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M. Gerardin, E. Gilibert, D. Horlait, P. Desgardin, G. Carlot, et al.. Effect of cavities induced by ion implantation on rare gases diffusion in uranium dioxide. SHIM-ICACS - 10th International symposium on swift heavy ions in matter & 28th international conference on Atomic collisions in solids, Jul 2018, Caen, France. cea-02338620

**HAL Id: cea-02338620**

**<https://cea.hal.science/cea-02338620>**

Submitted on 21 Feb 2020

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

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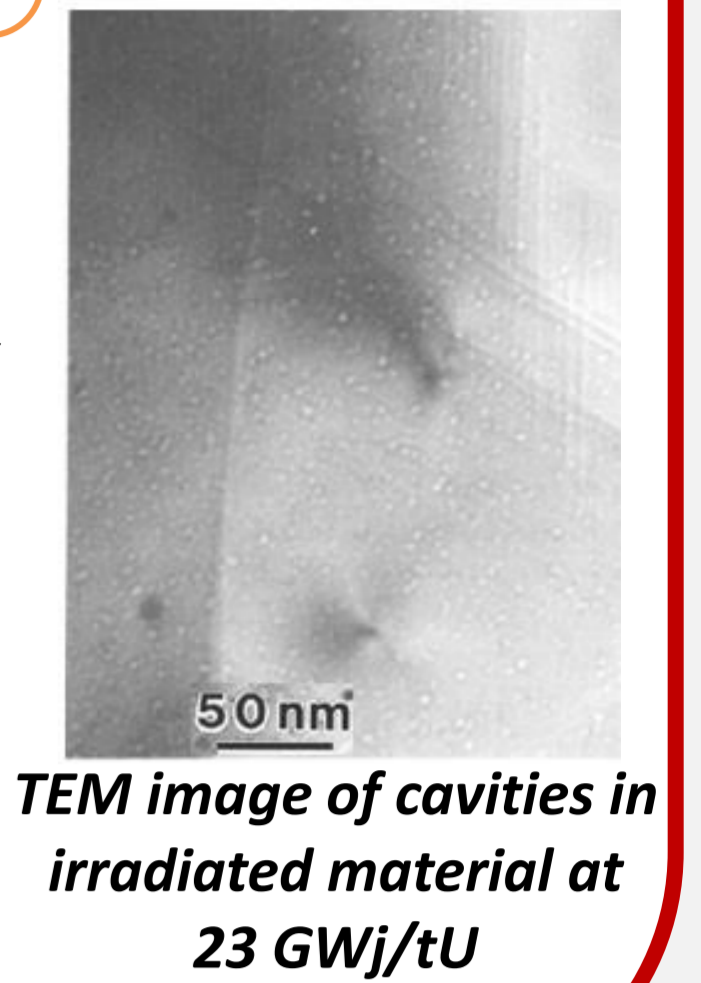
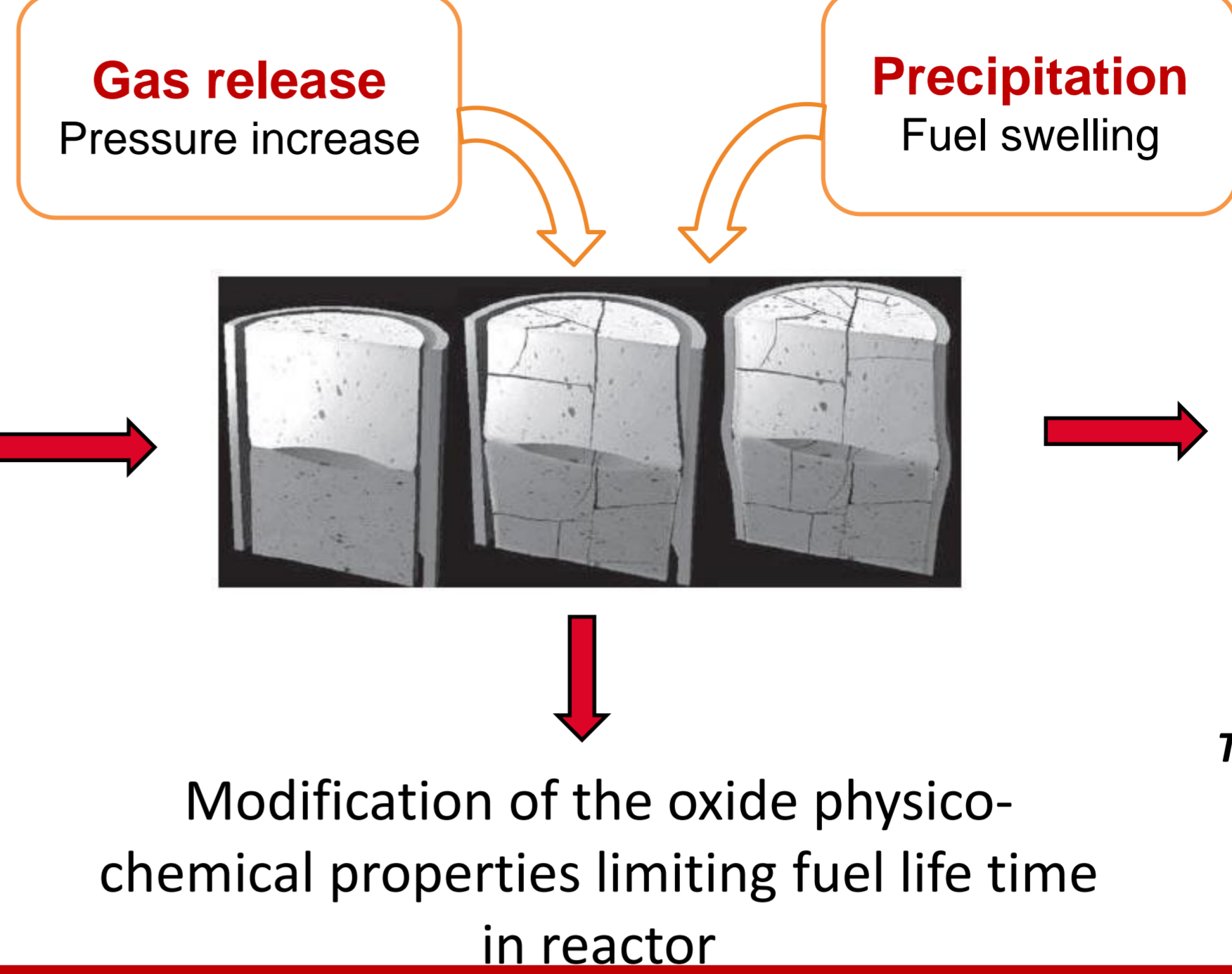
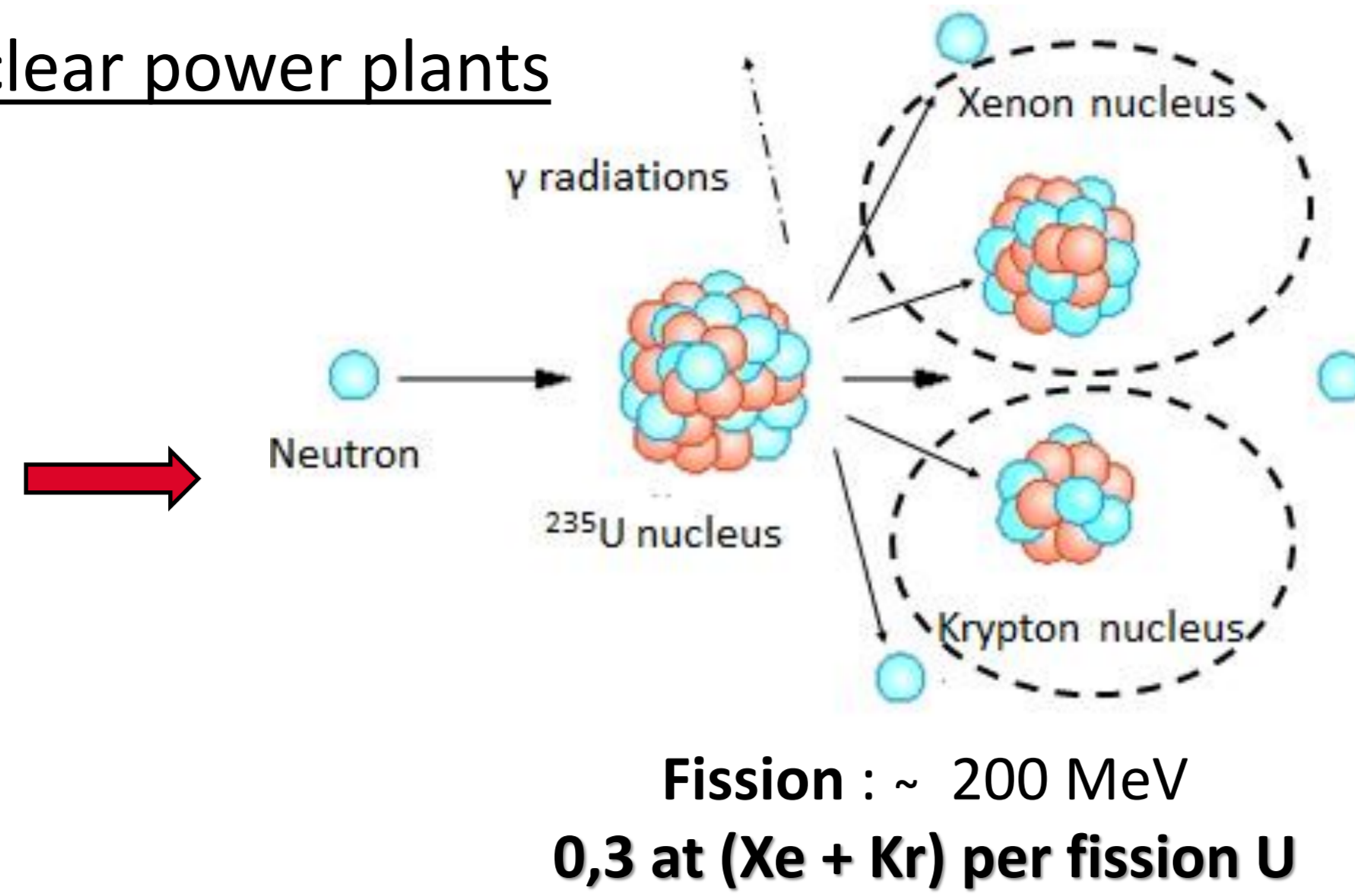
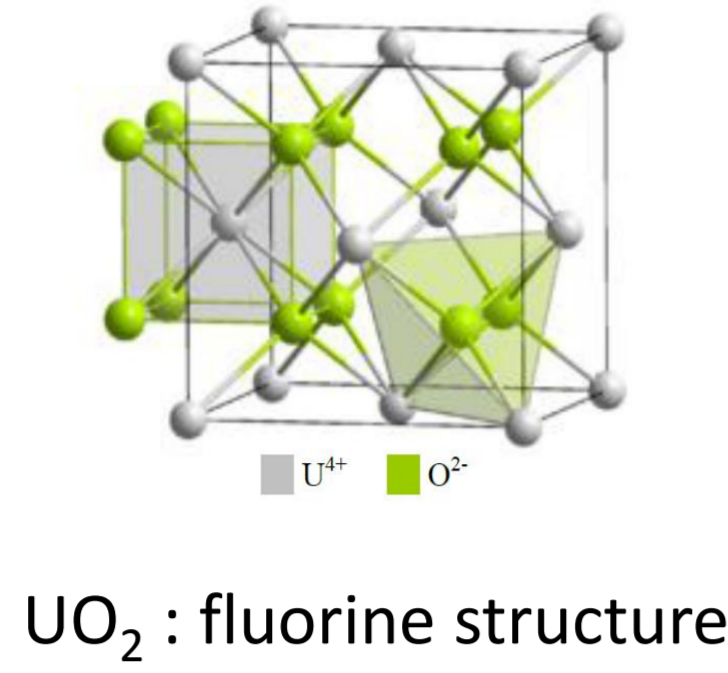
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## Context

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

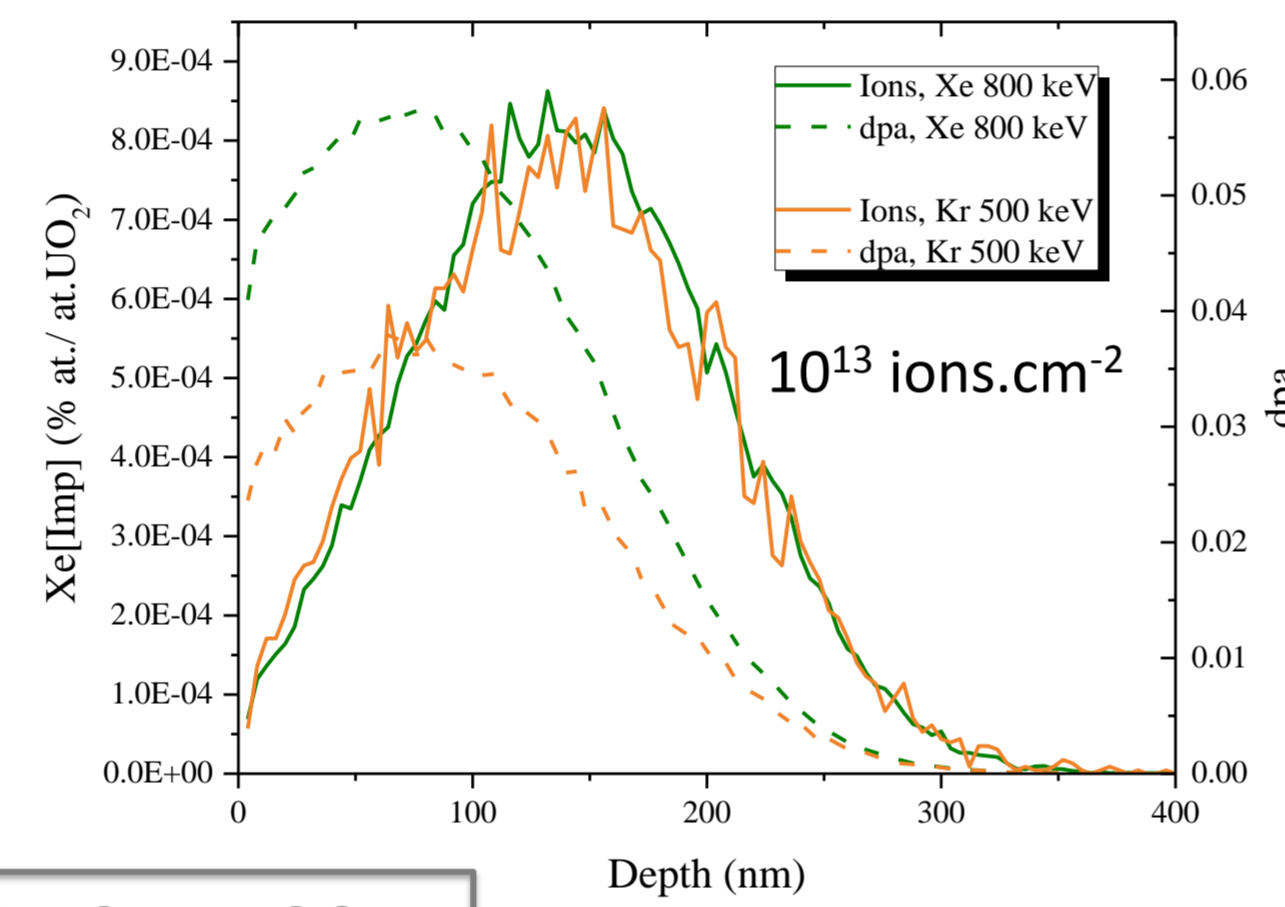
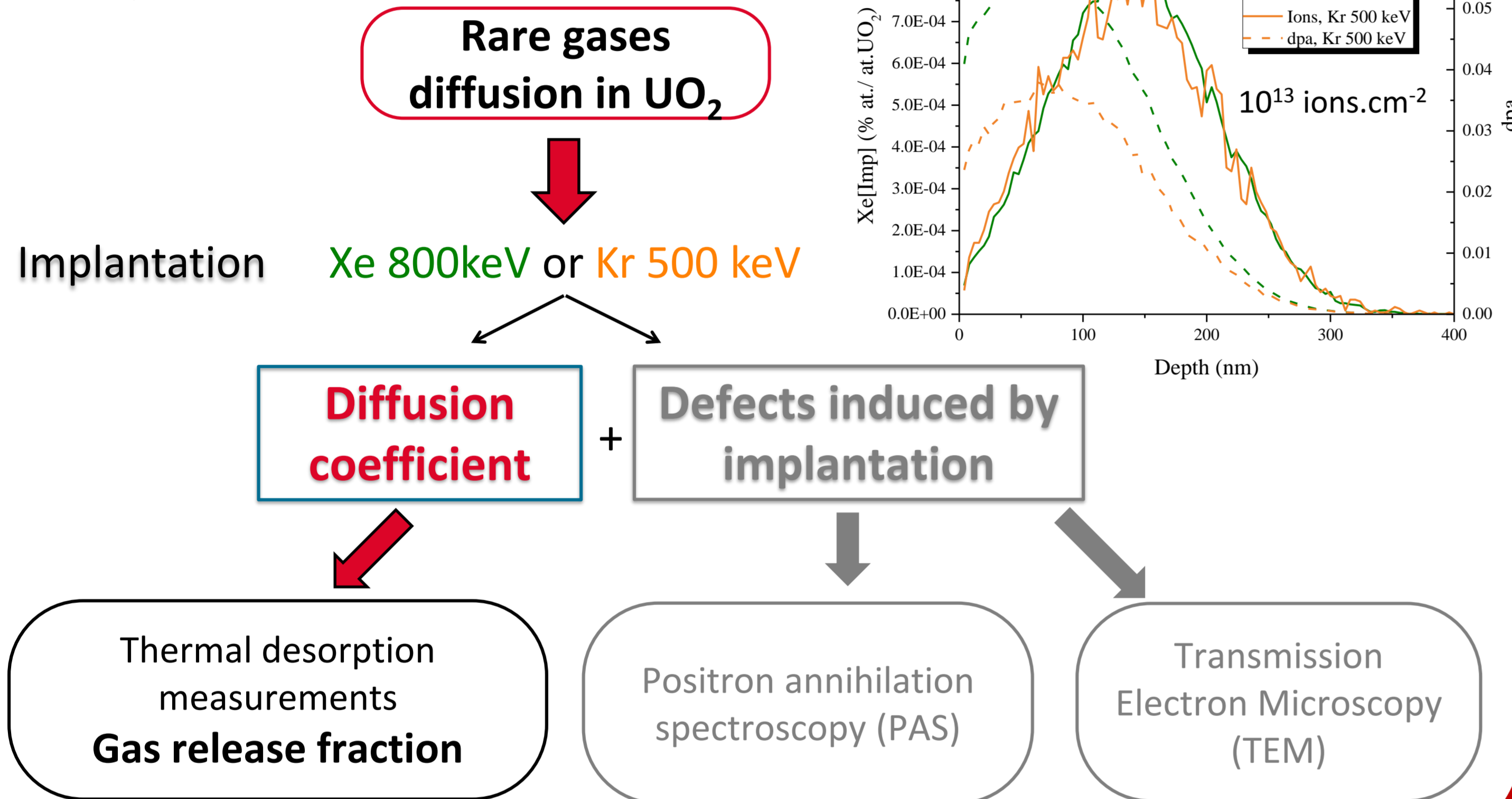


## Objectives

- 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

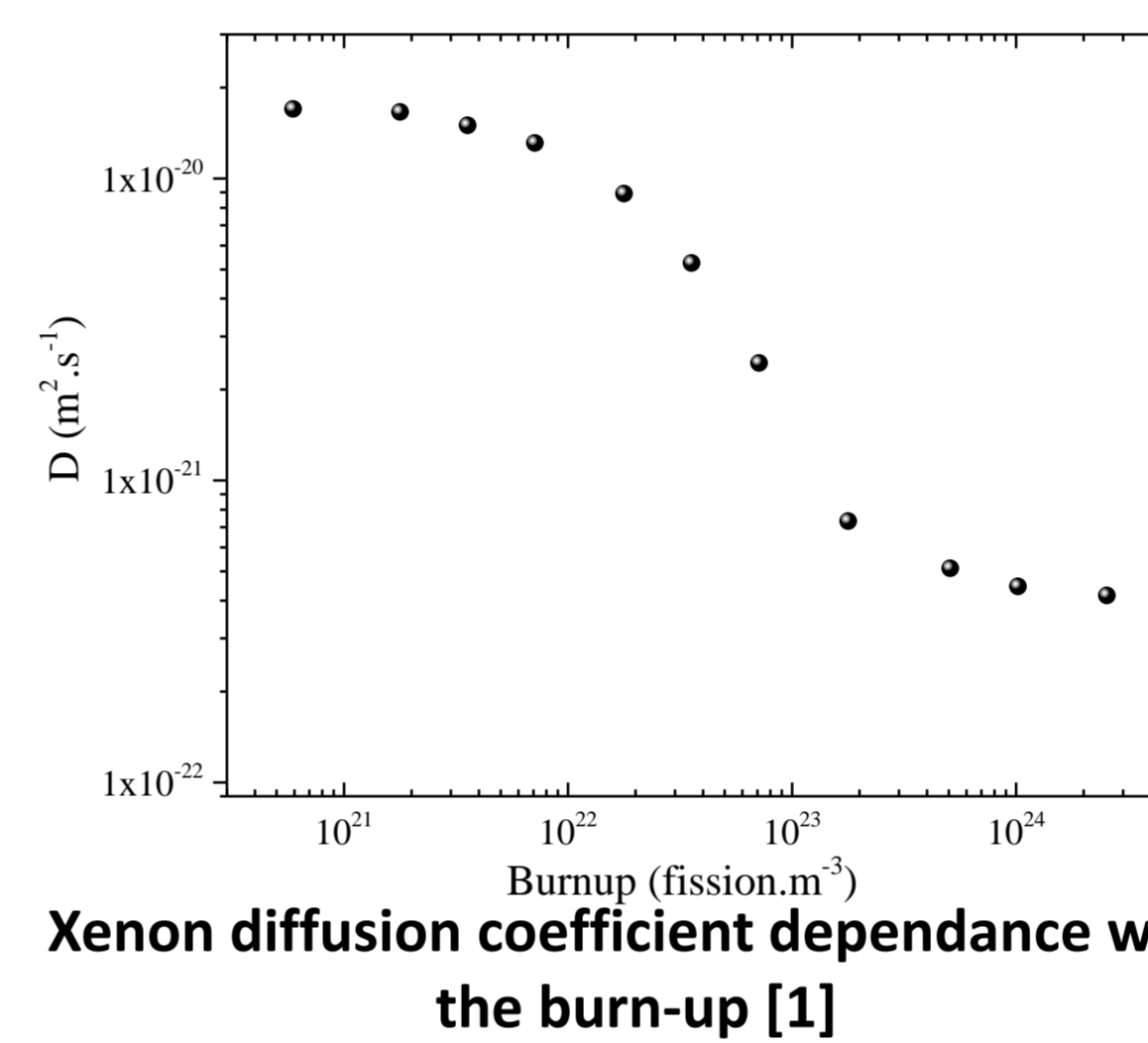
➤ Separated effect studies



## Literature

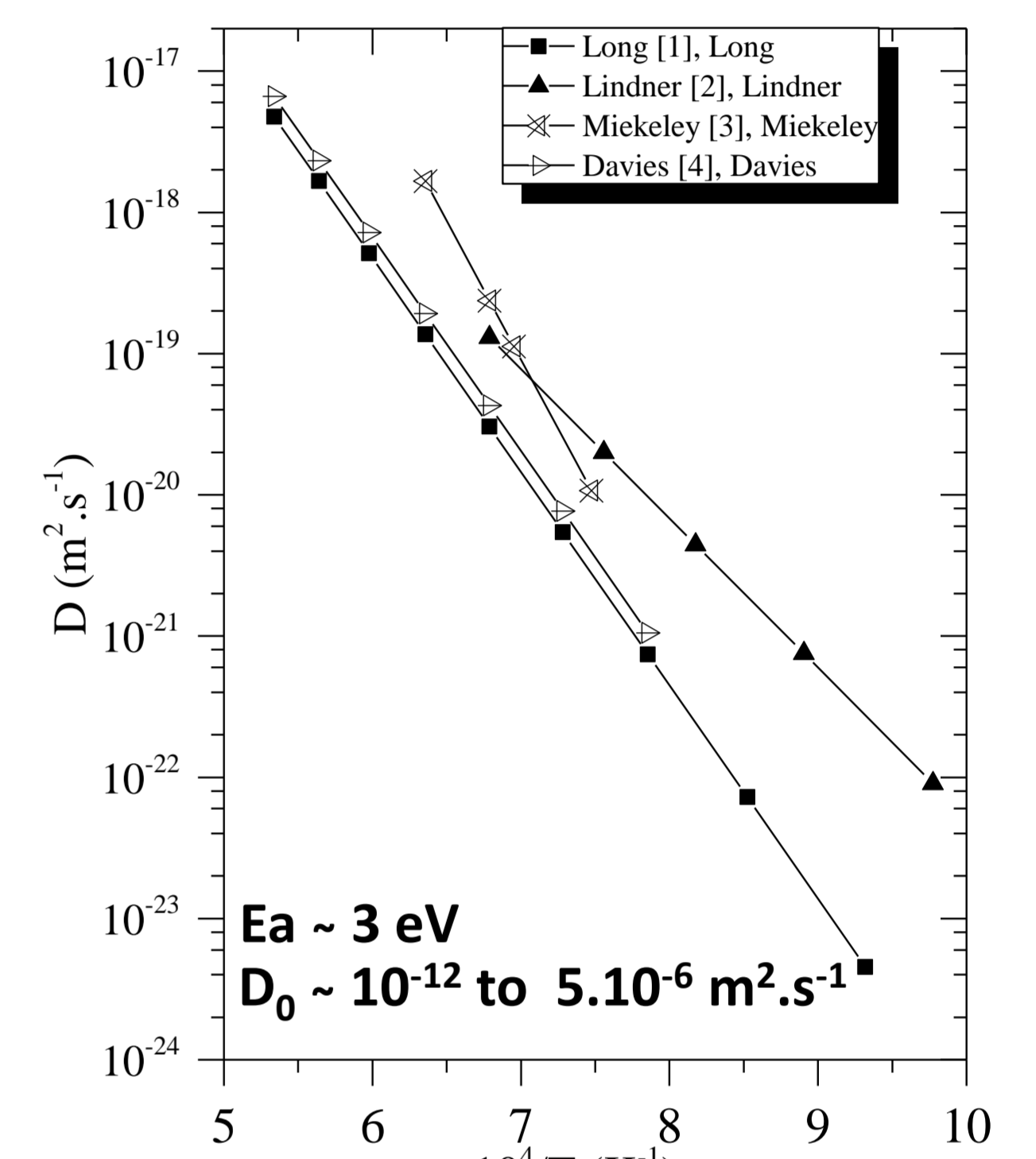
Diffusion coefficient dependance

- 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)

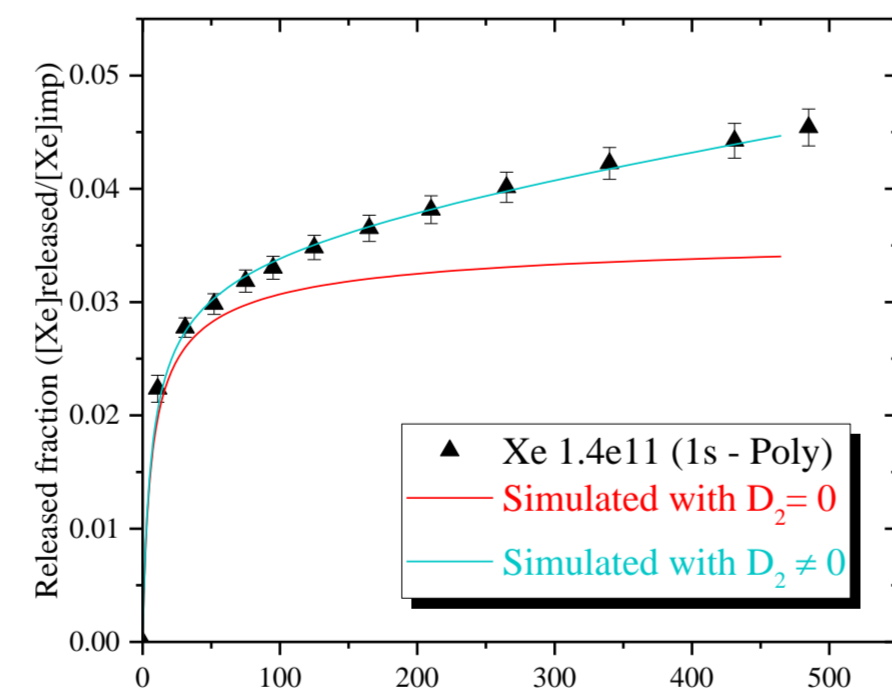
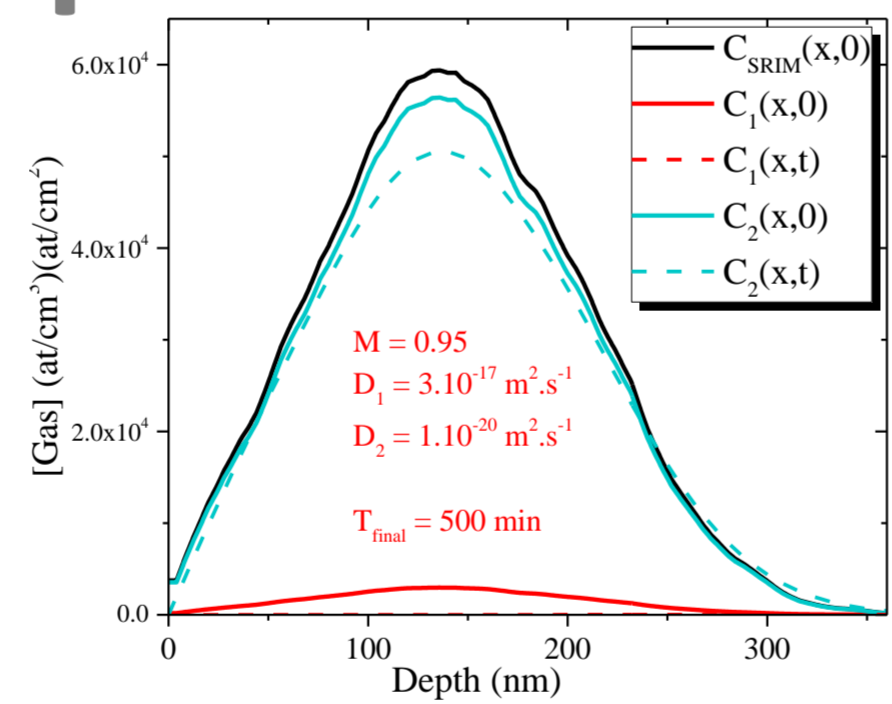
## Diffusion model : two populations

Second Fick law

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

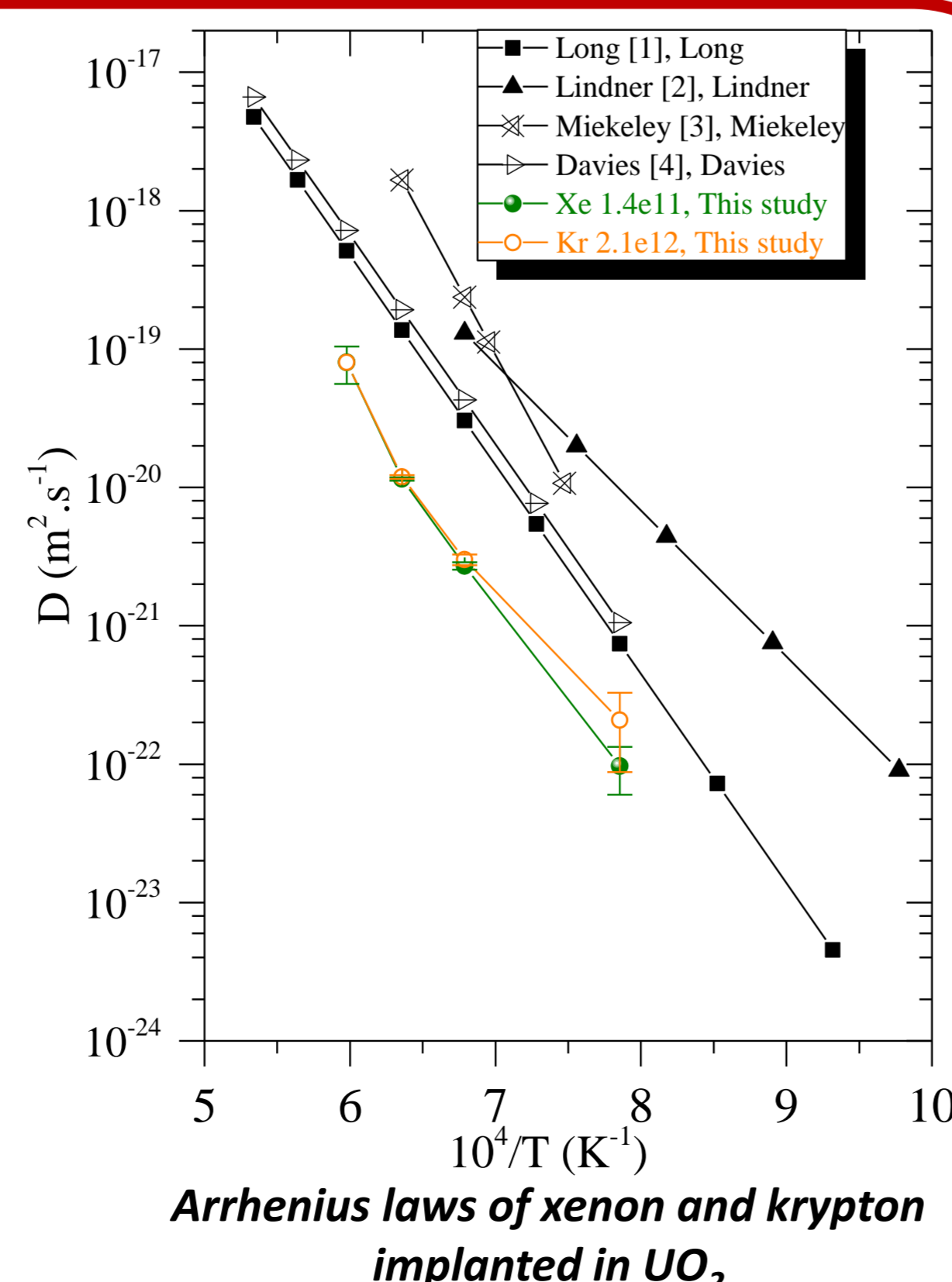
$C_2$  : Gas concentration mobile with  $D_2$  → Intrinsic diffusion

## 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  $UO_2$

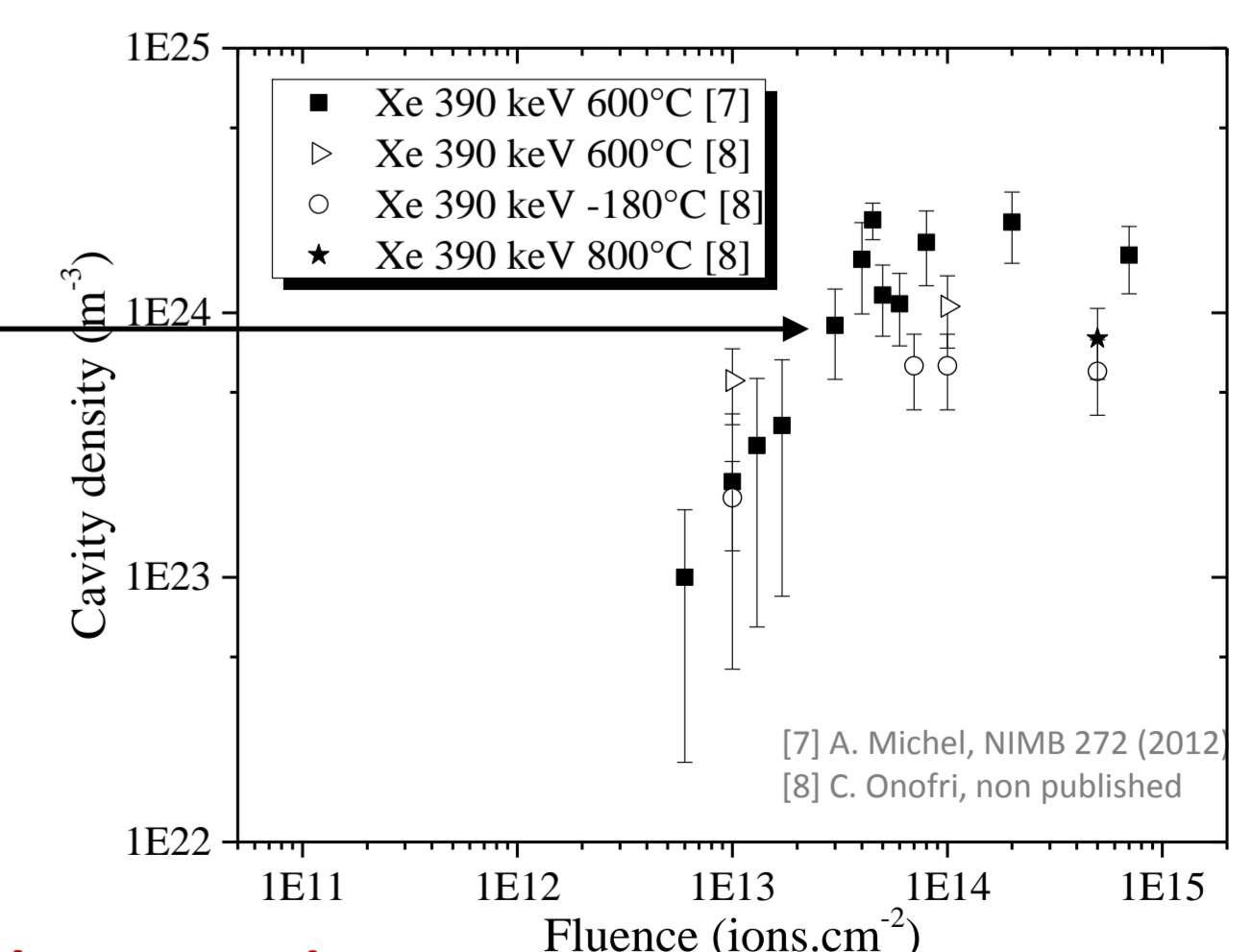
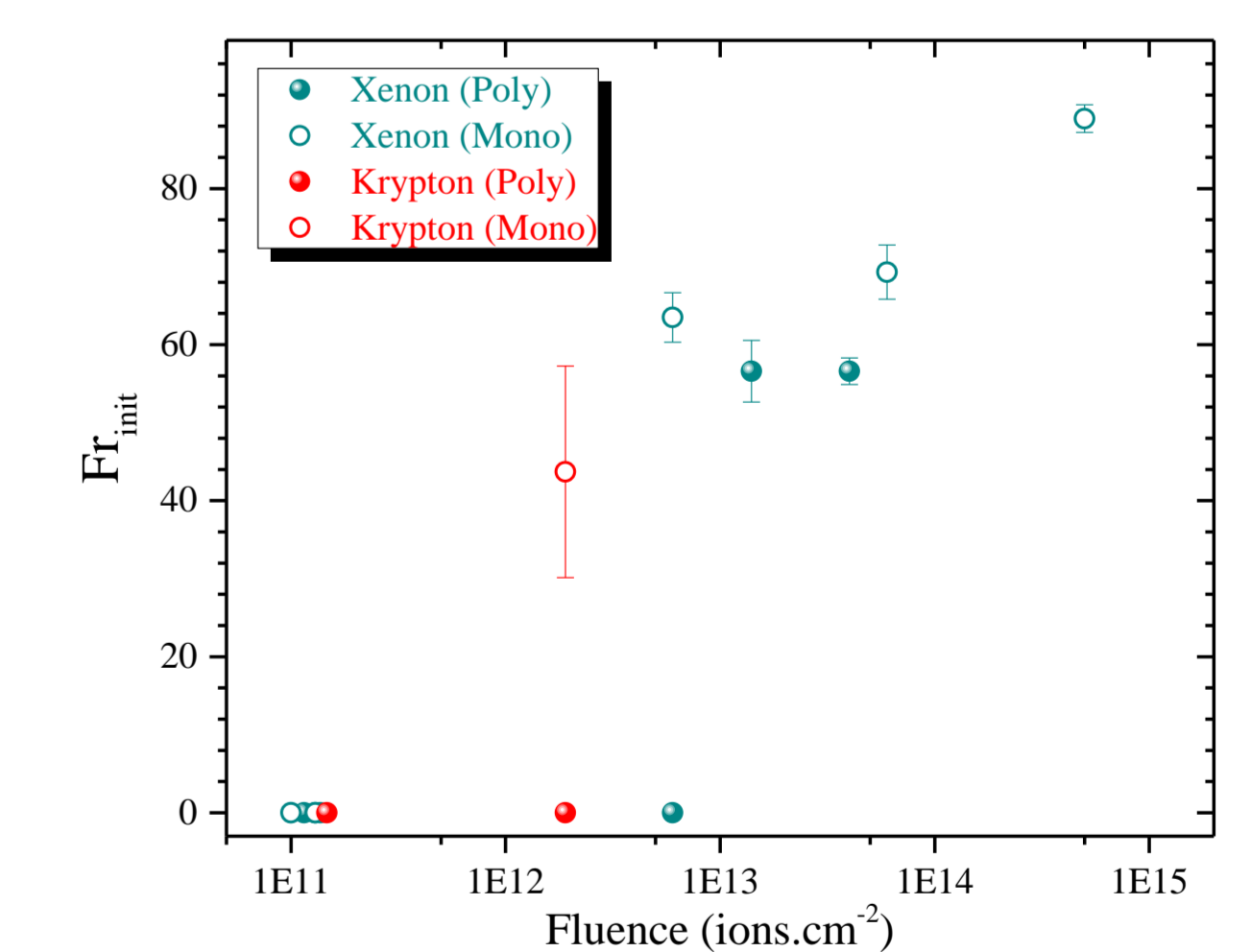
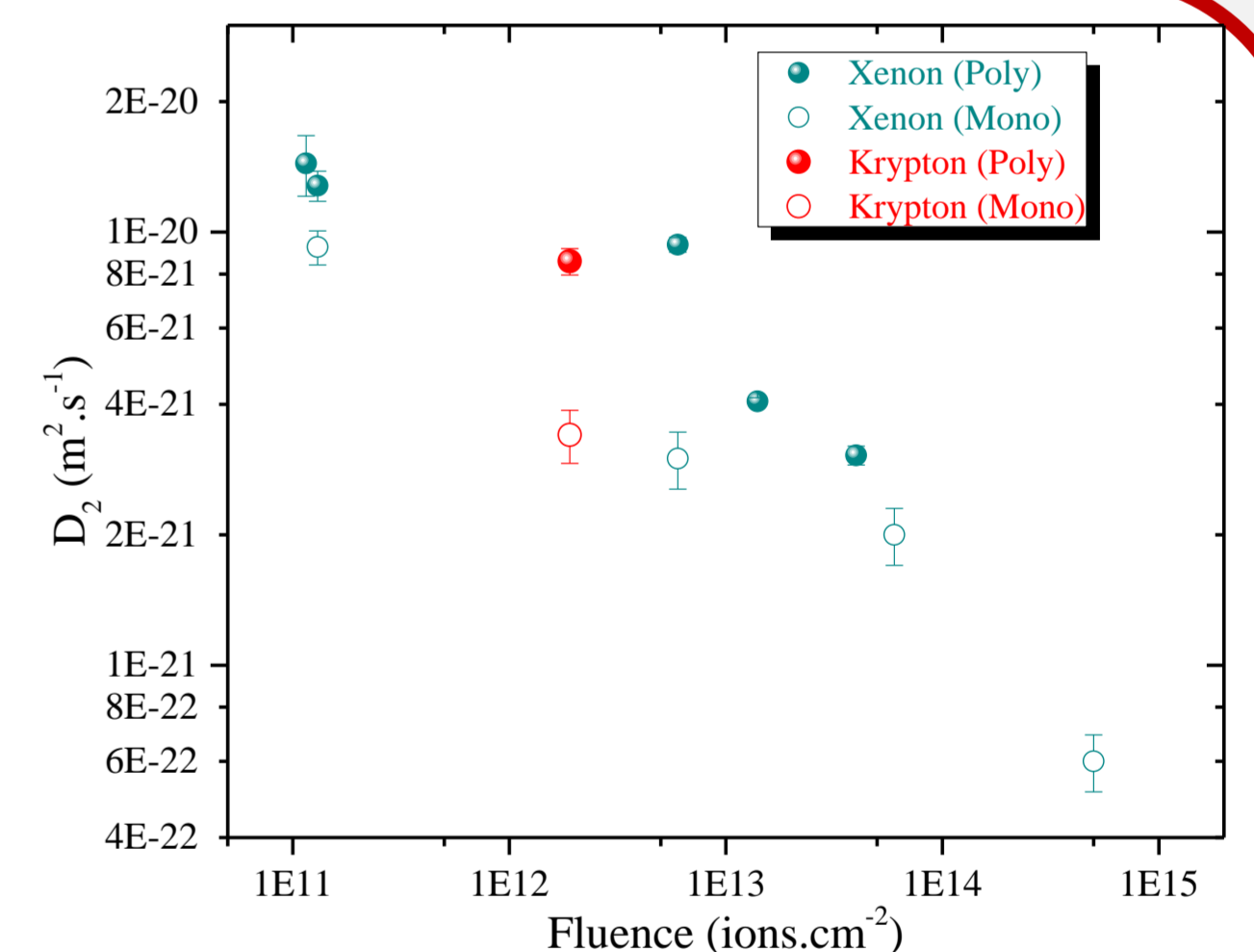
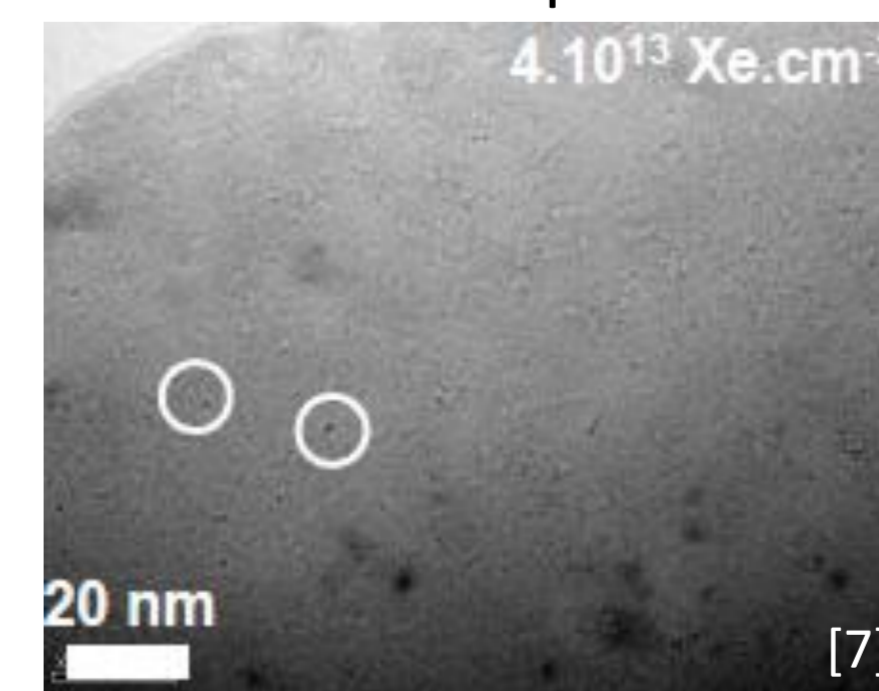
$$\begin{cases} C_1(x,0) = (1-M) \times C_{SRIM} Profile \\ C_2(x,0) = M \times (1 - Fr_{init}) \times C_{SRIM} Profile \\ C_p(x,0) = M \times Fr_{init} \times C_{SRIM} Profile \end{cases}$$

$Fr_{init}$  : 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