"Channeling 2008"

Analysis of Lattice Distortion by Dechanneling

G. D. Tolstolutskaya

National Science Center “Kharkov Institute of Physics and Technology”
1, Academicheskaya str., 61108 Kharkov, Ukraine, g.d.t@kipt.kharkov.ua

KIPT

Irradiation of structural materials creates the possibility of microstructure and mechanical properties changes, and even of external dimensions of structural components at the expense of swelling, growth and creep. Therefore, the radiation damage study of structural materials is of great importance for estimating the lifetime of components and the safe operation of the nuclear facilities.

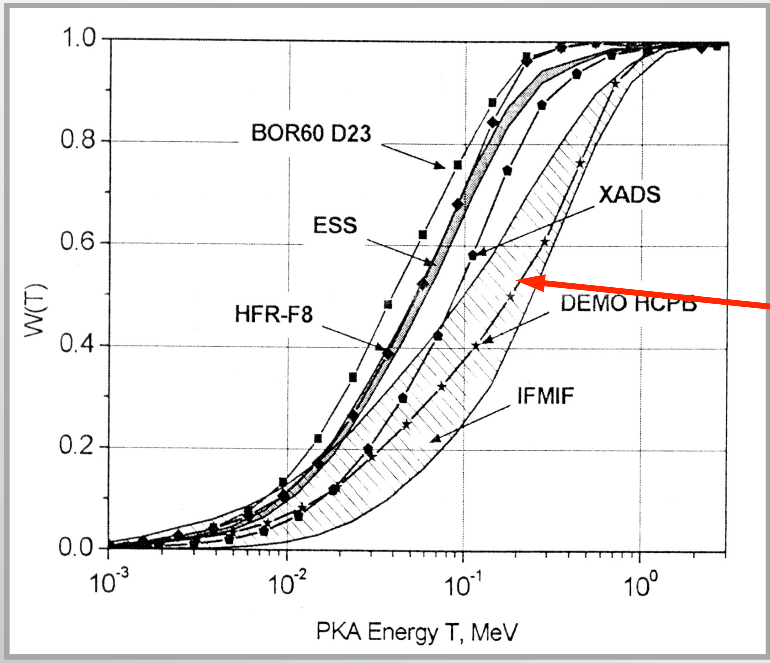
The main mechanisms of degradation and of size instability are: displacement of atoms in lattice, their subsequent migration, segregation and interaction with transmutants.

The ion beam analysis techniques including Rutherford backscattering spectroscopy (RBS), channeling, nuclear reaction analysis (NRA) and methodologies for the analysis of experimental data provide a comprehensive tool for studying crystal defects.

The present report discusses the application of Rutherford backscattering spectroscopy (RBS) + channeling and transmission electron microscopy in the complex investigation of displacement damage and detailed depth profiling of damage under irradiation of targets.

The distribution profiles of damage and interstitial under irradiation of targets Ni in wide range of doses and energies of inert gases particles (He^+, Ar^+, Kr^+, Xe^+ with energy 0.2-1 MeV, irradiation doses $1\cdot10^{15}$–$2\cdot10^{17}cm^{-2}$) were systematically studied.

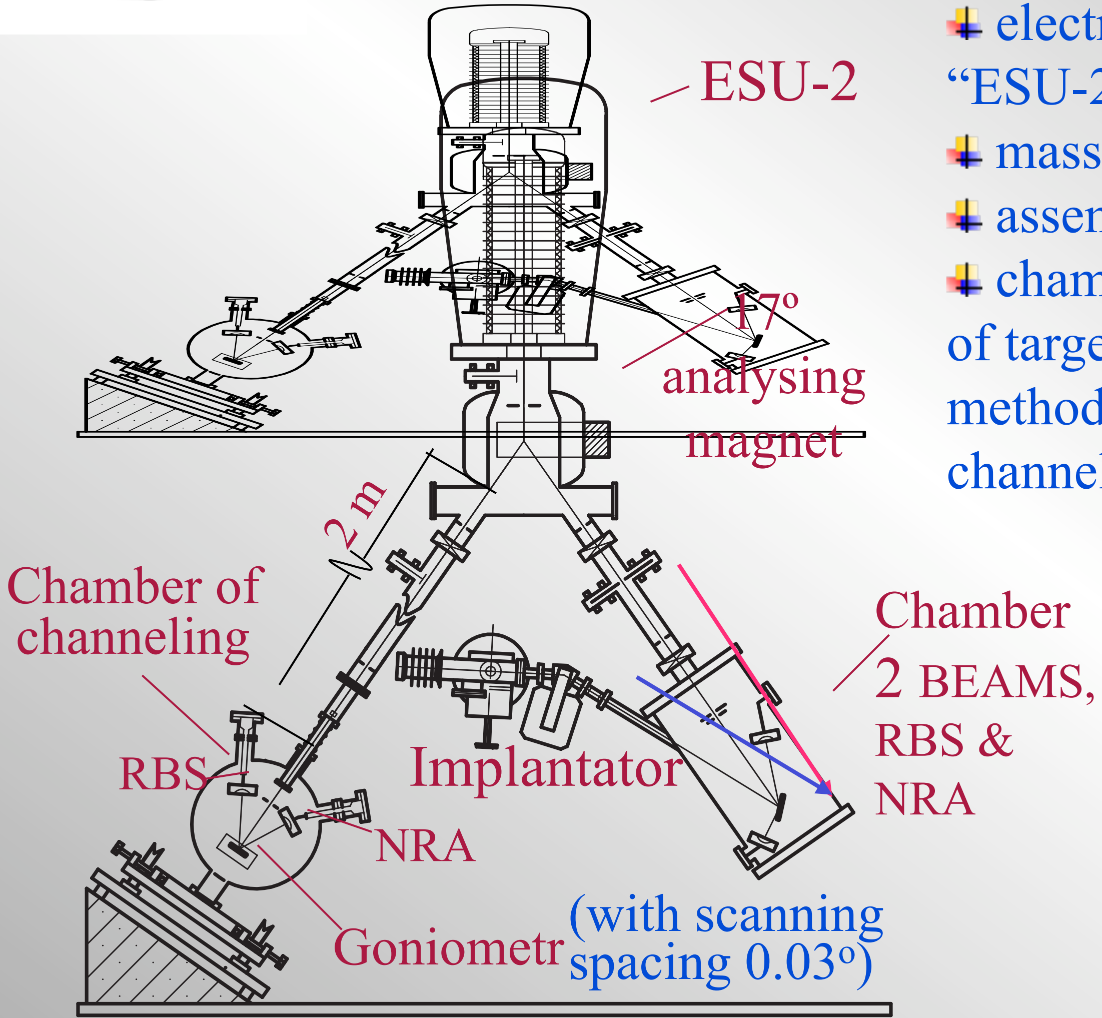
Energetic heavy ions irradiation has been used for modeling of defect cluster formation under displacement cascade condition so as to simulate fusion reactor environments.



- For DT fusion neutrons with the energy of 14 MeV, typical primary recoil atom energy for medium heavy target materials is around 100…1000 keV.
- The heavy inert gases (Ne and Ar) has been suggested as an analogue for helium which will generate in (n,α) transmutations in fusion facilities.

In view of the fact that nickel is widely used as designed material for study of stainless steel the system Ni+impurity (He, Ar, Kr, Xe) may serve as the representative object of investigation for the mentioned problem solution.

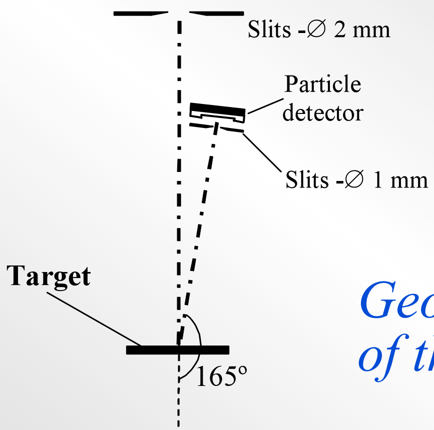
The configuration of measuring complex ESU-2



The experimental equipment consists of :

- electrostatic accelerator designated "ESU-2 MeV",
- mass-separator,
- assembly "Implantator",
- chambers for irradiation

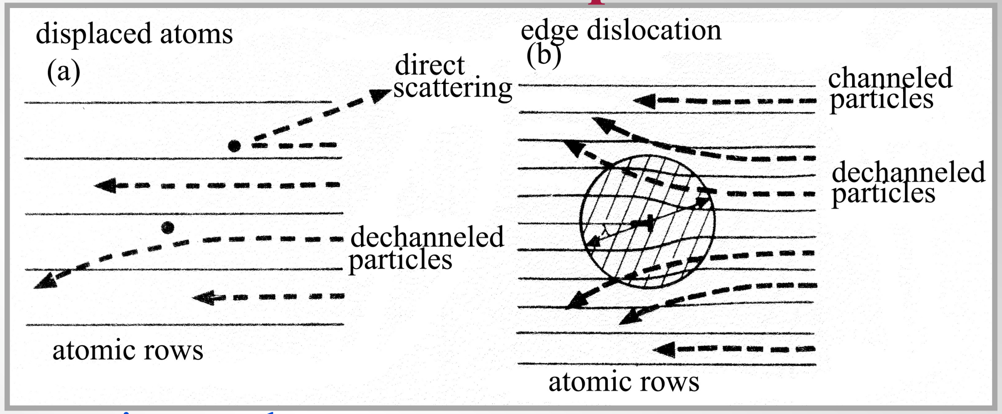
of targets and measurements using the methods of Rutherford backscattering, channeling and nuclear reactions.



Geometry of the experiment

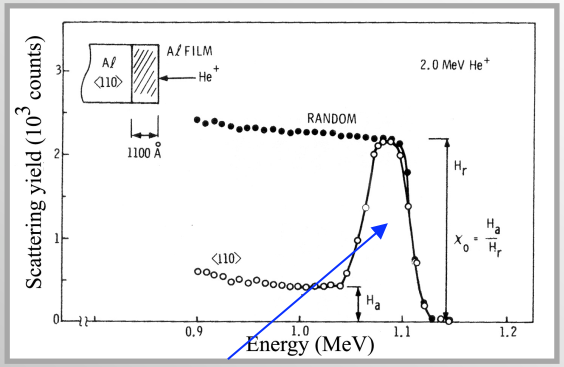
Schematic of the processes

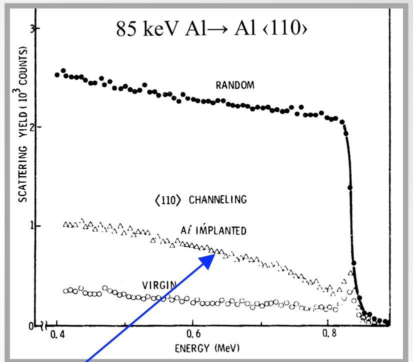
(S.T. Picraux et.al. Phys.Rev.1978).



(a) direct scattering and dechanneling by displaced atoms

(b) dechanneling by a dislocation





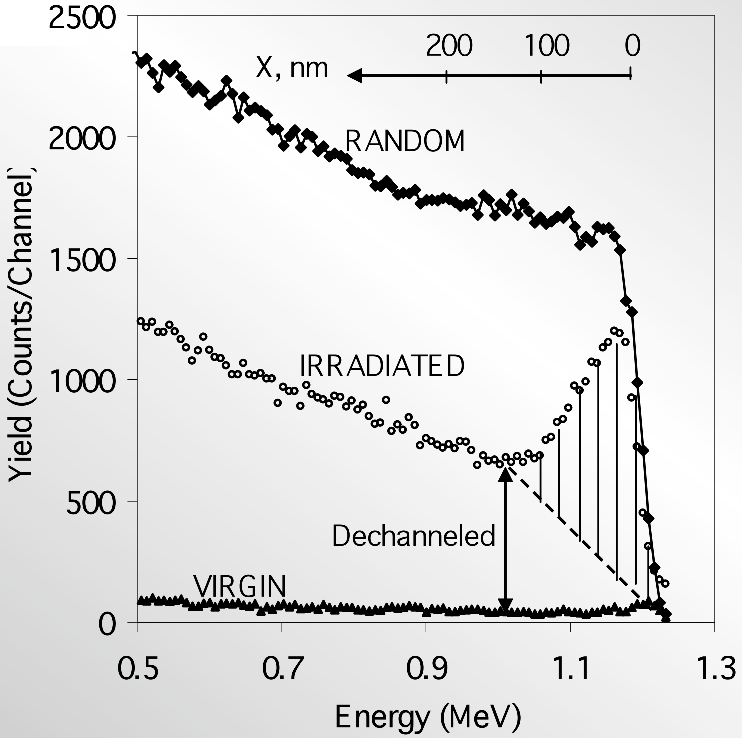
The dechanneling is associated with randomly displaced atoms

A thin Al film (thickness ~1100 Å) represents a layer of scattering centers randomly located

The dechanneling is associated with dislocations

A high density of dislocations (min ~10^9-10^{10} lines/cm^2) is required for detections by dechanneling measurements.

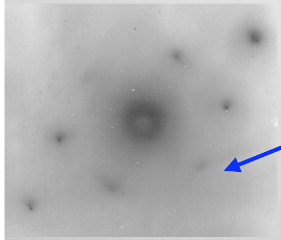
RBS-channeling spectra of Ni irradiated with heavy ions

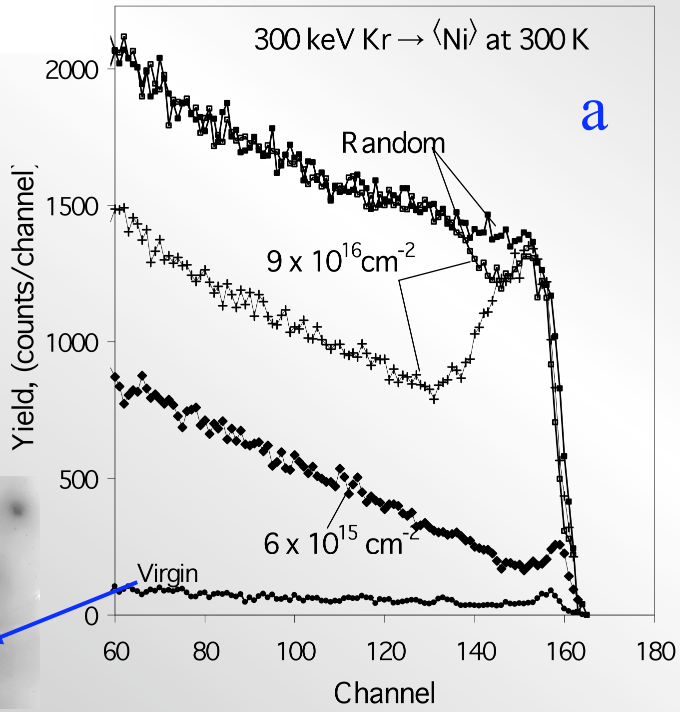


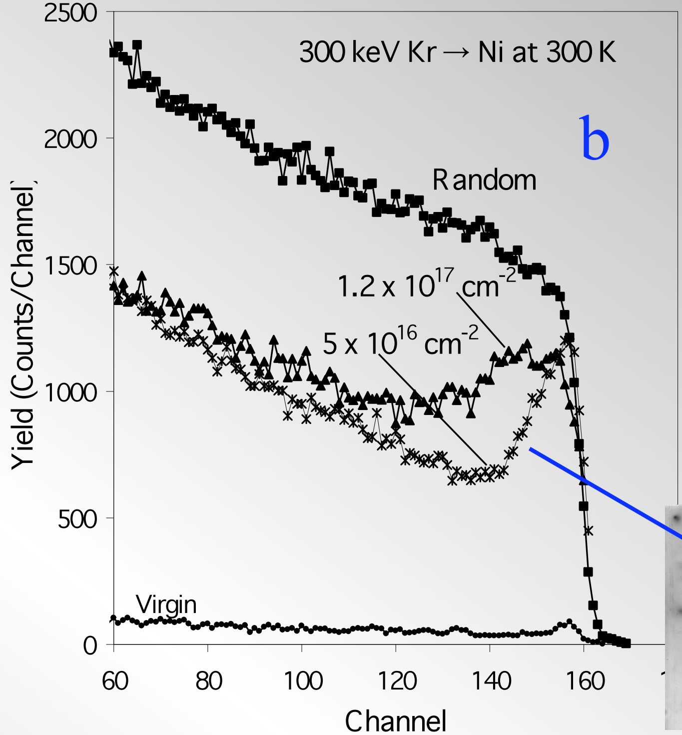
Backscattering energy spectra (random and axial) of He^+ ions with energy 1.6 MeV in Ni <110> crystal in initial and Kr^+ ions (300keV) implanted up to dose $5 \cdot 10^{16}$ cm^{-2} at room temperature.

The common feature characteristic practically for all spectra measured in conditions of axial channeling is the presence of peaks in near-surface area and several times increase of backscattering yield in comparison with initial non-irradiated crystal.

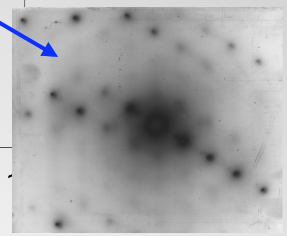
The drastic increase in the disorder to near-random level







Selected area diffraction pattern



Data obtained under irradiation with krypton ions (dose $9 \cdot 10^{16} cm^{-2}$) (a) demonstrate the monocrystal disordering of near-surface region. In this case the yield of backscattering in the peak attains the level of signal obtained for disoriented crystal. Broadening of the peak under the unchanging dechanneling (b) means the sputtering and generating of scattering centers in near-surface region.

Minimum backscattering yield (dechanneled fraction) defined as RBS yield ratio of an aligned spectrum to a random spectrum, is a measure of the degree of lattice disorder.

$$n_d(t) = N\frac{\chi_d(t) - \chi_r(t)}{1 - \chi_r(t)}$$

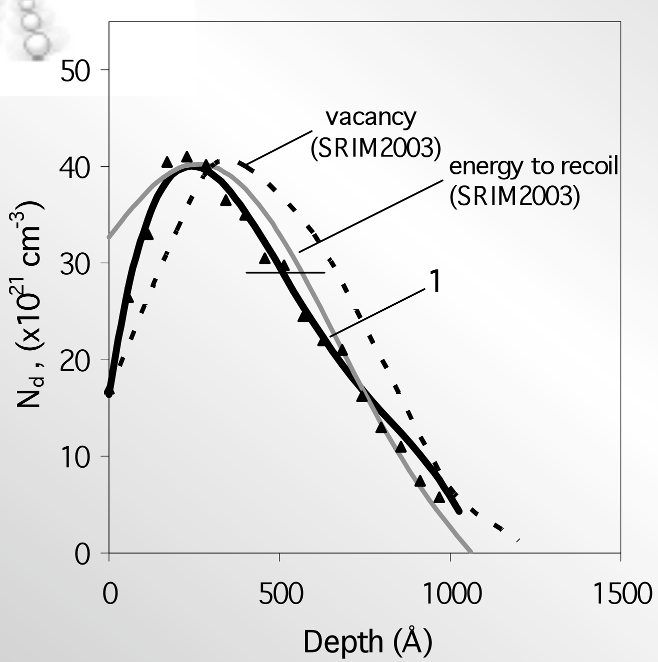
$$Y_d(t) = Y_H(t\left[\chi_r(t)\frac{N - n_d(t)}{N} + \frac{n_d(t)}{N}\right]$$

$$F(t) = [1 - \chi_v(t)]\left\{1 - \exp\left[-\int_0^t \sigma_D n_d(t')dt'\right]\right\}$$

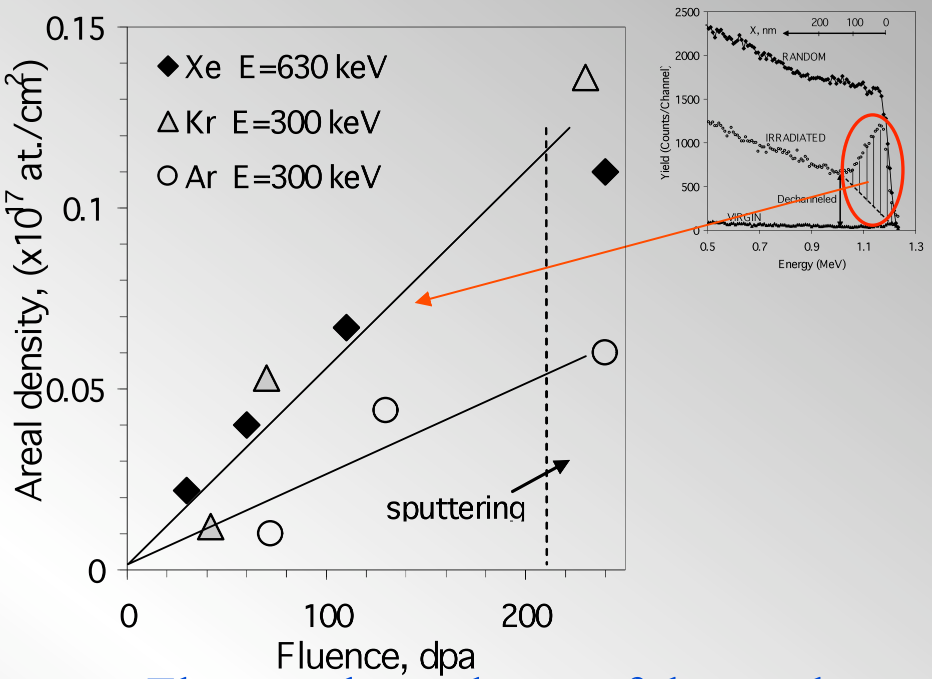
Dechanneling parameter on depth t the normalized yield of backscattering for damaged (χ_d) and virgin crystal (χ_v) crystals is F_d=-ln[1-χ_d(t)]/[1-χ_v(t)] .

Information on depth distribution of the extended defects is obtained by analysis of the rate of dechannelling parameter variation (F_d).

Depth profiles of defects and total amount of damage



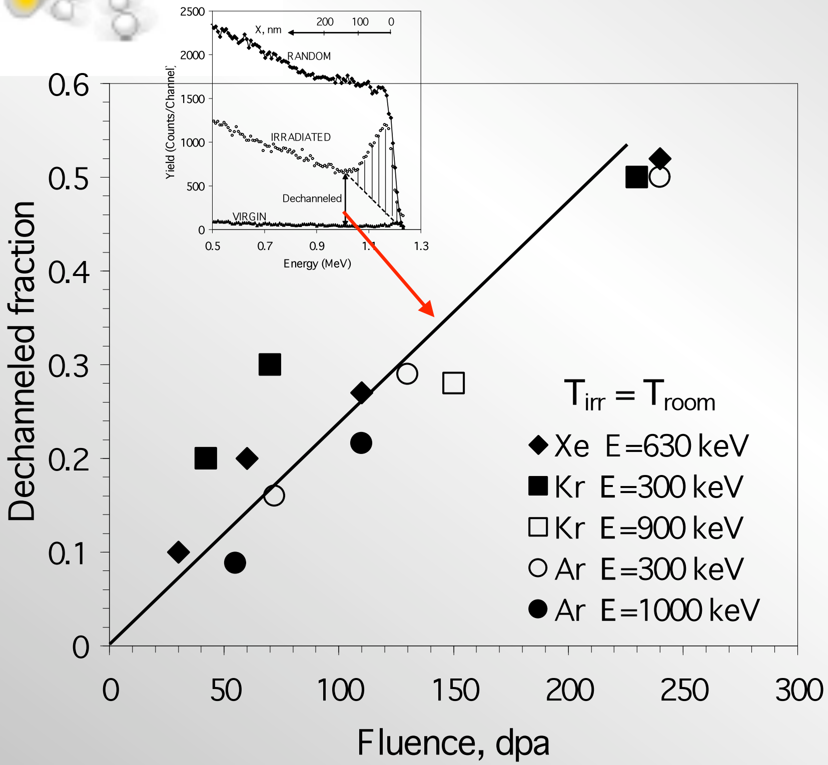
Profiles of damage (1) produced in Ni by irradiation with ions of krypton with energy 300 keV up to the doses $5 \cdot 10^{16} cm^{-2}$ under the room temperature.



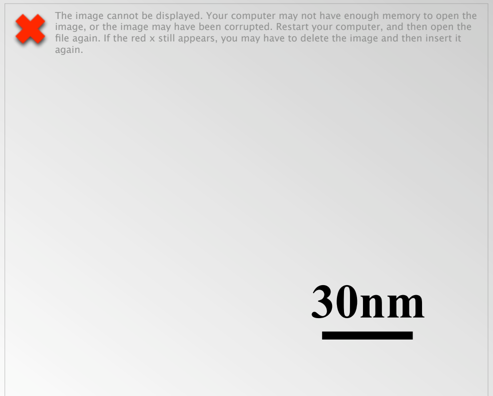
Fluence dependence of the total number of scattering centers

Ion / Parameters	Ar	Kr	Xe
E, keV	300	300	630
E_{recoil}, eV/ion/Å	140	400	600

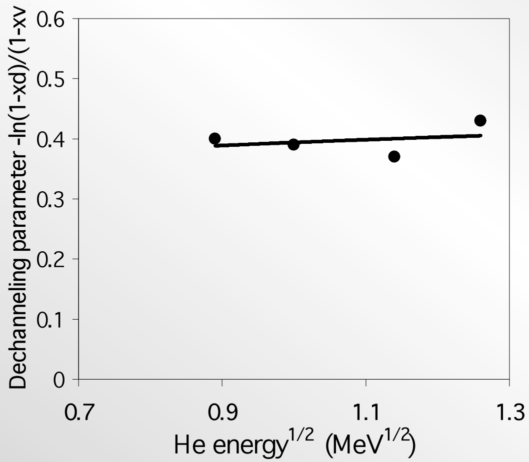
Defect accumulation vs fluence



Dechanneled fraction vs fluence

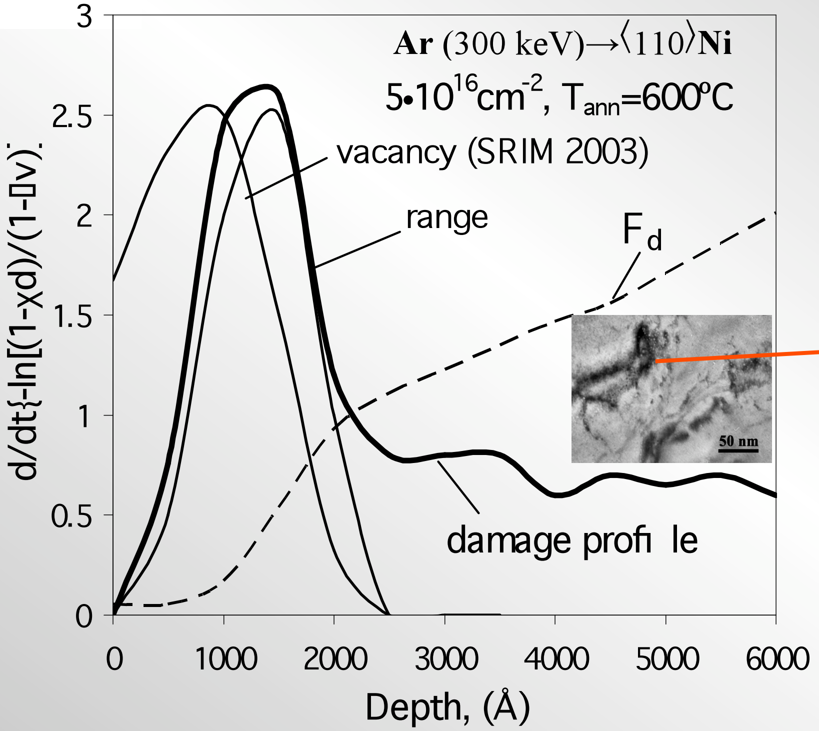


TEM image of Ni crystal irradiated by 300 keV Ar^+ to $5 \cdot 10^{16}$ cm^{-2} at T_{room}

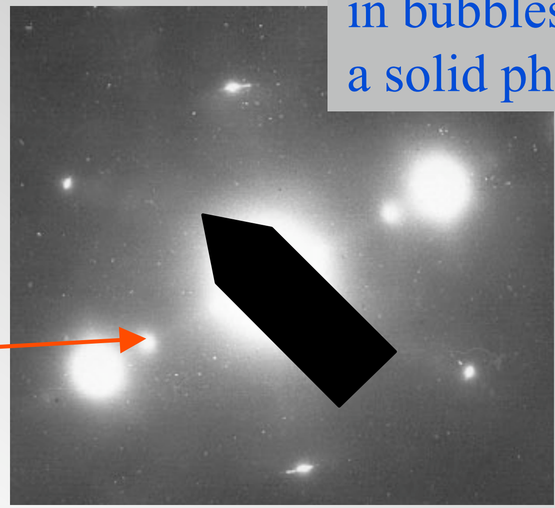


Dechanneling parameter for Ni irradiated by 300 keV Ar^+ plotted as a function of the square root of the incident ^4He energy.

Depth profiles of extended defects



Experimental and computed by program SRIM 2003 damage profile in nickel (vacancies and range distribution) for argon ions with energy 300 keV.

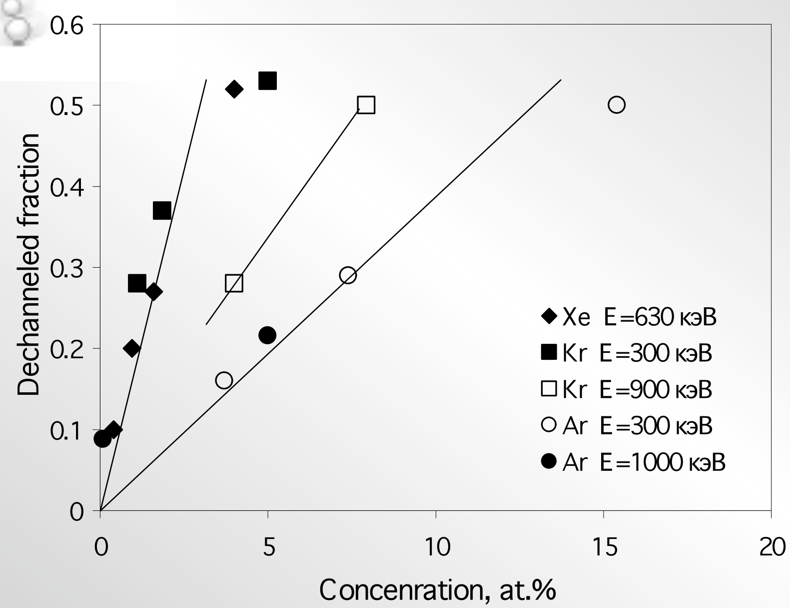


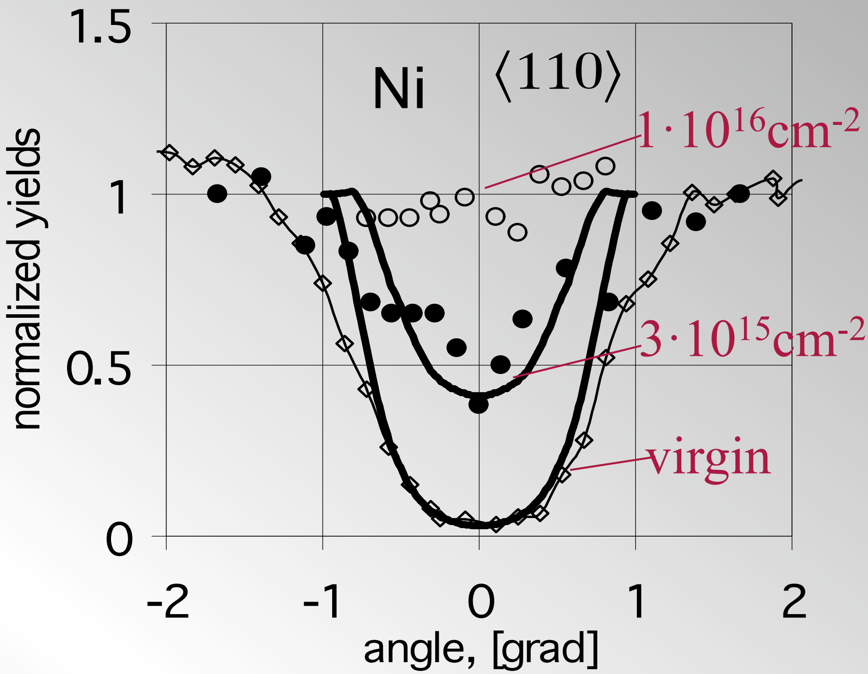
Kr precipitate in bubbles into a solid phase

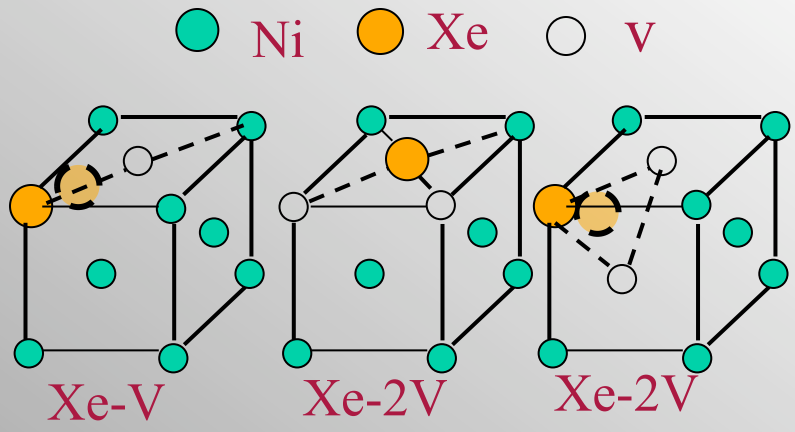
Electron diffraction patterns

The lattice distortion extended to the greater depth in comparison with a vacancy and defect distribution calculated by SRIM 2003 (for argon and krypton with energy 300 keV, xenon with energy 630 keV)

Lattice location of implanted noble gas atoms and dechanneling





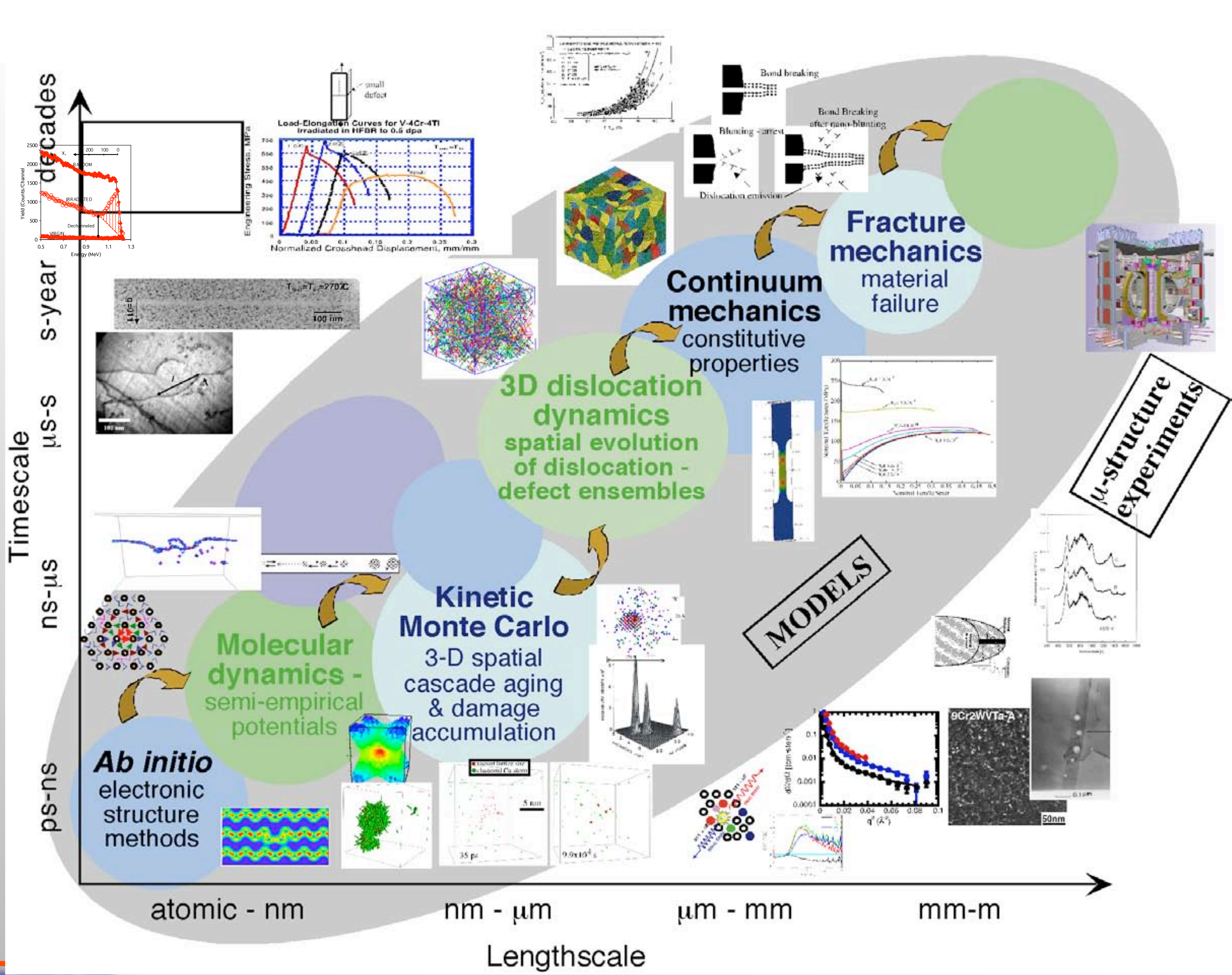


The best fitting of experimental and of calculated values of angular dependencies is obtained when under irradiation dose of $3 \cdot 10^{15}cm^{-2}$ 85% of Xe atoms are in the complexes Xe+v, 15%-in complexes Xe +2v. Under the dose of $6 \cdot 10^{15}cm^{-2}$ 60% of Xe atoms form the complexes Xe+2v.

CONCLUSION

1. The accelerators and ion beam analysis techniques are useful for the simulation of displacement damage and detailed investigation of distribution profiles of damage and impurity atoms under irradiation of targets in wide range of doses and energies of particles. Charged particle- materials interaction research may produce very important information for nuclear materials R & D.
2. Damage profiles agree with profile of the energy deposited in nuclear collisions.
3. Total disorder in the Ni lattice increases linearly with fluence.
4. Profile of extended defects coincides with calculated **range distribution** in the case of 200 keV helium and 300 keV argon ions irradiation. But in the case of argon the damage on depth Rp +ΔRp doesn`t decreases to zero; there is some degree of damage that extends to the depth several times exceeding projected range plus range spread.
5. The possible reason of observed particularities may be that:
   the heavier inert gases precipitate as solid bubbles;
   the difference in the processes proceeding in cascades.

Radiation damage is inherently multiscale with interacting phenomena ranging from ps to decades and nm to m



Thank you for your attention !