

# Effect of cavities induced by ion implantation on rare gases diffusion in uranium dioxide

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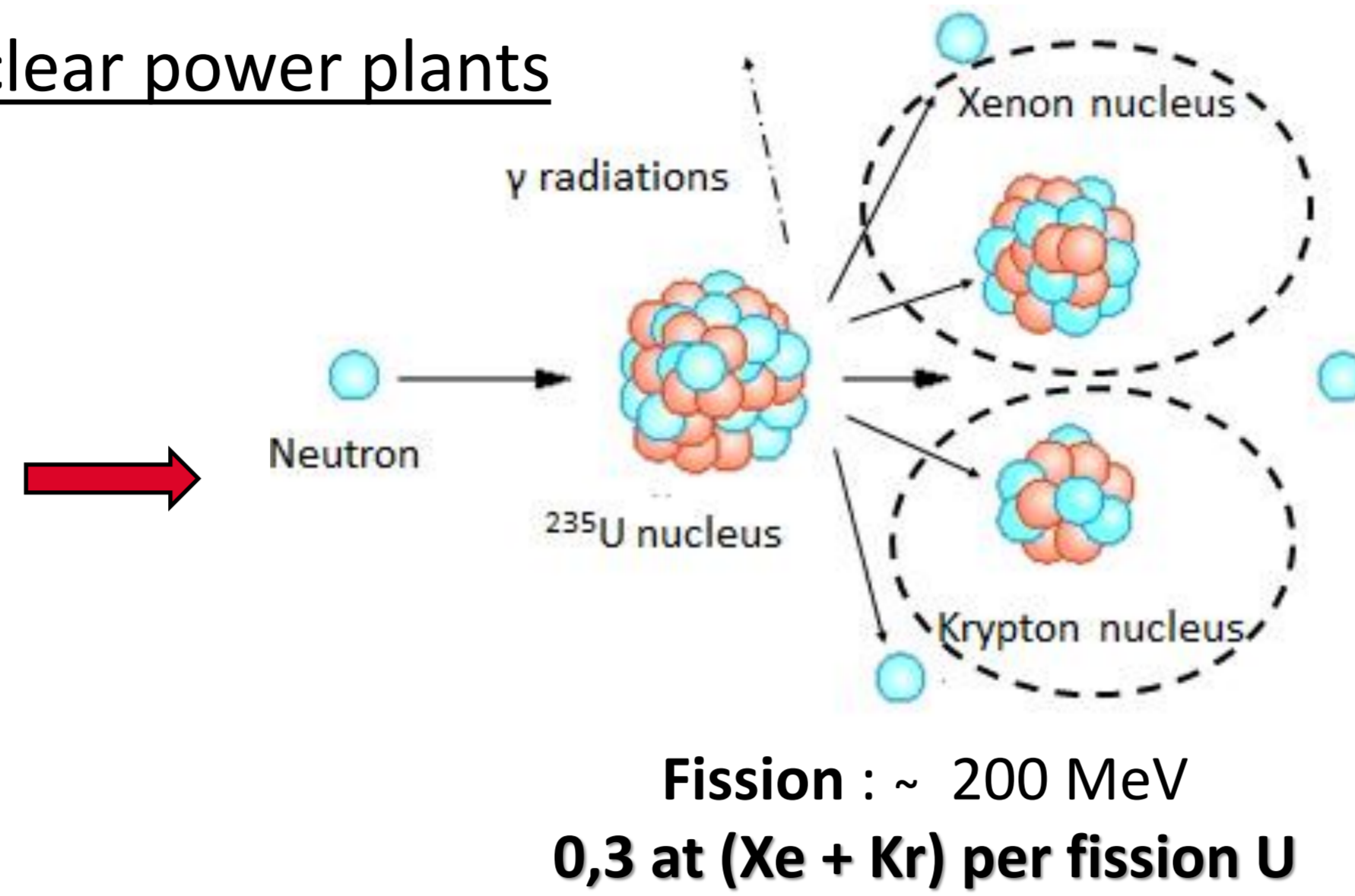
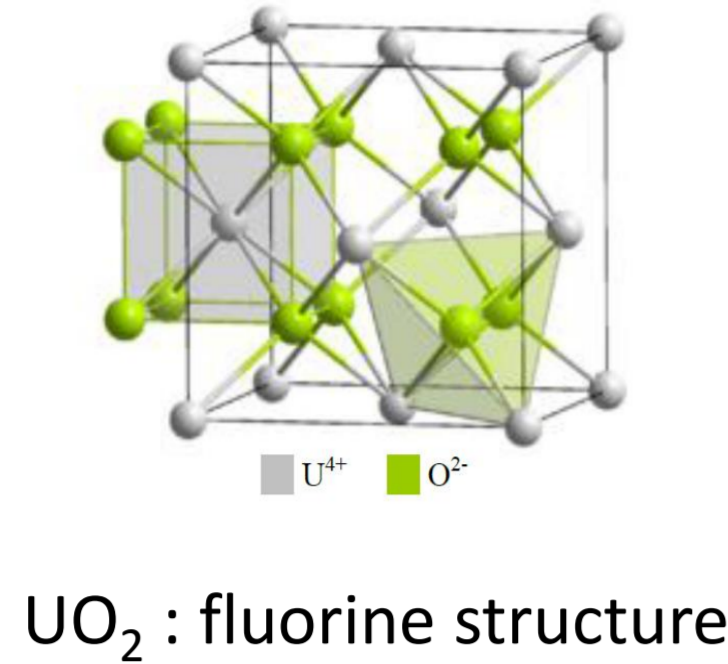
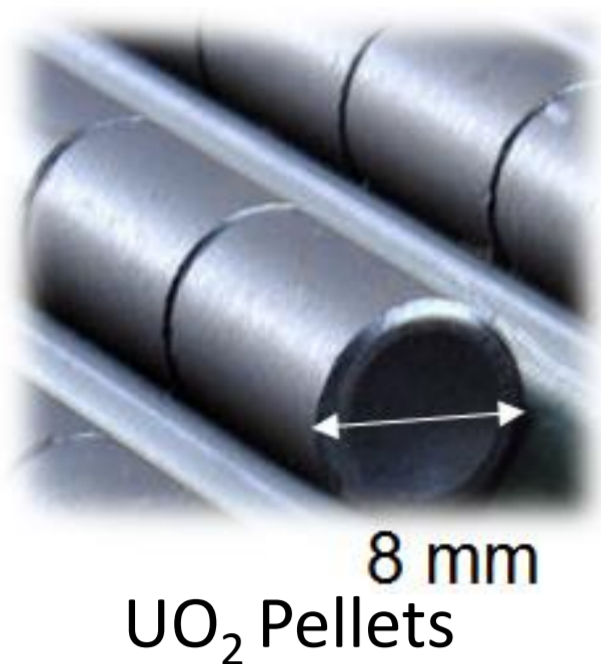
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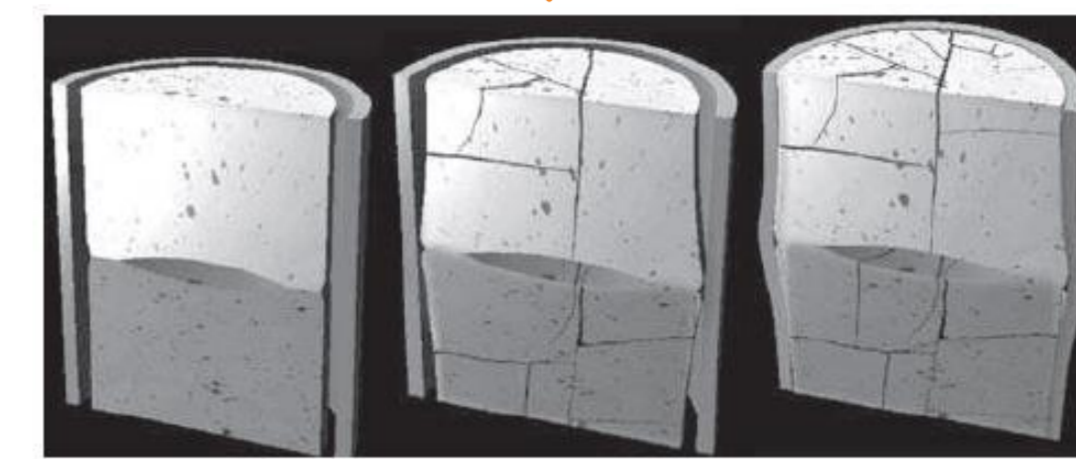
## Context

➤  $UO_2$  is the most used fuel in nuclear power plants

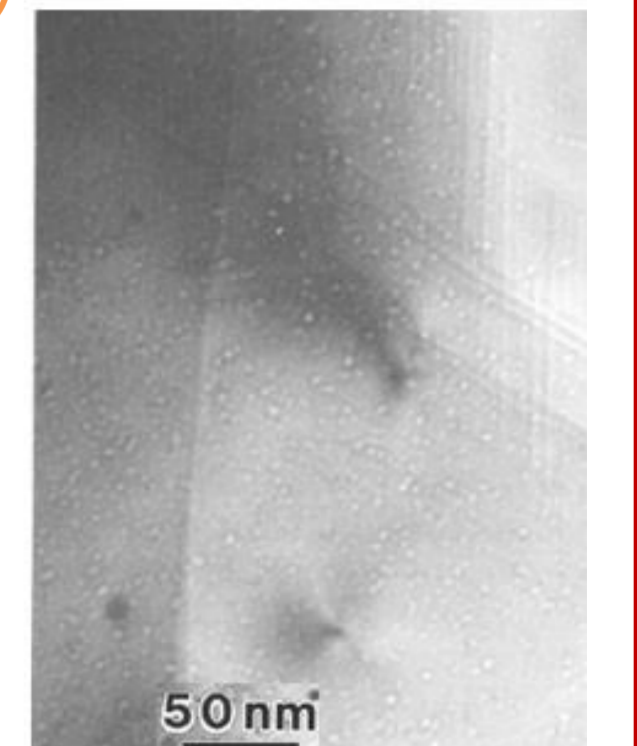


Gas release  
Pressure increase

Precipitation  
Fuel swelling



Modification of the oxide physico-chemical properties limiting fuel life time in reactor



TEM image of cavities in irradiated material at 23 GWj/tU

## Objectives

- Improve the modelling of fission gas thermal diffusion mechanisms to better predict  $UO_2$  fuel behaviour under irradiation
- Study the interaction between gas and defect induced by irradiation

## Experimental approach

➤ Separated effect studies

Rare gases diffusion in  $UO_2$

Implantation Xe 800keV or Kr 500 keV

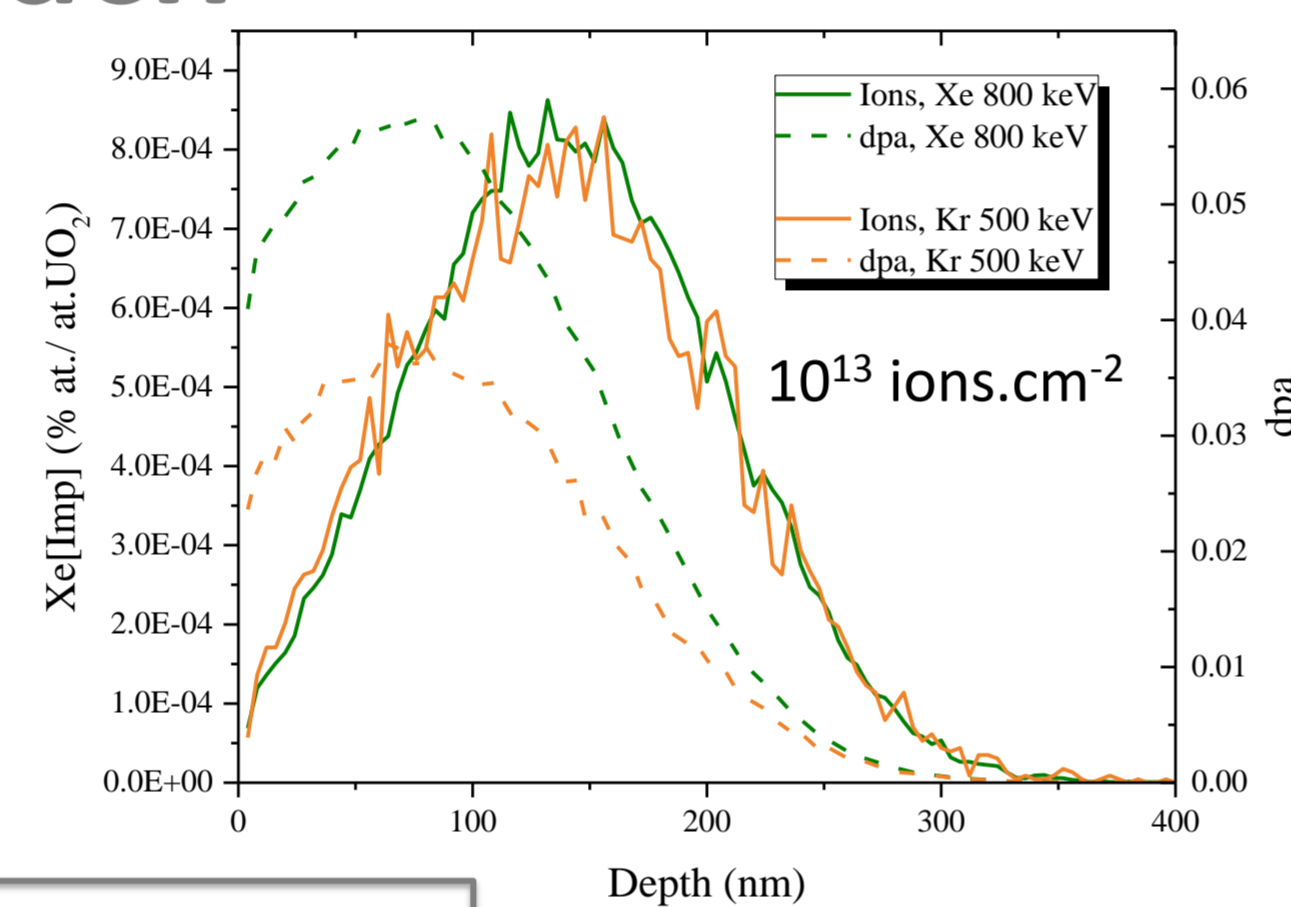
Diffusion coefficient

Defects induced by implantation

Thermal desorption measurements  
Gas release fraction

Positron annihilation spectroscopy (PAS)

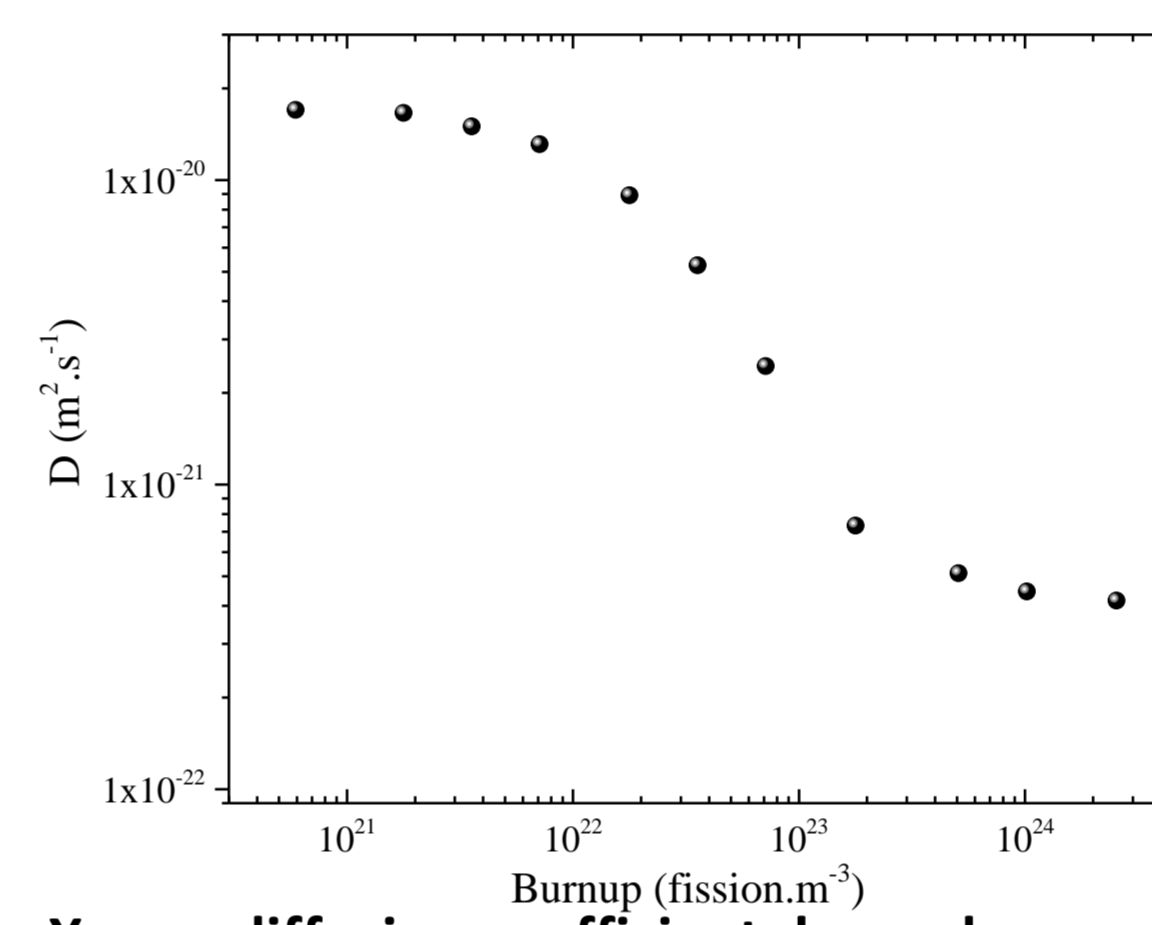
Transmission Electron Microscopy (TEM)



## Literature

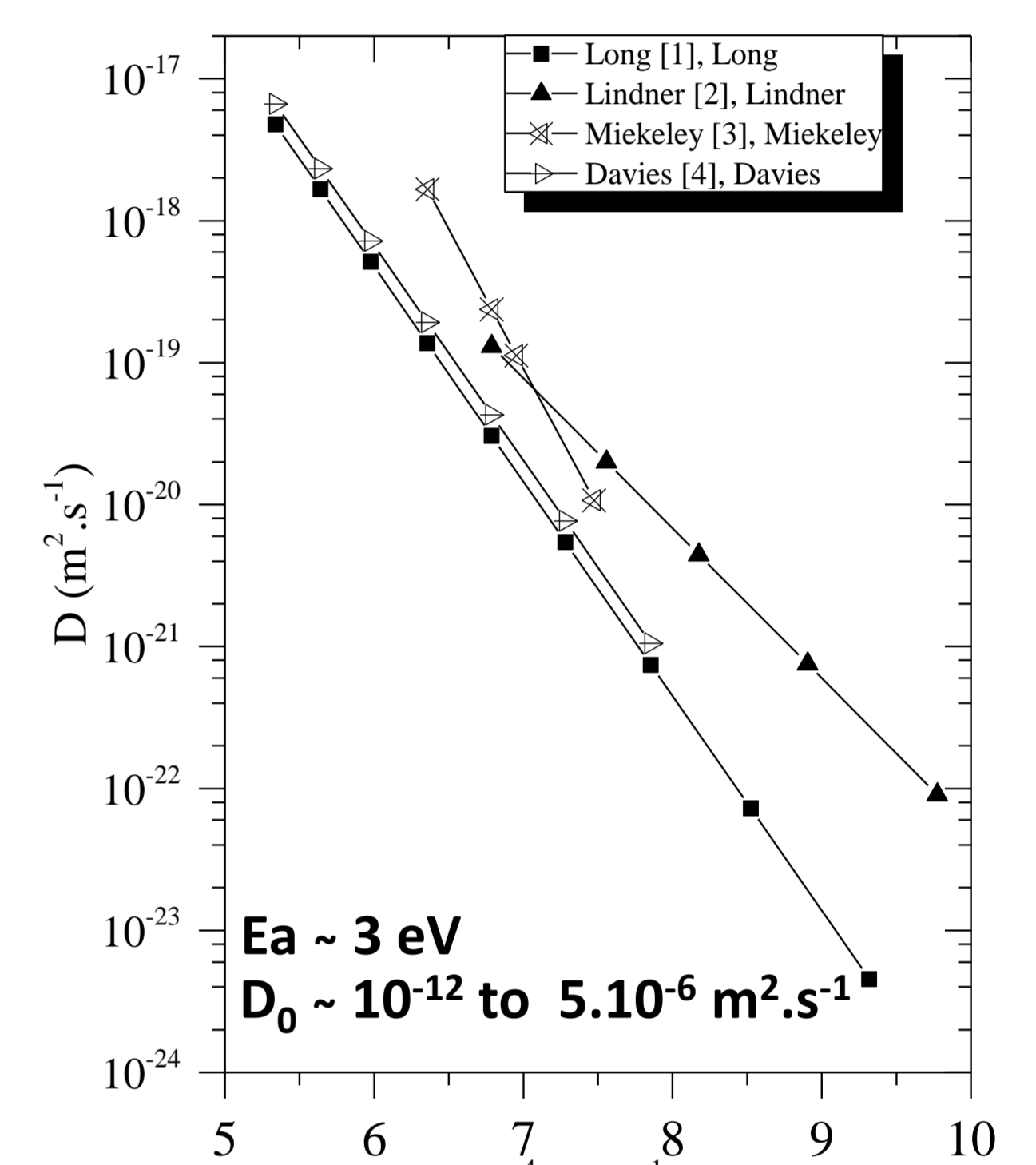
Diffusion coefficient dependance

- Stoichiometry of the sample
- Burn up (fission. $m^{-3}$ )



Xenon diffusion coefficient dependance with the burn-up [1]

- Gases are trapped in  $UO_2$  for a burn-up  $> 2.10^{22} f.m^{-3}$
- In which defects ?



Arrhenius laws of xenon diffusion in  $UO_{2.00}$  irradiated at a low burn-up ( $< 2.10^{22} fission.m^{-3}$ )

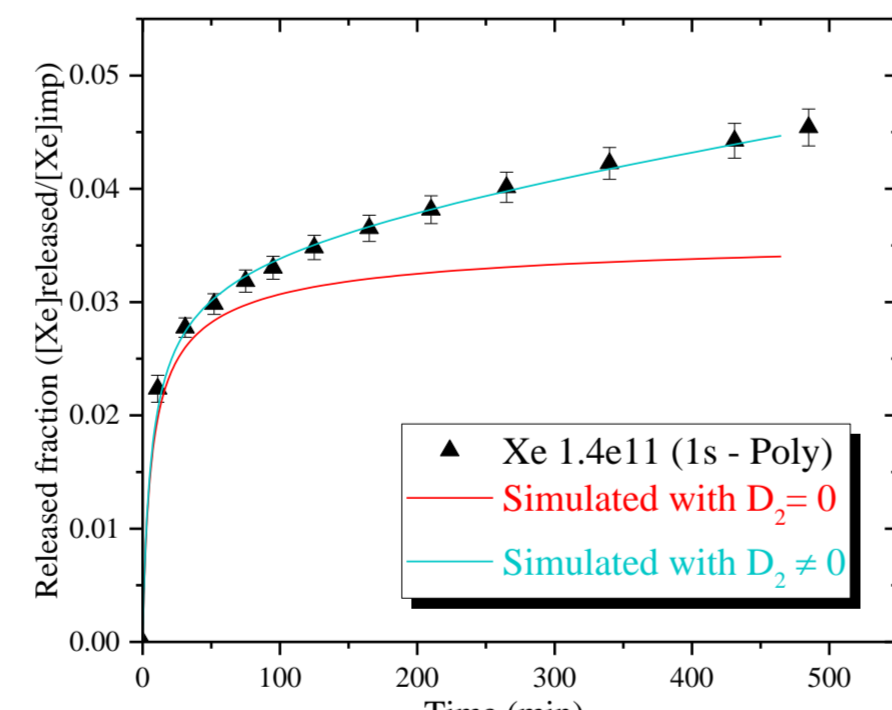
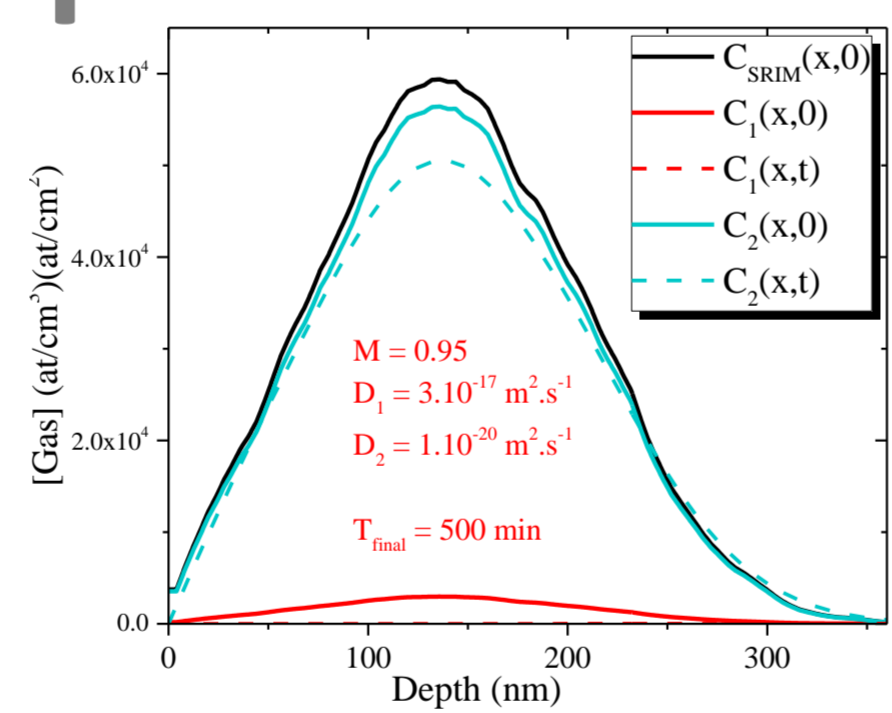
- [1] Long, Davies and Findlay, AERE-M1251 (1964)
- [2] Lindner and Matzke, Z. Naturforschung 14a (1959)
- [3] Mieleky and Felix, JNM 42 (1972)
- [4] Davies Long, AERE-R 4347 (1963)

## Diffusion model : two populations

Second Fick law

$$D_i \frac{\partial^2 C_i(x,t)}{\partial x^2} = \frac{\partial C_i(x,t)}{\partial t}$$

$$\begin{cases} C_i(0,t) = 0 \\ C_i(\infty,t) = 0 \\ C_1(x,0) = (1-M) \times C_{SRIM} Profile \\ C_2(x,0) = M \times C_{SRIM} Profile \end{cases}$$



$C_1$ : Gas concentration mobile with  $D_1$  → Burst effect

$M$ : Fraction of 2 populations

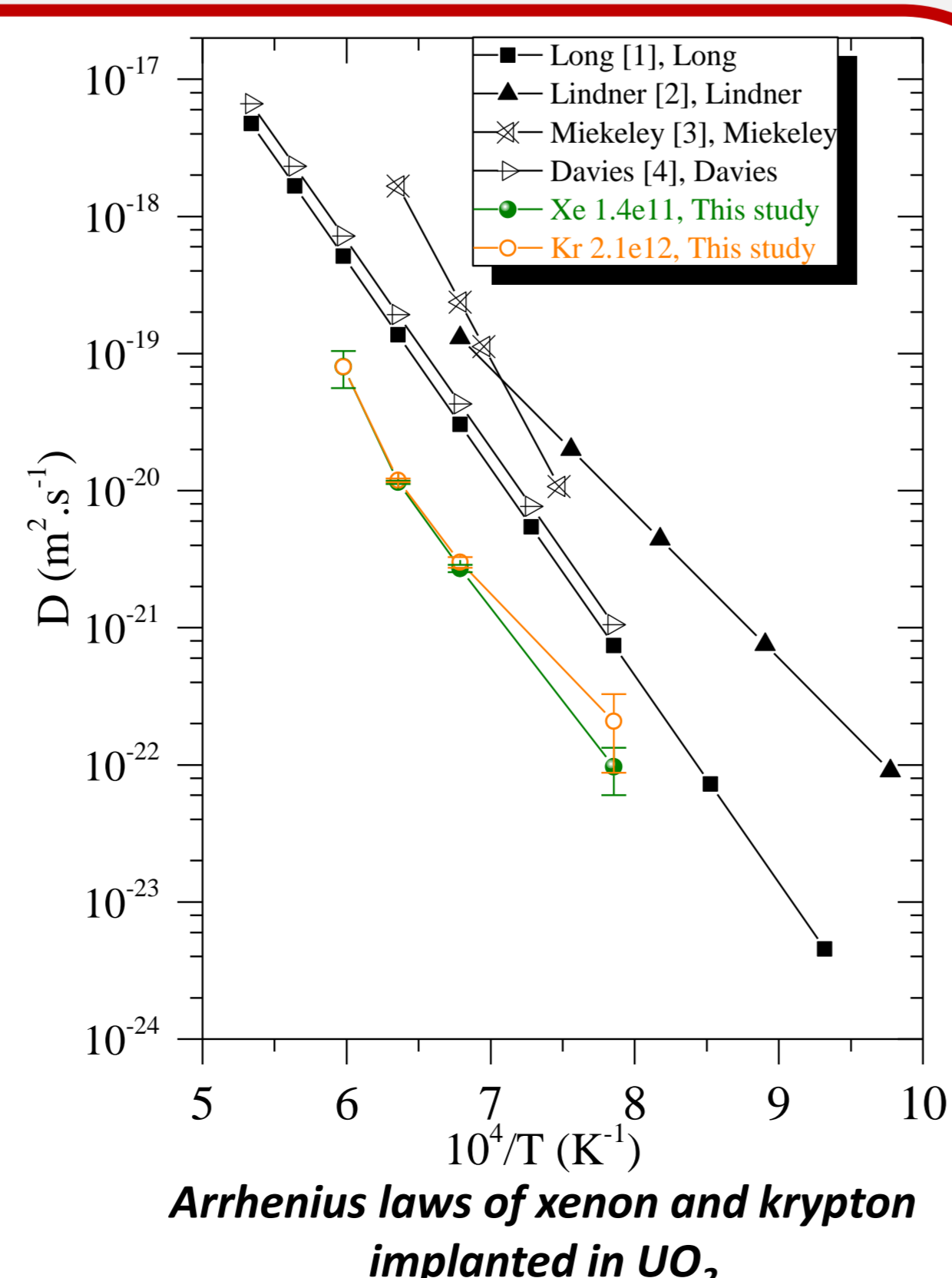
$C_2$ : Gas concentration mobile with  $D_2$  → Intrinsic diffusion

## Arrhenius law ( $D_2$ )

Xenon 800 keV at  $1.4.10^{11} Xe.cm^{-2}$   
 $E_a = 3.10 \pm 0.33$  eV  
 $D_0 = 1.62.10^{-10} m^2.s^{-1}$

Krypton 500 keV at  $2.1.10^{12} Kr.cm^{-2}$   
 $E_a = 2.81 \pm 0.45$  eV  
 $D_0 = 2.13.10^{-11} m^2.s^{-1}$

- Consistent with literature
- Same diffusion mechanisms between Xe and Kr



## Trapping effect

### 1. Thermal desorption

Diffusion coefficient ( $D_2$ ) determined on isotherms obtained at 1300°C for each dose

- $D_1$  remains constant
- $D_2$  decreases from
  - $10^{13} ions.cm^{-2}$  in polycrystals
  - $10^{12} ions.cm^{-2}$  in monocrystals

Trapping effect in implanted  $UO_2$

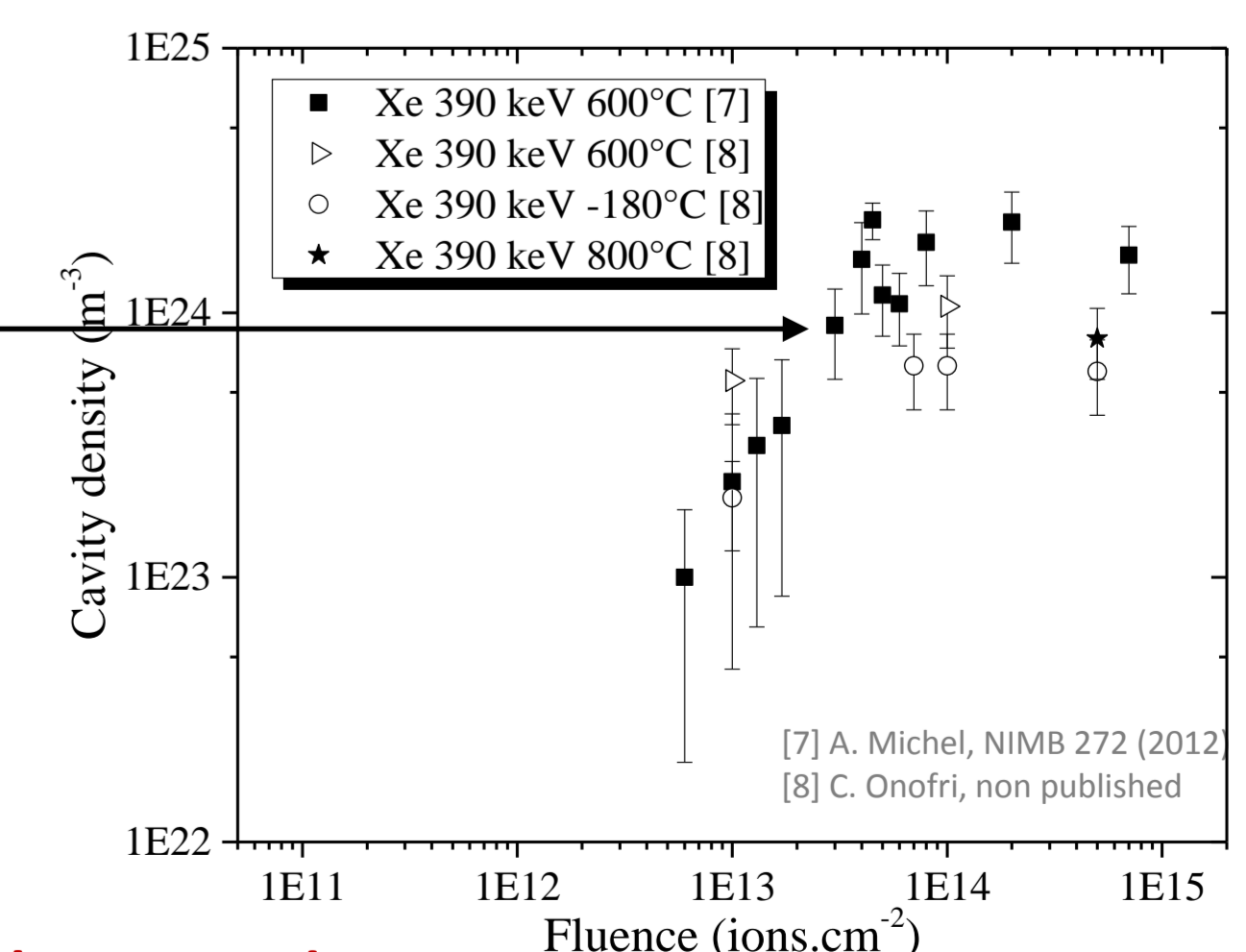
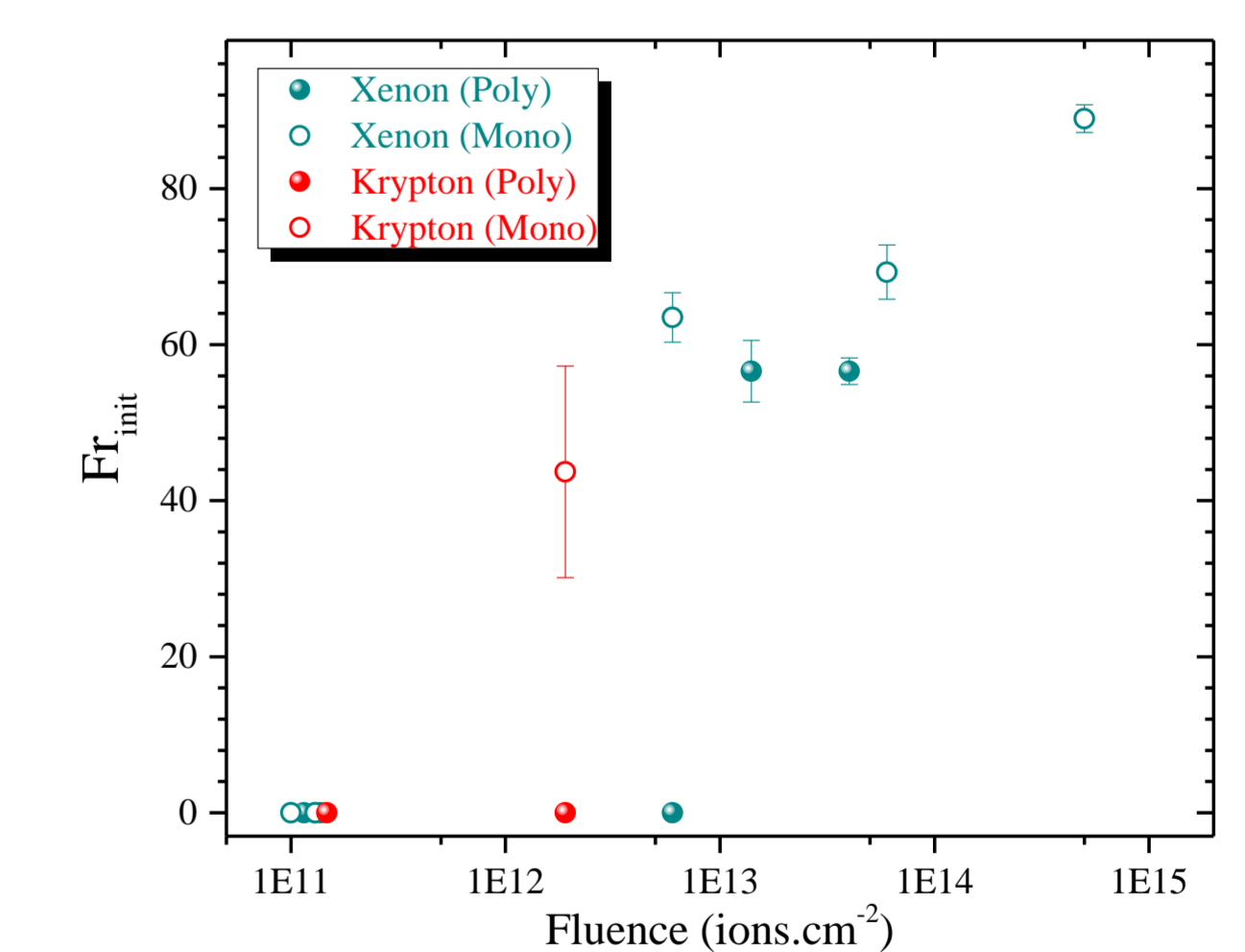
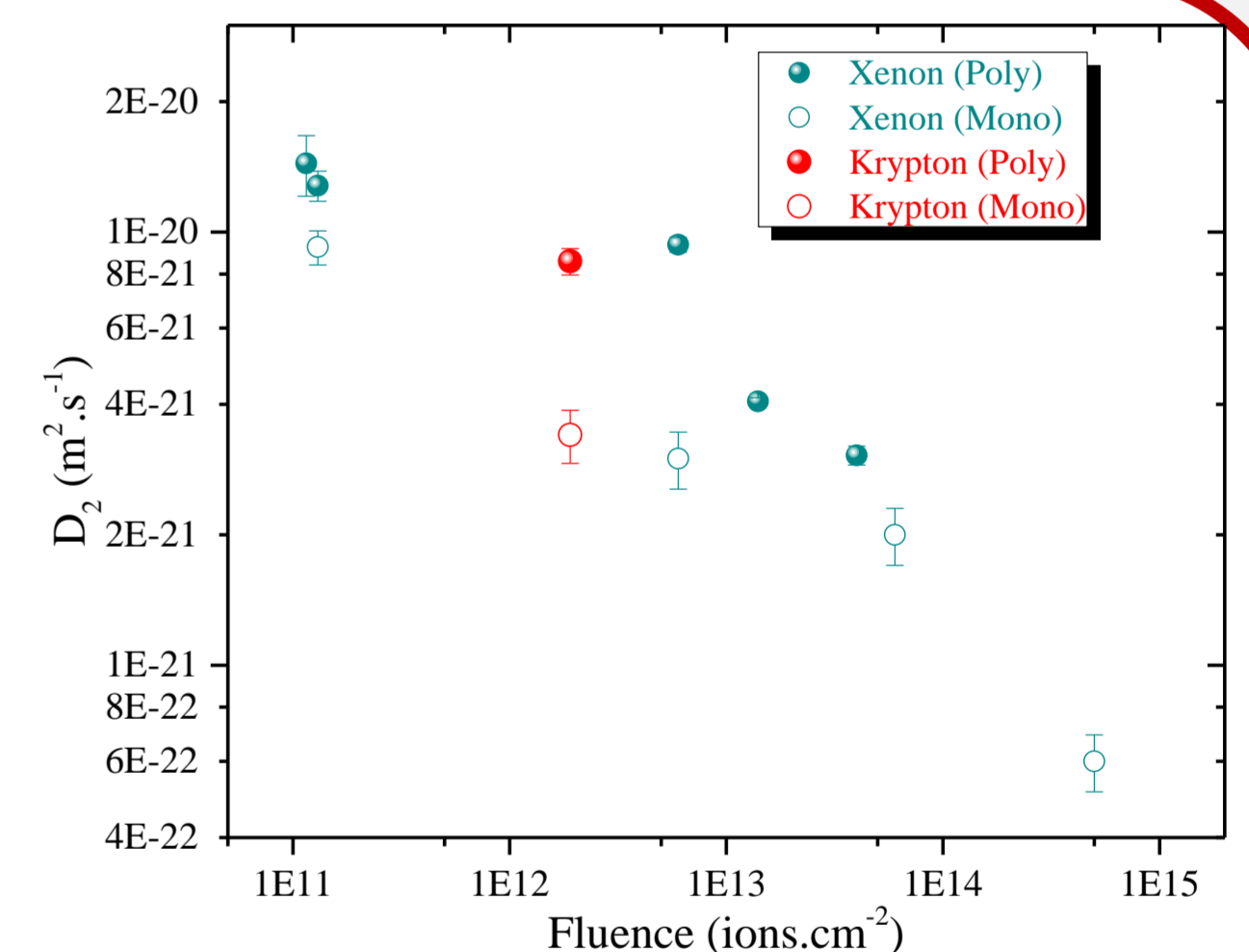
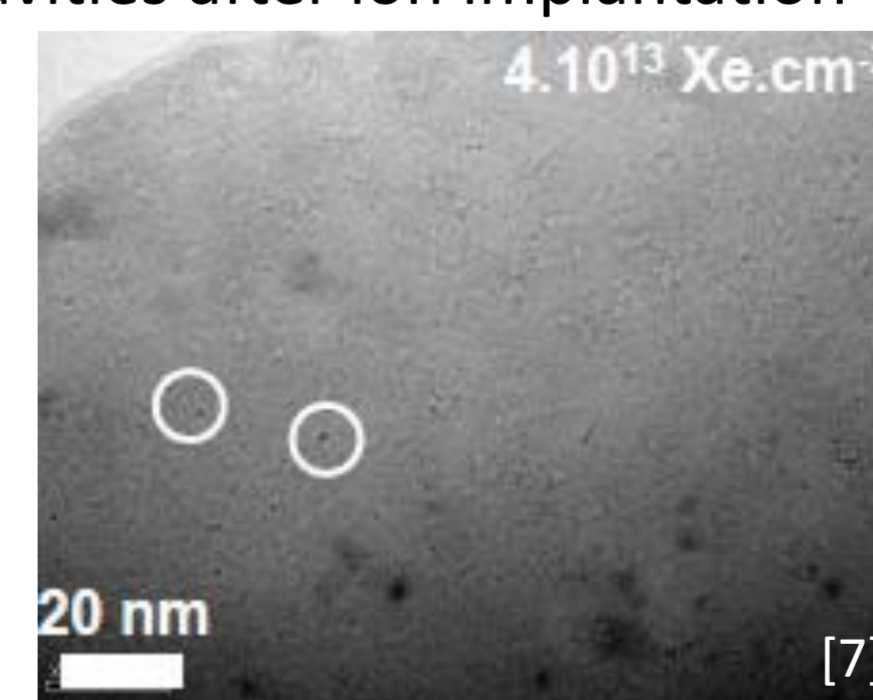
$$\begin{cases} C_1(x,0) = (1-M) \times C_{SRIM} Profile \\ C_2(x,0) = M \times (1 - Fr_{init}) \times C_{SRIM} Profile \\ C_p(x,0) = M \times Fr_{init} \times C_{SRIM} Profile \end{cases}$$

$Fr_{init}$ : Fraction of trapped gas atom

- Increases with the fluence

### 2. Trapping sites

TEM images of cavities after ion implantation



- Gas retained in cavities induced by irradiation

## Conclusions

- Same diffusion mechanism between xenon and krypton
- Good agreement with literature
- Rare gases trapped in cavities induced by irradiation