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

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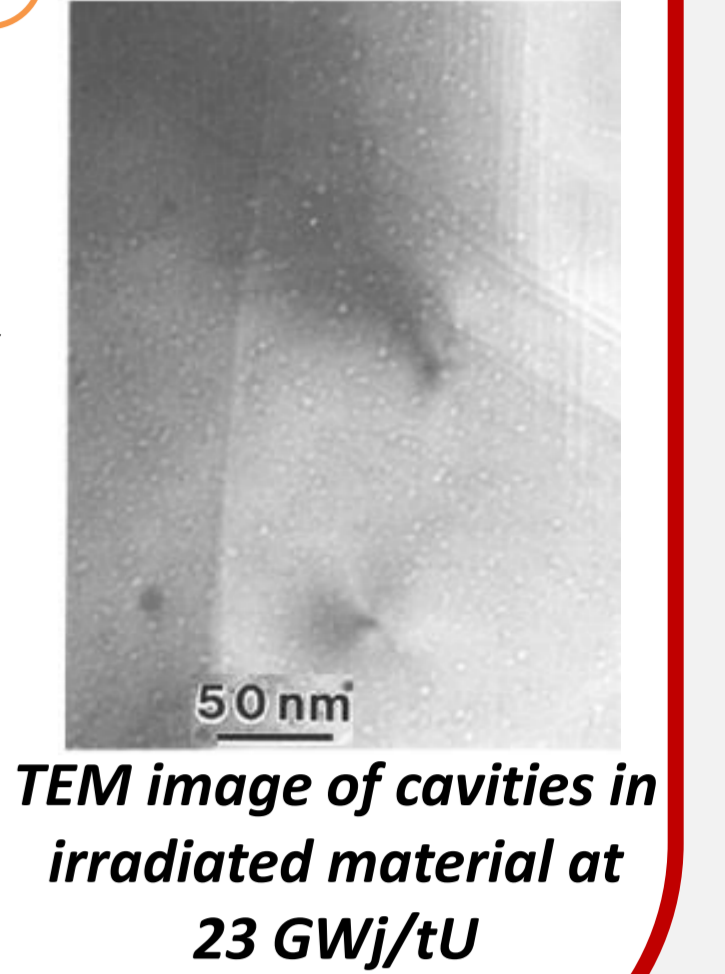
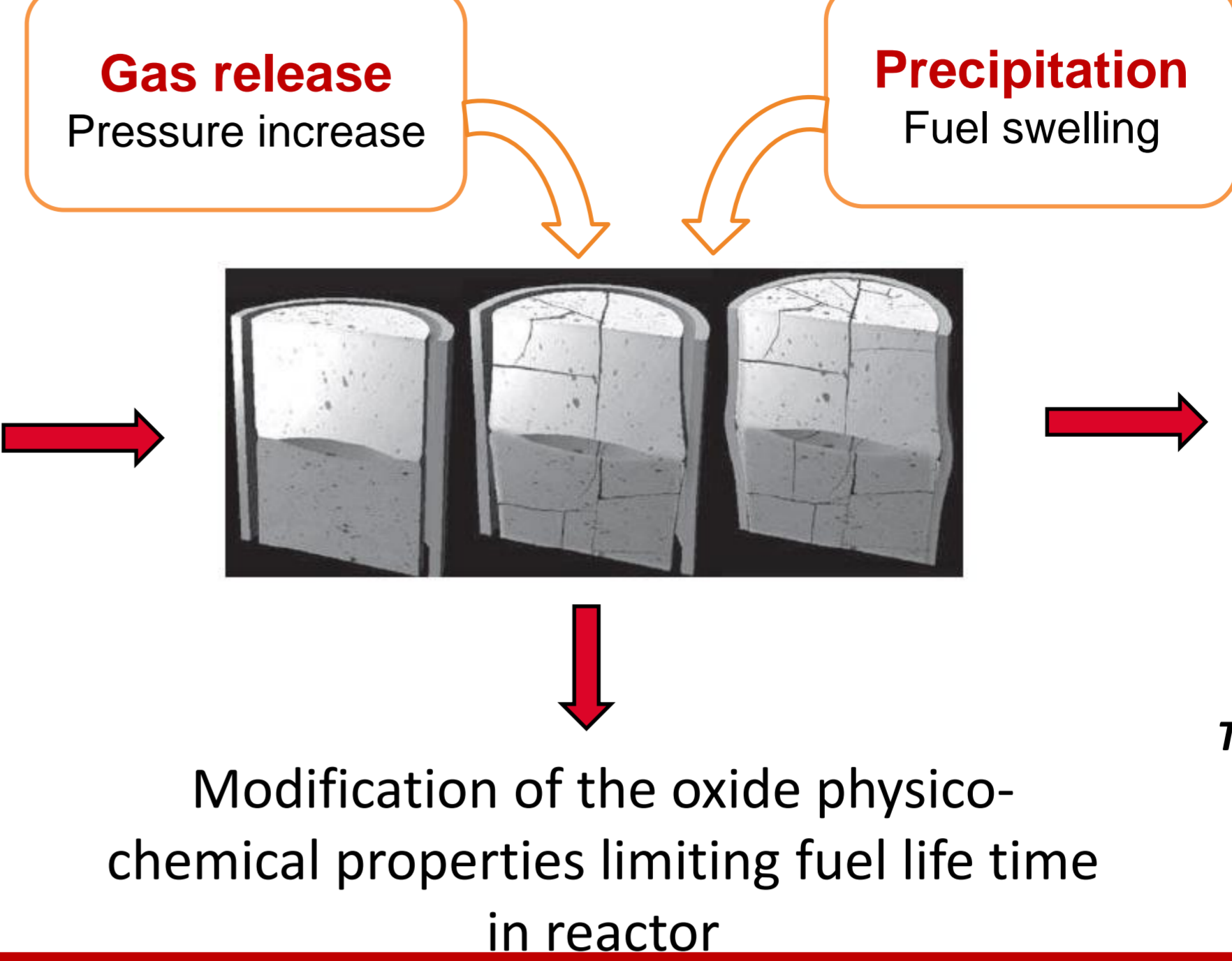
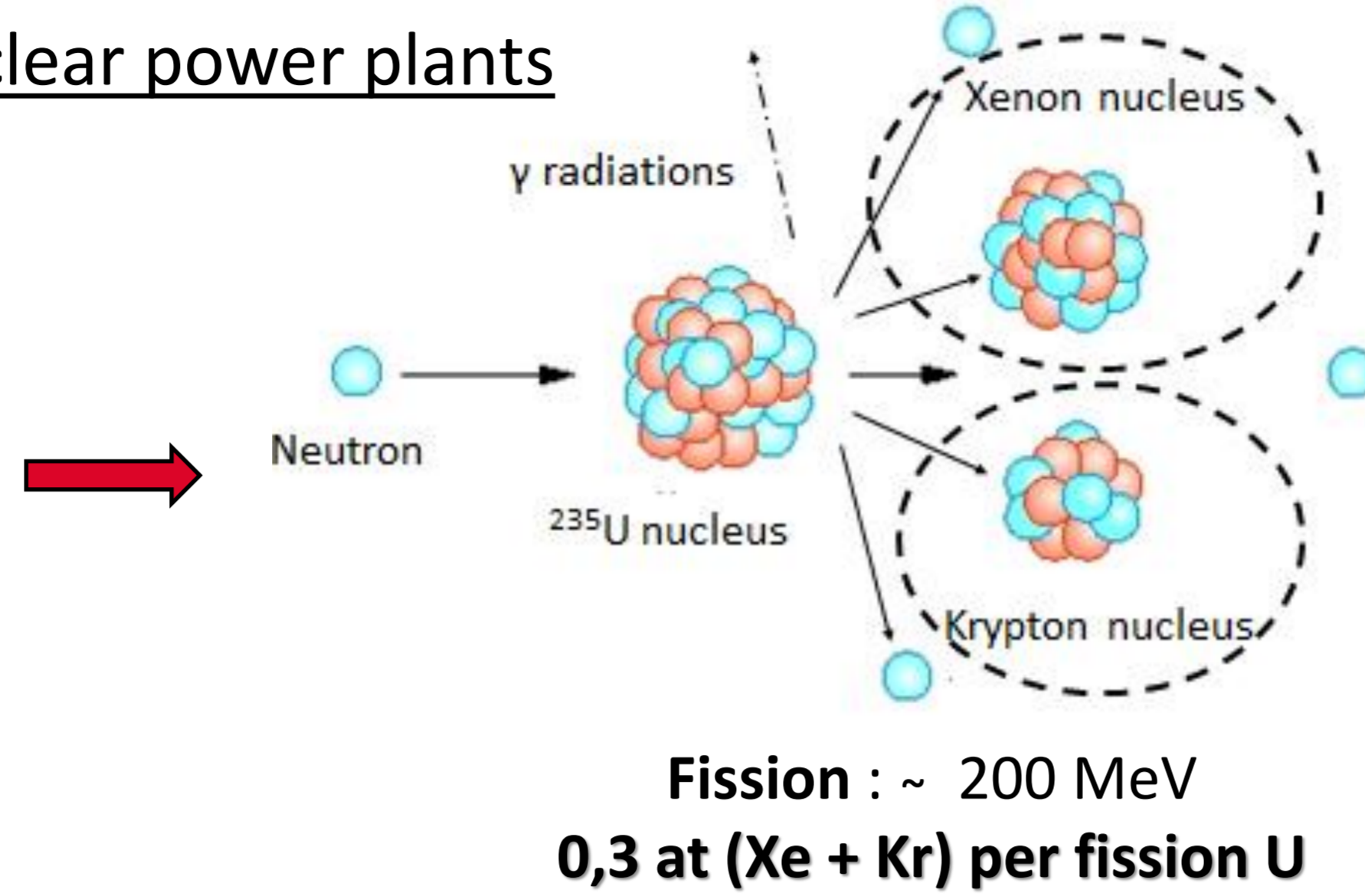
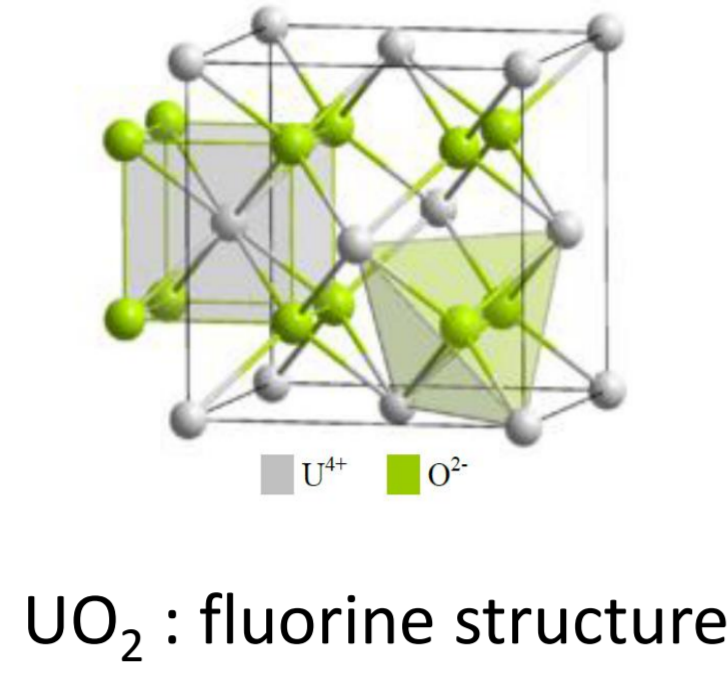
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Context

➤ UO_2 is the most used fuel in nuclear power plants

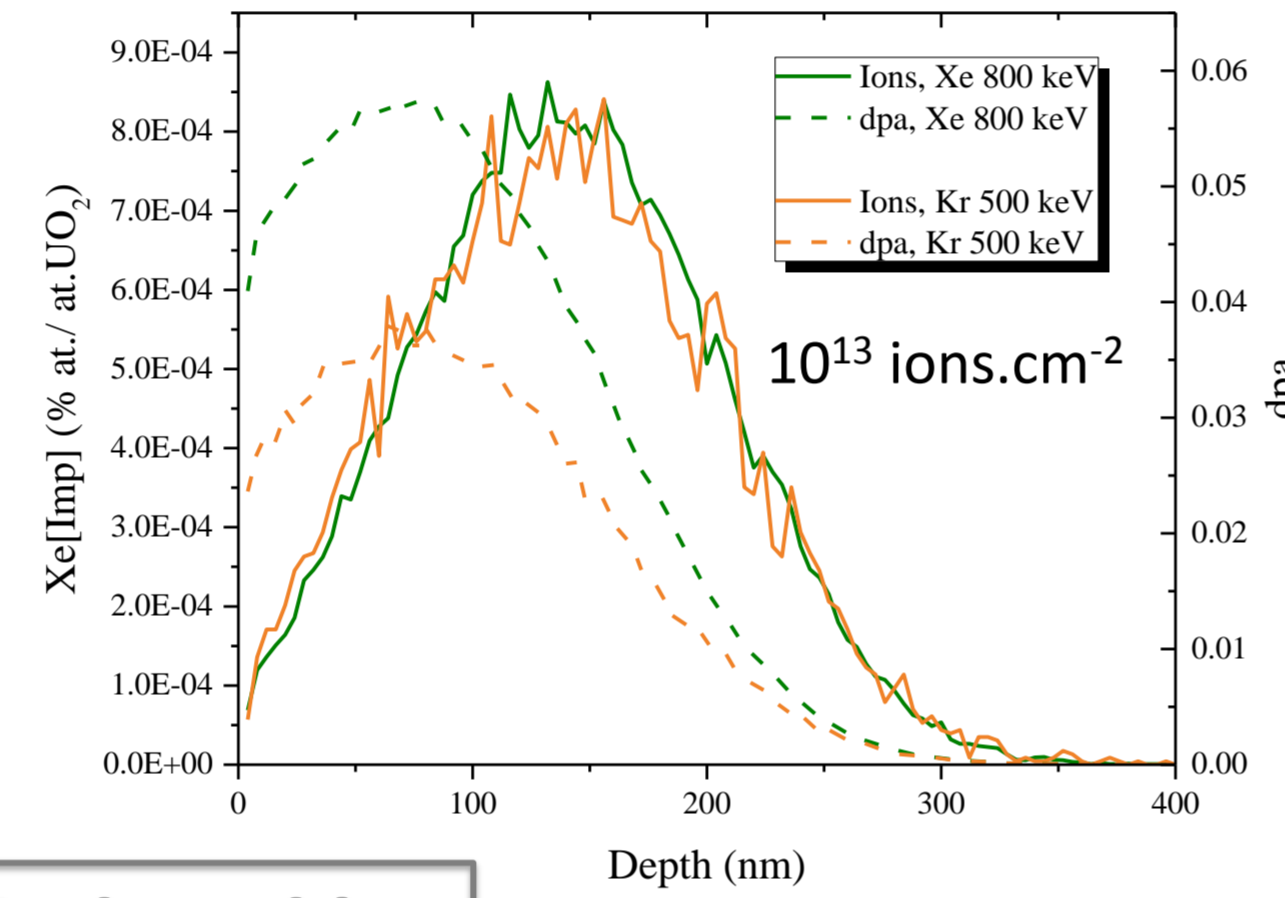
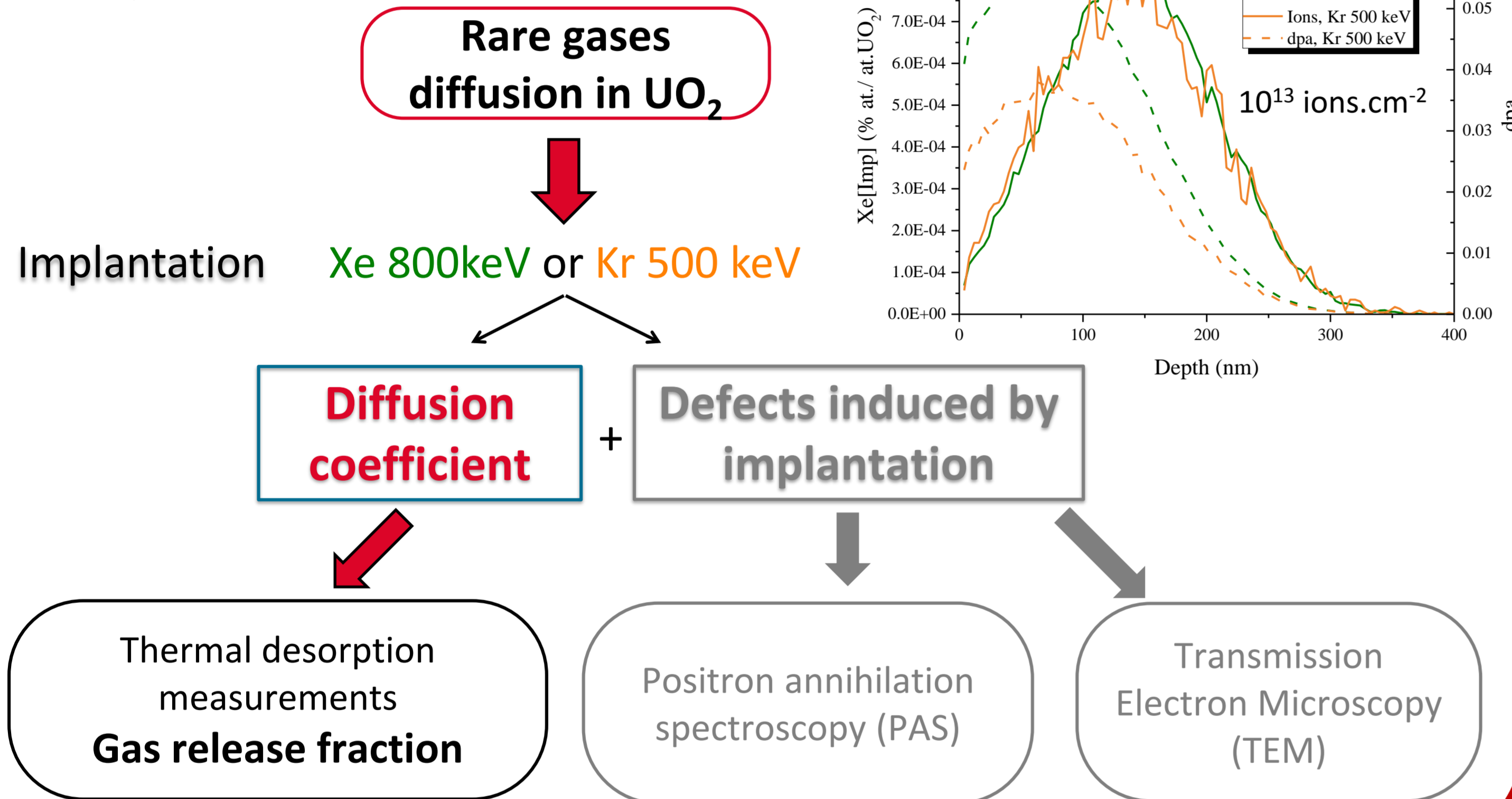


Objectives

- 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

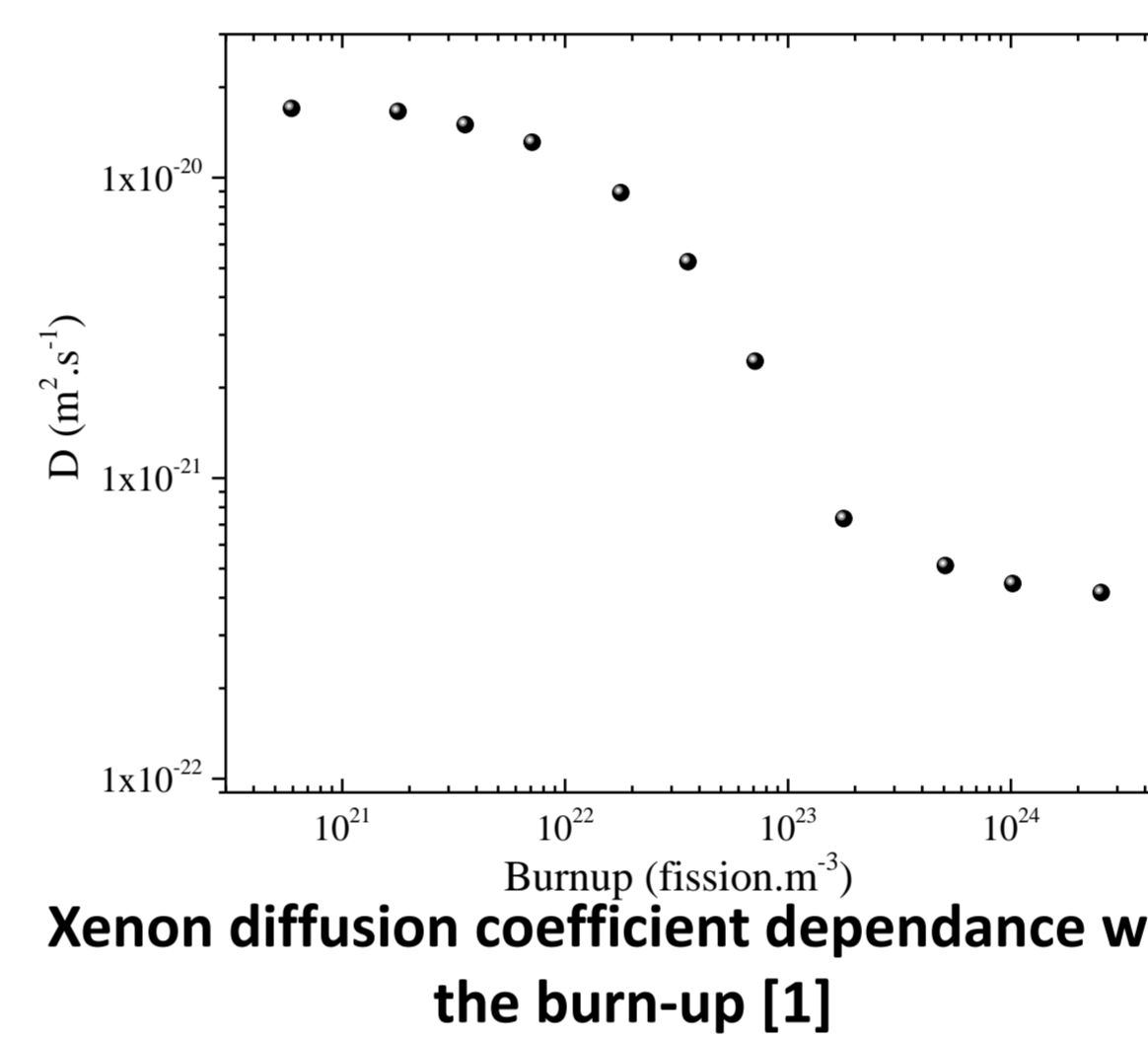
➤ Separated effect studies



Literature

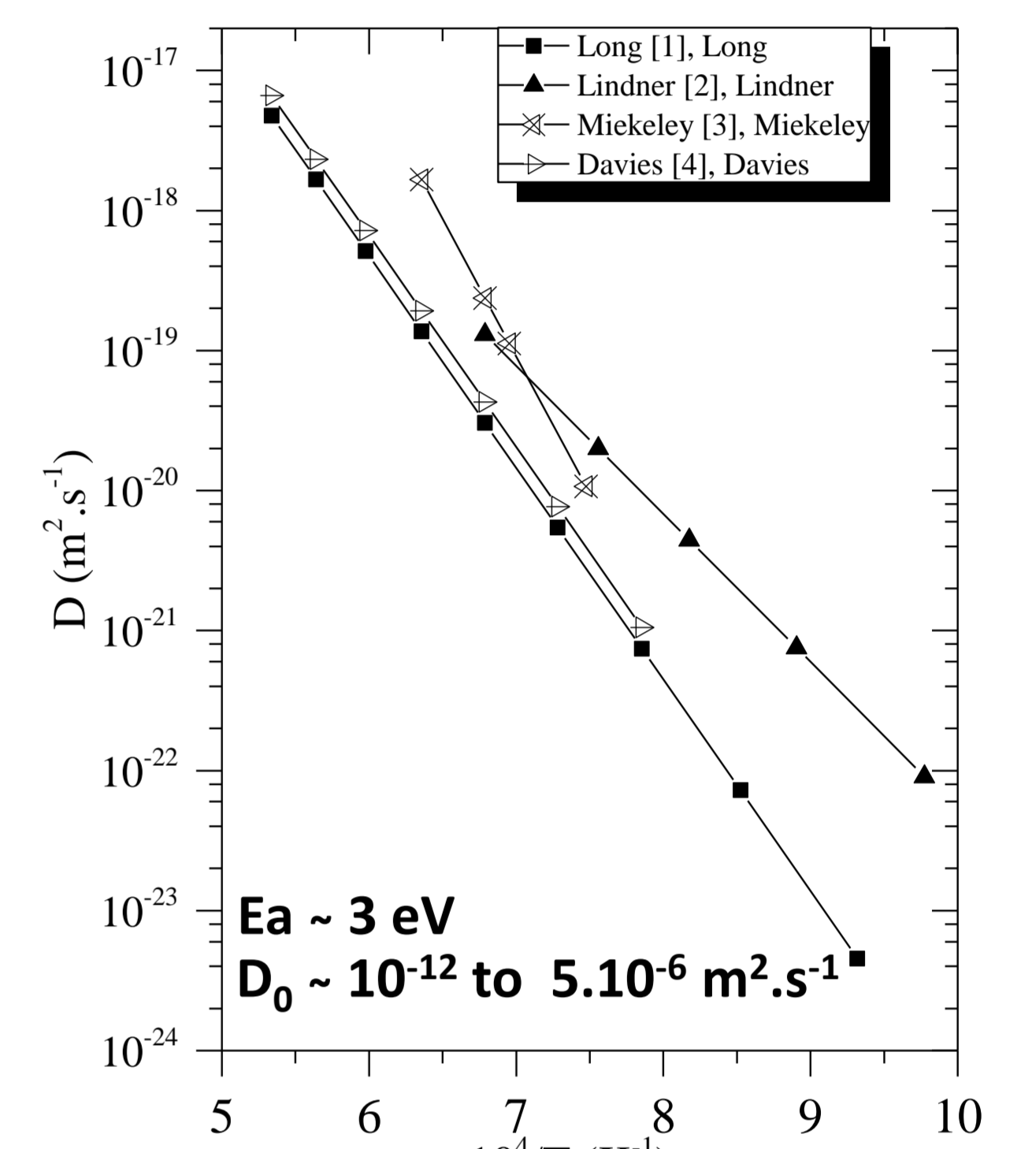
Diffusion coefficient dependence

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



Xenon diffusion coefficient dependence 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 Mätzke, Z. Naturforschung 14a (1959)
- [3] Miekeley and Felix, JNM 42 (1972)
- [4] Davies Long, AERE-R 4347 (1963)

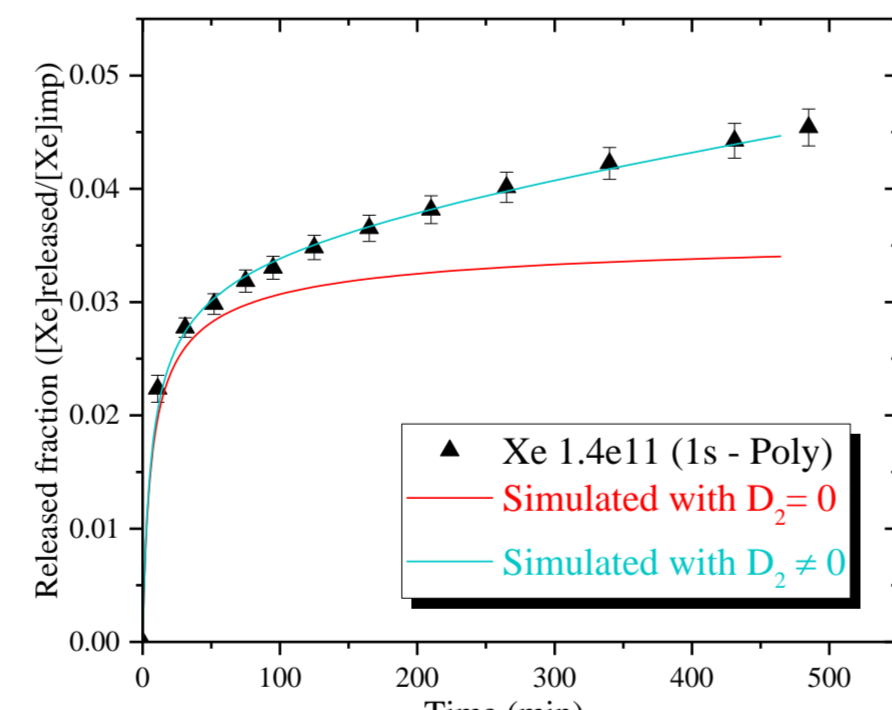
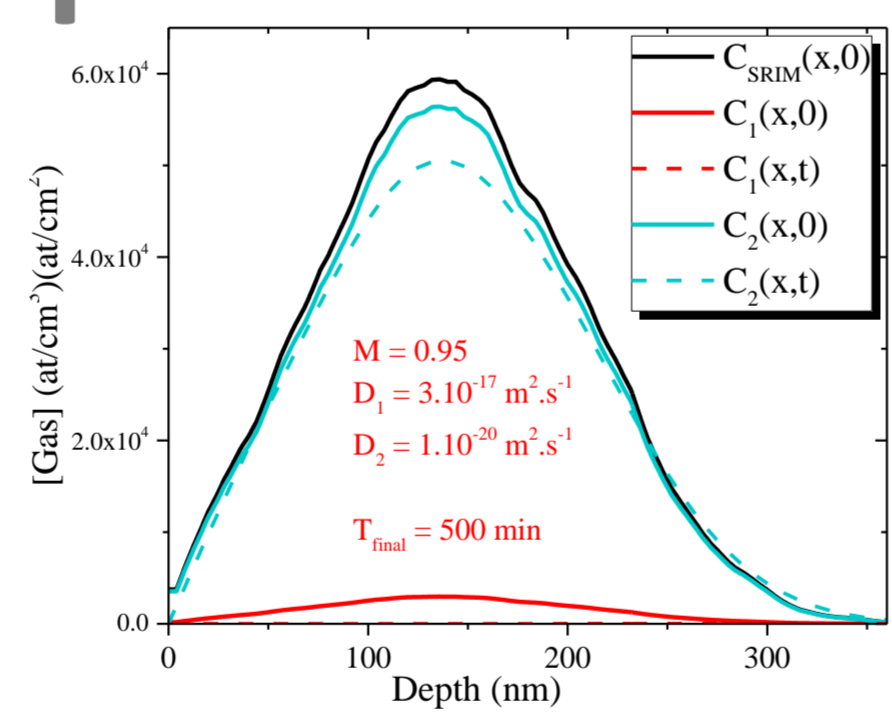
Diffusion model : two populations

Second Fick law

For $i = 1$ or 2 :

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

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



C_1 : Gas concentration mobile with D_1 → Burst effect

M : Fraction of 2 populations

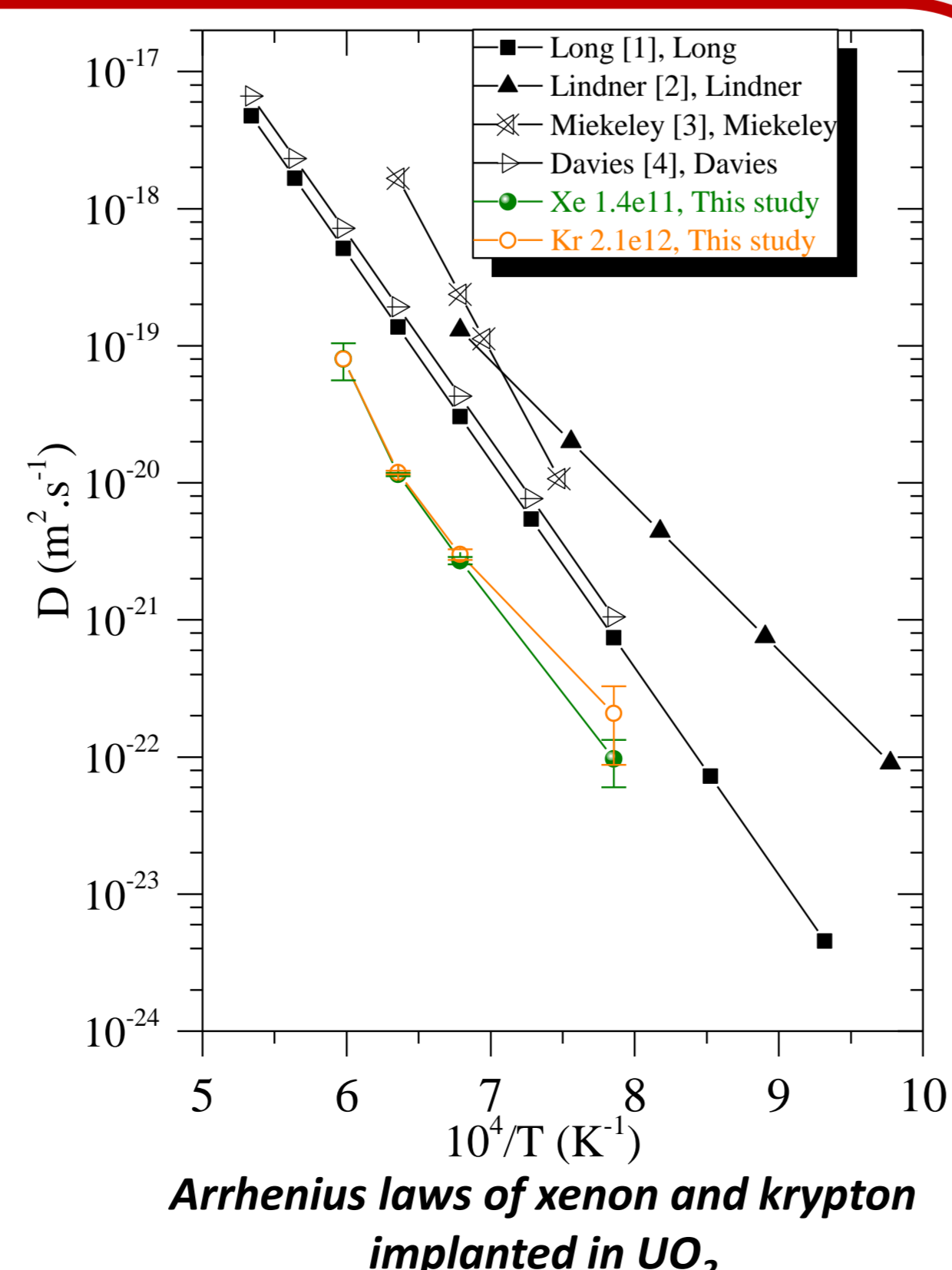
C_2 : Gas concentration mobile with D_2 → Intrinsic diffusion

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

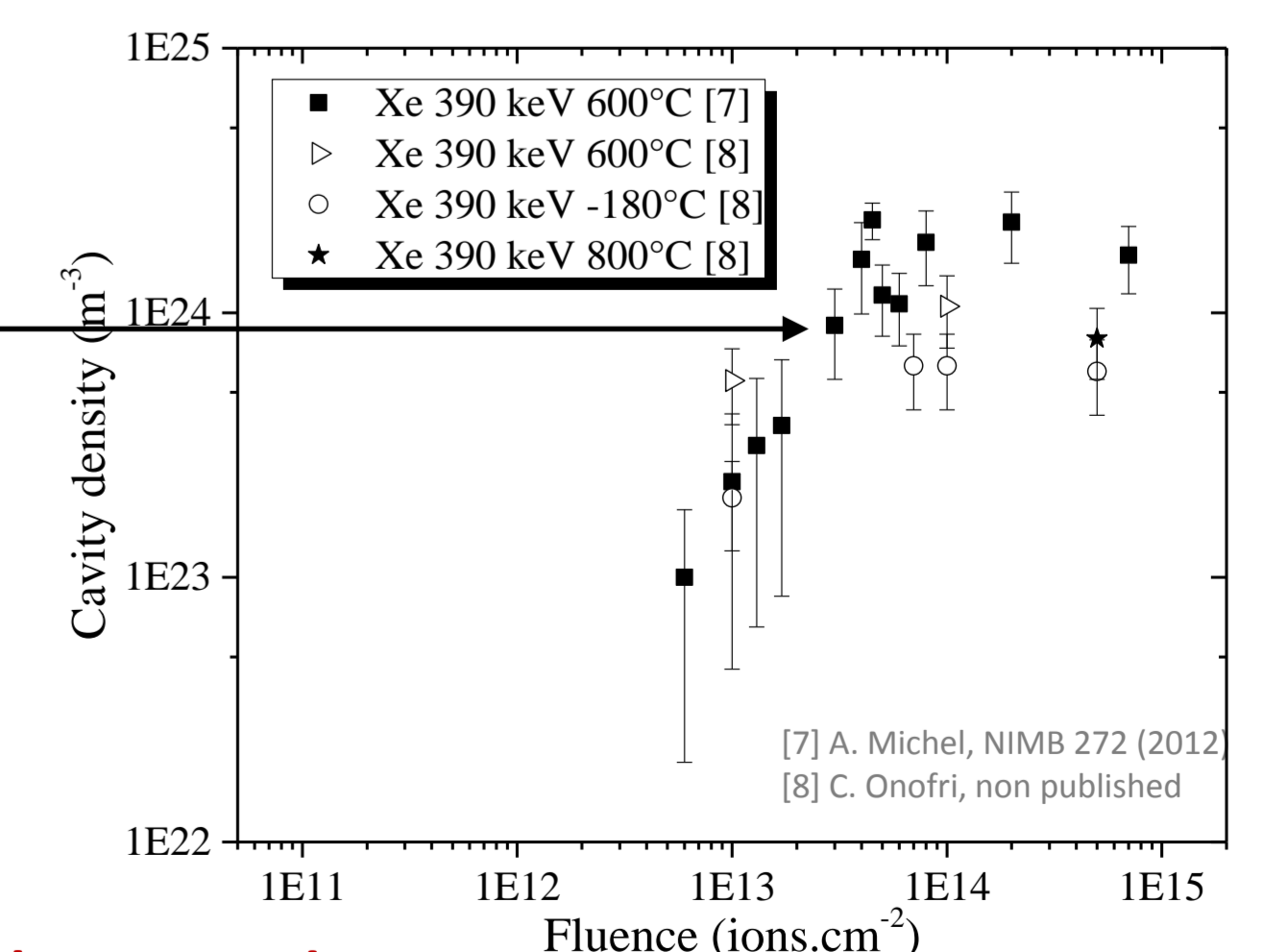
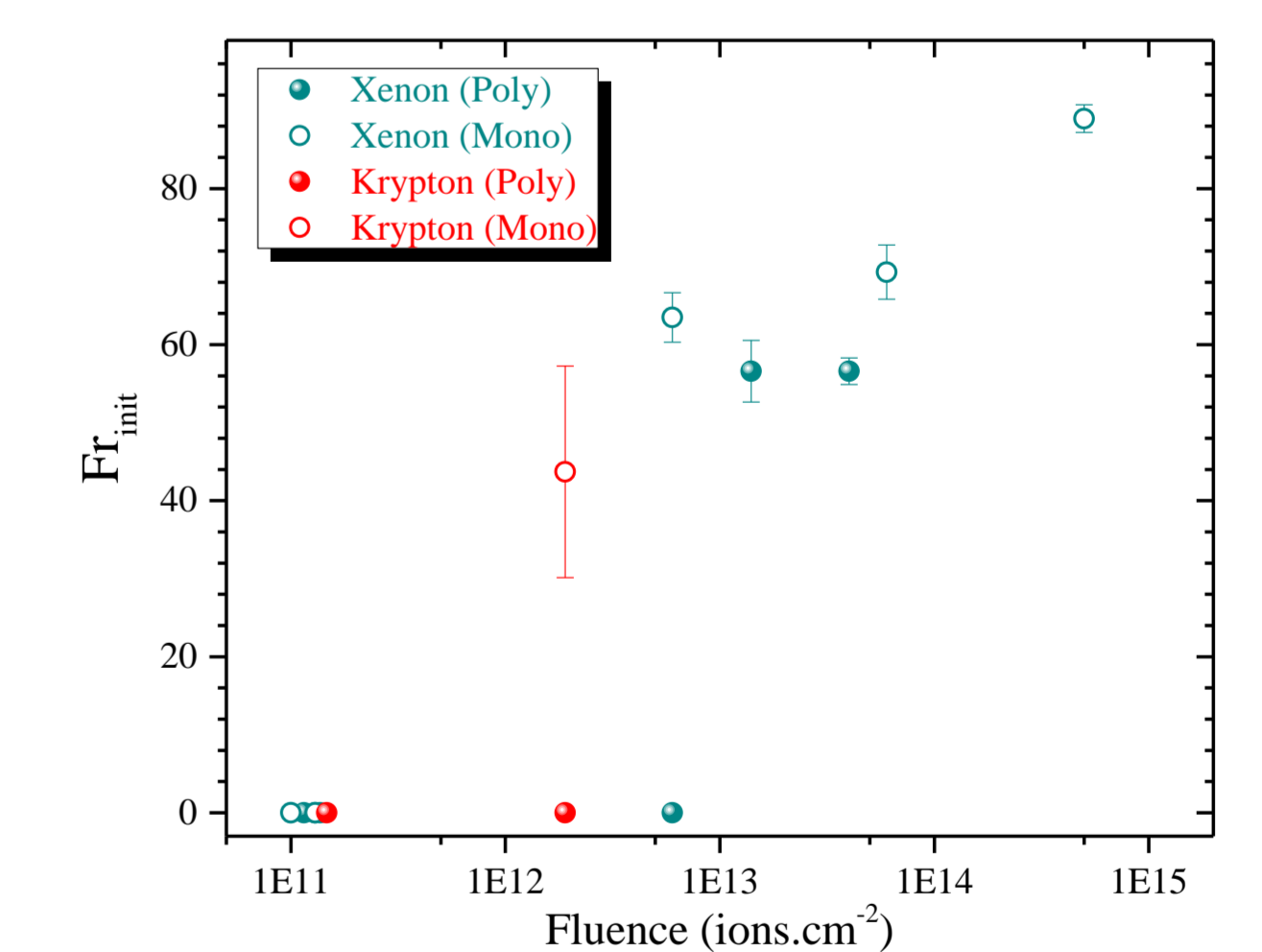
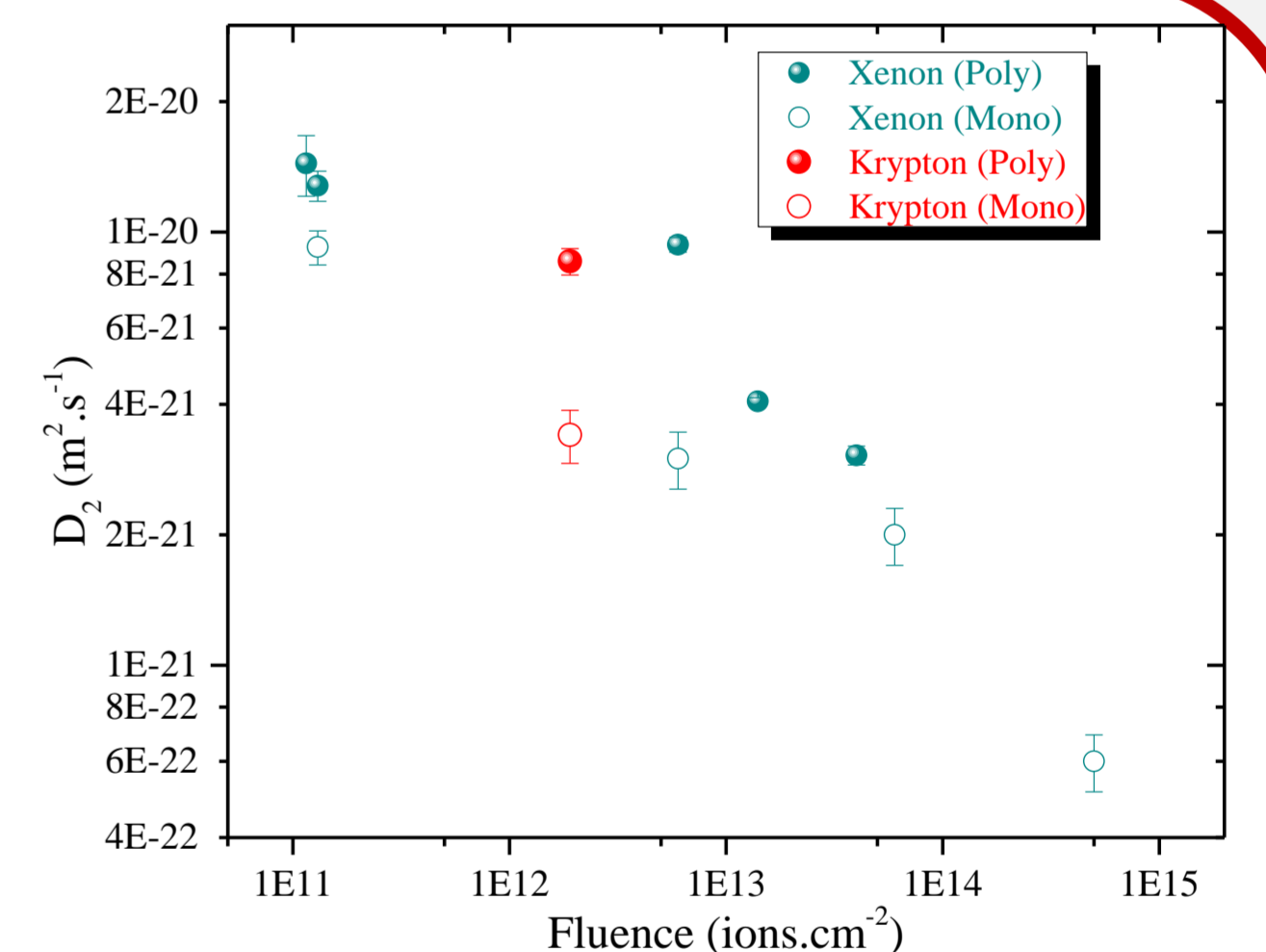
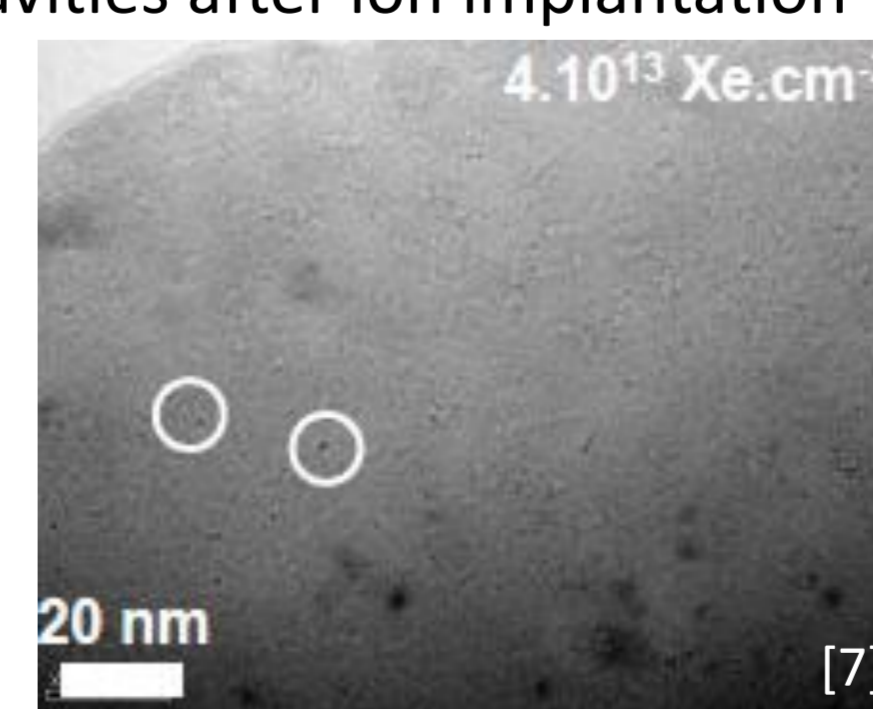
$$\begin{cases} C_1(x,0) = (1-M) \times C_{SRIM} Profile \\ C_2(x,0) = M \times (1 - Fr_{init}) \times C_{SRIM} Profile \\ C_p(x,0) = M \times Fr_{init} \times C_{SRIM} Profile \end{cases}$$

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