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+ undergrads François Viars, Flora Coulaud-Bastien

5th conference
Sustainable HEP

July 10th, 2026

Study MSSM:
Maximally
Sustainable
Shielding
Material

SuShi
sustainable shieldings

SUstainable SHIeldings
against ionizing radiations

why sustainable?

why shieldings?

- UN + states: Sustainable Development Goals
- CERN biannual environment reports
- Environmental objectives

IPAC-2022:

Project Region: Americas
BELLA 2nd Beamline and iP2
Status of the Advanced Photon Source Upgrade (APS-U) Project"
The Cornell-BNL ERL Test Accelarator (CBETA)
The Proton Power Upgrade Project at the Spallation Neutron Source (SNS)
Proton Power Upgrade Project

Project Region: Asia
Australian Synchrotron BRIGHT beamline expansion
Australian Synchrotron Operational Upgrades
China Spallation Neutron Source
Establishment of Heavy Ion Medical Accelerator
HIAF (High Intensity heavy ion Accelerator Facility)
Heavy Ion Research Facility at Lanzhou
High Intensity heavy-ion Acelerator Facility
RAON
RIBF upgrade project
Siam Photon Source-II (SPS-II) accelerator complex
Third RF station for storage ring of Taiwan Photon Source

Project Region: Europe
Diamond II
European Spallation Source (ESS)
Future Circular Collider (FCC) Feasibility Study
High Luminosity LHC (also: HiLumi LHC, HL-LHC)
IFMIF-DONES
MYRRHA (phase 1 – Implementation)

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SuShi
sustainable shieldings

1. Why sustainable materials could be interesting?
2. Preliminary results for photons.

Worse shielding than current materials…
…but can't address climate change w/o heavily changing the way we do.

→

- How much worse?
- What new constraints?

Shielding with blocks:

Concrete:

CERN / L.Sironi 2023
10.7712/120123.10795.20712

theconstructor.org

Sustainable material:

Markus Bühler

J. Faivre

It looks the same!

Why sustainable materials?

“Low carbon” concretes:

- Under development
- CO_2 emissions
- Resources (cement, sand, gravels, metal)
- Transport
- Grey energy

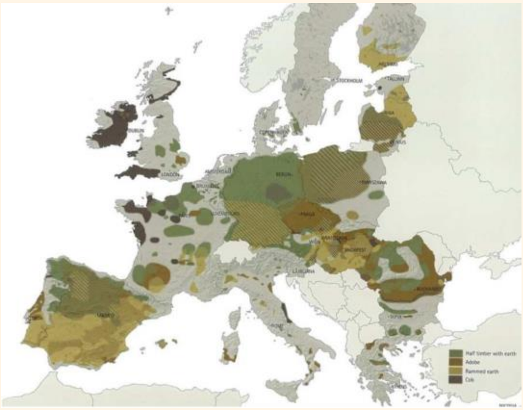
- Life cycle assessment:
  Irreversible setting (chemical)
  => not recyclable + transport, crushing

Sustainable materials:

Mastered for building

J. Faivre

Resources: abundant+local



ENTPE / P-A. Chabriac, Lotti and Mecca, 2011

~~sand~~
~~gravels~~
~~crushing~~ ~~x 2~~
~~heating~~
~~transport~~ ~~x 2~~
~~waste~~

CRAterre / Arnaud Misse

End of life: reversible setting

- reuse
- destroy on the site.

Recycled building:

J. Faivre

What sustainable materials?

Materials:

- raw earth,
- wood,
- vegetal fibers (straw, etc.).

hydrogen

Techniques:

- rammed earth (compacted earth),
- compressed earth blocks (CEB),
- adobe bricks (eg earth + straw).

Why can earth shield?

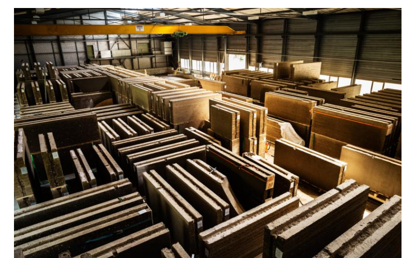
Ingredients of concretes:

Cement concrete:		**Earth** concrete (earth for building):		
• cement = clays (heated),		• clays (raw),		10-20%
• sand, • gravels.	added	• sand, • gravels.	already in earth	90-80%


Cédric Favero / CERN

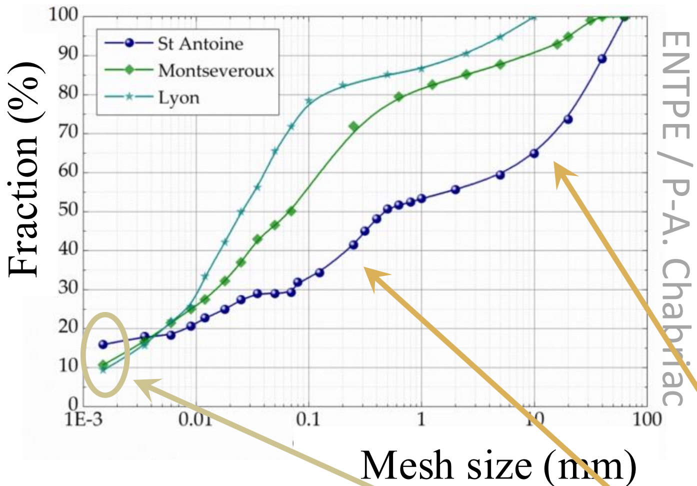
- $\simeq$ same Z
- $\simeq$ same density

=> same shielding!


Markus Bühler

What material is earth?

H					C		O			Na	Mg	Al	Si					K	Ca						Fe
1					6		8			11	12	13	14					19	20						26



Variations in atomic densities

- **composition:** sand+gravels? (90%) **(silicious vs calcareous)**
  clays? (10%) e.g. $(K,H_3O)\,(Al,Mg,\mathbf{Fe})_2\,(Si,Al)_4\,O_{10}\,[(OH)_2,(H_2O)]$
- variable earth **humidity** 1-5%:
  $M_{H2O} < M_{Si}$ => + 1% in mass = + 3.4% nuclei.
- **density**: +/- dense material:
  (1.5) 1.7 – 2.0 (2.2) g/cm^3. (concrete: $\rho \geq 2.3$ g/cm^3)

Interaction of MeV-photons:

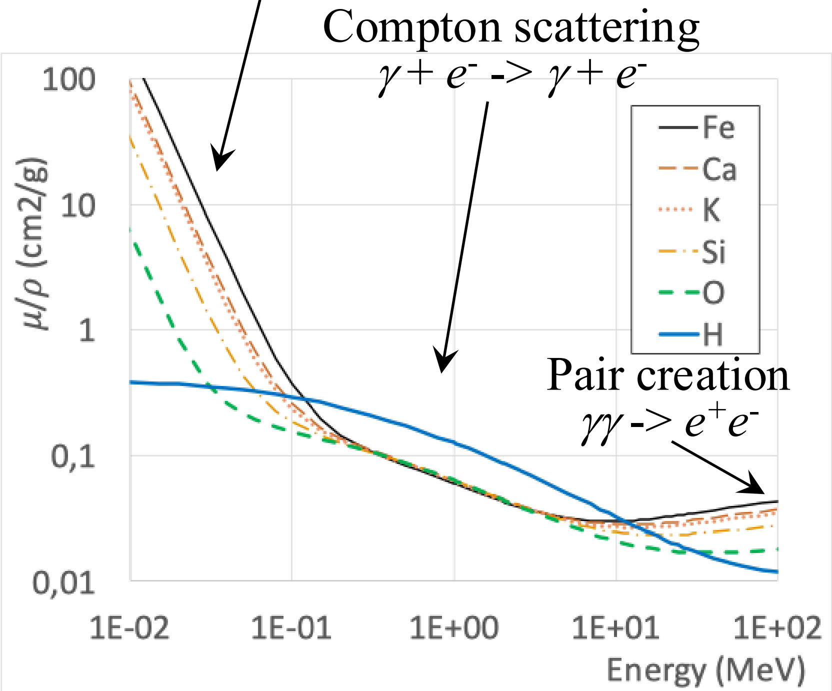
- $N(x) = N_0\, e^{-\mu x}$ $\mu = n\sigma$ (density, Z) (linear attenuation coeff.)
- Raw reasoning:
  - material composition (Z) influences screening for Eγ < 100 keV ($\sigma_{\text{photoel.}} \propto Z^4$),
  - also for Eγ > 100 MeV (showers: Z^2)
  - not really between 0.1 and 100 MeV.
- Calculations:
  - use NIST XCOM tables μ/ρ vs E,
  - set several material compositions,
  - calculation μ_{eq} material.

$$\left(\frac{\mu}{\rho}\right)_{\text{éq}} = p_{m_1}\left(\frac{\mu}{\rho}\right)_1 + p_{m_2}\left(\frac{\mu}{\rho}\right)_2$$

$(\mu/\rho = \sigma\mathcal{N}_A/M)$

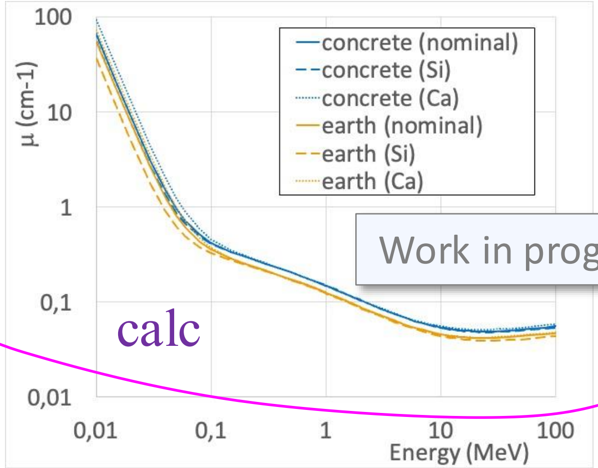
- Quantification:
  - linear attenuation coefficient μ_{eq},
  - characteristic thickness for given flux reduction : $x_{1/1000}(E) = \ln 1000 \,/\, \mu(E)$
  - or flux reduction factor $F(E) = N_0/N(x) = e^{\,\mu(E)\times x}$ for given x=50 cm thickness

photoel. effect $\gamma + X \to e^- + X^+$

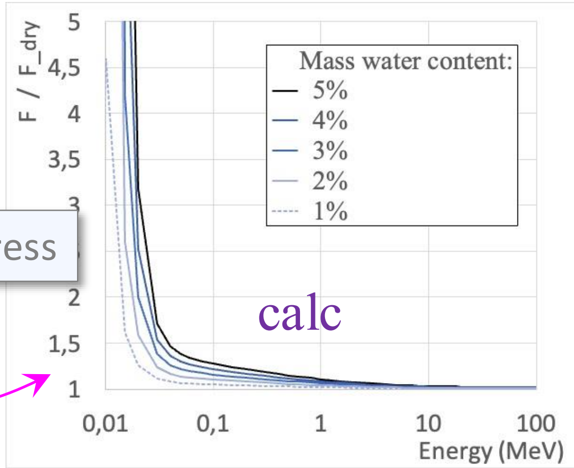


MeV-γ, results 1:

- **Sand+gravels composition:** no influence except < 100 keV.



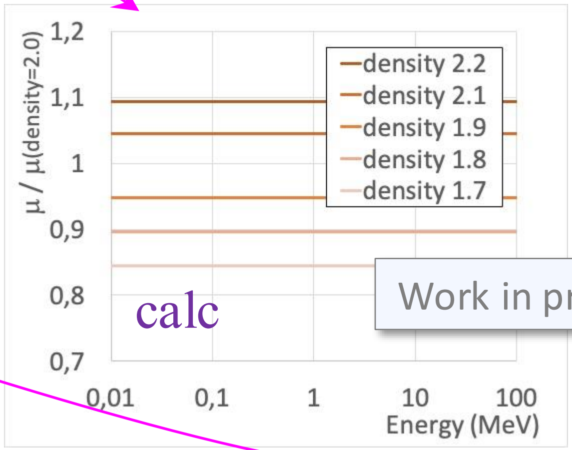
- **Clays nature:** no influence (to check).
- **Earth humidity:** + atoms => + shielding, especially < 100 keV.



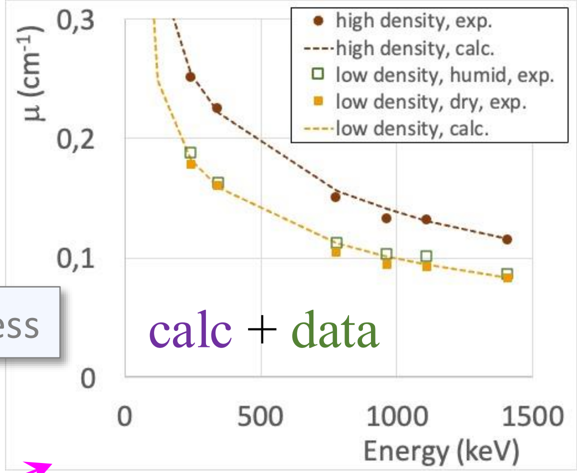
- **Density:** concrete 2.3 vs earth 1.9 – 2.1

  Dominant factor.

  < 20% extra-thickness.



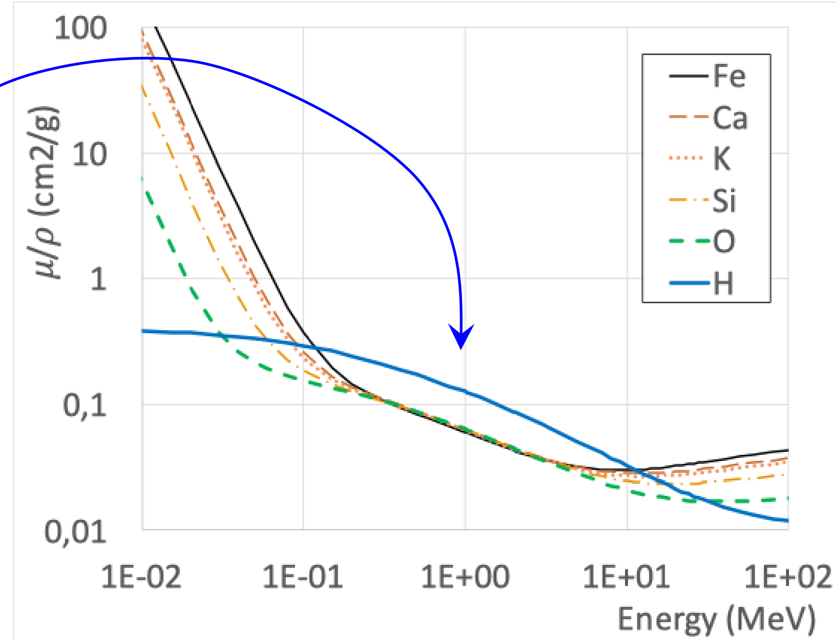
- **Experimentally:** OK (but difficult < 200 keV).



MeV-photons, result 2:

- Compton scattering:

$$\frac{\mu_{Compton}}{\rho} = \frac{\mathcal{N}_A}{M}\sigma_{Compton} \simeq \frac{\mathcal{N}_A}{A} \times kZ = k\mathcal{N}_A \boxed{\frac{Z}{A}}$$



- Better absoption in MeV range by enriching material in H?

- **Too small effect** because $A_H/A_C = 1/12 \ll 1$

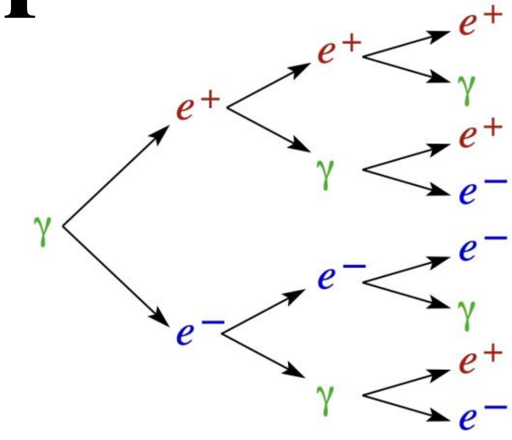
$$\left(\frac{\mu}{\rho}\right)_{equivalent} = \underbrace{\left(1 + \frac{1}{1 + \left(\frac{A_C}{A_H}\frac{N_C}{N_H}\right)}\right)}_{\text{could reach 2}} \left(\frac{\mu}{\rho}\right)_C$$

could reach 2
but need $N_H / N_{not\text{-}H} \gg 1$!

- 2 approximations made ($\mu/\rho \propto Z/A$ and $(\mu/\rho)_H = 2\,(\mu/\rho)_C$)
but also true ◇ with database μ/ρ
◇ experimentally (fir wood).

Interaction of GeV-photons:

- Electromagnetic shower
  (pair creations + Bremsstrahlung)
- Shower length:



Initial energy

$$L(E_0) = \frac{X_0}{\ln(2)} \ln\left(\frac{E_0}{E_c}\right)$$

/!\ compound

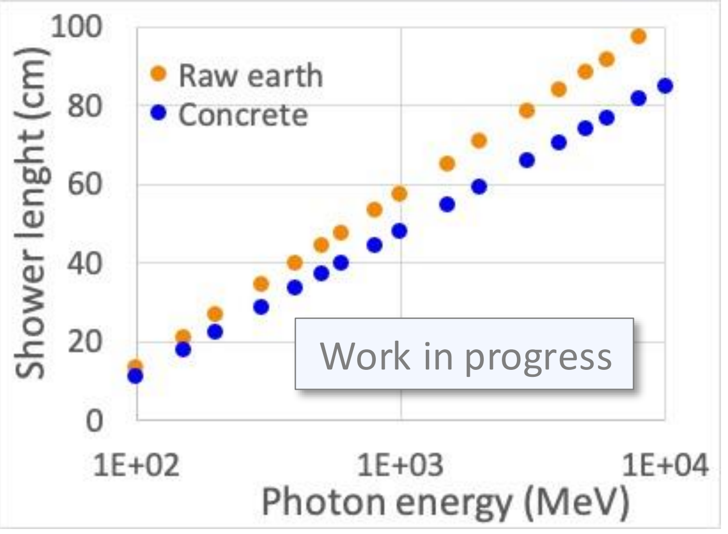
Database:
pdg.lbl.gov/2025/AtomicNuclearProperties/

$$X_0 = \frac{1}{\rho_c} \frac{1}{\sum_i \frac{F_i}{X_{0,i}\rho_i}}$$

pure Z

Material density and composition

- Raw earth density 1.94 g/cm³
- Assumption: same E_c earth and concrete
  => ratio of lengths is constant with E_γ.
- Driving factor = **density**,
  +20% shower length in raw earth wrt concrete.



Conclusions:

- **Sustainable materials** can be **relevant** for shielding.
- **Photons:** price to pay ~ **+20% thickness**.

Prospects:

- Hadronic showers
- Activation
- Tests with **MeV neutrons**

+ technical matters:

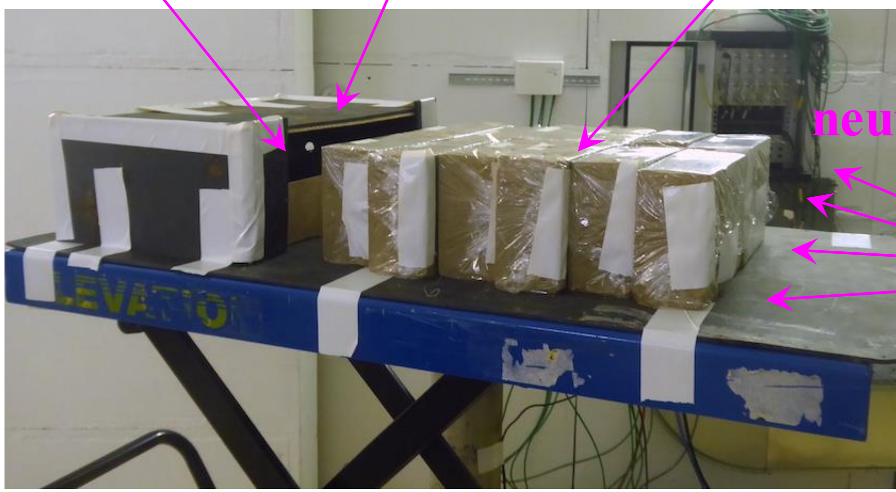
- mechanics
- how to transport
- reaction to irradiation

recycled earth

Franck Ribard

Julien Faivre

Dania Bellon



Julien Faivre

- 1 week data-taking
- A lot of data analysis ahead!

Hodabalo Kondo-Feou

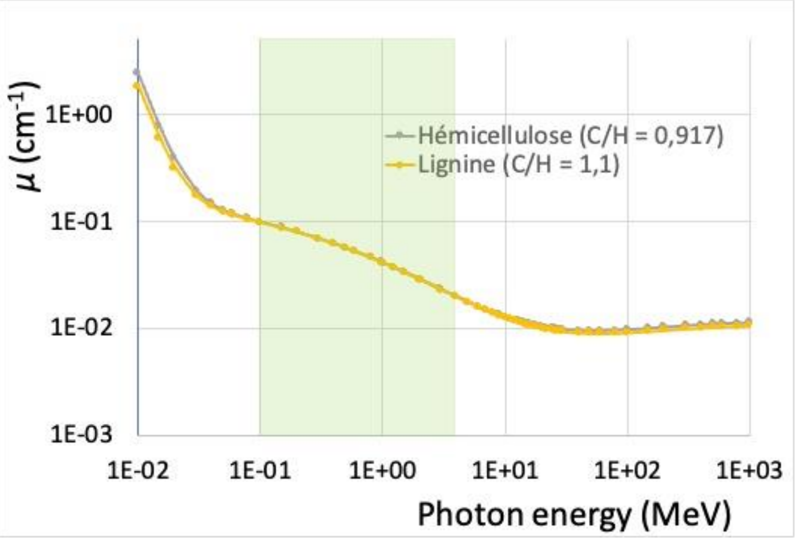
Julien Faivre

Hodabalo Kondo-Feou

BACKUP

MeV-photons, result 2:

- Complete calculation with XCOM μ/ρ values: **same conclusion**.



- **Measurements** with wood: **well described** by calculations.