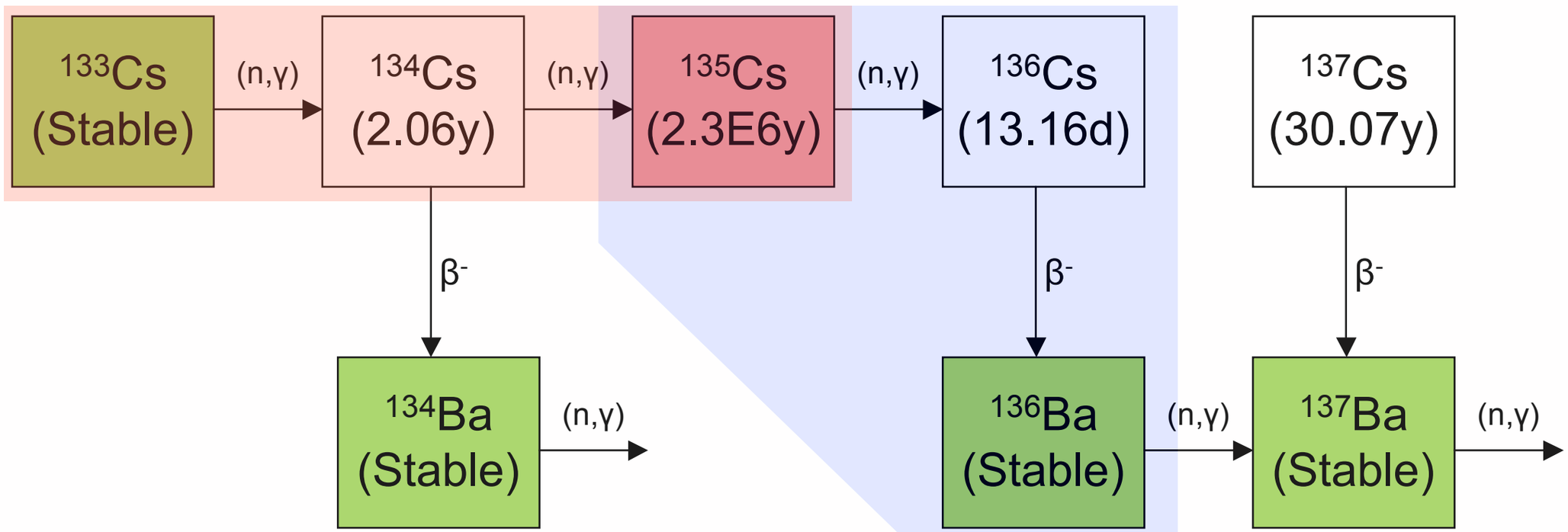
- Both radioactive and non-radioactive isotopes exist

  ^{137}Cs, ^{135}Cs, ^{133}Cs

- Isotope separation: to separate different isotopes in mixture

Why isotope separation demanded?

- To qualify neutron balance in transmutation



Some nuclides need isotope separation before their transmutation.

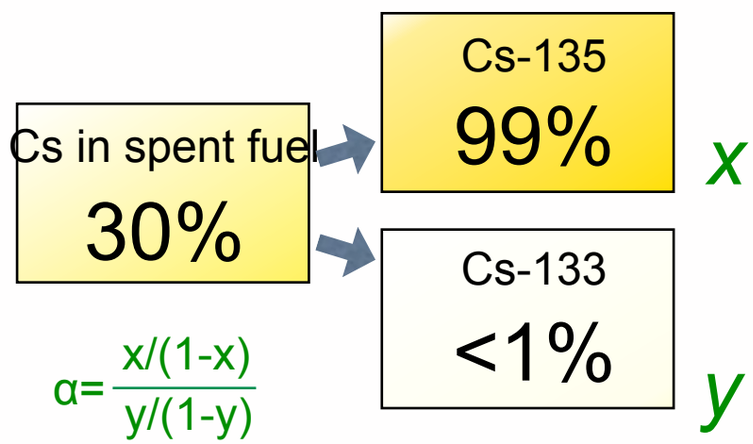
- To collect valuable rare metals from spent nuclear fuels without radioactivity ^{106}Pd, ^{107}Pd

Principal difficulty in the isotope separation

- Request for extremely high selectivity

Separation factors for cesium separation and uranium enrichment

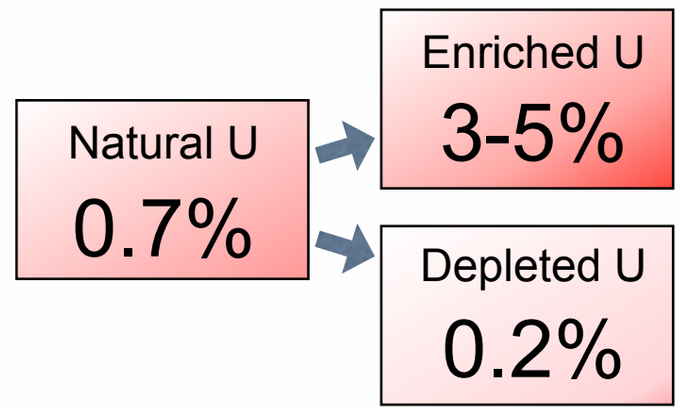
Cesium separation



$$\alpha = \frac{x/(1-x)}{y/(1-y)}$$

Separation factor α~9800 !

Uranium enrichment



α~20

Require three-orders of magnitude higher SF

→ A paradigm shift is desired.

Why so small separation factor?

- No chemical method different from element separation

- Only mass-difference usable

- Very small mass difference in LLFP ^{135}Cs, ^{133}Cs

- Separation factor and cascade number in known methods

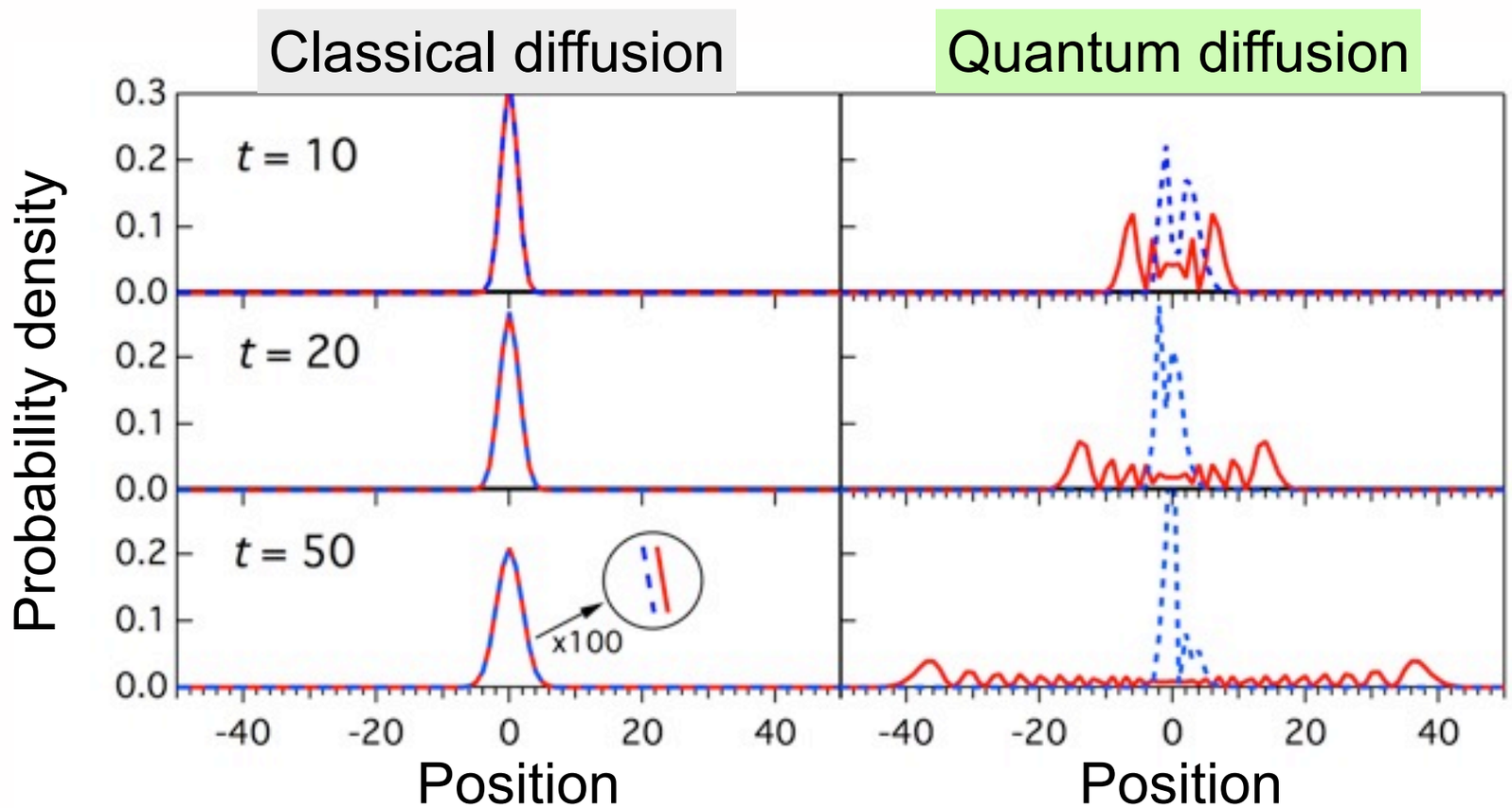
	Gas diffusion	Gas centrifuge	Molecular laser
Separation factor	1.003	1.4	<10
Cascade number	1000	10	1

- Laser method with as many cascade as gas diffusion method?

→ We proposed “quantum-diffusion method”.

Quantum diffusion, how innovative

- From the classical mechanics to the quantum
- Surprisingly high isotope selectivity



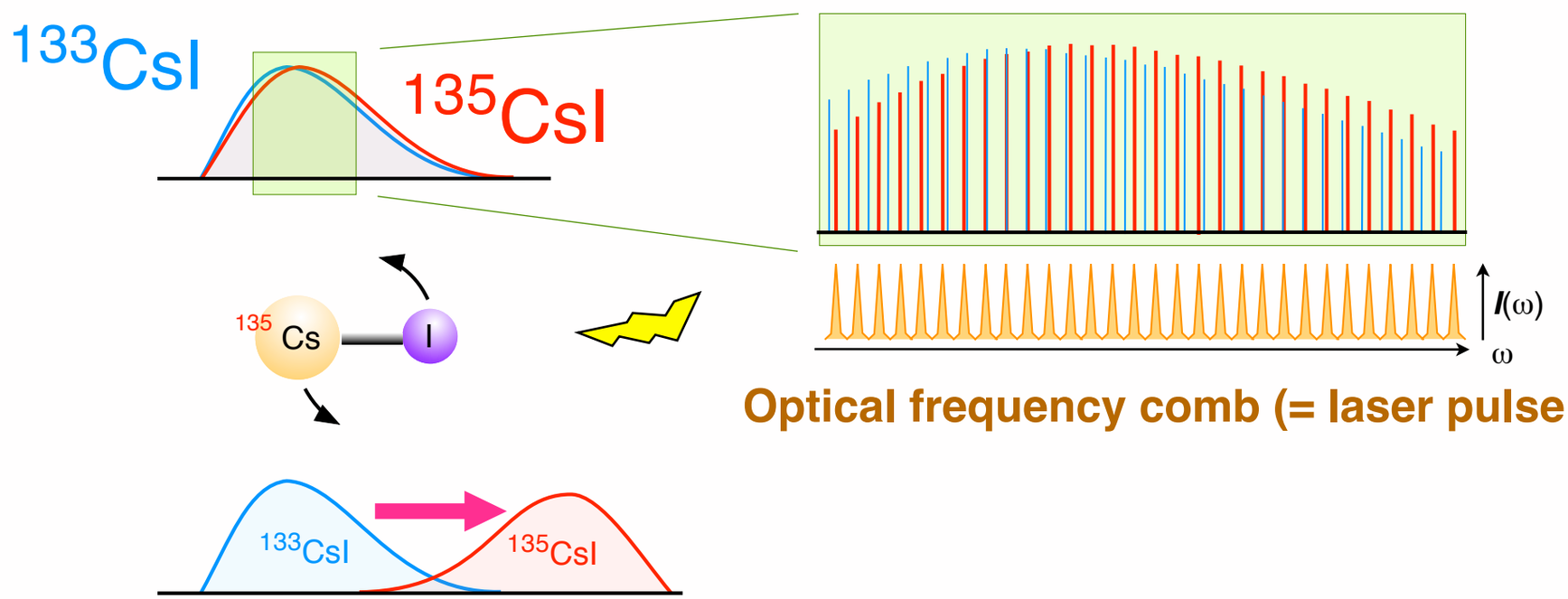
- Relying on two hot topics in mathematics
  → "Quantum walk" and "Anderson localization"

How to realize quantum diffusion

- Repeatedly irradiate THz-wave laser pulse to diatomic molecules
  → Quantum diffusion realizes in the angular momentum space of molecular rotation

L. Matsuoka et al., J. Korean Phys. Soc. 59, 2897 (2011).

Pure rotational transition spectrum



Optical frequency comb (= laser pulse train)

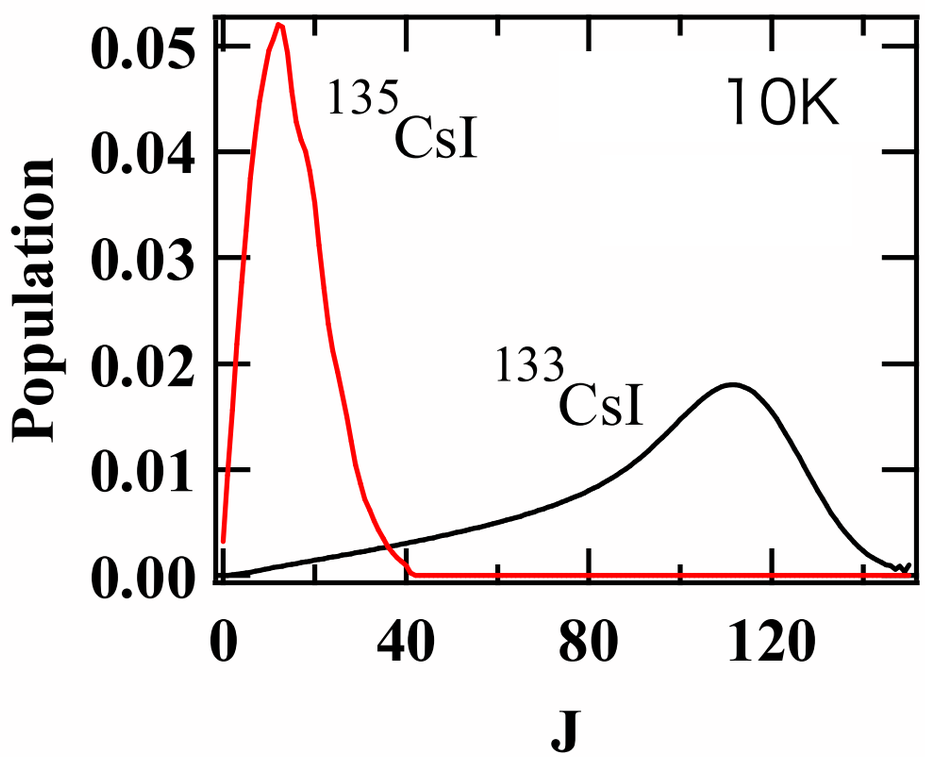
Quantum diffusion enables "isotope-selective heating"!?

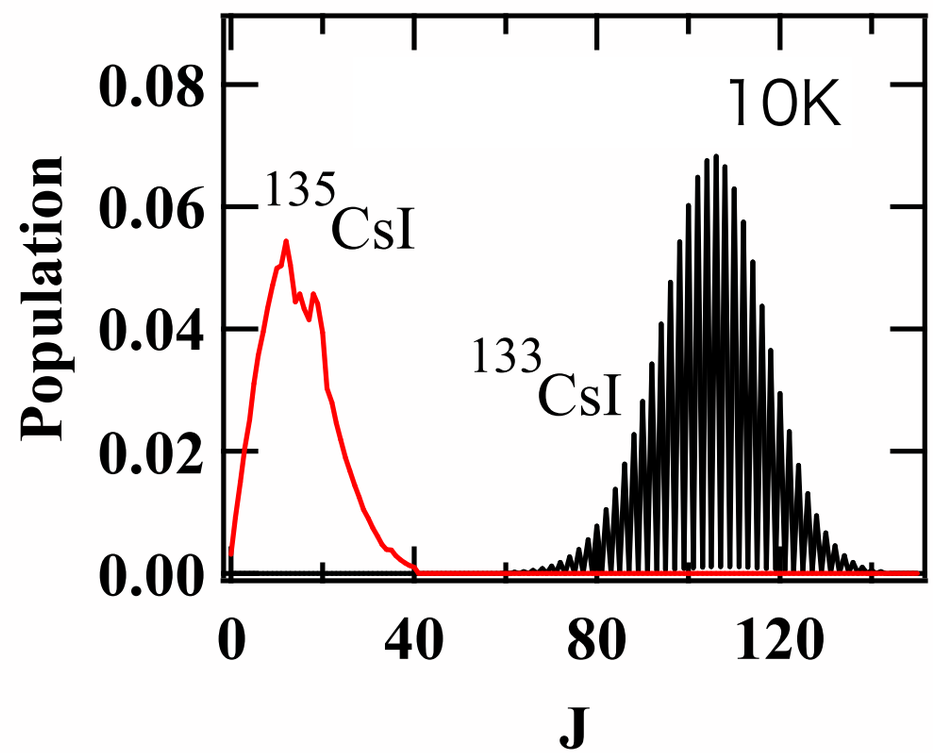
- Corresponding to a laser method with a large-scale cascade as large as the gas diffusion method

Numerical simulation

- Pronounced isotope selectivity in the CsI molecule

L. Matsuoka et al., GLOBAL2011, 392063





- By further pulse shaping, perfect separation possible

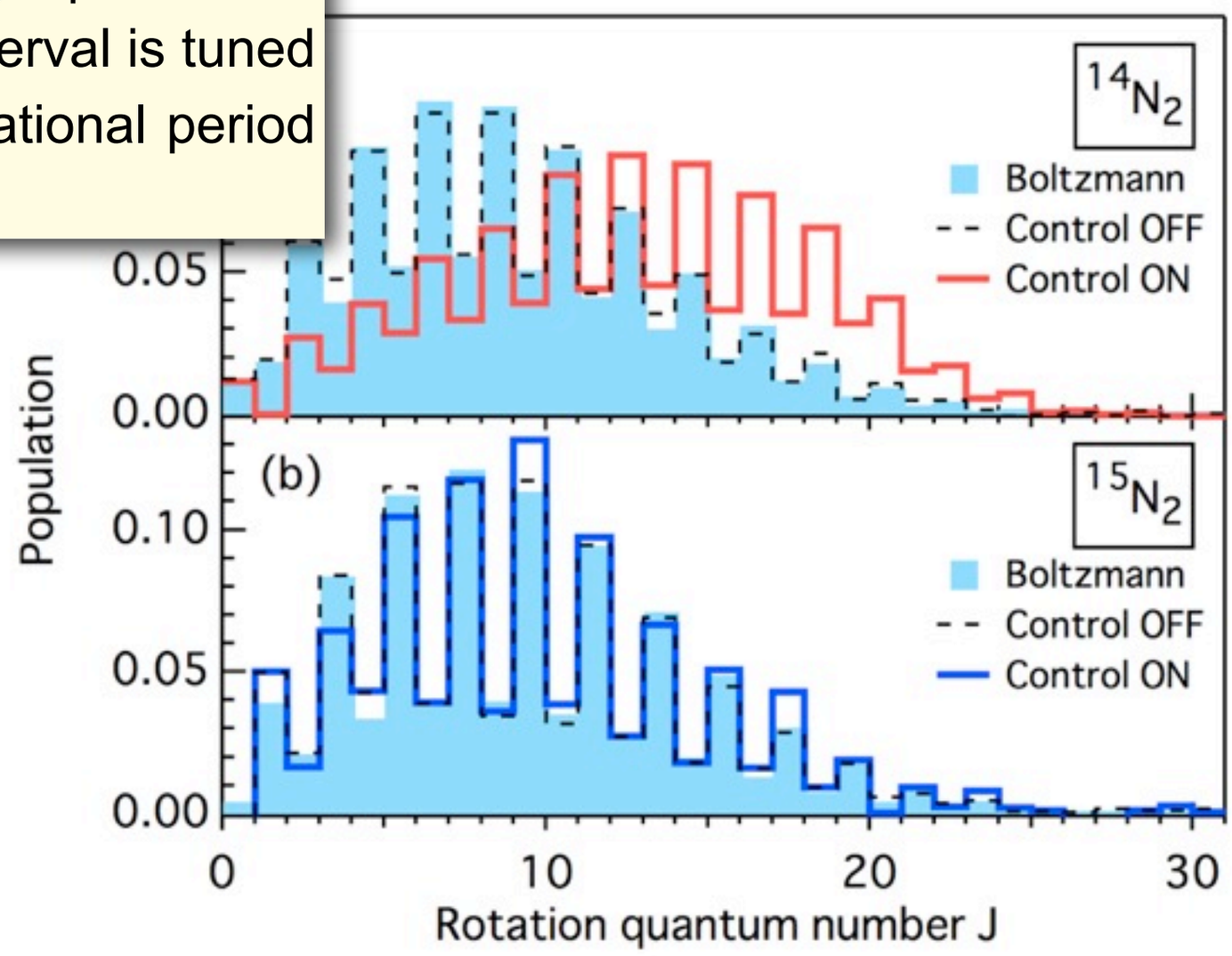
- Predicting a separation factor of 8000 for CsI @ 1000K

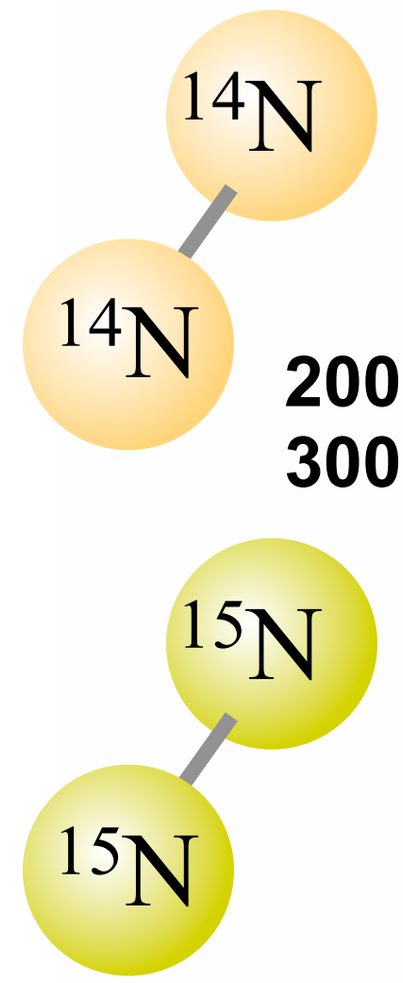
Experimental demonstration

- Demonstrated with an ordinary laser in place of the THz laser

K. Yokoyama and L. Matsuoka, *ATOMOΣ*, **56**, 525-528 (2014).

Irradiating a pulse train whose interval is tuned to the rotational period of $^{14}N_2$





200 Torr
300 K

- THz-wave laser is under development for the true demonstration

Prospect to realization and key techniques

<u>Strong point</u>

- Molecular laser method without ultracold gaseous feed

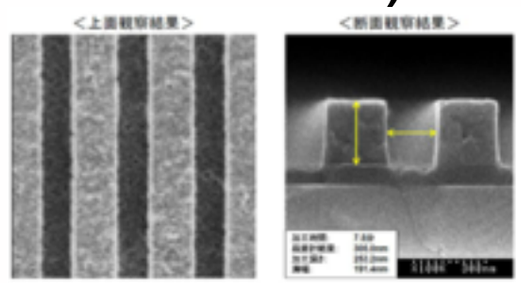
  (Such a process has already been industrialized.)

<u>Techniques to be developed</u>

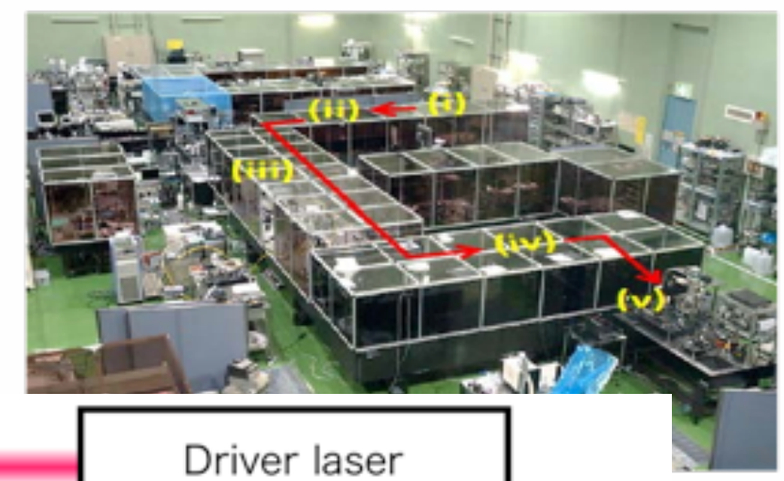
- Recovery scheme
- High-power THz-wave laser
- Precise manipulation of THz-wave pulses

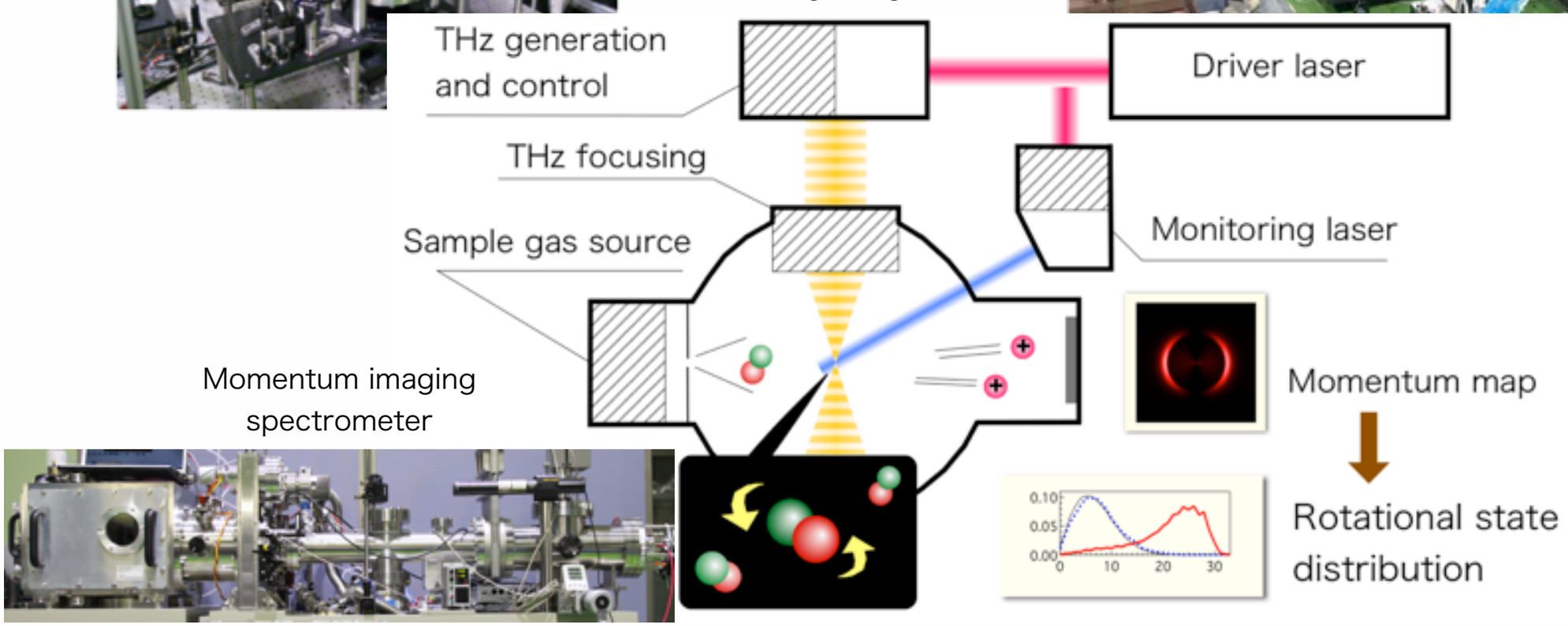
Framework of the project and current activity

- @JAEA Kansai Photon Science Institute (Kizu, Kyoto)
- THz-wave laser (Nagashima, Ochi, Maruyama, Tsubouchi, Kono, Kiriyama, Okada, Kosuge)
- Demonstration (Matsuoka, Hashimoto, Yoshida) ・ Recovery (Ichihara, Kurosaki, Kobayashi)

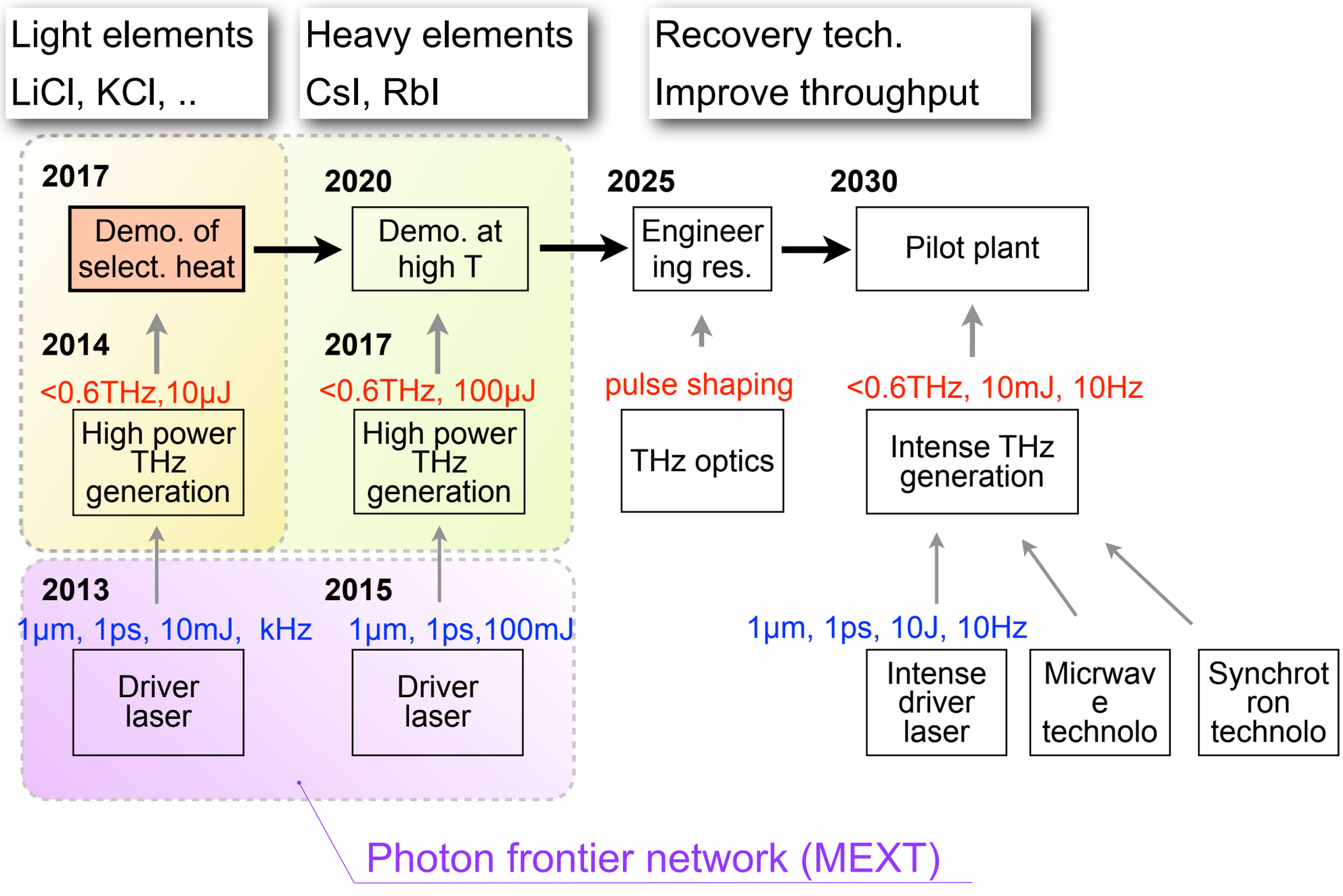


THz generating device with contact grating tech.





Road map


Light elements
LiCl, KCl, ..
Heavy elements
CsI, RbI
Recovery tech.
Improve throughput
2017
2020
2025
2030
Demo. of select. heat
Demo. at high T
Engineering res.
Pilot plant
2014
<0.6THz,10μJ
High power THz generation
2017
<0.6THz, 100μJ
High power THz generation
pulse shaping
THz optics
<0.6THz, 10mJ, 10Hz
Intense THz generation
2013
1μm, 1ps, 10mJ, kHz
Driver laser
2015
1μm, 1ps,100mJ
Driver laser
1μm, 1ps, 10J, 10Hz
Intense driver laser
Micrwave technolo
Synchrotron technolo
Photon frontier network (MEXT)

Summary

- We proposed a new isotope-selection scheme using quantum diffusion to override the difficulty in the isotope separation of heavy elements.

- Some fundamental studies are running at KPSI to realize quantum diffusion method.

Advocation of zero release of nuclear waste will drive germination of new science and technology.