31-01-2020
Mini-workshop on Geopolymers

The effect of gamma irradiation on CaO-FeOx-SiO2 slag based inorganic polymers

Radiation-induced mechanical degradation in alkali activated materials:
a combined experimental - computational approach

drs. ing. BRAM MAST
Hasselt University

Promotor:
prof. dr. SONJA SCHREURS UH

Co-promotor:
prof. dr. BRAM VANDOREN UH
prof. dr. YIANNIS PONTIKES KUL

NuTeC
UHASSELT
KU LEUVEN

Inorganic Polymers

as safety material for nuclear industry

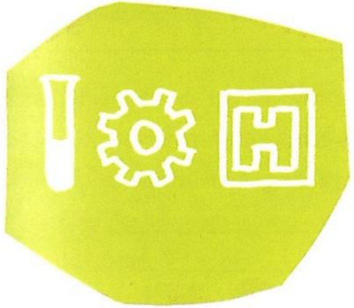
Belgian nuclear waste management

Possibilities of IPs in nuclear industry

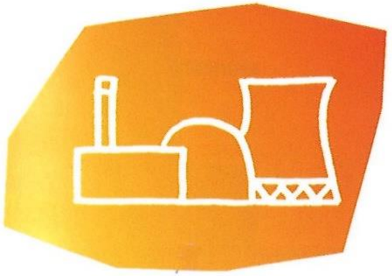
Effect of gamma irradiation on
Fe-rich inorganic polymers

Belgian nuclear waste management

Radioactive Wastes

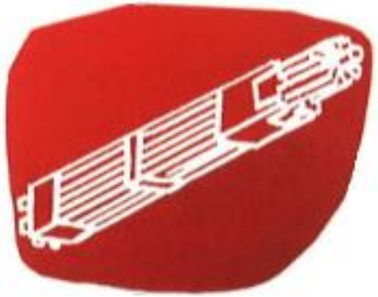


Nuclear medicine
Research
Industry



Energy production

Dimolition



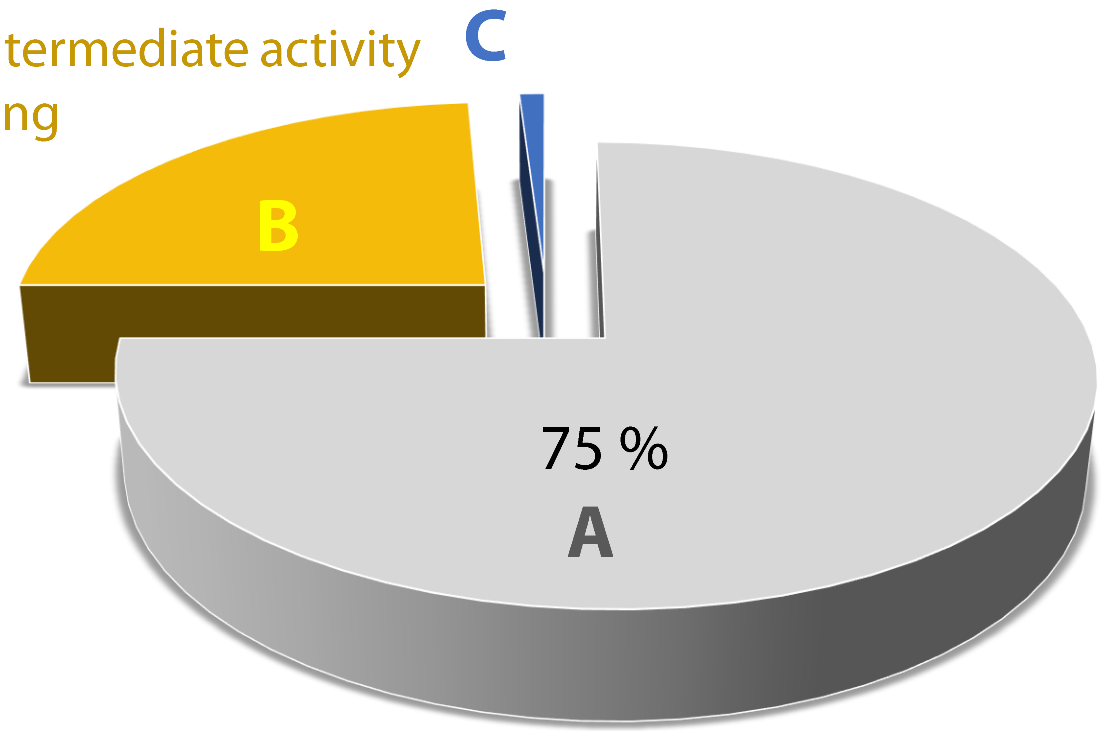
Nuclear fuel cycle

https://www.niras.be/

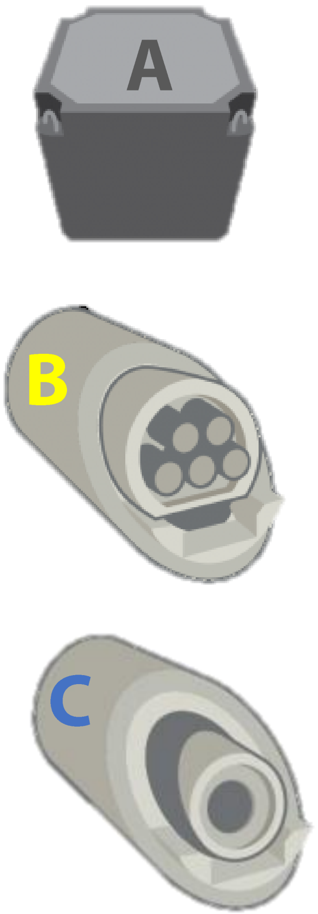
Belgian nuclear waste management

- High activity
- Long living

- Low & Intermediate activity
- Long living



- Low & Intermediate activity
- Short living



https://www.niras.be/

Challenges of Long-term storage of radioactive wastes

- Durability up to 100,000 – 1,000,000 years service life?

  ➔ Dependent on type of nuclear waste & country specific

- Binding of radionuclides
- Low heat evolution
- Dimensional stability
- Controlled corrosion of reactive metals
- **Stability under irradiation**
- Properties of activated components
- …

Challenges of Long-term storage of radioactive wastes

Possible effects of ionizing radiation on concrete:

- Dehydration

Radiolysis
→ decomposition of water

Heating
→ evaporation of water

- Radiation-induced carbonation

Radiolysis
→ formation of H_2O_2

→ $CaO_2.H_2O$ → $Ca(OH)$

→ $CaCO_3$

Drying & Shrinkage

Decomposition

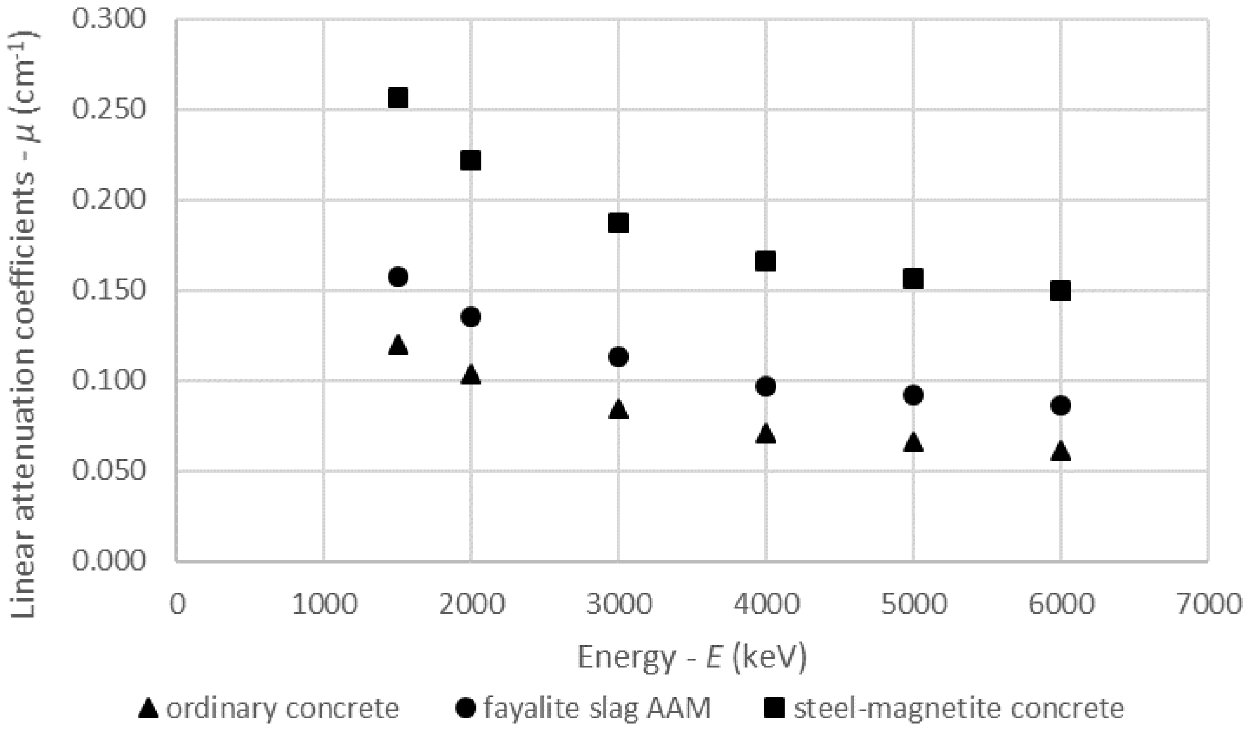
Cracking & Loss of strength

Possibilities of IPs in nuclear industry

B. Mast, Y. Pontikes, W. Schroeyers, B. Vandoren, and S. Schreurs,
"00135 Alkali Activated Materials - The use of alkali activated materials in nuclear industry,"
in *Comprehensive Nuclear Materials*, 2nd ed., 2020.

IPs as shielding material

- **Low radiolytic H_2 yield**
- **No damage as a result of dehydration**
- **Good Shielding of γ-radiation**



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IPs as shielding material

- Low radiolytic H_2 yield
- No damage as a result of dehydration
- Good Shielding of γ-radiation
- Activation with $Ba(OH)_2$ could improve the shielding performance due to high atomic number
- Boron could subsitute Al for good neutron shielding
- Better neutron shielding than aged OPC concrete
- Neutron activation of ^{40}Ca can be reduced

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IPs as shielding material

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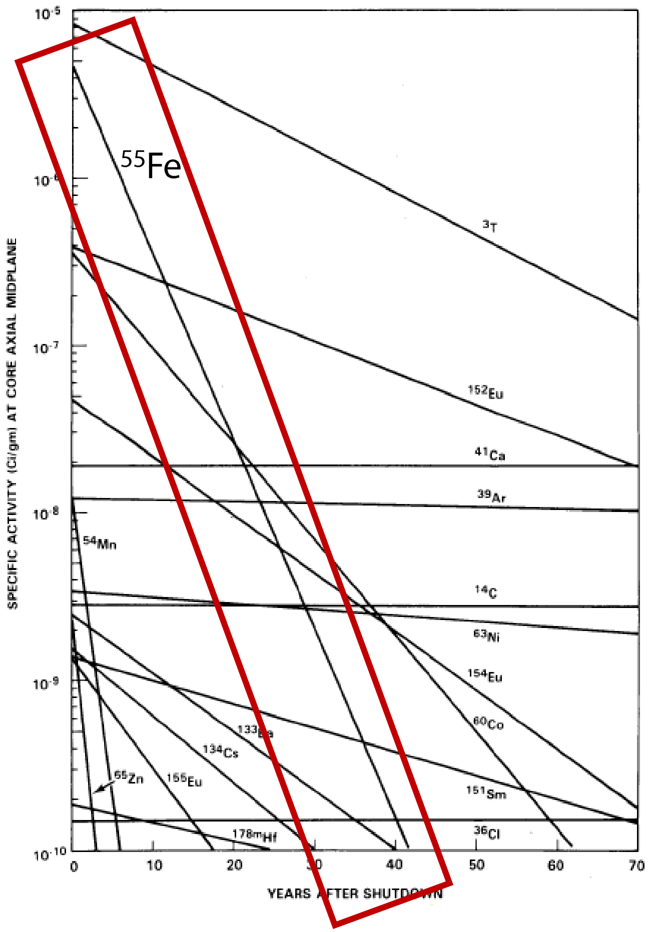

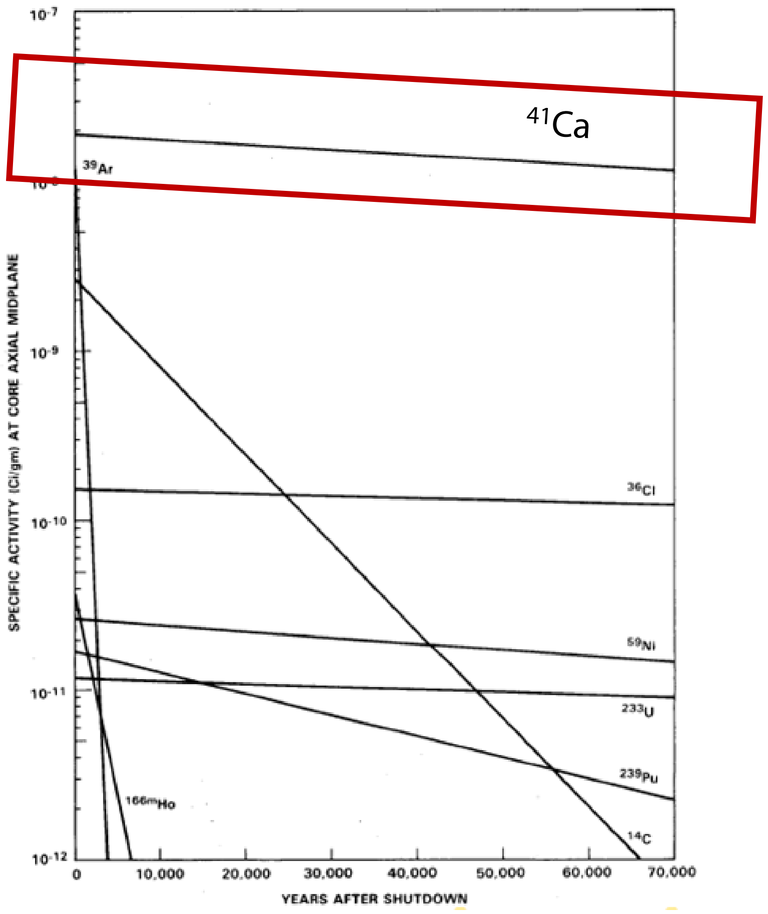

IPs as conditioning material

Advantages

- Absence of $Ca(OH)_2$
- Reduced water content
- High alkalinity
- Excellent fire resistance
- Low porosity

Mechanisms

- Uptake as charge-balancing ion in the structure
- Incorporation in aluminosilicate structure
- Formation of precipitates
- Adsorption on self-generated or introduced zeolite structures

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IPs as conditioning material

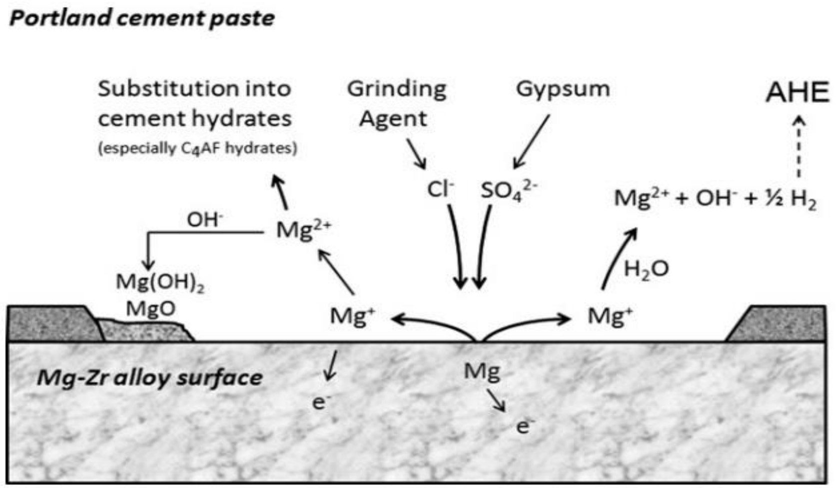
Example: Mg-Zr alloys

At high pH:
High hydrogen gas generation as result of $Mg(OH)_2$ formation

Solution:
Addition of sodium fluorine as Mg corrosion inhibitor → formation of passivation layer

Problem in OPC:
Formation of CaF_2 precipitates → deterioration
Destabilization of protection layer

Solution:
Ca-free low pH IPs



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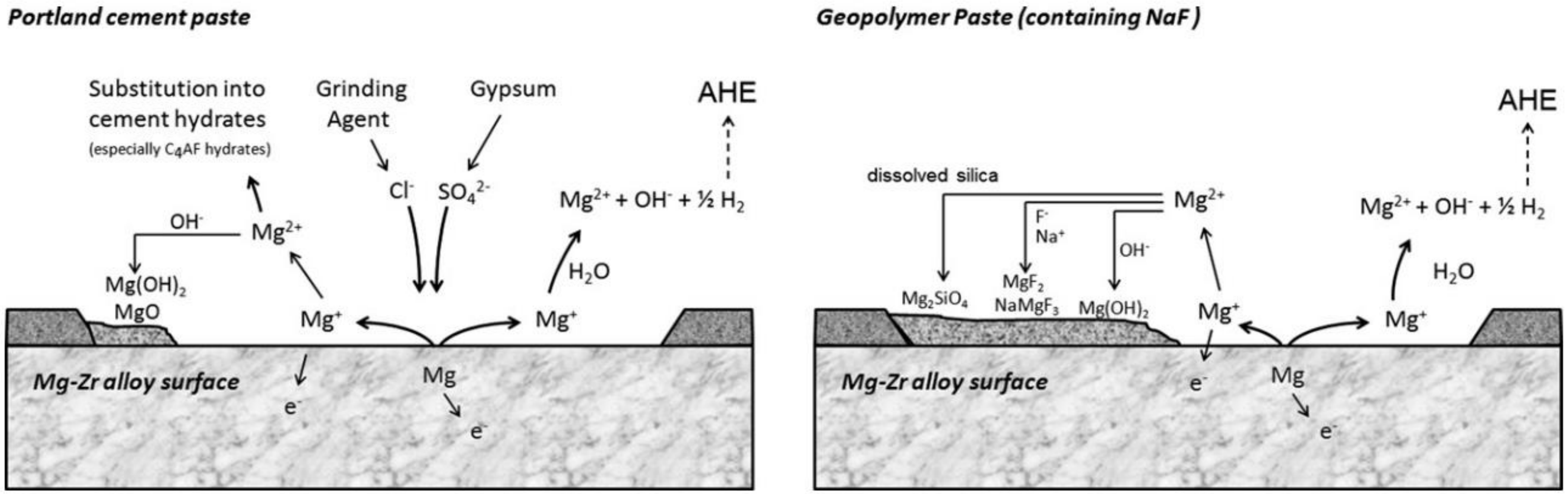
IPs as conditioning material

Example: Mg-Zr alloys

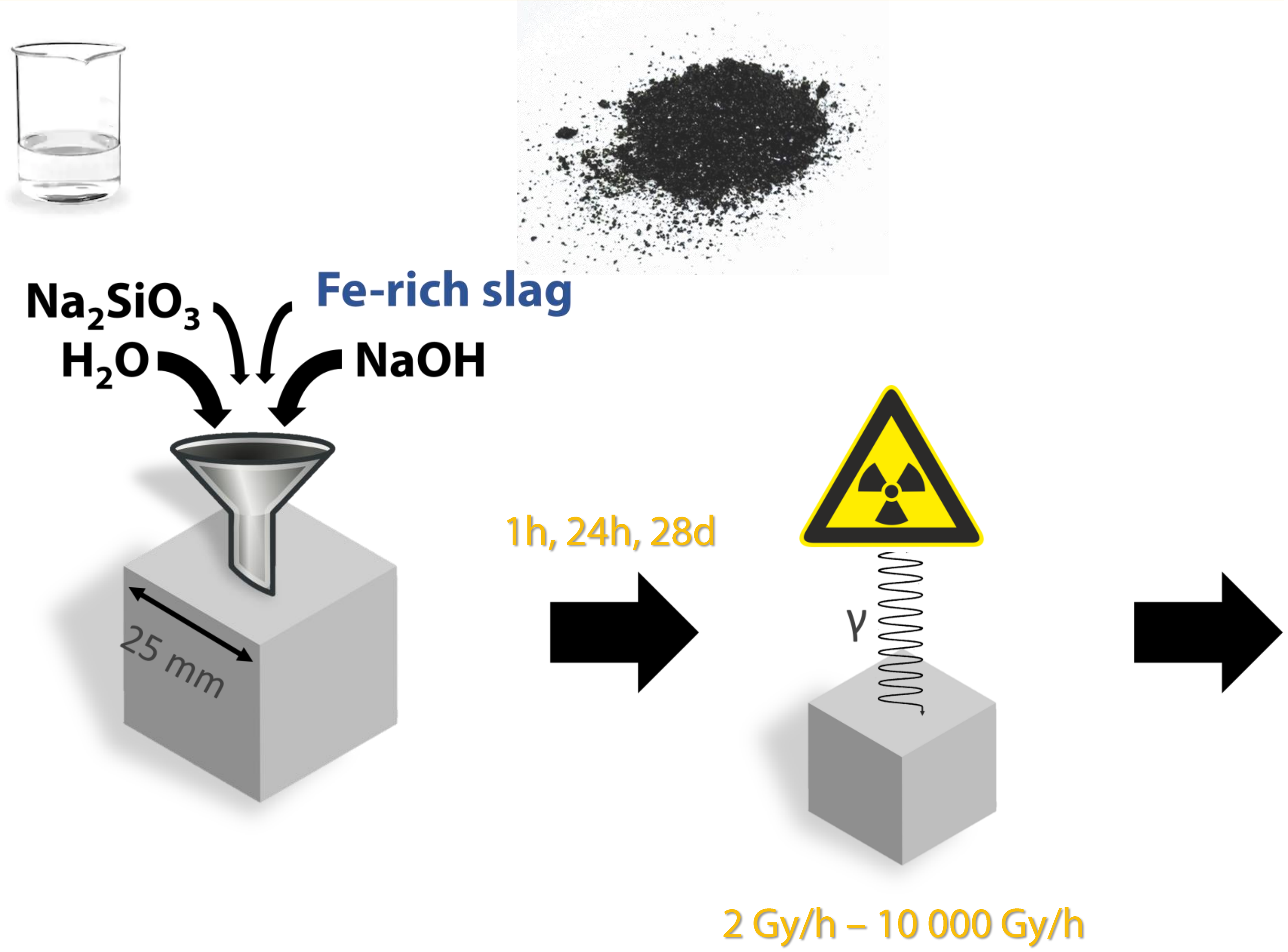
Solution:
Ca-free low pH IPs

- Formation of $MgSiO_4$ passivation layer



Effect of gamma irradiation on Fe-rich inorganic polymers

Effect of gamma irradiation on Fe-rich inorganic polymers

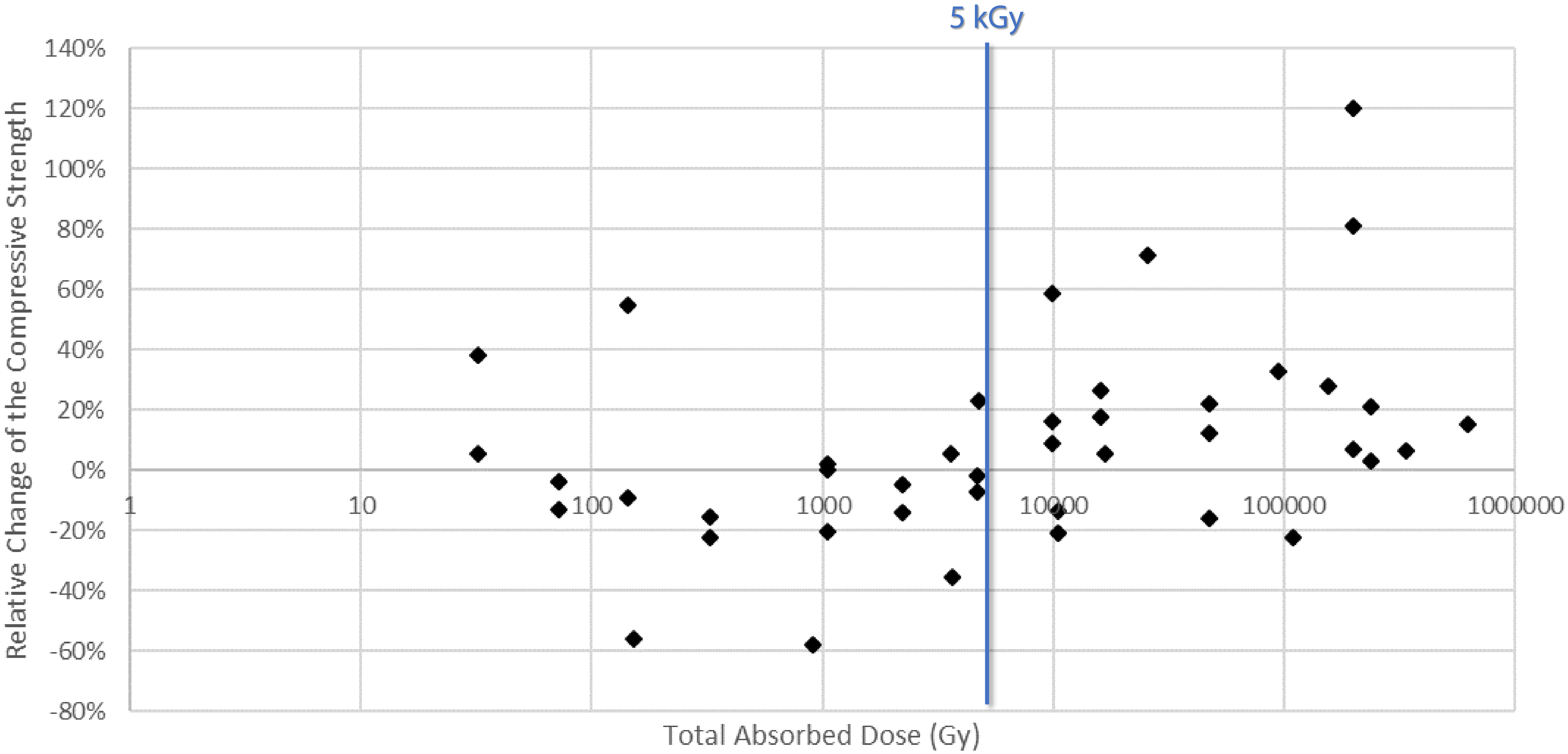


Evaluation:

- Nanoindentation
- Compression strength test
- ATR-FTIR
- NMR
- MIP
- SEM
- TGA
- ^{57}Fe Mössbauer spectroscopy

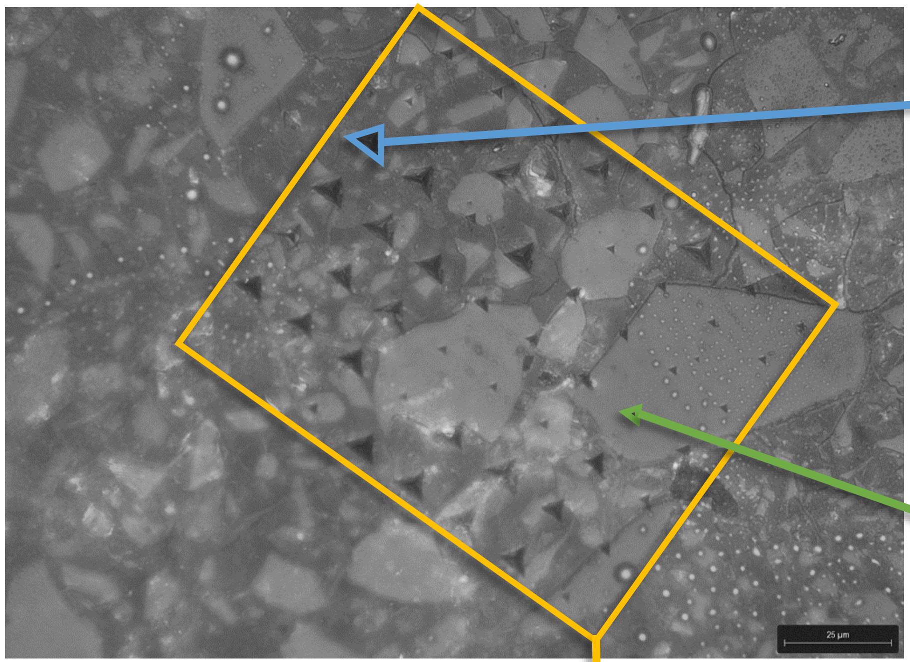
Effect of gamma irradiation on Fe-rich inorganic polymers

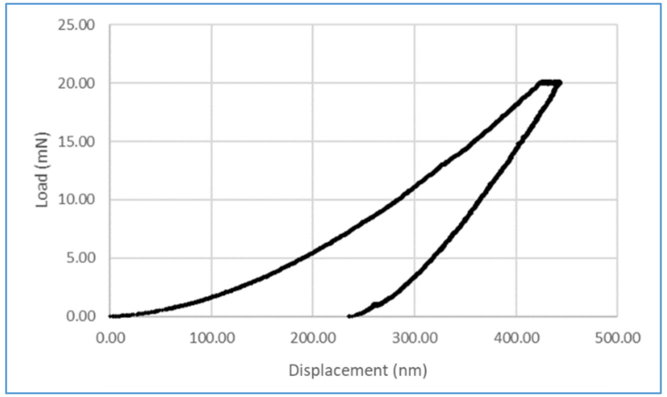
Increase in compressive strength > 5 kGy

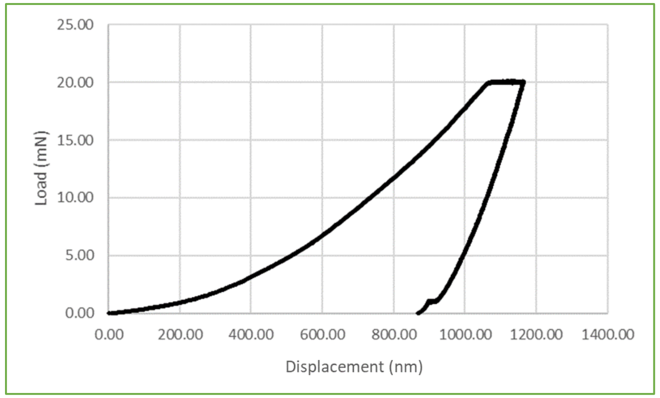


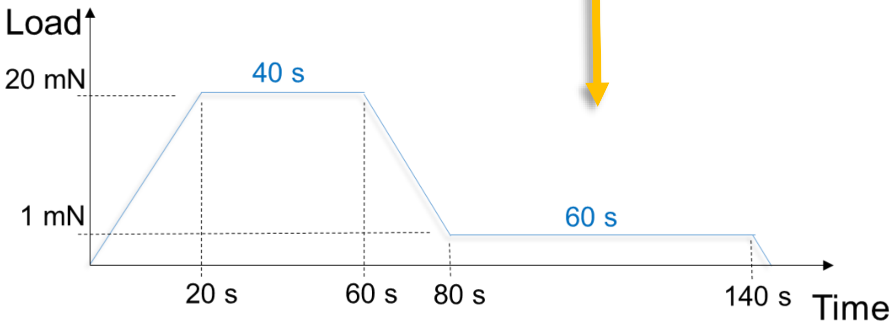
Effect of gamma irradiation on Fe-rich inorganic polymers

Nanoindentation : methodology









- Hardness
- Young’s modulus
- Creep

The experimental data used in this research were generated through access to the ActUsLab under the Framework of access to the Joint Research Centre Physical Research Infrastructures of the European Commission (IP4NA project, Research Infrastructure Access Agreement Nr. 35433)

Effect of gamma irradiation on Fe-rich inorganic polymers

JRC
EUROPEAN COMMISSION

Nanoindentation: effects on the binder

(1h) – 10 kGy/h

- Hardness ↓
- Young's modulus ↓
- Creep ↓

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Effect of gamma irradiation on Fe-rich inorganic polymers

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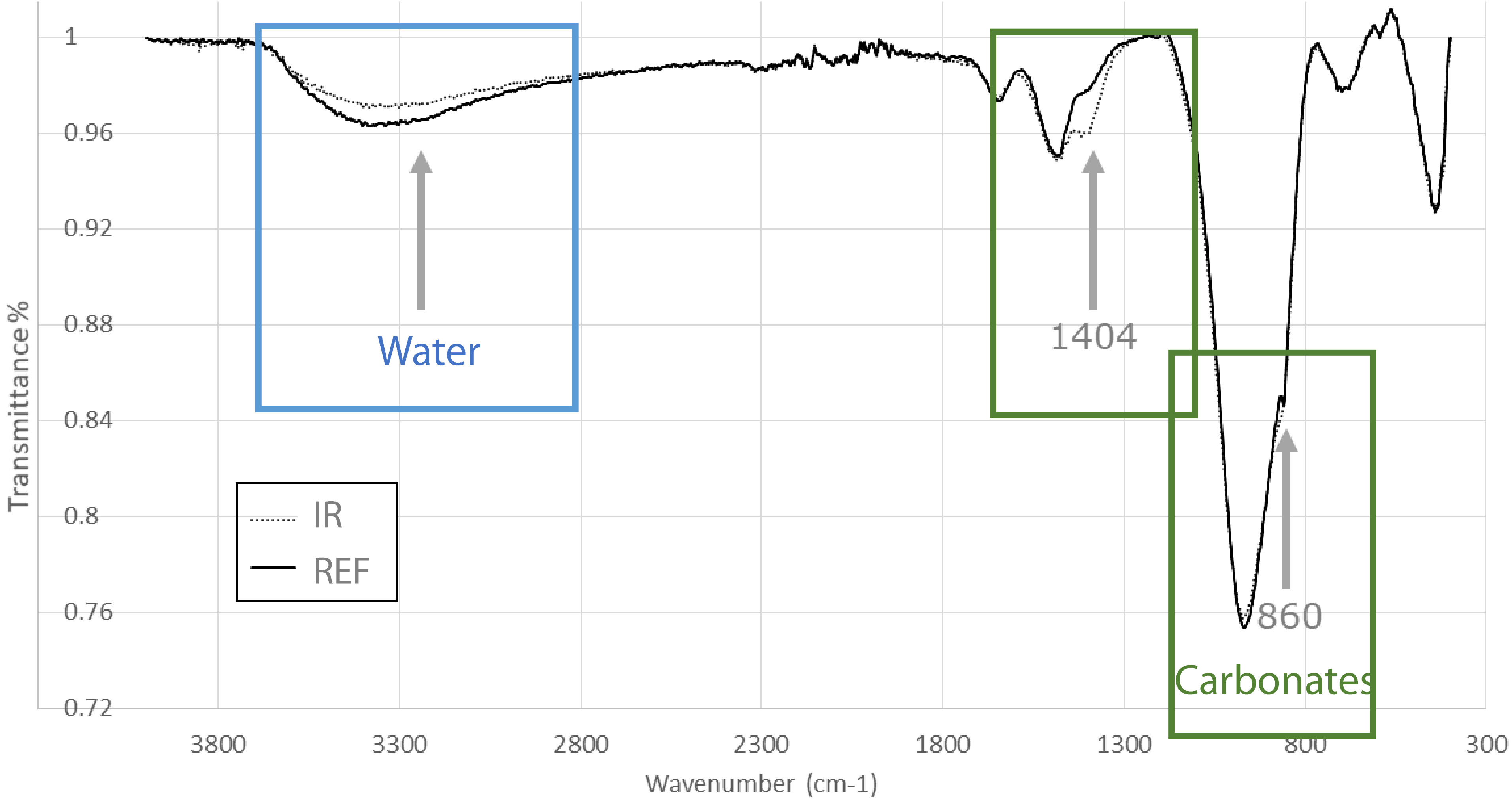
FTIR: radiation-induced carbonation + dehydration

(1h) – 152 Gy/h



Effect of gamma irradiation on Fe-rich inorganic polymers

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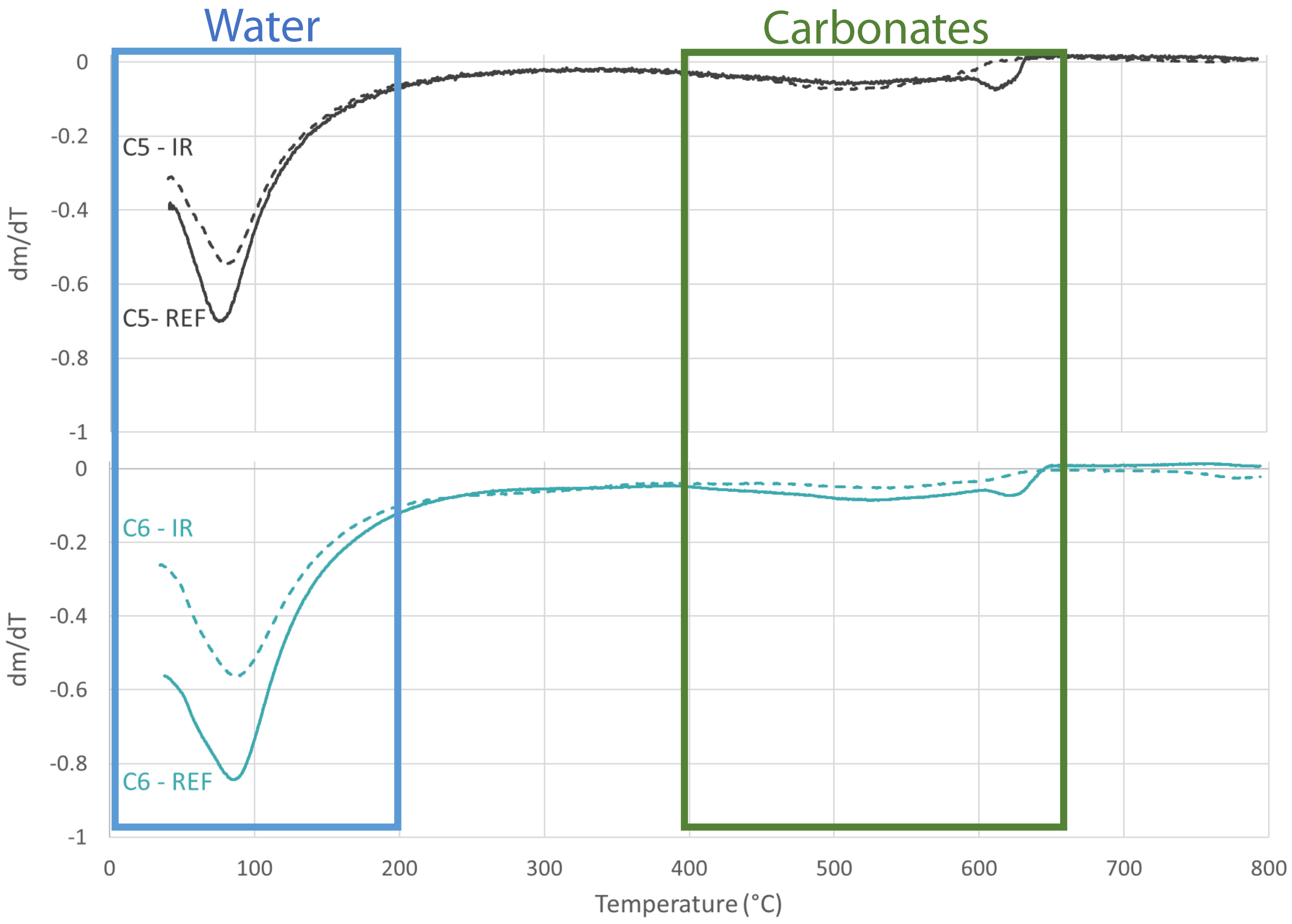
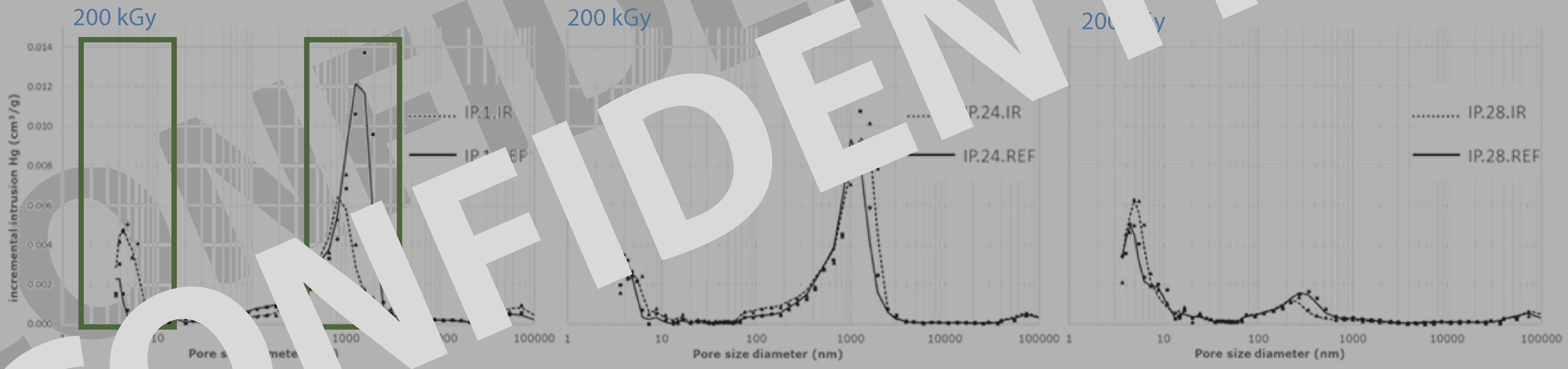
TGA: radiation-induced carbonation + dehydration

(1h) – 152 Gy/h



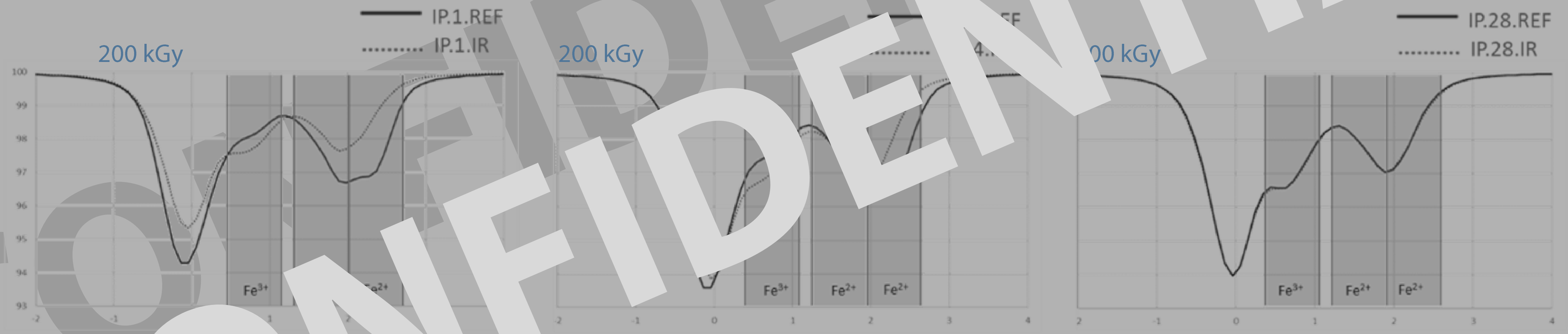
Effect of gamma irradiation on Fe-rich inorganic polymers

- Decrease in porosity
- Shift to the smaller pore sizes



hour 24 hours 28 days

Effect of gamma irradiation on Fe-rich inorganic polymers



hour

24 hours

28 days

$^{3+}_{REF}$: 20

39 %

Fe^{3+}_{REF} : 24 %
Fe^{3+}_{IR} : 38 %

Fe^{3+}_{REF} : 43 %
Fe^{3+}_{IR} : 43 %

Summary

Radiation-induced:

- Carbonation
- Dehydration
- Iron oxidation

Leading to:

- Decrease in porosity
- Decrease in E-modulus
- Increase in Fe^{3+}

Resulting in:

- Increased strength

Contact

Bram Mast
PhD-researcher
Nuclear Technology Centre

bram.mast@uhasselt.be
+32 498 20 08 72

https://brammast.wixsite.com/mysite

Agoralaan Building H – Office B107
BE-3590 Diepenbeek