FEW REMINDERS & NEWS

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- **Reserve table(s) for dinner**
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➔Networking event preparation

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➔ (a) write down a question in the field of radiation damage & protection

➔ (b) put it in an industrial and/or scientific context

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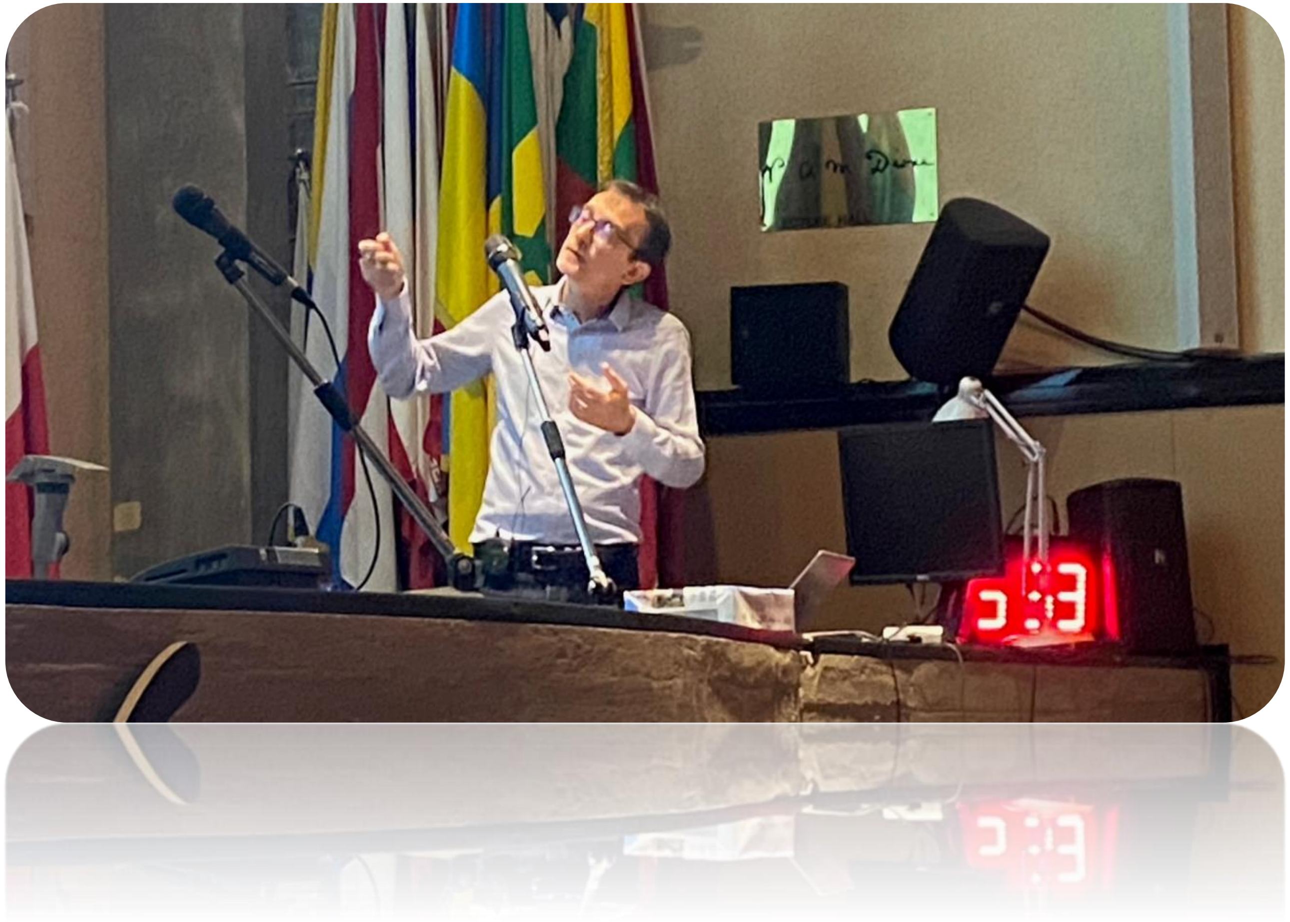
Daily Highlights

What Did You Learn Today?

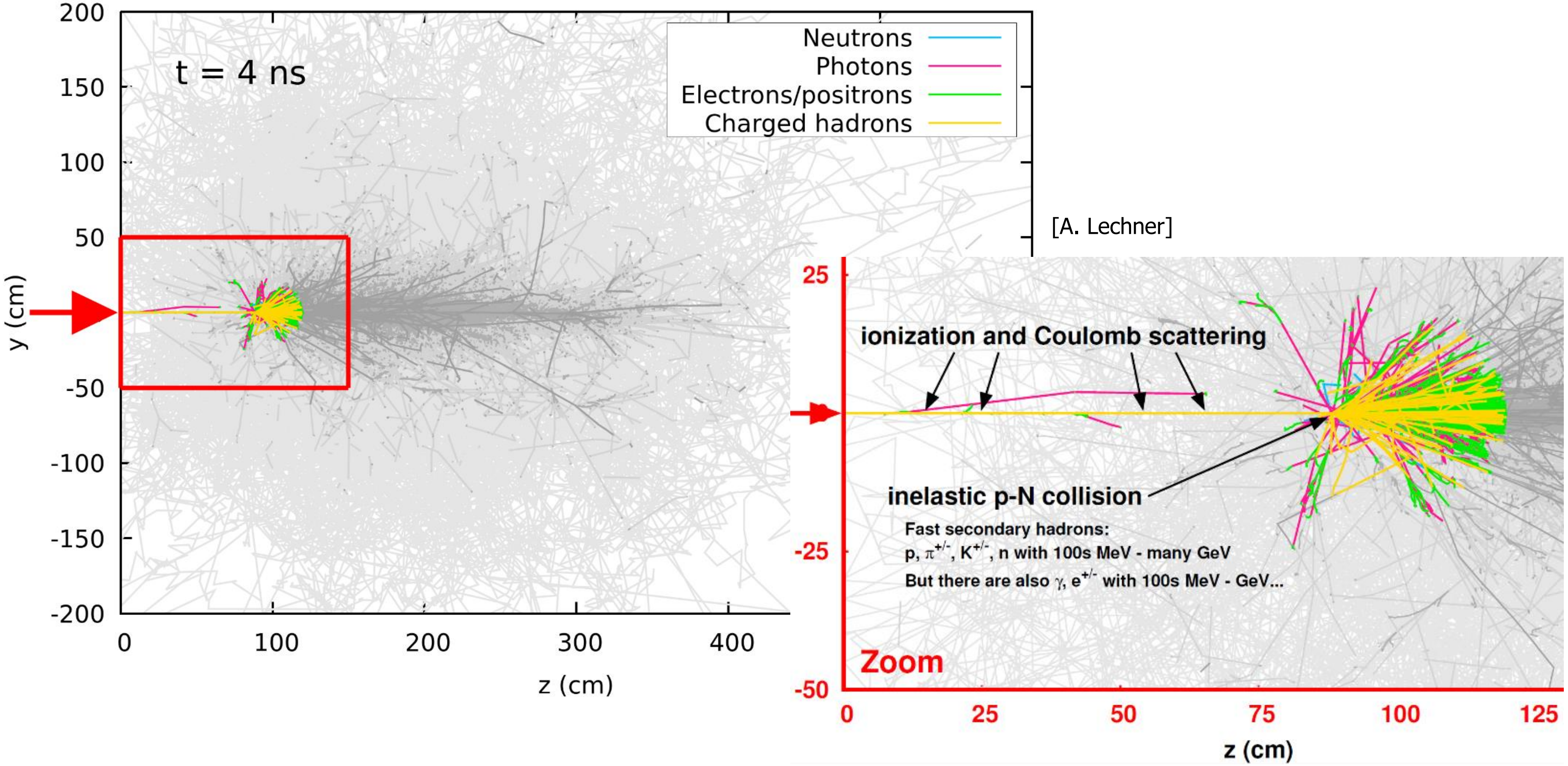

0 00
PLEASE CONCLUDE
TIME OUT



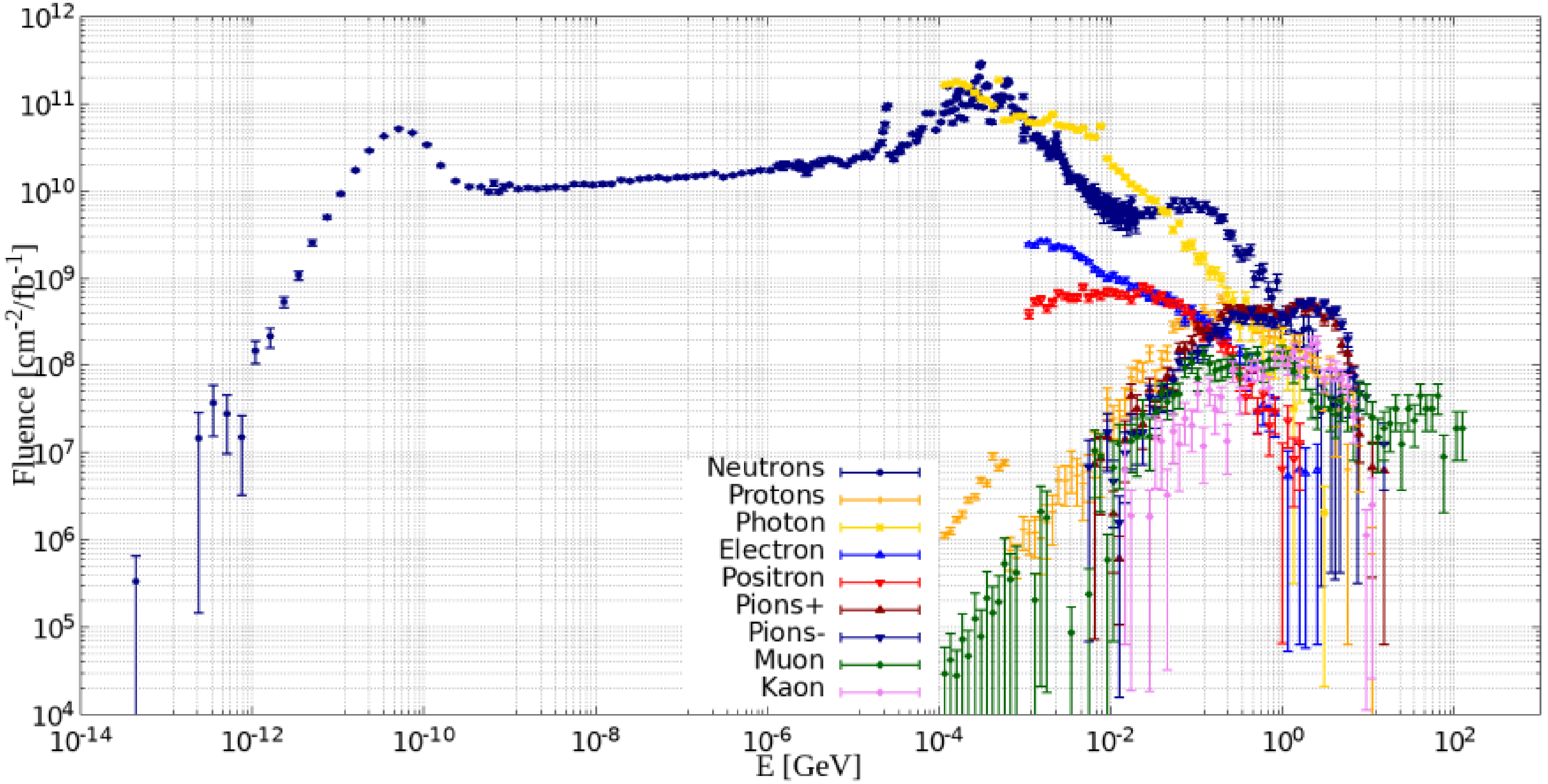
How to get from MeV to TeV and beyond

THE MICROSCOPIC VIEW [1/4]

one 450 GeV proton on aluminum



THE RADIATION FIELD [2/3]



at floor level (below the LHC final focus quadrupoles)

CONSEQUENCES

	relevant macroscopic quantity
Heating	energy deposition (integral power)
Thermal shock	energy deposition (power density)
Quenching	energy deposition (power density)
Deterioration	energy deposition (dose), particle fluence, DPA
Oxidation, radiolysis, ozone production	energy deposition
Gas production	residual nuclei production
Single event effects in electronic devices	high energy hadron fluence [+ neutron fluence, energy deposition (dose)]
Shielding requirements	particle fluence (*prompt* dose equivalent)
Access limitations, radioactive waste, air activation	*residual* dose rate and activity
Beam Loss Monitors (BLM)	energy deposition
Radiation Monitors (RadMon)	thermal neutron and high energy hadron fluence
Tumor cell destruction	energy deposition (dose, biological dose)

How Isotopes are produced and what to do about them…

Contents

Illustration of residual vs. prompt radiation at hadron/ion accelerators

Residual dose and its (analytical) calculation

(Analytical) shielding assessments with respect to residual radiation

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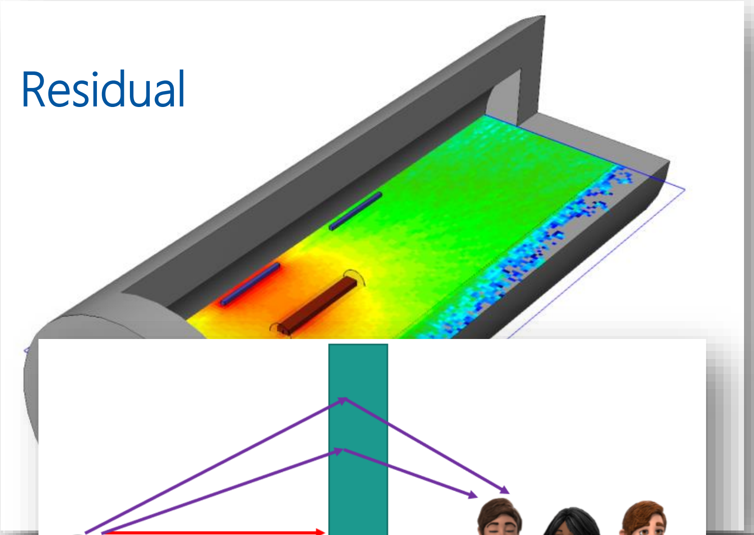

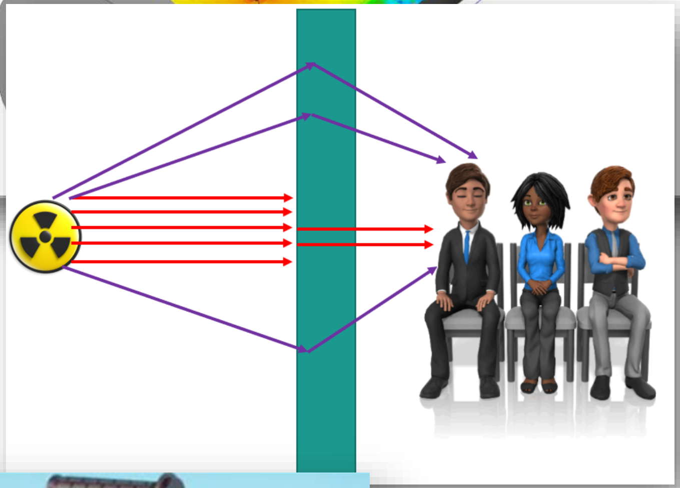


g-spectrometry samples


Total gamma counters

Handheld BGO counters
(Bismuth Germanate scintillators)

While air in space is lacking, radiation is quite abundant…

Particles causing Single Events Effects:

- Galactic cosmic rays
- Solar particles
- Trapped protons in radiation belts
- ***Note**: protons are only significant for Silicon components with LET_{th} < 15 MeV cm²/mg (usually…)*

Particles causing long term degradation radiation damage:

- Trapped electrons in radiation belts (TID, TNID@GNSS)
- Trapped protons in radiation belts (TID, TNID)
- Protons from solar flares

Particles causing Internal charging:

- Electrons

Summary

- **There are three main source of radiation in space**
  - Trapped particles (electrons and protons)
  - Solar particles (protons and heavier ions)
  - GCRs (protons and heavier ions of very high energy)
- **Defining the space radiation environment is an essential input to cope with radiation effects in EEE components and materials during space missions**.
  - An accurate spacecraft model will lower radiation requirements
  - In electrons dominated orbits, Sector/ray trace analysis could significantly overestimate radiation levels
  - For protons dominated orbits, Sector/Ray trace analysis goives a reasonably good estimate of dose levels
- **Numerous future challenges**:
  - Need for updated, more accurate and dynamic models taking into account e.g. solar cycle activity variations
  - Better predictions of space weather is essential for future manned missions to the Moon and Mars

What smoke detectors have to do with structural and material damage...

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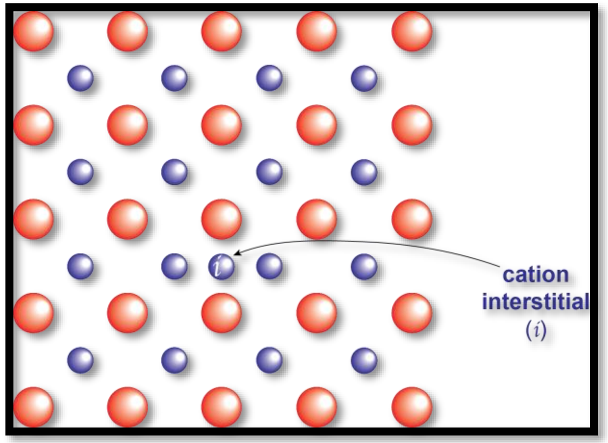
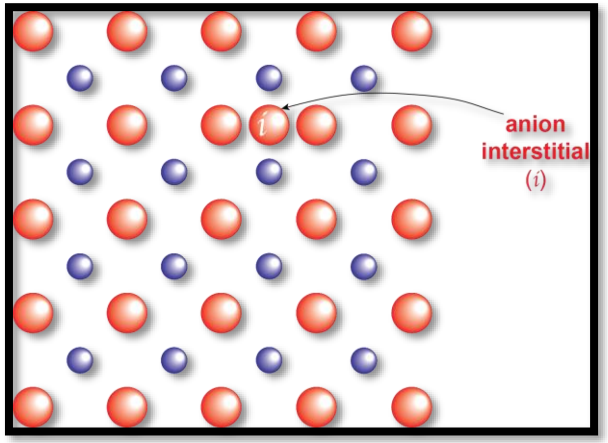
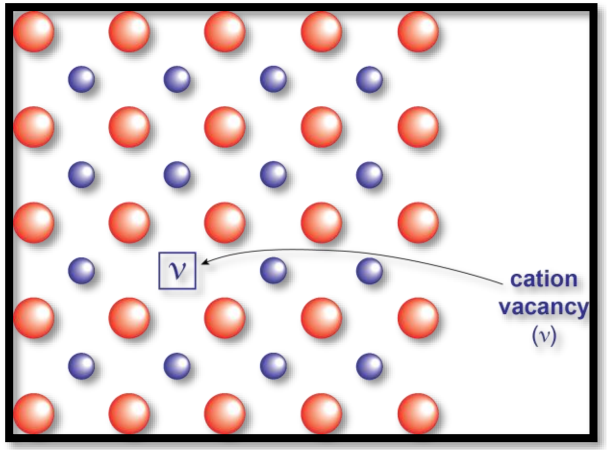
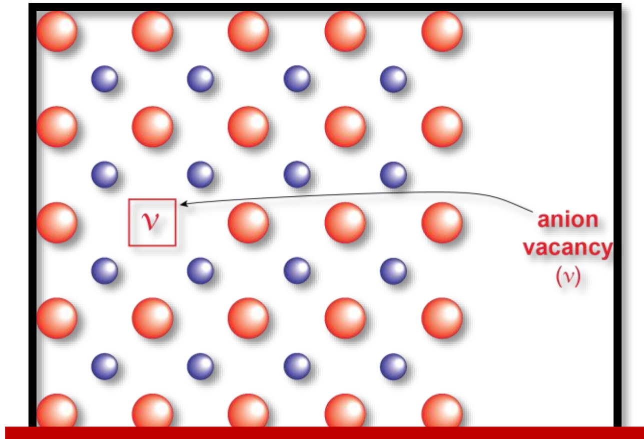
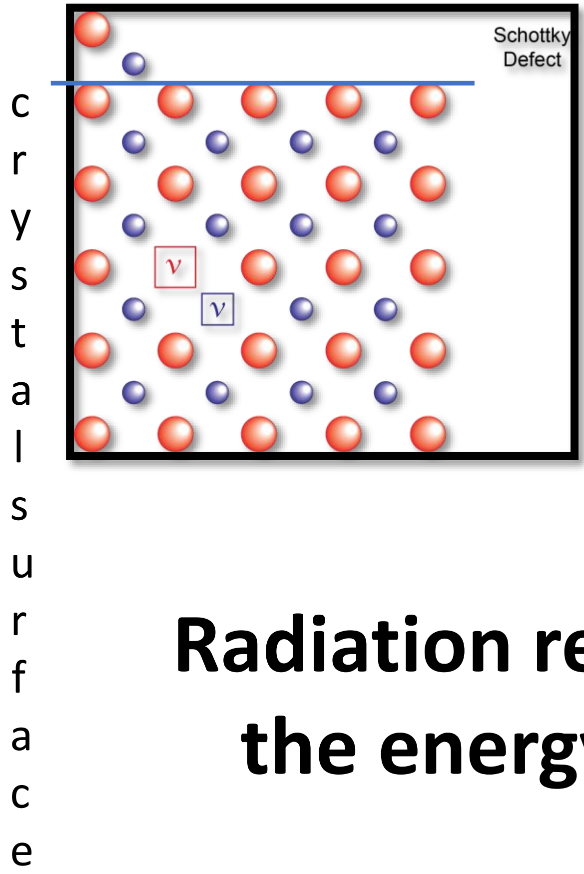
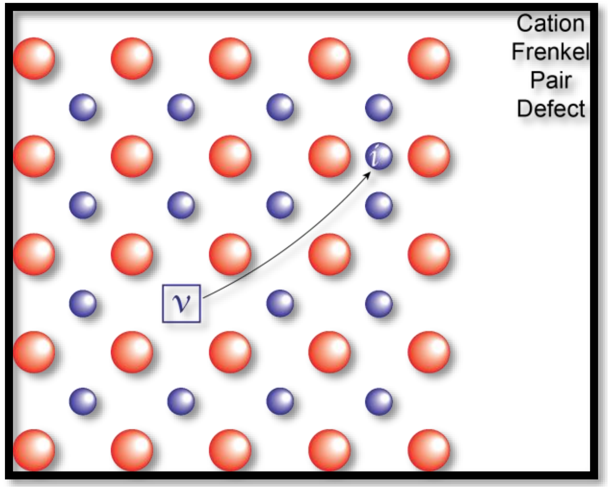


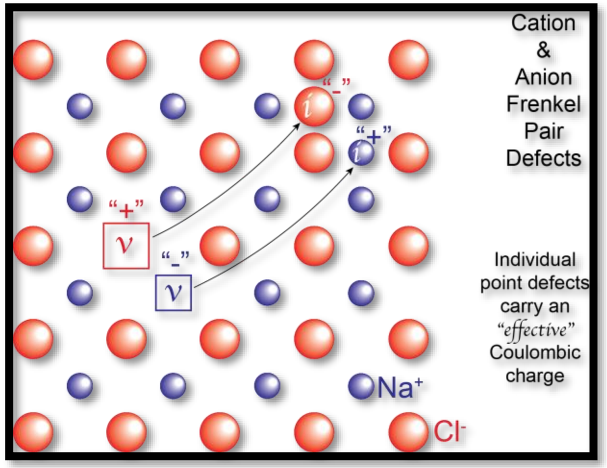


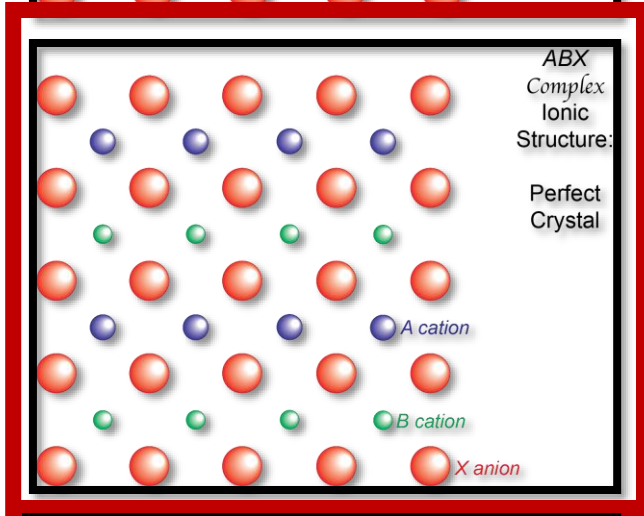


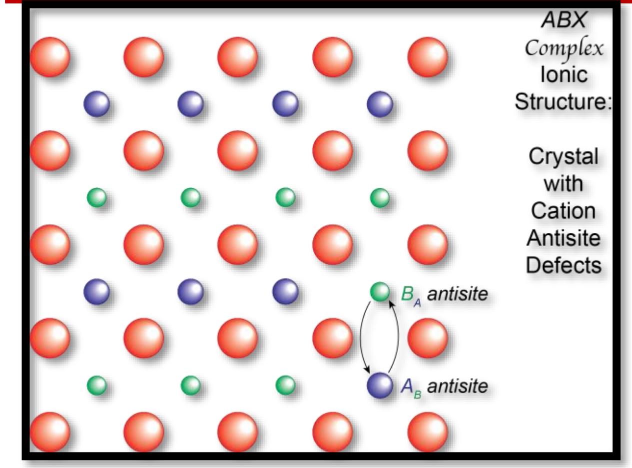






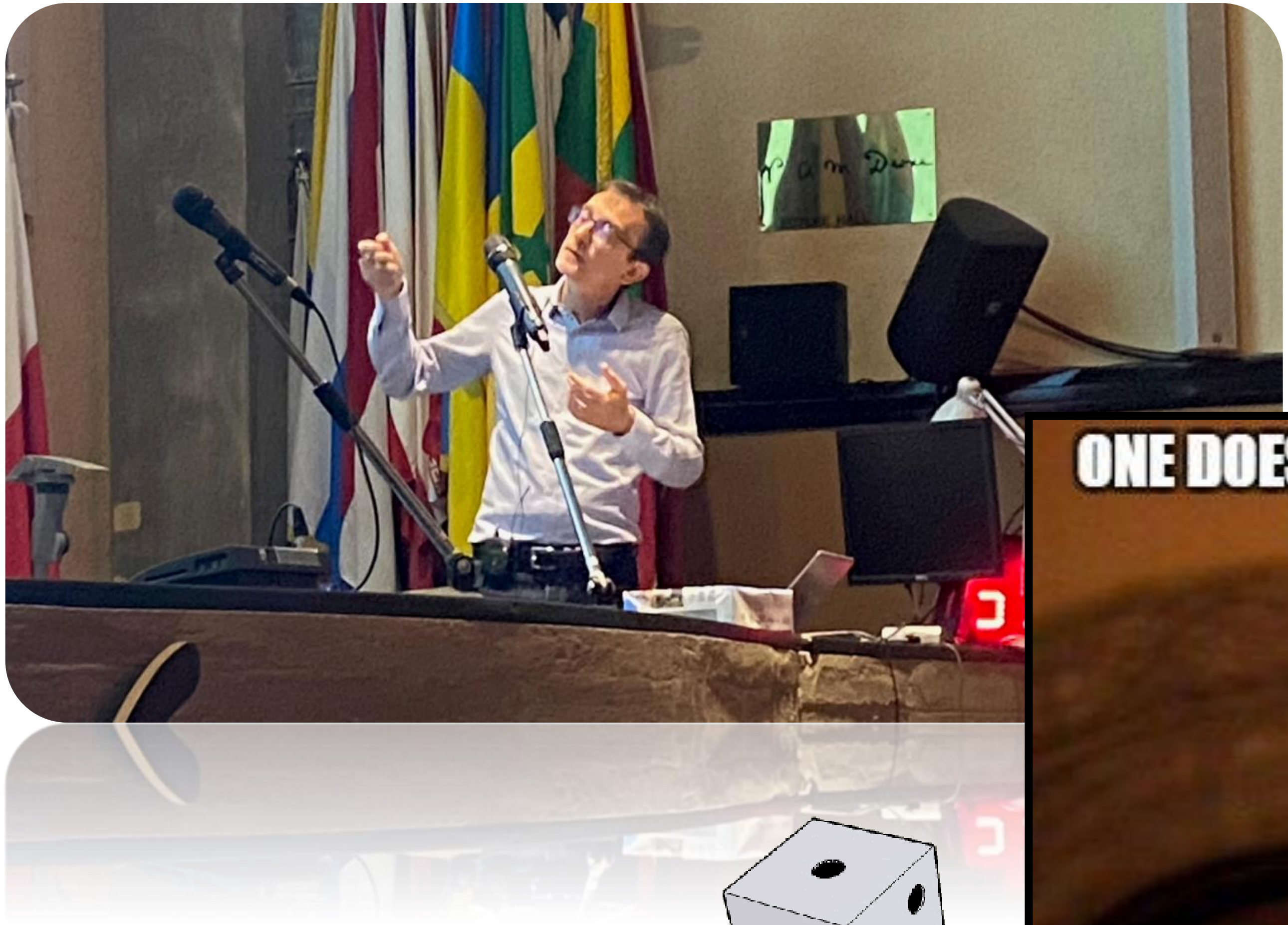


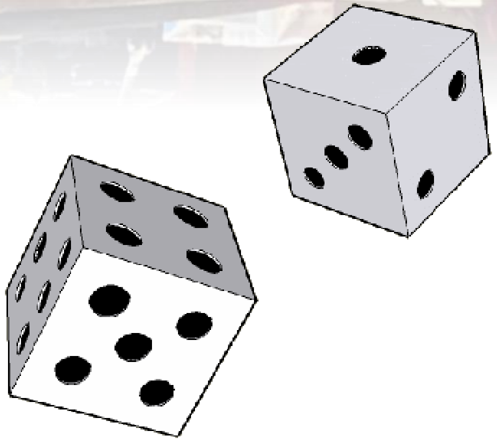


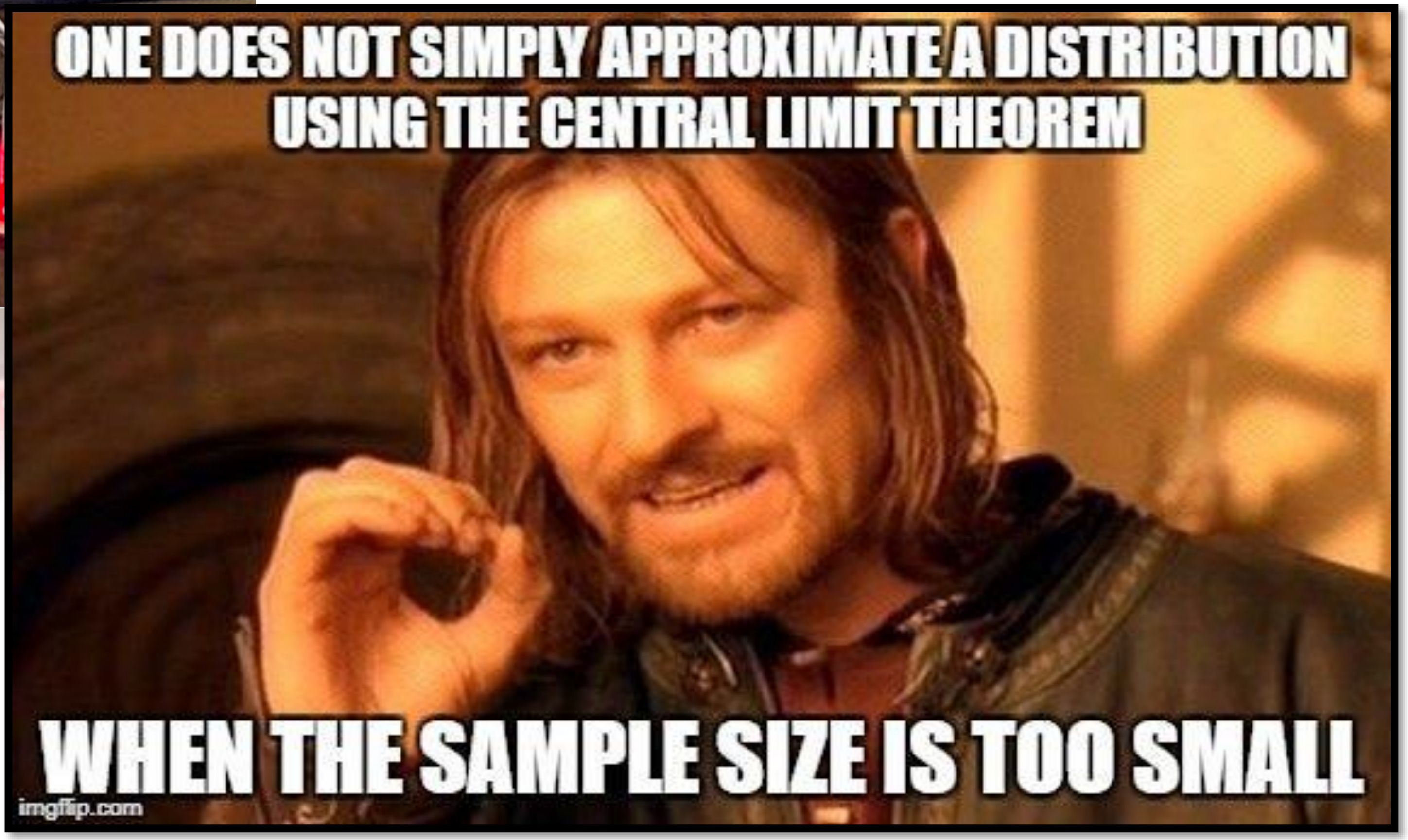


Radiation resistant materials are those where the energy required to recombine is small

Let's play Monte-Carlo…







Probability and statistics primer

Assumptions, limitations, and sources of uncertainty

Continuous processes

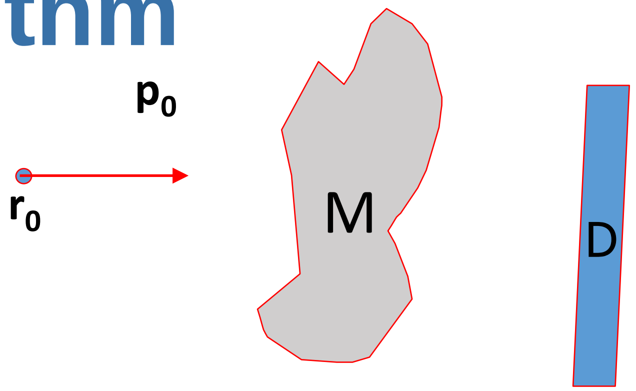
Discrete processes

Scoring

Biasing

Relative error	Quality of Tally
50 to 100%	Garbage
20 to 50%	Factor of a few
10 to 20%	Questionable
< 10%	Generally reliable

Simplified Monte Carlo simulation algorithm



Loop over n_p primary events:

1. Initialize source particle position and momentum
2. If particle is in vacuum, advance it to next material boundary
   (or sample step length to ***decay*** if unstable)
3. Determine total interaction cross section at present energy and material: σ
4. Evaluate the mean free path to the next interaction: $\lambda = 1/(N\sigma)$
5. Sample step length to next interaction from $p(s) = (1/\lambda)\, e^{-s/\lambda}$
6. Decide nature of interaction: $P_i = \sigma_i / \sigma, \quad i=1,2,\ldots,n$
7. Sample the final state of the selected interaction mechanism i. Add generated secondary particles to the stack if any
8. Score contribution of the track/event to the desired physical observables
9. Go to 2 unless particle energy drops below user preset threshold or particle exits the geometry

Let’s get ballistic …

7

12

13

18

19

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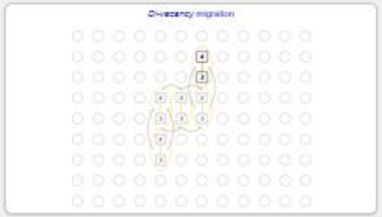
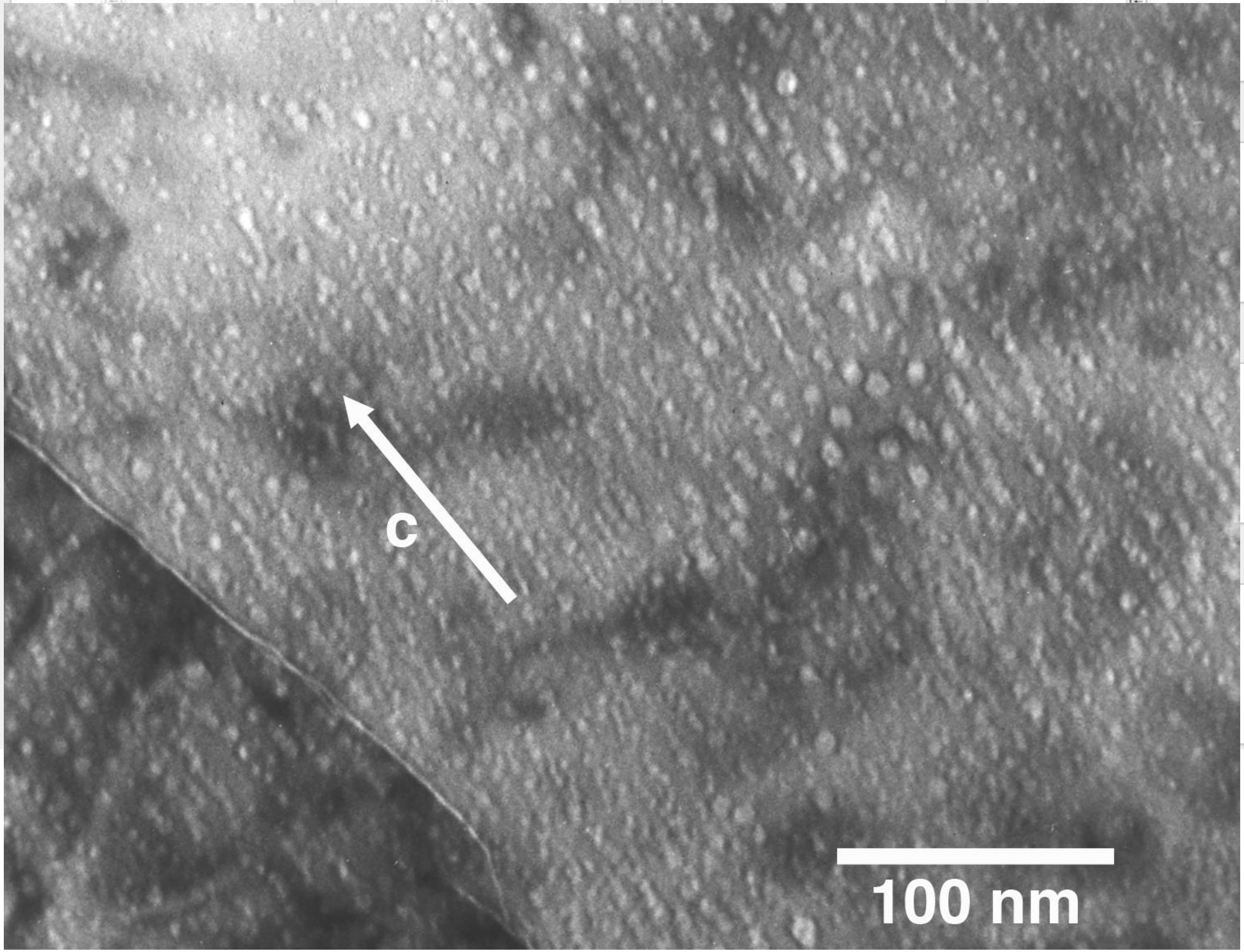




Radiation Tolerance of Oxide Minerals and Ceramics

Criteria for Radiation Tolerance:

1. **Resistance to *amorphization* (i.e., to *metamictization*)**
2. **Resistance to *extended defect formation***

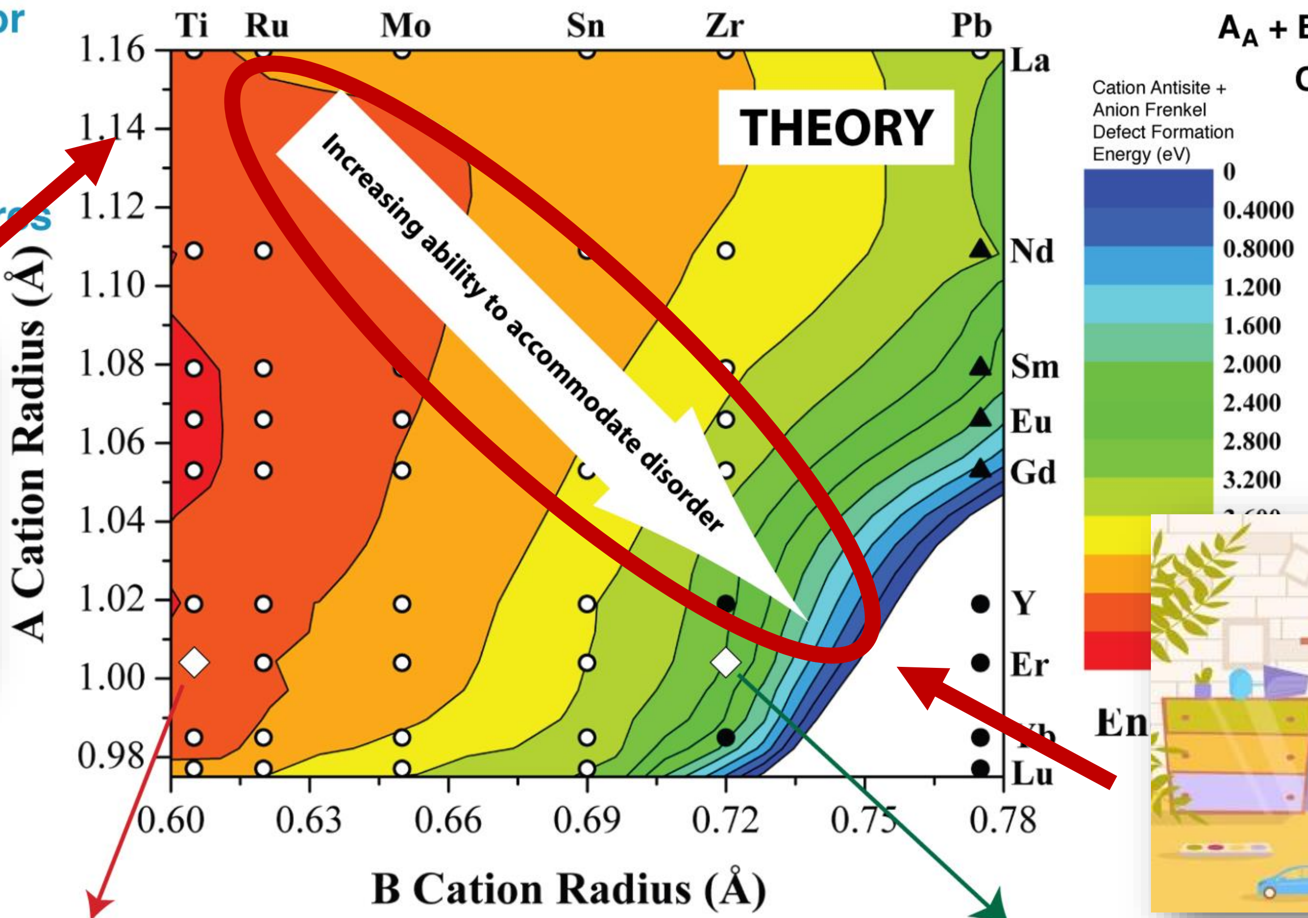
Historical Evolution of Radiation Tolerance Concepts for Minerals and Ceramics:

1. ***Ionic* bonding better than *covalent* bonding**
2. **Crystalline compounds that exhibit *intrinsic disordering tendencies* are the best**

Relationship Between Disordering Tendencies and Radiation Tolerance

Energy Contours for Cation Antisite + Anion Frenkel Defect Formation in $A_2B_2O_7$ Pyrochlores

K.E. Sickafus et al., Science **289** (2000) 748-751.



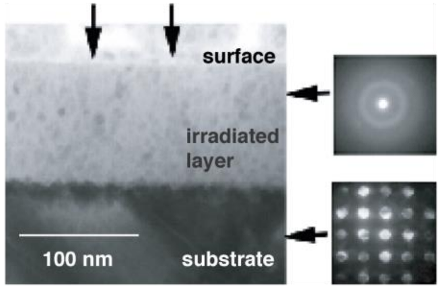
$A_A + B_B \rightarrow A_B' + B_A^{\bullet}$

$O_O \rightarrow V_O^{\bullet\bullet} + O_i''$

C.R. Stanek, R.W. Grimes, J. Amer. Ceram. Soc. **85** (8) (2002) 2139-2141.

BAD radiation tolerance

350 keV Xe^{++} ions $\Phi = 1\cdot10^{15}$ Xe/cm^2

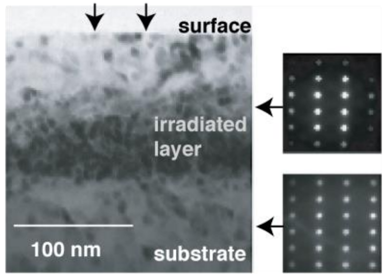


$Er_2Ti_2O_7$

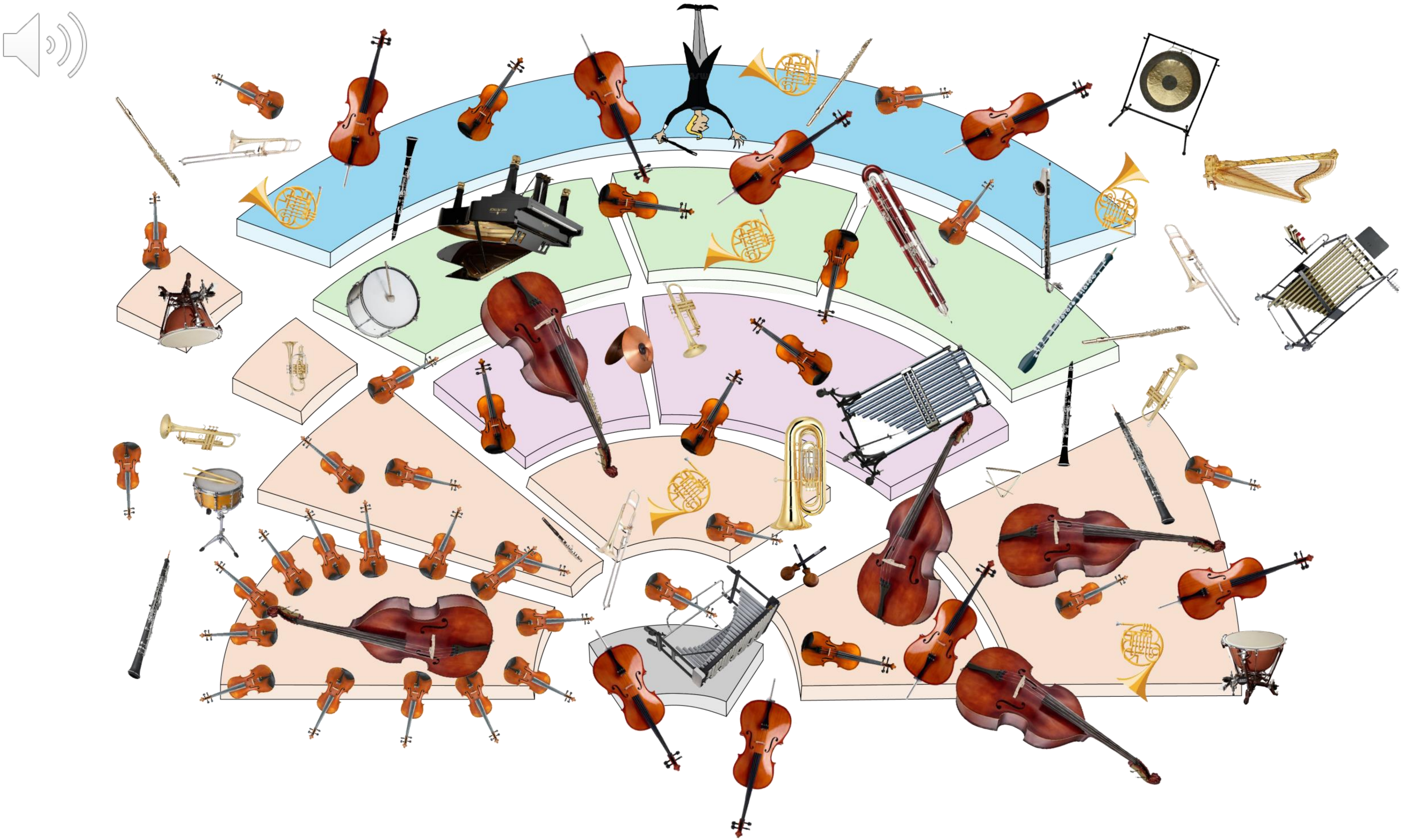
EXPERIMENT

GOOD radiation tolerance

350 keV Xe^{++} ions $\Phi = 1\cdot10^{16}$ Xe/cm^2



$Er_2Zr_2O_7$



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