Impact of Concrete Composition on Criticality Safety Studies

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Introduction and Issue (1/2)

- Concrete is a common material
- A reflector (e.g. walls) or absorber
- In this presentation: reflector

- A "good" reflector
- Accurately modelled
  - Complex composition
  - Different impacts of concrete elements are expected on reactivity (e.g. water or Fe)

- Concrete composition proposed in literature or in codes libraries

Element	Weight percentage
H_2O	11.0 %
SiO_2	66.3 %
Al_2O_2	5.8 %
Fe_2O_3	2.3 %
CaO	8.9 %
MgO	1.4 %
SO_3	0.5 %
Na_2O	1.9 %
K_2O	1.9 %
Cl^-	< 0.01 %

ICSBEP composition LST0008

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Introduction and Issue (2/2)

- Concrete compositions proposed (weight percentage)

Element	ARH-600 Portland Concrete	SCALE *REG CONCRETE*	CRISTAL 9 %
H_2O	8.9 %	8.9 %	8.9 %
Si	33.7 %	33.7 %	33.6 %
Ca	4.5 %	4.5 %	4.4 %
Na	2.9 %	2.9 %	4.6 %
Al	3.4 %	3.4 %	3.4 %
O	45.2 %	45.2 %	45.0 %
C	-	-	-
Fe	1.4 %	1.4 %	-
S	-	-	-

Simplified compositions

2 differents water content

Different elements considered

Element	MONK *Windscale concrete*	CRISTAL 3 %
H_2O	3.3 %	3.0 %
Si	15.5 %	35.8 %
Ca	26.7 %	4.7 %
Na	-	4.9 %
Al	1.4 %	3.6 %
O	46.8 %	48.0 %
C	6.0 %	-
Fe	1.0 %	-
S	0.2 %	-

- What is the impact of the water content on reactivity?
- Does a water content of 3 % is realistic?
- What are the margins associated to the use of simplified compositions compared to a realistic one?

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Concrete Definition (1/3)

- **Regular concrete**
- **Concrete is a mixture of several components:**
  - **Cement:**
    - Powder of mineral material ($CaCO_3$, $Al_2(SiO_3)_3$ …)
    - Minerals react with water → paste
  - **Water:**
    - Hydratation + Workability
    - Ratio mass cement to mass water ~ 0.43 - 0.5 (max)
  - **Aggregates:**
    - Majority of concrete
    - Different types: sand, gravels and crushed stones
  - **Chemical additives:**
    - Improve concrete quality (accelerators or plastizicers)
    - Commonly used for the last 10-20 years

Material	Mass / m³	Wt%
Cement	400 kg	16.7
Sand	1800 kg	75
Gravel/Stones		
Water	200 kg	8.3

- **Concrete manufacturing depends on:**
  - Origin and quality of these components
  - National and local regulations
  - Conditions of manufacturing …

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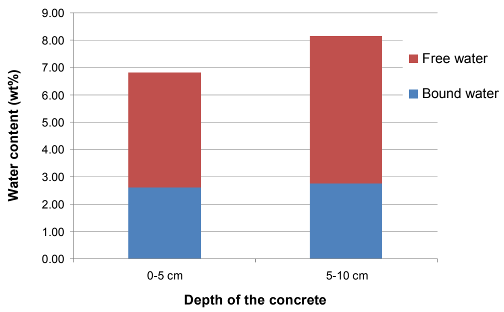
Concrete Definition (2/3)

- **Water can be divided in two categories (one for each function during manufacturing)**
  - **Bound water**
    - For cement **hydratation** e.g. $CaO + H_2O \rightarrow Ca(OH)_2$
    - In the concrete matrix and removed at **high temperature** (> 100 °C)
    - $\boxed{\frac{\text{bound water mass}}{\text{cement mass}} = 0.23 - 0.25}$ **Proportion in concrete ~ 3 wt% - 4 wt%**
  - **Free water**
    - Ensure the workability
    - In concrete pores or fixed to aggregates
    - Removed between 0 °C and 100 °C (drying)

Concrete Definition (3/3)

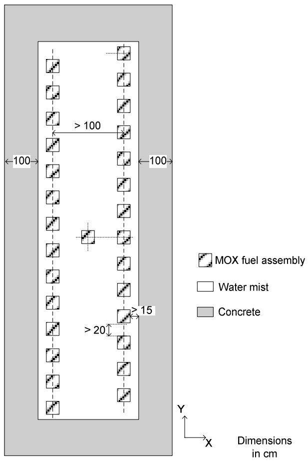
- **During concrete drying**
  - **Content of water depends on concrete depth**
  - **Analysis on a concrete dried (20°C)**



- **Conclusion:**
  - **Difficult to define a bounding composition (too many components used for concrete manufacturing)**
  - **Only bound water content can be guarantee in concrete**
  - **After few cm of concrete depth the water content is above the bound water content**

Impact of concrete composition on a MOX fuels storage reactivity (1/6)

- **Calculation configuration**
  - **Fictive Fuel Assemblies storage (PWR and BWR)**
    MOX FA ($UPuO_2$ – 12.5 % PuO_2)
  - **100 cm of concrete in reflection**
  - **Various water mist density similar in storage and in FA**
  - **Reactivity leads by two phenomena:**
    - **Low water mist density:**
      Reactivity of one FA is low
      Interaction between assemblies
    - **High water mist density:**
      Reactivity of one FA is high
      Low interaction between assemblies
      and low concrete reflection



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Impact of concrete composition on a MOX fuels storage reactivity (2/6)

- **Calculation results: Consideration of CRISTAL 3 % and 9 % concretes**
  - **Identical atomic compositions except for water concentration**
  - **3 % water content bounds the lack of free water (low content)**

Calculations performed for σ = 0.0015

Water mist density (g/cm^3)	**k_{eff} + 3σ CRISTAL 3 % concrete**	**k_{eff} + 3σ CRISTAL 9 % concrete**
0	0.758	0.747
0.01	0.82	0.79
0.04	0.954	0.916
0.05	0.96	0.923
0.055	**0.96**	0.927
0.06	0.954	0.924
0.1	0.897	0.89
0.5	0.749	0.75
1	0.94	**0.939**

- **Diminution of water content leads to increase k_{eff} value**
- **Diminution of water content in concrete improves reflection in this storage configuration**
- **Δk_{eff} at the optimum of reactivity is equal to 2100 pcm**
- **Water content value impacts the water mist condition at the optimum of reactivity**
- **Consideration of a water content of 3 % in concrete is conservative**
  maybe too conservative?

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Impact of concrete composition on a MOX fuels storage reactivity (3/6)

Element	Real concrete (wt%)	CRISTAL 3 % concrete (wt%)
Ca	17.8	4.7
Si	23.5	35.8
Al	2.3	3.6
Mg	0.4	-
Fe	1	-
Na	0.6	4.9
K	0.7	-
P	0.03	-
Cr	0.03	-
Ti	0.1	-
Mn	0.03	-
S	0.1	-
C	3.7	-
H (H2O)	0.5 (4.5)	0.33 (3)
N	< 0.005	-
O	49.2	50.6
Density	2.36 g/cm^3	2.16 g/cm^3

- **Calculation results:** **Consideration of a realistic concrete composition**
  - **Composition from chemical analysis (measurement uncertainties low)**
  - **More elements**
  - **More Ca (4.7 wt% in CRISTAL 3 % concrete)**

Water content equal to
4.5 % = free water + bound water

For a ratio $\frac{\text{bound water mass}}{\text{cement mass}} = 0.2$

→ **Bound water content = 2.9 %**

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Impact of concrete composition on a MOX fuels storage reactivity (4/6)

- **Calculation results:** **Consideration of a realistic concrete composition**
  - **Performing calculations for a realistic composition**
    - Two water contents 4.5 % and 2.9 %

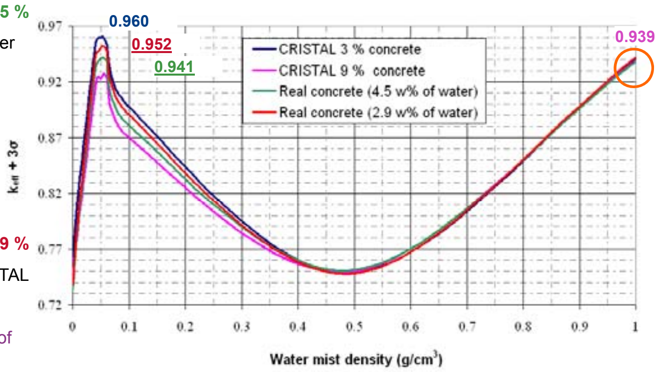
CRISTAL 3 % and real concrete 4.5 %

• Optimum of reactivity for a low water mist for CRISTAL 3 % and realistic concretes

• The use of CRISTAL 3 % concrete instead of a realistic one
=> margin of 1 900 pcm

CRISTAL 3 % and real concrete 2.9 %

•For a similar water content in CRISTAL and realistic concrete
Δk_{eff} = 800 pcm.
Difference due to the consideration of other elements (Fe, K …)



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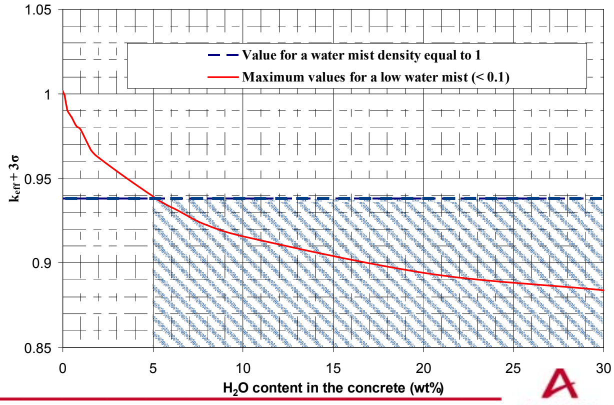
Impact of concrete composition on a MOX fuels storage reactivity (5/6)

- **Calculation results:** **Impact of concrete elements on reactivity**
  - **To have a better understanding on calculation results**
  - **Variation of one element concentration and other concentrations are considered constant**
  - **Variation of the density from 1.8 g/cm^3 to 3 g/cm^3 (no significant impact of this variation on results)**
  - **Impact of water**

• Increase of water content leads to decrease the reactivity

• Impact less for high contents

• For water contents > 5 % no impact of water content



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Impact of concrete composition on a MOX fuels storage reactivity (6/6)

- **Calculation results:** **Impact of concrete elements on reactivity**
  - **Impact of Fe and K**

• Consideration of 1.5 % content leads to decrease k_{eff} value of 300 pcm for Fe or K

• For contents above 1.5 % - no impact of Fe and K

  - **Impact of Ca and Na**

• Consideration Ca and Na leads to decrease the reactivity (impact lower)

• Considering of the real Ca content is interesting:

4.7 % in CRISTAL 3 % concrete
17.8 % in a realistic concrete
} Variation from 4 % to 20 % leads to decrease the k_{eff} value of **1 000 pcm**

  - **Impact of O and C**

• Consideration C and O leads to increase the reactivity

• Consideration of a C content of 3.7 % leads to increase k_{eff} value of 300 pcm

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Conclusions

- **Difficult to define a bounding composition of concrete**
- **The knowledge of water content in concrete is complex**
  - Water content evolves during the concrete drying
  - Only the bound water content could be guaranteed => content close to 3 wt% - 4wt
- **For a MOX fuel storage configuration**
  - Use of CRISTAL 3 % is conservative and leads to consider margins close to 2 000 pcm compared to a realistic concrete
  - Impact of water important (reactivity and optimum of reactivity)
  - Impact of other elements Ca, Fe, K, C, …
  - Consideration of additional elements in CRISTAL concretes could highlight margins on reactivity:
    - Fe, K or C
    - Real content of Ca
- **Interesting to consider:**
  - Steel reinforcing bars
  - Water gradient
  - Other configurations

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