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ROSATOM

ON THE POSSIBILITY OF OBSERVING THE STIMULATED DE-EXCITATION OF THE NUCLEAR ISOMER ^{186m}Re IN THE PLASMA OF Z-PINCH AT THE ANGARA-5-1 FACILITY

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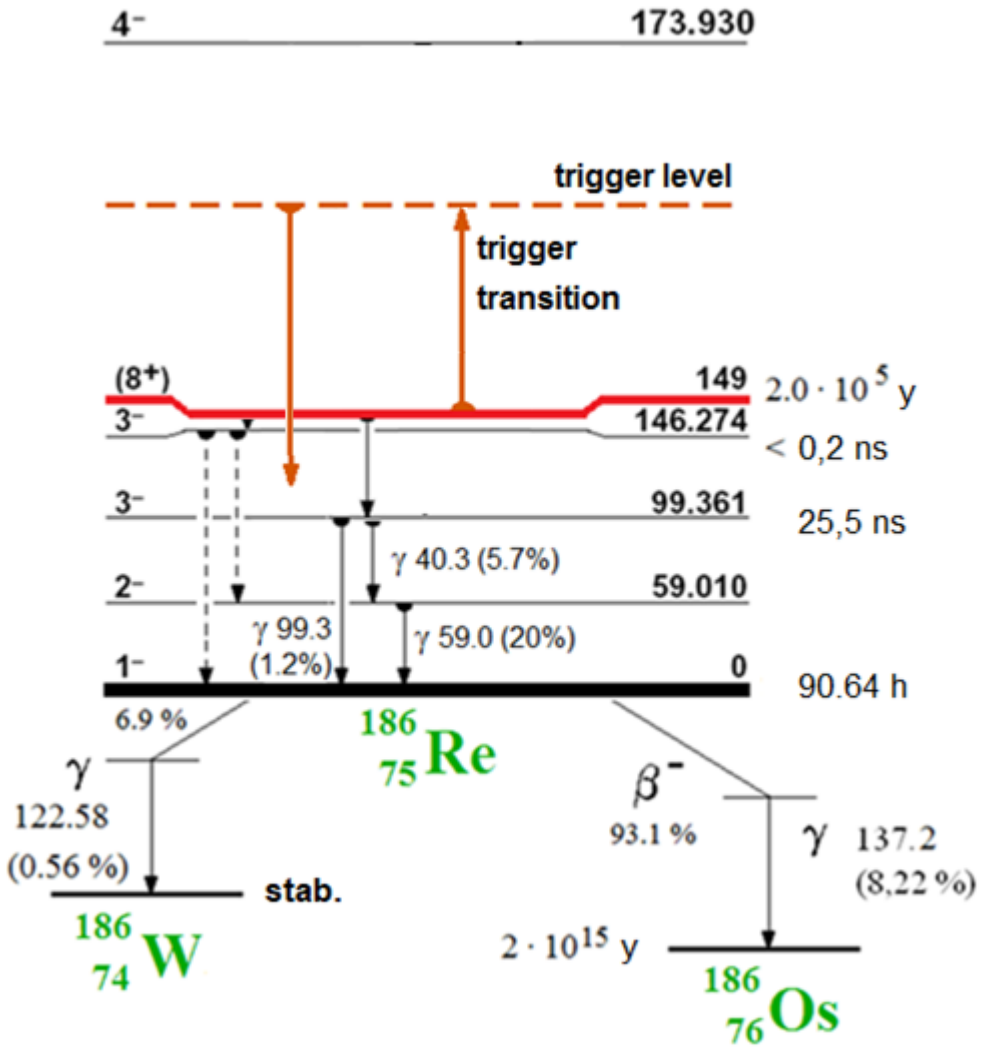
^{186}Re nucleus level diagram



Up arrow – the possibility of exciting the trigger level.

Advanteges of the ^{186m}Re isomer::

- Very long life time.
- Radiochemistry can isolate the pure ^{186m}Re isomer.
- An efficient energy source can be developed based on the stimulated de-excitation of the isomer.

Complicating circumstances:

- Now the trigger level parameters are unknown.

The known level diagram is incomplete. This was shown by measurements of the decay curve of ^{186}Re, obtained in the reaction $^{186}W\,(p\,,n)\,^{186}Re$ (*Koltsov, Rimsky-Korsakov, Karasev, 2018*).

Stimulated de-excitation of nuclear isomers (SDENI) is most effective in plasma

In a plasma with isomeric nuclei at an electron temperature $\Theta_e \sim \Delta E$, the following are simultaneously present:

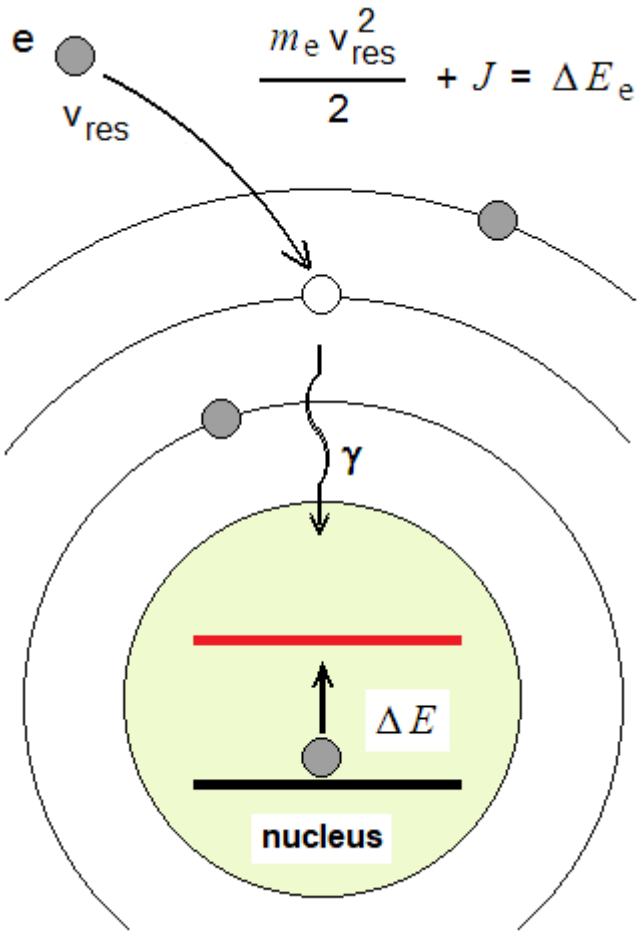
1. Intense X-ray radiation at the nuclear transition frequency.
2. Intense fluxes of electrons and ions.
3. High degree of ionization of atoms with isomeric nuclei.

The probability P_{SDENI} is proportional to the plasma lifetime.

Outline

1. Nuclear excitation by electron capture (NEEC) by ions for de-excitation of nuclear isomers in plasma.
2. Studies with isomeric ^{186m}Re nuclei in laser plasma.
3. Advantages of the electric discharge plasma of the Angara facility for de-excitation of ^{186m}Re isomers.
4. Details of the experimental technique for obtaining an electric-discharge plasma with isomeric ^{186m}Re nuclei.
5. Prospects for studying the de-excitation of the ^{186m}Re isomers in the plasma of the Angara facility.

The effective mechanism for the excitation of a trigger nuclear level in plasma is the nuclear excitation by electron capture (NEEC) by ions *(Gol'danskiy and Namiot, 1976)*



J – electron binding energy in the atom.

NEEC cross section (maximum in resonance)

$$\sigma \sim \lambda\!\!\!^{-2}_{e} = \left(\hbar / m_e v_{res} \right)^2$$

The probability P_{excit} of nucleus excitation in equilibrium plasma *(Koltsov, 2018)*

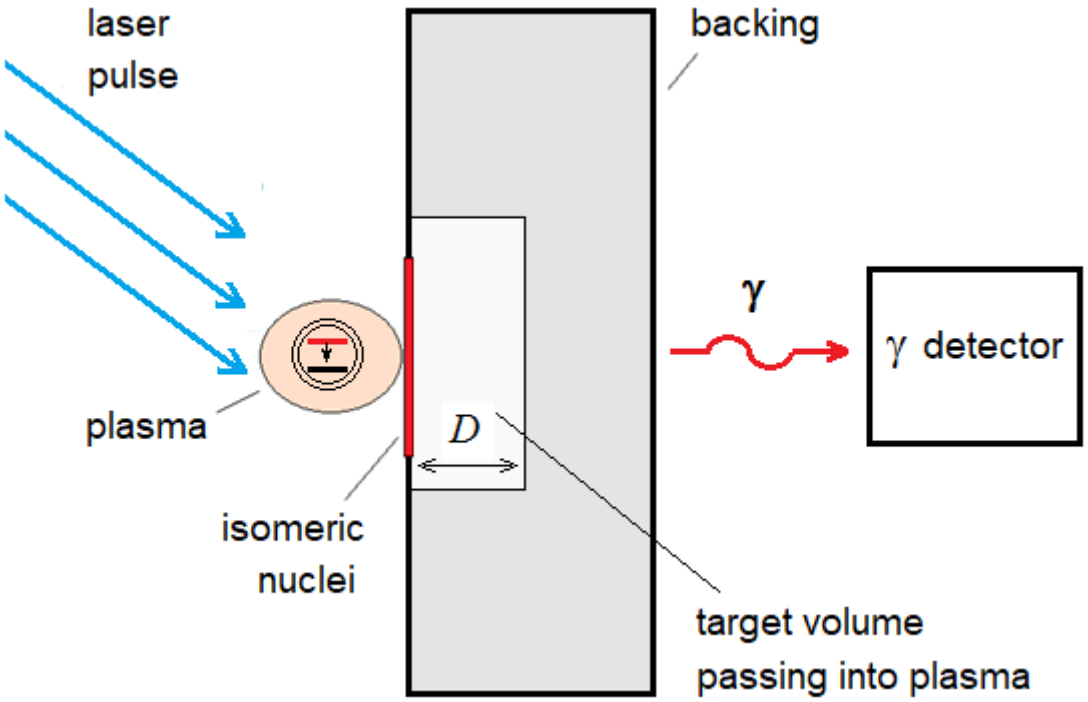
$$P_{excit.} \sim \frac{1}{\pi^2} \frac{\Gamma \tau}{\hbar} e^{-\Delta E / \Theta_e}$$

Θ_e – plasma temperature; τ – plasma lifetime,

Γ – width of the conversion transition from the trigger level to the isomer.

Optimally: $\Theta_e \geq \Delta E$

Experiments with laser plasma



Stimulated de-excitation of isomers can be detected

- by promt **γ**-quanta radiation ,
- with less sensitivity by nonequilibrium **α, γ, e** $^-$ radiation after de-excitation of the isomer.

Features of laser plasma:

1. The plasma lifetime is of the order of the laser pulse duration.
2. Depth D < 1 μm, the number of isomer nuclei in plasma depends on the concentration of the isomer in the target material.

Stimulation of ^{186m}Re isomer de-excitation in laser plasma

(*Vatulin, Jidkov, Rimsky-Korsakov, Koltsov, …, 2017*)

Target camera of Iskra-5 laser facility

(*Institute of Experimental Physics, Sarov, Russia*).

Laser pulse :

- λ = 1.3 μм,
- энергия ≈ 300 J,
- duration 0.3 ns,
- Intensity ~ 10^{15} W / cm^2.

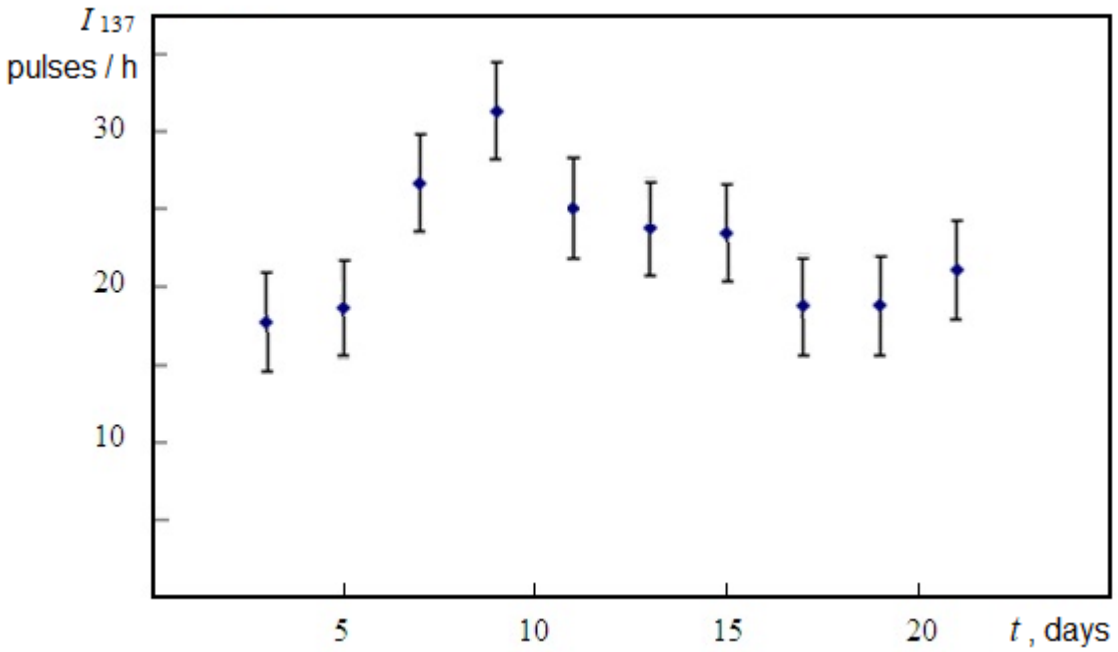
Plasma temperature Θ_e ~ 1 keV.

Targets:

- isomer ^{186m}Re on W or Fe backings,
- isomer atomic concentration ^{186m}Re ~ 0.001 %.

Isomer production - irradiation of a natural Re in reactor, flux ~ $1 \cdot 10^{20}$ neutron / cm^2.

Intensity of the 137 keV line in the γ-spectrum of ^{186m}Re irradiated in a laser plasma



Intensity decay corresponds to $T_{1/2}$ = 112 ± 10 hours

If the effect is due to the stimulated discharge of ^{186m}Re nuclei, then the discharge of ~ 10^{-5} % of the ^{186m}Re nuclei is stimulated.

We have to assume that there is an unknown excited state in the ^{186}Re nucleus with $T_{1/2}$ for several days, which is populated upon stimulated discharge of the ^{186m}Re isomers.

Plasma of electric explosion of conductors – an alternative to laser plasma for ^{186m}Re stimulated de-excitation *(Koltsov, 2018)*

Plasma expansion is slowed down by the magnetic field.

Attainable plasma parameters (*Angara-5M facility, Troitsk Institute for Fusion Research , TRINITI, Moscow, Russia*) :

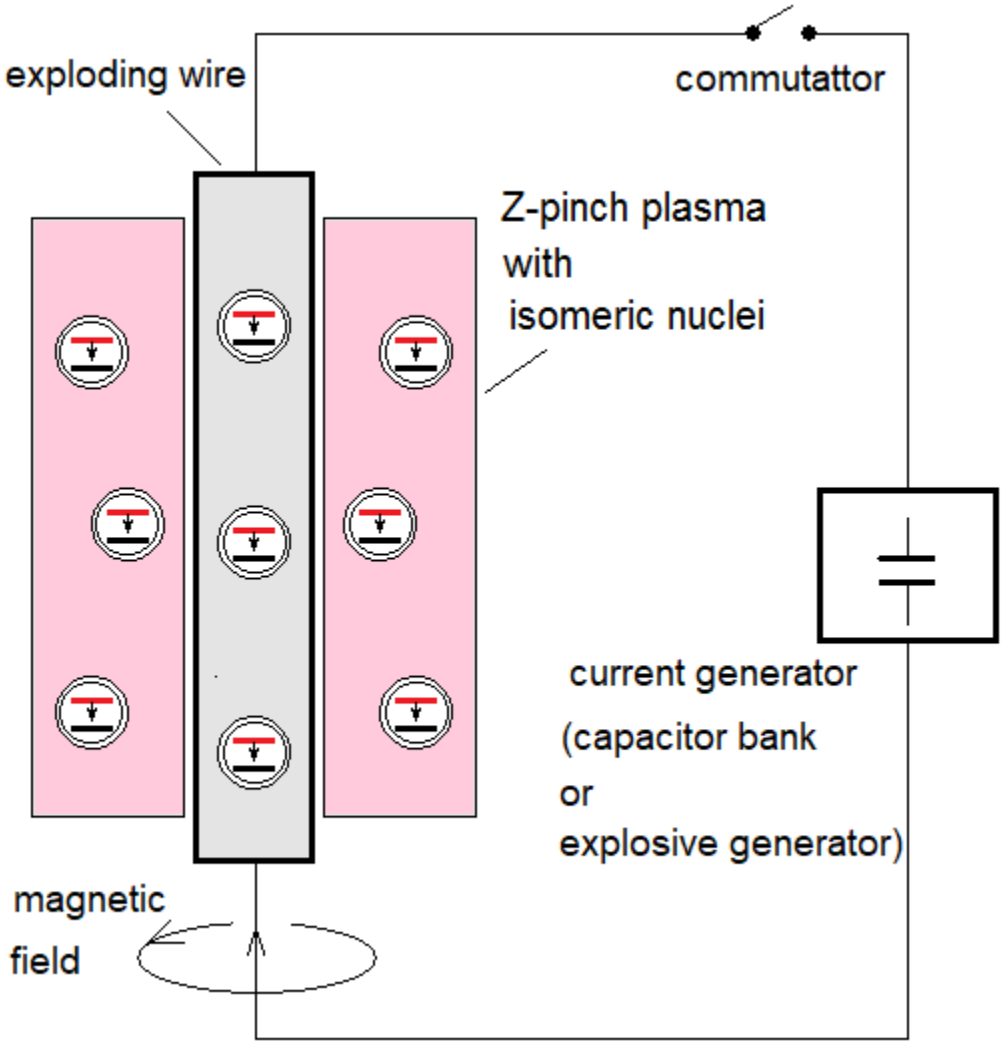
– current $I_{max} \approx$ 6 MA;

– temperature Θ_e ~ 1 keV;

– puls energy ~ 1 MJ;

– plasma lifetime τ = 10 – 100 ns.

"Exploding wire" is usually in the form of a liner - a set of wires for optimal plasma heating.

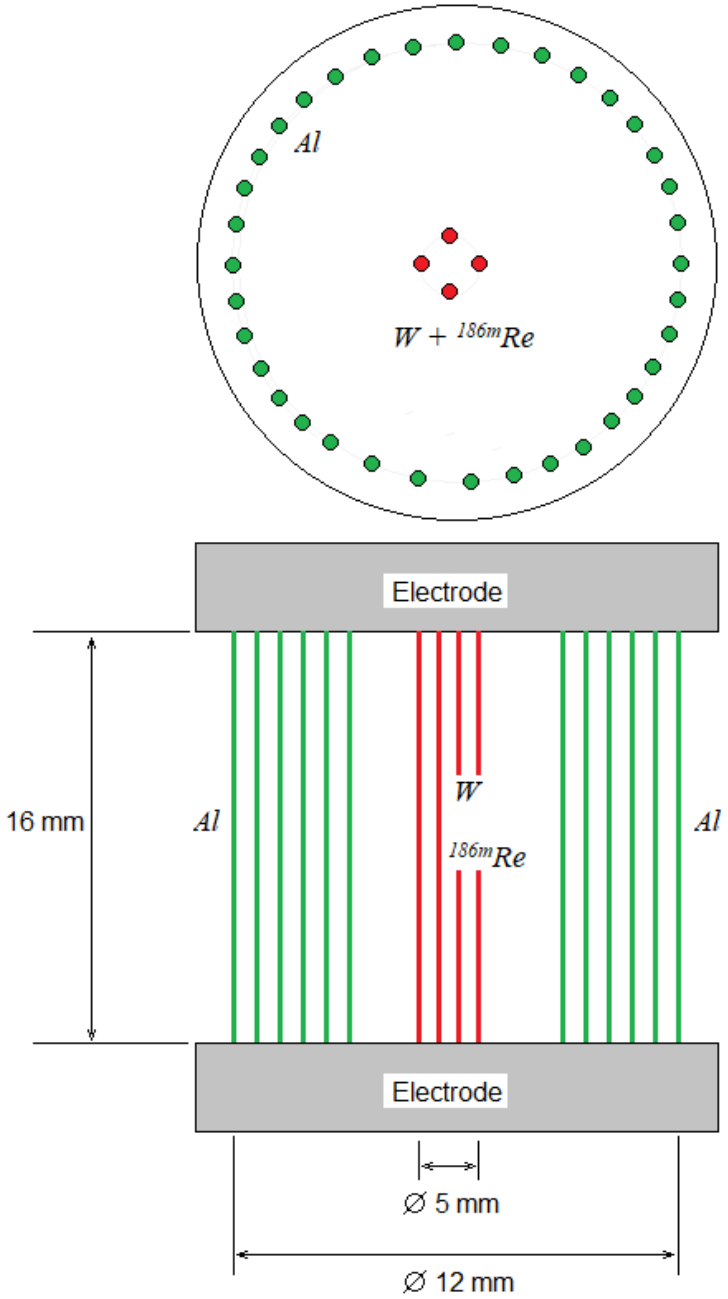


Scheme of electric explosion of conductors.

Angara-5 facility for producing the electro-discharge plasma

Troitsk Institute for Innovation and Fusion Research (TRINITI). $I_{max} = 6\ MA.$

Composite liner for plasma formation with ^{186m}Re ions

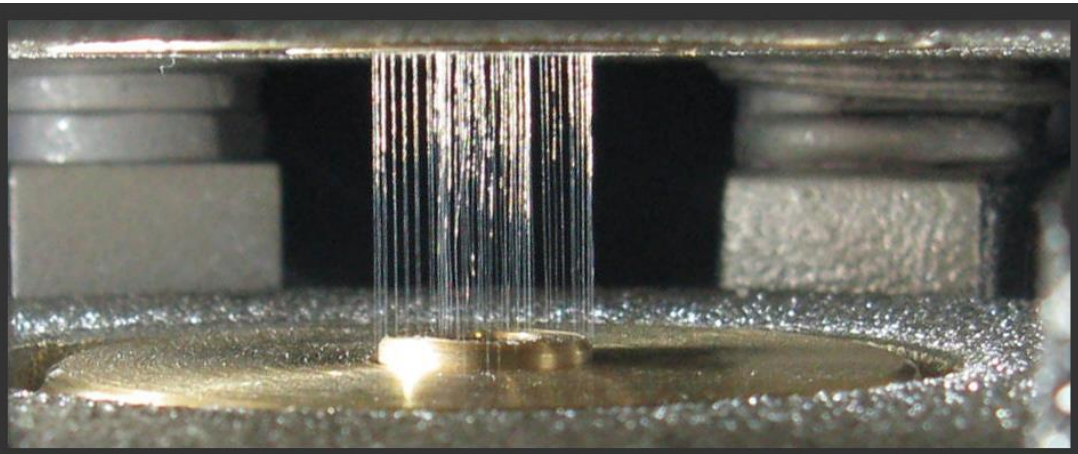


The liner is composite since plasma of only heavy elements cannot be heated strongly due to the high radiation intensity *(Volkov, Zaitsev, Grabovsky, Fedulov, Aleksandrov, Lakhtyushko, 2010).*

The outer cylindrical shell of forty *Al*-wires ∅ 18 μm provides a high-temperature high-density Z-pinch plasma.

The material of four $W + {}^{186m}Re$ wires ∅ 6 μm located inside the cylinder also transforms into high-temperature plasma.

Composite liner for formation of plasma with heavy Ions



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Когда 02.08.2021

Deposition of the ^{186m}Re isomer onto W-wires

W-wire ∅ 6 μm attached to *Cu*-copper wire ∅ 1 mm.

Requirements:

- Need *Re*-metal in the middle of the *W*-wire.
- The length of the *W*-wire is 20 cm according to the liner assembly technology.

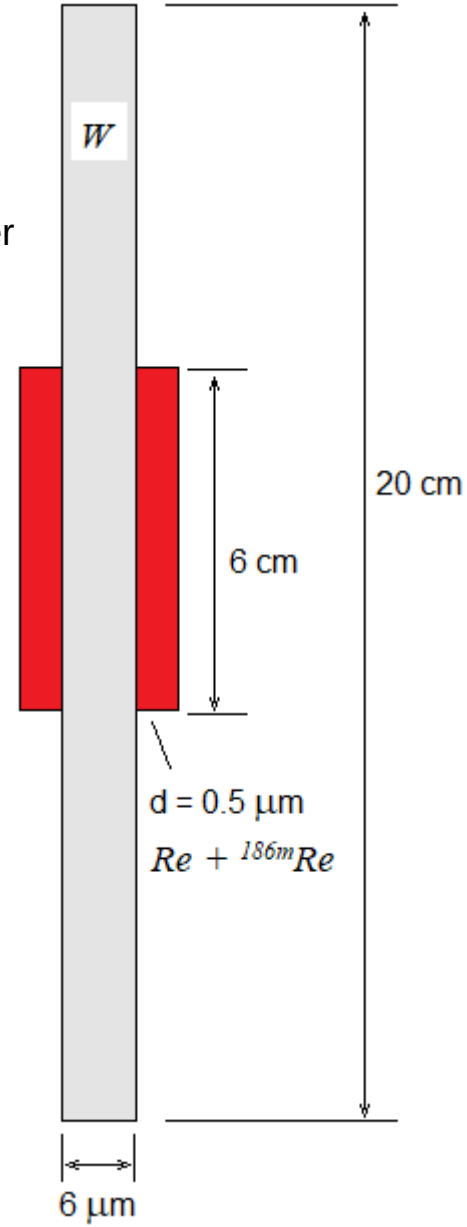
***Re* deposition method**

- Electrodeposition of *Re* on a *W*-wire.
- Annealing the sample in hydrogen to reduce *Re* to metal.

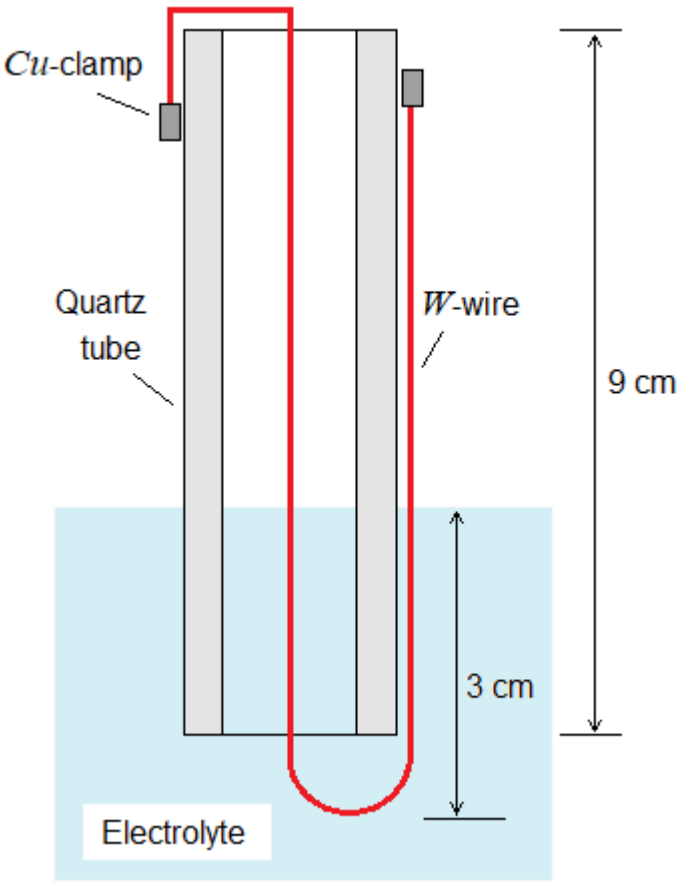
W-wire for assembly of the liner.

0.001% ^{186m}Re isomer concentration in *Re*-metal.

^{186m}Re activity is 0.13 Bq.



Electrodeposition of Re on a W-wire



Cathode module in electrolyte:

W-wire is fixed on a quartz tube

Electrodeposition:

- Electrolyte 35 ml :
  - sulfuric acid 70 g/l
  - ammonium sulfate 40 g/l
  - Ammonium perrhenate NH_4ReO_4 (Re-metal 80 mg)
  - 0.001% ^{186m}Re isomer concentration in Re-metal.
- Electrodeposition on five cathode modules at once.
- The current ≈ 0.7 mA.
- Control of the mass of electrodeposited Re by the activity of the ^{186m}Re isomer.

Annealing in hydrogen of Re on W-wires directly in the assembly with quartz tubes.

Prospects

- Experiments in laser plasma showed: the probability of stimulated de-excitation of the ^{186m}Re isomer is $P_{SDENI} \sim 10^{-5}$ % in a plasma of temperature Θ_e = 1 keV and lifetime of 0.3 ns.
- The lifetime of an electric-discharge plasma is ~ 100 times longer → $P_{SDENI} \sim 10^{-3}$ % at Θ_e = 1 keV.
- Experiment sensitivity $P_{SDENI} \sim 10^{-6}$ % .
- P_{SDENI} depends on temperature Θ_e and on the trigger transition energy ΔE.

$$P_{SDENI,\,\Theta_{e,i}} \sim P_{SDENI,\,\Theta_{e,1keV}} \, e^{-\Delta E \left(\frac{1}{\Theta_{e,i}} - \frac{1}{\Theta_{e,1keV}} \right)}$$

Plasma electron temperature Θ_e, keV	P_{SDENI}, %		
	ΔE = 1 keV	ΔE = 3 keV	ΔE = 10 keV
1.0	$1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$
0.5	$4 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	$5 \cdot 10^{-8}$
0.2	$2 \cdot 10^{-5}$	$6 \cdot 10^{-9}$	$2 \cdot 10^{-25}$
0.1	$5 \cdot 10^{-8}$	$2 \cdot 10^{-15}$	$1 \cdot 10^{-42}$

Conclusion: stimulated de-excitation of the ^{186m}Re isomer can be observed in the plasma of the Angara facility.

Thanks !