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Criticality Safety Demonstration using low fissile concentration in waste

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Pu contaminated waste

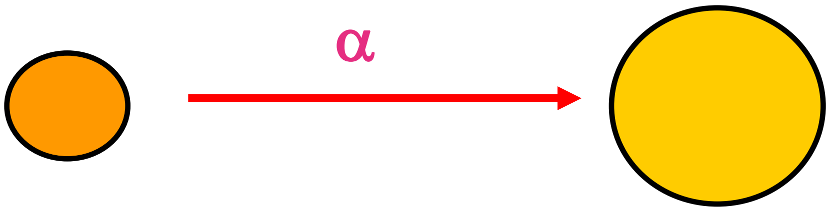
- **Critical values of ^{239}Pu (d ≤ 19.86 g/cm³) moderated by water**
  - **M_{cr} ≈ 500 g (H/Pu=800, [Pu] ≈ 33 g/L)**
  - **V_{cr} ≈ 0.293 L (H/Pu=0)**

  for full water reflection

- **« Low » concentration of Pu**
  - **For liquid waste or solid waste stored under water**
    - Subcriticality is ensured for ^{239}Pu, if H/Pu > 3680 ([Pu] < 7.2 g/L)
  - **For varying water content**
    - Critical mass > 500 g (for moderation by water)
    - Critical volume > 0.293 L
    - Values can be estimated by core-density conversion

Core-density conversion formula

- Core-density conversion for a bare (unreflected) sphere



- All dimensions [cm] are multiplicated by α, except microscopic cross sections σ [cm^2]
  - Radius [cm] — $R' / R = \alpha$
  - Volume [cm^3] — $V' / V = \alpha^3$
- Equivalent when
  - Mean free path [cm] — $\lambda' / \lambda = \alpha$
  - Macroscopic cross section [cm^{-1}] — $\Sigma' / \Sigma = \alpha^{-1}$
  - Density [g.cm^{-3}] — $\rho' / \rho = \alpha^{-1}$

➔ $R' / R = (\rho' / \rho)^{-1}$, $V' / V = (\rho' / \rho)^{-3}$, and $M' / M = (\rho' / \rho)^{-2}$

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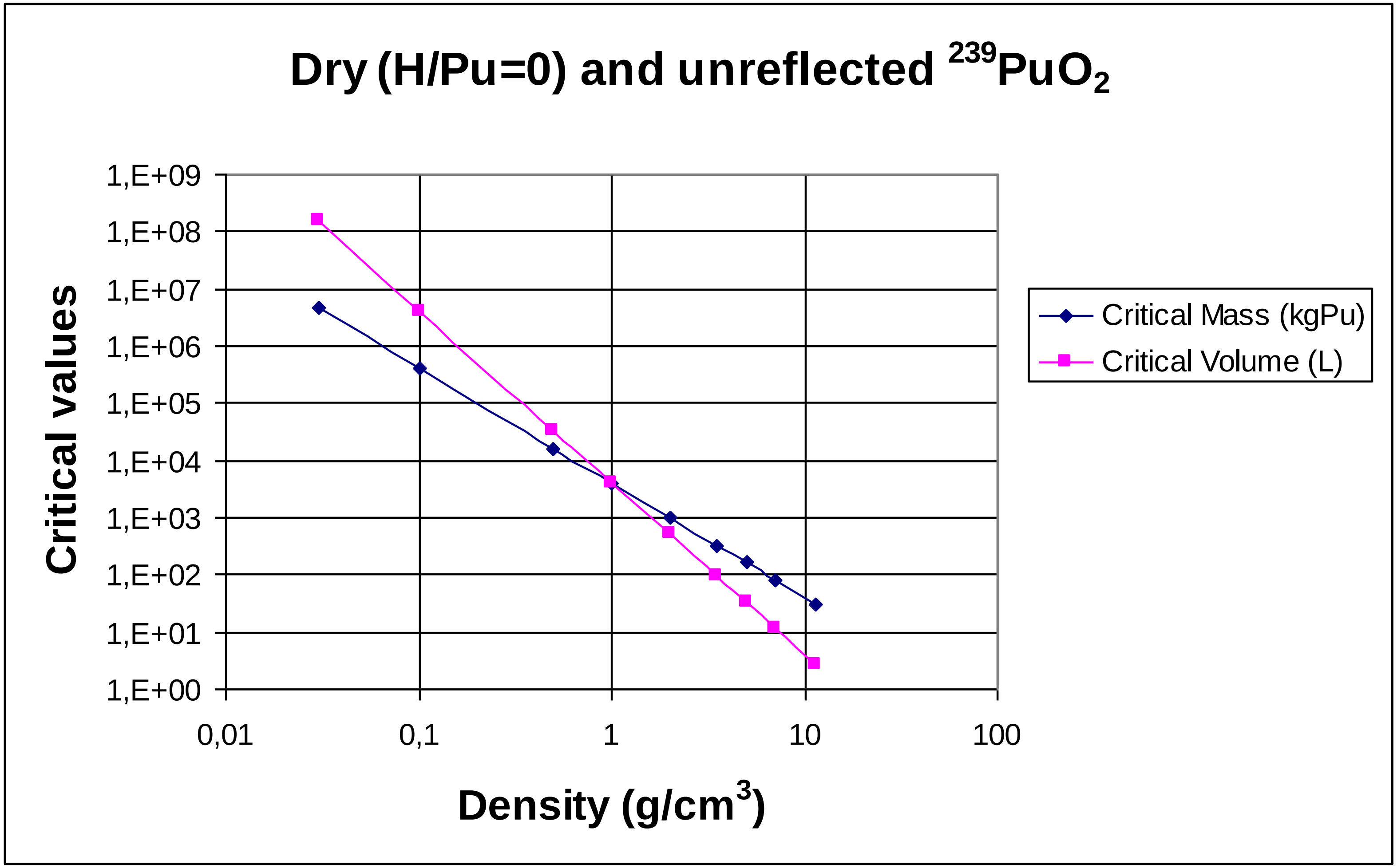
Example of core-density conversion



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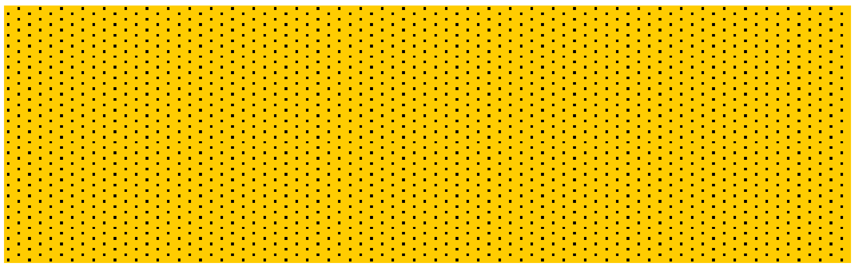
Waste considered as Pu-water mixture

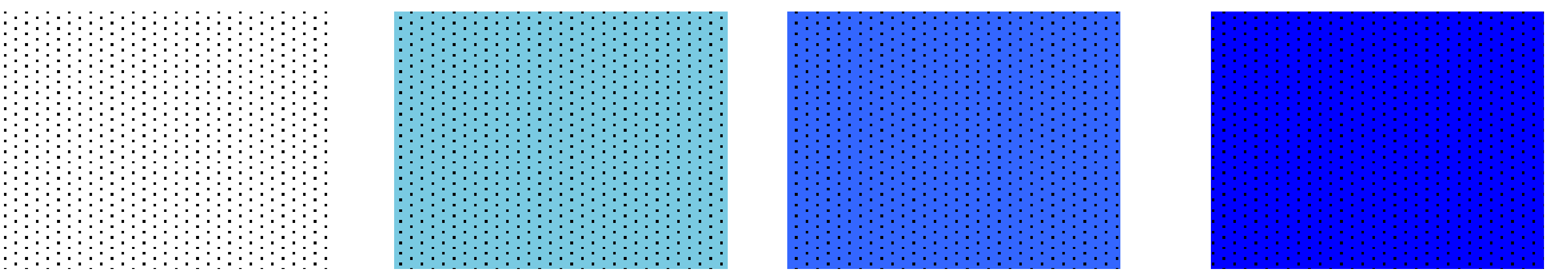
- **Low Pu concentration in waste**



- **Plutonium**
  C(Pu) ≤ C_{max}
- **Waste real composition**

- **Low density plutonium in water mist of varying density**

- **Plutonium (d_{Pu} = C_{max})**
- **Water (d_{H2O} = 1 g/cm³)**



Mist density: d_{mist} = 0 | d_{mist} = 0,1 g/cm³ | d_{mist} = 0,5 g/cm³ | d_{mist} = 1 g/cm³

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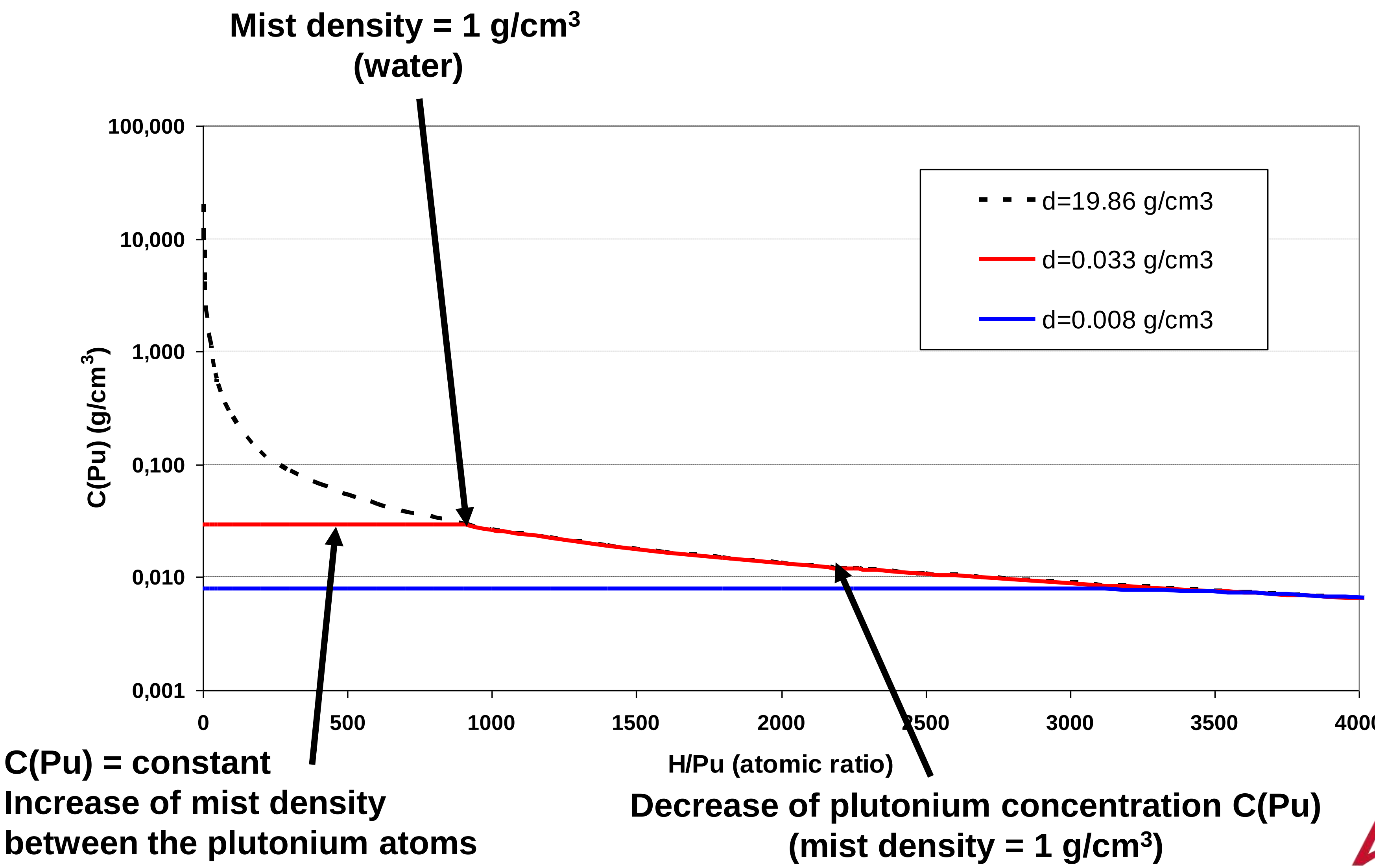
Density law for the Pu-water mixture



Optimum moderation for low fissile concentration

- **For « usual » cases (e.g. C(Pu) ≤ 3 g/cm³ for oxide powder)**
  - **M = C(Pu) × V with C(Pu) ↓ when H/Pu ↑ in the « region of interest »**
  - **➔ H/Pu atomic ratio is <u>higher</u> for the minimum critical mass than for the minimum critical volume**

- **For sufficiently low Pu concentration**
  - **M = C(Pu) x V with C(Pu) = constant over the « region of interest »**
  - **➔ H/Pu atomic ratio is <u>identical</u> for the minium critical mass and for the minimum critical volume**
  - **This optimum H / Pu ratio is the same for all concentrations < 11.76 g/L**
  - **For « usual » cases**
    - This configuration is not possible:
    - It could only be reached for water density > 1 g/cm³

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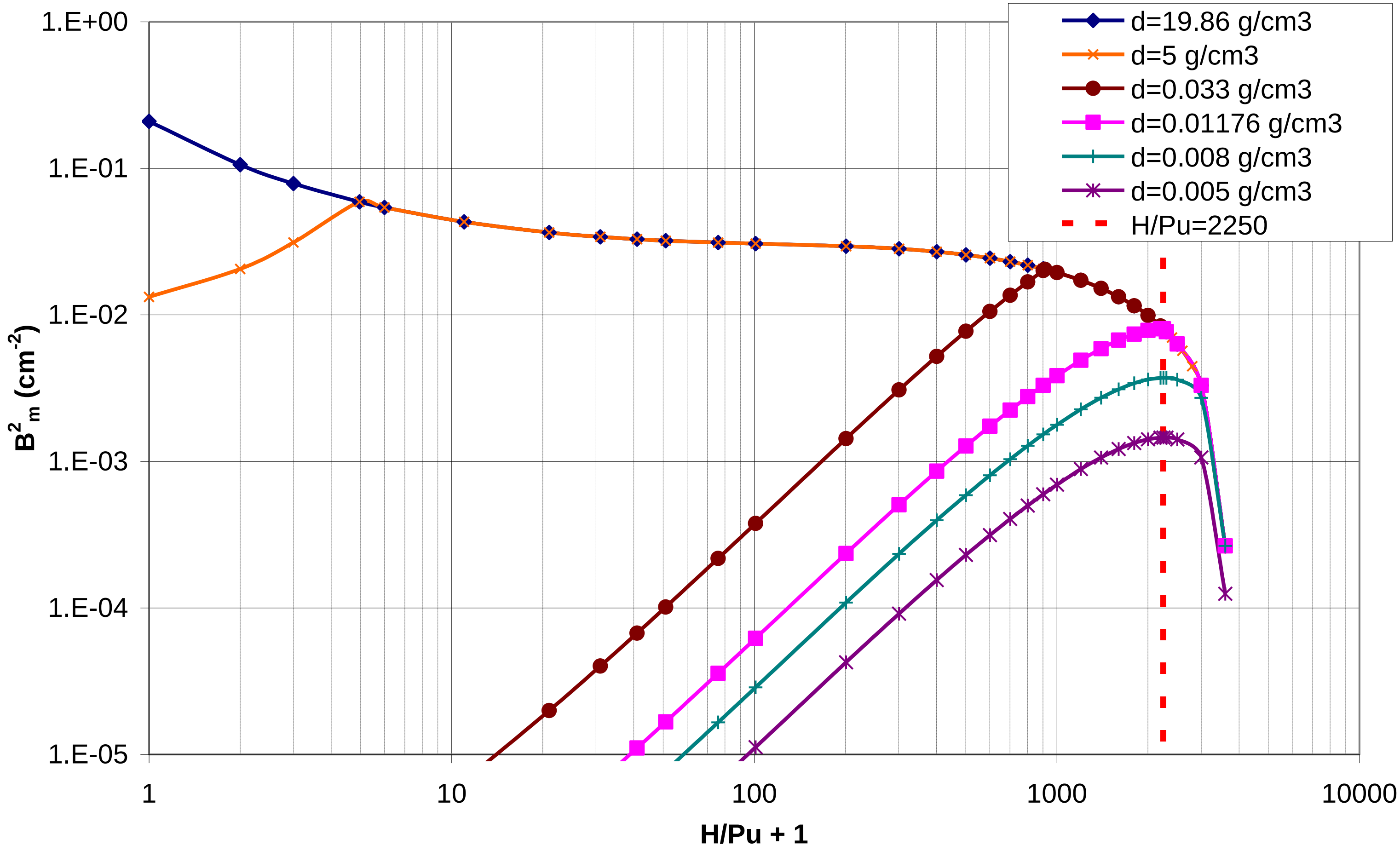
Material buckling B^2_m for low fissile concentration



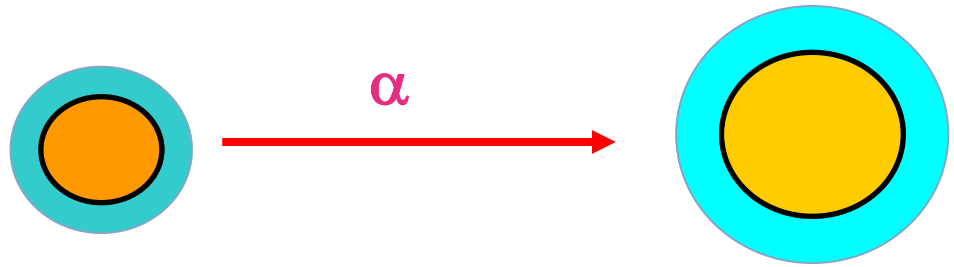
Effects due to the reflector (1/4)

- **Critical configuration of a bare (unreflected) sphere**
  - $B^2_m = B^2_g$
  - $B^2_g = (\pi / R)^2$ for a bare sphere of radius R

- **For critical configuration with reflector**
  - Reflection is equivalent to an additional fissile layer of thickness δ
  - → $B^2_g = (\pi / R_{eq})^2 = [\pi / (R+\delta)]^2$ for a reflected sphere of radius R

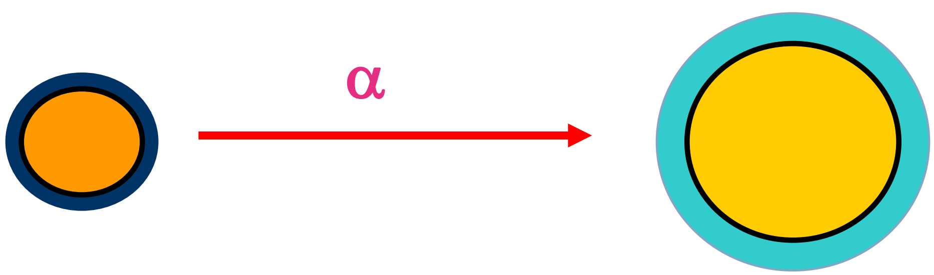
- **Full water reflection is affected by core-density transformation**

Effects due to the reflector (2/4)



Reflection by
20 cm water, d=1 g/cm^3

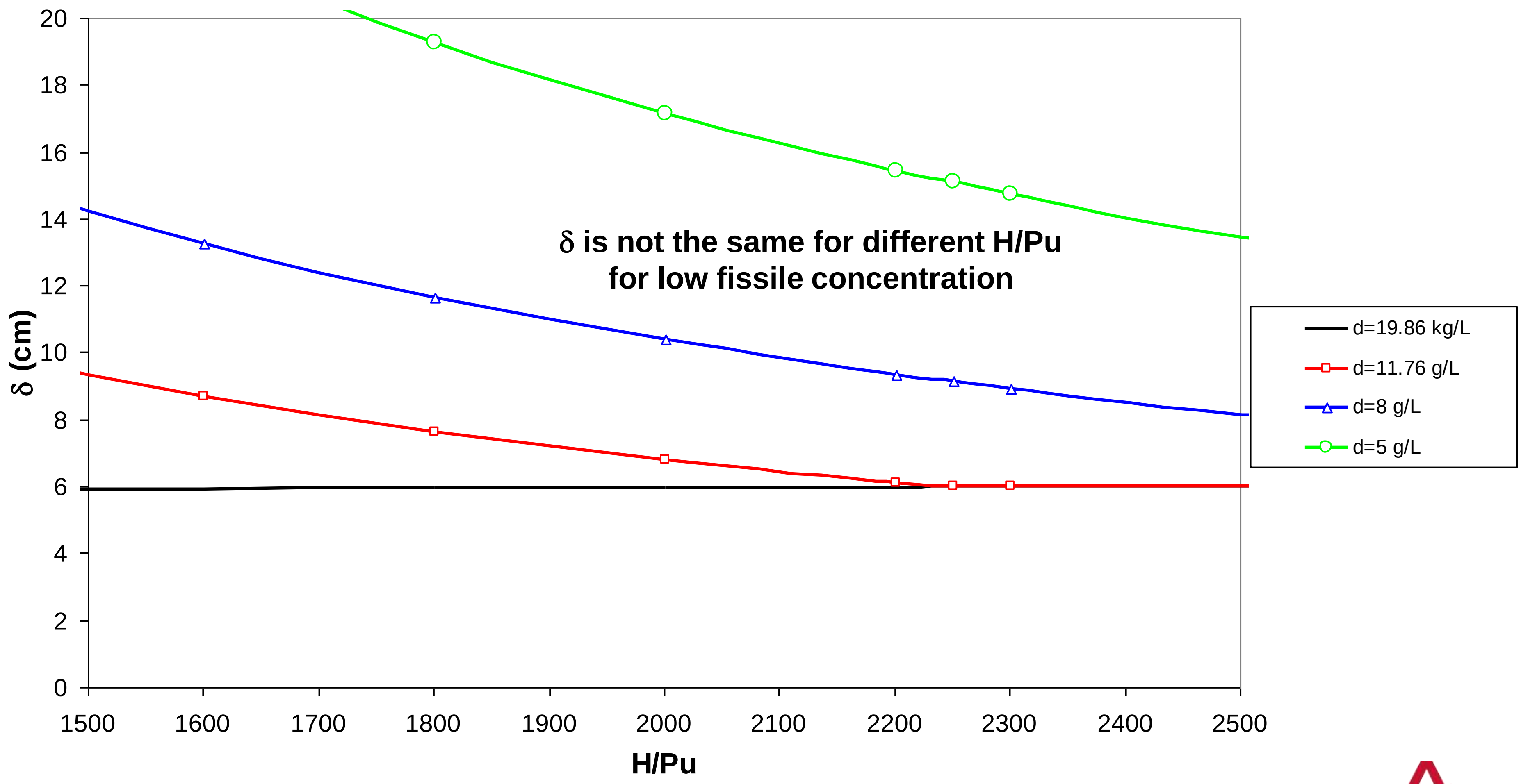
Reflection by
α×(20 cm) water mist, d=(1/α) g/cm^3



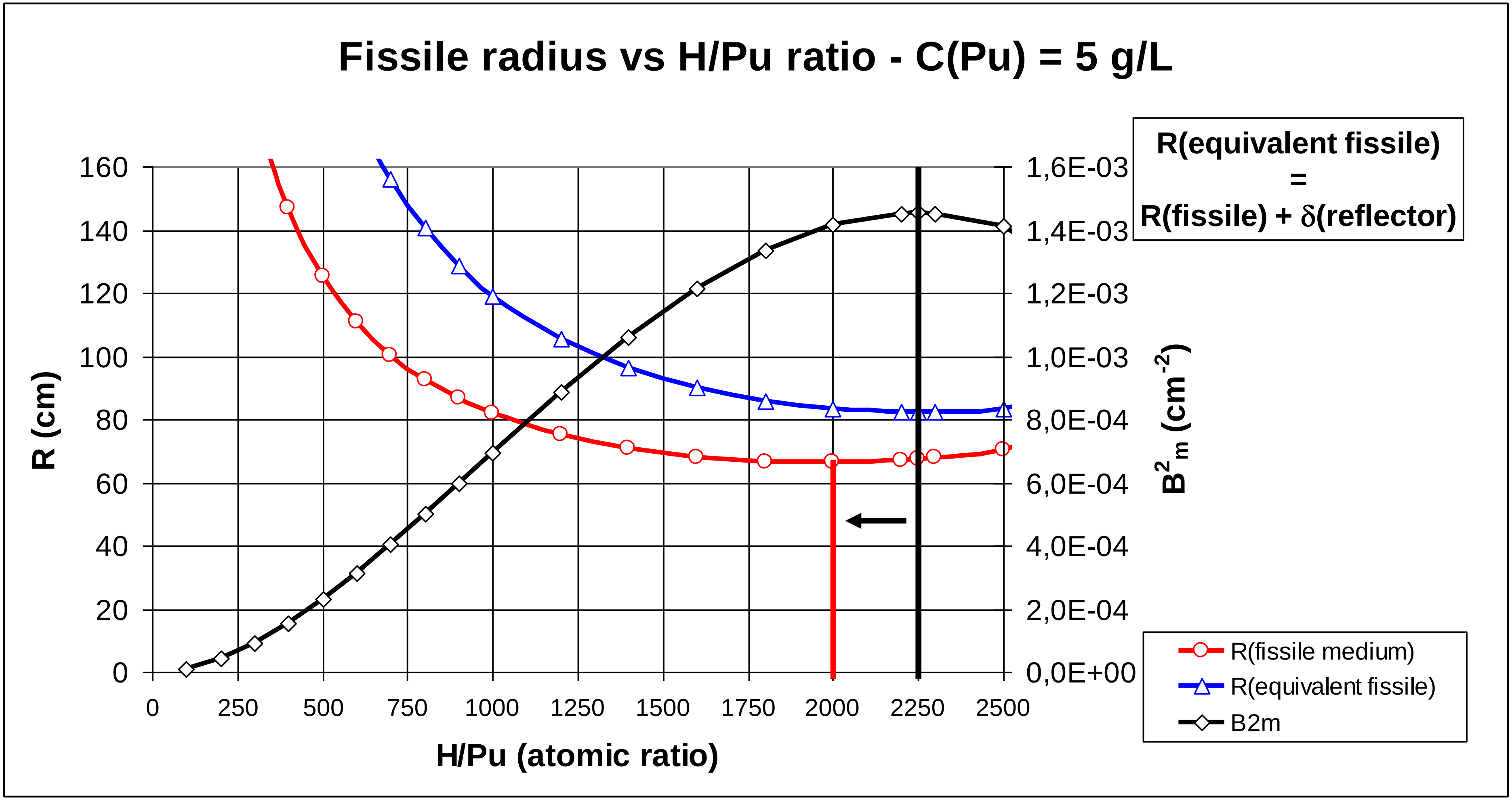
Reflection by
(20 cm)/α water mist, d=α g/cm^3

Reflection by
20 cm water (d=1g/cm^3)

Effects due to the reflector (3/4)



Effects due to the reflector (4/4)



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Application of core-density formula and comparison to code results

ρ_{Pu0} (g/cm^3)	APOLLO2-Sn		Core-density conversions	
	Critical Mass (kg) (H/Pu)	**Critical Volume (L) (H/Pu)**	**Critical Mass (kg) (H/Pu)**	**Critical Volume (L) (H/Pu)**
19.86	0.501 (H/Pu = 800)	0.293 (H/Pu = 0)	0.501 (H/Pu = 800)	0.293 (H/Pu = 0)
5	0.501 (H/Pu = 800)	2.01 (H/Pu = 3.96)	0.501 (H/Pu = 800)	2.00 (H/Pu = 3.96)
0.033	0.501 (H/Pu = 800)	15.17 (H/Pu = 800)	0.501 (H/Pu = 800)	15.17 (H/Pu = 800)
0.01176	1.165 (H/Pu = 2000)	99.09 (H/Pu = 2000)	1.165 (H/Pu = 2000)	99.15 (H/Pu = 2000)
0.008	2.454 (H/Pu = 2000)	306.9 (H/Pu = 2000)	2.458 (H/Pu = 2000)	307.5 (H/Pu = 2000)
0.005	6.117 (H/Pu = 2000)	1223 (H/Pu = 2000)	6.103 (H/Pu = 2000)	1222 (H/Pu = 2000)
0.0027	20.05 (H/Pu = 2000)	7608 (H/Pu = 2000)	20.11 (H/Pu = 2000)	7455 (H/Pu = 2000)

Low C(Pu) (rows 0.01176 to 0.0027)

Scattering effects (1/2)

- **Reality vs Pu-water mixture**
  - **Waste is not composed of water**
  - **Some elements may affect the results**
  - **The Pu concentration is ensured by the presence of these elements**
- **Scattering materials with low absorption may**
  - **Moderate the neutron more effectively than water mist**
  - **Decrease the leakage (« drunk man » effect)**
  - **e.g. Graphite, Silica**
- **Other elements may disappear**
  - **In case of a fire, of chemical reactions**
  - **Due to mechanical segregation**

  ➔ Pu concentration may changes: specific NCS analysis is needed

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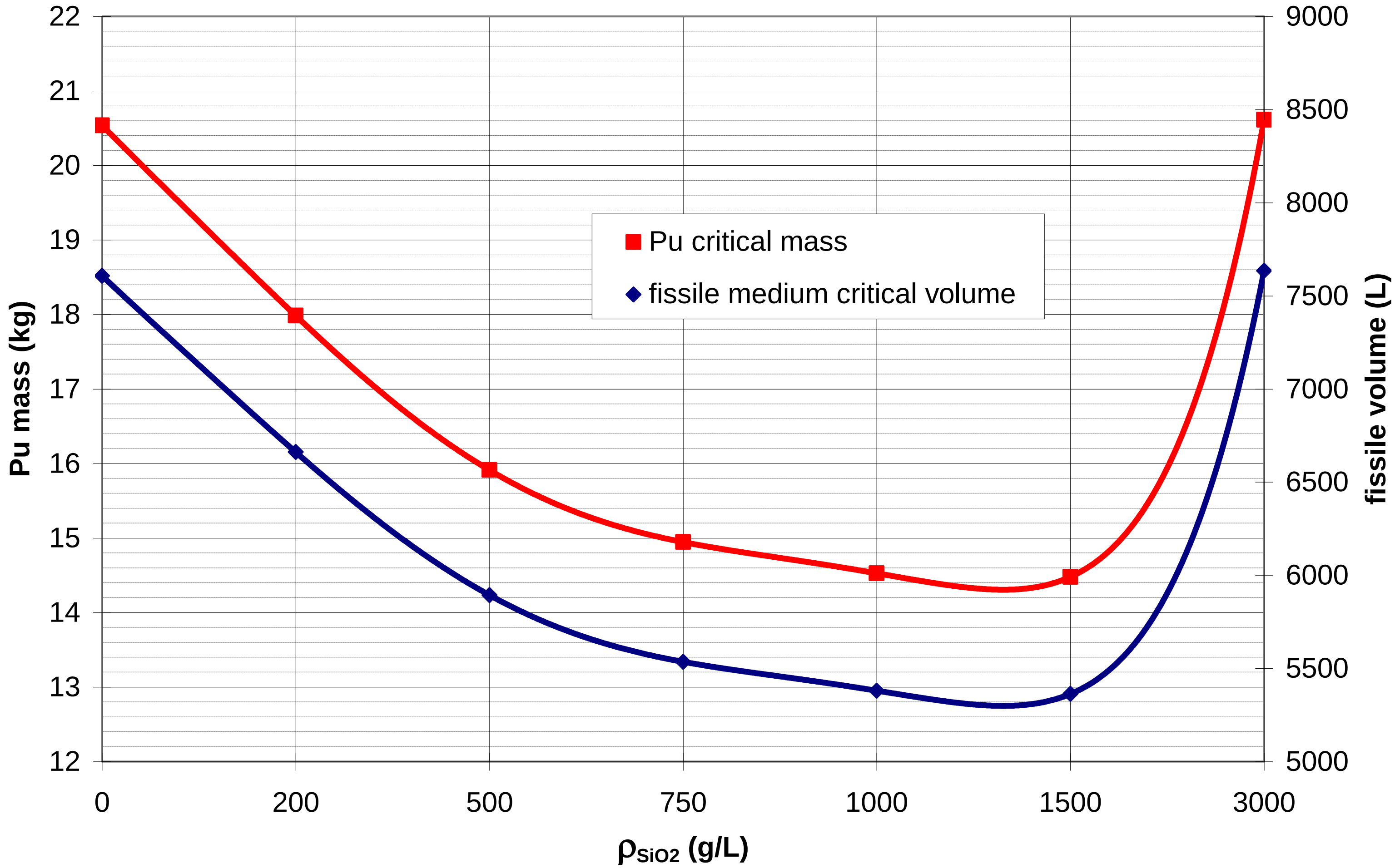
Scattering effects (2/2)



Conclusion

- **For low fissile (Pu) concentration**
  - **Taking into account the maximum Pu concentration allows to increase the critical mass and volume**
  - **Simple core-density formula allow a quick calculation of critical values**
  - **Critical mass and volume occur at the same H/Pu if the concentration is « sufficiently » low**
  - **Presence of the real elements in the waste composition shall be analyzed**