Nuclear Physics for Materials Science & Cultural Heritage

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Correlations in Partonic and Hadronic Interactions

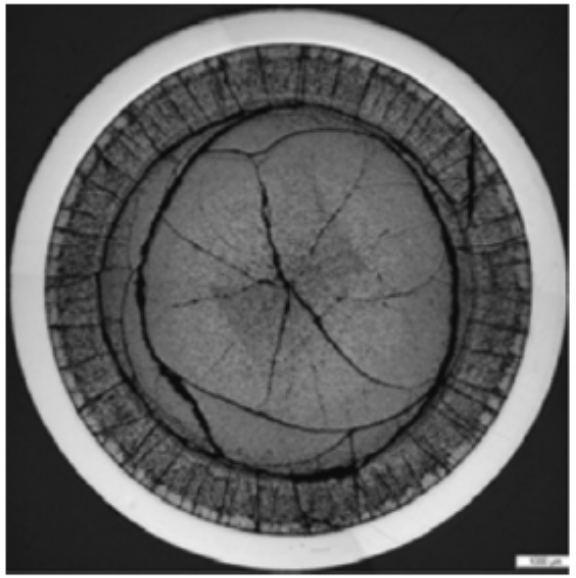
24 - 28 September 2018, Yerevan, Armenia

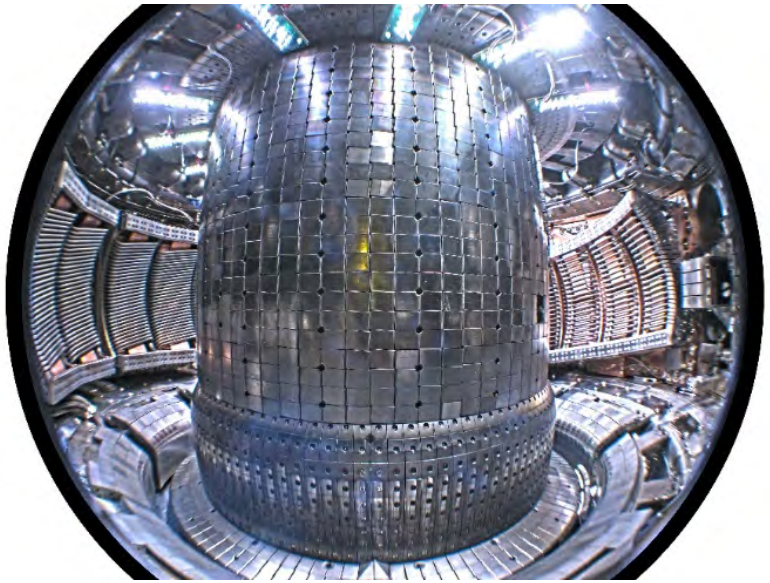
Outline

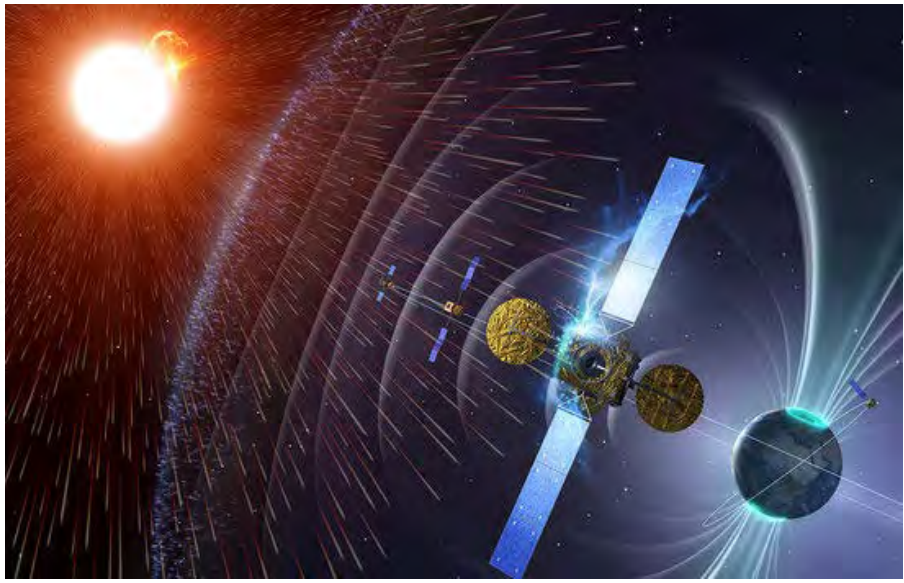
- ***Radiation damage of materials***
- ***Positive aspect of radiation on materials***
- ***Targets for nuclear physics***
- ***Ion beam analysis for cultural heritage objects***

Radiation Damage of Materials

- Expansion
- Radiation-induced segregation
- Thermal conductivity
- Embrittlement
- Cracking, etc.

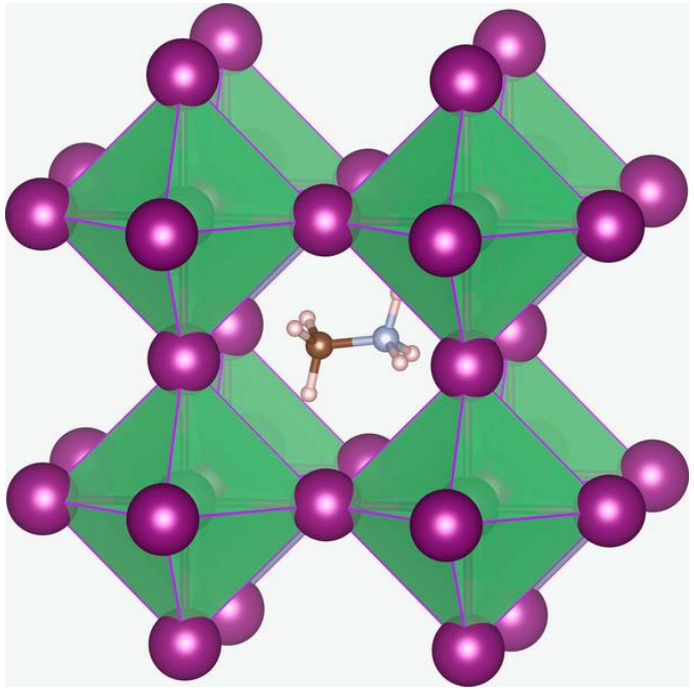






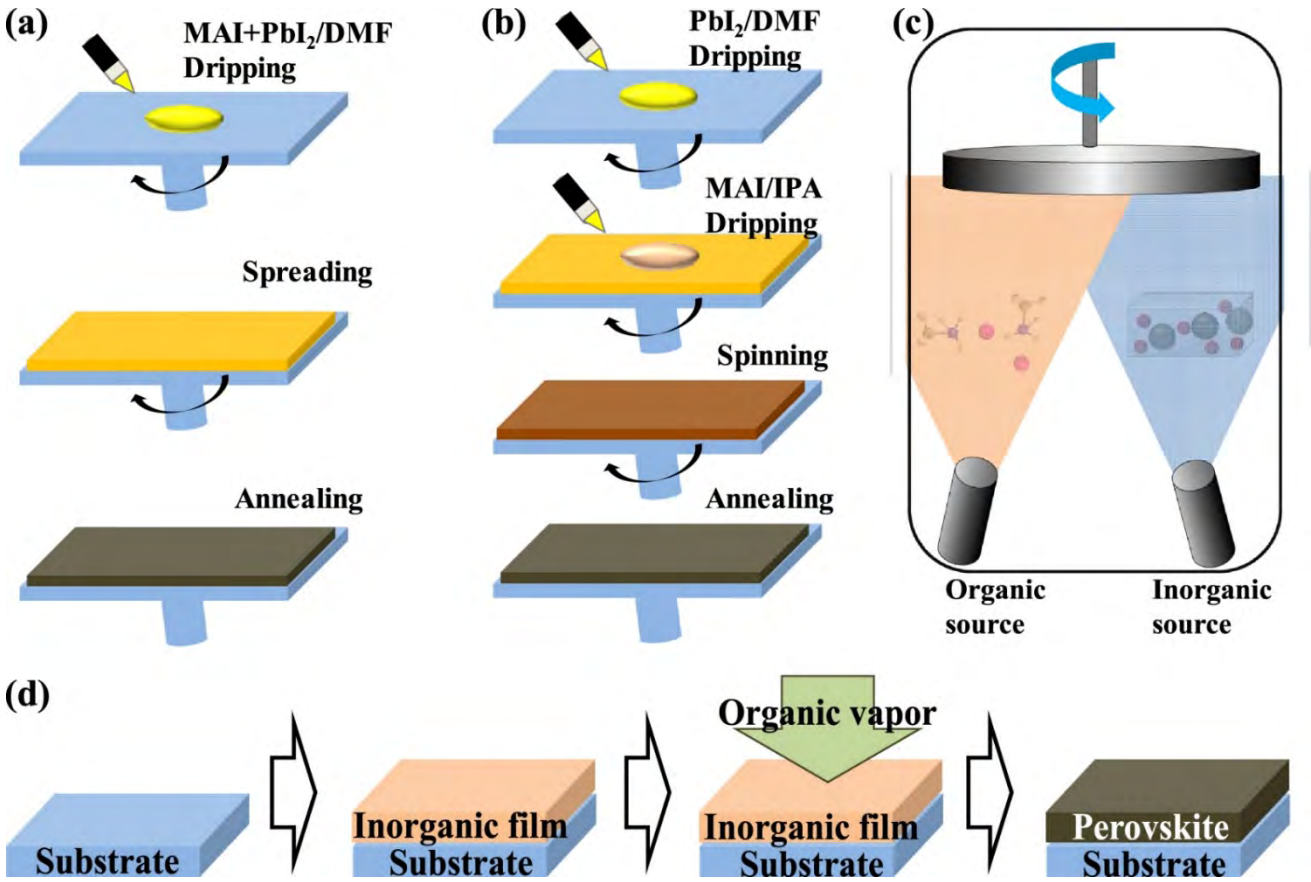
Radiation Damage in nuclear fuel and rector materials

Hybrid organic-inorganic perovskite solar cells

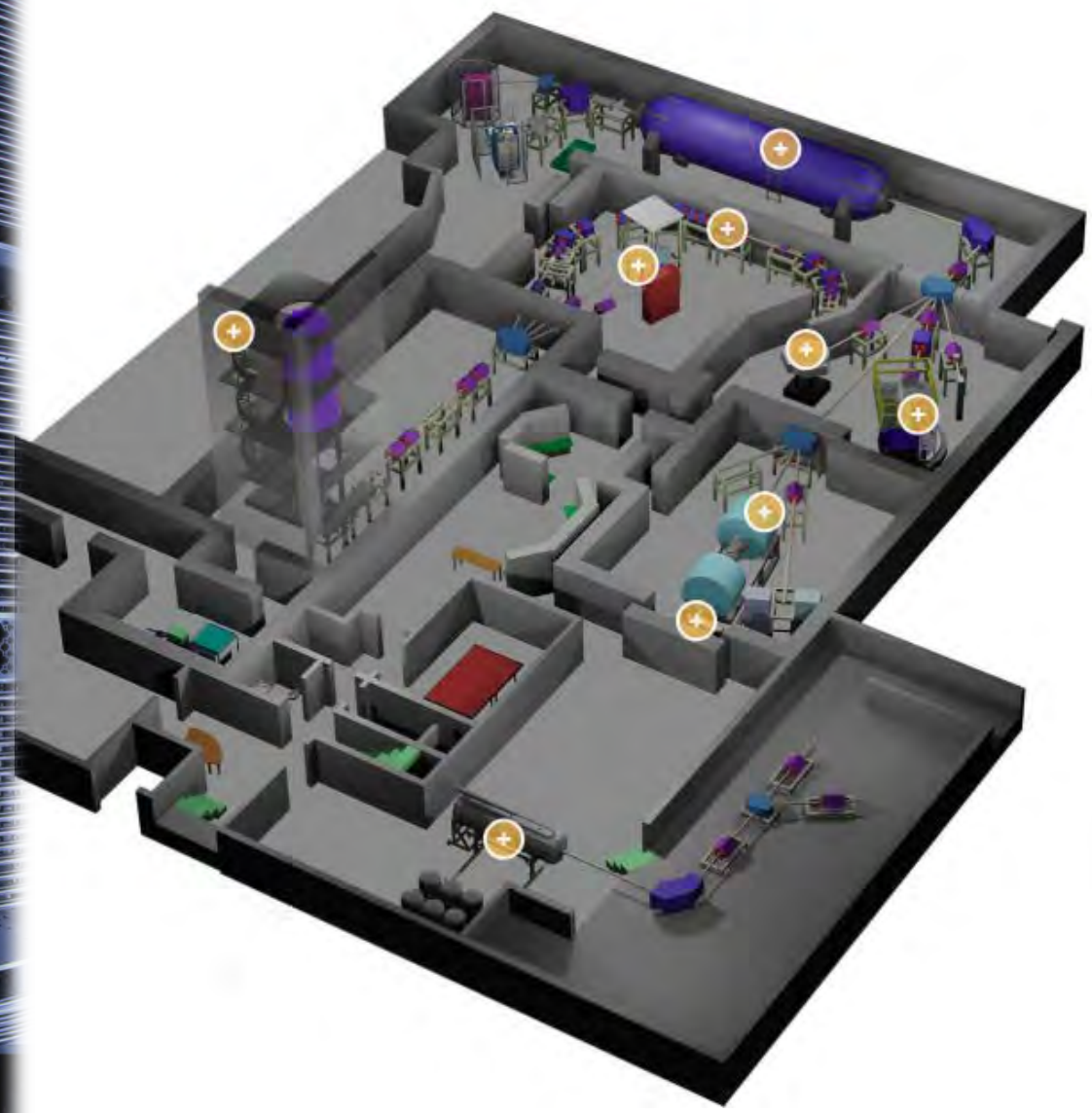


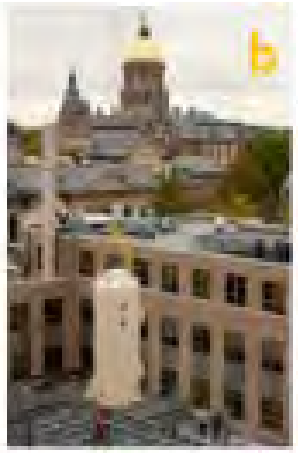
$CH_3NH_3PbX_3$ perovskites (X=I, Br and/or Cl).
The methylammonium cation ($CH_3NH_3^+$) is surrounded by PbX_6 octahedra

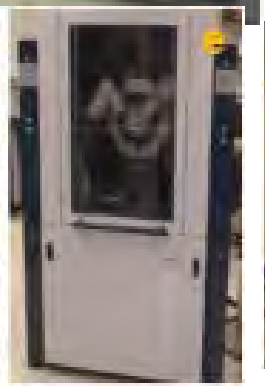
- Tunable optical bandgap (1.5 - 2.3 eV)
- High solar efficiencies (23 - 27%)
- Easy and affordable processing



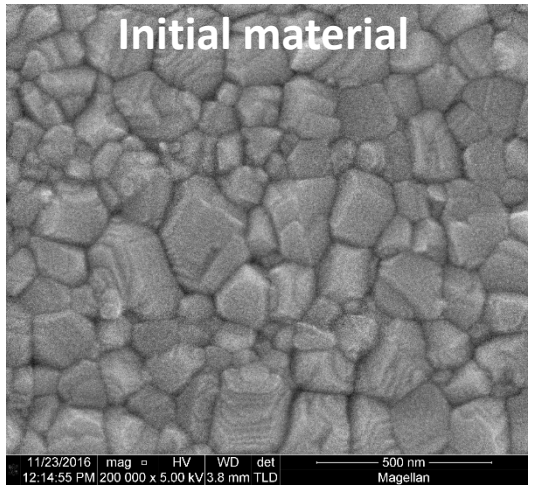
Nuclear Science Lab at Notre Dame

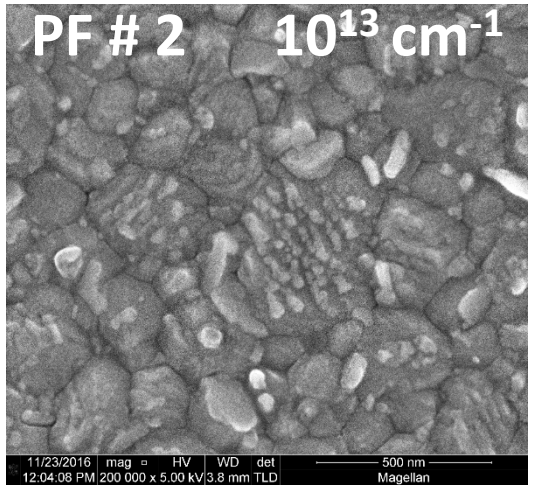


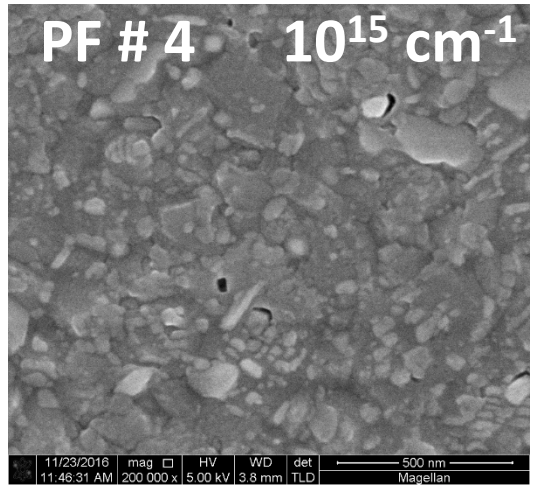


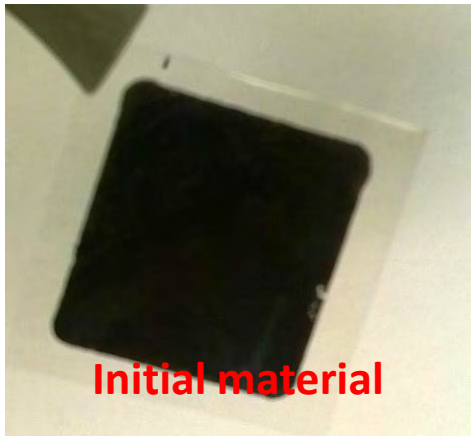


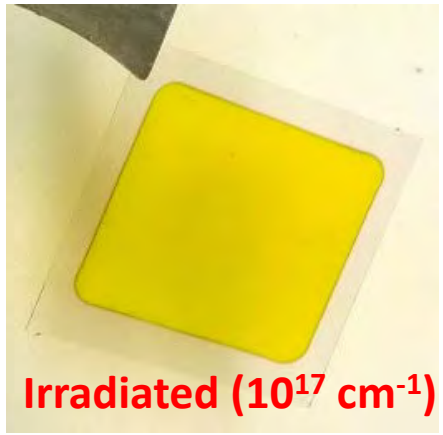
Irradiation perovskite with 1MeV proton beam

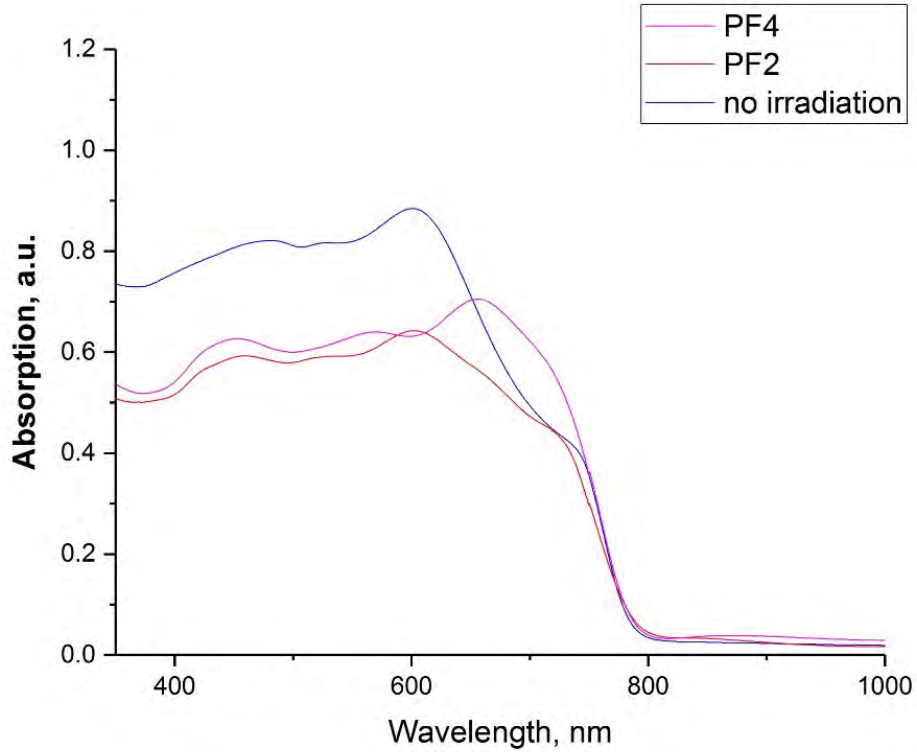








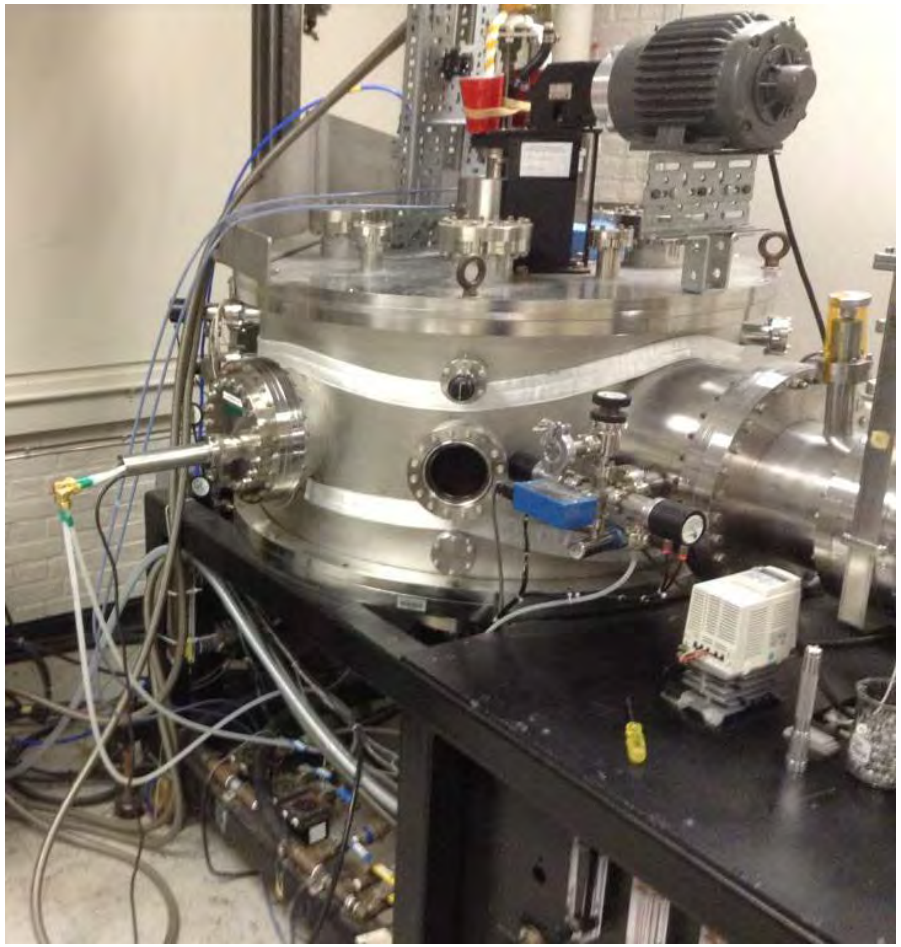


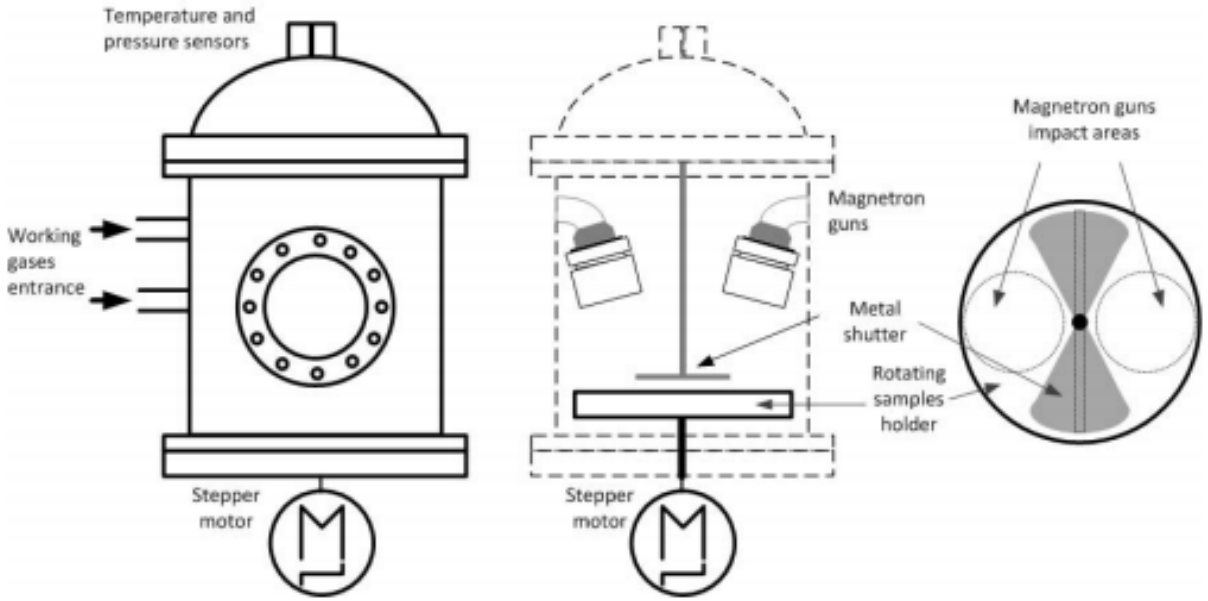


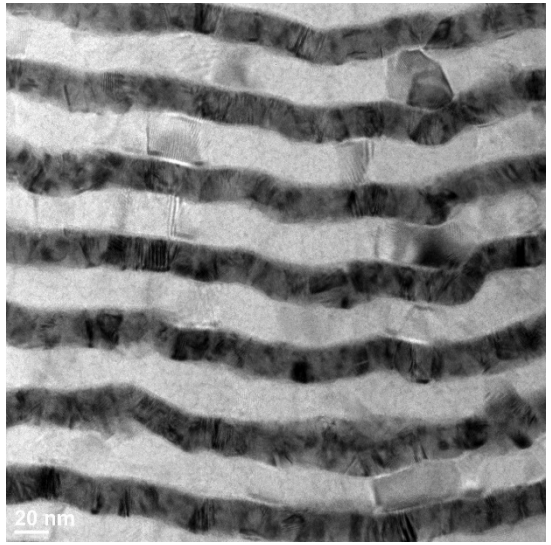
Positive aspect of radiation on materials

Irradiation effects on chemical reactivity

Magnetron sputtering of Ni-Al multilayer foils





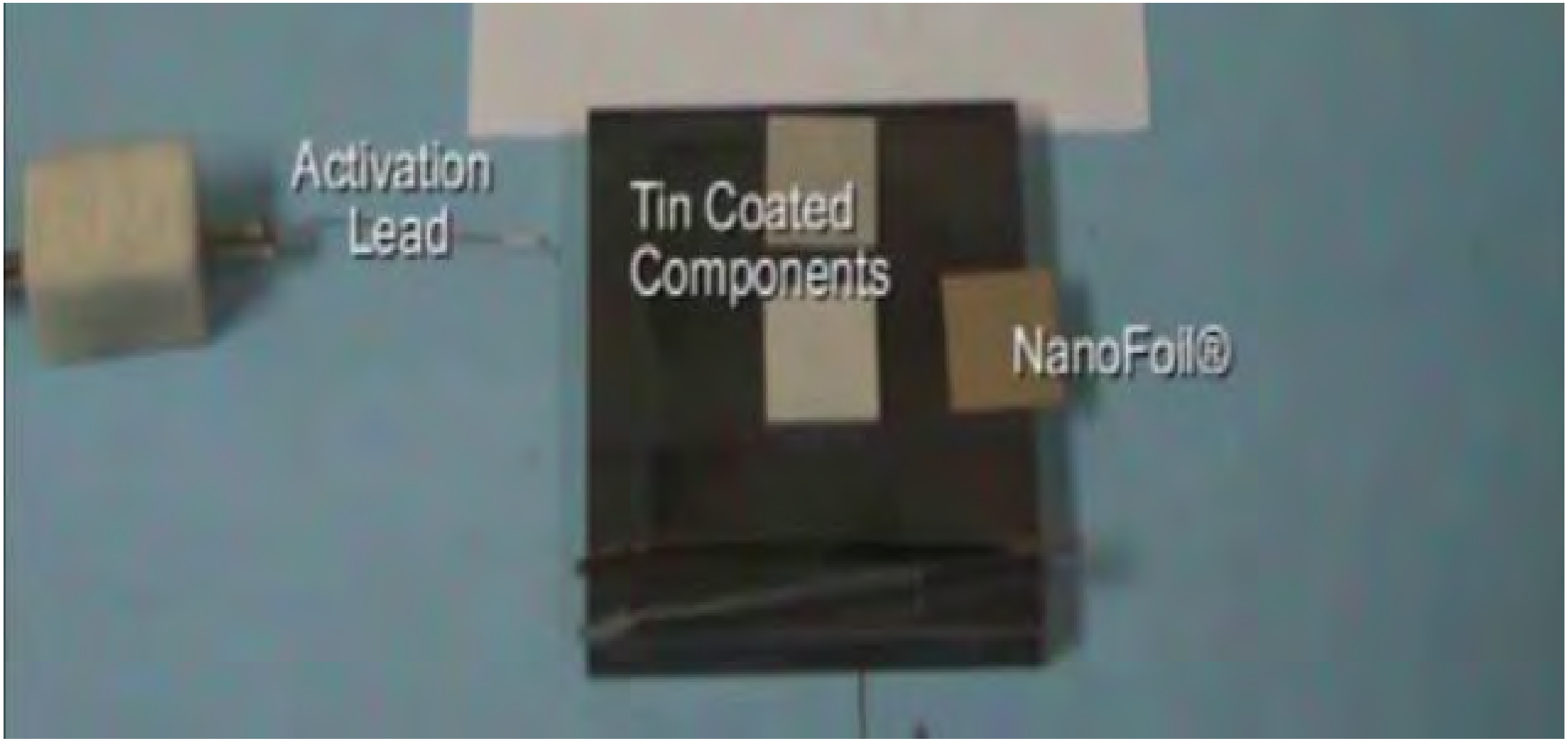


Reactive multi-layer nano-foils

Ni + Al = NiAl (intermetallic material)

Temperature increases to 1600^{o}C within few milliseconds

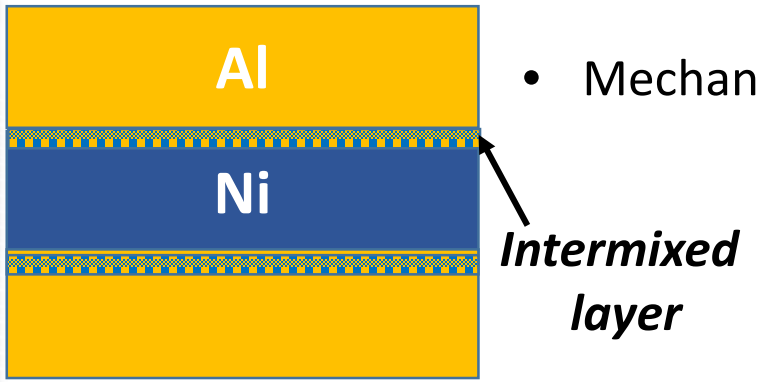
Bonding of materials



Application of accelerated ion beam for tailoring the properties

Focus of previous works

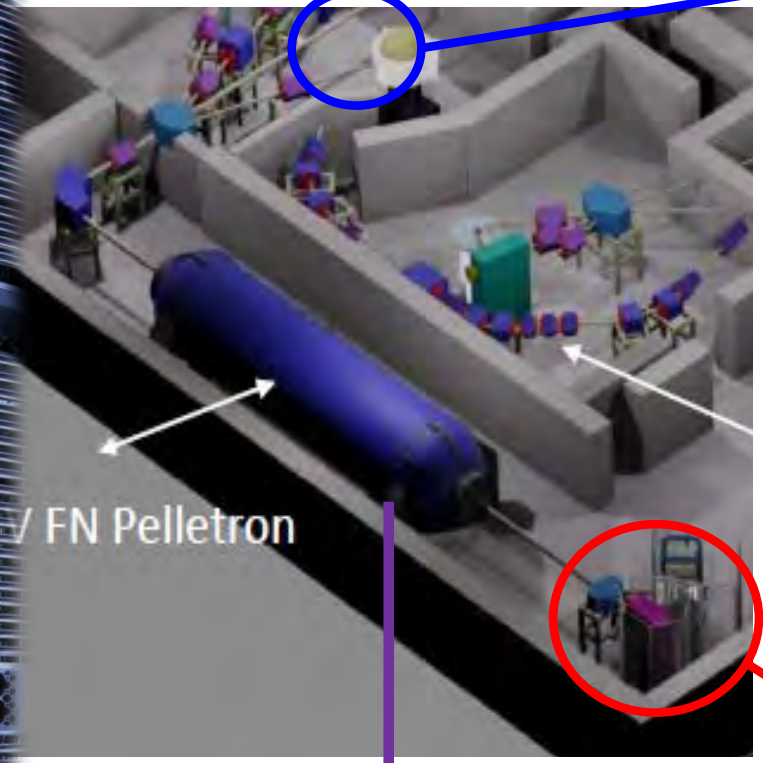
- Influence of bilayer thickness on reaction heat and velocity
- Effects of thermal properties on the reaction front
- Mechanism of phase transformation.



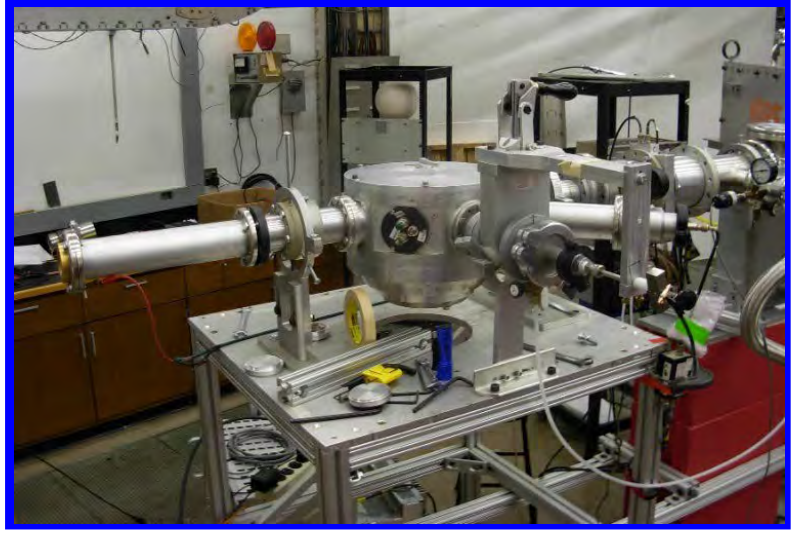
Key open issues

- **The influence of intermixing and atomic defects on ignition and combustion characteristics**
- **The nucleation processes at early stages of reaction.**

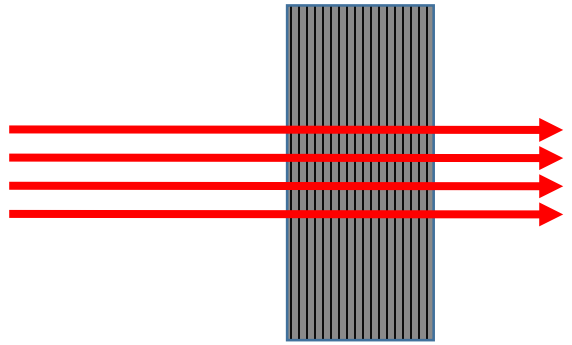
Accelerated ion beams are used tailor the atomic structure of Ni/Al reactive nano-foils and study the *atomic structure - nucleation - reactivity* relationship.



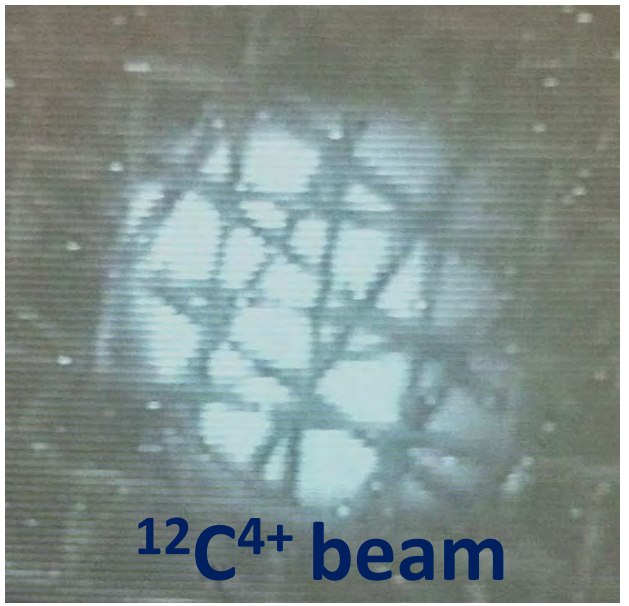
General Purpose Chamber



Ni/Al foil



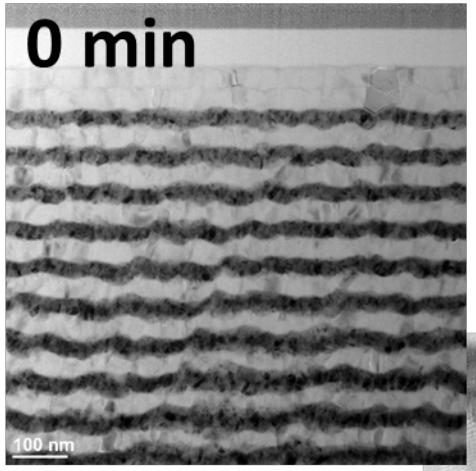
SNICS Ion Source

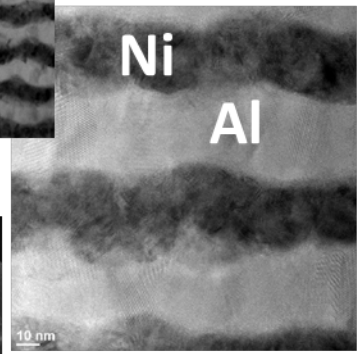


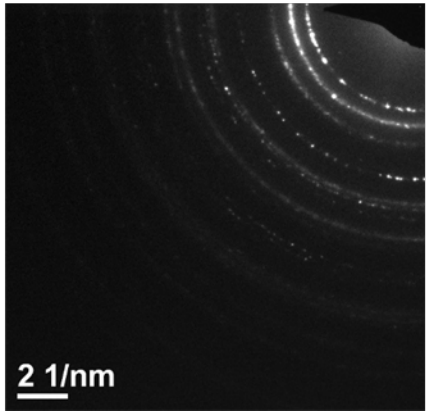
Transmission Electron Microscope (TEM) sample preparation and imaging

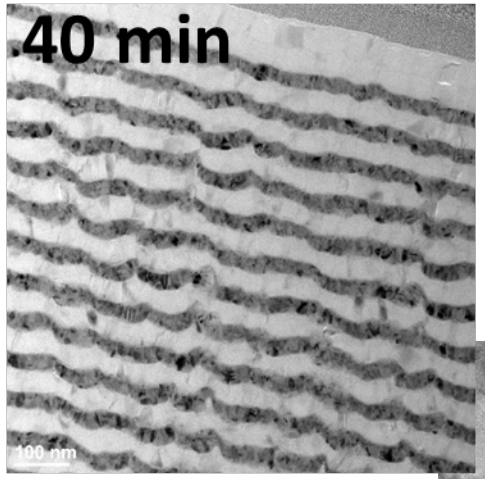
Focused Ion Beam Milling / Scanning Electron Microscopy FIB/SEM

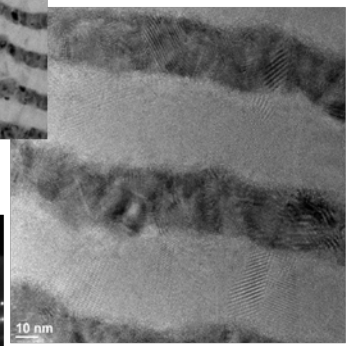
TEM analysis of foils bombarded with $^{12}C^{4+}$ beam

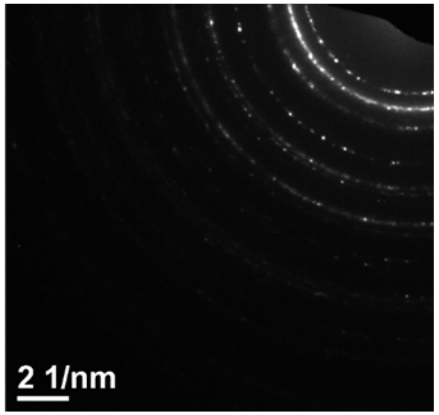


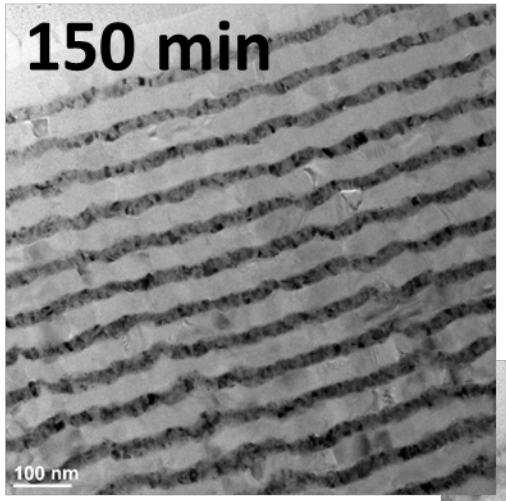


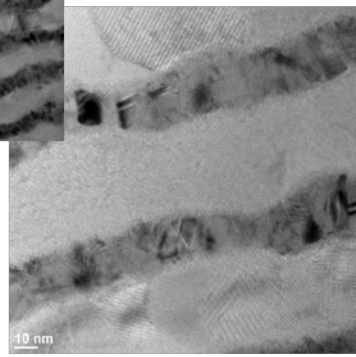


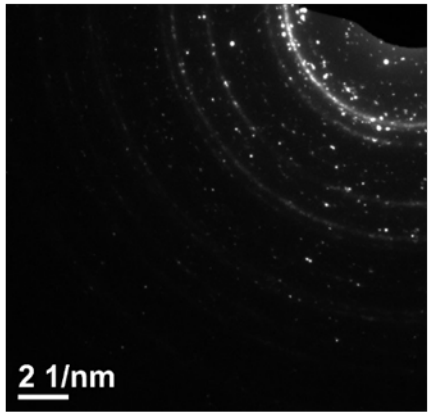








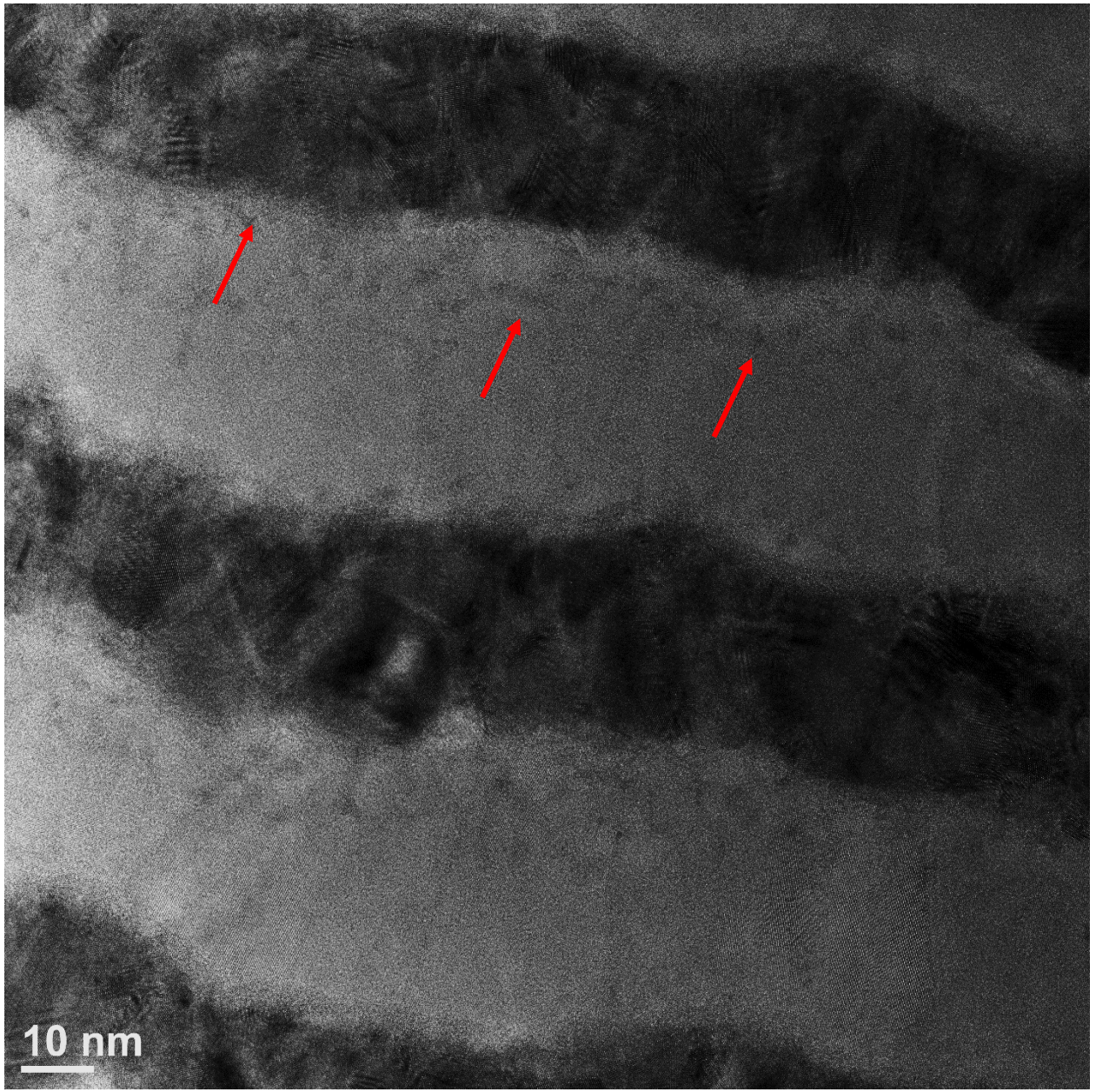




SAD patterns of 0 and 40 bombardment times have similar rings.
A foil bombarded for 150 min contains Al_3Ni and Ni_3Al along with Ni and Al

Beam powder ~0.4W

HRTEM analysis of foils bombarded with $^{12}C^{4+}$ beam (40 min)



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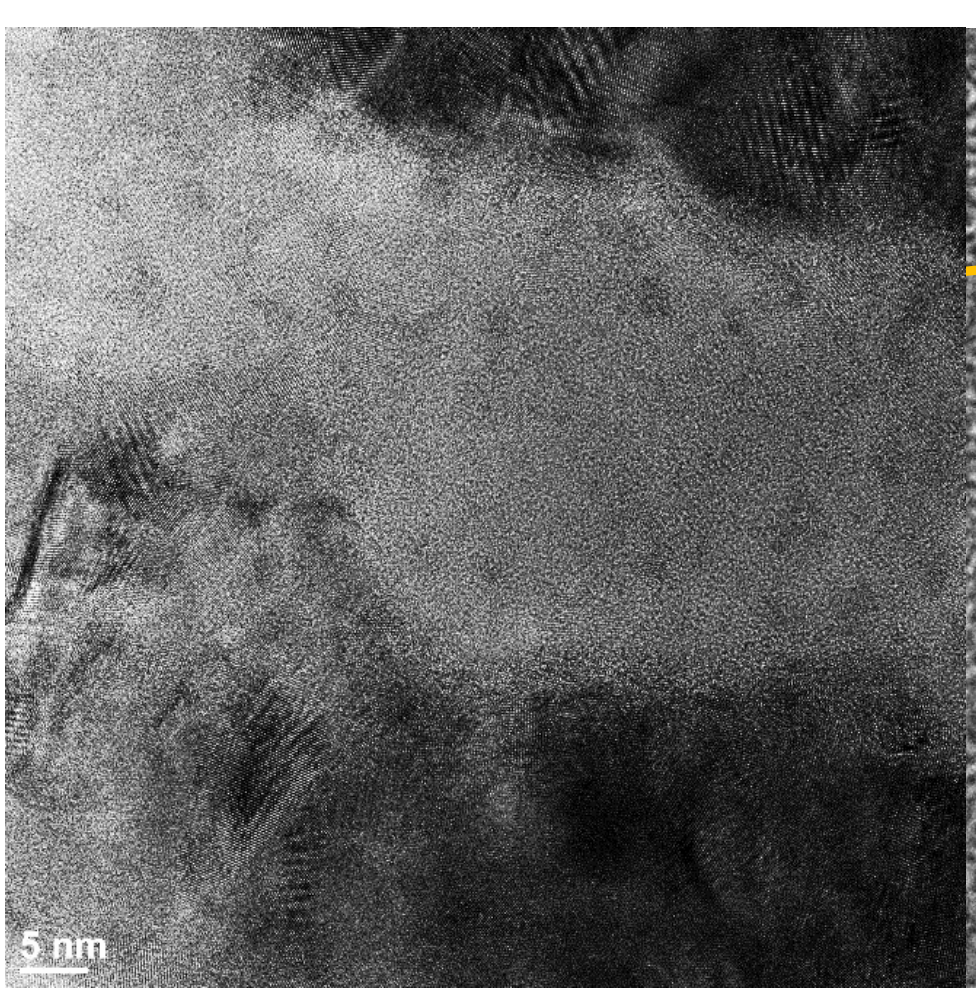
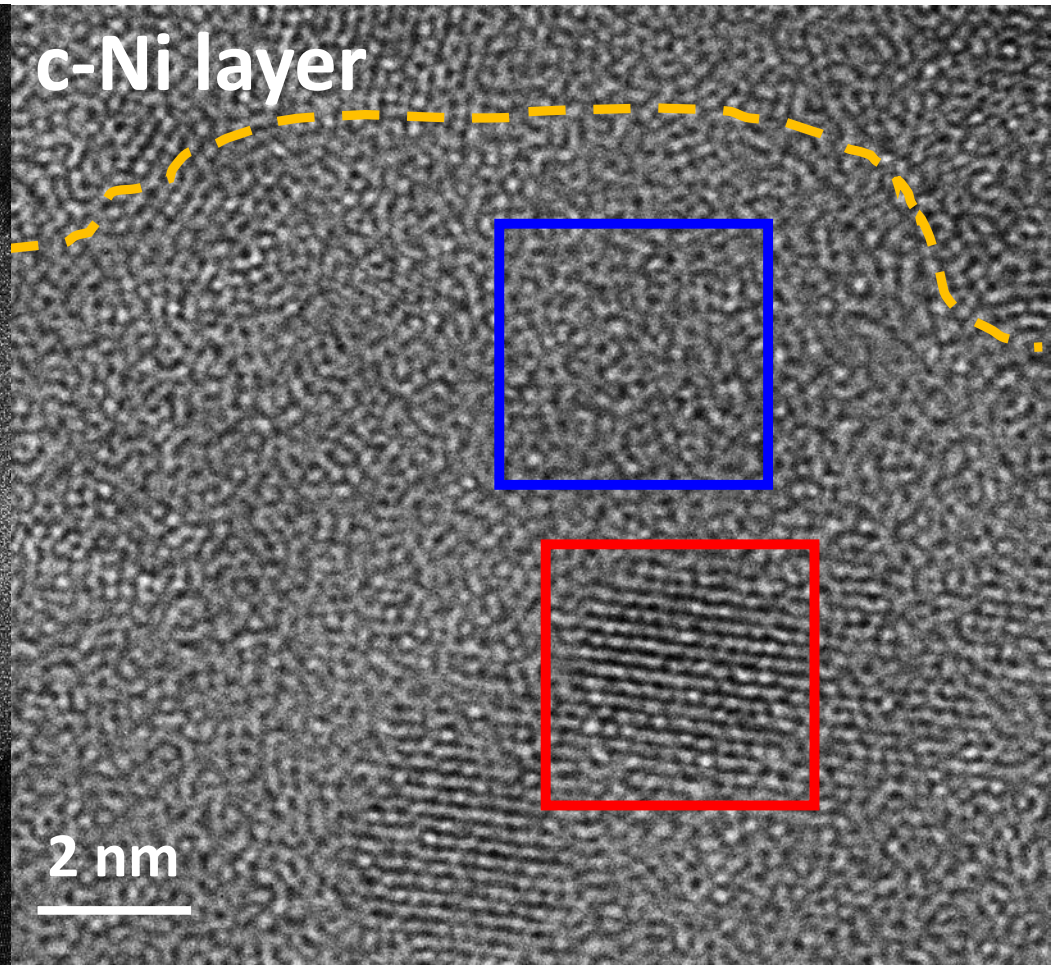
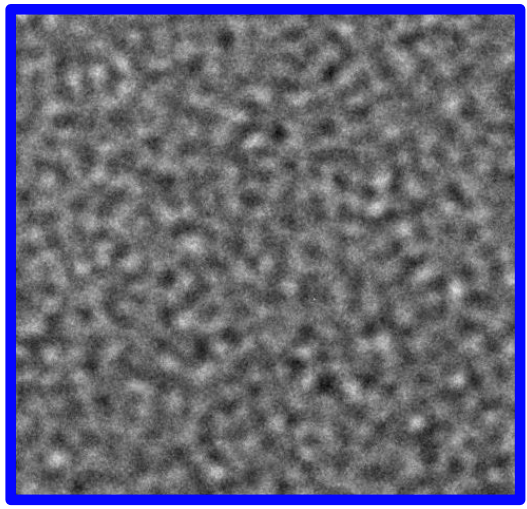
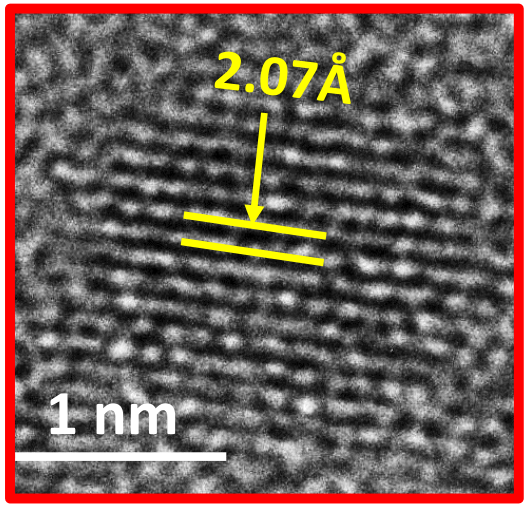


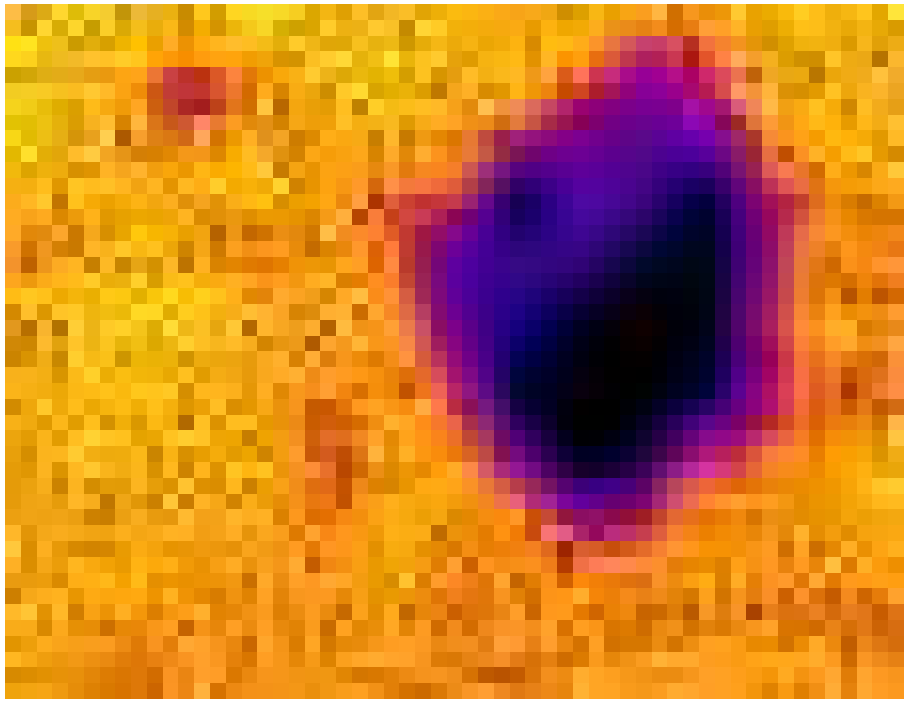


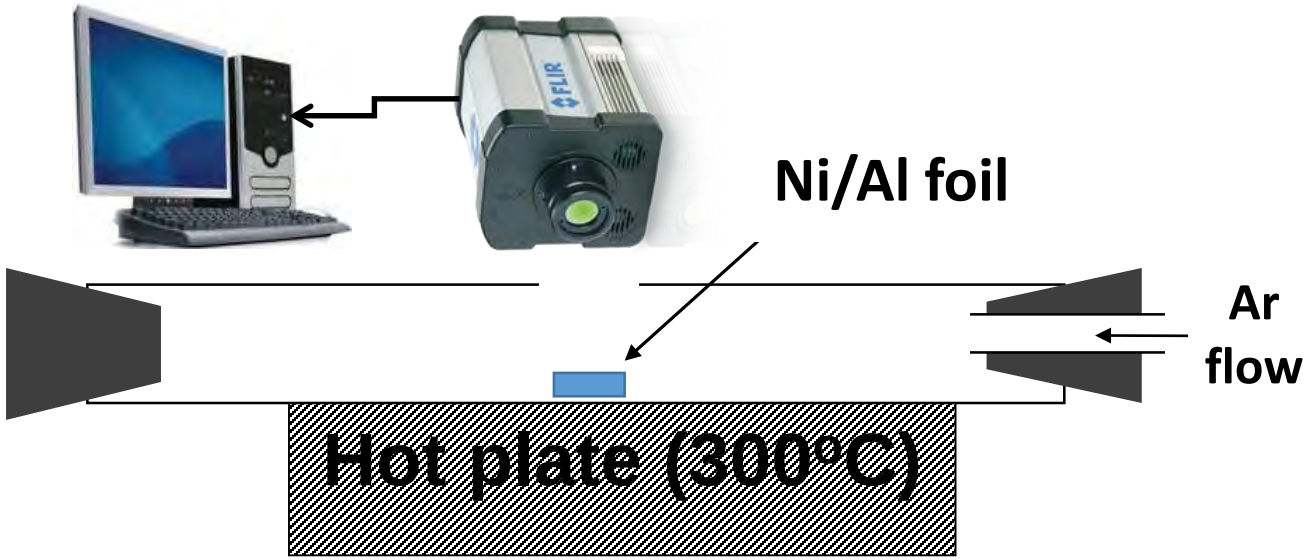




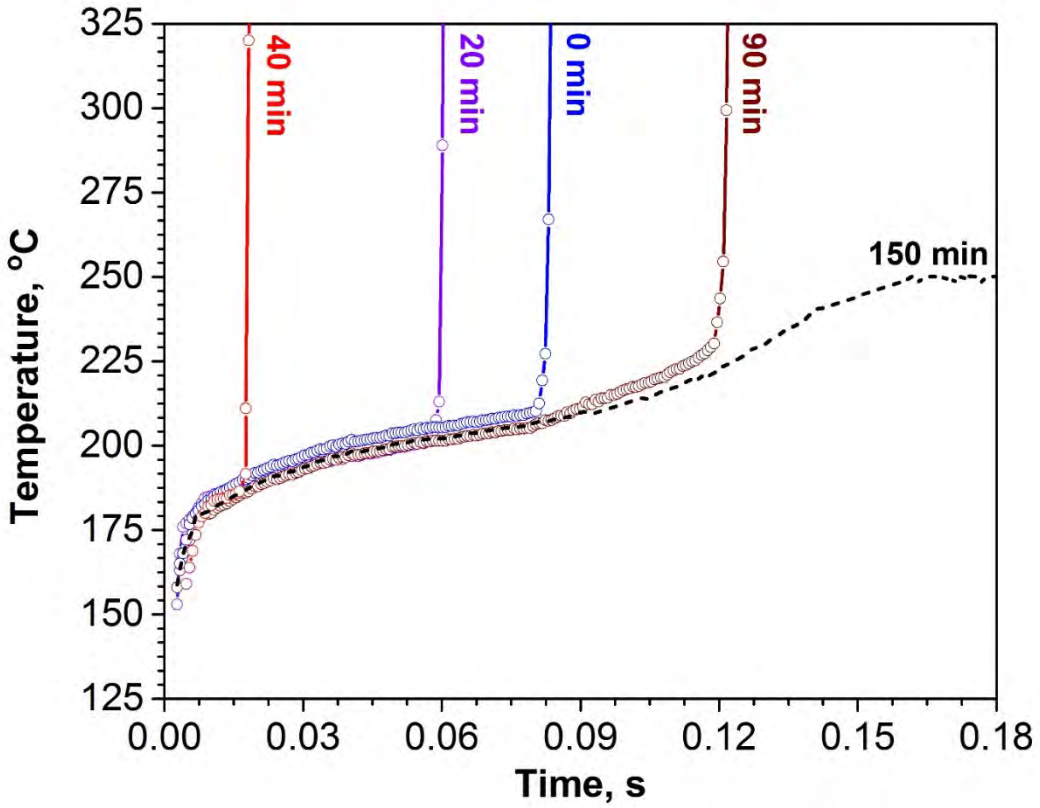
Al_3Ni nuclei in intermixed amorphous layer

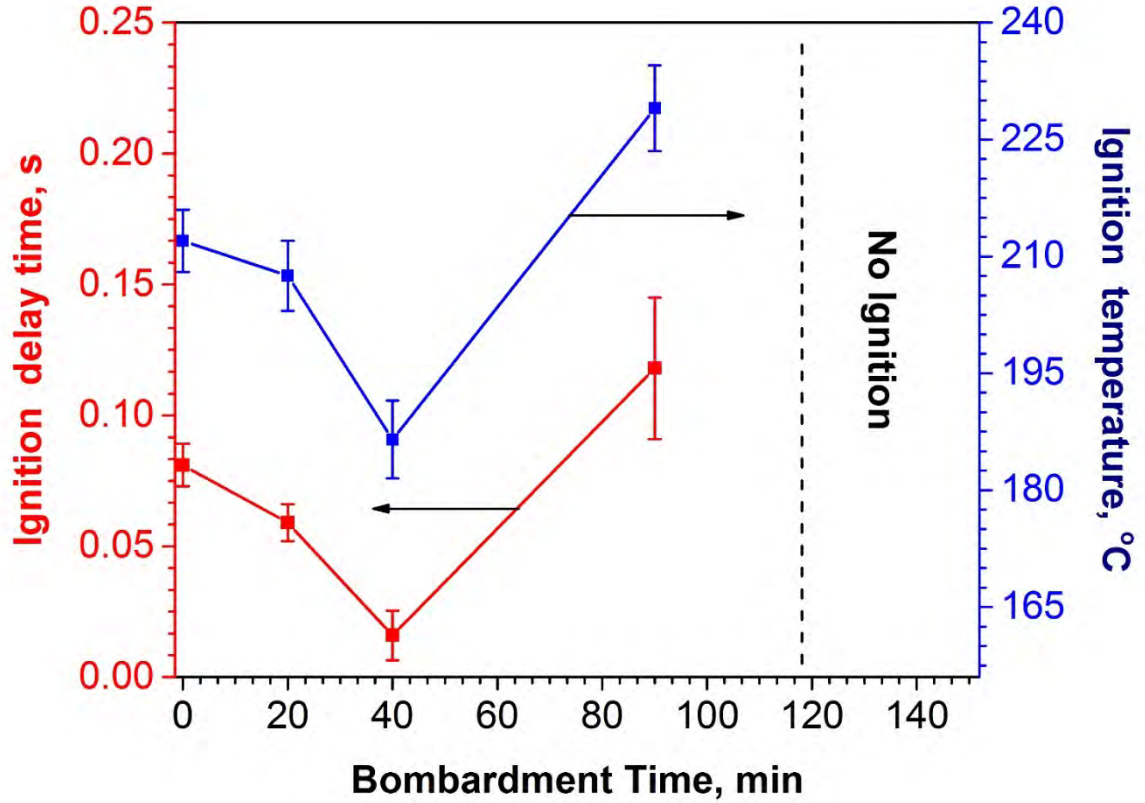
Ignition characteristics of bombarded foils





Ignition characteristics of bombarded foils



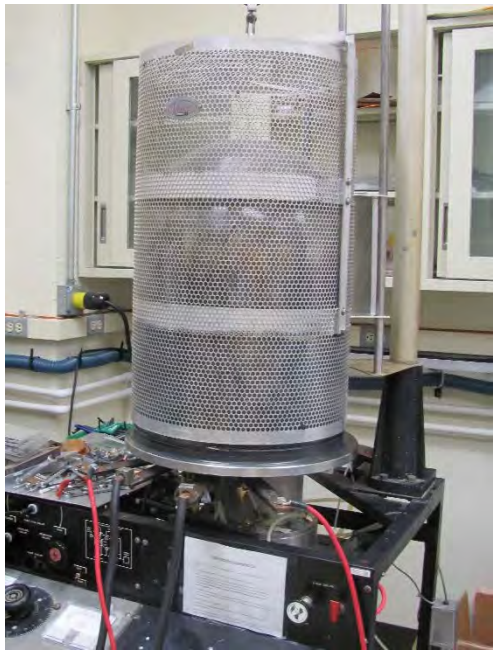


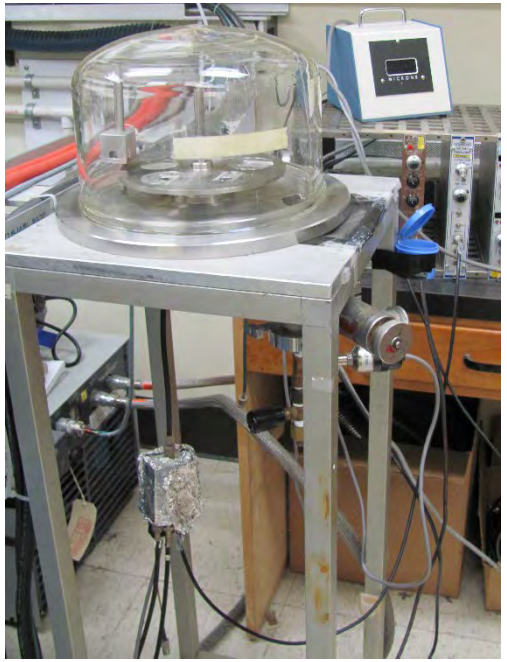
Short-term bombardment: Al_3Ni nuclei formed in intermixed layer significantly decrease ignition temperature and ignition delay time.

Targets for nuclear physics

Targetry

- Routine preparation of natural and isotopically pure targets
- Characterization of targets using nuclear physics and materials science tools
- Development of new processes and materials for targets





Characterization of targets

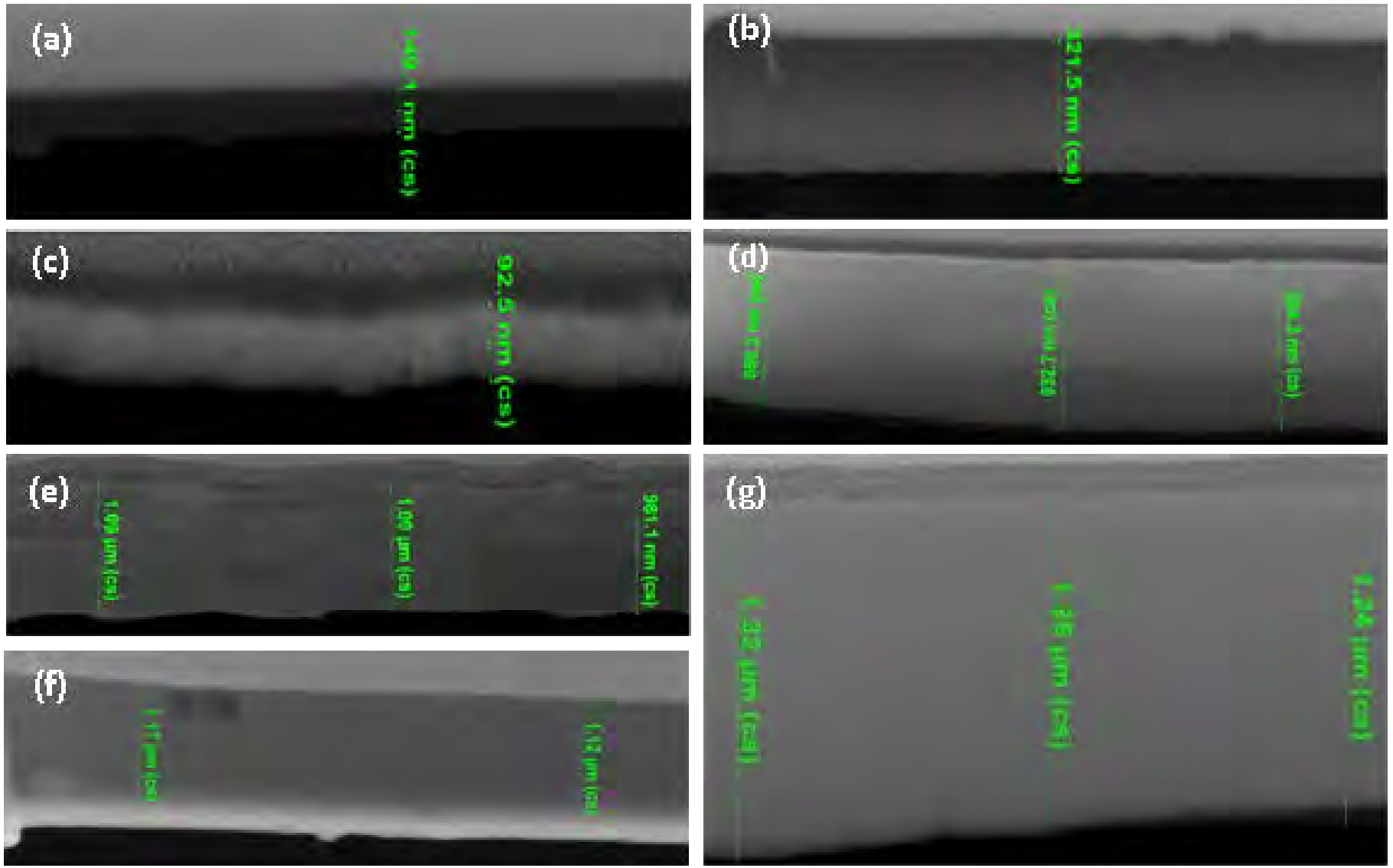
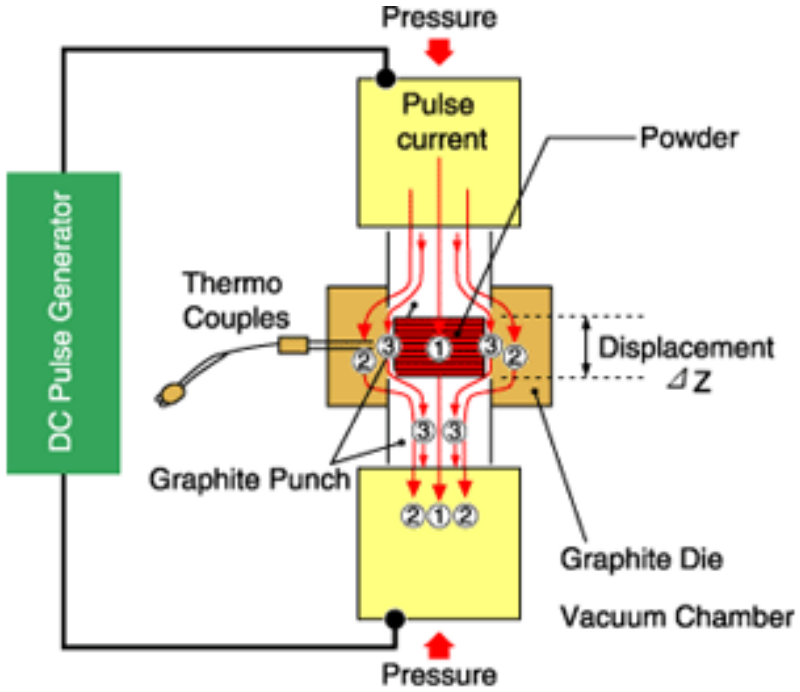
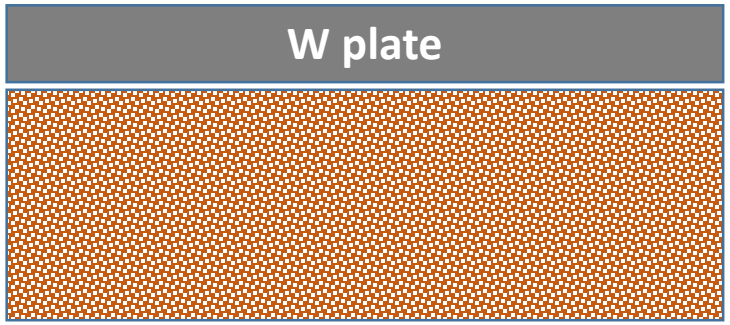


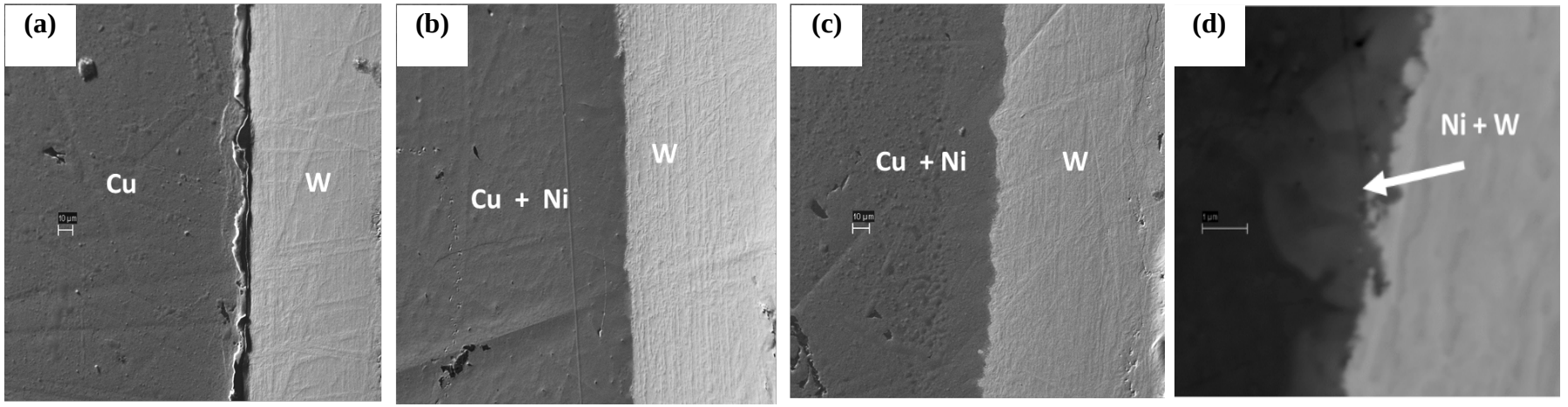
Figure 2: Cross-sectional SEM images for carbon-20(a), carbon-60 (b), gold(c), platinum (d), nickel (e), aluminum (f) and tin (g) targets

Development of new materials for targets

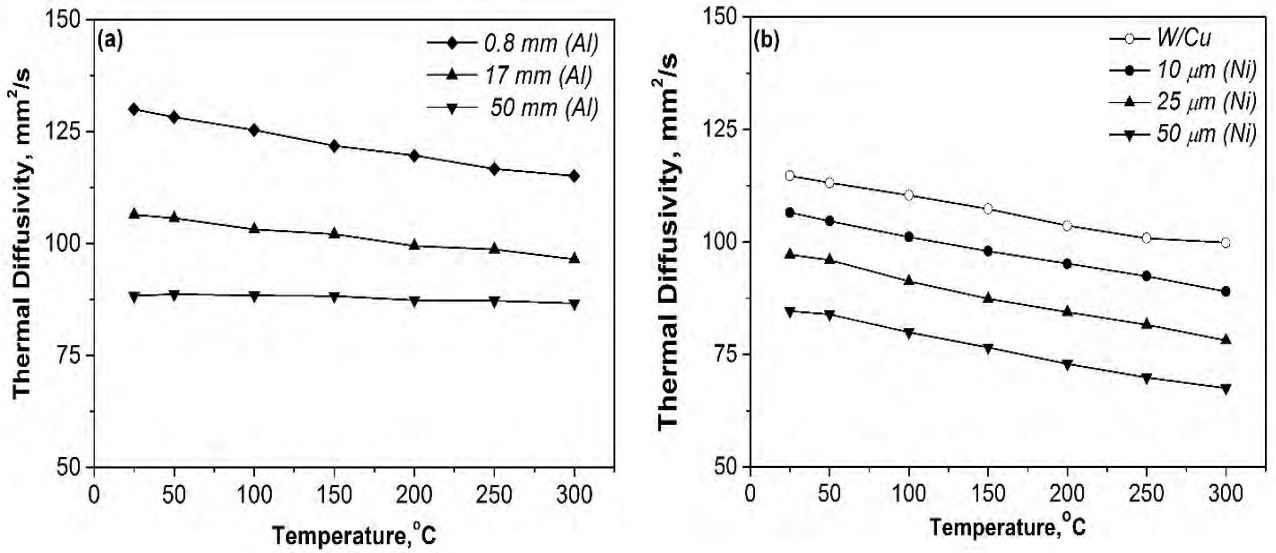




Development of new materials for targets

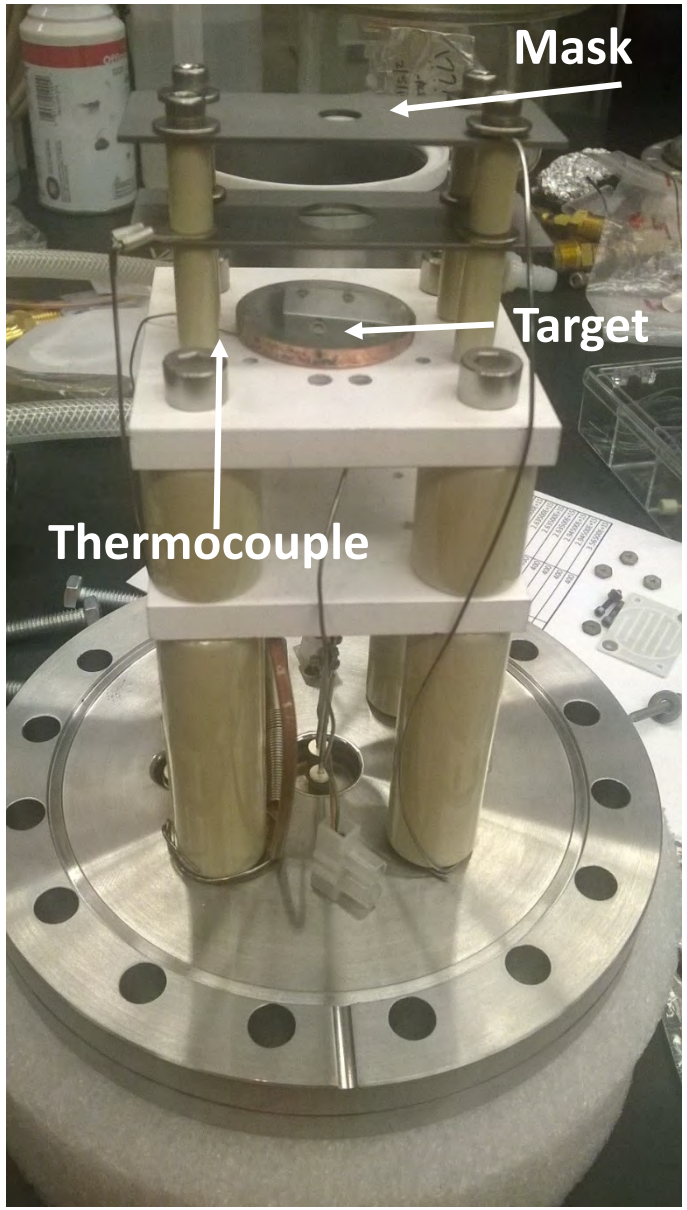


Microstructure of joined W-Cu sample: (a) without nickel of soldering layer, (b) and (c) with Ni soldering layer with 25 mm of thickness, high magnification image of Ni-W joining layer (d)

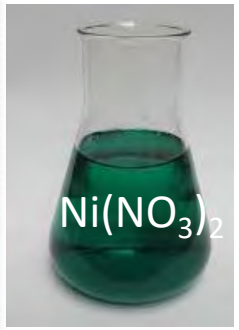


Thermal diffusivity of joined W/Al/Cu (a), W/Ni/Cu and W/Cu (b) samples

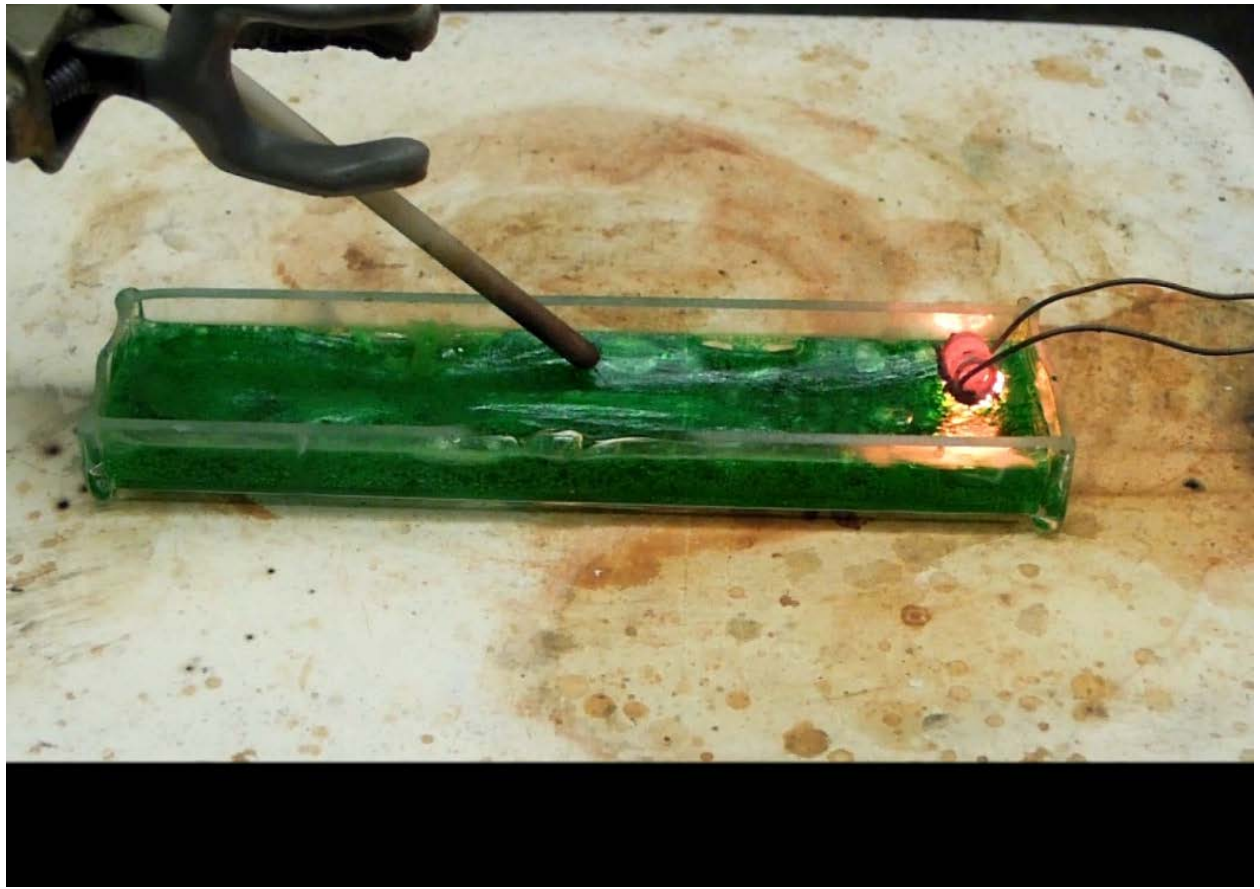
Development of new materials for targets



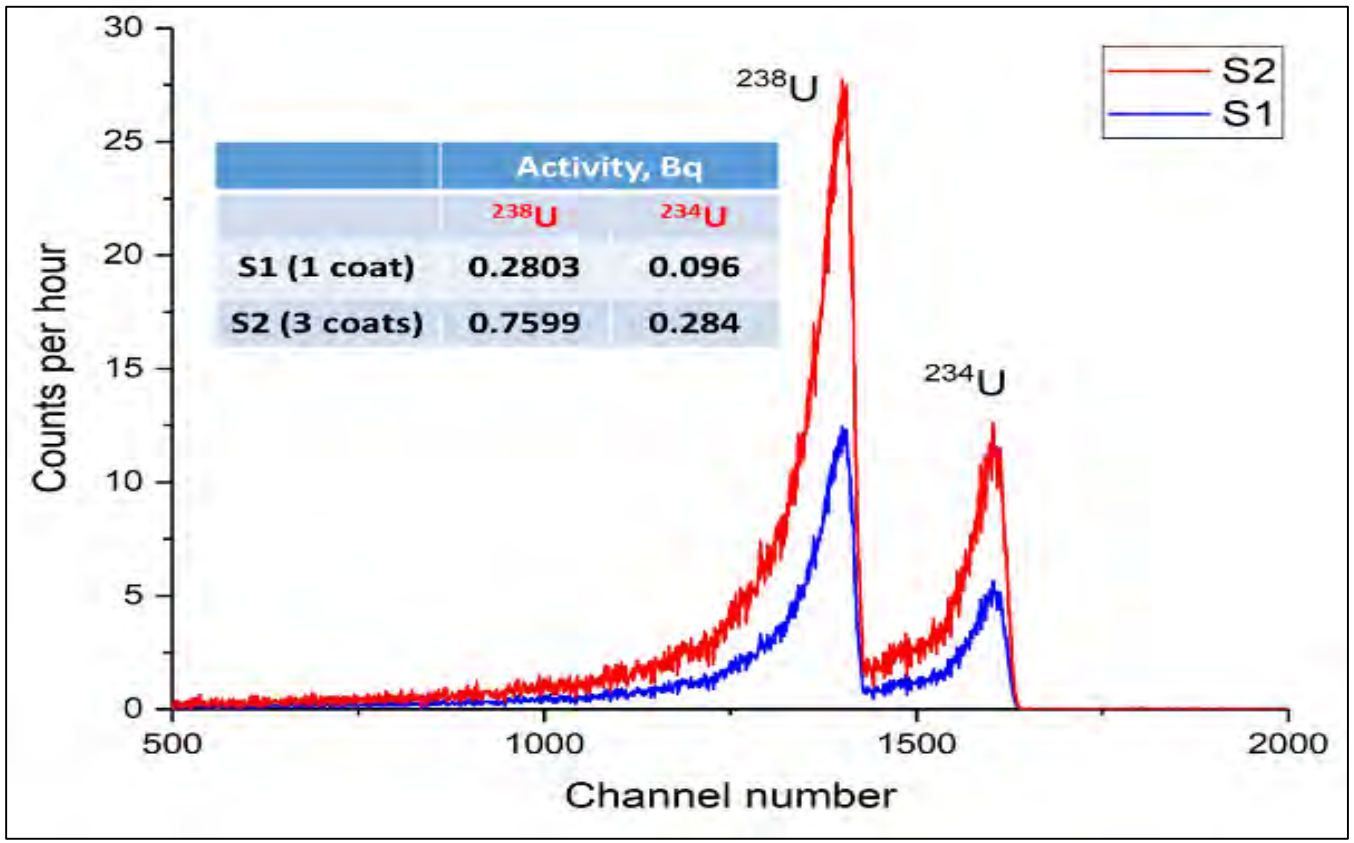
Development of new processes and materials for targets



Oxidizers	Reducers	Solvents
Metal nitrate hydrates $Me^n(NO_3)_n \cdot xH_2O$, *where Me = Fe, Ni, Zn, Al, Cu, Sr, La, Bi, Zr, Li, Co, U, etc.* n - metal valence	**Urea**, CH_4N_2O **Glycine,** $C_2H_5NO_2$ **Glucose,** $C_{12}H_{22}O_{12}$ **Hydrazine** (N_2H_4)	**Water,** H_2O Liquid hydrocarbons:



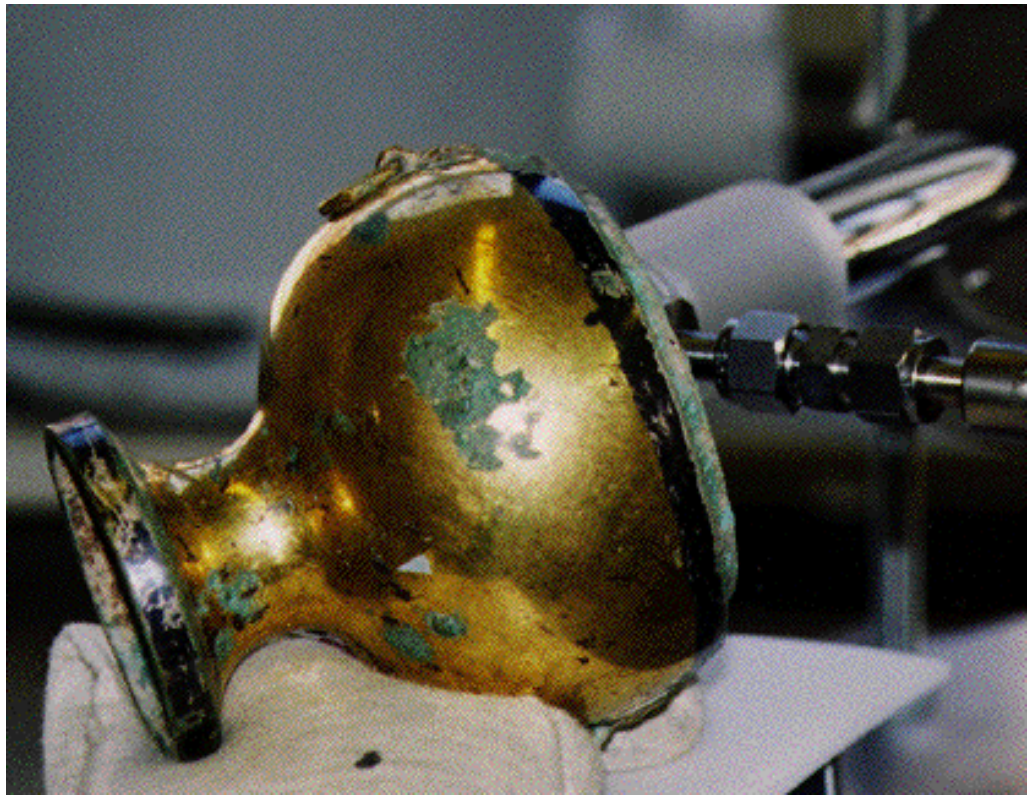
Novel methods for targets preparation



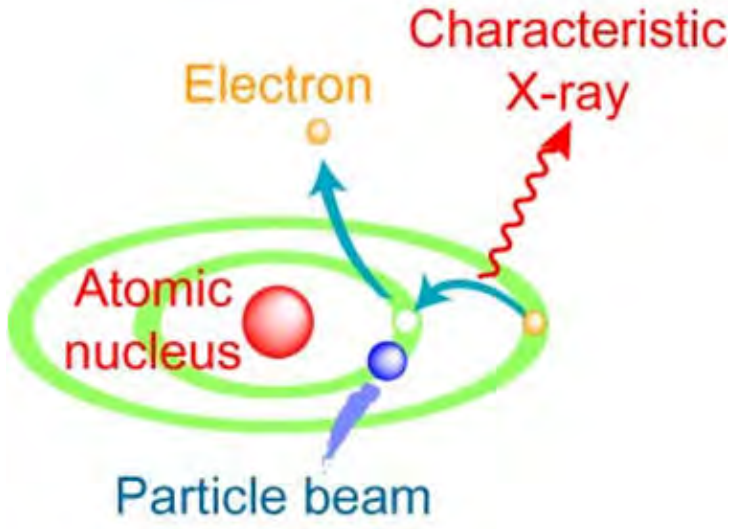
Alpha particle counting by a silicon detector

Ion beam analysis for cultural heritage objects

Particle-induced X-ray emission (PIXE)



Protons transmit energy to the inner-shell electrons, ionize atoms with subsequent X-ray de-excitation



PIXE/XRF analysis of Roman silver coins

Lucretius Trio 136 BC | Publius Clodius 42 BC | Marcus Antonius 31 BC

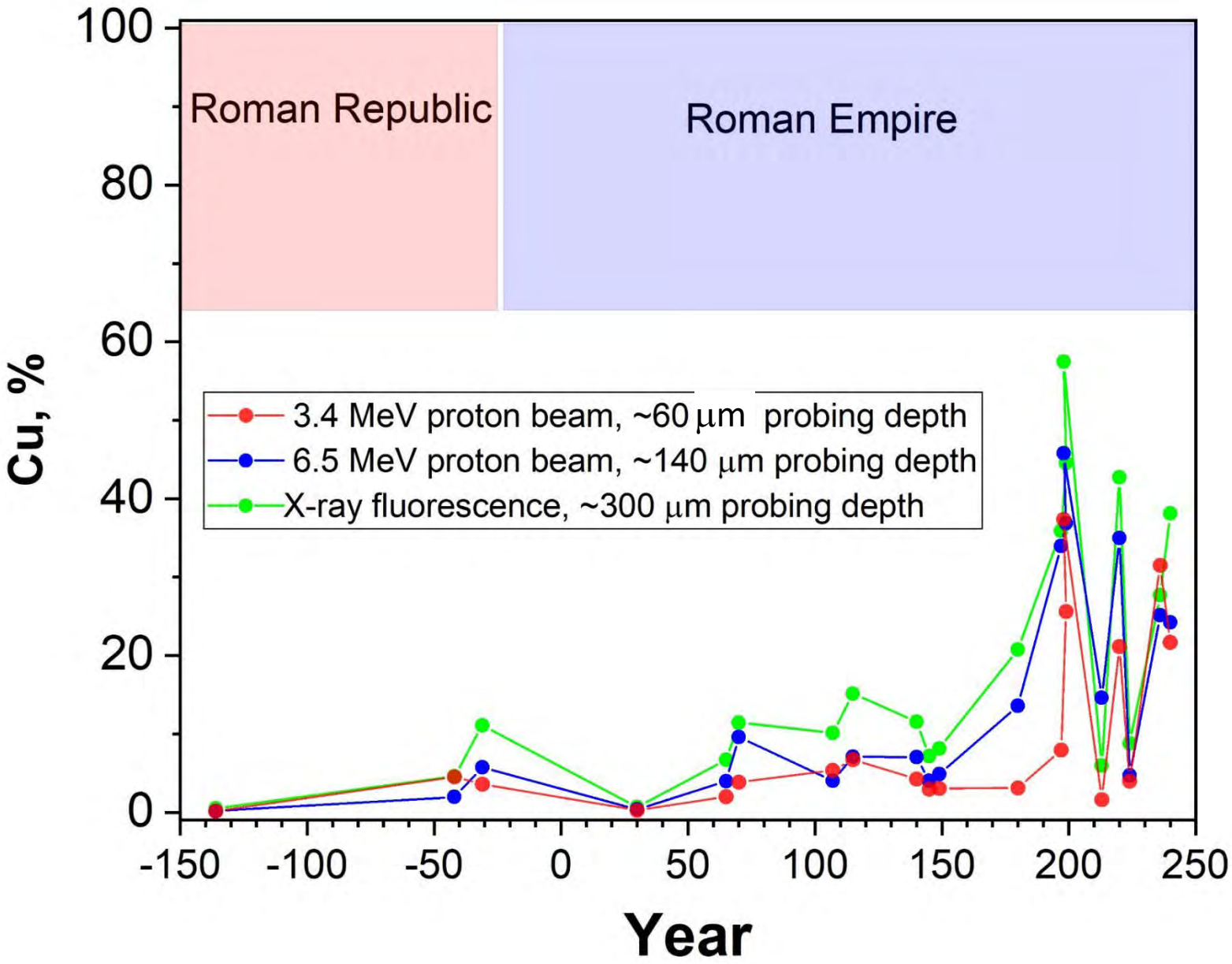
Nero 55 AD | Vespasian 74 AD | Trajan 107 AD

Trajan 115 AD | Antoninus Pius 142 AD | Marcus Aurelius 145 AD

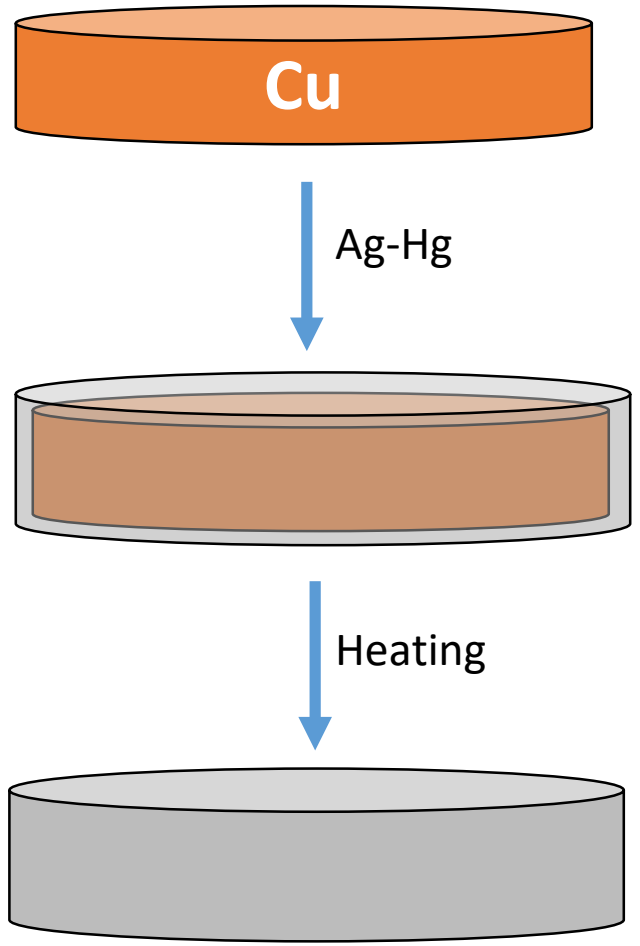
Marcus Aurelius 149 AD | Commodus 189 AD | Septimus Severus 197 AD

Septimus Severus 199 AD | Geta 200 AD | Caracalla 213 AD

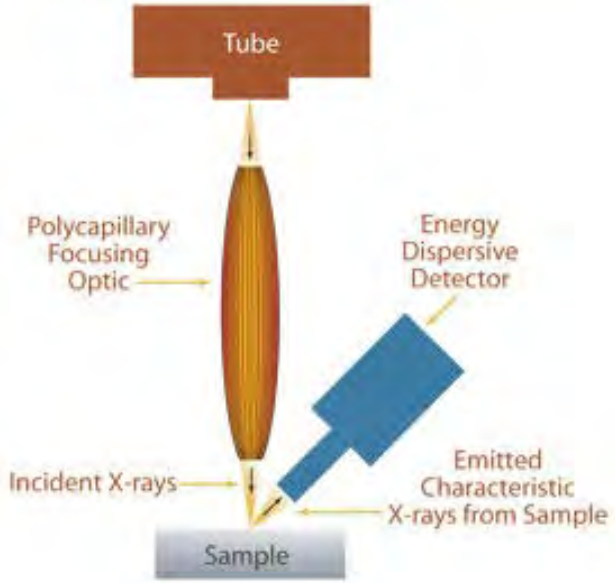
Elagabalus 220 AD | Severus Alexander 224 AD | Maximius I 235 AD

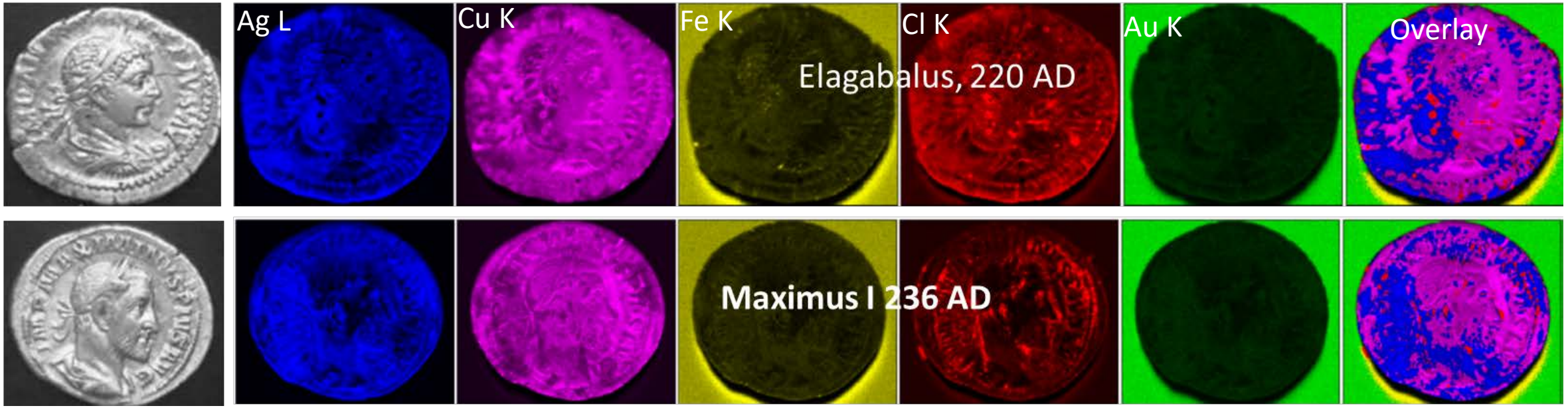


Silvering of Copper coins



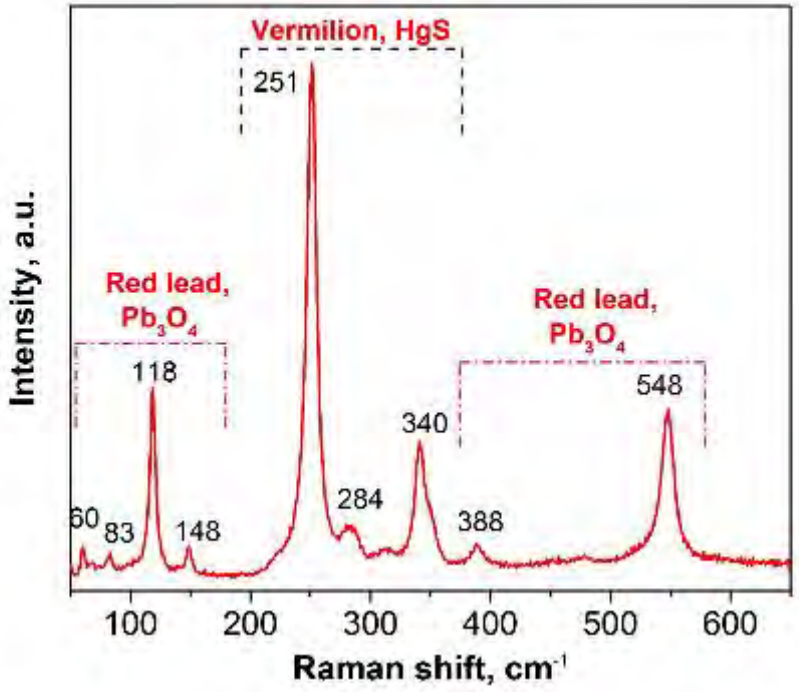
X-rav fluorescence (XRF) mapping





Large scale XRF mapping combined with Raman spectroscopy

Shines from other side of the leaf

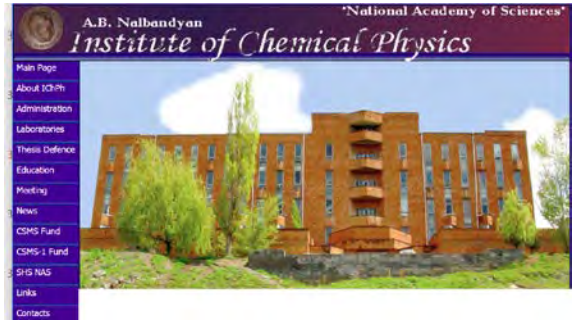


Potential collaborations

Applied R & D Division

- Solid State Radiation Physics
- Optics and Spectroscopy

Matenadaran



Institute of Chemical Physics NAS RA

Thank you !!!