Institute of Fundamental Technological Research
Polish Academy of Sciences

# Exposure of heavyweight concrete to gamma irradiation in spent fuel pool

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# Outline

- Purpose of the research
- Concrete mix design
- Reactor Maria – spent fuel pool
- Preliminary tests: physical properties of concrete; strength and permeability
- Concluding remarks

# Purpose of the research

Laboratory-based fundamental investigation to study influence of gamma radiation on properties of heavyweight concrete

- possibility of testing in the spent fuel pool

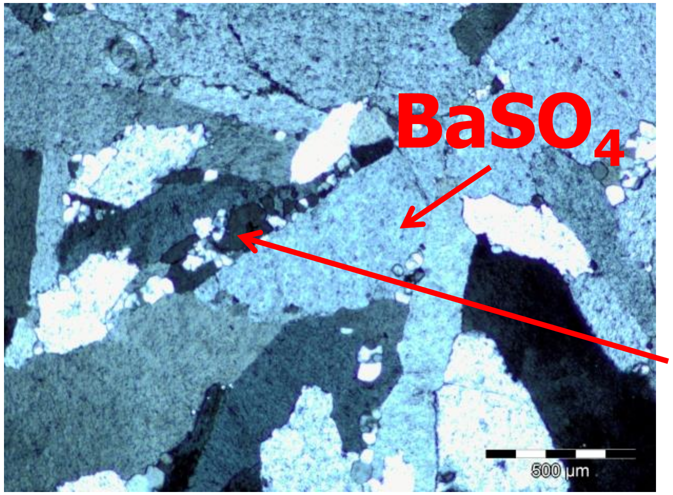
- Ensure long-term durability (normal and emergency operating condition of the NPP)
- Attenuation of the radiation NPP and other sources
- Impermeability of concrete containment (potential contaminated gases and liquids)

The composition of heavyweight concrete was focus on shielding properties (gamma radiation) and its impermeability

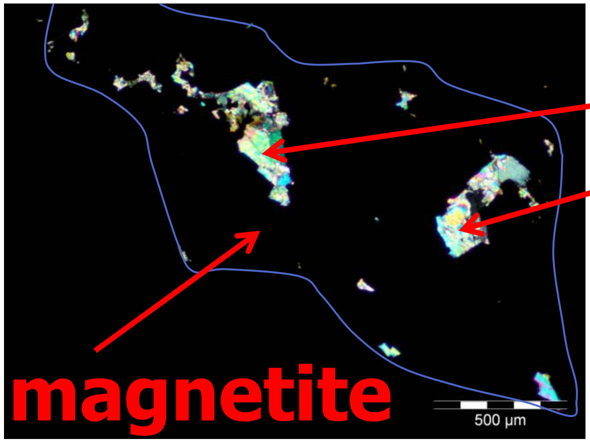
# Special aggregates

**Attenuation of γ radiation (heavyweight aggregate)**

- Barite; ρ= 4.2 g/cm$^3$


- Magnetite; ρ= 4.8 g/cm$^3$

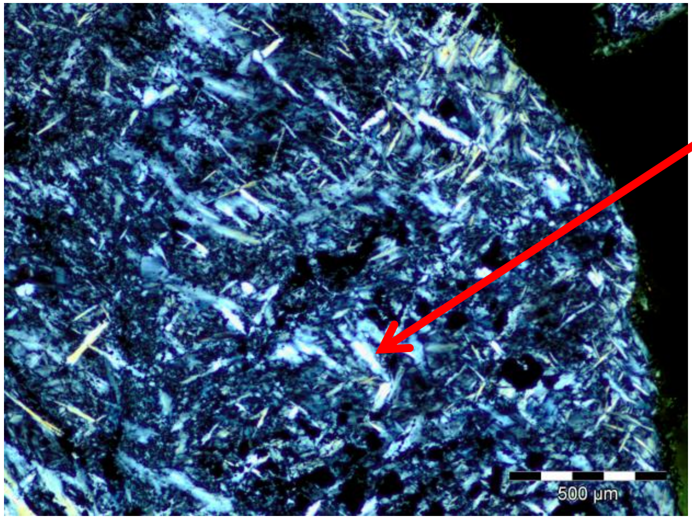




**Thin section images**

# Special aggregates

**Attenuation of neutron radiation (chemical bonded water)**

- Serpentinite
  11% crystalline water in aggregate


**Thin section image**

**fibrous serpentine:**

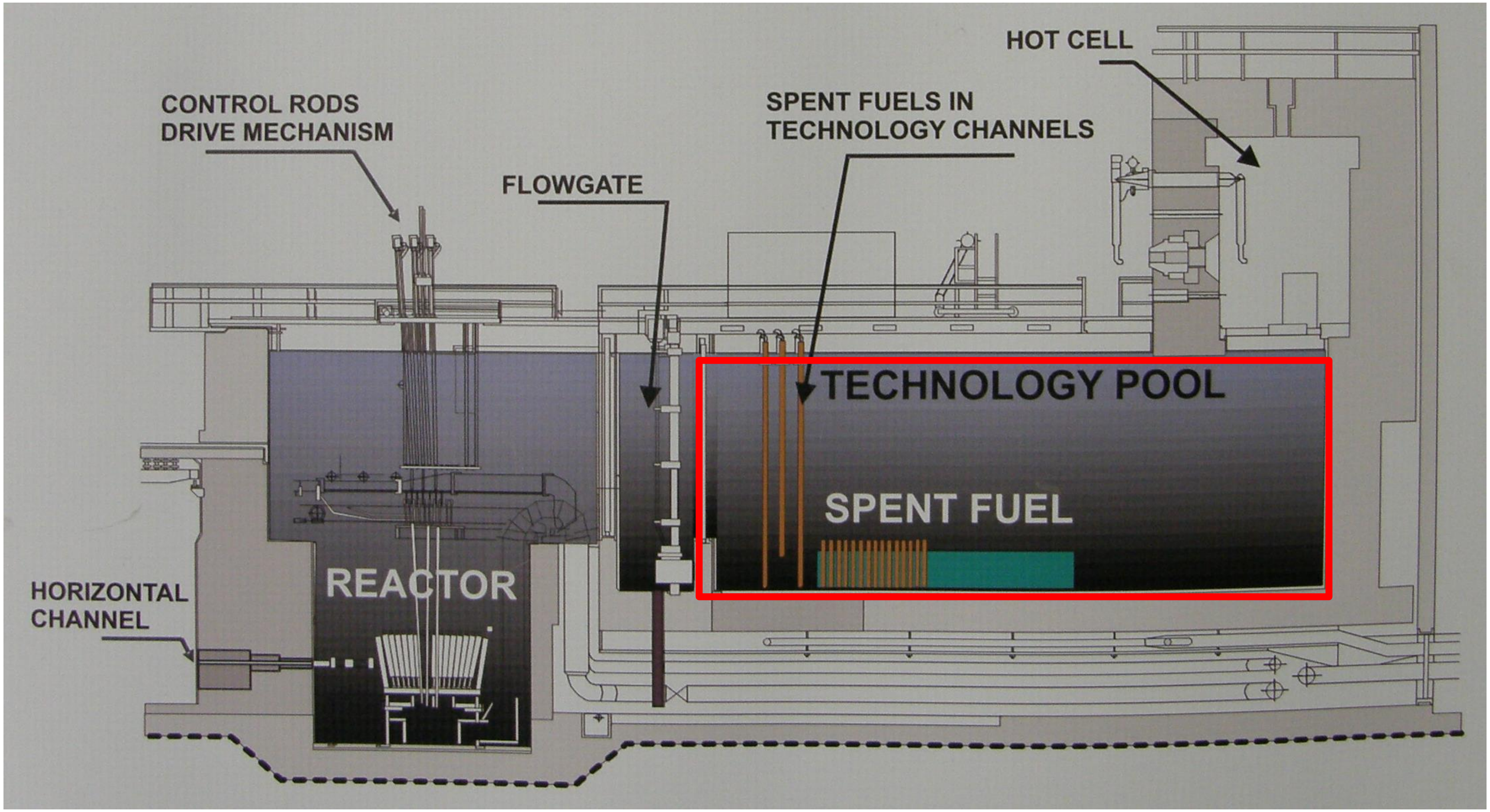
- **chrysotile**
- **lizardite**
- **antigorite**

# Concrete mix design

- Cement: Portland clinker and 55% of GGBFS (CEM III/A) **350 kg/m³**
- Siliceous sand
- ***w/c* = 0.48**
- Slump: 60-100 mm
- Curing age: 90 days
- Aggregates diameter: up to 16 mm
- **Aggregates ratio:**

| Designation / [% of volume] | **M80** | **S80** | **M53 S27** | **M27 S53** | **B100** | **B80** | **B53 S27** | **B27 S53** |
|---|---|---|---|---|---|---|---|---|
| Sand (0-2 mm) | 20 | 20 | 20 | 20 | - | 20 | 20 | 20 |
| Magnetite | 80 | - | 53 | 27 | - | - | - | - |
| Barite | - | - | - | - | 100 | 80 | 53 | 27 |
| Serpentinite | - | 80 | 27 | 53 | - | - | 27 | 53 |
| **Density of concrete [kg/m³]** | **3600** | **2400** | **3150** | **2800** | **3450** | **3200** | **2950** | **2650** |

# Exposure to gamma irradiation

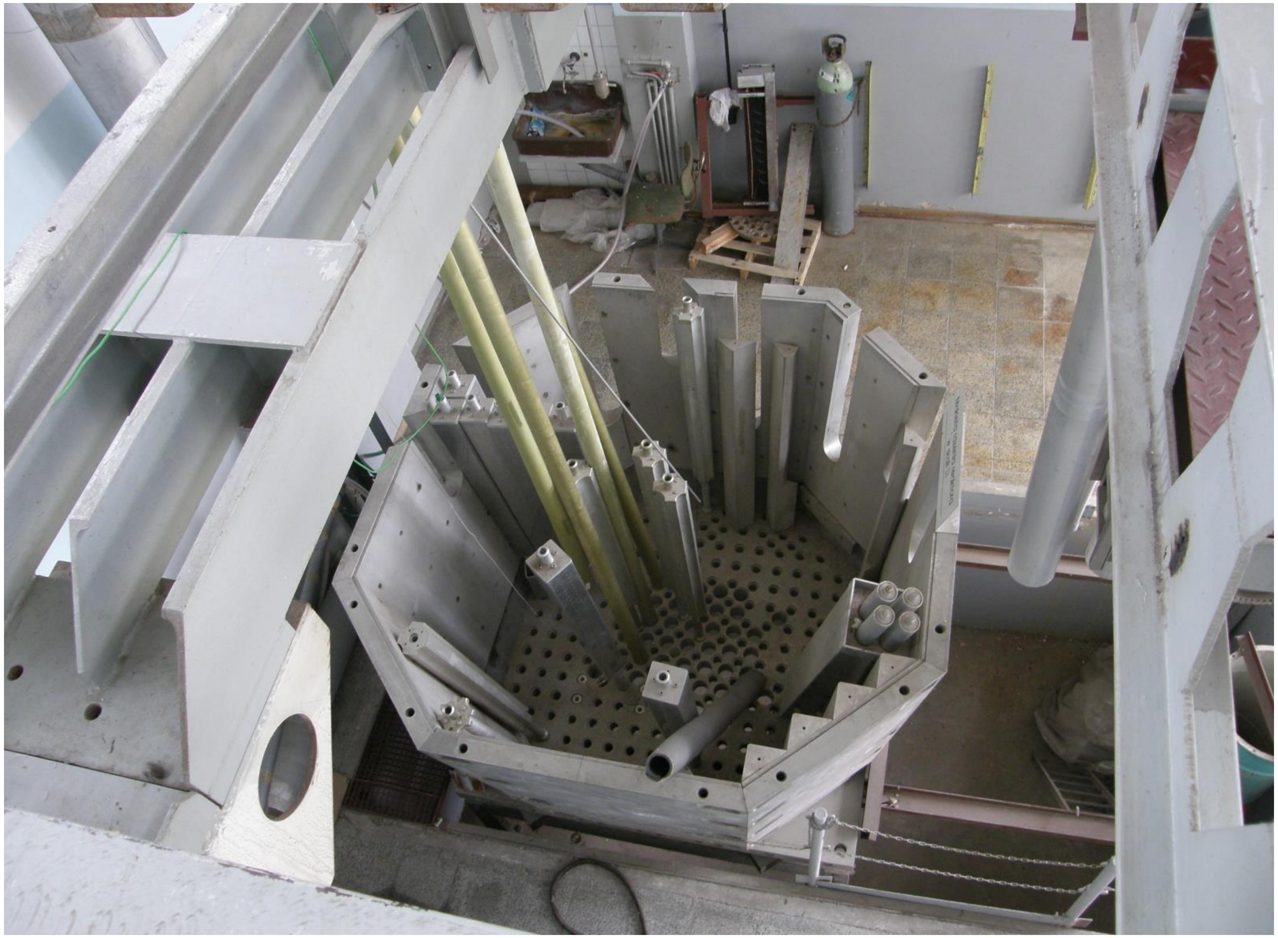



**Research reactor „MARIA" at National Center for Nuclear Research**

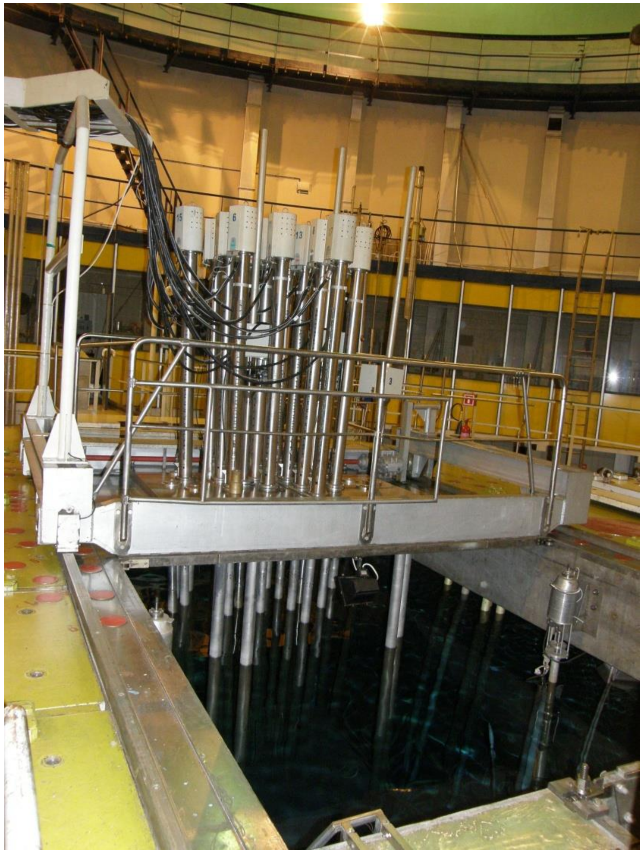
# Exposure to gamma irradiation

**Learning by doing**

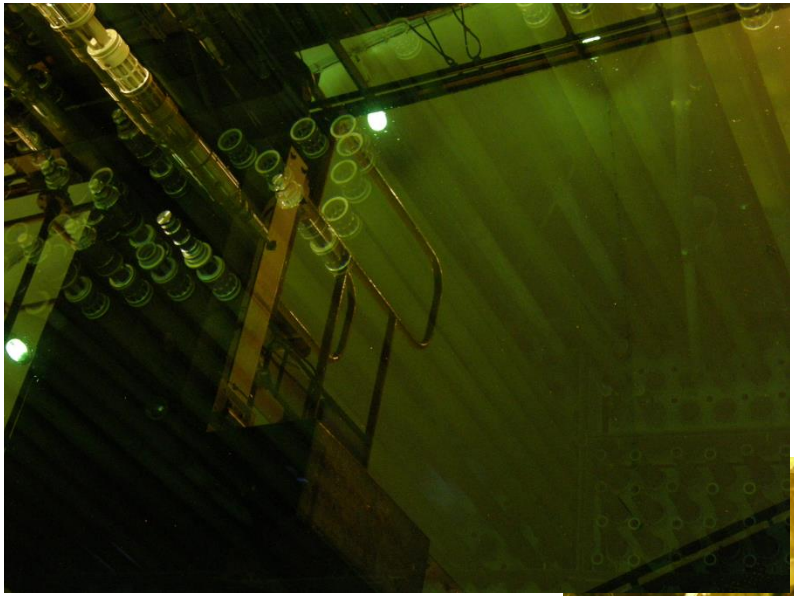
**Exercises: How to set the fuel rods …**

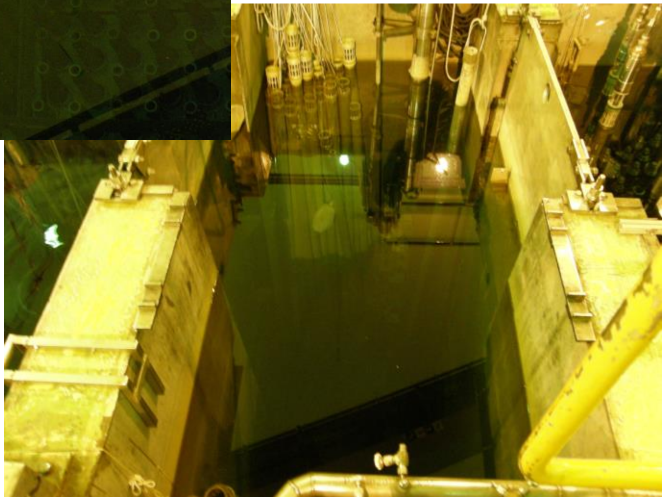


# Exposure to gamma irradiation



**Spent fuel pool – demineralized water**



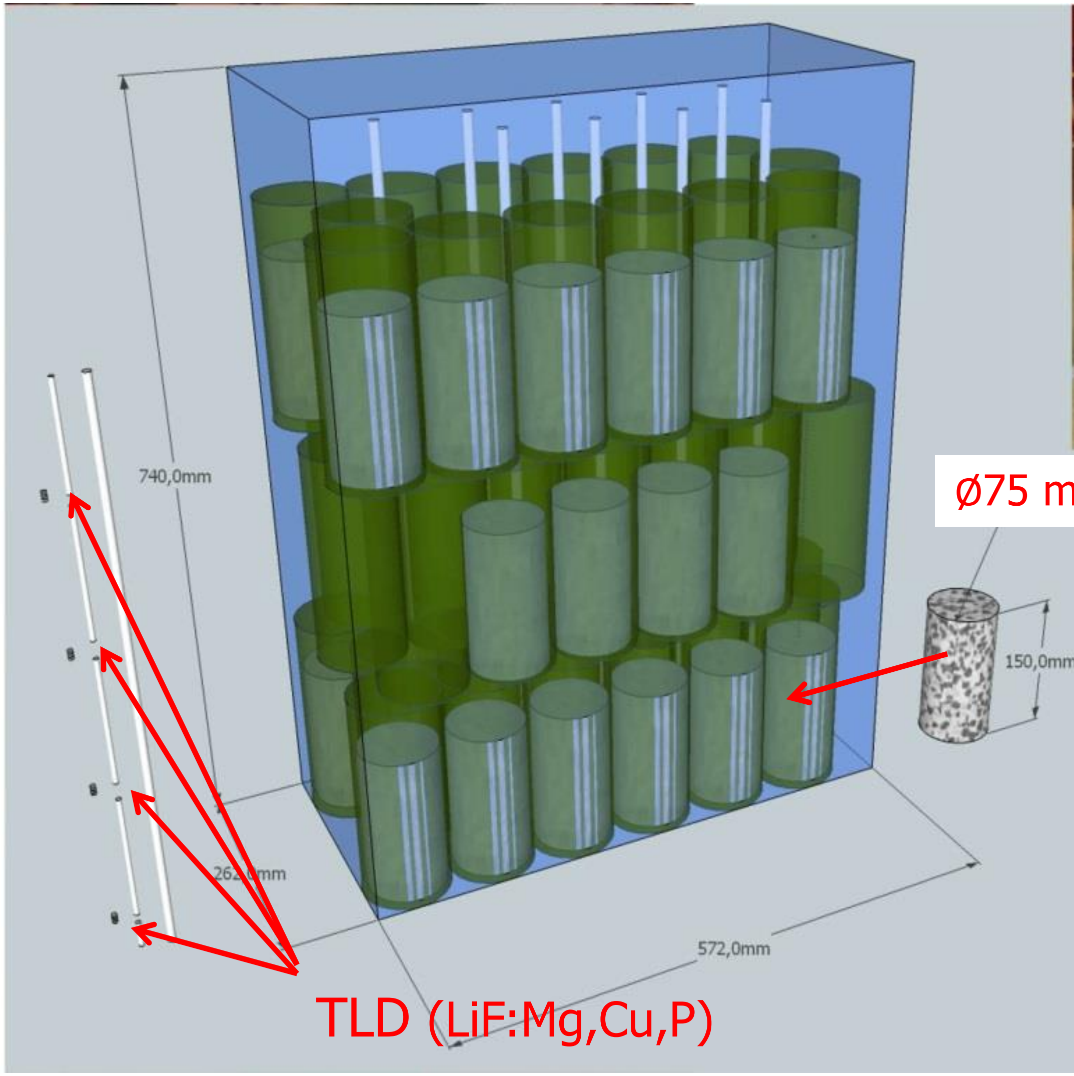


**Flow gate**

# Exposure to gamma irradiation

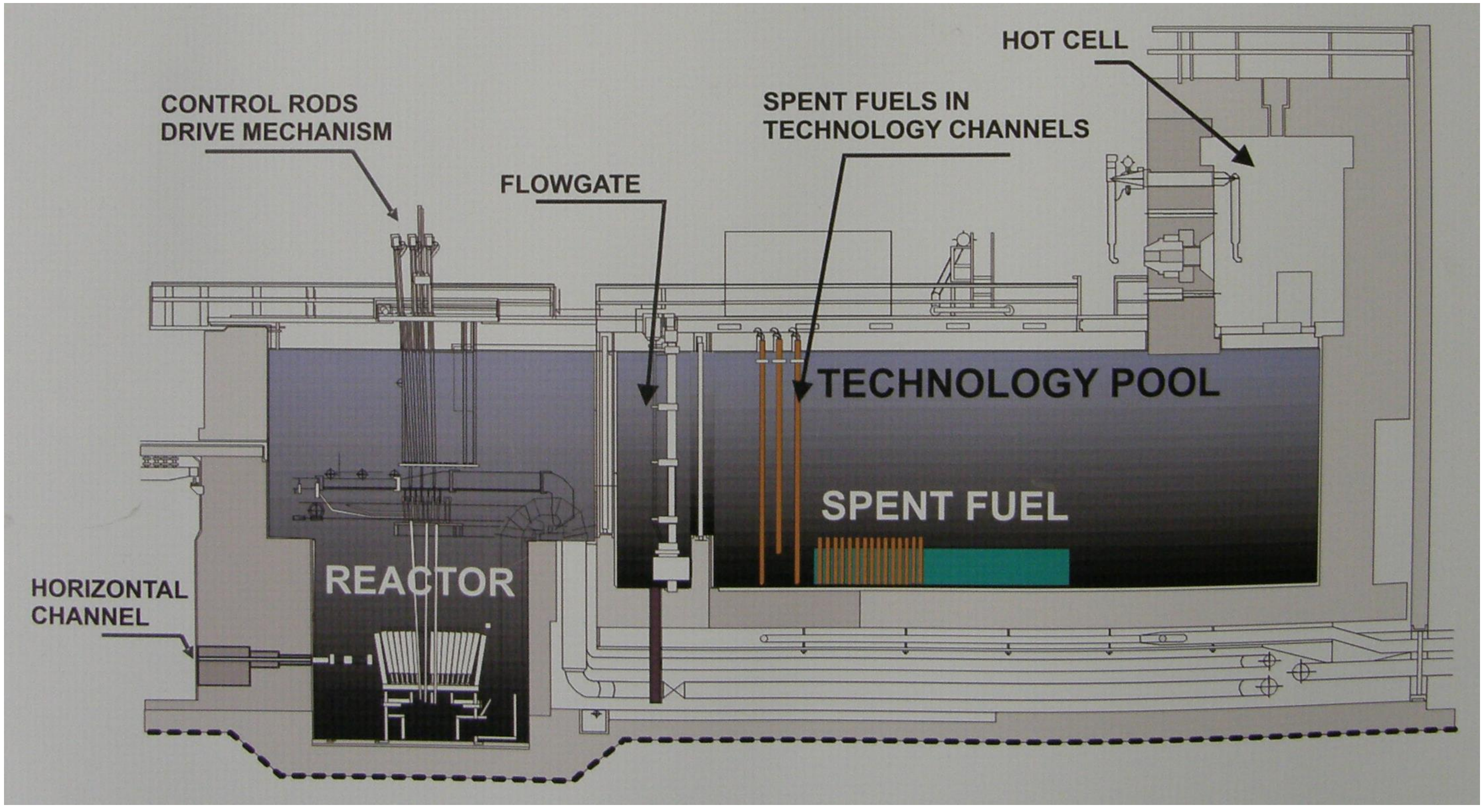
**The most important … safety on board**

# Exposure to gamma irradiation




# Exposure to gamma irradiation

Time of gamma irradiation: **6 months ≈ dose 1.9 – 2.4 MGy**



# Test methods

- Compressive strength
- Porosity accessible to water
  - NF P18-459
- Rate of water absorption
  ASTM C 1585
- Mercury intrusion porosimetry (MIP)
- SEM observation
- X-ray diffraction
- Differential scanning calorimetry (DSC)

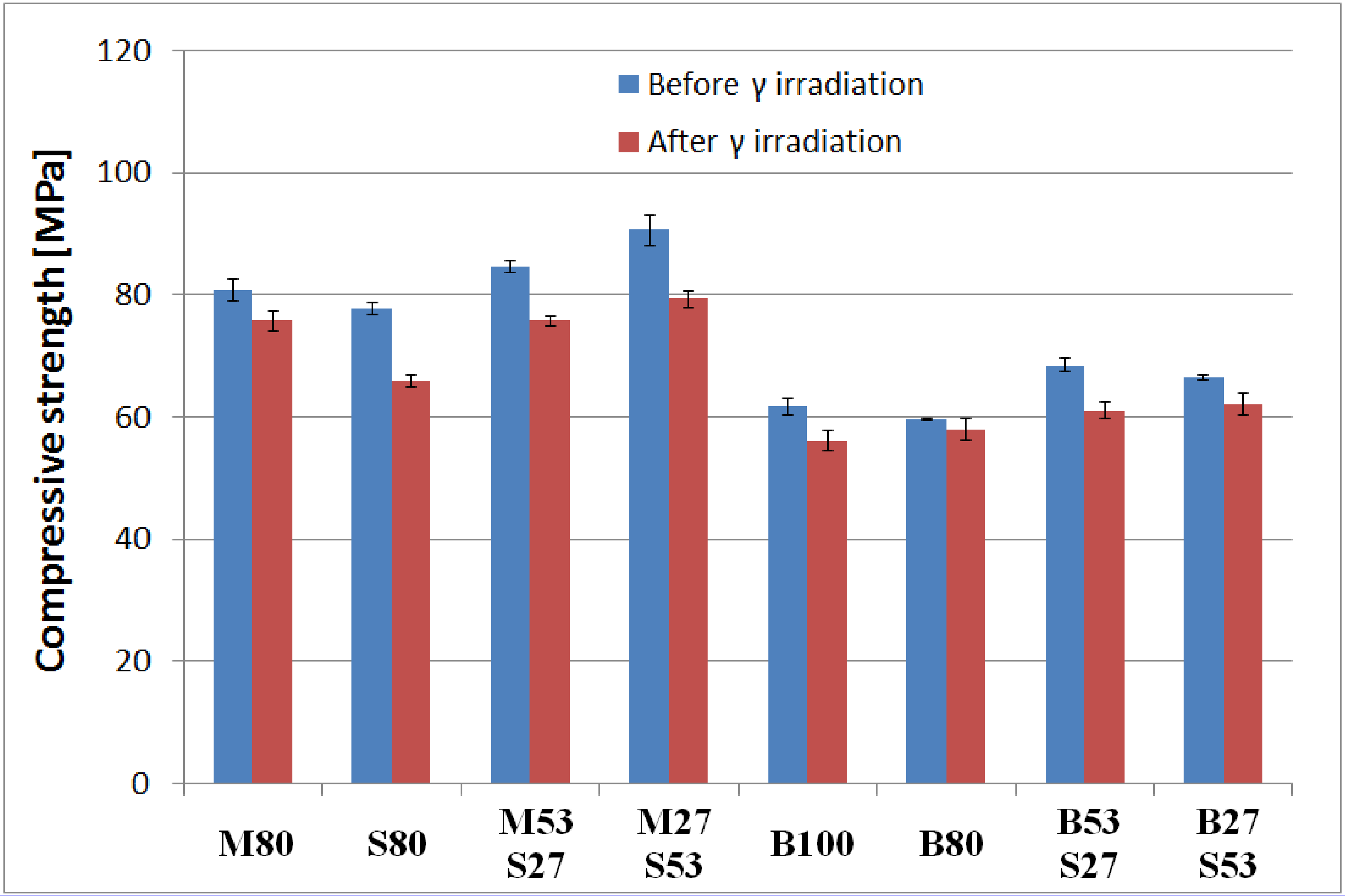
Permeability (porosity accessible to water; rate of water absorption)

Microstructure (MIP; SEM observation)

Structural changes (X-ray diffraction; DSC)

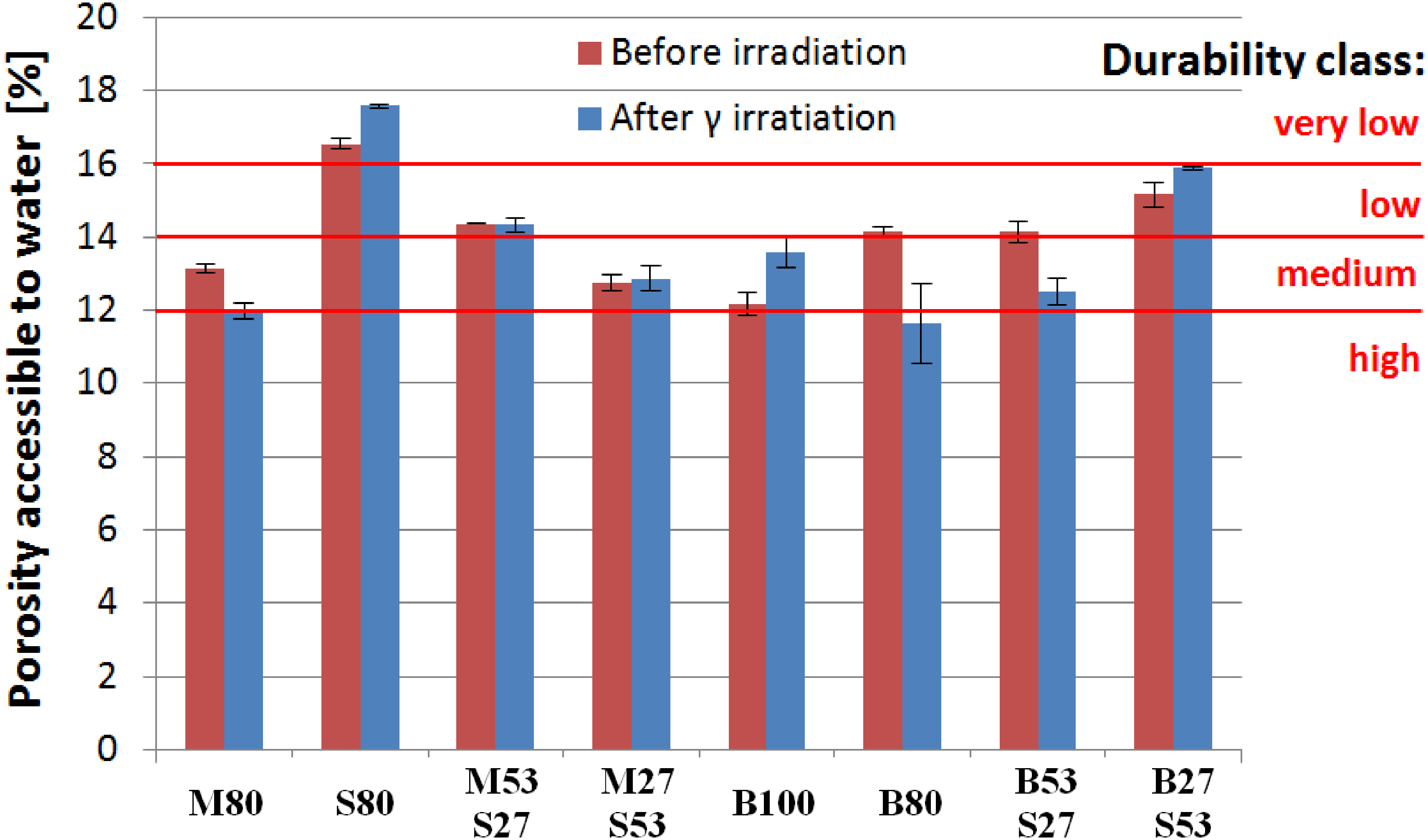
# Compressive strength

Average of 3 specimens (cylinder: Ø=75 mm, h=75 mm)



# Porosity accessible to water NF P18-459

Average of 3 specimens (cylinder: Ø=75 mm, h=45 mm)

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# Rate of water absorption ASTM C 1585

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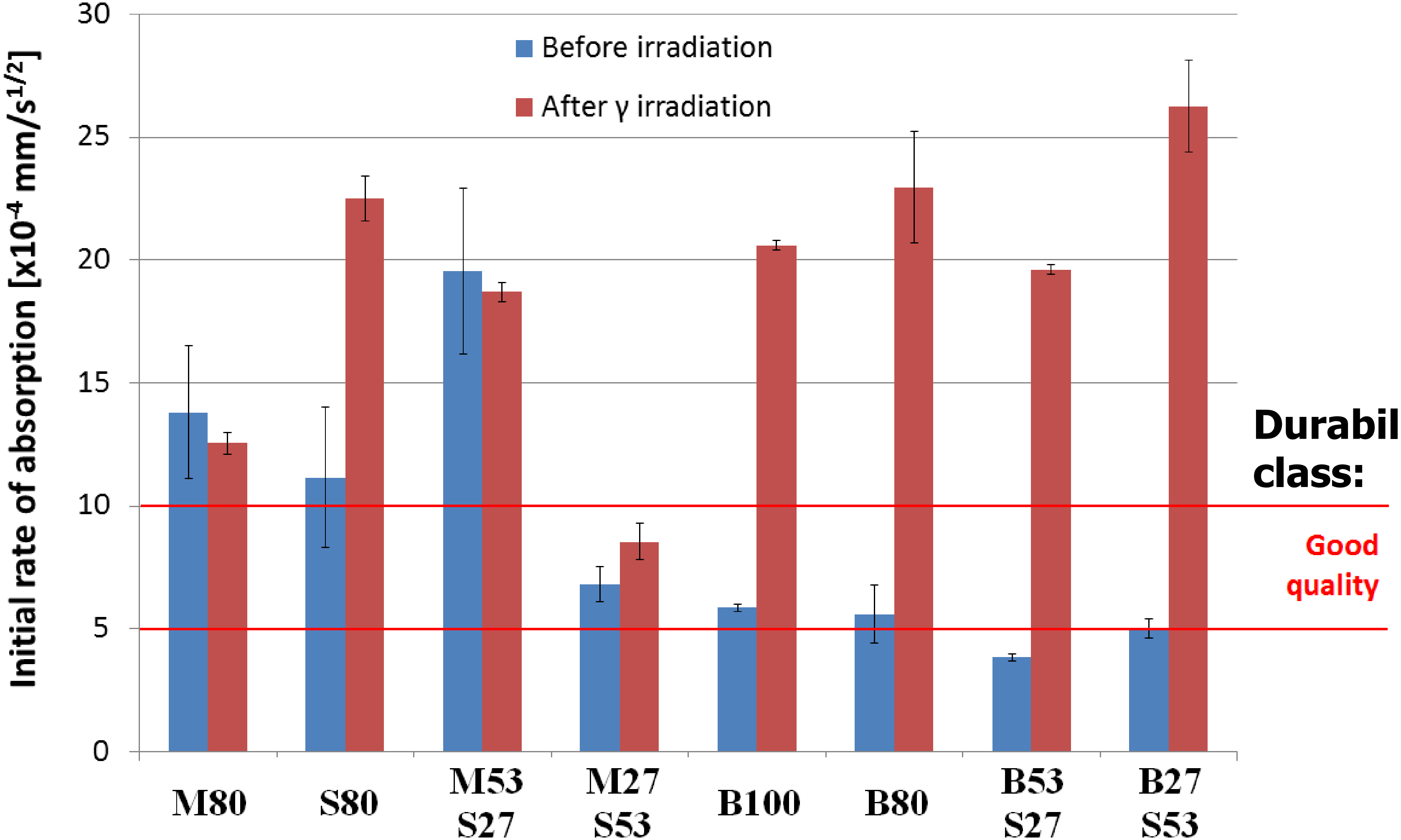
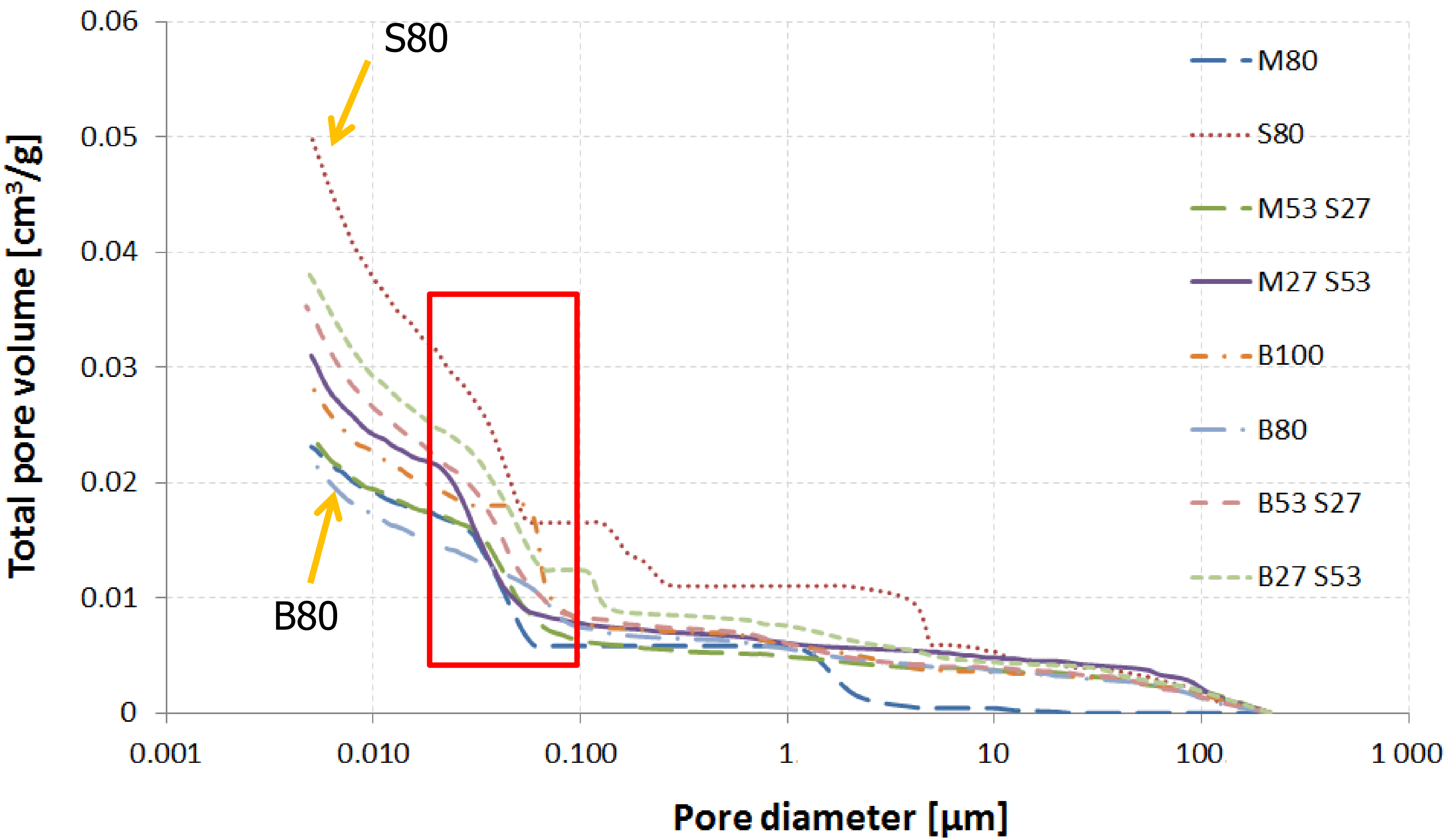


# Matrix porosity before γ irradiation - MIP

Results from 3 drilled cores: Ø=16 mm, h=20 mm

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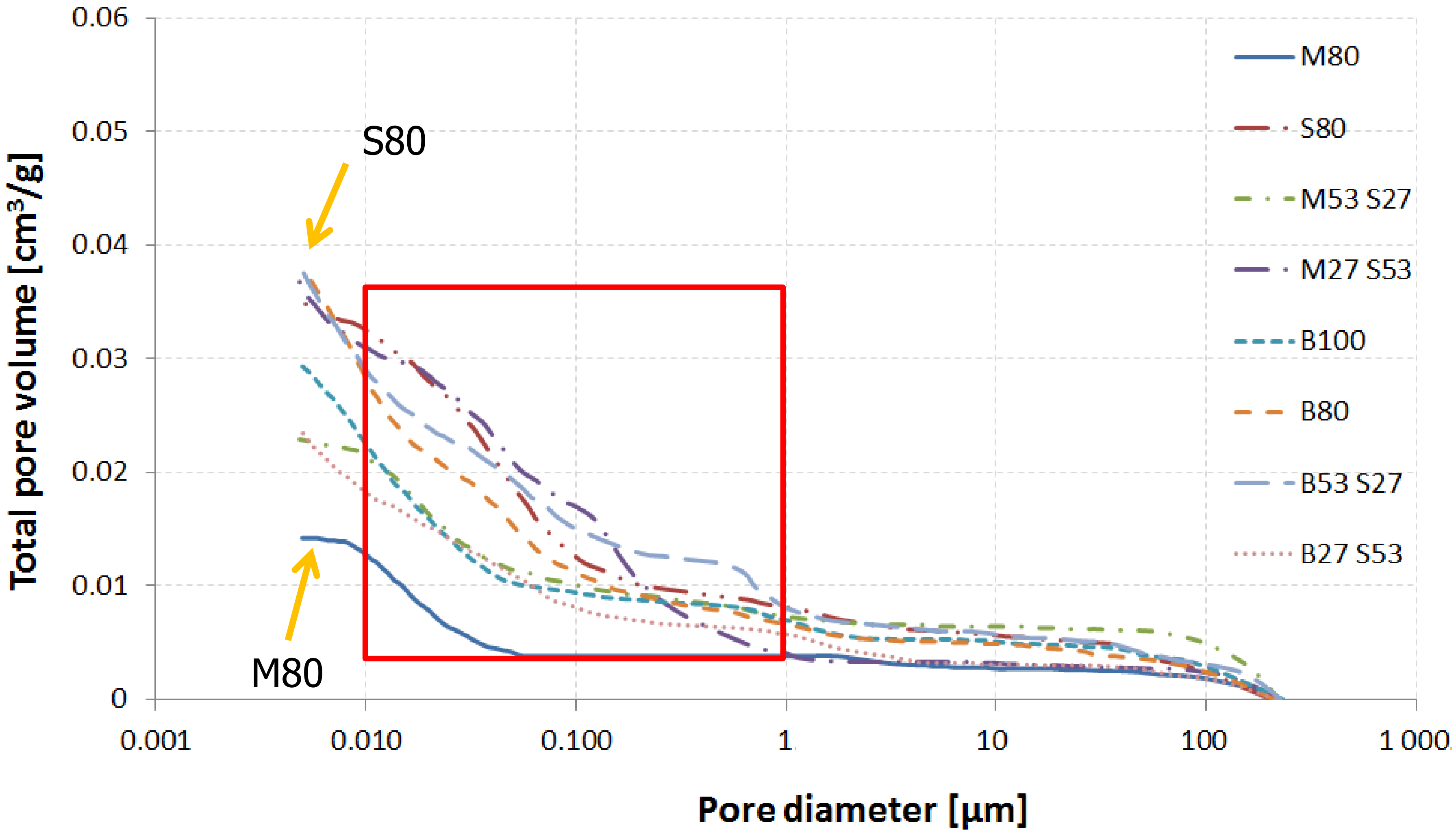


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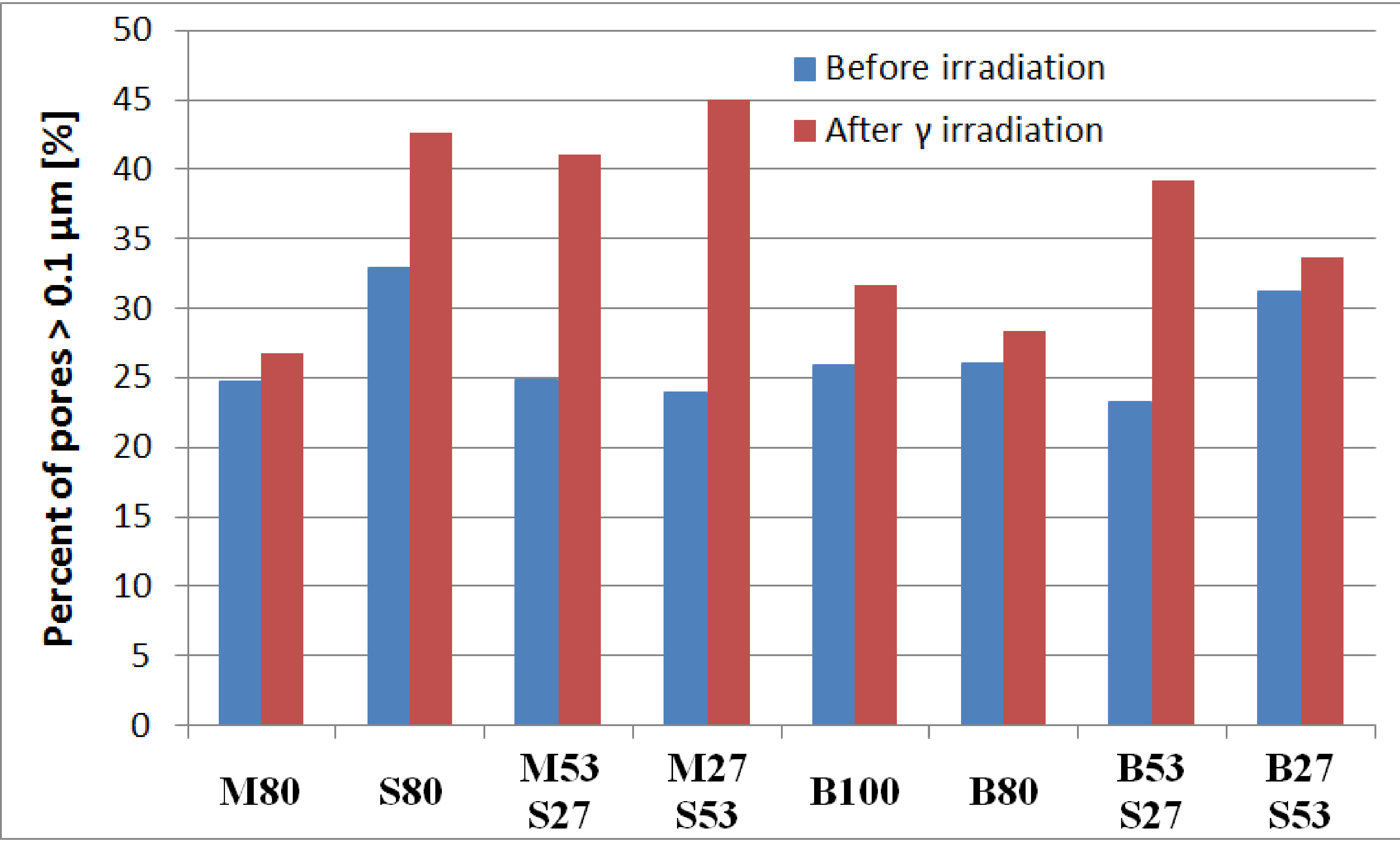
# Porosity larger than 0.1 µm - MIP



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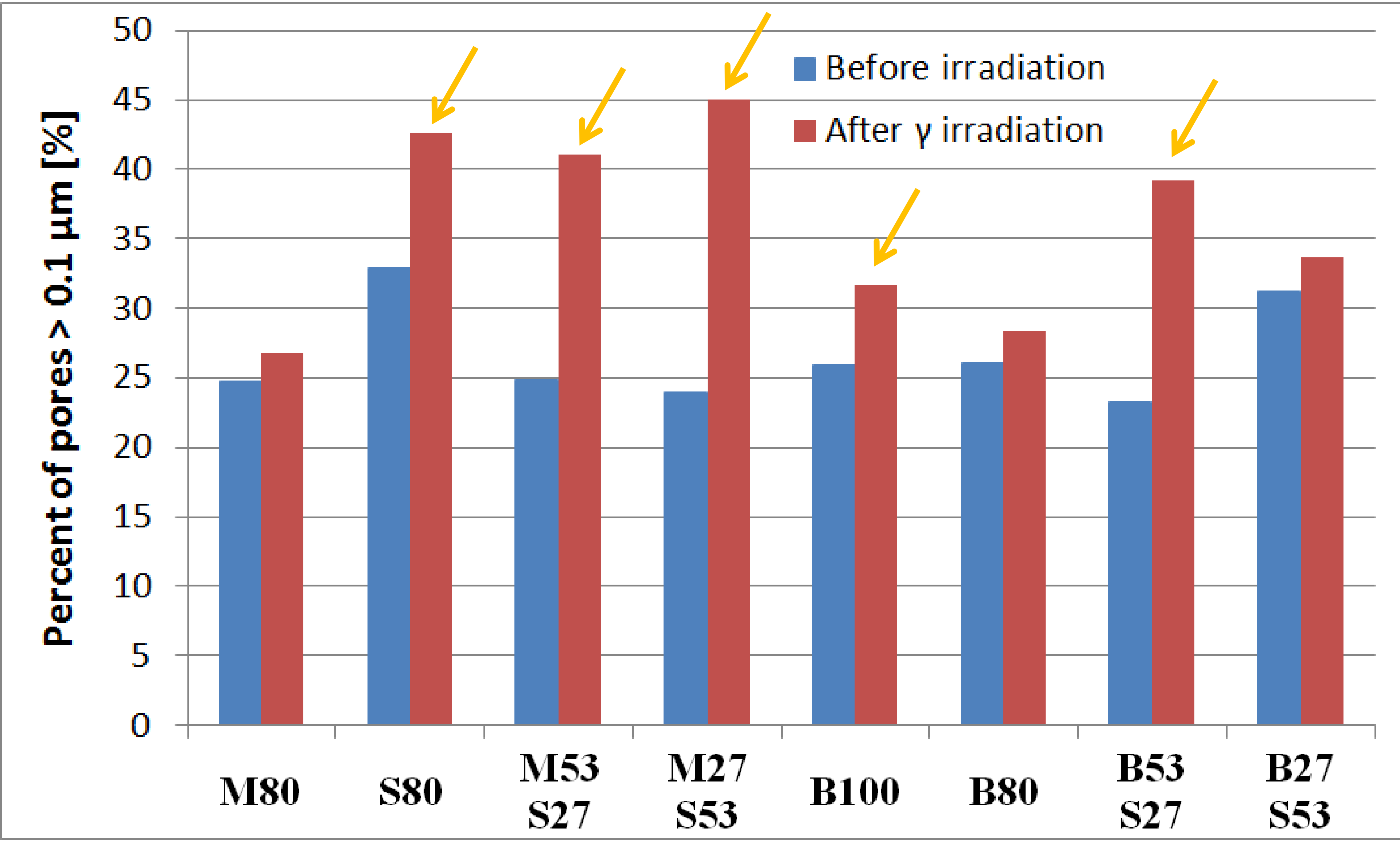
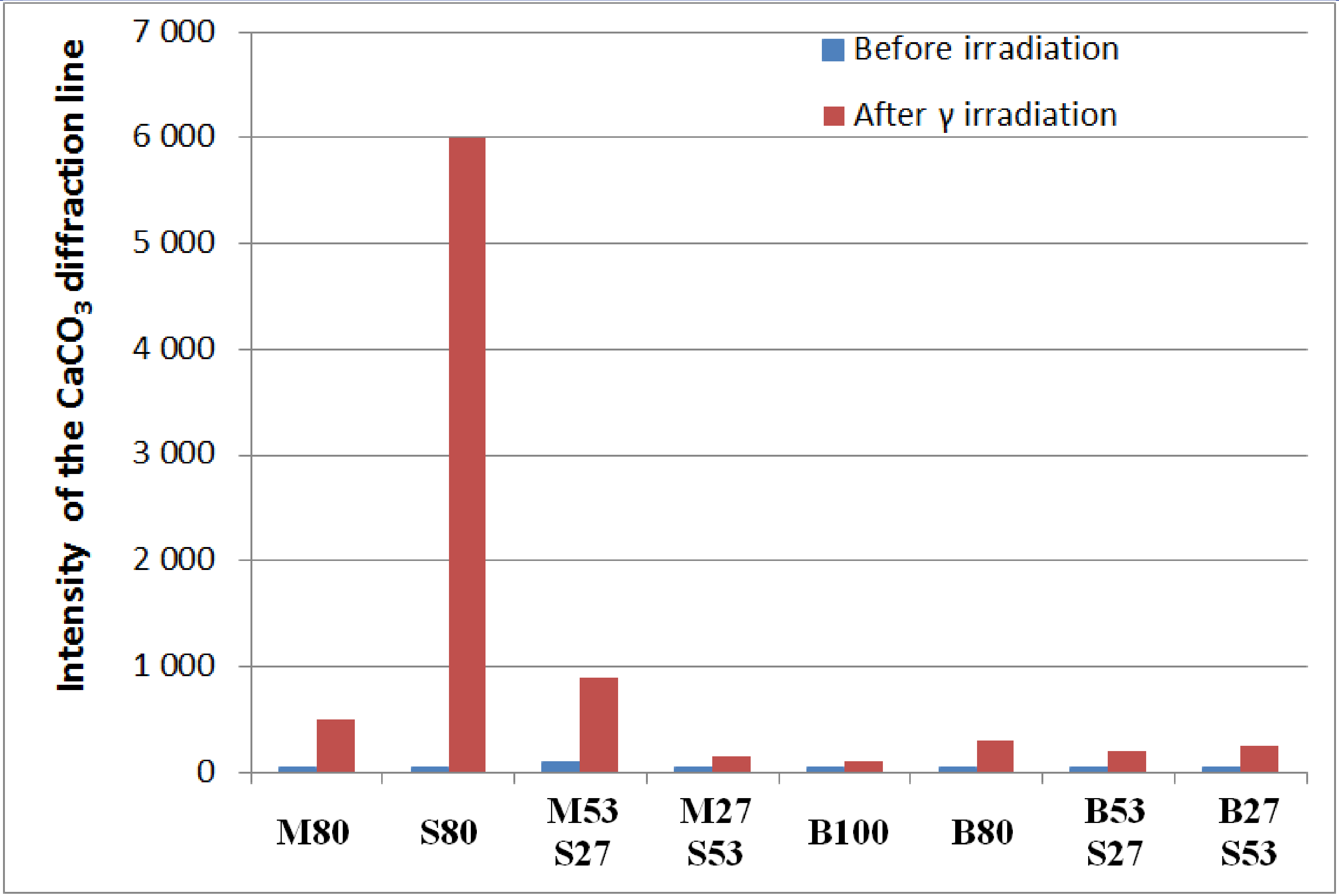


# Formation of calcite - XRD



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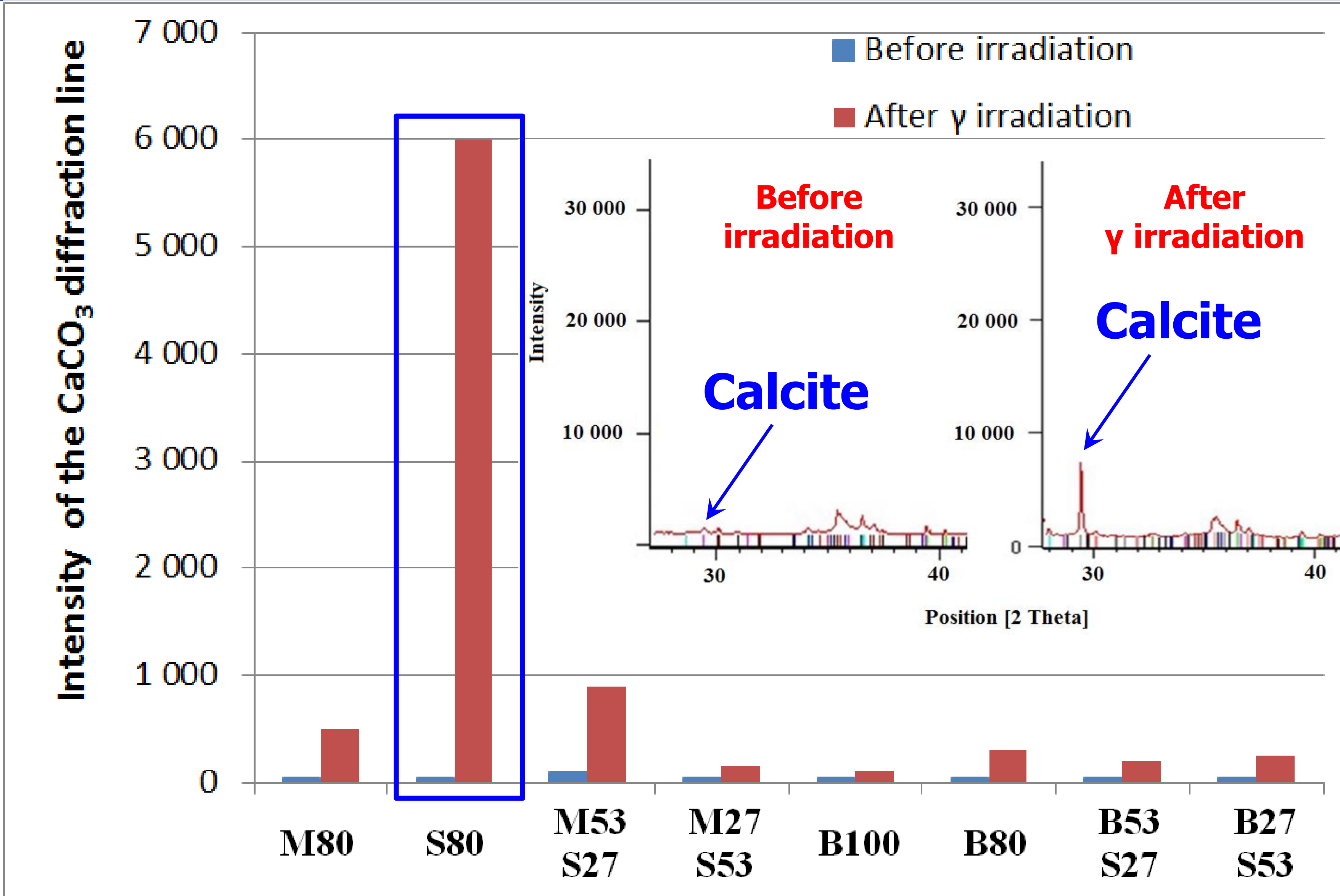
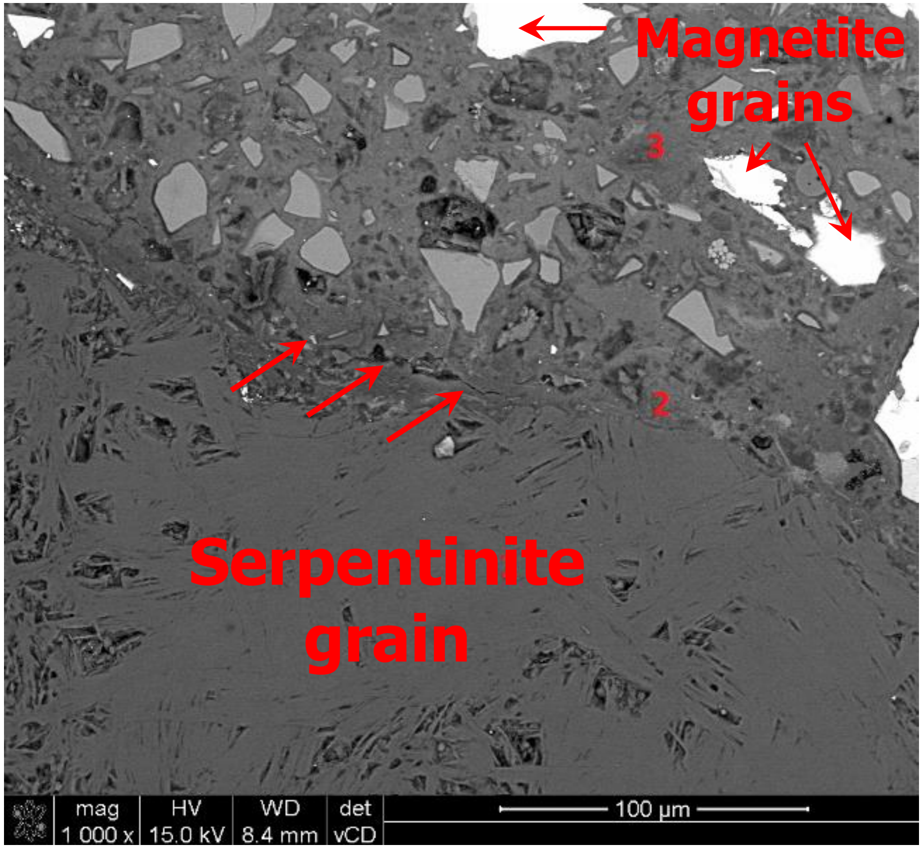
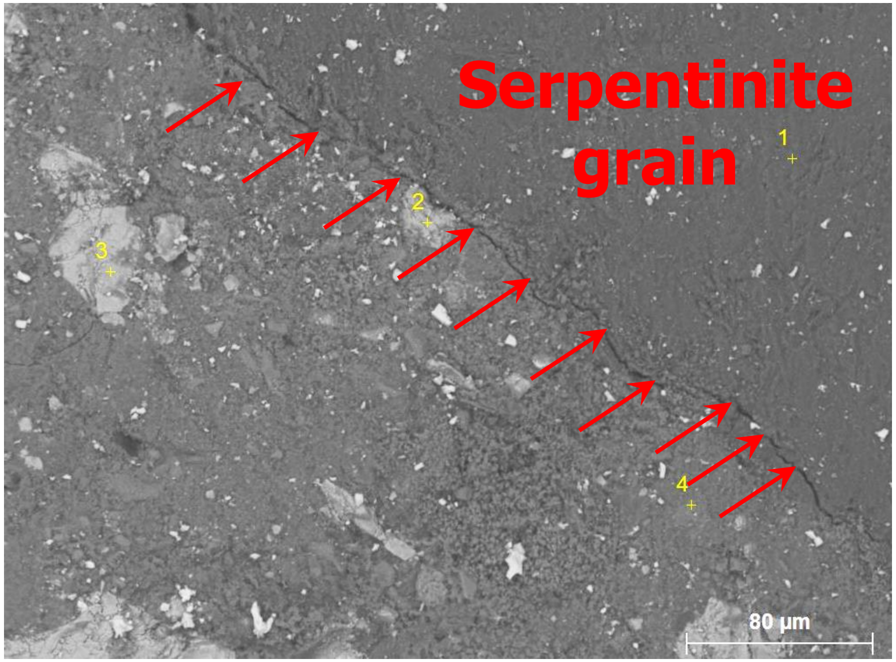


# Microstructural observation

Before irradiation



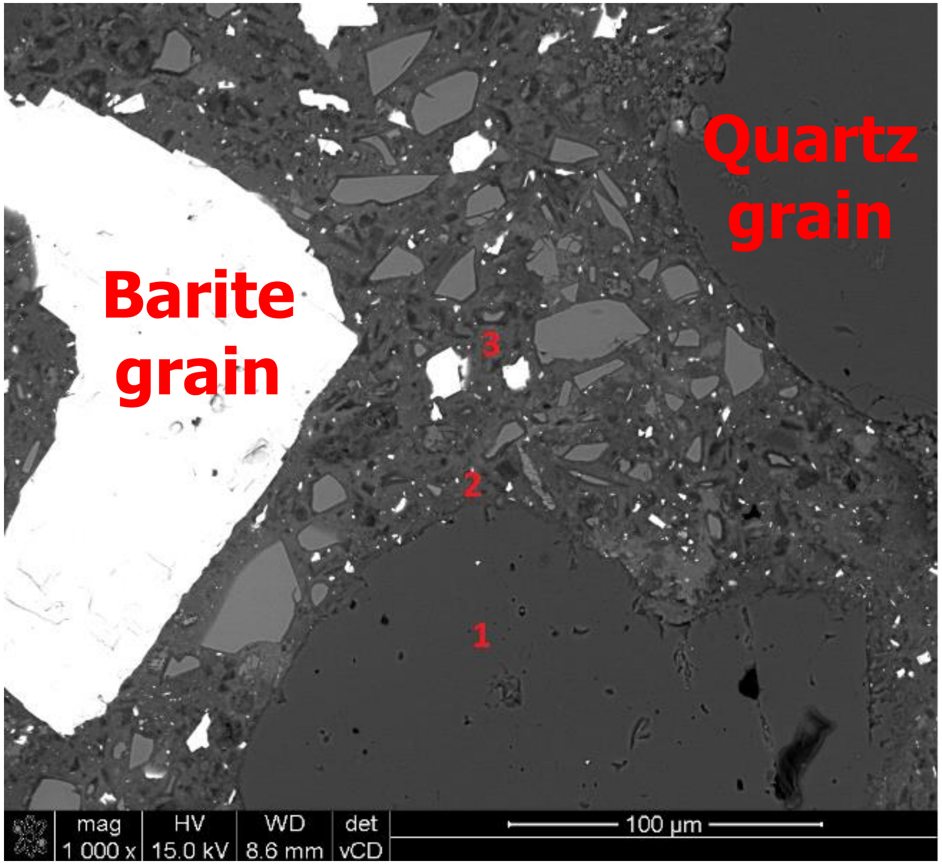

After γ irradiation



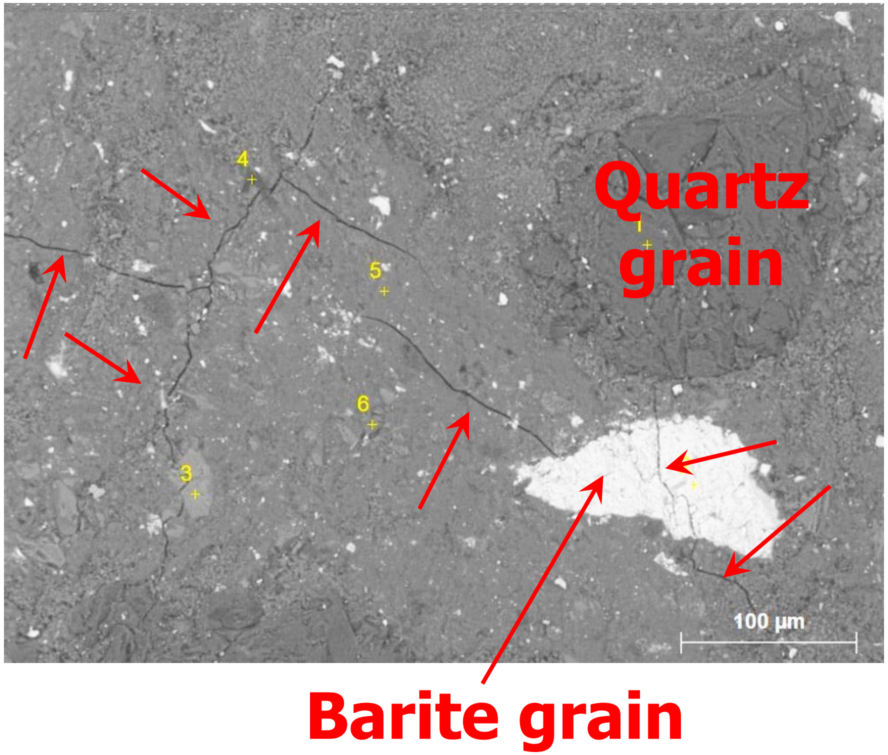

**SEM images of specimen M23 S56**

# Microstructural observation

Before irradiation




After γ irradiation




**SEM images of specimen B23 S56**

# Concluding remarks

- The method of exposure to gamma irradiation of concrete specimens in spent fuel pool has been elaborated
- Characterization methods of concrete have been chosen, which were able to reveal the effect of gamma irradiation of concrete
- Experiments showed some effects of concrete composition …

# Concluding remarks

- Dose of 2 MGy of gamma irradiation in concrete caused decrease of compressive strength up to 10%, especially for concrete with serpentinite aggregates
- Gamma irradiation caused increase of capillary porosity larger than 0.1 μm. It is related to appearance of microcracks after gamma irradiation.
- Concrete with barite aggregate revealed additional cracks across the barite grains. That was probably the reason of 3-5 times increase of water absorption of concrete.

# Acknowledgements

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