Channeling, Focusing and Range

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A simple picture of slowing down

- The slowing down process of an ion impacting on a surface:

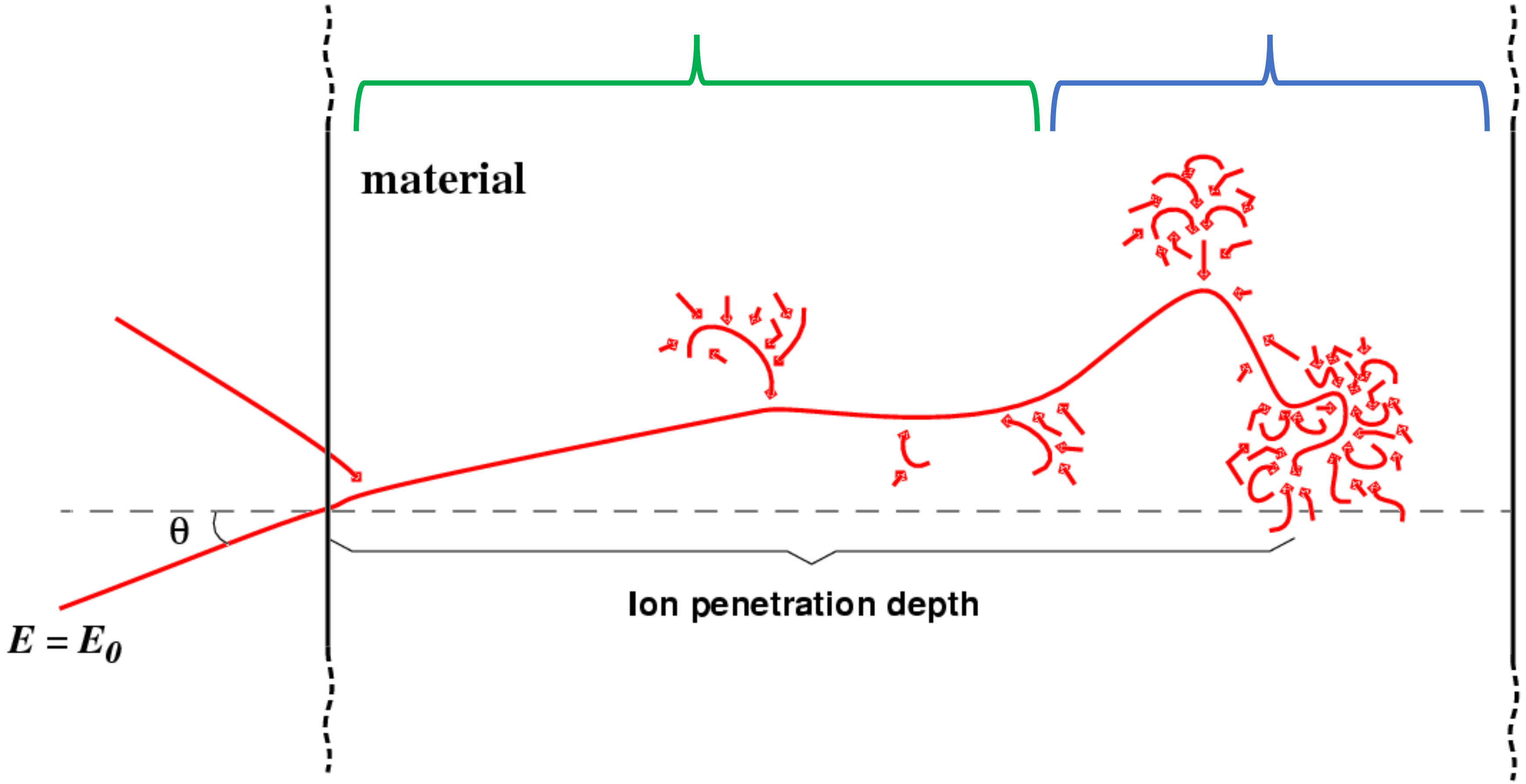


Image: Kai Nordlud

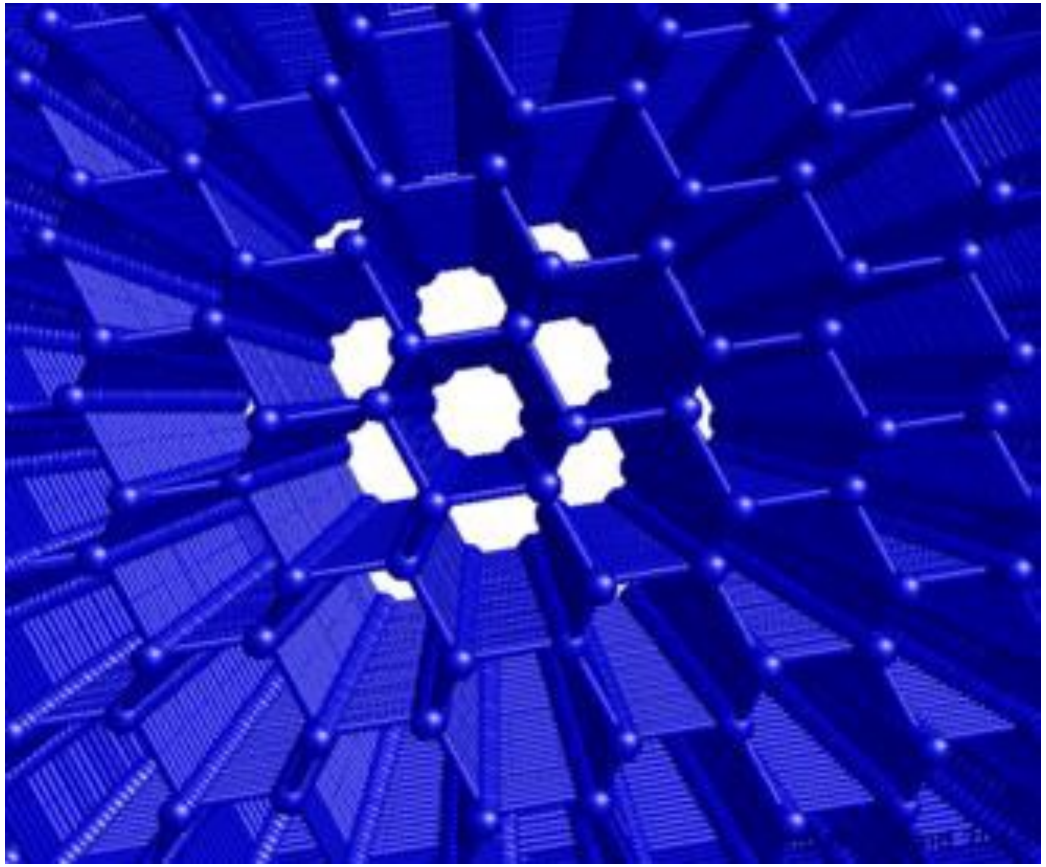
Modifications to K-P Model

3. Effect of crystallinity:

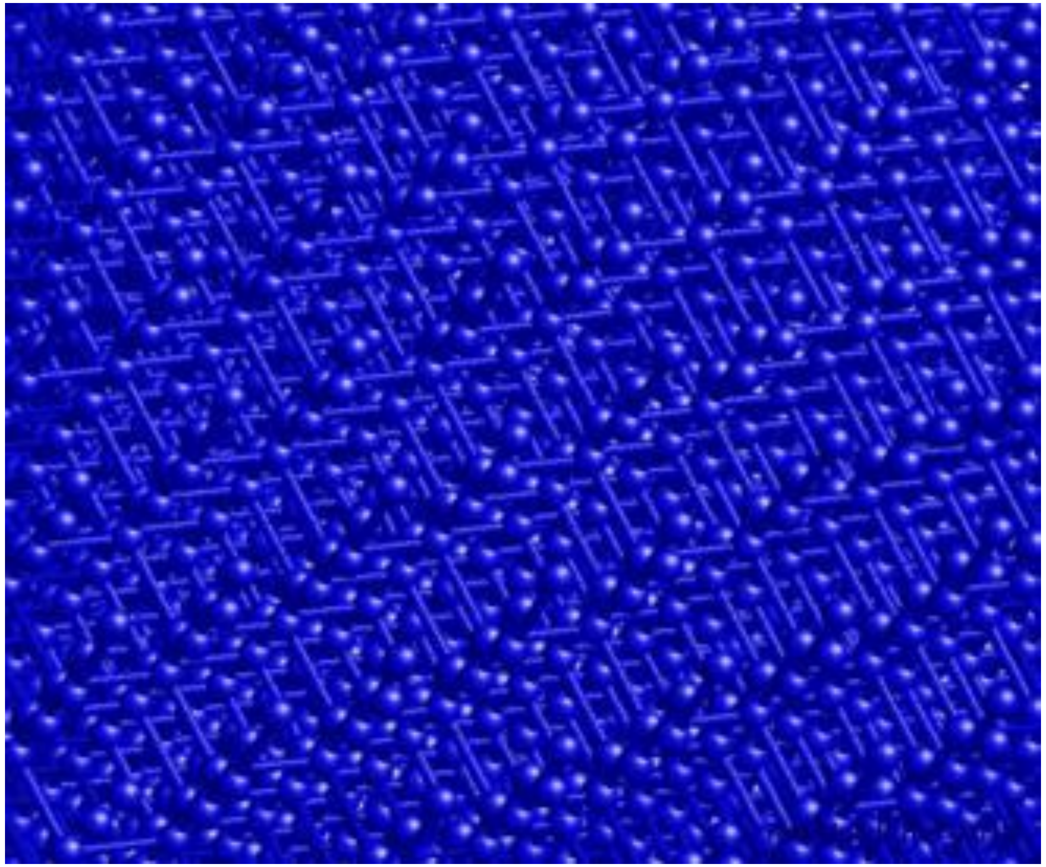
Focusing

Channeling

Channeling



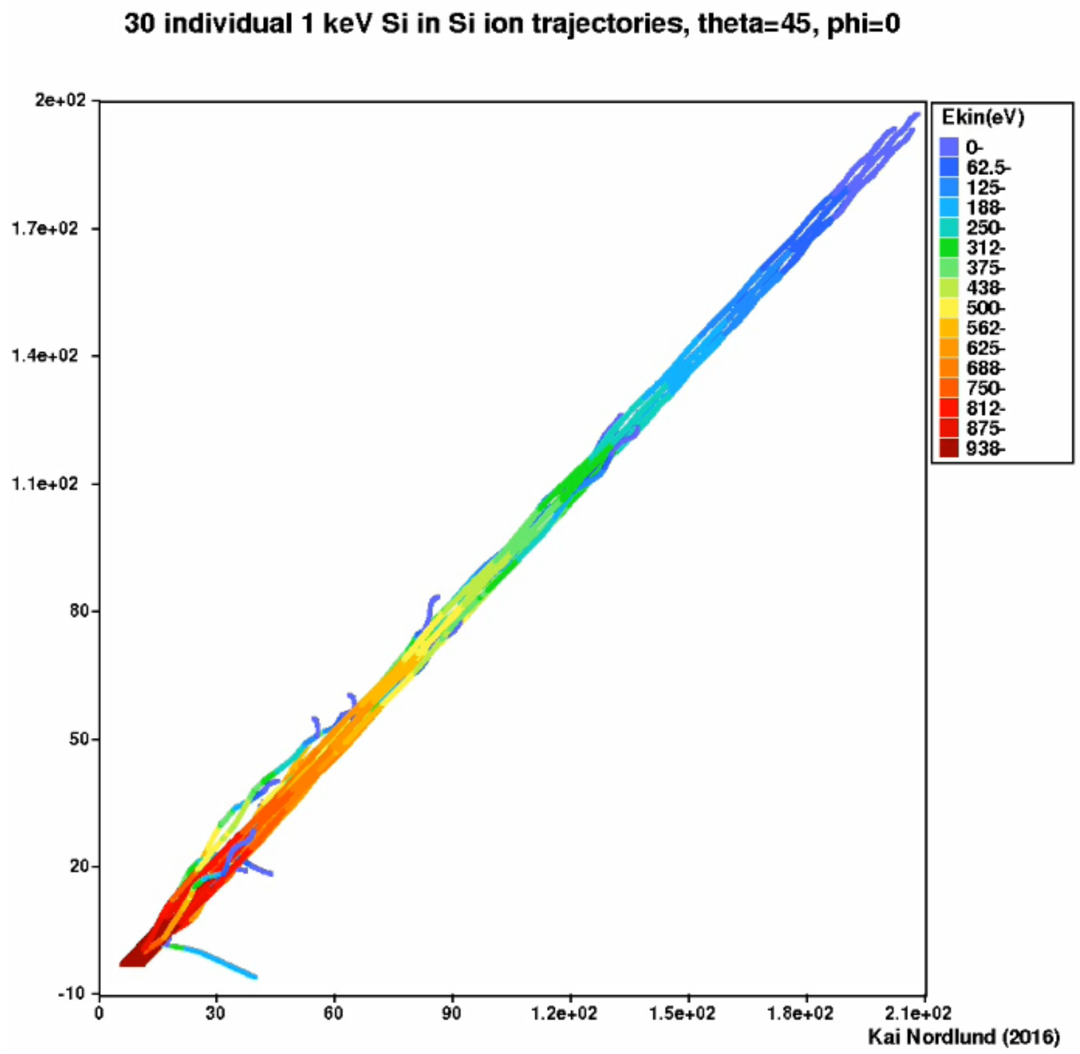
Down a primary zone axis

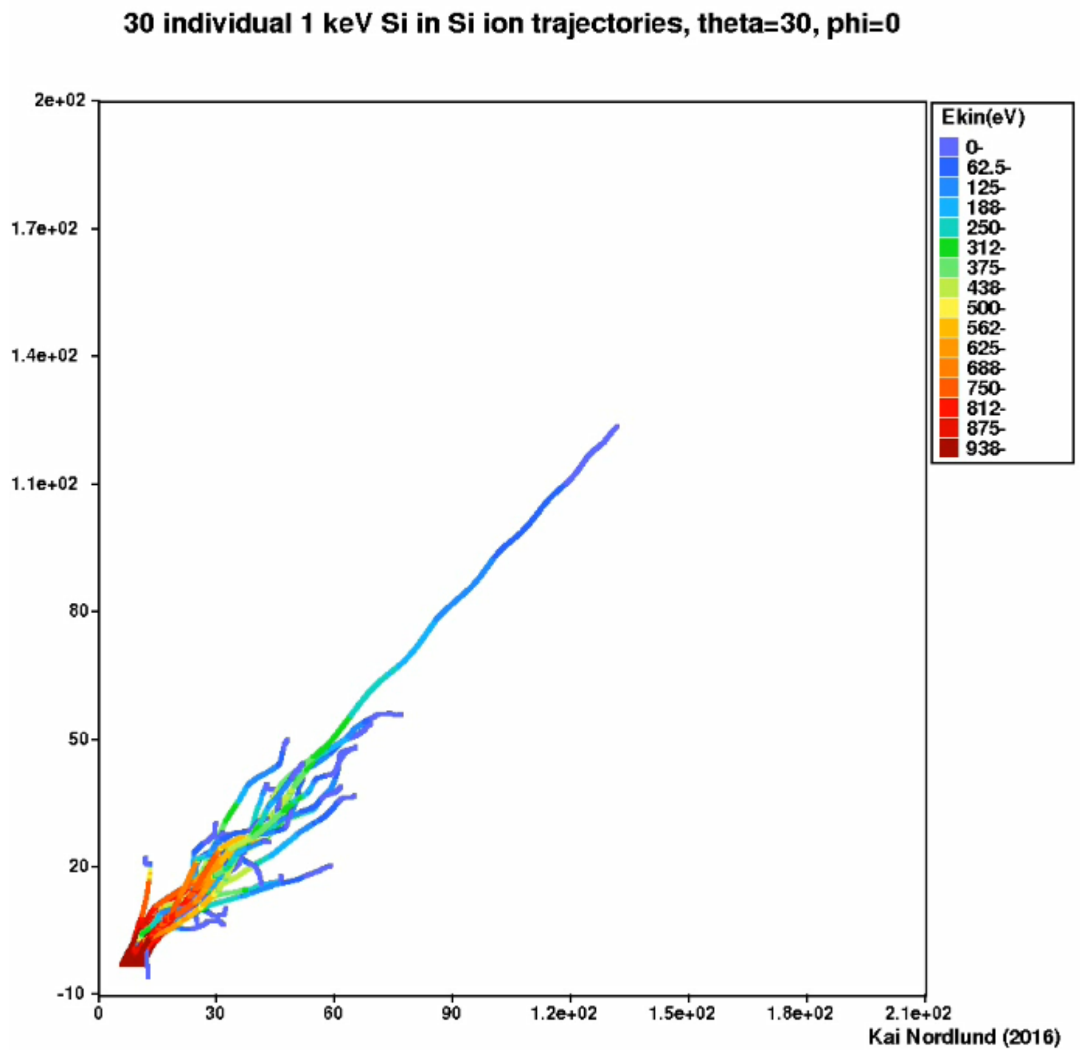


Down a random orienation

Images from Kai Nordlund

Channeling illustration





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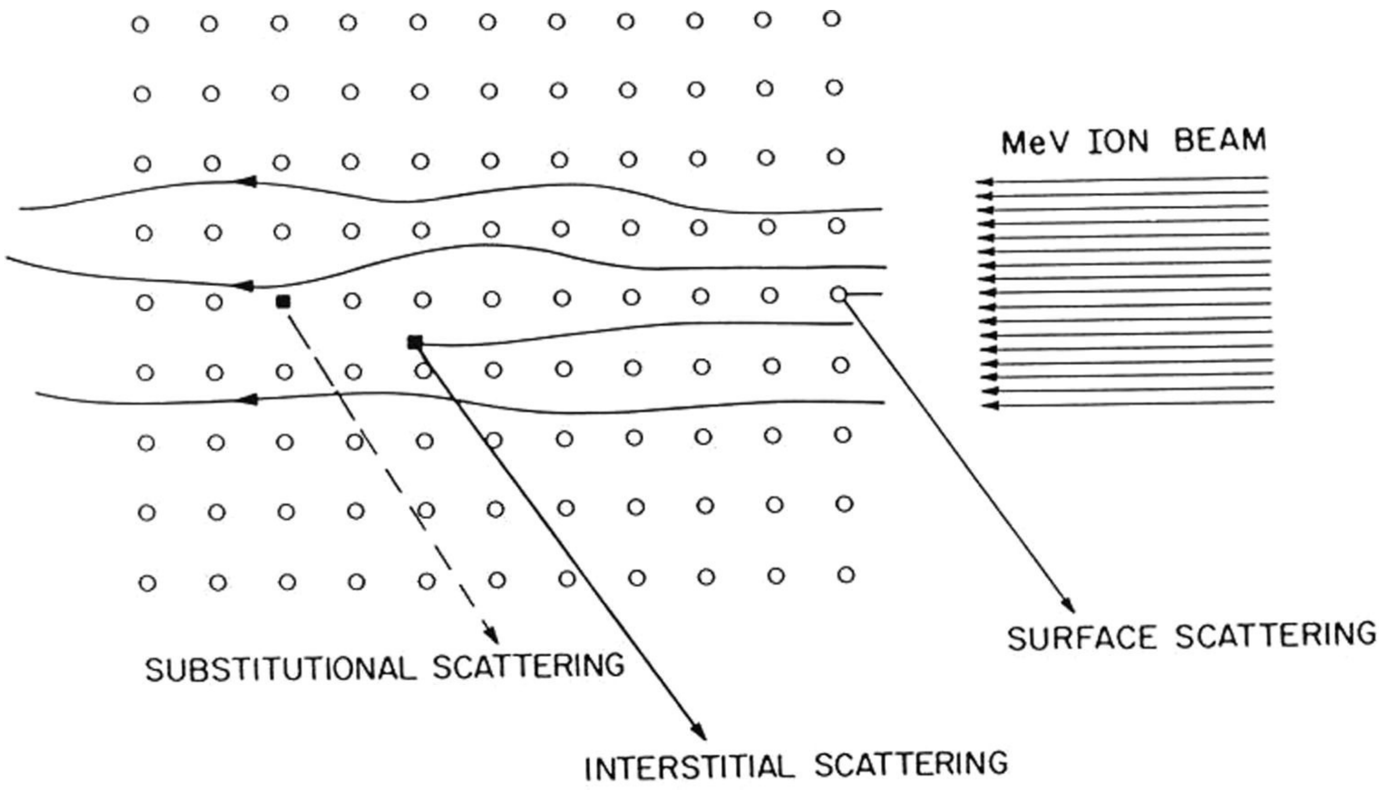
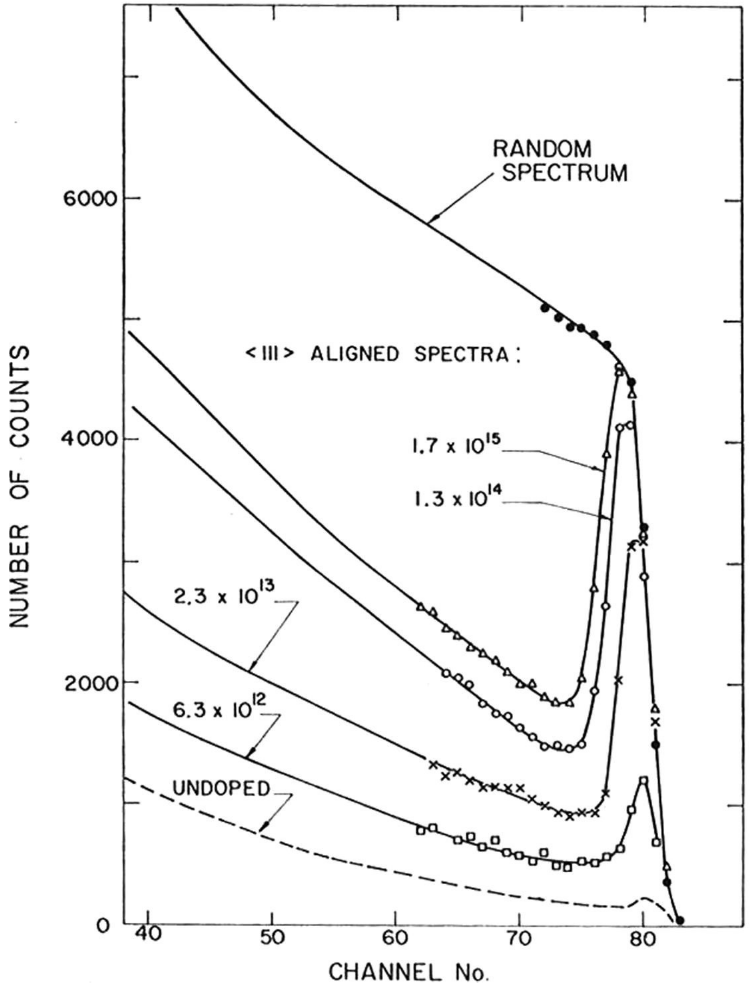
Practical Applications of Channeling





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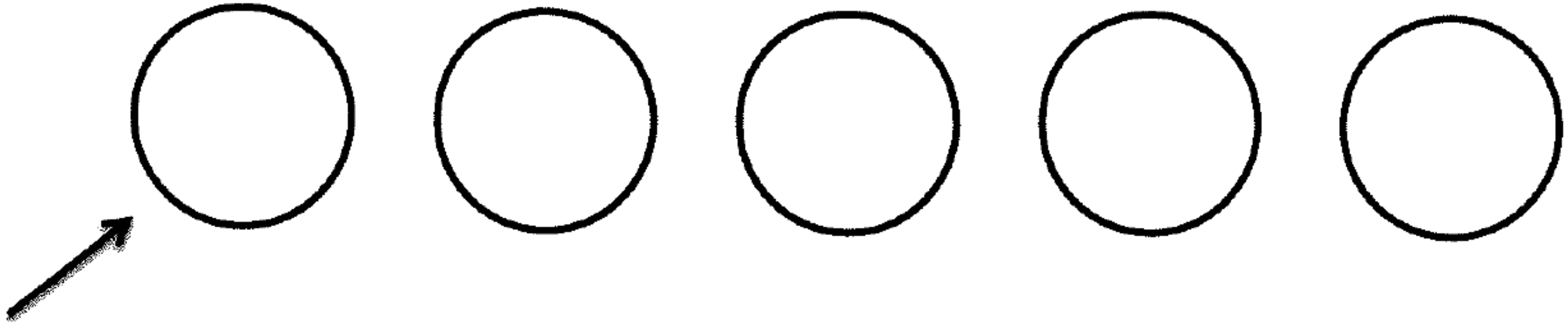
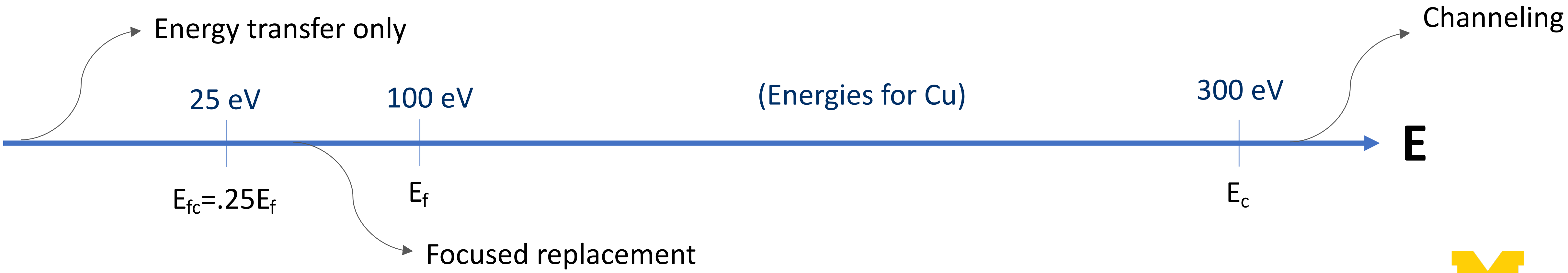
Focusing



- Close-packed energy transfer
- Simplest formalism assumes hard sphere collisions



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Coming back to determining v(T)

Assumption	Correction to $v(T)$	Equation in text
#3 – loss of E_d	$0.56\left(1+\frac{T}{2E_d}\right)$	(2.31)
#4 – electronic energy loss cut-off	$\xi(T)\left(\frac{T}{2E_d}\right)$	(2.50)
#5 – realistic energy transfer cross-section	$C\frac{T}{2E_d},\ 0.52 \le C \le 1.22$	(2.33), (2.39)
#6 – crystallinity	$\frac{1-P}{1-2P}\left(\frac{T}{2E_d}\right)^{(1-2P)} - \frac{P}{1-2P}$	(2.104)
	$\sim\left(\frac{T}{2E_d}\right)^{(1-2P)}$	(2.105)

NRT Model

- NRT:

Accounts for Frenkel pair defect efficiency

Used in ASTM E693 to convert neutron flux to dose rate (dpa/s) for steels!!!

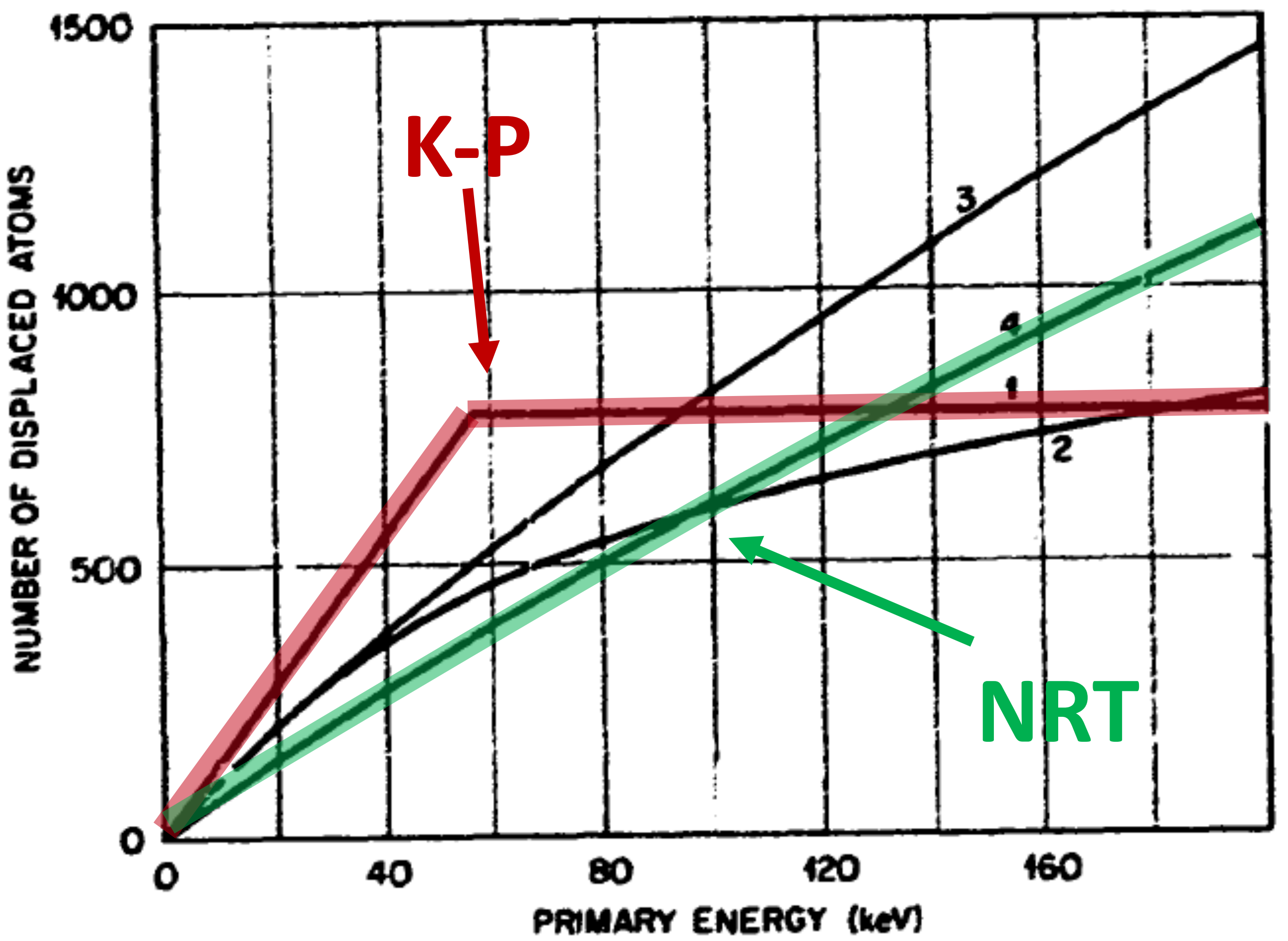

Fig. 2. Comparison of number of displaced atoms generated in bcc iron by a primary knock-on atom. Calculated results correspond to: (1) Kinchin–Pease model with $E_d = 40$ eV and $E_1 = 56$ keV; (2) the half-Nelson formula [4]; (3) earlier computer calculations of Norgett [18], using Torrens–Robinson computer simulation program [11]; and (4) the proposed formula, eqs (5)–(10).

Arc-dpa model

- Over the past 30 years it has become clear that the NRT method for determining dpa in metals is not correct
  - This is due to recombination, which we'll discuss in a few lectures
- To correct the NRT model, the "athermal-recombination corrected dpa", arc-dpa equation was proposed:

$$N_{d,arcdpa}(T) = \begin{bmatrix} 0 & \text{when} & T < E_d \\ 1 & \text{when} & E_d < T < 2E_d \\ \dfrac{0.8\,T}{2E_d}\xi(T) & \text{when} & 2E_d < T < \infty \end{bmatrix}$$

$$\xi(T) = \frac{1 - c_{arcdpa}}{(2E_d/0.8)^{b_{arcdpa}}} T^{b_{arcdpa}} + c_{arcdpa}$$

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How many Cheesecake Factories operate within North America?

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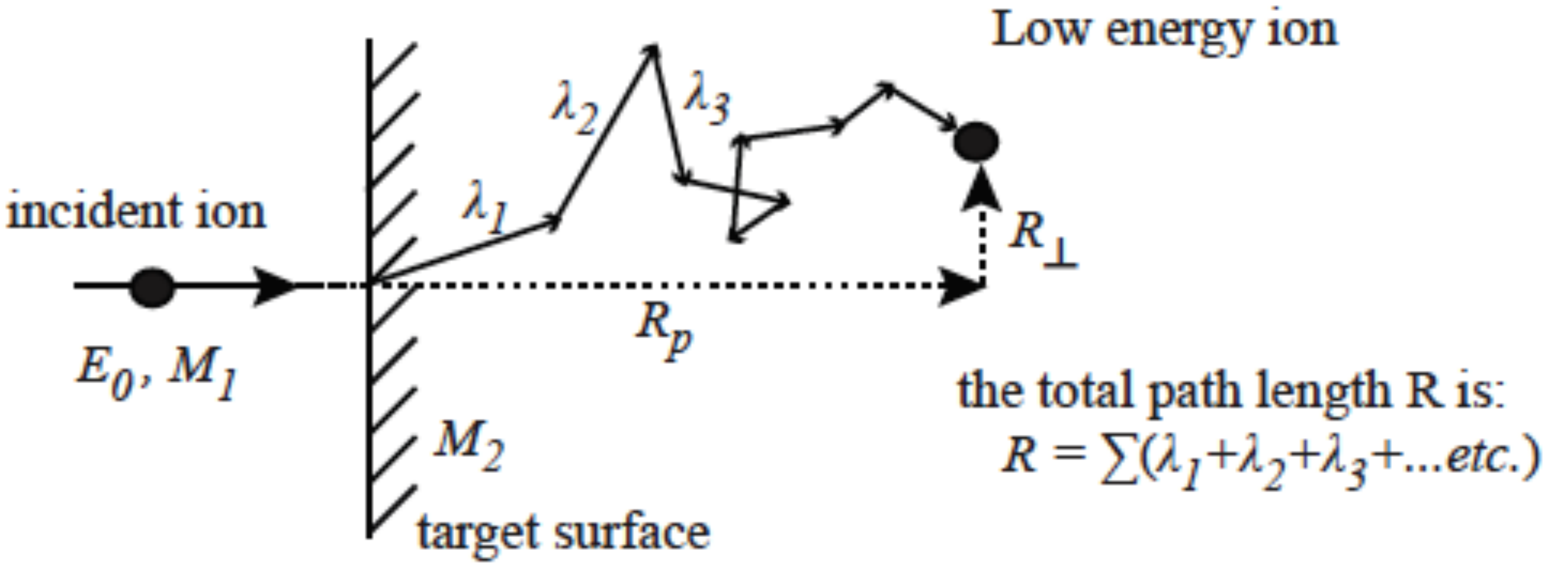
Definition of Range

- Range, R – total path travelled by a particle before it stops
- Projected Range, R_p – protection of R onto the initial direction of the projectile path



Range

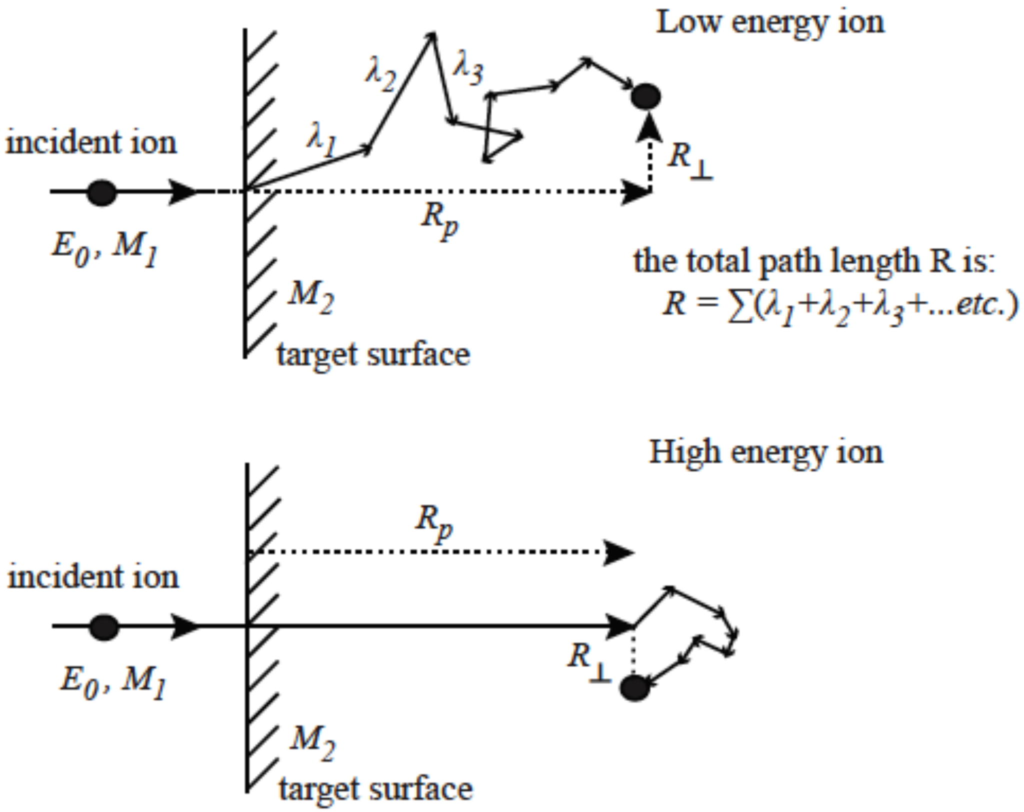
- Assume: Nuclear and electronic energy losses are independent:

$$S_T = S_n + S_e = \frac{1}{N}\left(\left(-\frac{dE}{d}\right)_n + \left(-\frac{dE}{dx}\right)_e\right)$$

- Integrate inverse of stopping power over the energy range of the particle:

$$Range = R = \int_0^{E_{max}} \frac{1}{S(E)} dE$$

$$R = \int_0^{E_{max}} \frac{dE}{S_n(E) + S_e(E)}$$



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Simple Example

- Protons by electronic energy loss

Example

- Determine the range using the appropriate potential considering $E_i < E_{C}$:

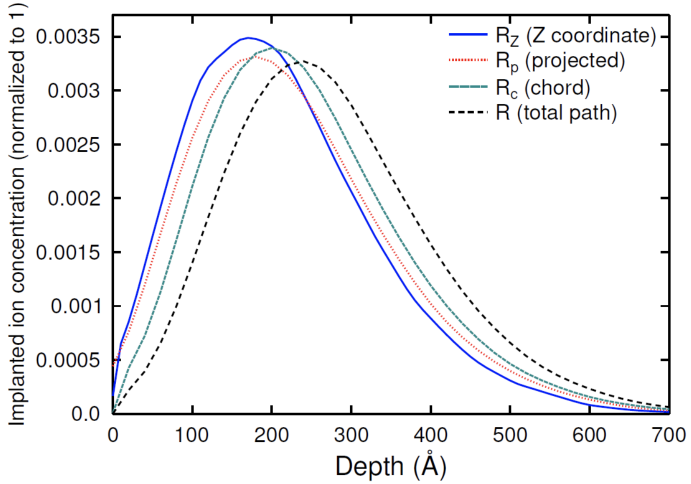
Modifications for range

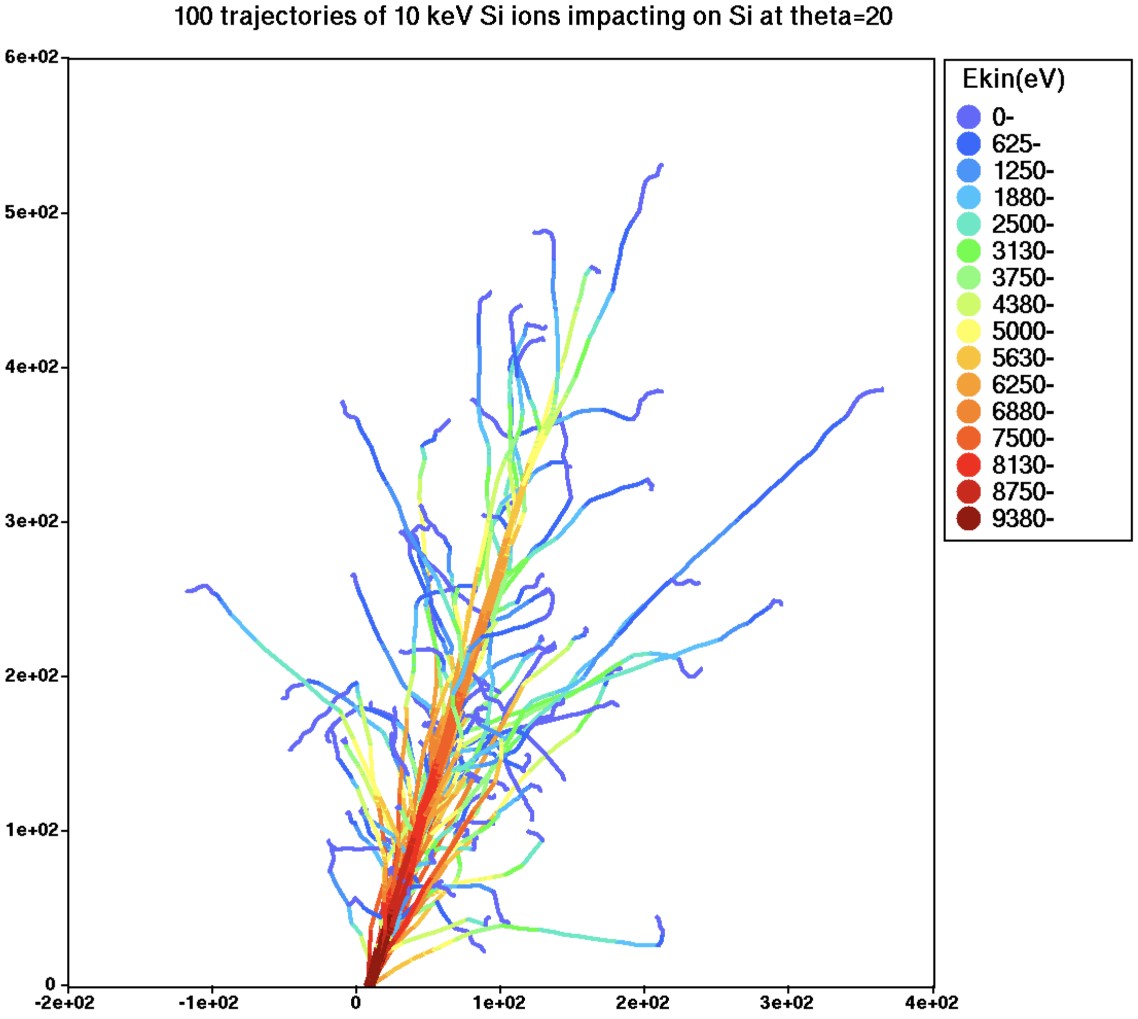
- The calculation:

$$Range = R = \int_0^{E_{max}} \frac{1}{S(E)} dE$$

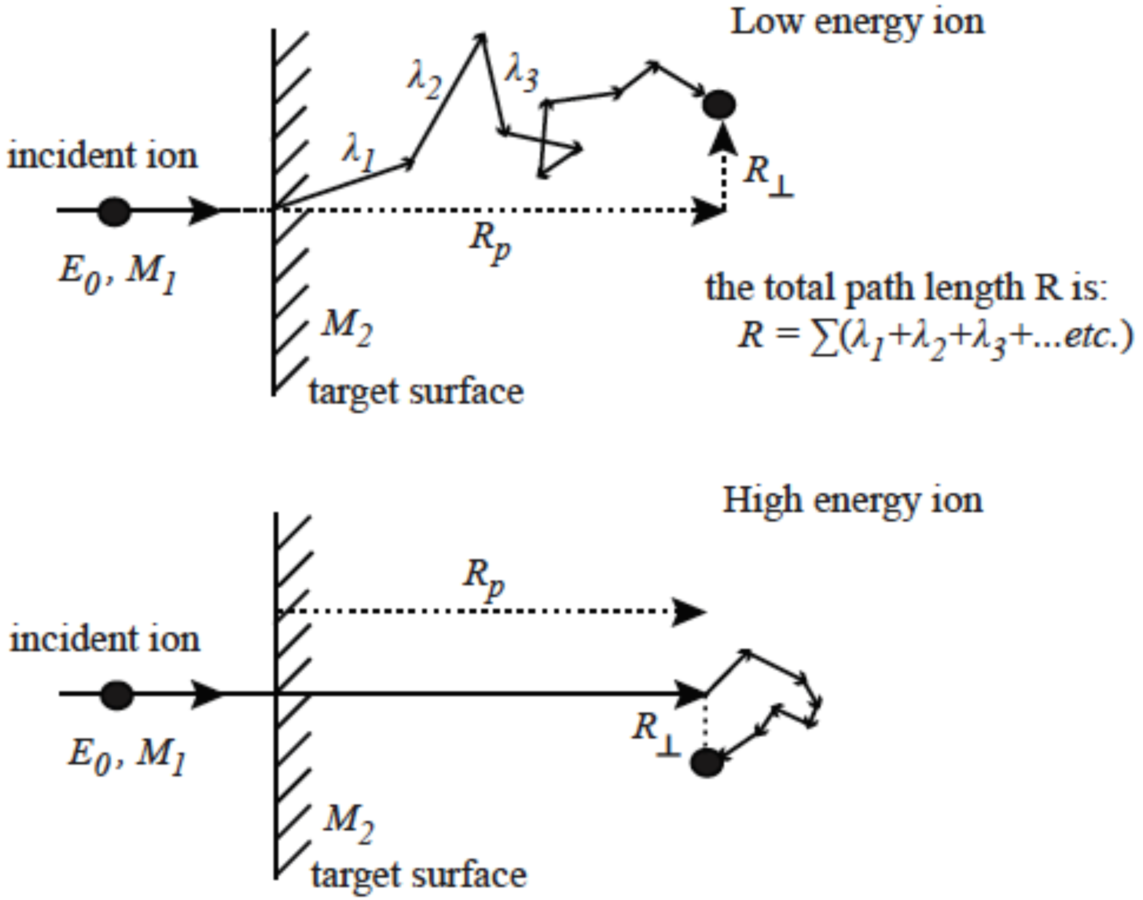
  is only useful as an estimation of the maximum range, i.e. the range of those ions that happen to travel in a straight path

- For most cases, ions don't travel in a straight path!



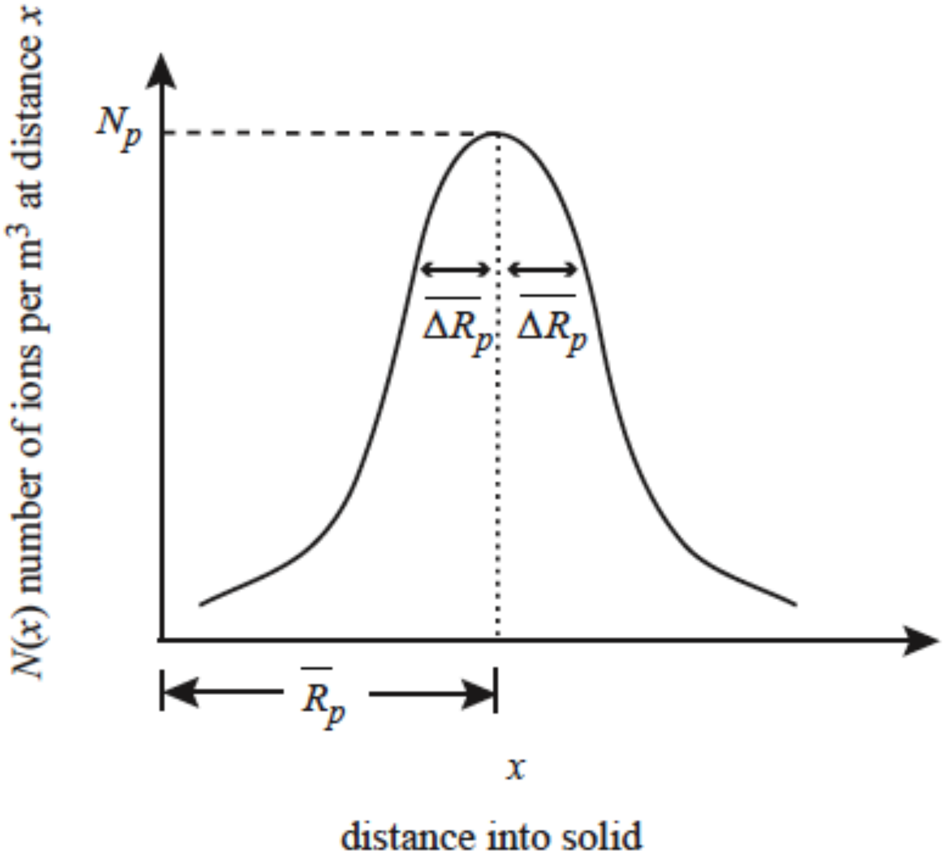


Projected Range - Cases



Concentration

- The stopping positions are distributed according to a Gaussian:



Concentration depends on:

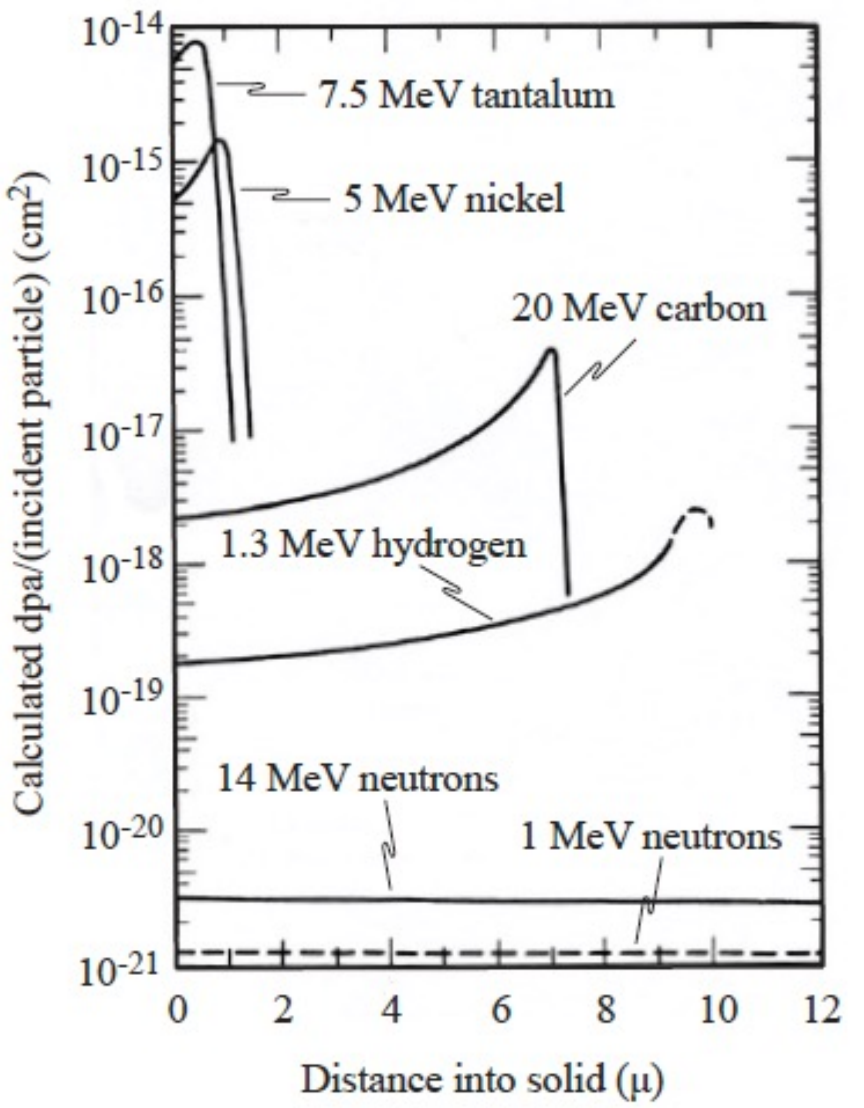
Practical Implications of Range

At low energies where S_n and S_e are comparable, the stopping positions are distribution according to a Gaussian:

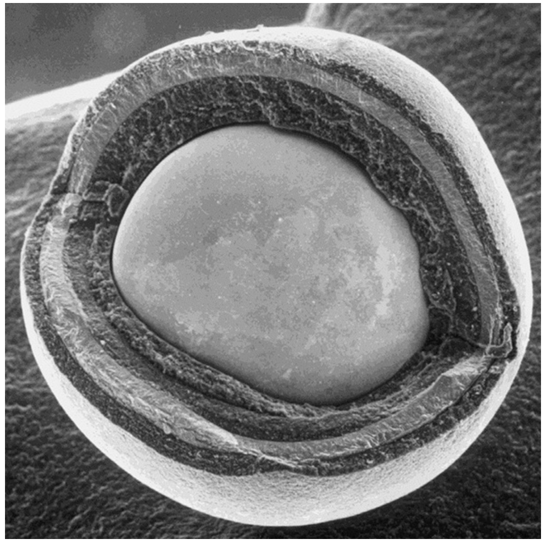
$$N(x) = \frac{0.4N_s}{\Delta R_p} exp\left(-1/2 \left\{ \frac{x - R_p}{\Delta R_p} \right\}^2 \right)$$

Maximum concentration, N_p:

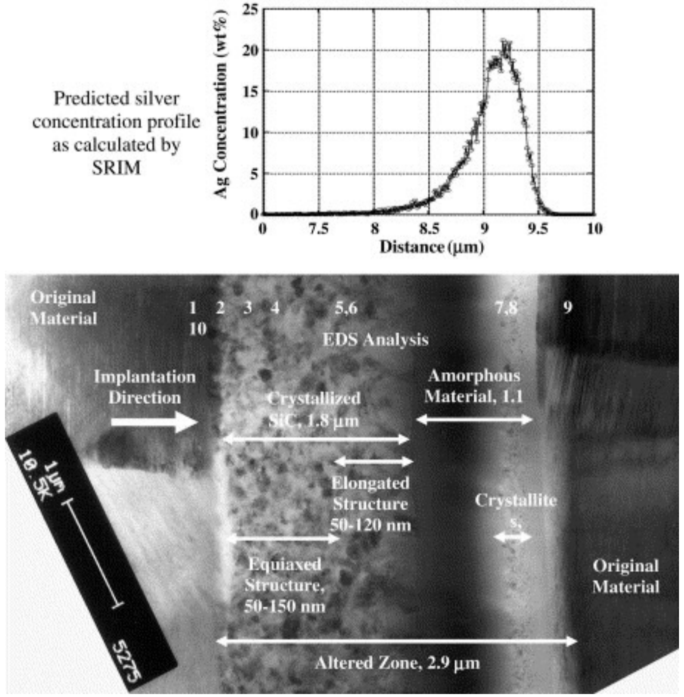
$$N_p \sim \frac{0.4N_s}{\Delta R_p}$$

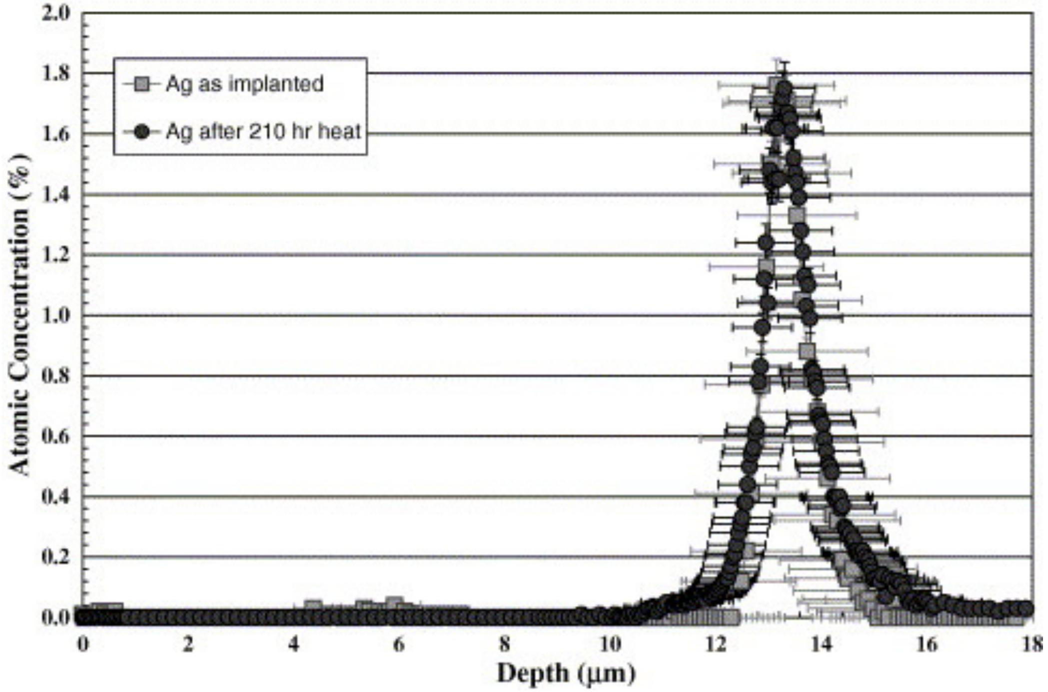


Practical Implications of Range



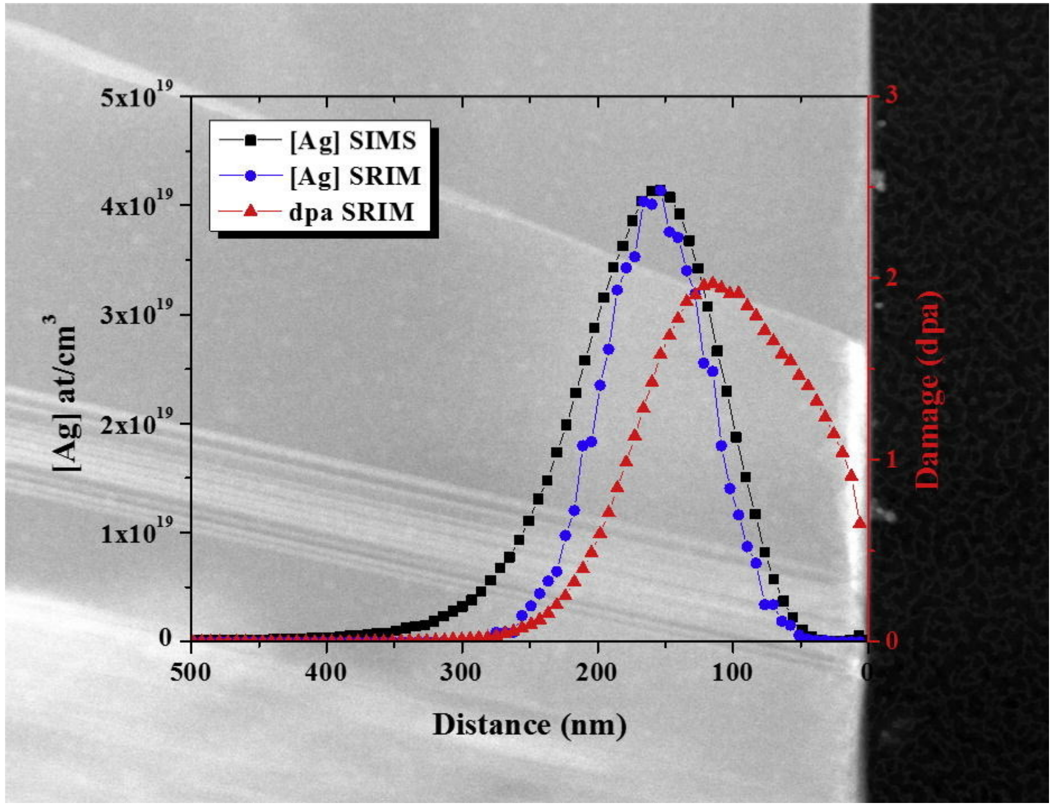
A TRISO fuel particle

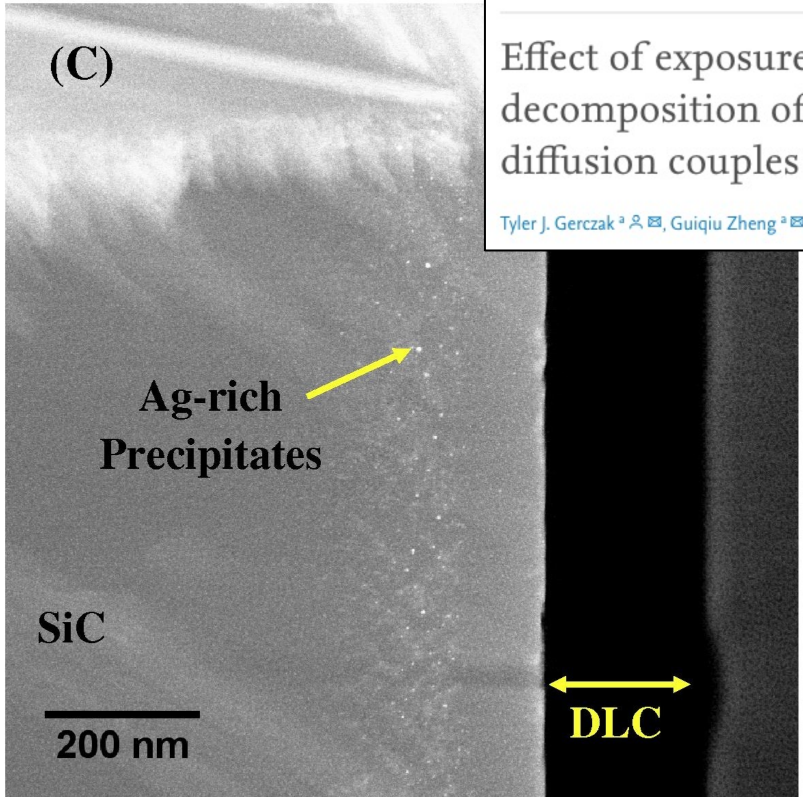




https://doi.org/10.1016/j.jnucmat.2006.05.043

Practical Implications of Range





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Effect of exposure environment on surface decomposition of SiC–silver ion implantation diffusion couples

Tyler J. Gerczak [a], Guiqiu Zheng [a], Kevin G. Field [b, 1], Todd R. Allen [c]

10 citations!

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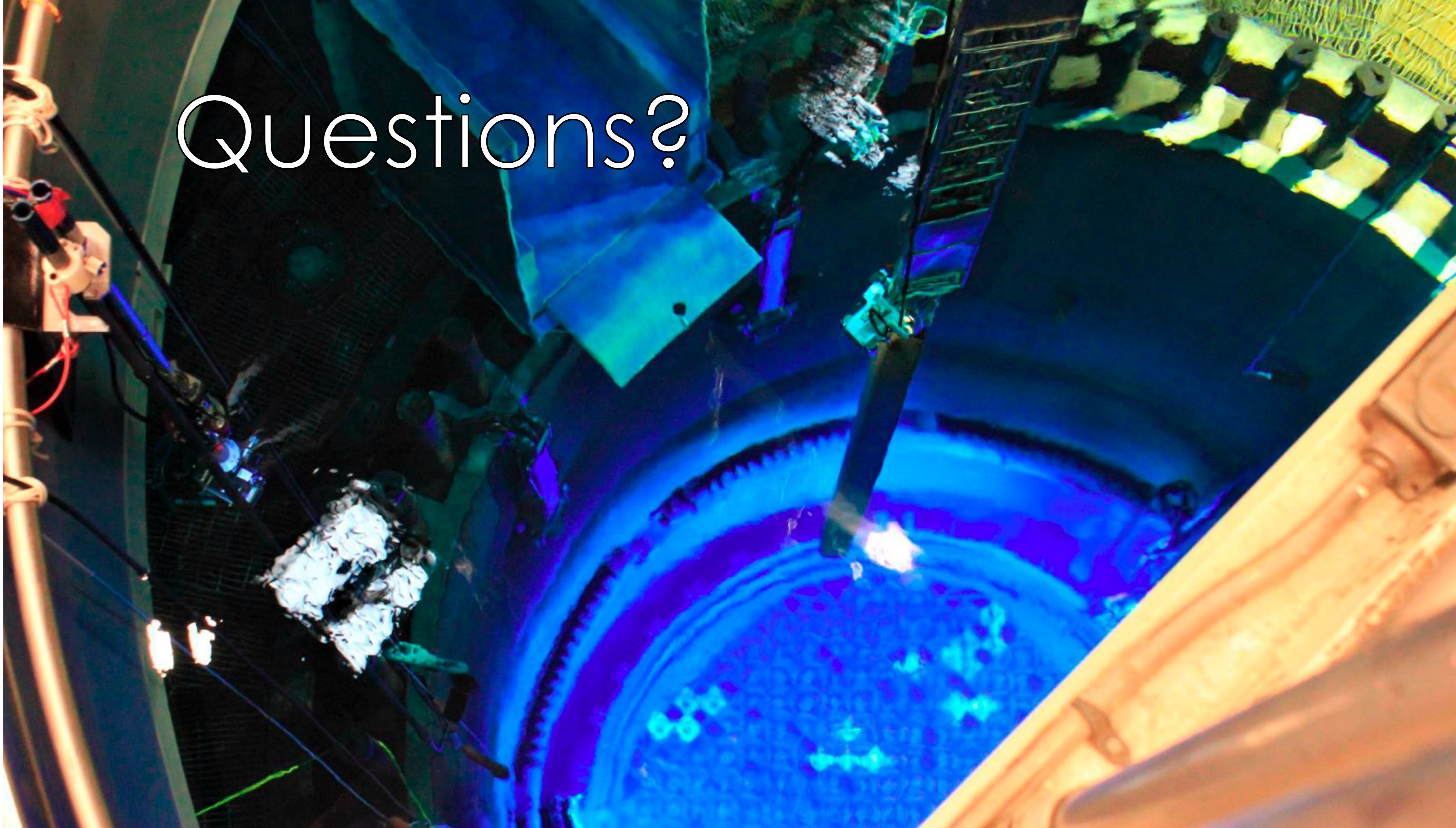
Questions?