Material analysis using RBS/C and ERDA/C techniques

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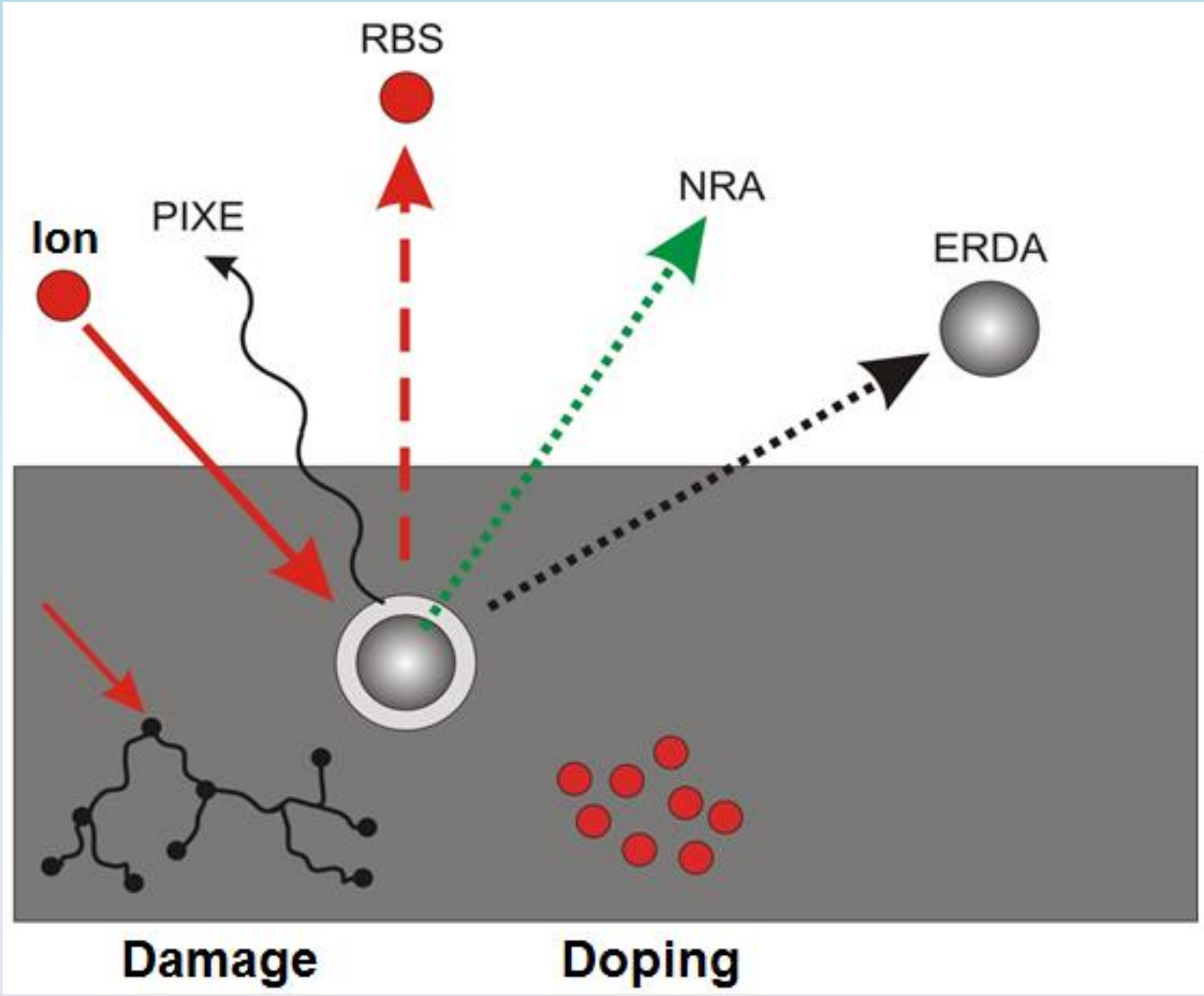
French – Ukrainian workshop on instrumentation developments for high energy physics

Orsay, France

Ion beam interaction with target

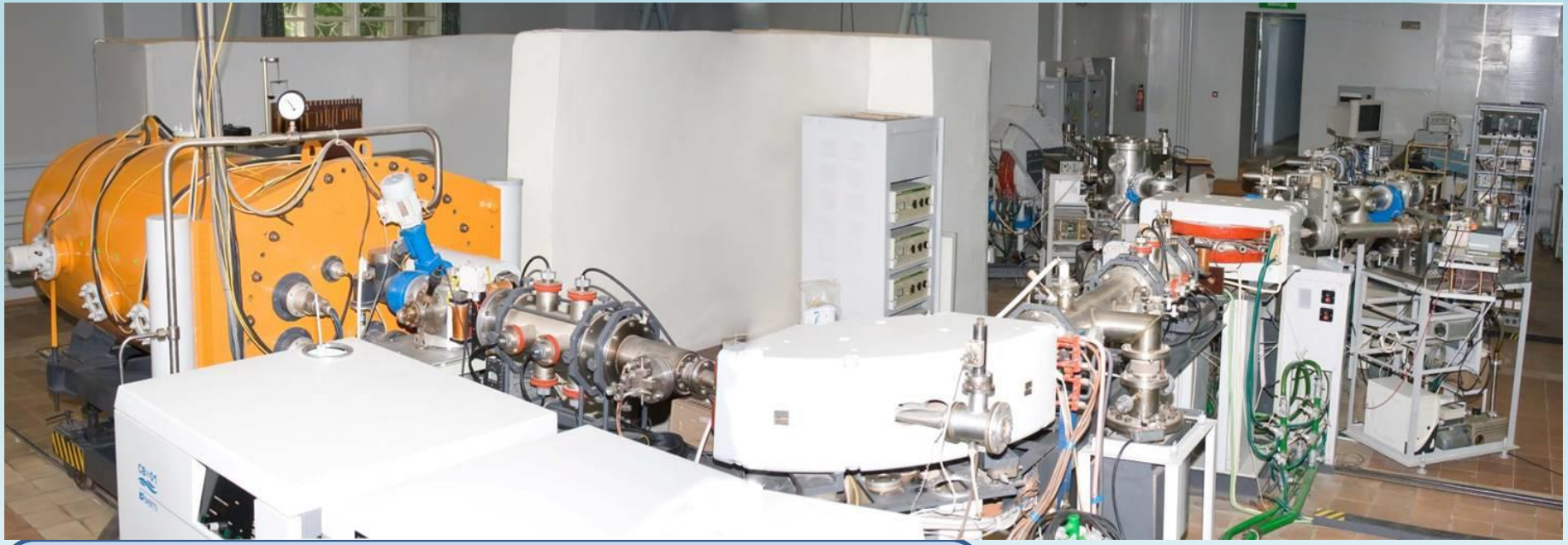
Applications of ion beam analysis

- Quantitative analysis of thin films (thickness, composition)
- Elemental depth profiles in the near-surface layer of solids
- Element identification impurity analysis



All these techniques may be realized in one laboratory on one accelerator via electrostatic charge particle accelerators (EA).

IAP NASU accelerator-based facility



- **2 MV electrostatic accelerator** (horizontal “Sokol” type)
  H+, He+ ,He++ ions (RF ion source);

Accelerator voltage instability < 1 keV at 1 MV voltage (*ΔE/E*<10-3)

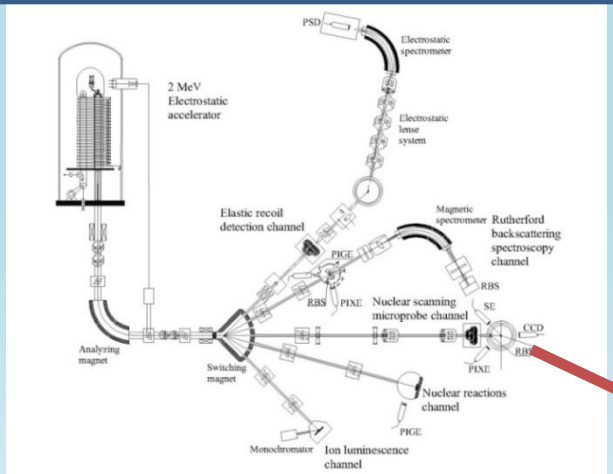
- **Beam transport system** with an analyzing magnet, distributive magnet and ion guides;

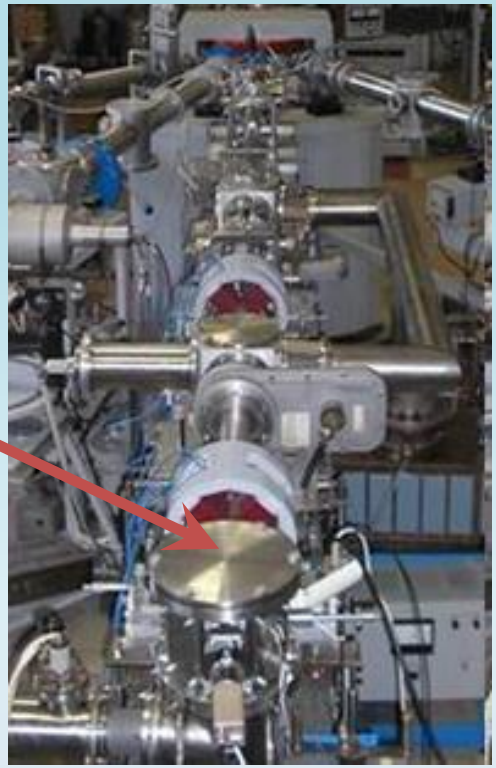
- **Six end-stations** (+seventh is under construction)
  - resonant nuclear reactions (RNRA, PIGE);
  - ion luminescence (IL);
  - scanning nuclear microprobe with *μ*PIXE, *μ*RBS and *μ*ERDA techniques;
  - high-resolution Rutherford backscattering spectrometry (HRBS);
  - high-resolution elastic recoil detection (HERDA);
  - quasimonochromatic X-ray source based on electrostatic accelerator;
- *proton beam writing – under construction.*

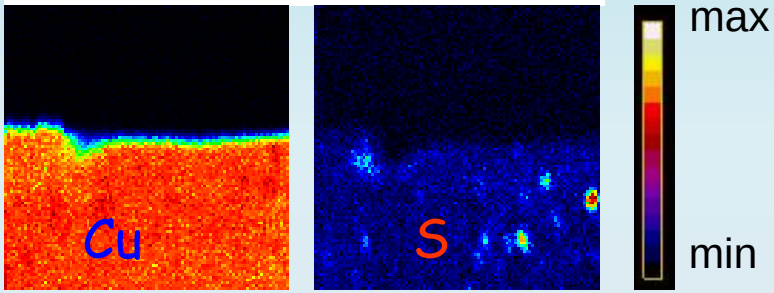
The facility is applied for

- ✓ fundamental research of interaction between accelerated ion beam and substance,
- ✓ studying composition and structure of materials for nuclear engineering,
- ✓ application problems in cultural heritage and nuclear forensics.

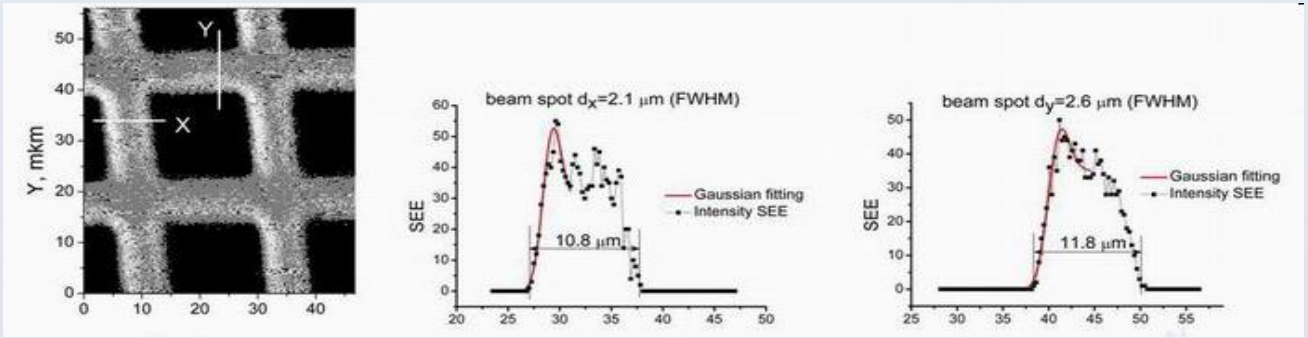
Scanning nuclear microprobe







Distribution microimpurity sulfur in the copper sample (zone of joint of heterogeneous materials)



Ion beam is focused to a spot on the sample with magnetic quadrupole lenses (high performance).

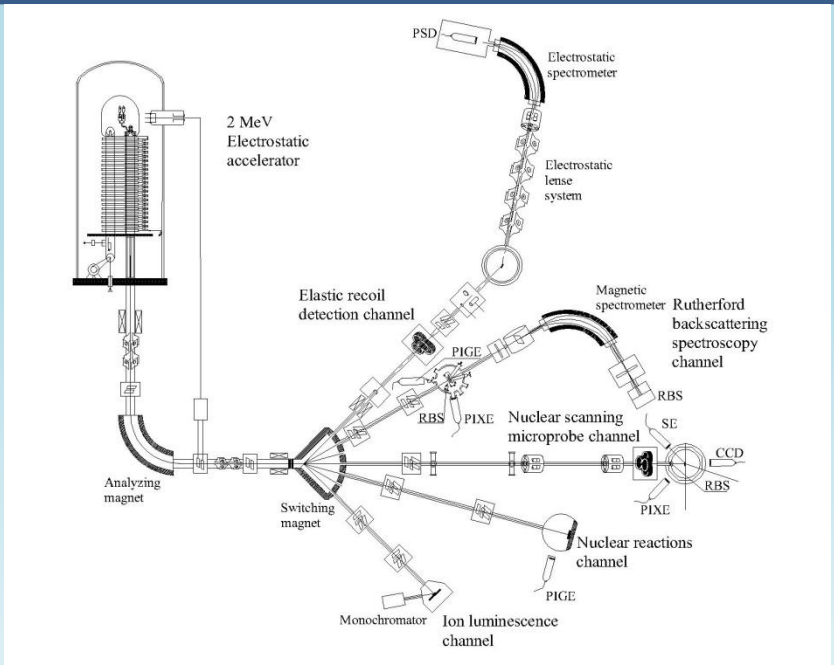
(so called «russian quadruplet»).

Scattering chamber is equipped with secondary electrons, charged particles and X-ray detectors for 2D and 3D element mapping.

The yields of the secondary electrons by scanning a copper mesh determines the size of the focused beam.

1,9×2 μm,
ion current -100 pA

Resonant nuclear reactions

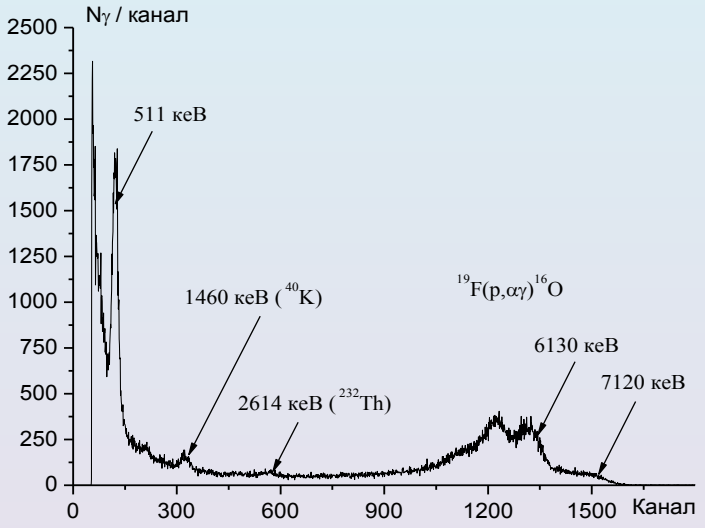


Resonant nuclear reaction end-station is intended for studying materials by PIGE (Particle Induced Gamma-ray), and equipped with two gamma-detectors:

- NaI scintillation-type detector (sodium iodide)
- high-purity germanium detector (HpGe).

allows to measure the concentration profiles with high depth resolution (5 - 10 nm).

Image on the right is gamma-spectrum from the LiF specimen (**19F(p,αγ)16O** resonance).



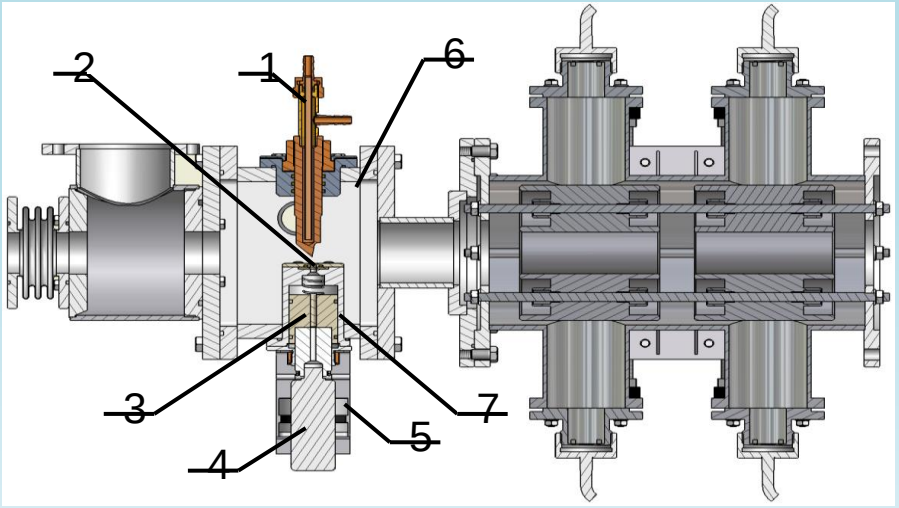
X-ray quasi-monochromatic source based on electrostatic proton accelerator

The main advantages:

The combination of high-current low-energy proton beam with the radiation generation chamber allowed obtaining very intense source of monochromatic X-rays with low background and high monochromaticity.

Application

- determination of elements in the surface layers of structural and biological materials by XRF and μXRF methods;
- study of the radiation influence on individual cells.

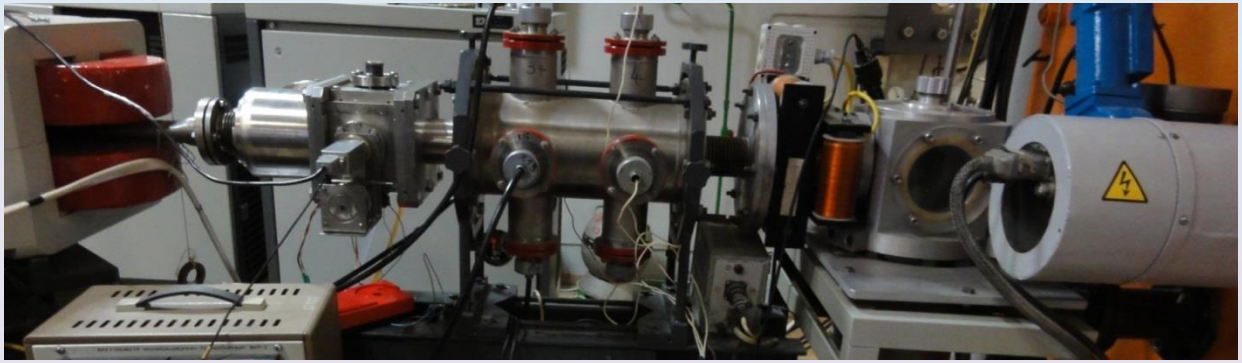


Pic. 2. Model of converter chamber and doublet of electrostatic quadrupole lenses (ion optical system)

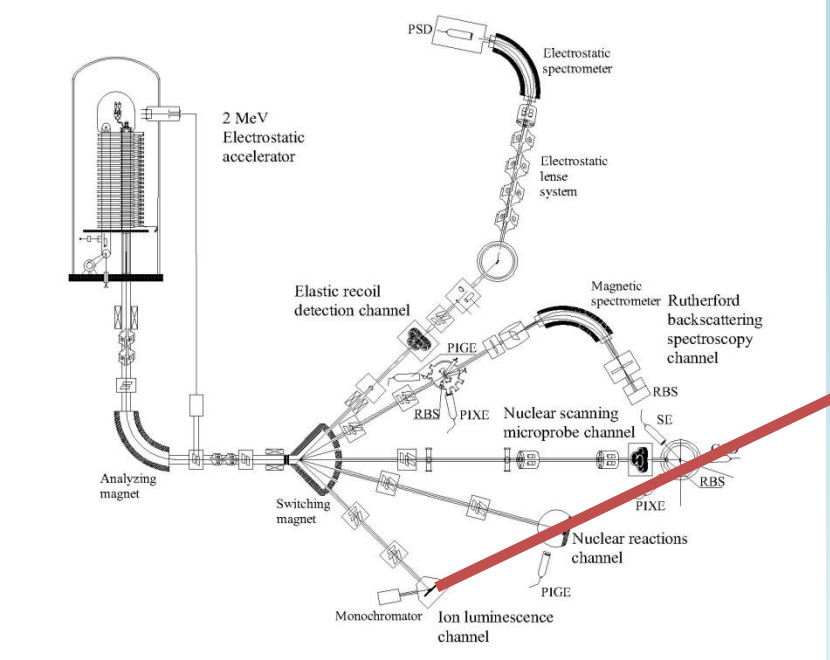
1 – converter; 2 – X-ray exit window; 3 – polycapillary lens holder; 4 – X-ray detector; 5 – polycapillary lens and X-ray detector positioning system; 6 – converter chamber; 7 – tube.

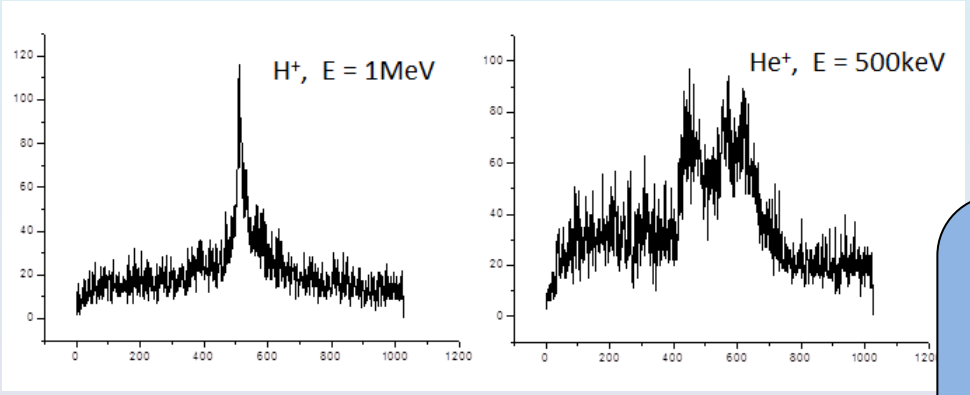
Source is installed on micro analytical facility..

On the right is proton accelerator, on the left is analyzing magnet.



Ion luminescence end-station



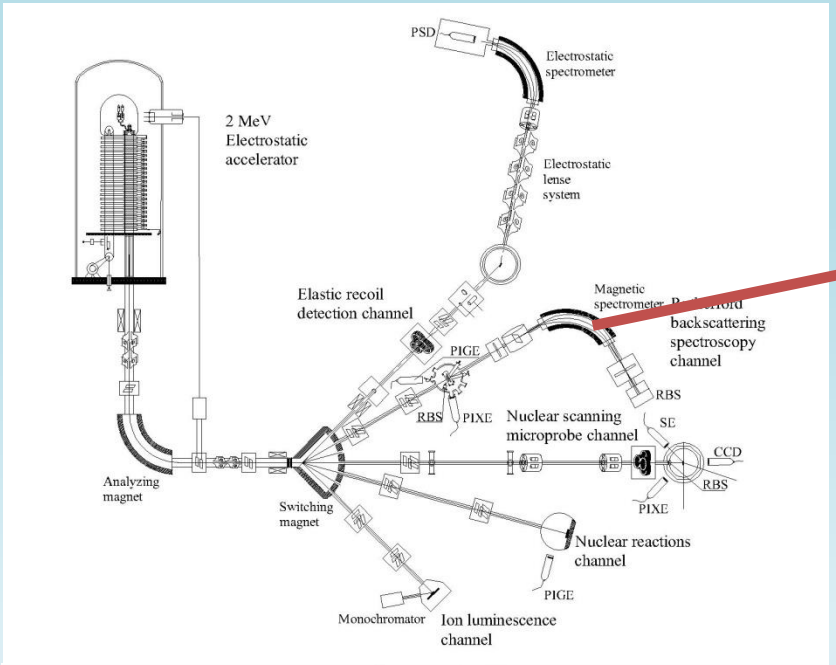


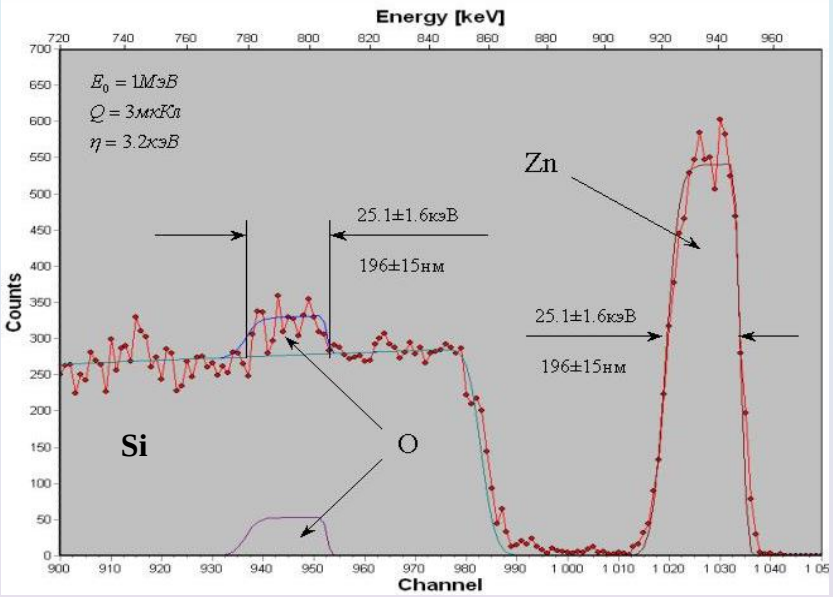
Spectra of the ions luminescence of plastic scintillators PILOT U and NE102.

Determination: identification and characterization of non-organic materials; study of X-ray damage, electronic structure and dynamics of electronic transitions.

- measurements in real-time and in situ,
- operational range of wave length 200...800 nm..
- inverse linear dispersion – 3...4 nm/mm..

High-resolution RBS end-station





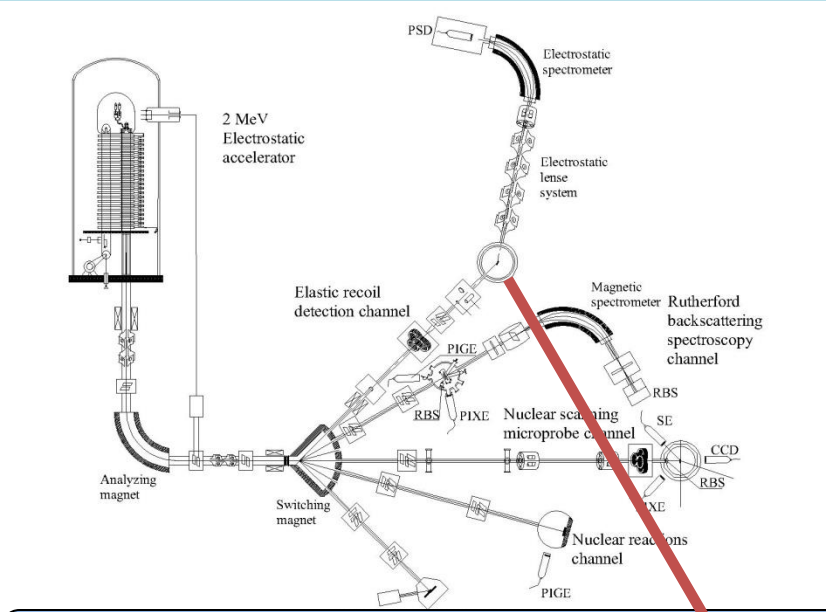
Magnetic spectrometer with double focusing ($\Delta E/E$=3,2×10^{-3})

The end-station is equipped with a magnet spectrometer registering energy of elastically scattered particles with a 3÷4 keV resolution.

On the left there is an HRBS spectrum from ZnO thin film deposited on Si substrate (approximation is depicted with solid lines).

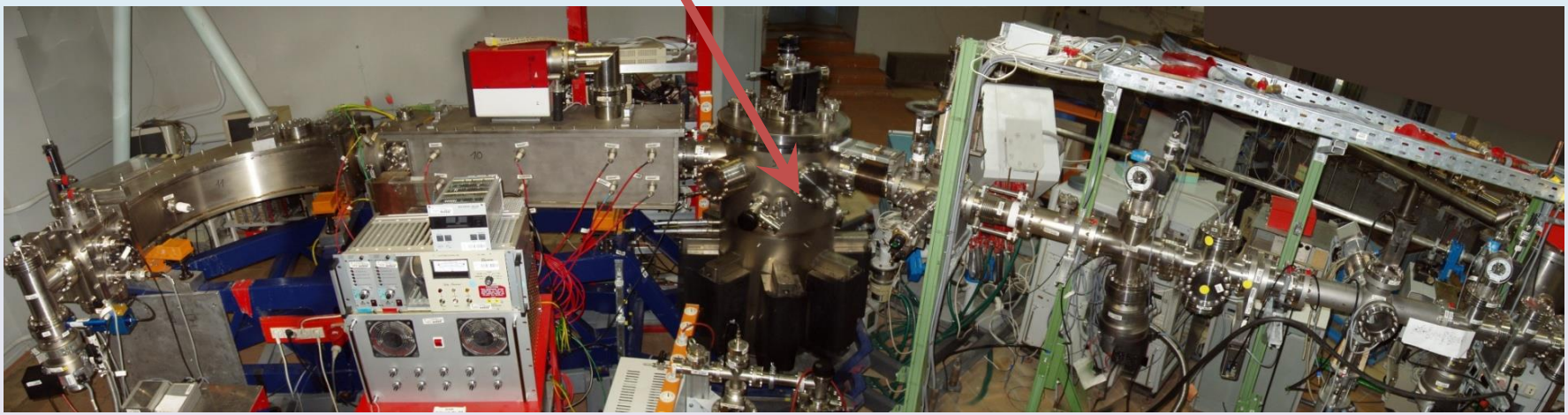
Determination: study of a structure and composition of film coatings of structural materials.

High-resolution elastic recoil detection



Determination: non-destructive qualitative analysis of hydrogen concentration in materials

HERDA end-station with the high-resolution electrostatic spectrometer ($\Delta E/E<1.5\times10^{-3}$)



Ion channeling

Channeling is the steering of an ion beam through the open spaces between rows or planes of atoms in a crystal that produces to intense reduction of the backscattering events, the emitted X-rays and gamma rays.

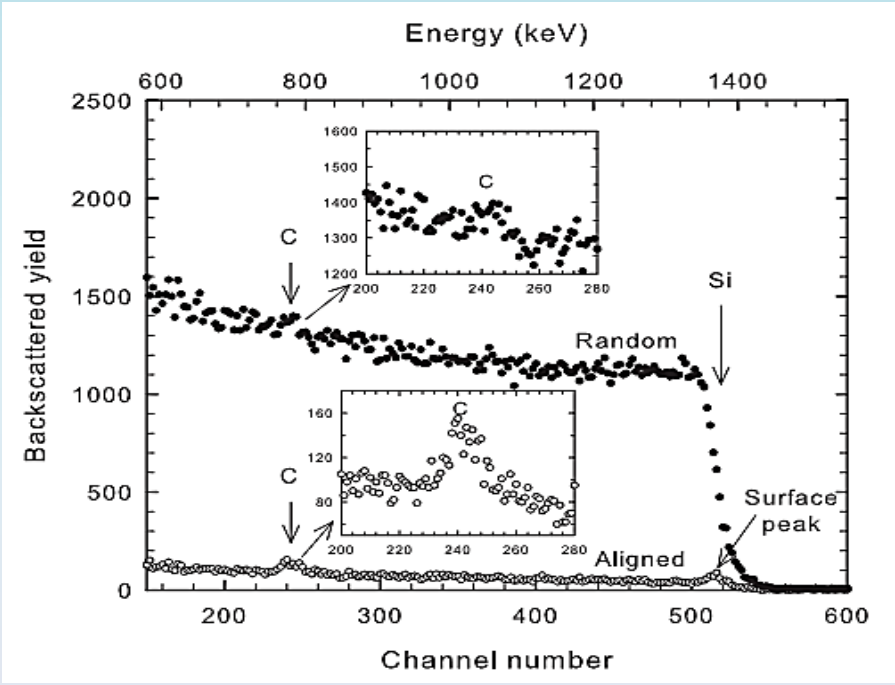
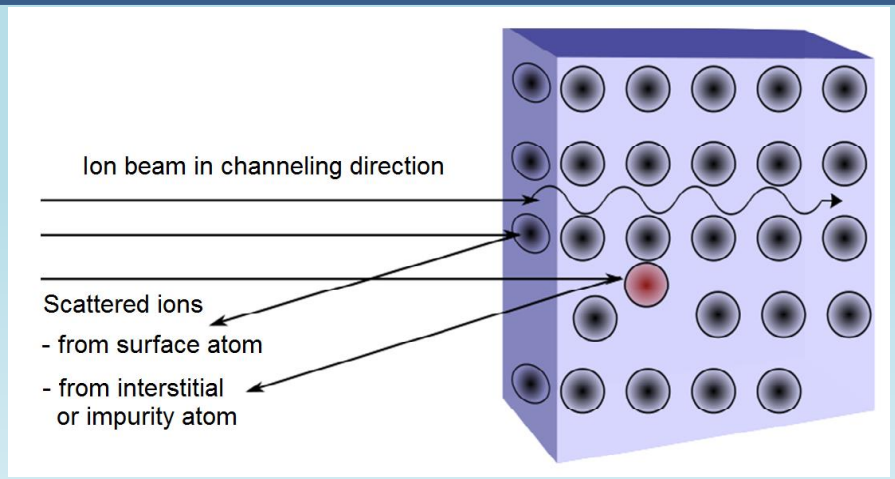
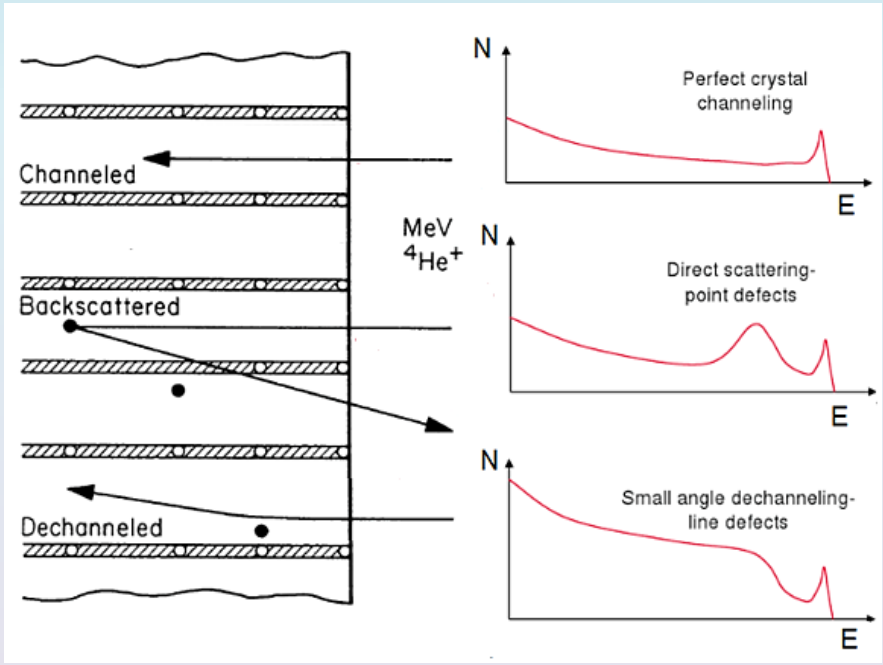
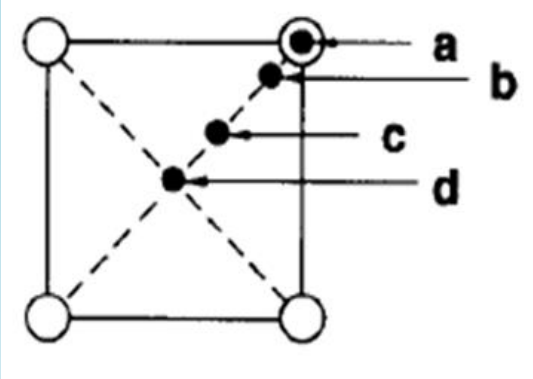


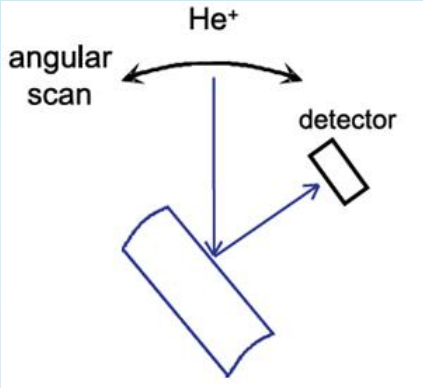
Fig. 1. Comparison of RBS spectra for a random and aligned oriented crystal of Si(100) wafer with 3 nm thick C film on top. Arrows indicate the expected position of He 2+ -ions backscattered from C and Si atoms on the surface (multiplying fraction by the density of the material gives an estimate for the concentration of displaced atoms)

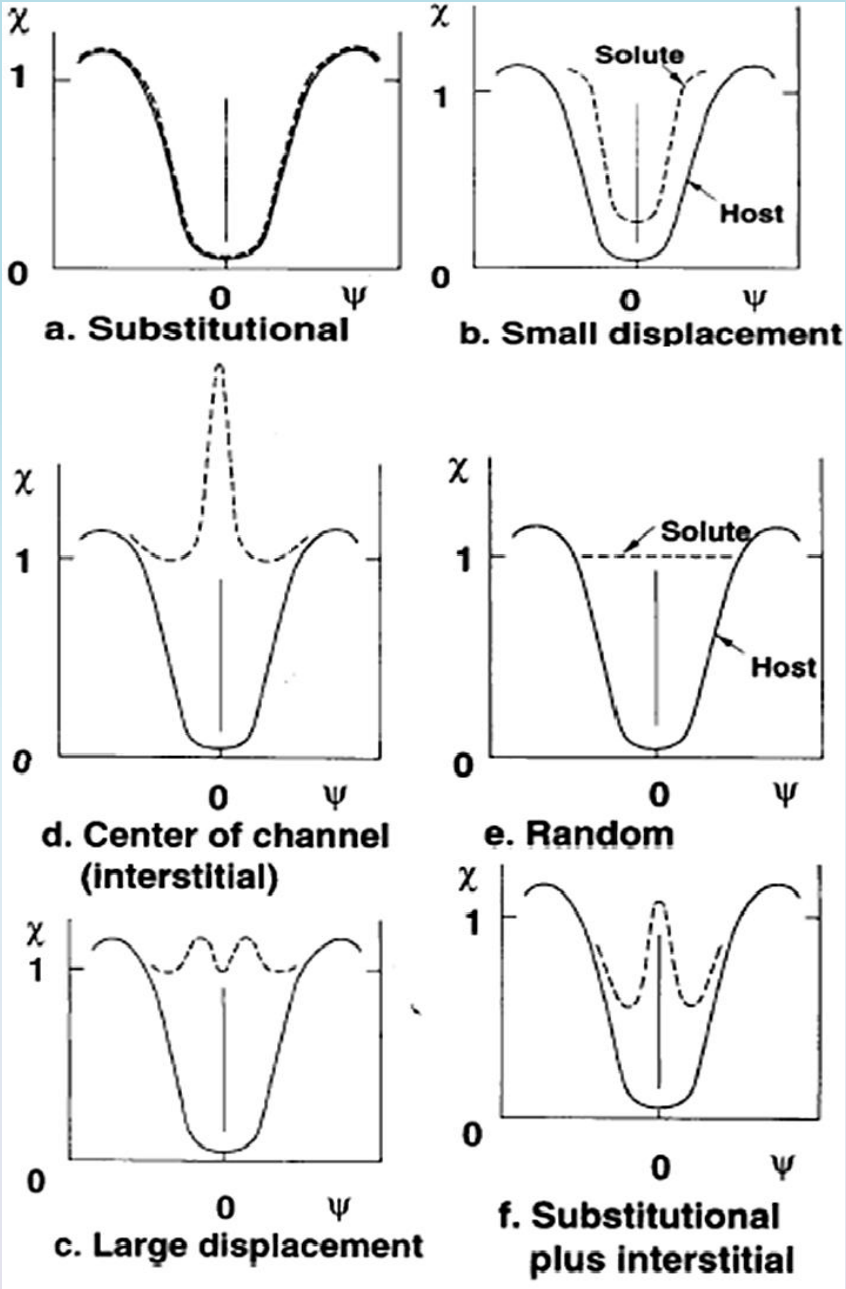




Ion channeling: impurity lattice location



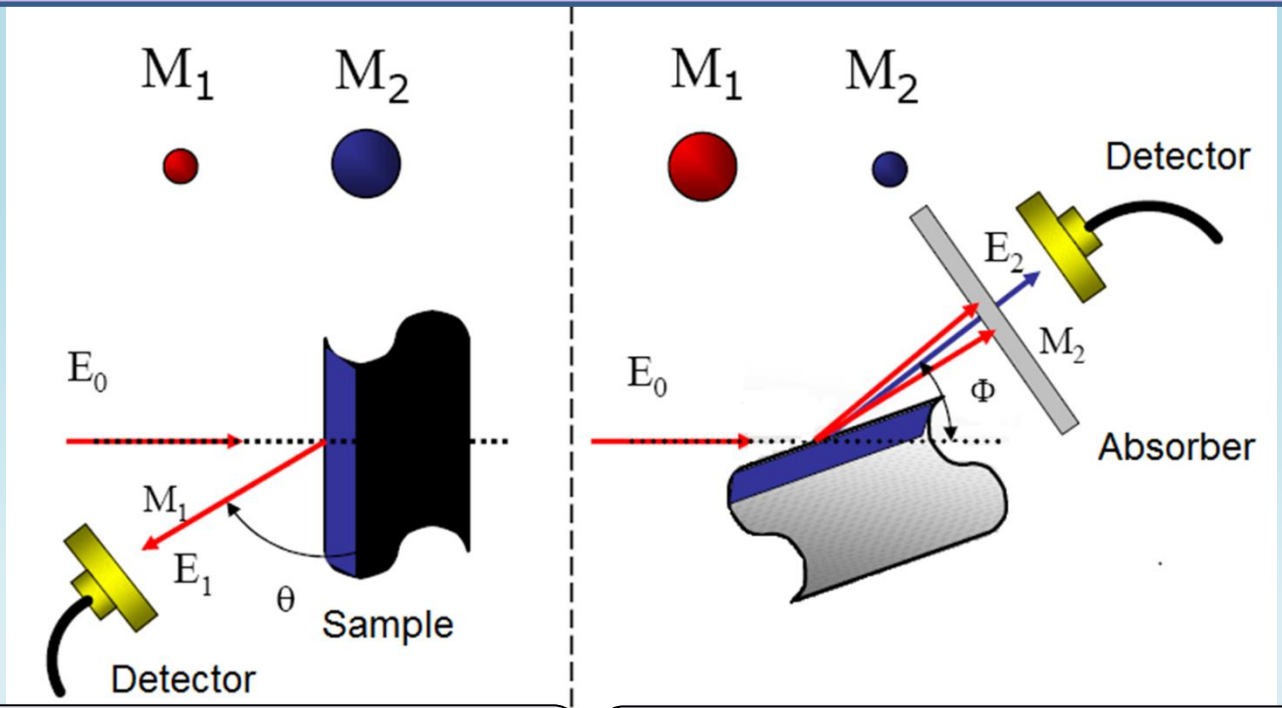




Angular scanning is used to determine the yield as a function of the sample tilt angle with respect to a main axial or planar direction.

At the analysis of shape of the yield of the angular scanning is determined location of the impurity atoms in the channel.

Comparison of RBS/C and ERDA/C



RBS:

- High sensitivity for heavy elements on a light substrates
- Elements detected: B-U
- Depth analysis – nm.

ERDA:

- Profiling elements lighter than the primary ions
- Elements detected: H, B-O
- Depth analysis – microns.

The use of the channeling effect imposes certain requirements on the divergence of the ion beam and the accuracy of the positioning of the crystals.

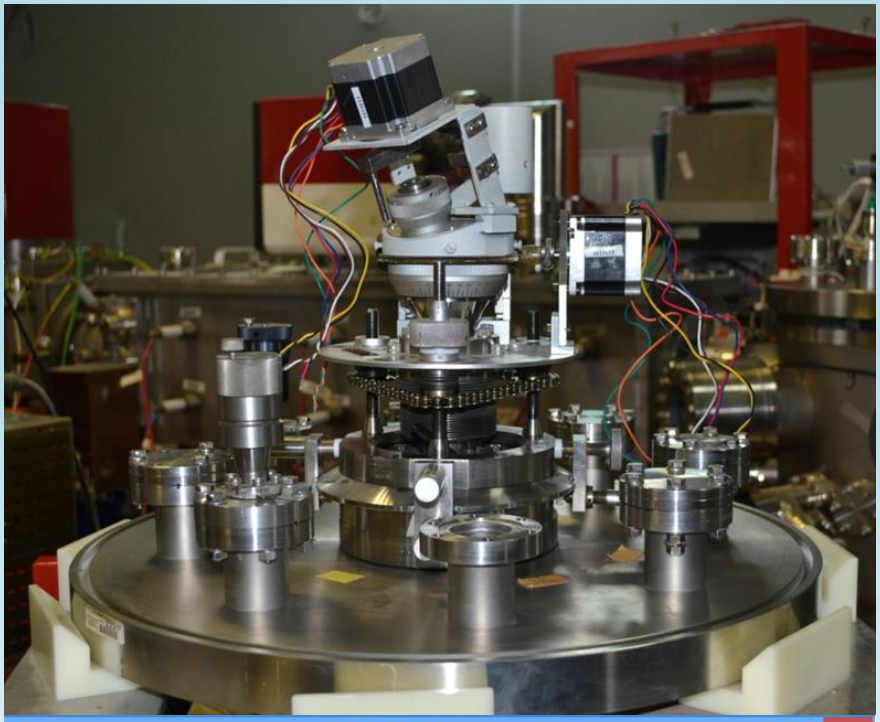
Application of RBS, PIXE, and NRA methods

For	Best choice
Channeling studies of crystal perfection Lattice location of impurities (the impurity mass>host atom mass)	RBS
Surface studies involving some elements that are difficult for RBS	Combination of RBS and NRA
Light impurity element in a heavy-element host lattice	NRA and characteristic X-ray
Intermediate –mass impurities in heavy host lattice	Characteristic X-ray

Determination by RBS and ERDA /channeling

- the concentration and structure of defects,
- surface and interface configurations,
- lattice location of impurities and defect in single crystal,
- lattice parameter,
- thickness of amorphous or defective epitaxial surface layers.

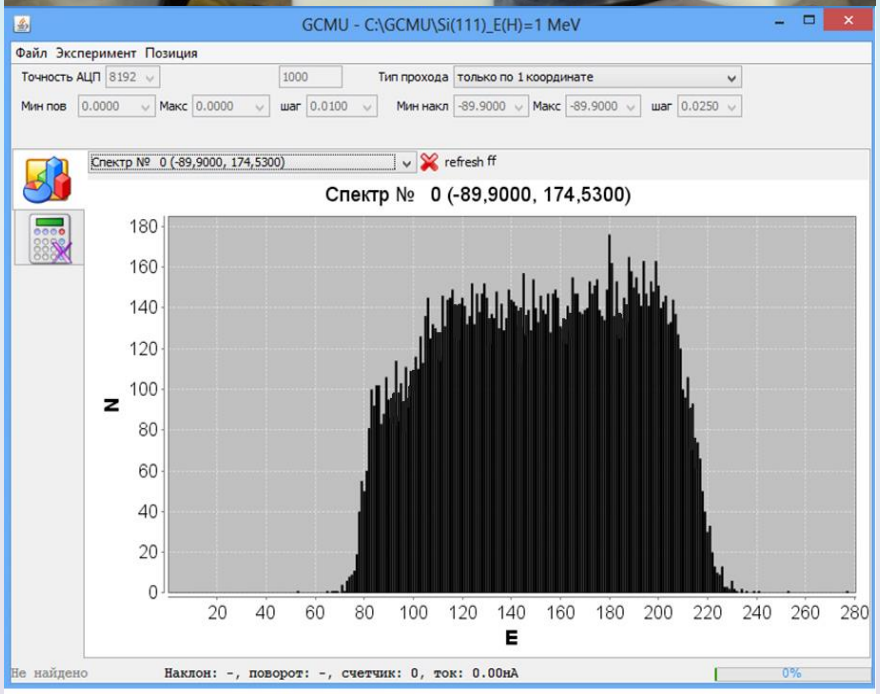
Automated goniometer

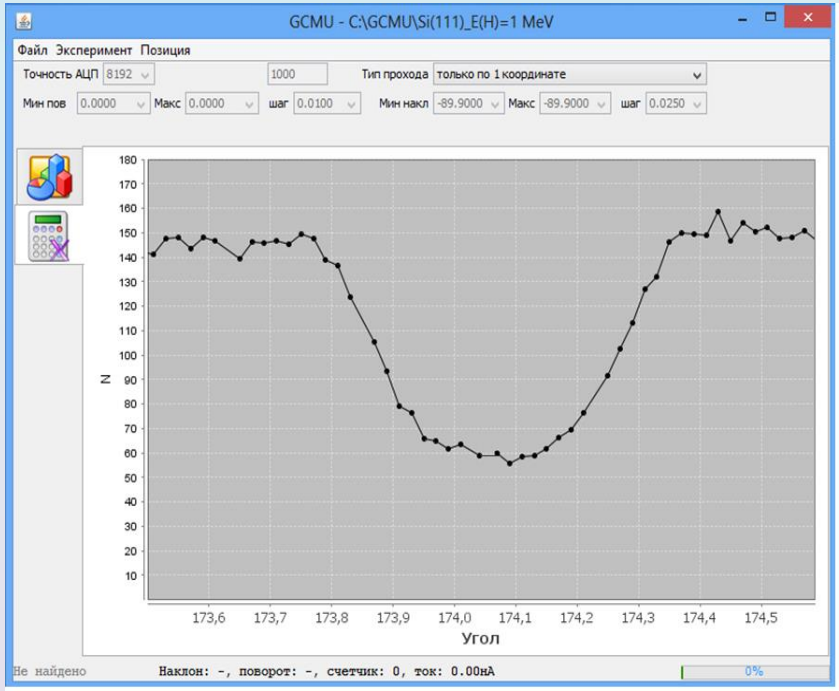


The automation system and Data Acquisition are based on a universal computer appliance and used as device for visualization and data analysis.

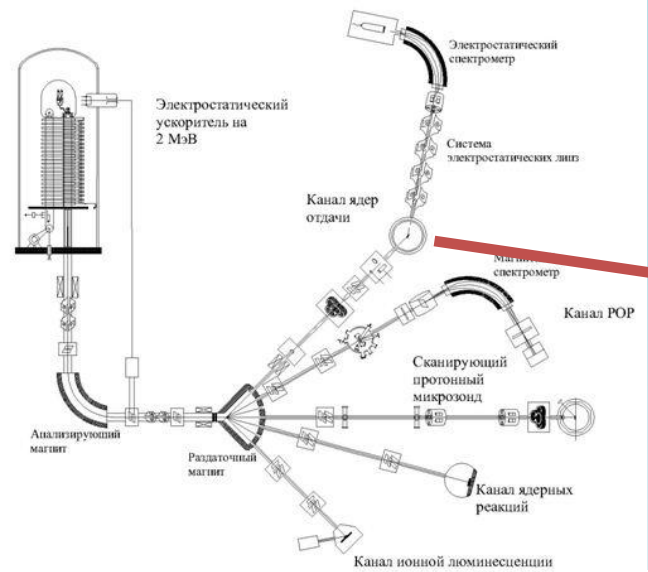
step - 0.01˚, accurate within - 0.01 angstrom

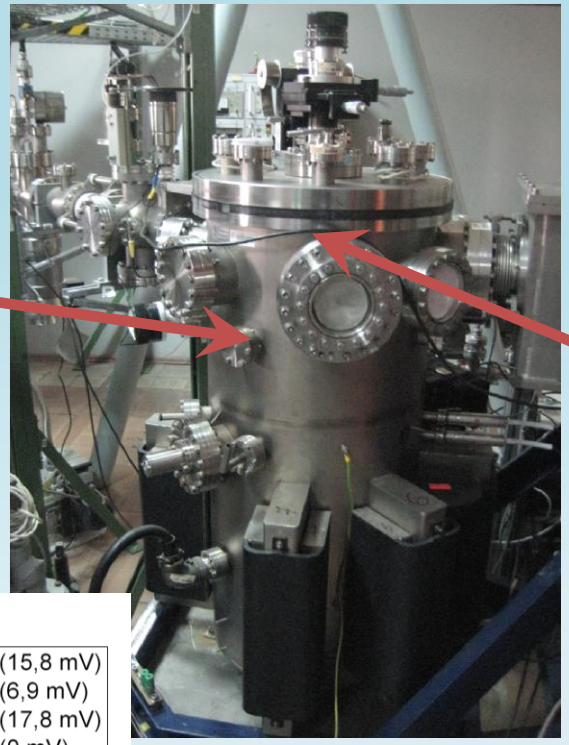
RBS spectra for a random oriented crystal of Si (111), E (H+)=1 MeV.

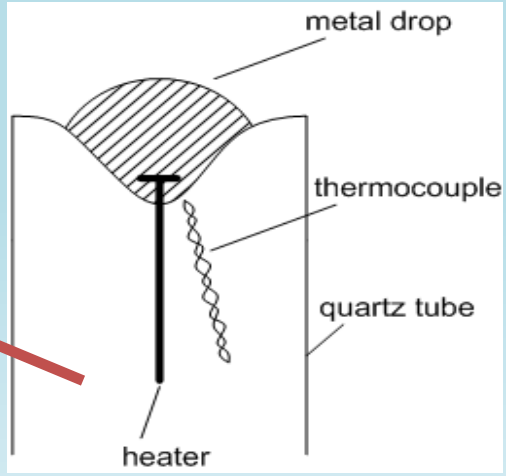




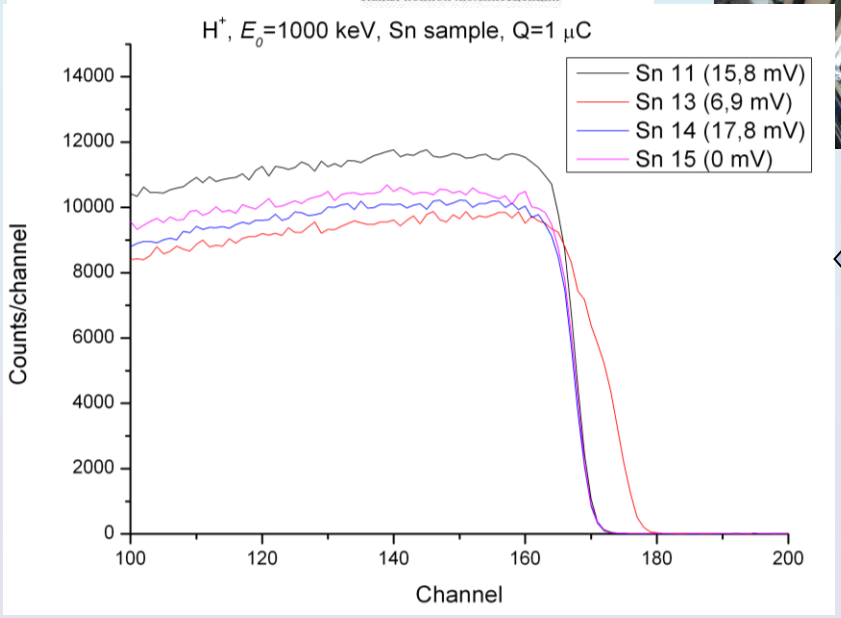
Experimental study of melting metals in real time and in situ using RBS







Quartz tube with a heater and a thermocouple for the study of surfaces melt-represented metals by RBS in situ.



The energy spectra of a sample of tin RBS at different temperatures (from room temperature to melt and after melting).

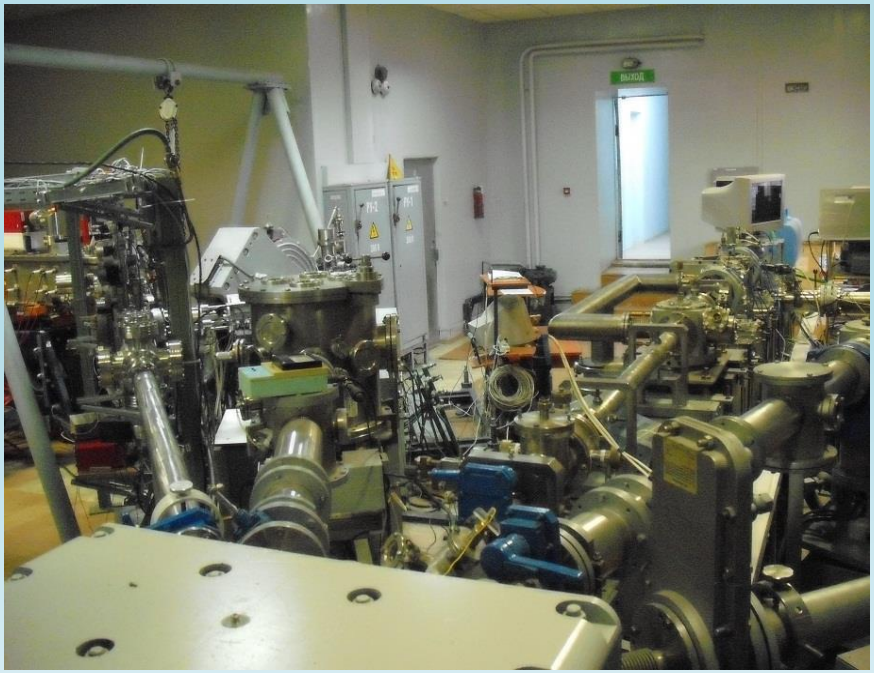
Determination: study of surface defects (diffusion in the alloys, the segregation of impurities on the surface) in the liquid metal alloys used as a heat carrier in the reactor of a new generation.

Summary

- At Institute of Applied Physics of NAS of Ukraine equipment for investigation of orientation effects in single crystal is developed;
- The main purpose of the new equipment is quantitative non-destructive investigation of hydrogen in materials by elastic recoil detection technique.
- RBS/C and ERDA/C techniques can be used for the determination concentration and structure of defects, surface and interface configurations, lattice location of impurities and defects in single crystalline samples.

Future plans

To investigate the influence radiation damage on the structure of construction materials (Be, W, Zr) are used in nuclear reactors of the new generation.



Thank you for attention!

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