Anna V. Golubeva

NRC 'Kurchatov Institute', Moscow, Russia

Hydrogen retention in RAFMs – Current status of investigation

Perspectives of fusion research in Russia

Fusion investigations (tokamaks) give no visible benefit for humanity for decades

Nobody can promise that fusion power plant will be built and work properly within 20, 50 years

The only direction where fusion can give practical use relatively quickly, in our lifetime – hybrid reactors with a tokamak as a neutron source for fission (subcritical nuclear reaction & radioactive waste processing)

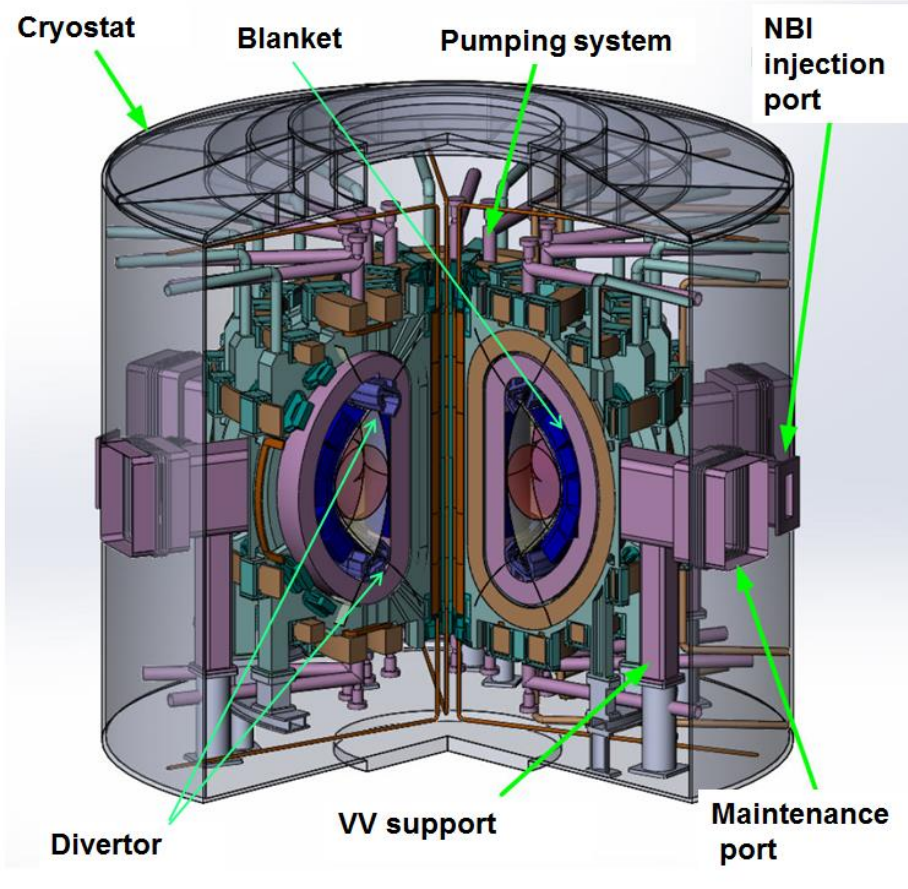
Status of DEMO-FNS Development

Head of the project: B.Kuteev

Fusion-fission hybrid facility based on superconducting tokamak DEMO-FNS is under development in Russia

fusion power up to 40 MW

fission power up to 400 MW



FEC-26 Yu.S. Shpanskiy et al. FIP/O7-4

Aspect ratio R/a, m	3.2/1
Toroidal magnetic field	5 T
Electron/ion Temperature, keV	11.5/10.7
Beta normalized β_N	2.1
Plasma current I_{pl},	5 MA
Neutron yield G_N	$1.3 \cdot 10^{19}$/s
Neutral injection power	36 MW
ECR heating power	6 MW
Discharge time	5000 h Capacity factor 0.3
Life time	30 years
Consumed/ generated power	200 MW

Facility is considered in RF as main source of technological and nuclear science information that complement the ITER research results in the fields of burning plasma physics and control

ITER, FNS and DEMO in neutron damage

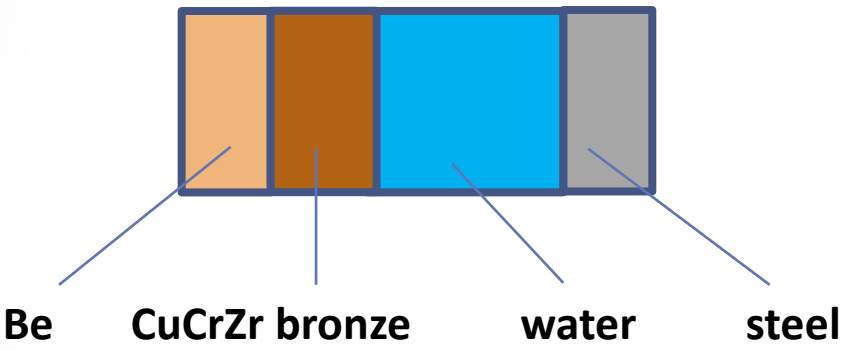
	ITER	DEMO-FNS	DEMO	FBR
Fusion power	0.5 GW	0.05 GW	2-5 GW	-
Heat flux (first wall/divertor)	0.2 /10 MW/m^2	0.2 /10 MW/m^2	0.5 /20 MW/m^2	-
Neutron load (First wall)	0.8 MW/m^2	0.2 MW/m^2	2 MW/m^2	
Integrated Neutron load (First wall)	0.07 $MW{\cdot}y/m^2$ (3-years operation)	2 $MW{\cdot}y/m^2$	5-8 $MW{\cdot}y/m^2$	
dpa	4 dpa	~30 dpa (3-3.2 dpa/fpy)	50-80 dpa	80 dpa/fpy
He production	40 appm	300-400 appm	500-800 appm	3 dpa/fpy
	[D.Stork]	[Yu. Spanskiy, V. Khripunov]	[D.Stork]	[V. Chernov]

ITER, FNS and DEMO in neutron damage

Current status: from pre-conceptual to technical design (different systems)

Main efforts: to provide maximum neutron flux

Current status of FNS First wall:



Problem: properties of bronze properties become unacceptable after a few d.p.a.

A use of steel instead of bronze is discussed
Problem: thickness of steel is limited to provide necessary thermoconductivity, by 1 mm

RAFMs can be used without Be cladding in some remote areas

Damage created at work of a fusion device

(in particular at neutron irradiation, radiogenic He formation in materials)

will change parameters of H-material interaction

The aim of the project:

Modelling of influence of neutron damages on deuterium retention in RAFMs for fusion

1. Radiogenic He arise
2. n-irradiation (by Fe and H ions irradiation)

3. Selective sputtering study

Seeding of samples with He

Helium will appear in the bulk of fusion materials as a result of tritium decay

$$_1T^3 \rightarrow {}_2He^3 + e^- + \nu$$

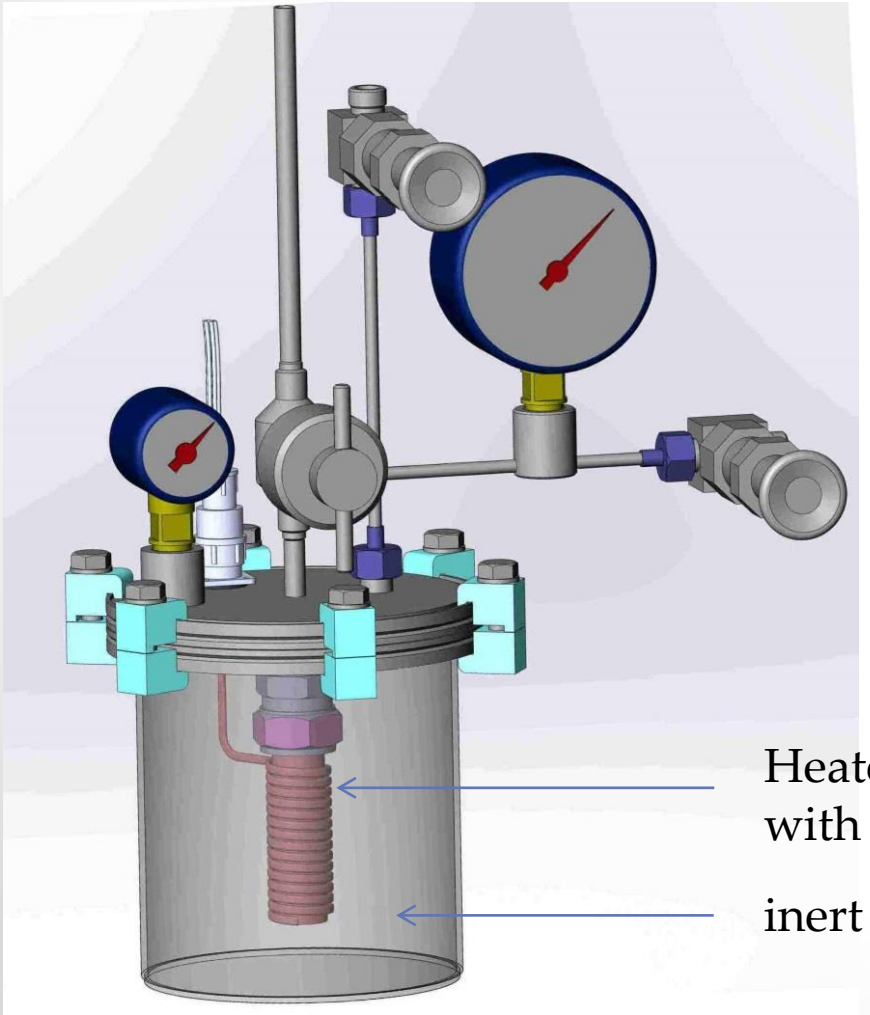
The best way to introduce He is "tritium trick“ (introduce tritium, wait for He formation, remove remaining T at annealing)

Main advantages:

- No additional defects (as it would be at He implantation
- He is distributed over all material (at ion or plasma irradiation it would be only in a thin layer)

Installation for exposure in tritium gas

A.A. Bochvars institute of Inorganic Materials, Russia

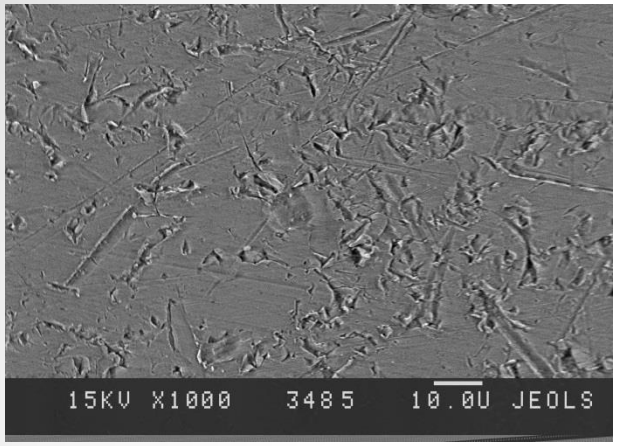


Installation is designed and mounted
in a special room
with a reduced pressure
(to prevent T leakages outside)

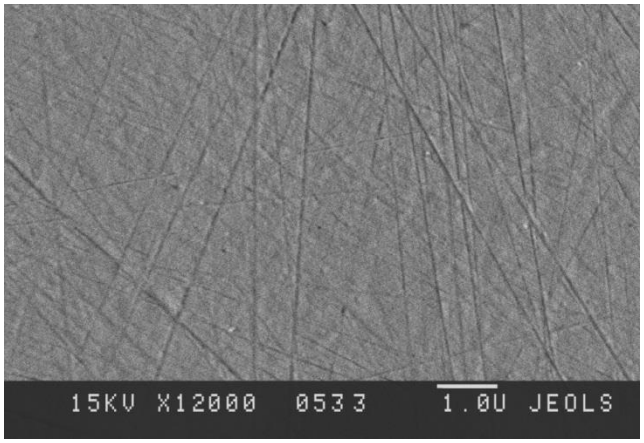
1. Container with T cooled in liquid nitrogen
2. Container is filled with T gas (5 atm)
3. Container if heated up to necessary T (P↑)

Materials for investigation:

Rusfer (deployed tube)

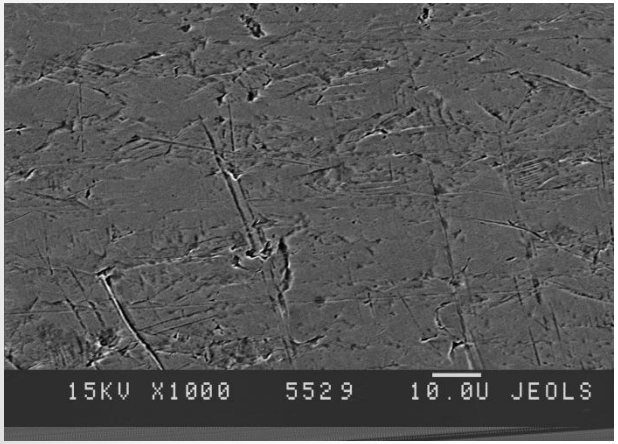


Eurofer

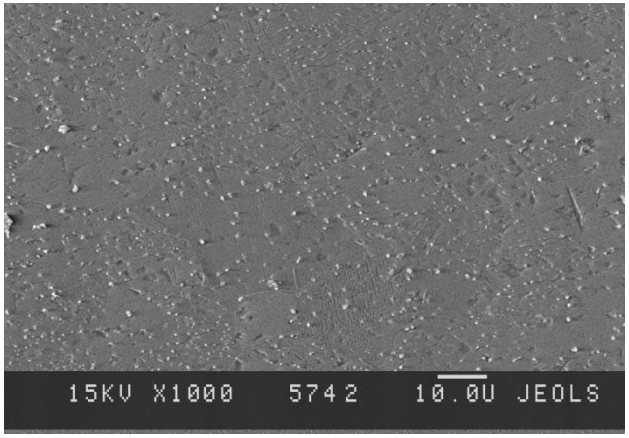


Samples
10x10 mm
0.5 or 1 mm thick
polished
annealed

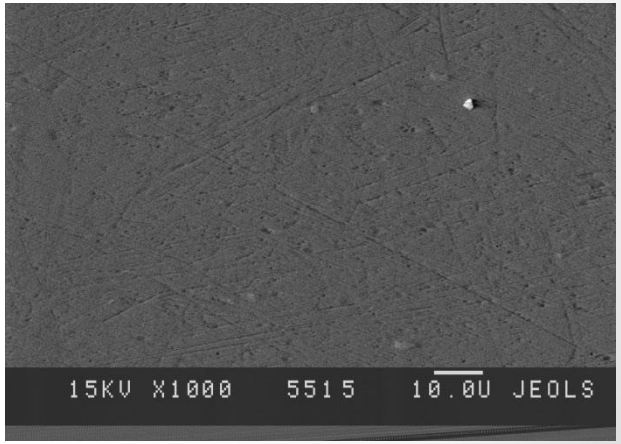
ChS-68 (deployed tube)



W (Goodfellow)



Bronze (ITER grade)



Currently available Rusfer:

New portion of Rusfer was produced recently. Flat rolled material can be available

BUT

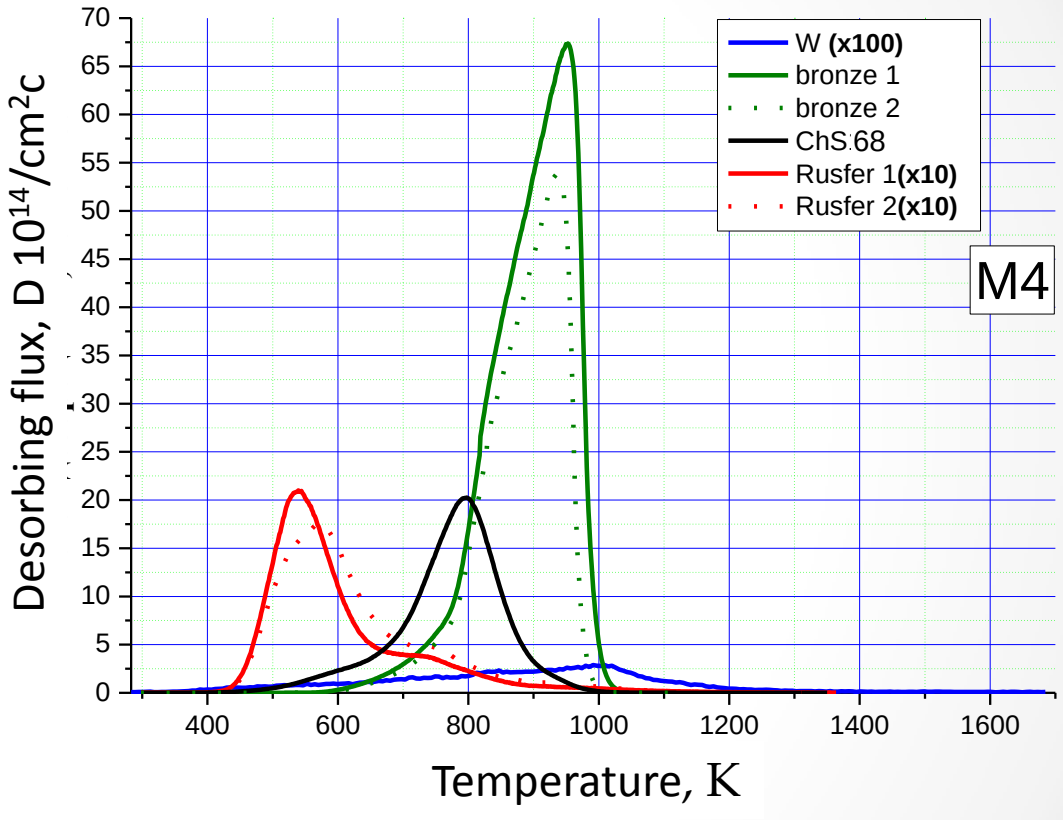
There are at least 10 standard procedures of thermal treatment, leading to different thermomechanical properties.

What are the requirement to RAFMs properties as a material of next-step fusion device?

Test exposure in D gas

TDS, MEPhI

P = 20 atmospheres
T = 673 K (400 C)
Rusfer (RAFMs), **W, CuCrZr**
t = 24 hours
ChS-68 (Austenite)
t = 10 hours



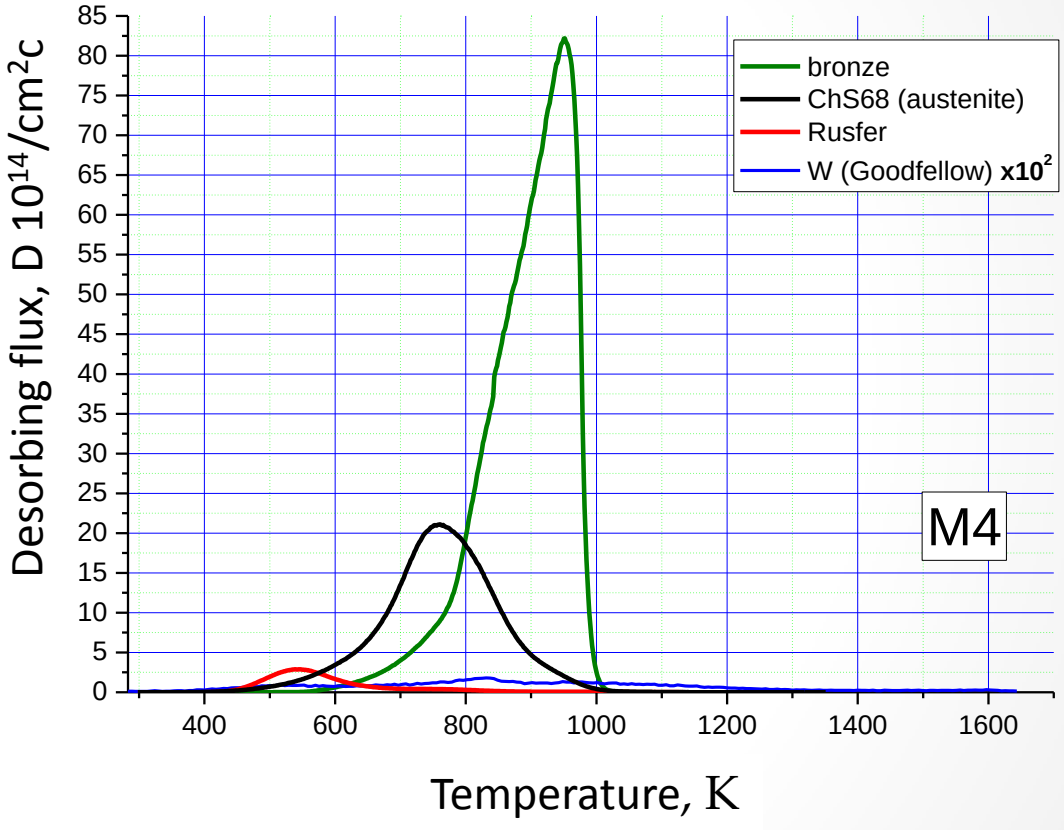
- Repeatability of results
- Retention:
  Bronze>Austenitic steel>RAFMs>>W

Test exposure in D gas

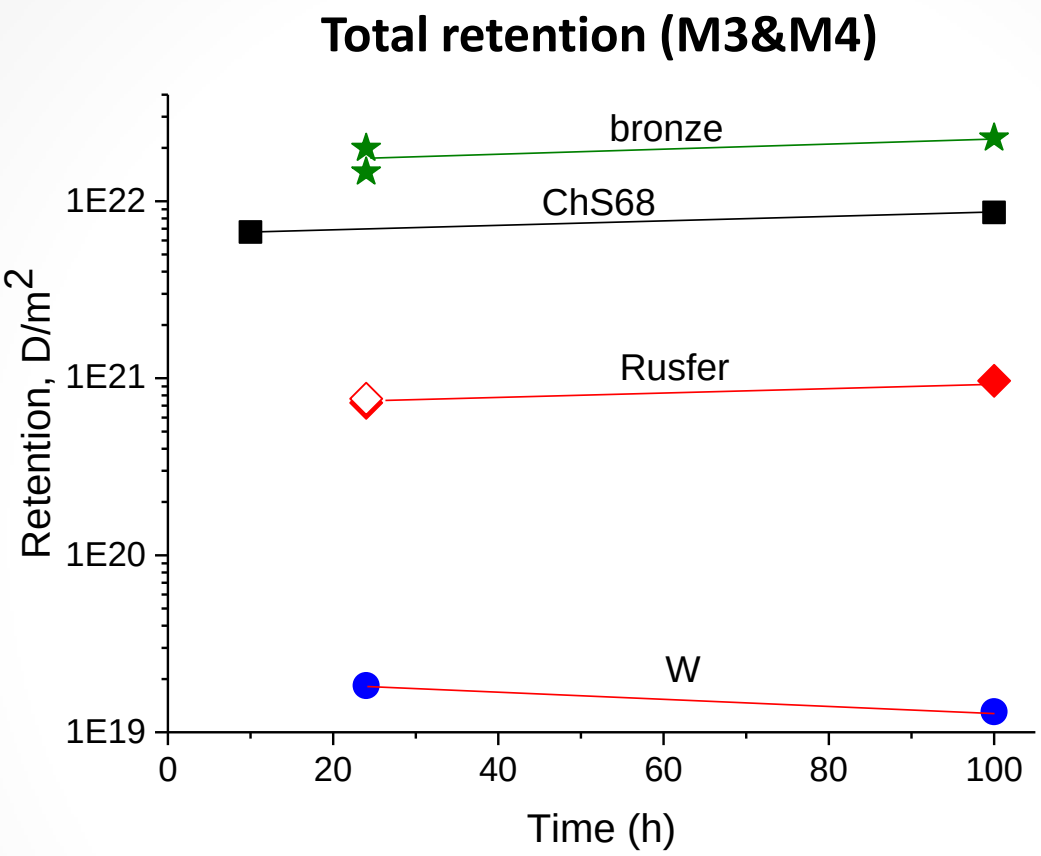
TDS, MEPhI

Do define weather
we reach a full saturation:

ChS-68, Rusfer, W, CuCrZr
P = 20 atmospheres
T = 673 K (400 C)
t = 100 hours



Test exposure in D gas



- Total retention is slightly higher for 100 hour exposition but is within the error for all materials.
- For rational use of radioactive tritium and of time there is no science to expose samples in T (20 atmospheres, 673 K) longer than 24 hours

Exposure in T

Conditions: T= 673 K (400 C), P= 8 atmospheres, 24 hours

Exposed samples: **Eurofer** (Dr. Mayer, IPP)
10x10x1 mm
Rusfer (Ek-181) (**some of them pre-damaged by 10 MeV electrons**)
10x10x0.5 mm (deployed pieces of tubes)
Austenite ChS-68 (**some of them pre-damaged by 10 MeV electrons)**
10x10x0.5 mm (deployed pieces of tubes)
W (Goodfellow)
10x10x1 mm
Bronze (ITER grade)
10x10x1 mm

Exposure in T

Conditions: **T= 673 K (400 C), P= 8 atm, 24 hours**

How to define initial amount of tritium in samples?

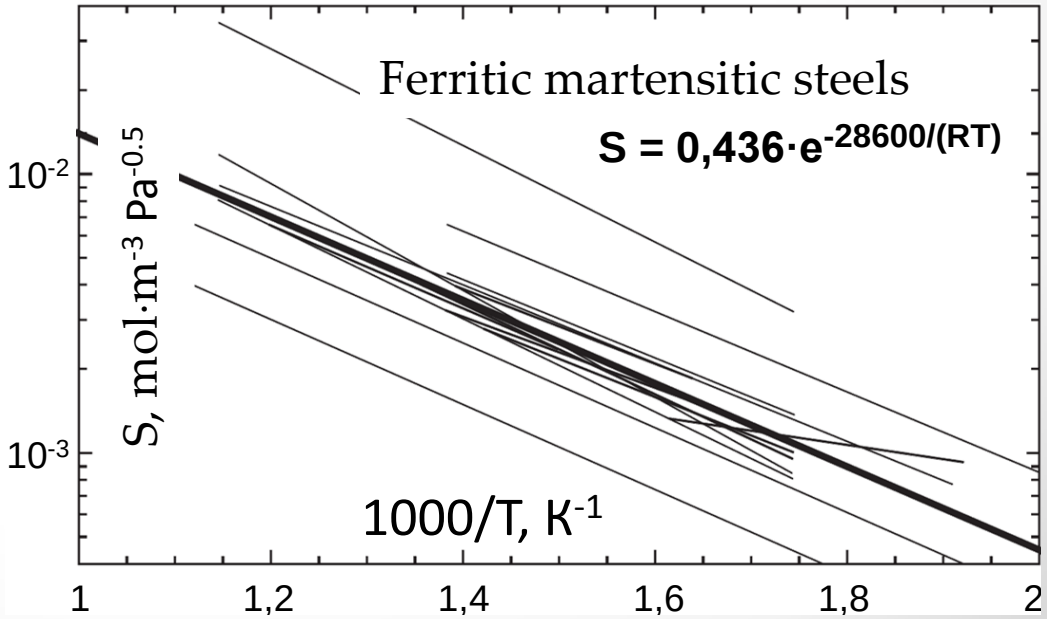
$$_1T^3 \rightarrow {}_2He^3 + e^- + \nu$$

$E_e = 5{,}7\ \text{keV}$

- Geiger counter can't detect electron of so small energy
- In Bochvar's institute – (though they have many detectors of β-particles) - no available detectors for such a small energies
- Estimation?

Sieverts low: $C=S\cdot p^{1/2}$

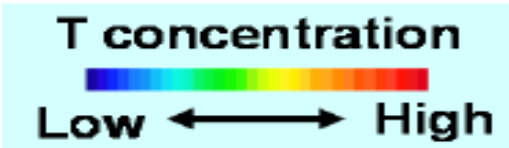
- No data for solubility at high pressures for RAFMs for fusion
- Problematic to extrapolate (8 orders of magnitude higher pressure)



Exposure in T

Conditions: T= 673 K (400 C), P= 8 atm, 24 hours

Method to measure activity: β-induced radioluminescence using imaging plate (IP)



Normally

P ~ tens of Pa, hours exposure in T,

hours of exposure samples to IP for

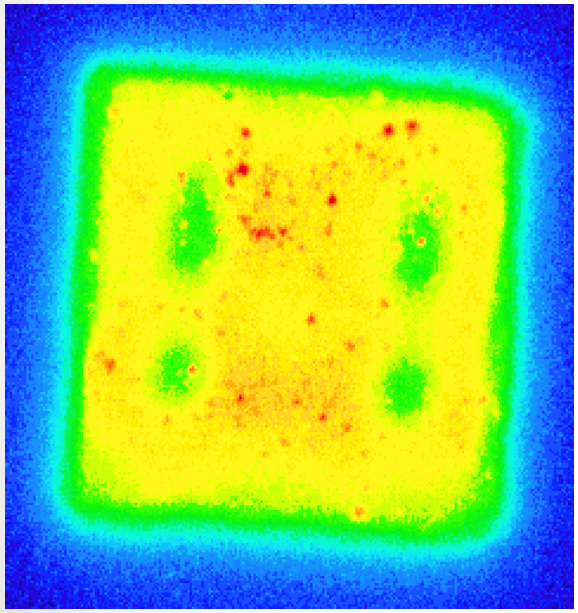
gives quantitative results using calibrative pattern

Exposure in T

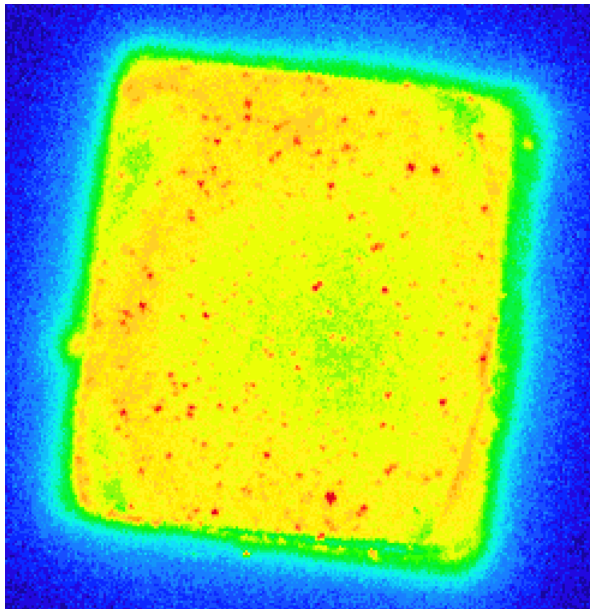
Conditions: T= 673 K (400 C), P= 8 atmospheres, 24 hours

T amount at surface is really huge, a minute is enough to light IP

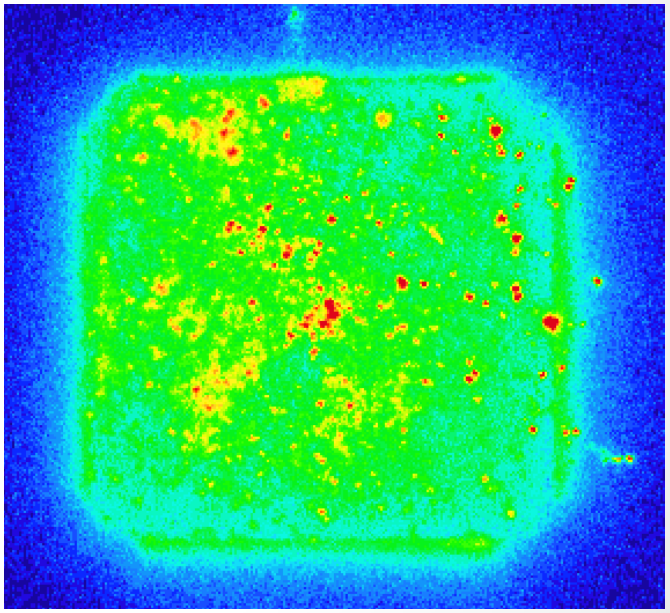
Samples was just pressed to IP for 10 seconds – very big uncertainty of measurement



Rusfer #3



ChS-68 #3



Eurofer

Depth distribution of T

What we can do:

1. Make a quality profiling at a cross-section using IP
2. Wait for formation of radiogenic He (year)
3. Make He depth-profiling using NRA (few μm layer below surface)
4. Define initial depth-profile of T (when we know time of T decay and final He concentration)
5. The shape of depth-profile of He should be the same as of T → restore profile across the sample

Ideal plan:

A very time-demanding experiment ($\tau_{1/2}$ ~12 years)

1. Exposition in T at elevated pressure and selected temperature
2. Image of surface and a cross-section of samples
3. Extracting a sample of each type every 0.5 year, detritization
4. If it is proven that the residual activity meets the security requirements
    - 4.1. Depth-profiling of He
    - 4.2. Loading with D gas, irradiation with D plasma
    - 4.3. Compare retention in samples containing radiogenic He and as received

Now we are waiting for first half-year of He production from tritium

New possibilities of damaging: accelerators of ITEP

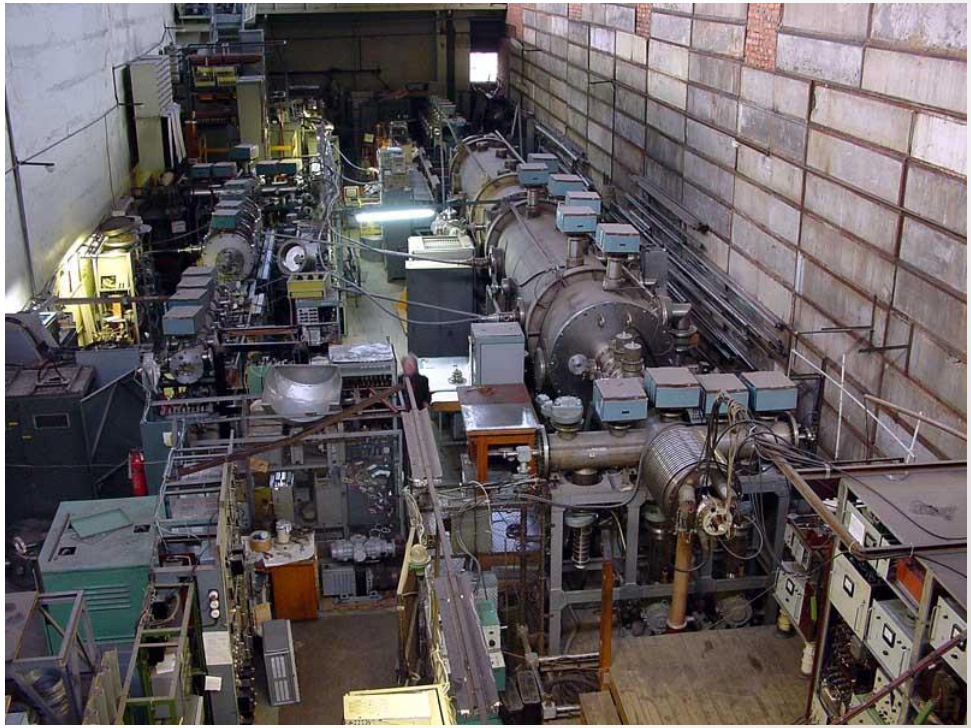
the Institute for Theoretical and Experimental Physics (ITEP), belongs to Kurchatov institute

T. Kulevoy, P. Fedin

Fe^{2+} accelerator

heavy ion RFQ HIP-1 (Radio Frequency Quadrupole Heavy Ion Prototype) with metal ion beams generated by ITEP Metal Vapor Vacuum Arc (MEVVA)

M/Z ≤ 60
E = 101 keV/a.m.u.
E(Fe^{2+}) ≤ 5.6 MeV
E(W ions) = 19 MeV
Ion beam density 3–6 mA/cm^2
Ion beam **pulse length** is 450 μs
1 pulse for 4 sec
P ≤ 2 ×10^{-6} mbar



New possibilities of damaging: accelerators of ITEP

T. Kulevoy, P. Fedin

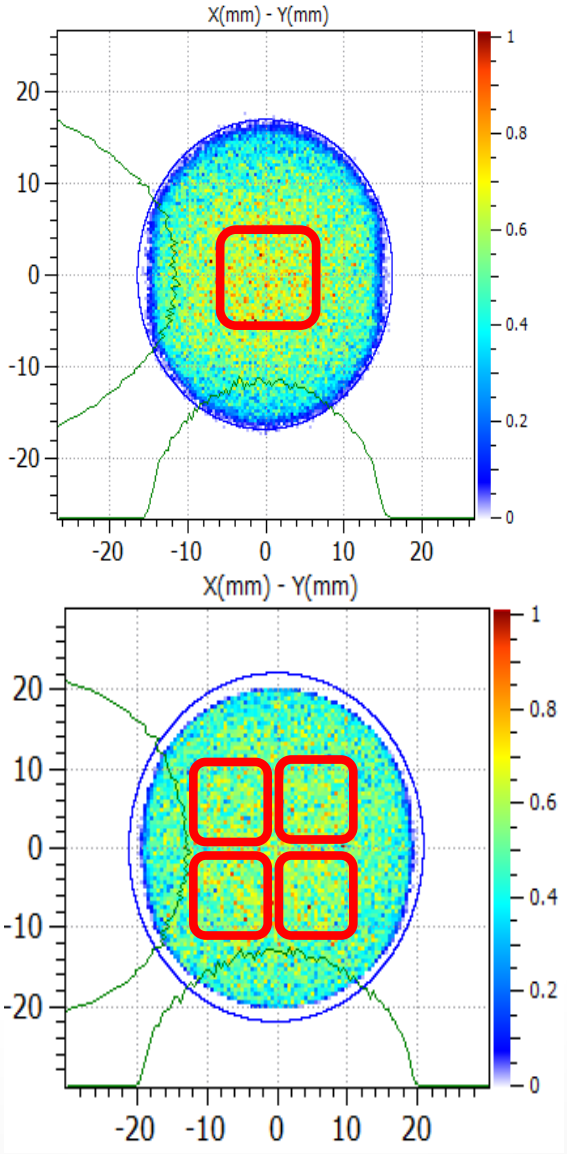
1 sample

1 sample 10×10 mm (current on the sample is 80 μA) → 1 hour for fluence 10^{14}cm^{-2}. The current density changes by 2.5% over a sample.

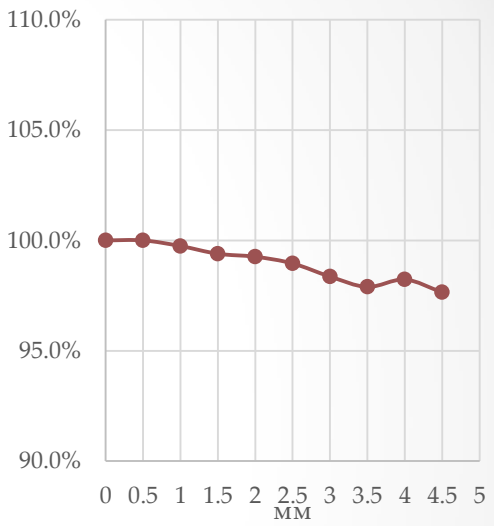
4 samples

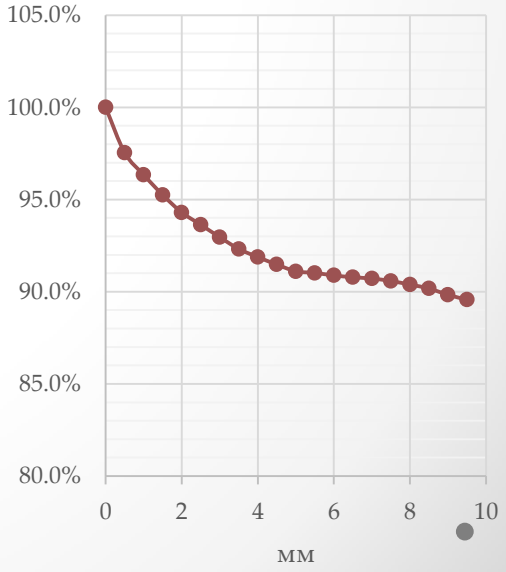
4 sample 10×10 mm (current on the sample is 120 μA) → 3 hour for fluence 10^{14}cm^{-2}. The current density changes by 11% over a sample

Fe^{2+} accelerator



current density distribution over a sample





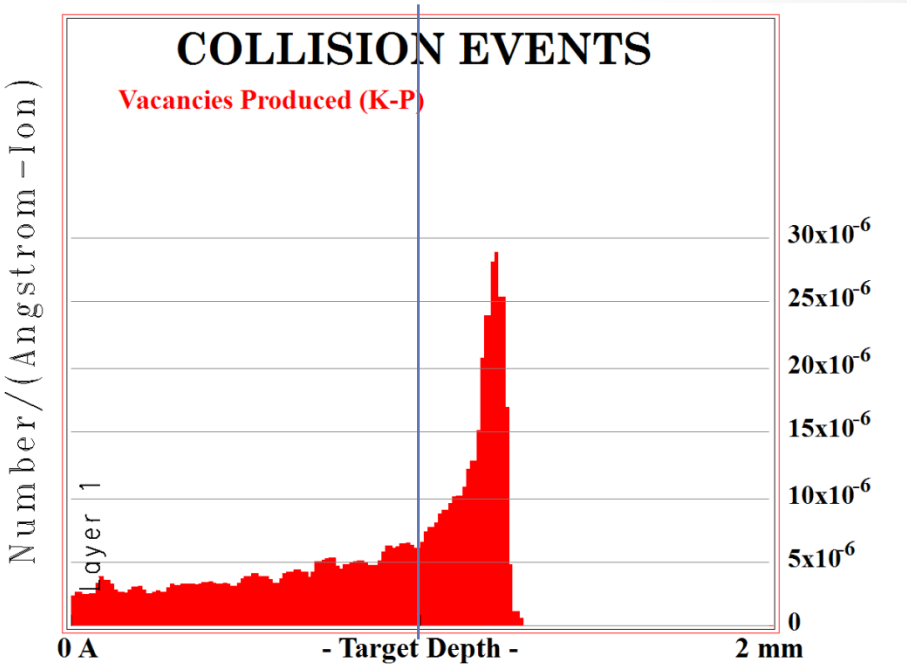
New possibilities of damaging: accelerators of ITEP

H^+ linear accelerator I-2

T. Kulevoy, P. Fedin

E, MeV	0.7÷24.6
I, mA	200
t, мкс	10
Ω, Hz	<1
I, particle/s	10^{13}
Length of resonator, m	18.4
Diameter of resonator, m	1.37

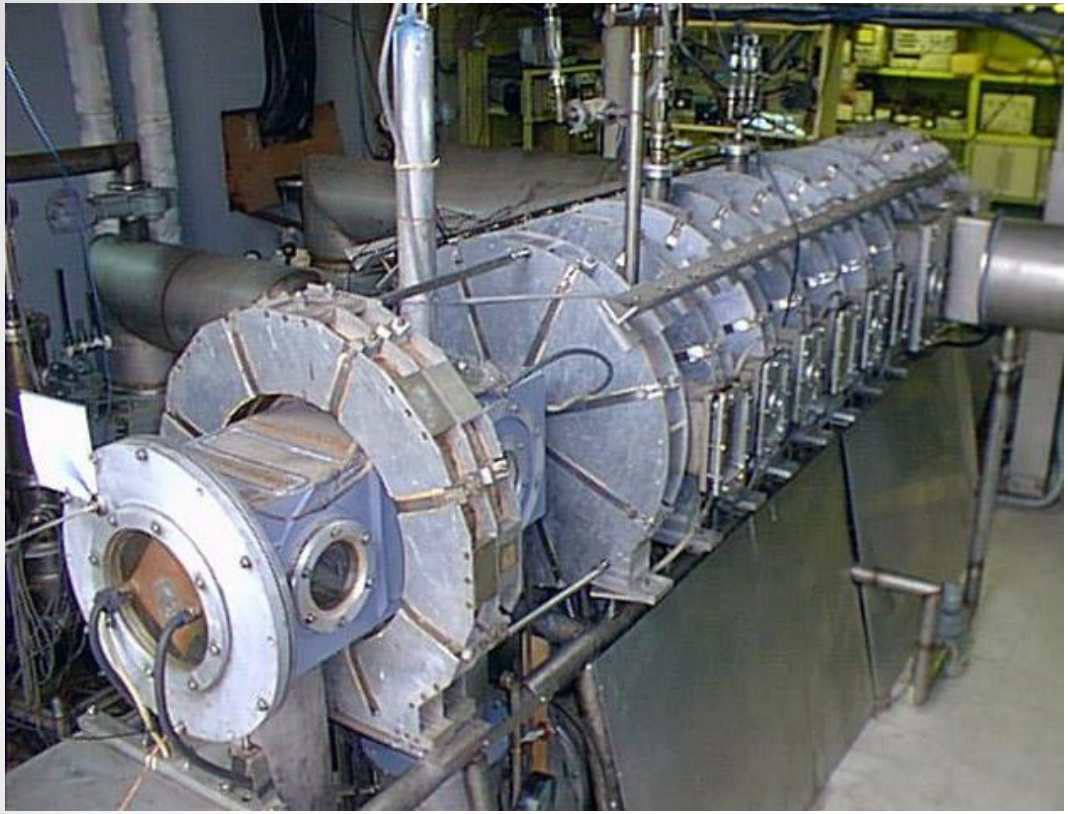
SRIM modelling:
Depth distribution of damage by 24,5 MeV H of SS (Fe-12%Cr-1%W)



Further plans

1. Investigation of influence of radiogenic He of D retention in RAFMs at exposure in gas and plasma irradiation
2. Investigation of influence of damaging by MeV H and Fe ions on D retention in RAFMS

Spattering of RAFMs



LENTA, Kurchatov insitute
B.I. Khripunov

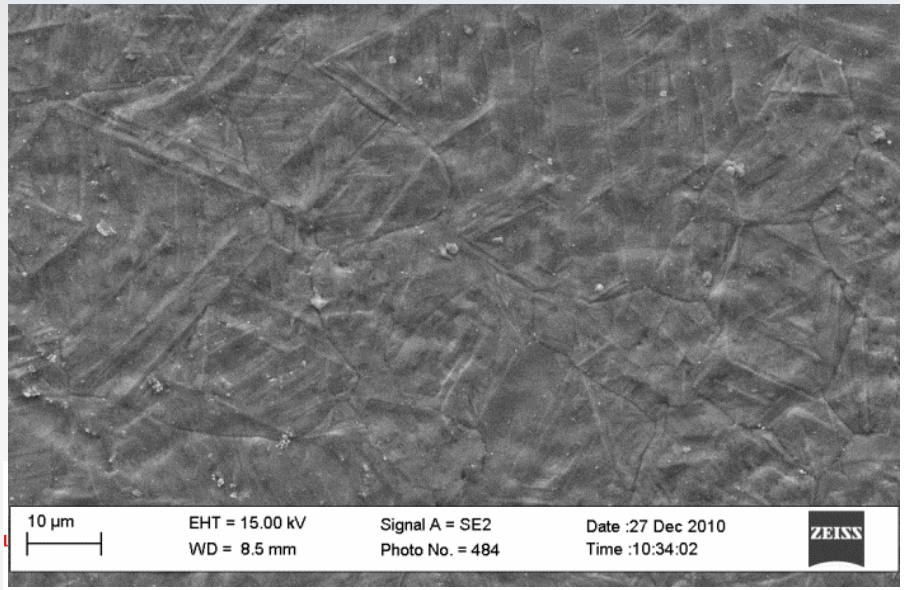
Iradiations of Rusfer samples:

E=50 eV
Plasma – H or D
Flux - $2,5 \cdot 10^{21}$ at./m^2s
Fluence - $7 \cdot 10^{24}$ at./m^2
T_1= 320 K, T_2= 600 K

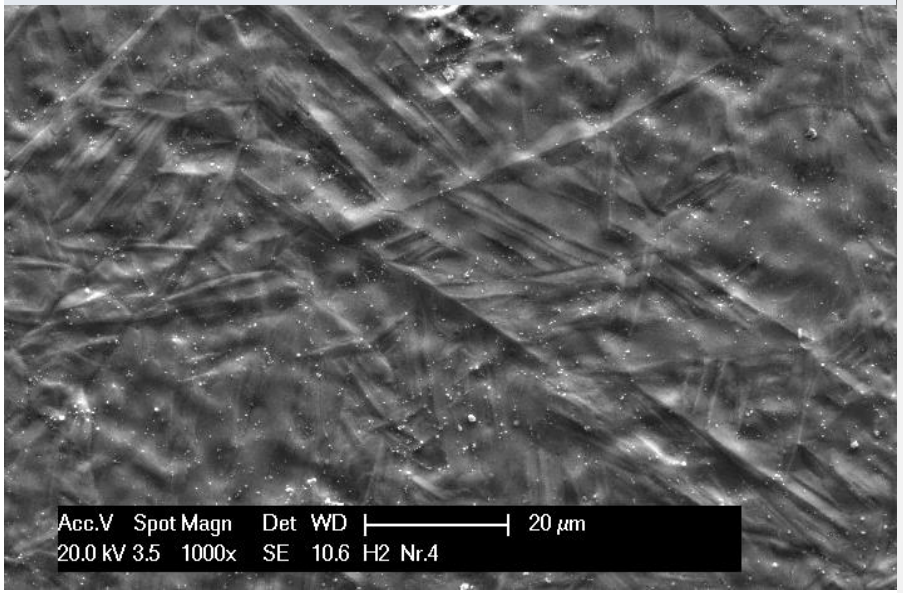
Spattering of RAFMs

Rusfer

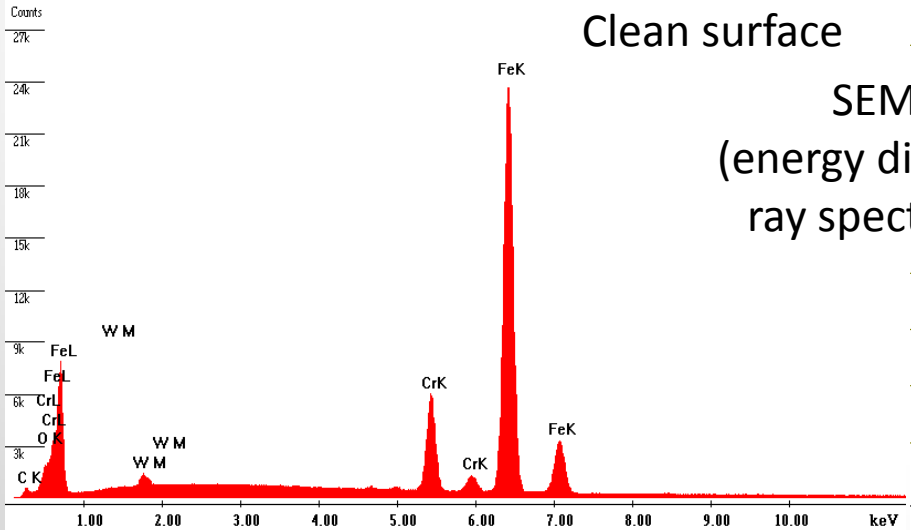
Not irradiated



Irradiated with 1.8×10^{24} D/m^2(plasma)

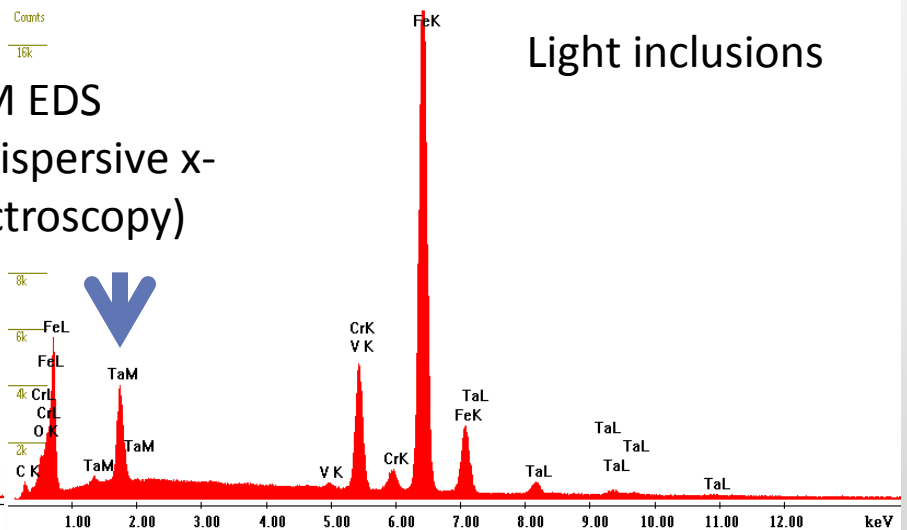


Clean surface



SEM EDS
(energy dispersive x-ray spectroscopy)

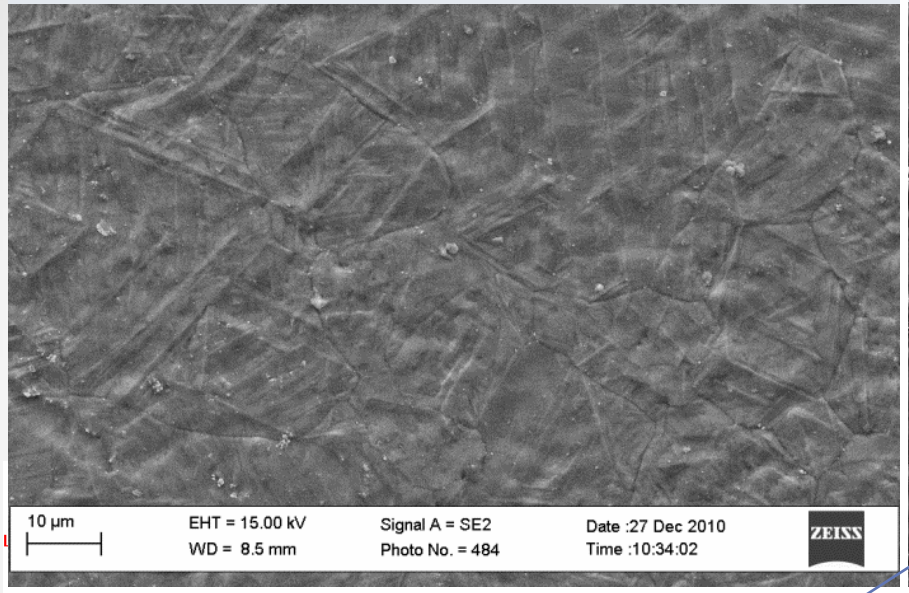
Light inclusions



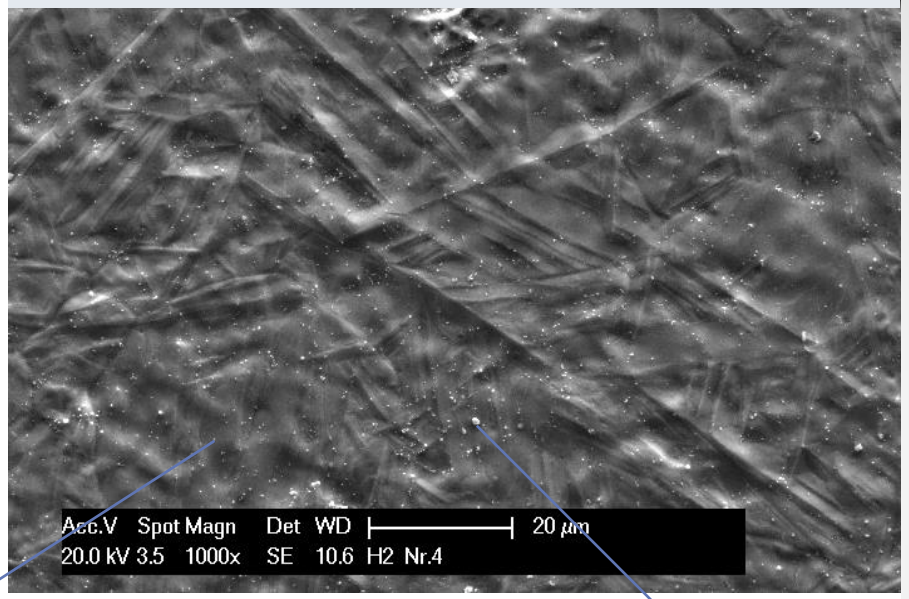
Spattering of RAFMs

Rusfer

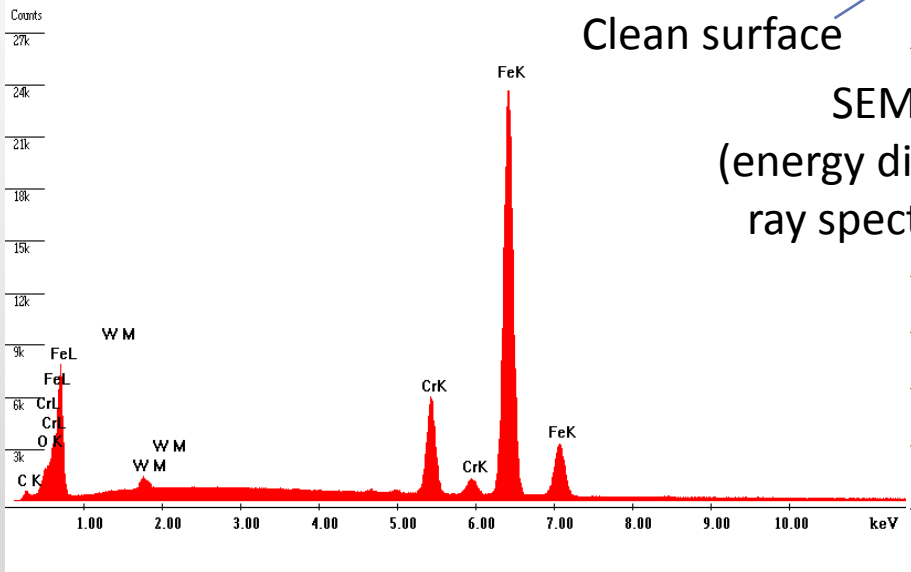
Not irradiated



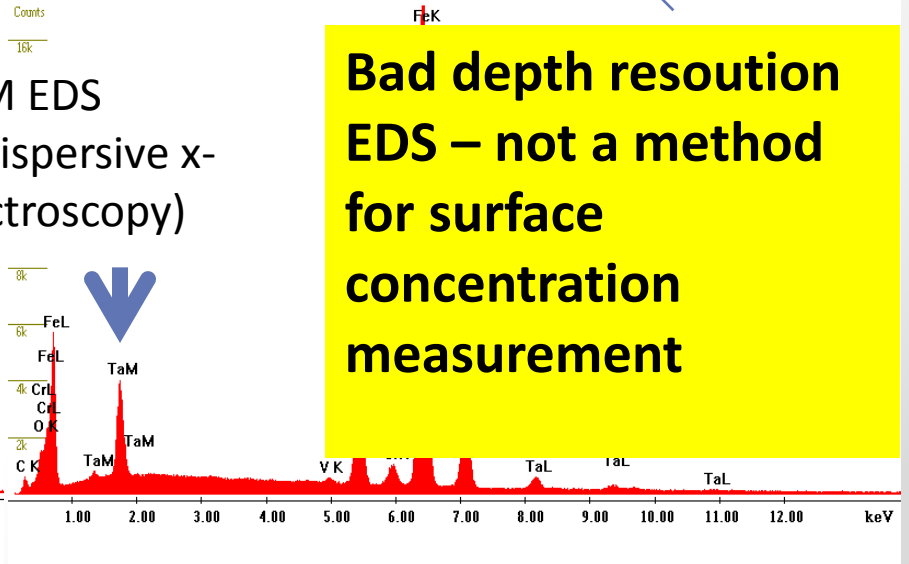
Irradiated with 1.8×10^{24} D/m^2(plasma)



Clean surface



SEM EDS
(energy dispersive x-ray spectroscopy)



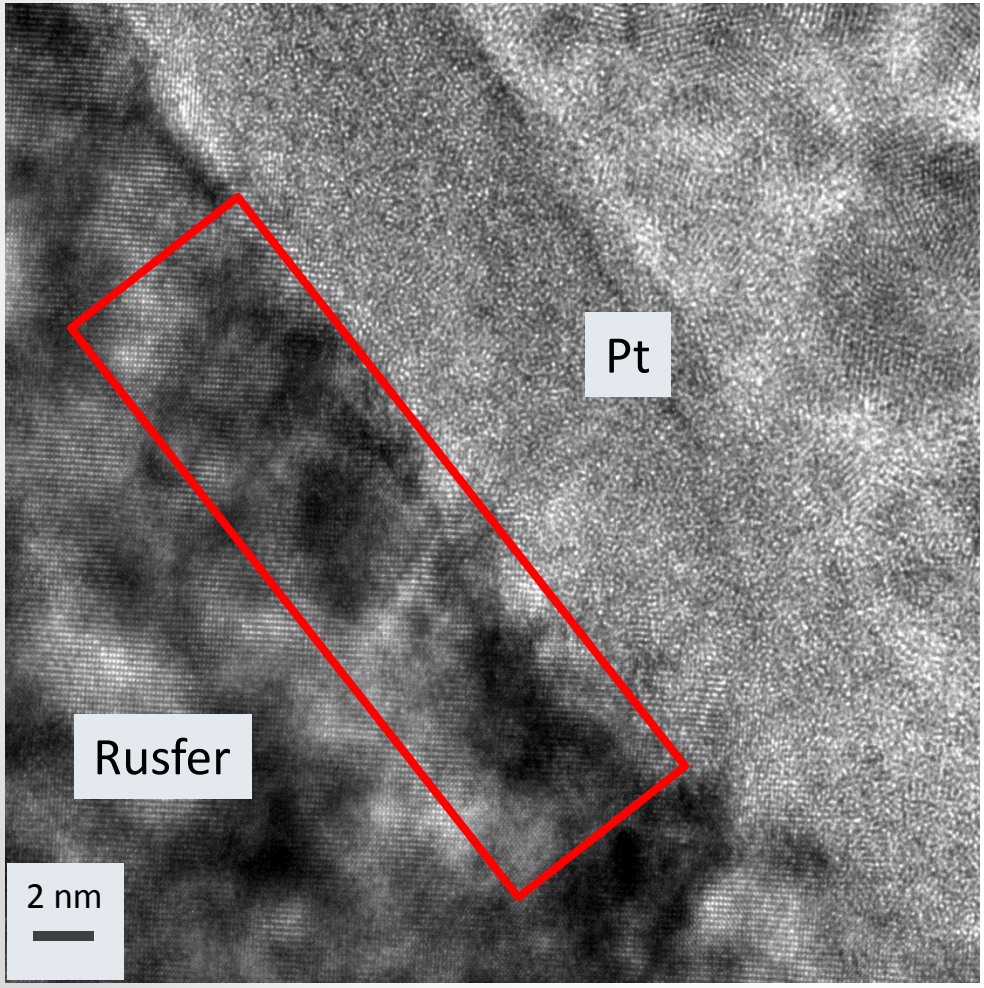
Bad depth resoution EDS – not a method for surface concentration measurement

Spattering of RAFMs

D-plasma irradiation, 600 K, $5 \cdot 10^{21}$ D/s·m^2, $7 \cdot 10^{24}$ D/m^2, LENTA facility

Kurchatov institute

Irradiated sample after TDS was coated with Pt, cut with focused ion beam (FIB)



Specification:

Rusfer contains 1.13 wt.% of W

Energy dispersive x-ray spectroscopy (EDX):

5 nm layer below surface

Element	Weight %	Atomic %
Cr(K)	8.52	9.20
Fe(K)	89.83	90.29
W(M)	1.64	0.50

Spattering of RAFMs

D-plasma irradiation, 600 K, $5 \cdot 10^{21}$ D/s·m^2, $7 \cdot 10^{24}$ D/m^2, LENTA facility

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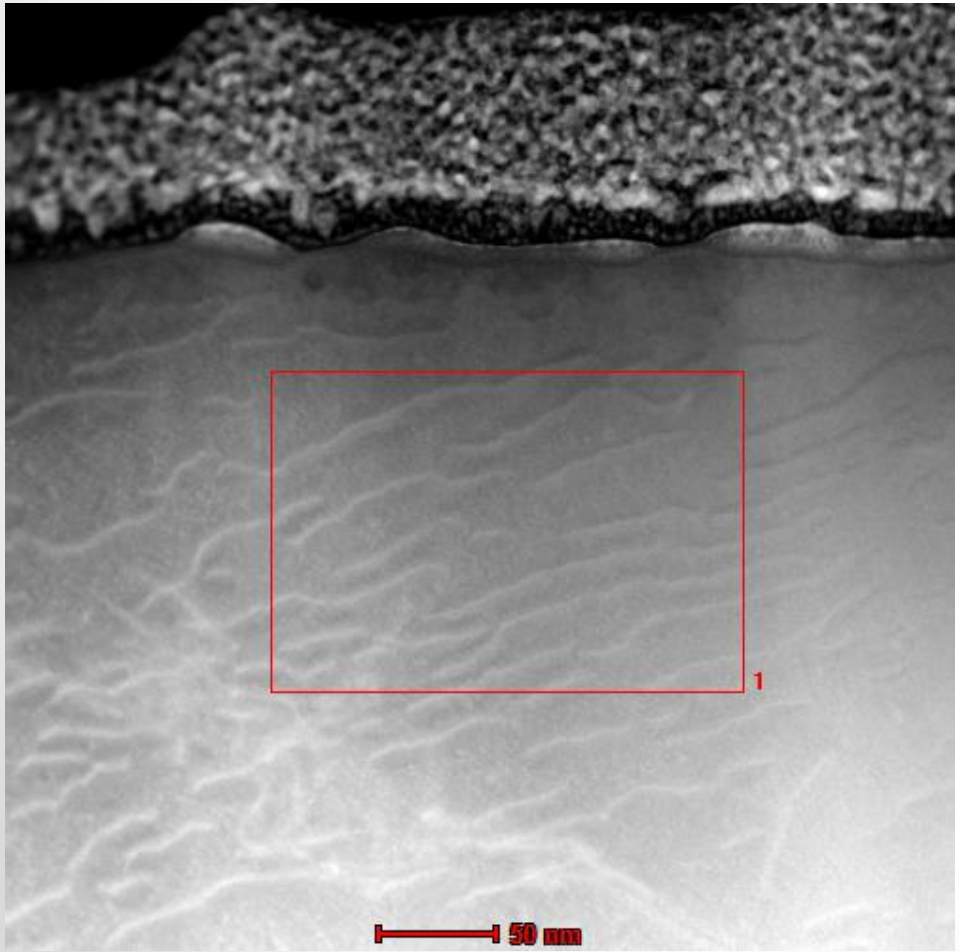

Layer 50-150 nm below surface

EDX:

Element	Weight %	Atomic %
Cr(K)	10.22	11.07
Fe(K)	87.46	88.21
W(M)	2.31	0.70

Probably, partially Pt-area was included in averaging

Uncertanty, even with a reference samples for normalization – 1 at.%

Spattering of RAFMs

D-plasma irradiation, 600 K, $5 \cdot 10^{21}$ D/s·m^2, $7 \cdot 10^{24}$ D/m^2, LENTA facility

Kurchatov institute

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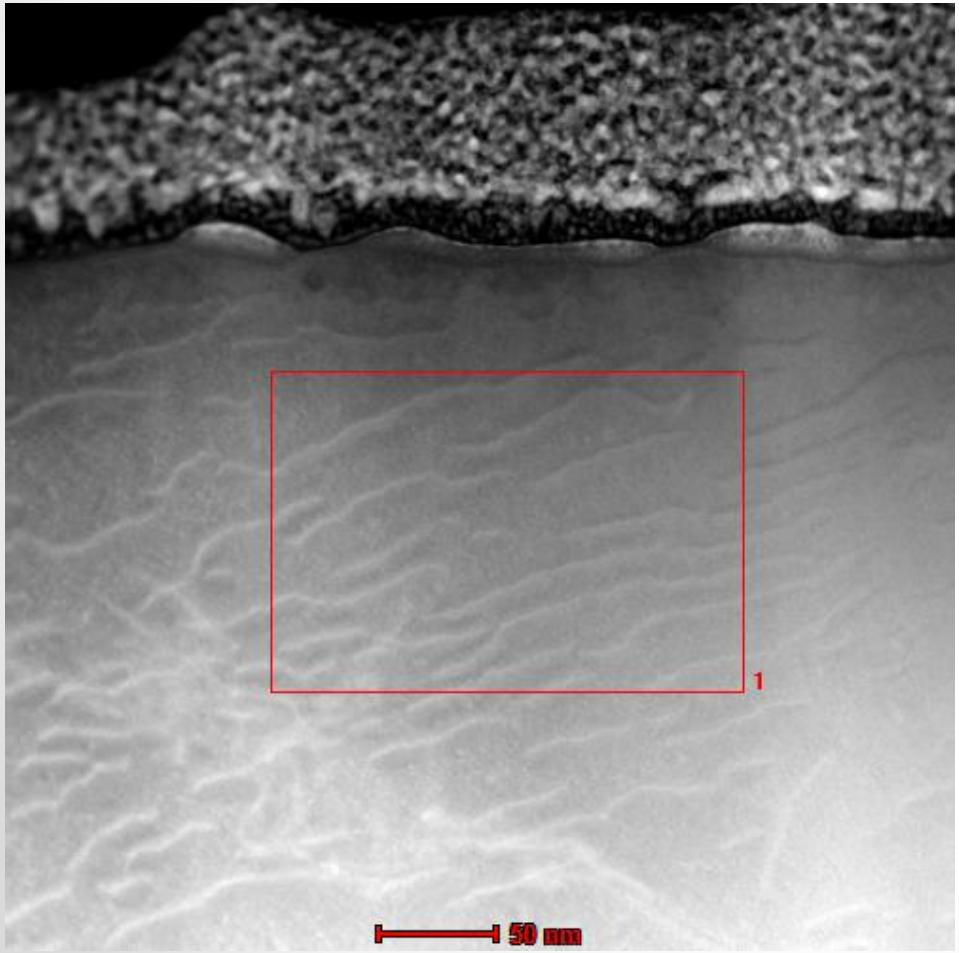

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EDX – not a method for surface concentration measurement

Further plans

1. Investigation of influence of radiogenic He of D retention in RAFMs at exposure in gas and plasma irradiation
2. Investigation of influence of damaging by MeV H and Fe ions on D retention in RAFMS
3. Try to find possibility define surface concentration of W

Thank you for your attention!

Russian Federation:
Priority directions of development of science, technology and engineering

1. Security and fighting terrorism

Grant system of funding of research

2. Nano-systems industry

3. Information and telecommunication systems

4. Life Sciences

5. Promising types of weapons, military and special equipment

6. Environmental management

7. Transport and space systems

8. Energy efficiency, energy conservation, nuclear energy