

HIGH-ENERGY ION IRRADIATION IN  
MATERIAL SCIENCE AT FLEROV  
LABORATORY OF NUCLEAR REACTIONS  
ON THE EXAMPLE OF SINGLE-WALLED  
CARBON NANOTUBES



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Joint Institute for Nuclear Research, Flerov Laboratory of Nuclear Reactions

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# OUTLINE

- Flerov Laboratory of Nuclear Reactions - structure, main research fields
- Sector 8 - possibilities and equipment
- Ion irradiation effects and research motivation
- Single-Walled Carbon Nanotubes (SWCNTs) - structure and applications
- Irradiation effects studies - Raman spectroscopy results
- Conclusions
- Acknowledgements





# FLEROV LABORATORY OF NUCLEAR REACTIONS

- Synthesis and properties of superheavy nuclei
- Formation and structure of heavy nuclei
- Chemistry of transactinides
- Mass-spectrometry and laser spectroscopy of heavy and superheavy nuclides
- Dynamics of heavy nuclei interaction, fission of heavy and superheavy nuclei
- Structure of light exotic nuclei
- Light radioactive and stable nuclei beams reactions
- Ion-implantation nanotechnology and radiation materials science
- Theoretical and computational physics
- Group of selective laser ionization and separation of nuclear reaction products



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# IC-100 CYCLOTRON POSSIBILITIES

- **Energies up to 1.2 MeV/nucleon**



<http://flerovlab.jinr.ru/flnr/ic-100.html>



## IC-100 CYCLOTRON POSSIBILITIES

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- **Electron Cyclotron Resonance (ECR) ion source developed in collaboration with LHE**



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## IC-100 CYCLOTRON POSSIBILITIES

- Energies up to 1.2 MeV/nucleon
- Electron Cyclotron Resonance (ECR) ion source developed in collaboration with LHE
- **Highly charged ions of Xe, Kr, Ar and other heavy elements**



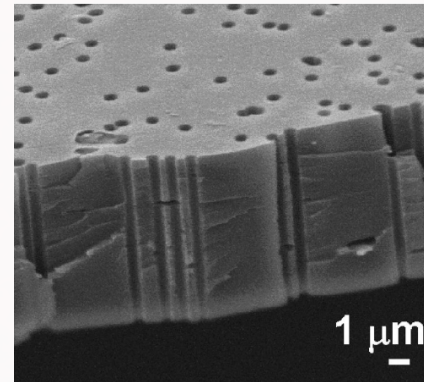
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# NANOTECHNOLOGY RESEARCH

- Scanning Electron Microscope

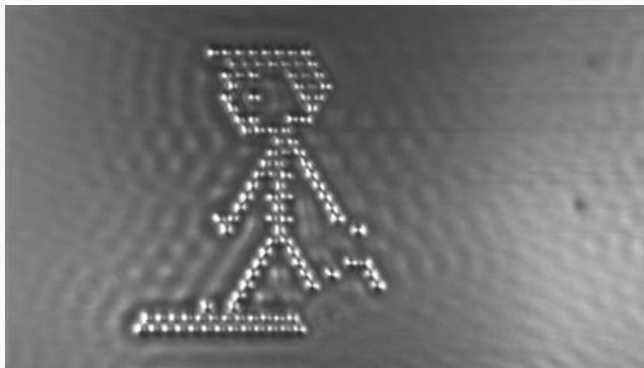
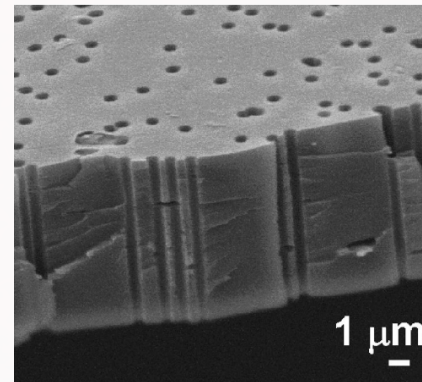


Tomás E. Gómez Álvarez–arenas, Pavel Yu. apel, and Oleg Orelovitch, Ultrasound Attenuation in Cylindrical Micro-Pores: Nondestructive Porometry of Ion-Track Membranes, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 2008 Nov;55(11):2442-9. doi: 10.1109/TUFFC.951  
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- Scanning Electron Microscope
- Scanning Tunelling Microscope

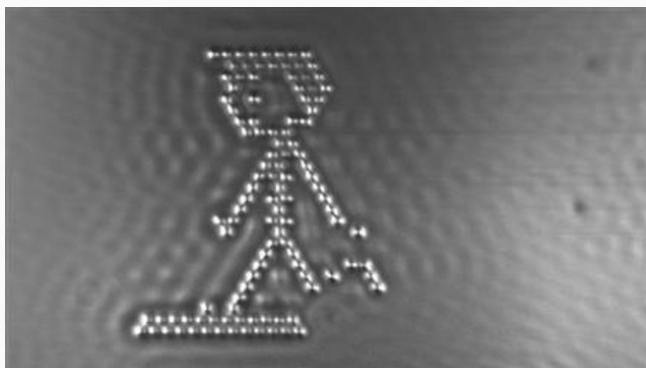
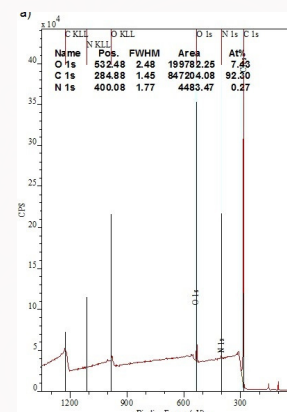
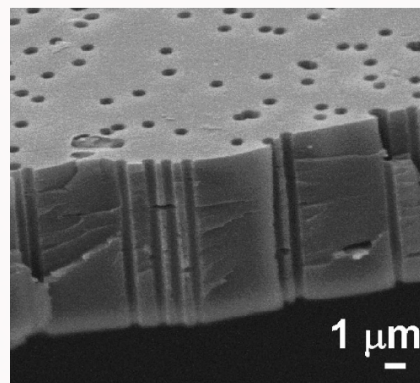


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# NANOTECHNOLOGY RESEARCH

- Scanning Electron Microscope
- Scanning Tunelling Microscope
- X-ray Photoelectron Spectroscopy



Tomás E. Gómez Álvarez–arenas, Pavel Yu. apel, and Oleg Orelovitch, Ultrasound Attenuation in Cylindrical Micro-Pores: Nondestructive Porometry of Ion-Track Membranes, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 2008 Nov;55(11):2442-9. doi: 10.1109/TUFFC.951

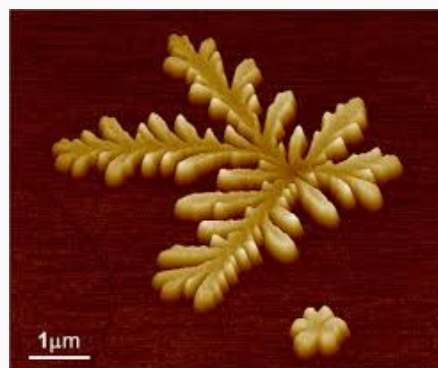
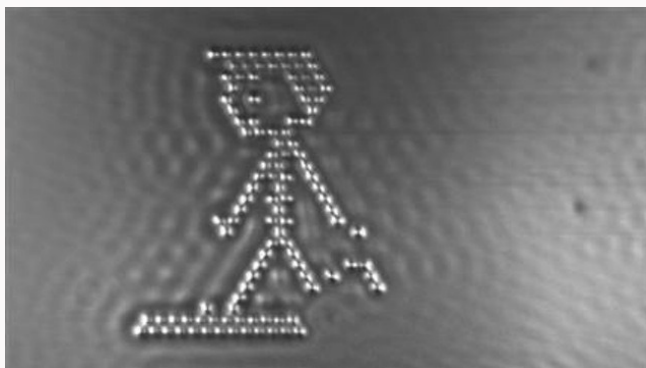
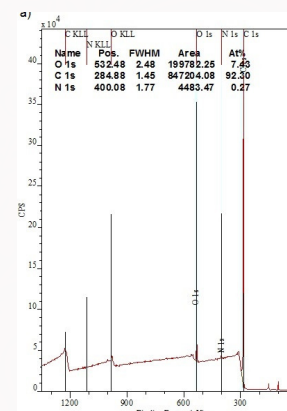
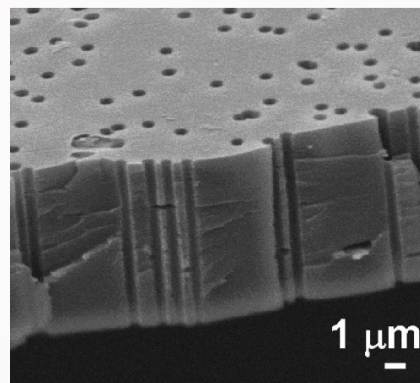
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# NANOTECHNOLOGY RESEARCH

- Scanning Electron Microscope
- Scanning Tunelling Microscope
- X-ray Photoelectron Spectroscopy
- Integrated AFM/Raman system



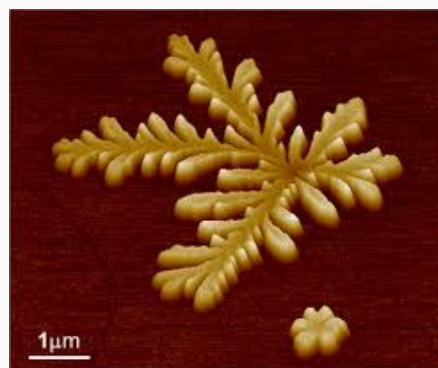
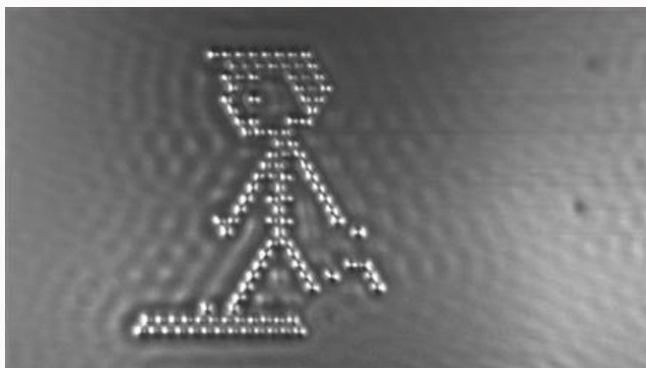
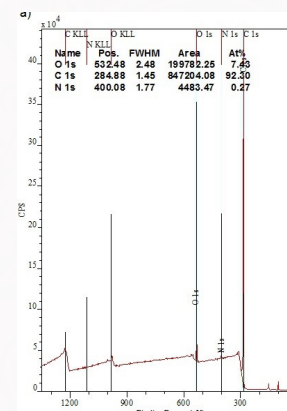
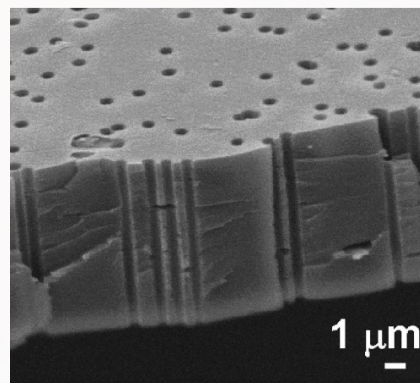
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# NANOTECHNOLOGY RESEARCH

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- X-ray Photoelectron Spectroscopy
- Integrated AFM/Raman system
- Sample preparation stations

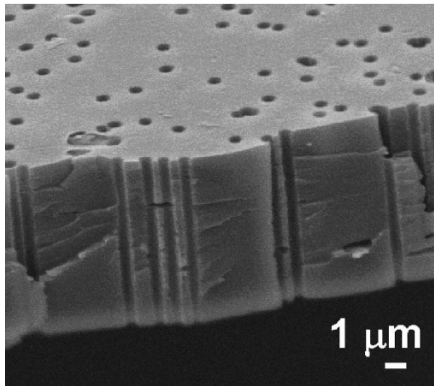


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# ION IRRADIATION EFFECTS AND RESEARCH MOTIVATION



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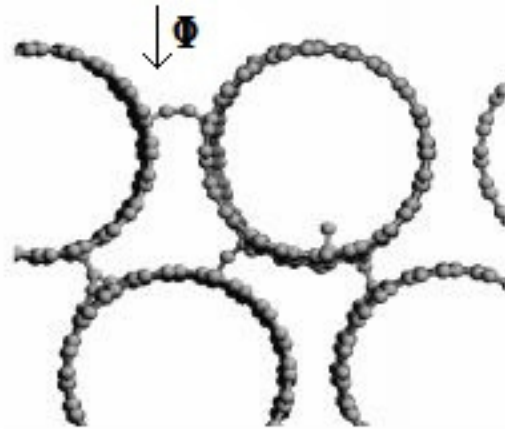
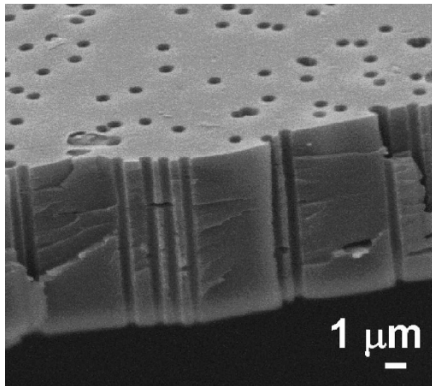
A. V. Krasheninnikov, K. Nordlund, J. Keinonen, and F. Banhart. Ion-irradiation-induced welding of carbon nanotubes. *Phys. Rev. B*, 66(24):245403, December 2002.

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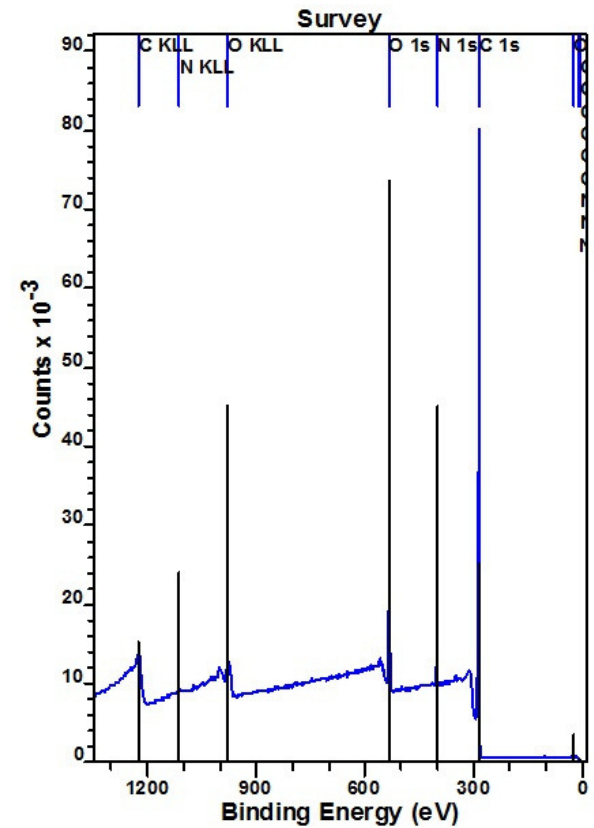
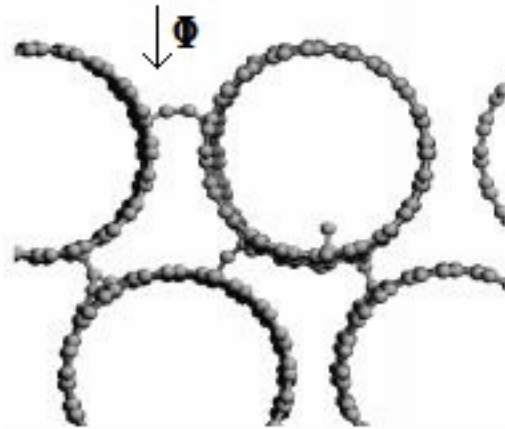
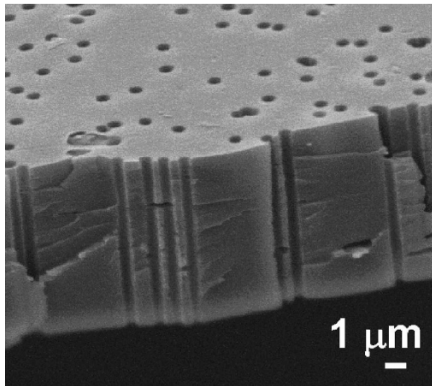
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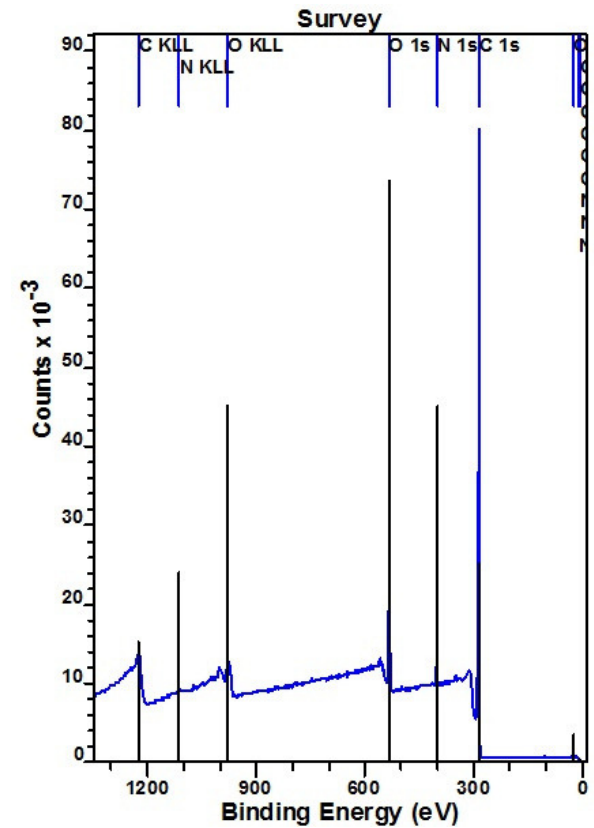
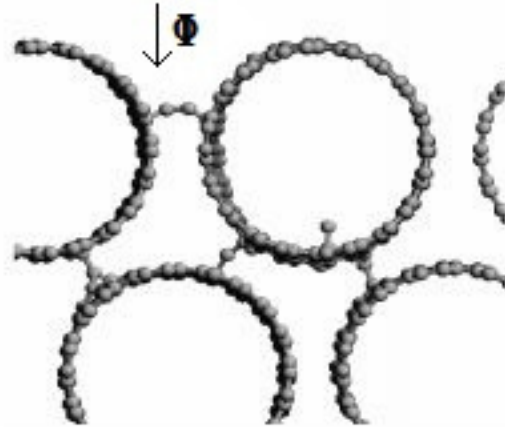
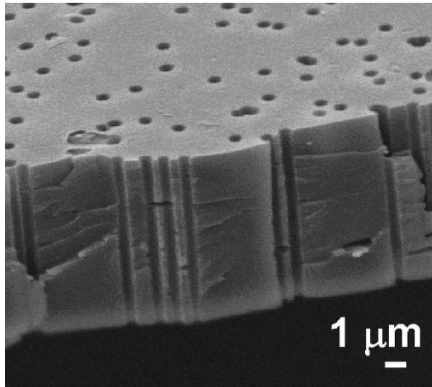
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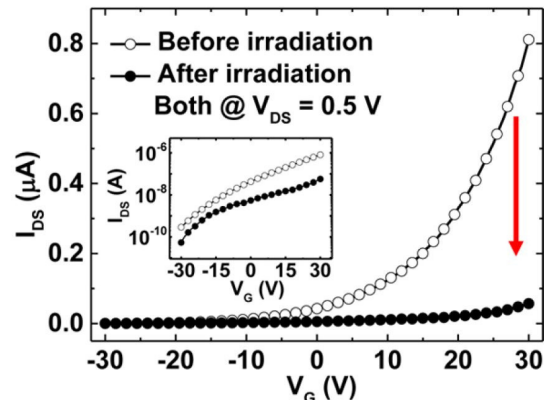
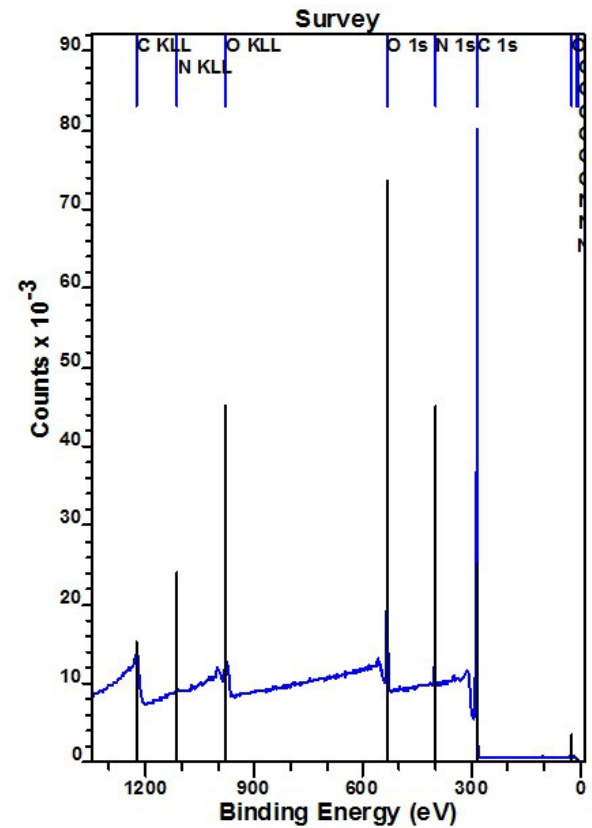
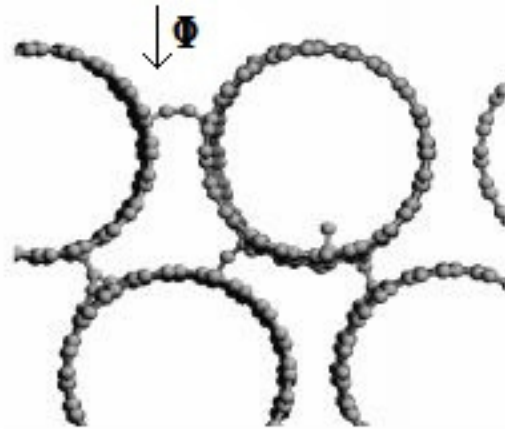
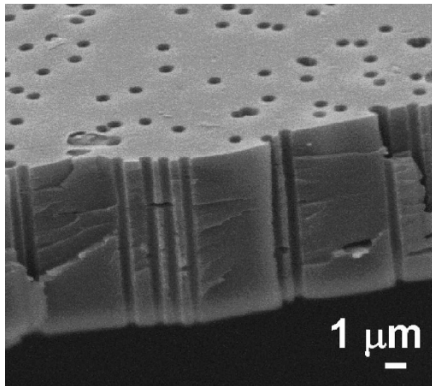
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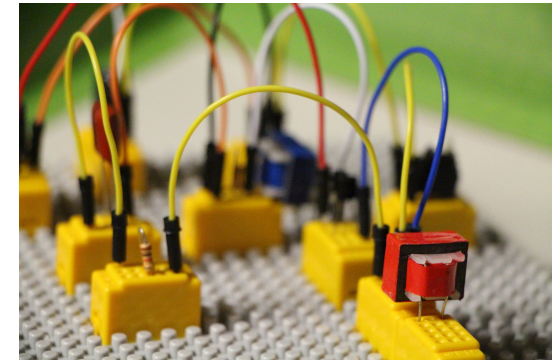
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# WHY IS THAT IMPORTANT?

- Electronics

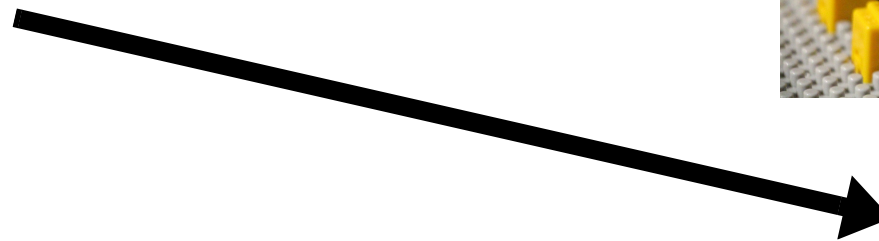
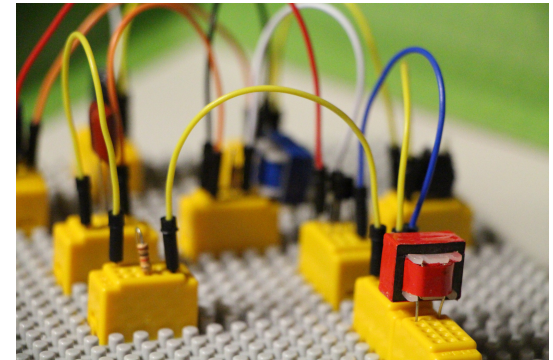






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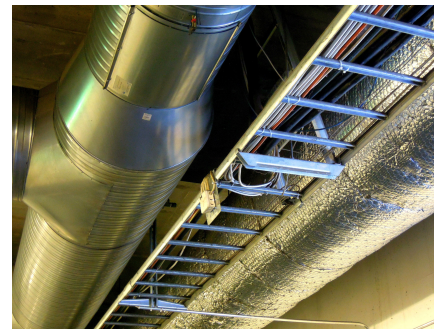
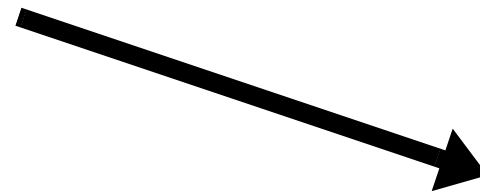
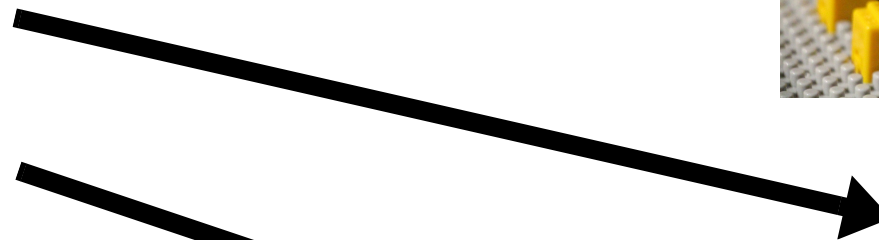
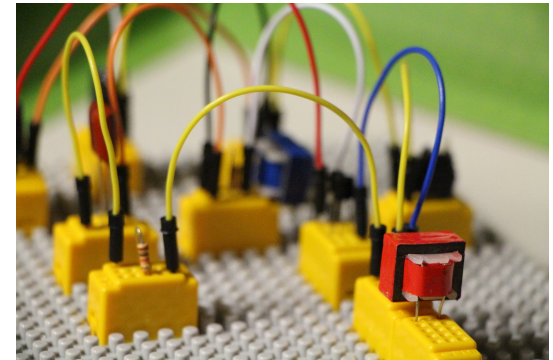
- Electronics
- Lubricants





# WHY IS THAT IMPORTANT?

- Electronics
- Lubricants
- Materials

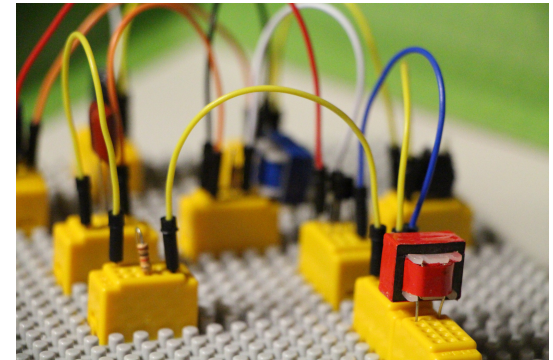




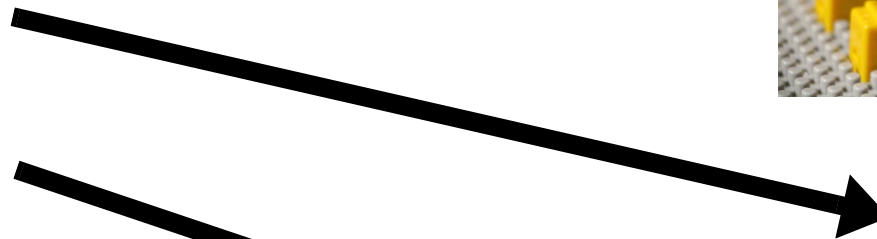


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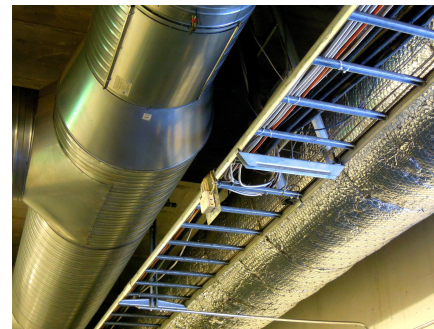
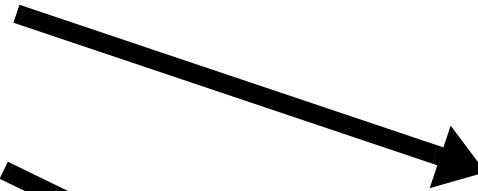
- Electronics



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- Materials



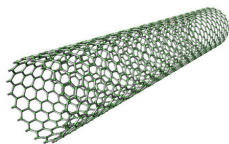
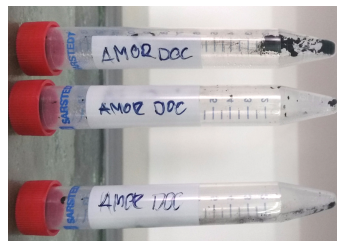
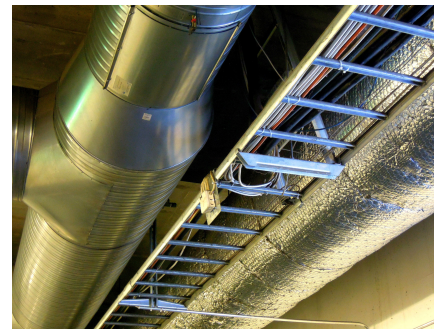
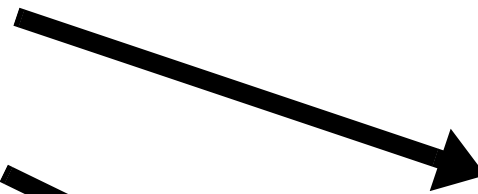
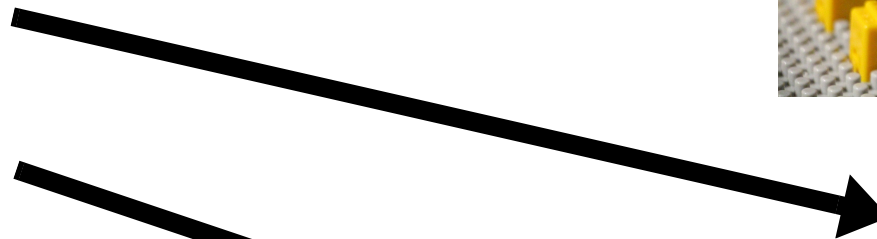
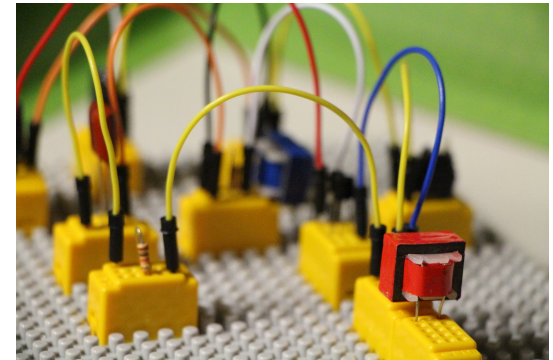
- Modification





# WHY IS THAT IMPORTANT?

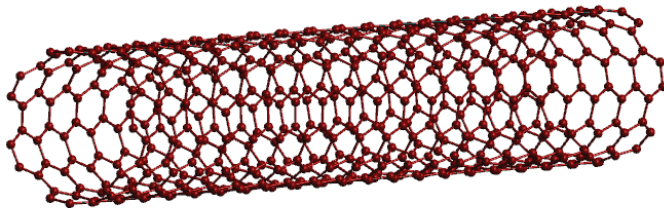
- Electronics
- Lubricants
- Materials
- Modification
- **New materials**





# SINGLE-WALLED CARBON NANOTUBES

- Rolled sheet of carbon with honeycomb structure (chirality)

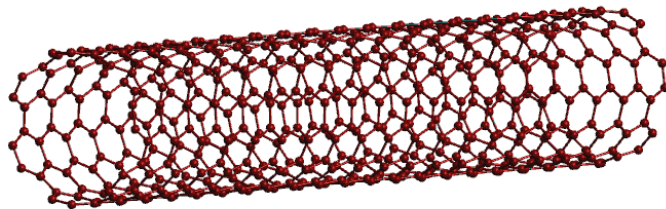




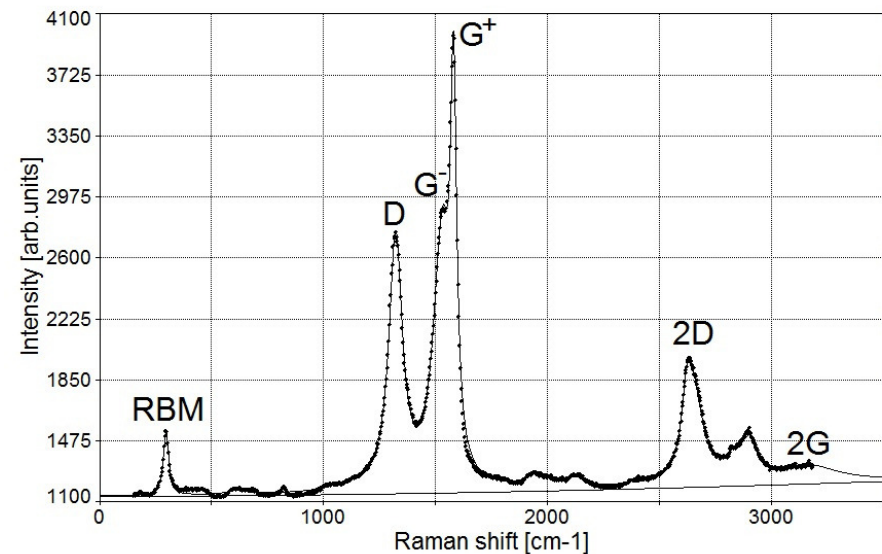


# SINGLE-WALLED CARBON NANOTUBES

- Rolled sheet of carbon with honeycomb structure (chirality)
- Diameter, length - RBM position



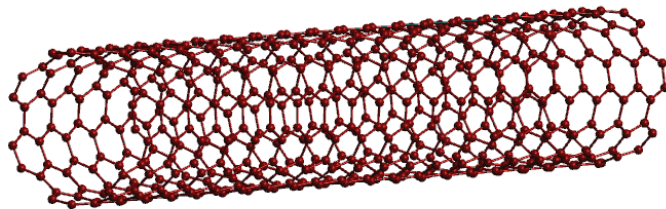
Example of SWNT Raman Spectrum



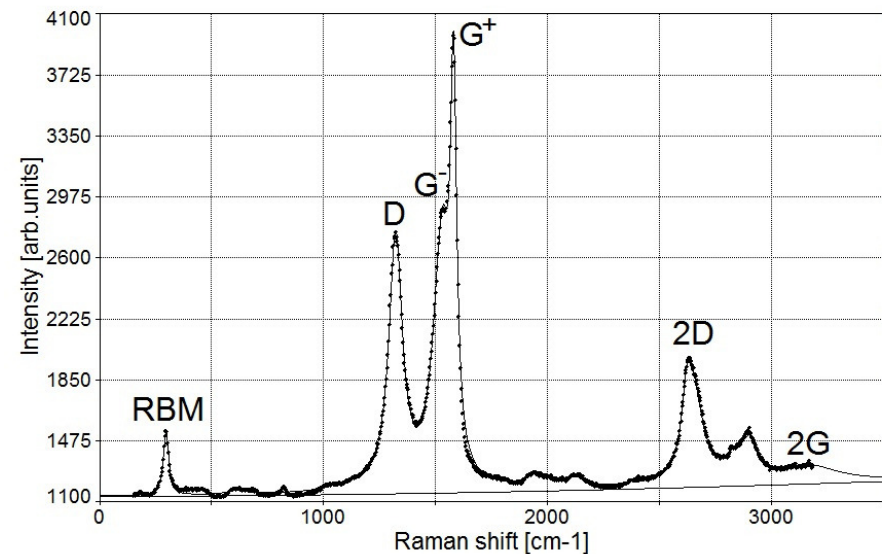


# SINGLE-WALLED CARBON NANOTUBES

- Rolled sheet of carbon with honeycomb structure (chirality)
- Diameter, length - RBM position
- Metallic or semiconductive (2/3) - shape of G bands



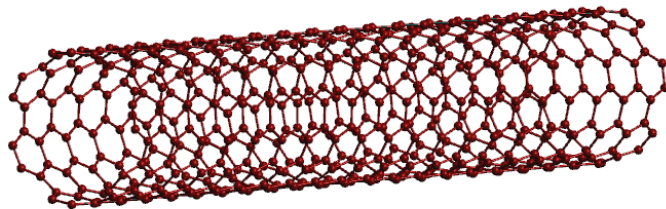
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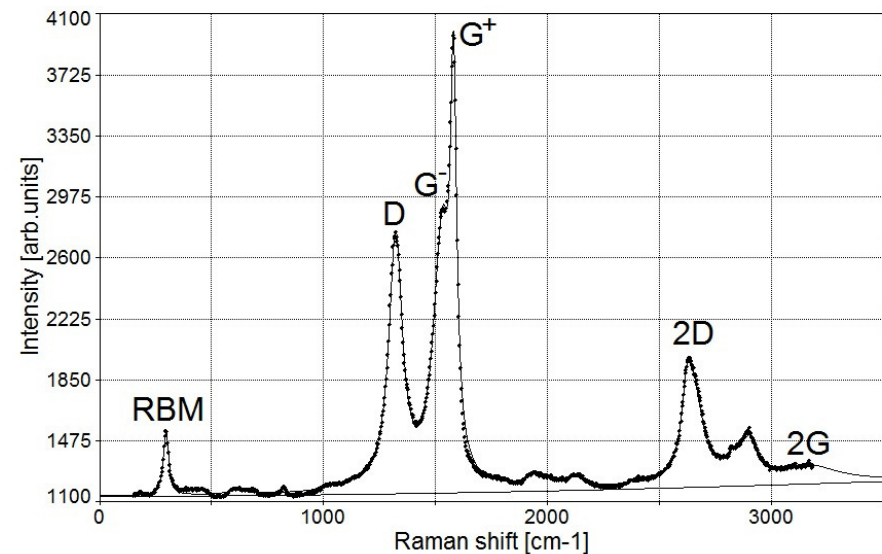


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- Electronics, photovoltaics, composite materials



Example of SWNT Raman Spectrum

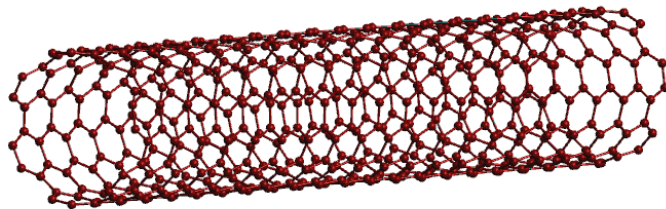




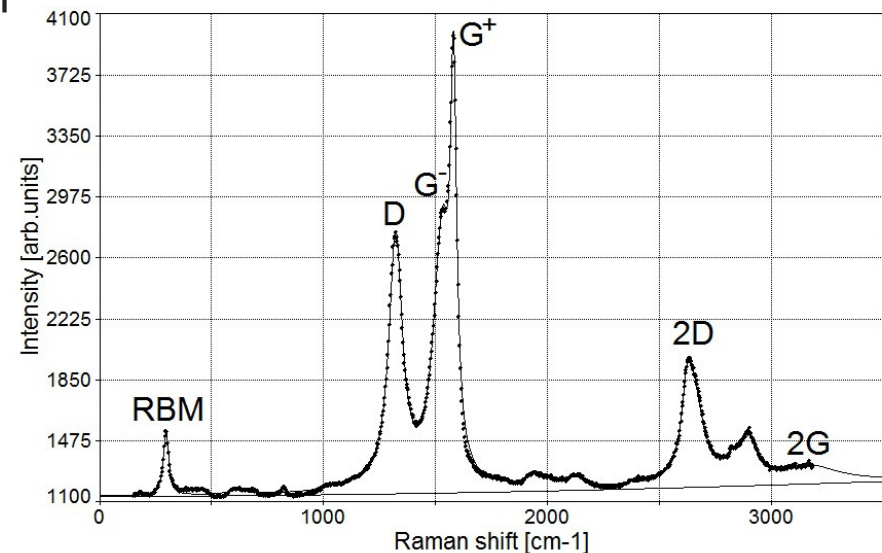


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- Rolled sheet of carbon with honeycomb structure (chirality)
- Diameter, length - RBM position
- Metallic or semiconductive (2/3) - shape of G bands
- Electronics, photovoltaics, composite materials
- Disorder parameter D and G+ peaks intensities ratio



Example of SWNT Raman Spectrum





# IRRADIATION STUDIES

- 7 specimens of commercially available SWCNTs



# IRRADIATION STUDIES

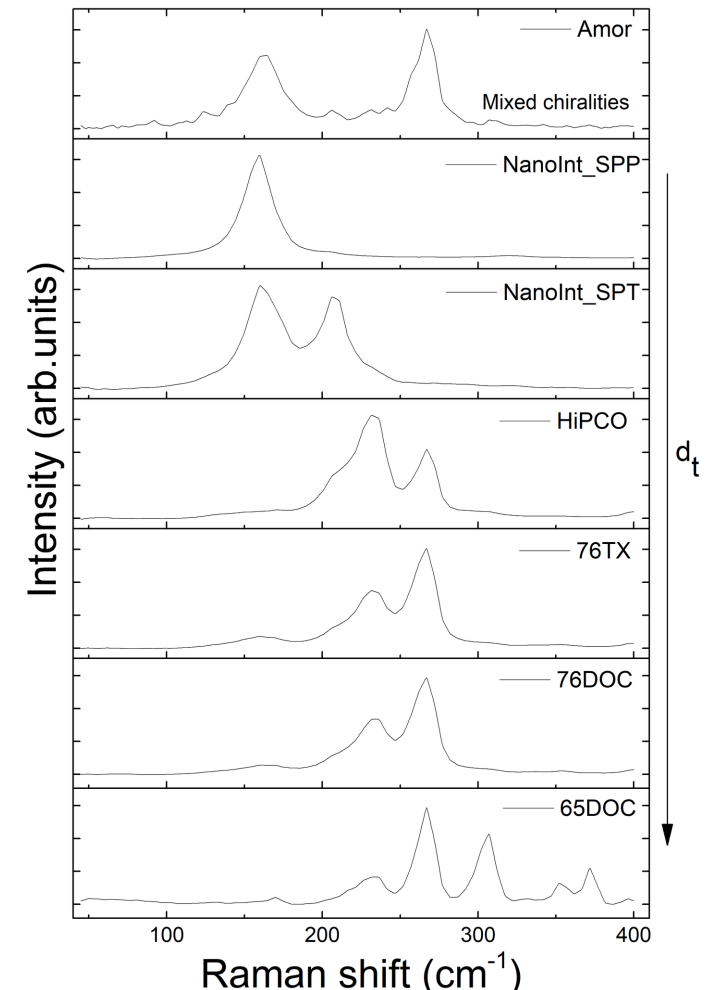
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- 167MeV Xe ions - 3 fluences





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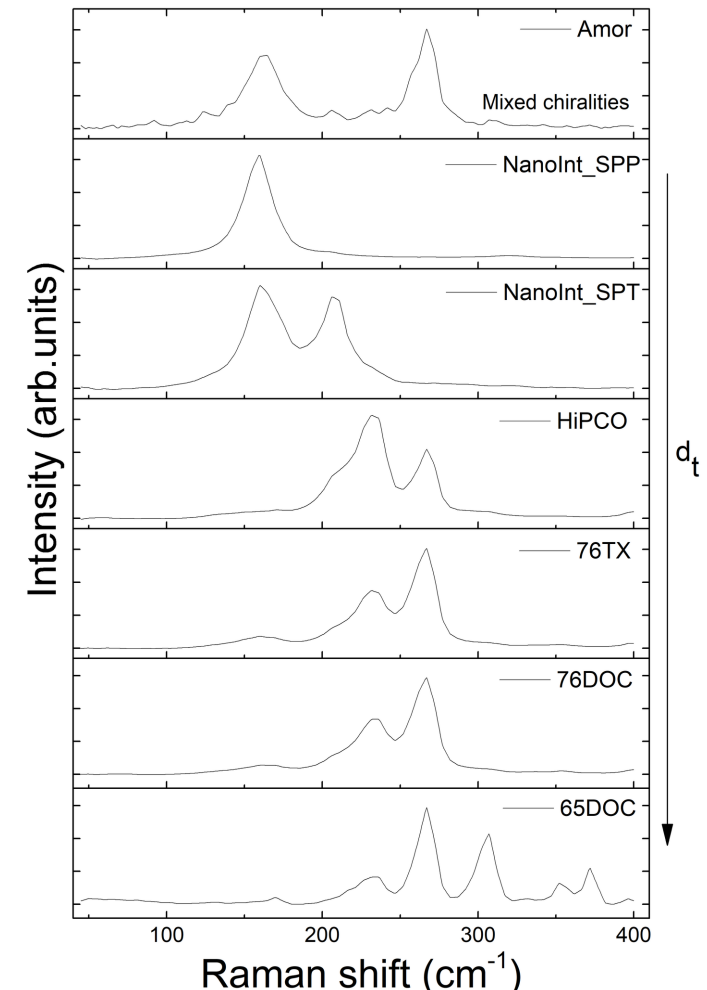
- 7 specimens of commercially available SWCNTs
- 167MeV Xe ions - 3 fluences
- Diameter based on RBM position (785nm) and provider specification





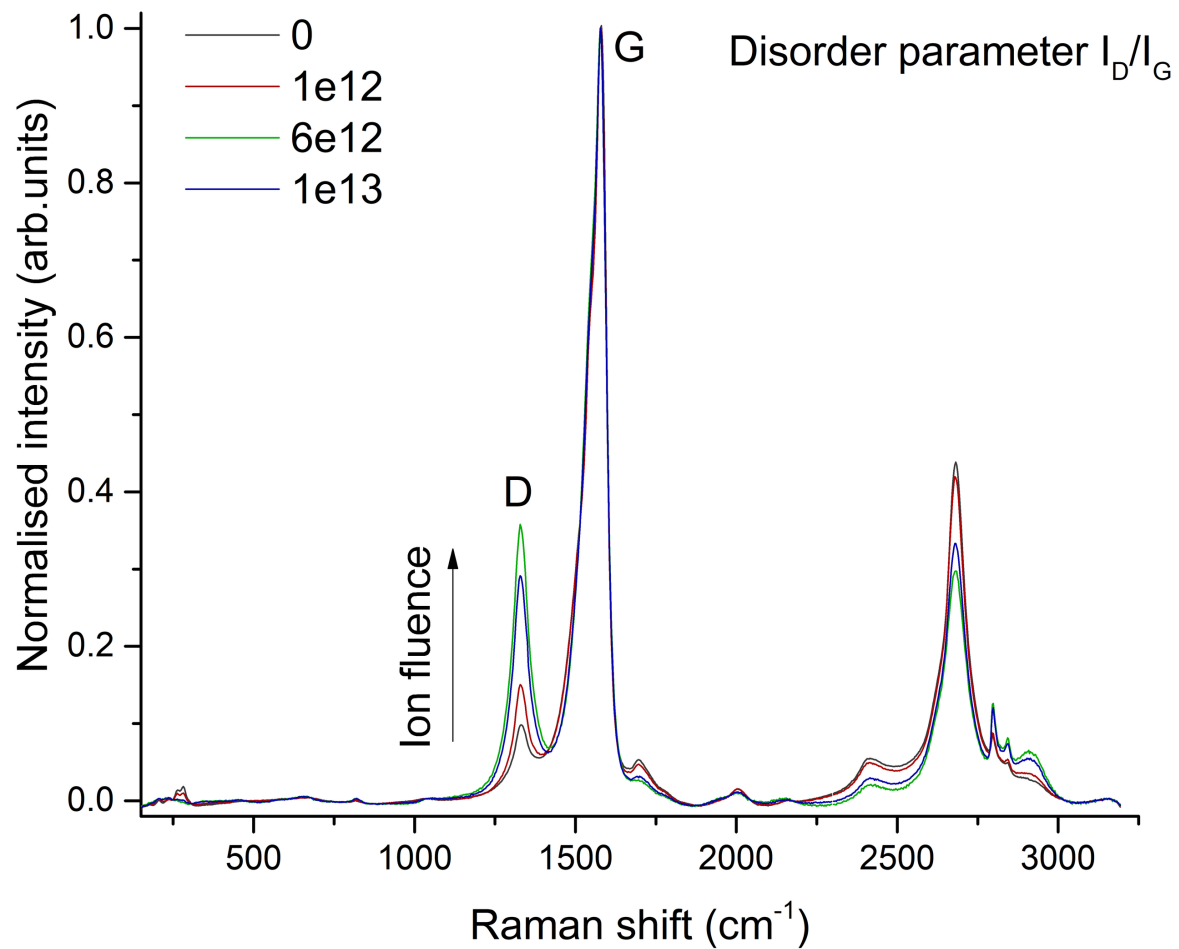
# IRRADIATION STUDIES

- Commercially available SWCNTs
- 167MeV Xe ions - 3 fluences
- Diameter based on RBM position (785nm) and provider specification
- Disorder parameter and its change (473nm)





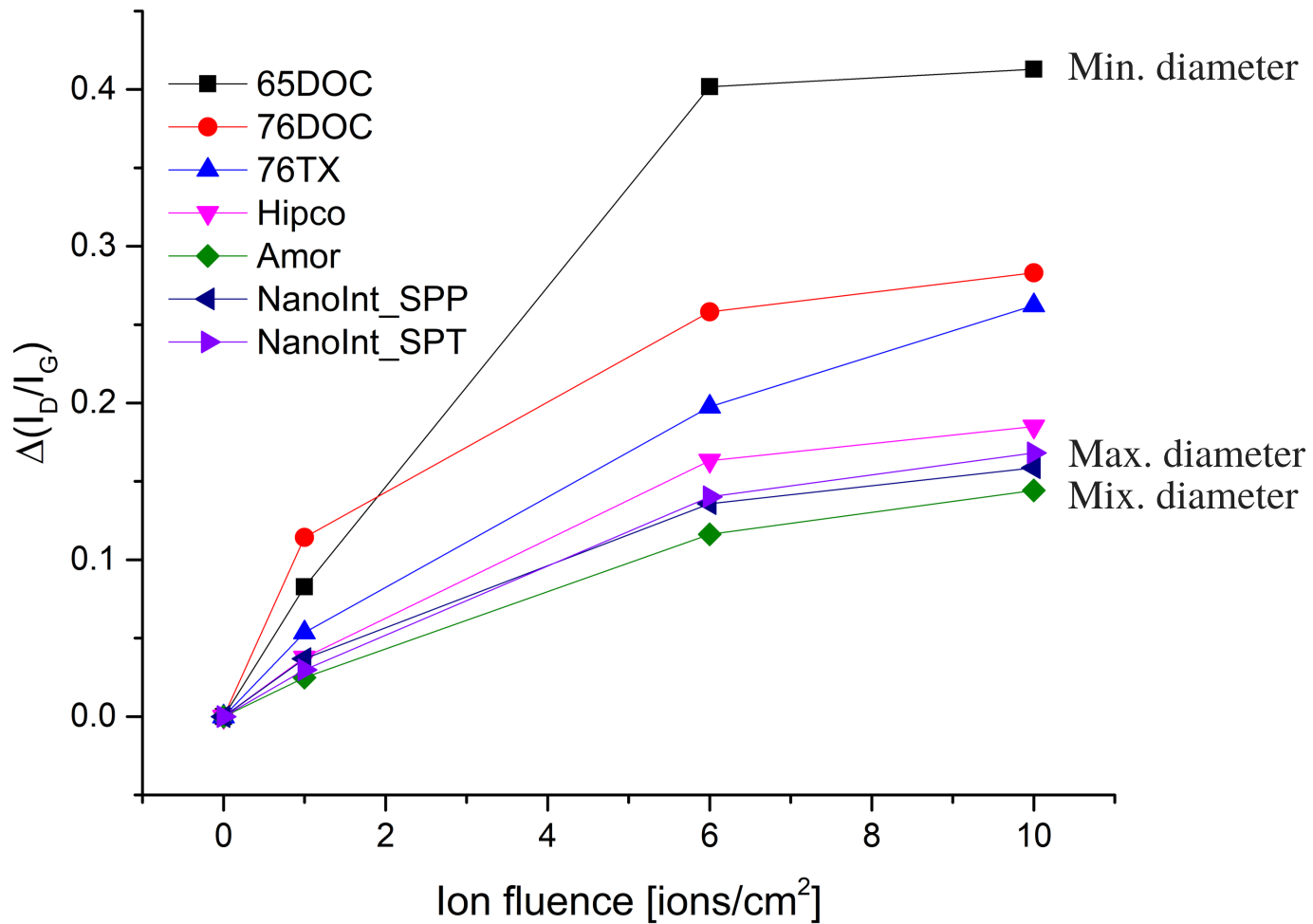
# DISORDER PARAMETER CHANGE







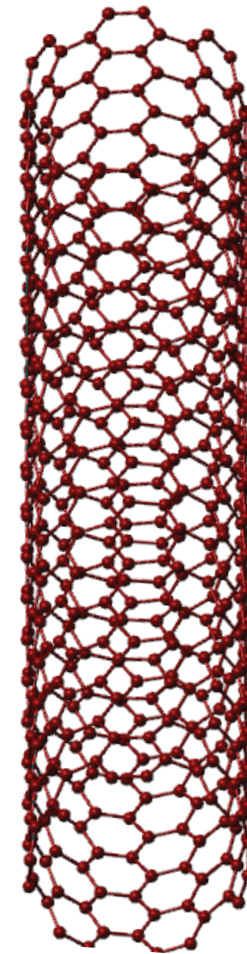
# DISORDER PARAMETER CHANGE





## CONCLUSIONS

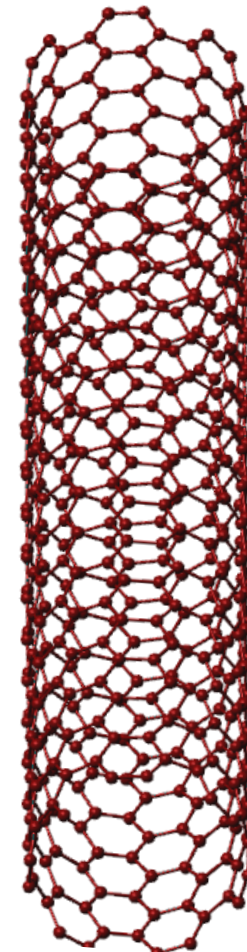
- Bigger diameter - better high-energy ion resistance





## CONCLUSIONS

- Bigger diameter - better high-energy ion resistance
- Other properties measurements (conductance, strength etc.)

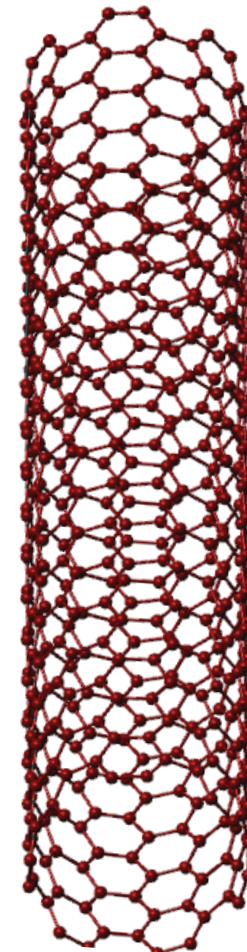






## CONCLUSIONS

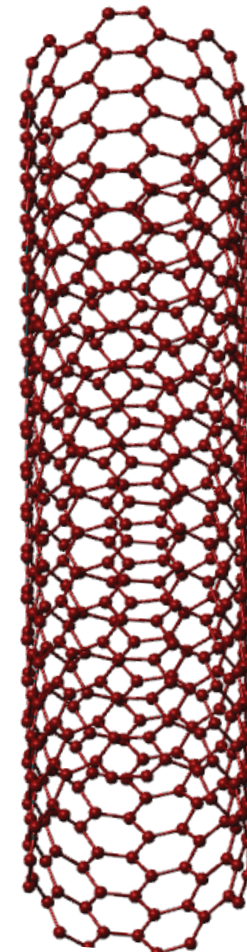
- Bigger diameter - better high-energy ion resistance
- Other properties measurements (conductance, strength etc.)
- Variety of materials can possibly be studied





## CONCLUSIONS

- Bigger diameter - better high-energy ion resistance
- Other properties measurements (conductance, strength etc.)
- Variety of materials can possibly be studied
- Crucial research for materials used in radiation conditions (experimental setups, space)





## ACKNOWLEDGEMENTS

Andrzej Olejniczak (UMK, FLNR JINR)

IC-100 cyclotron team

Kacper Druźbicki, PhD (UAM, FLNP JINR)



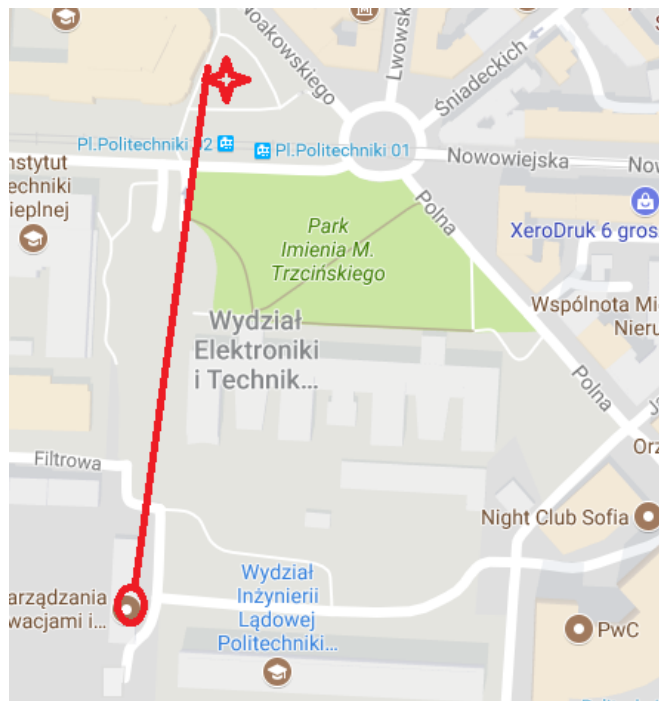


THANK YOU FOR  
ATTENTION





## Excursion on the 8-th of November (Wednesday) to National Centre for Nuclear Research – Świerk (Location of the only Polish Nuclear Reactor)



1. **Gather at 9:45** – in front of our building
2. Move to „Politechniki” square
3. **BUS** will be waiting on the square from **9:50**
4. Excursion **STARTS at 10:00**
5. We will spend at „Świerk” about 3 hours
6. **Come back** to conference building **at 15:00**

**TAKE THE PASSPORT OR ID WITH YOURSELF !!!**