Experimental assessment of interaction between boric acid enriched in boron-10 and cementitious matrix

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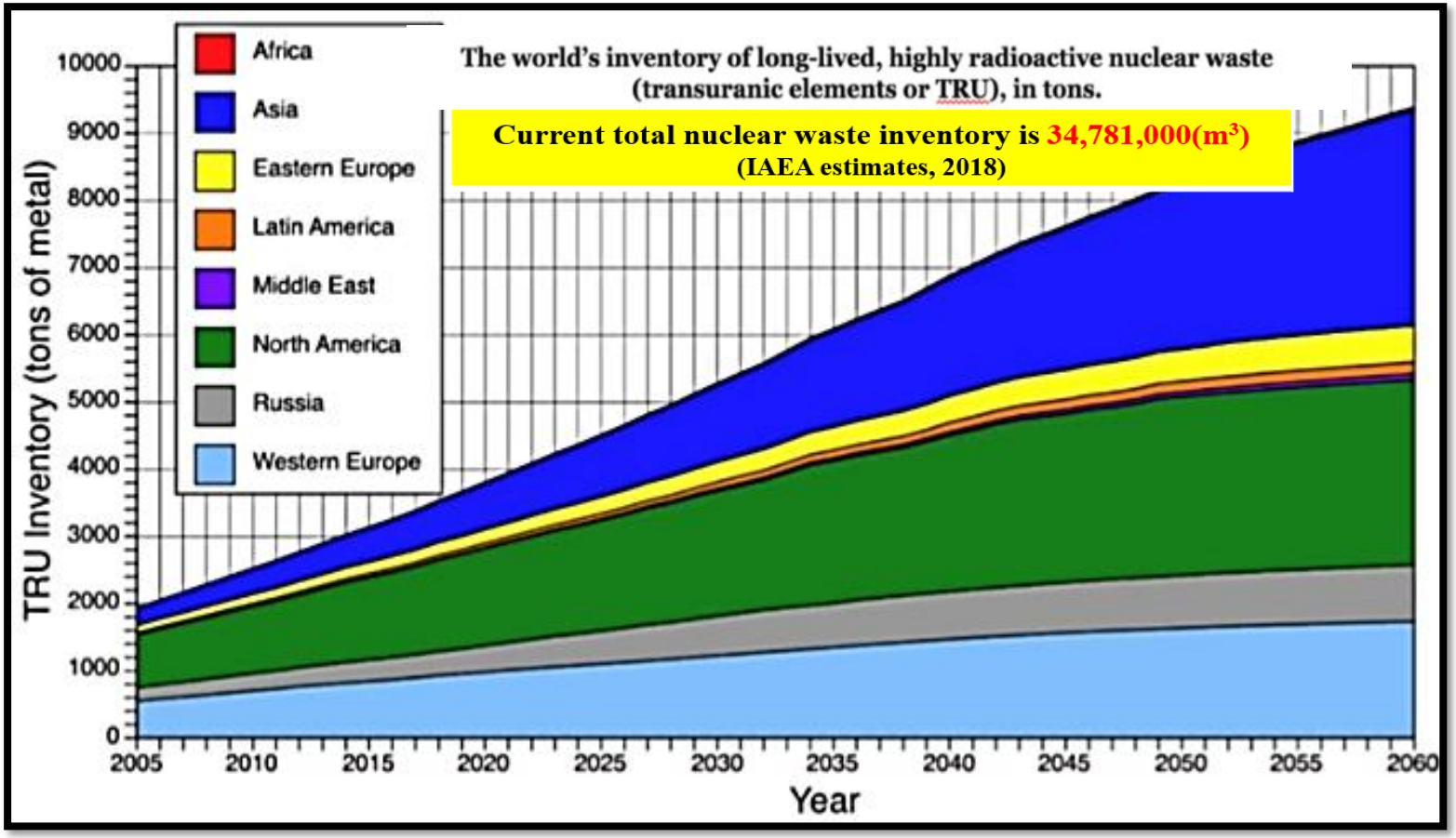
Introduction

- Nuclear technology has many advantages and a significant disadvantage
- The main concern about nuclear technology is nuclear waste
- The amount of waste is increasing in the world continuously



Trend of nuclear waste production (www.weforum.org)

Introduction - boric acid in nuclear power plants

- NPPs[1] are the main applicants of nuclear technology
- Boric acid is used because of its excellent neutron absorbing properties
- Main waste stream at a typical NPP is boric acid waste (volumetric)
- Production around 200 m^3/yr boric acid waste in a typical PWR[2] (Pacey et al. 2011)

Generation of huge amount of boric acid waste in NPPs (www.kaeri.re.kr/)

1 - Nuclear Power Plant
2 - Pressurized Water Reactor

Introduction - waste management of boric acid

- **Boric acid is conditioned for easy, secure and safe handling, storaging and disposal**
- **Common method for boric acid waste is stabilizing with cementitious matrix**
- **Boron has a high natural potential for releasing from the cementitious matrix** (Palomo and Palacios 2003)
- **There are some approved methods for decreasing the leachability of boron**

Packing the waste – Paks, Hungary

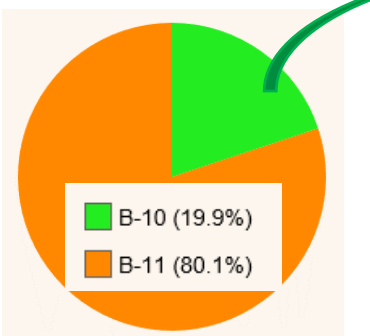
Cementation the packs – Bátaapáti, Hungary

Disposal at Bátaapáti, Hungary

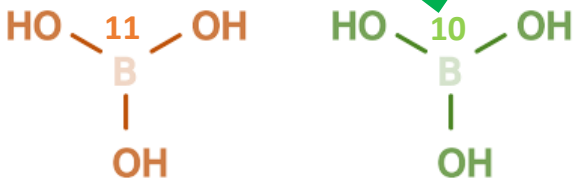
Introduction - natural boric acid or enriched boric acid solution?

- **Two ways for increasing the control ability of boric acid**
  - ✗ Increasing the boric acid concentration **(corrosion and leachability ↑↑)**
  - ✓ Using enriched acid boric **(recently used technology)**

- **What is the meaning of enriched boric acid?**



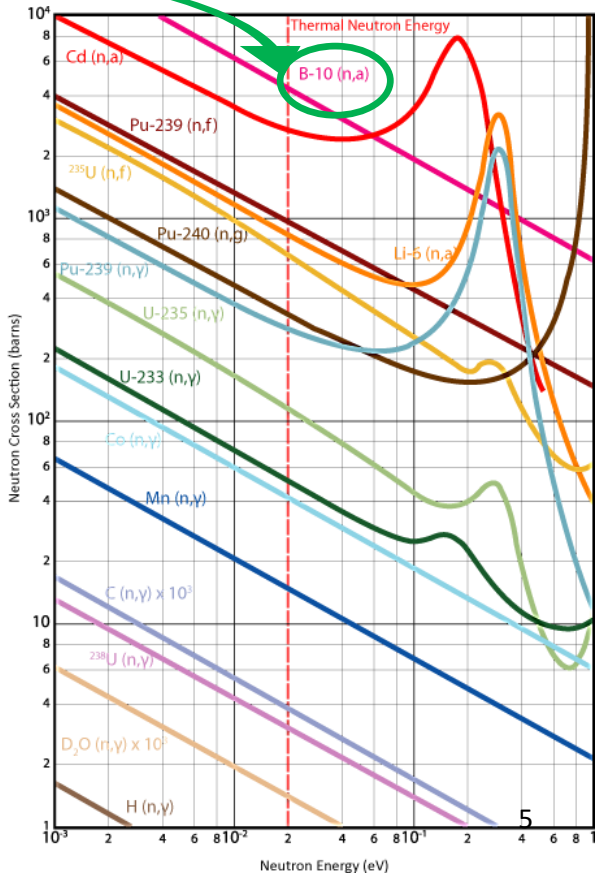
Natural abundancy of boron isotopes



Solid H_3BO_3

B-10 cross section is 3840 barns

B-11 cross section is 0.005 barns



- Natural boric acid has a fixed ratio of boron isotopes: **[(B-10)/(B-11)] = 0.248**
- Enriched boric acid in boron-10, i.e. changing the isotope ratio of **[(B-10)/(B-11)] > 0.248**

Questions - what is the effect of B-10 enrichment on cementitious matrix?

- **Currently we have information for the durability of the waste-form with NBA[1]**
- **There is no published information about the effects of using EBA[2] in cementitious matrix**
- **What is the leachability and durability of waste-forms including EBA?**

If the leachability of EBA/NBA is decreased in cementitious matrix, durability ↑↑ ☺

If the leachability of EBA/NBA is increased in cementitious matrix, durability ↓↓ ☹

1 - Natural Boric Acid (NBA)
2 - Enriched Boric Acid (EBA)

Materials and methods

❖ Materials

- Ordinary Portland Cement (European standard EN 197-1)
- Natural boric acid (NBA) and enriched boric acid (EBA) (> 99% B-10)
- Demineralized water

❖ Leachability test

- logical index for comparison of the durability of samples
- ASTM C1308-08 (2017) is an approved method for leachability test

❖ Analytical methods

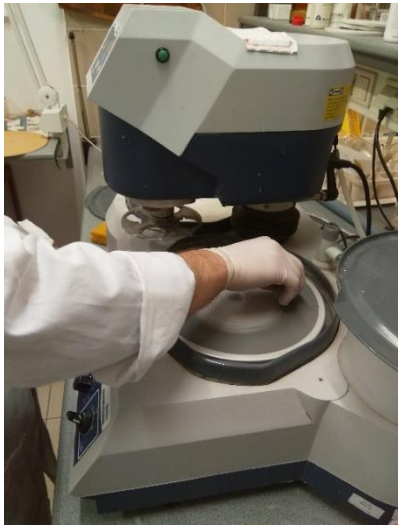
- ICP-OES/MS for analysising of the solutions
- XRD, ATR-FTIR, SEM and Raman-spectroscopy for phase analysis
- Geochemical modeling with PHREEQC code

First experiments – sample preparation (EK[1] & ELTE[2])

- Cement paste samples were prepared containing boric acid
- Three w/c ratios of 0.35, 0.4 and 0.428 were used
- Samples were cured for 28 days
- Powdering for XRD and ATR-FTIR
- Surfaces polished for SEM and Raman

Mixing mortar with boric acid - EK

Removing samples from molds - EK



Preparing of samples for SEM - ELTE

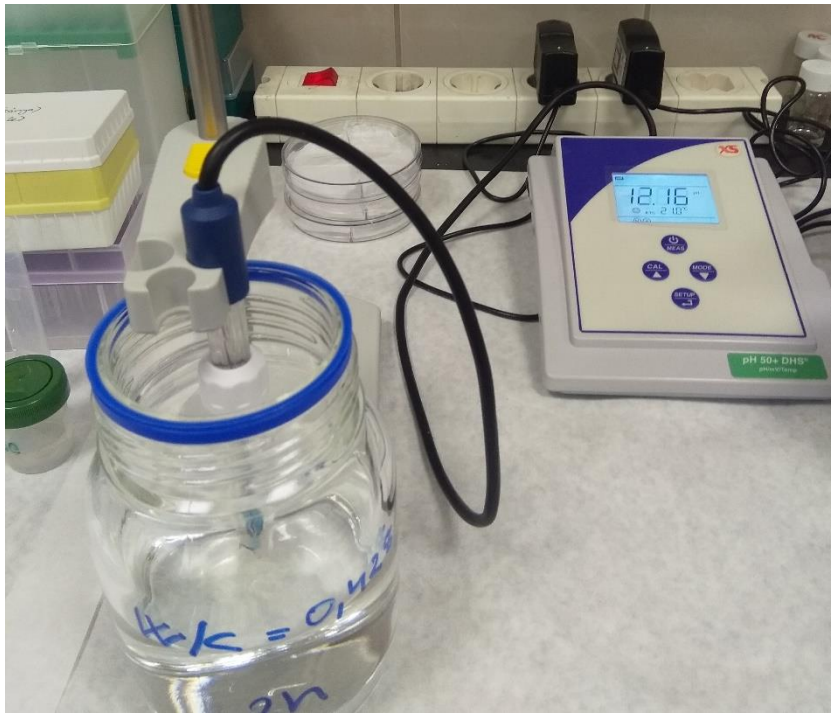
Preparing of samples for XRD - ELTE

1 - Hungarian center for energy research
2 - Eötvös Loránd University

First experiments – leaching test

- Cured samples were soaked in leachantes (DM water) for specified times
- pH detected for each batch and solution samples collected

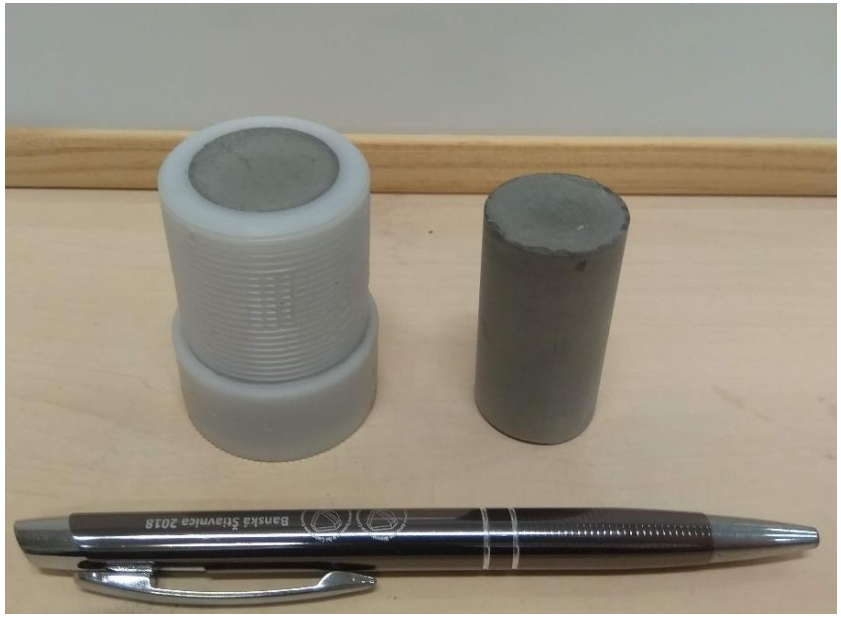
Liquid – solid interaction for leachability test - EK



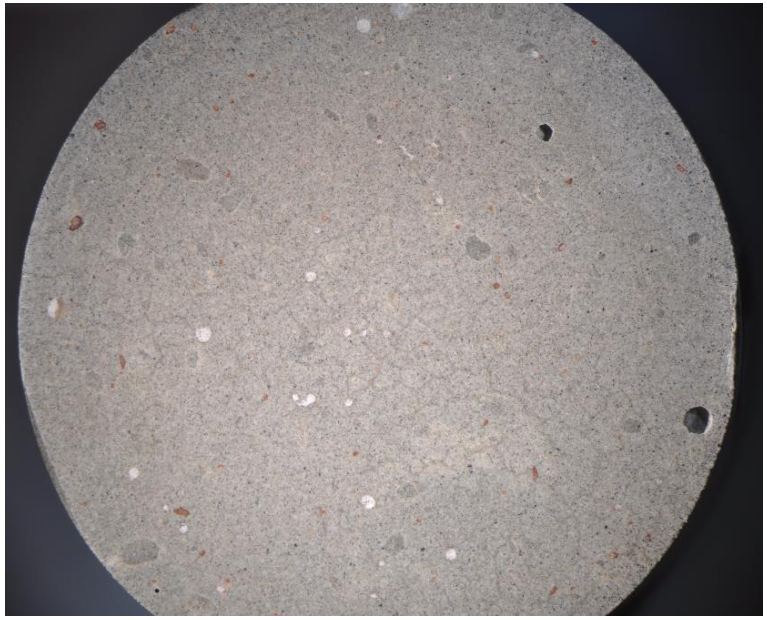
Leachate pH-metery - EK

Preliminary results - phase analysis

- **Alite, ettringite, larnite, brownmillerite, portlandite and inyoite are detected phases in the cementitious matrix by XRD**
- **The abundance of unhydrated phases are higher in lower w/c ratio samples**



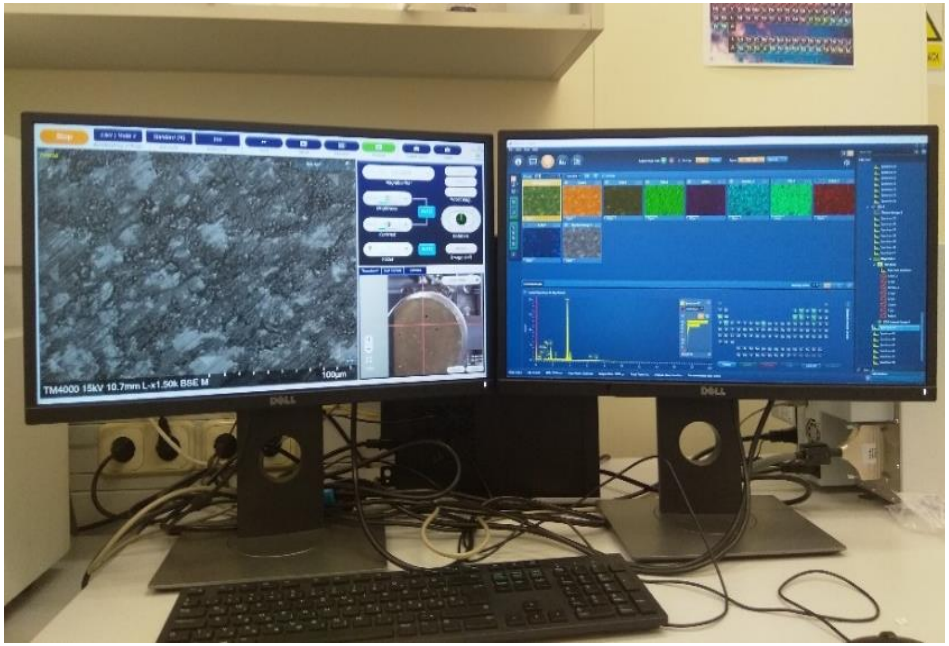
Cured sample -EK



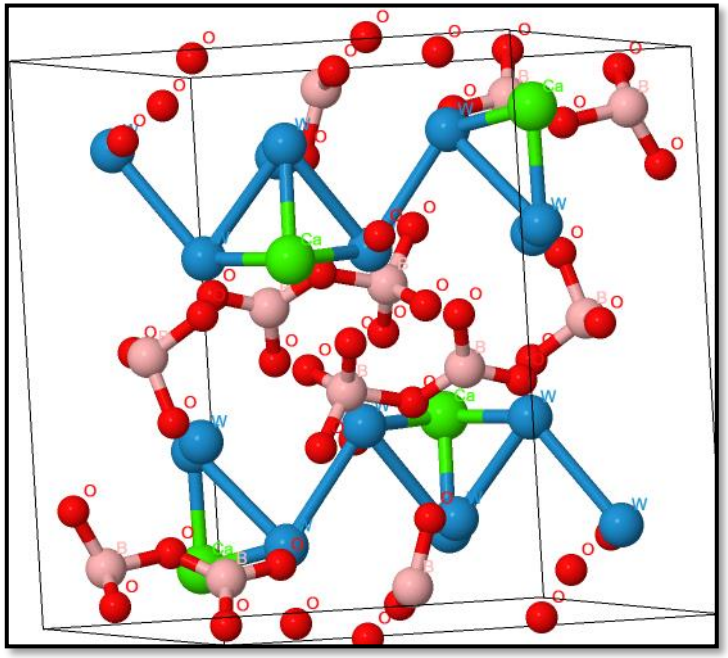
Microscopic view of samples surface - ELTE

Preliminary results - phase analysis

- **Inyoite** ($CaB_3O_3(OH)_5 \cdot 4H_2O$) **is the only phase detected containing boron**
- **Samples with higher w/c ratio, have lower concentration of inyoite**
- **Increasing of w/c can increase the boron release from the matrix**



SEM analysis - ELTE



Inyoite 3D structure including boron (www.mineralienatlas.de)

Summary

- **Boric acid is one of the most important waste streams in all kind of NPPs**
- **Its stabilization for long storage and disposal is done by cementation process**
- **Many tests for durability of the cementitious matrix have been done already with natural boric acid (NBA)**
- **Some modern NPP's have started to using enriched boric acid (in B-10) in recent years, while there is no published data about stabilizing it in cementitious matrix**
- **EBA and NBA might have different leachability and durability properties in the cementitious matrix** (Marschall and Foster 2016)
- **Experiments have already started in this doctorate project to better understand and predict geochemical processes in EBA vs. NBA cementitious systems**

Thank you for your attention!

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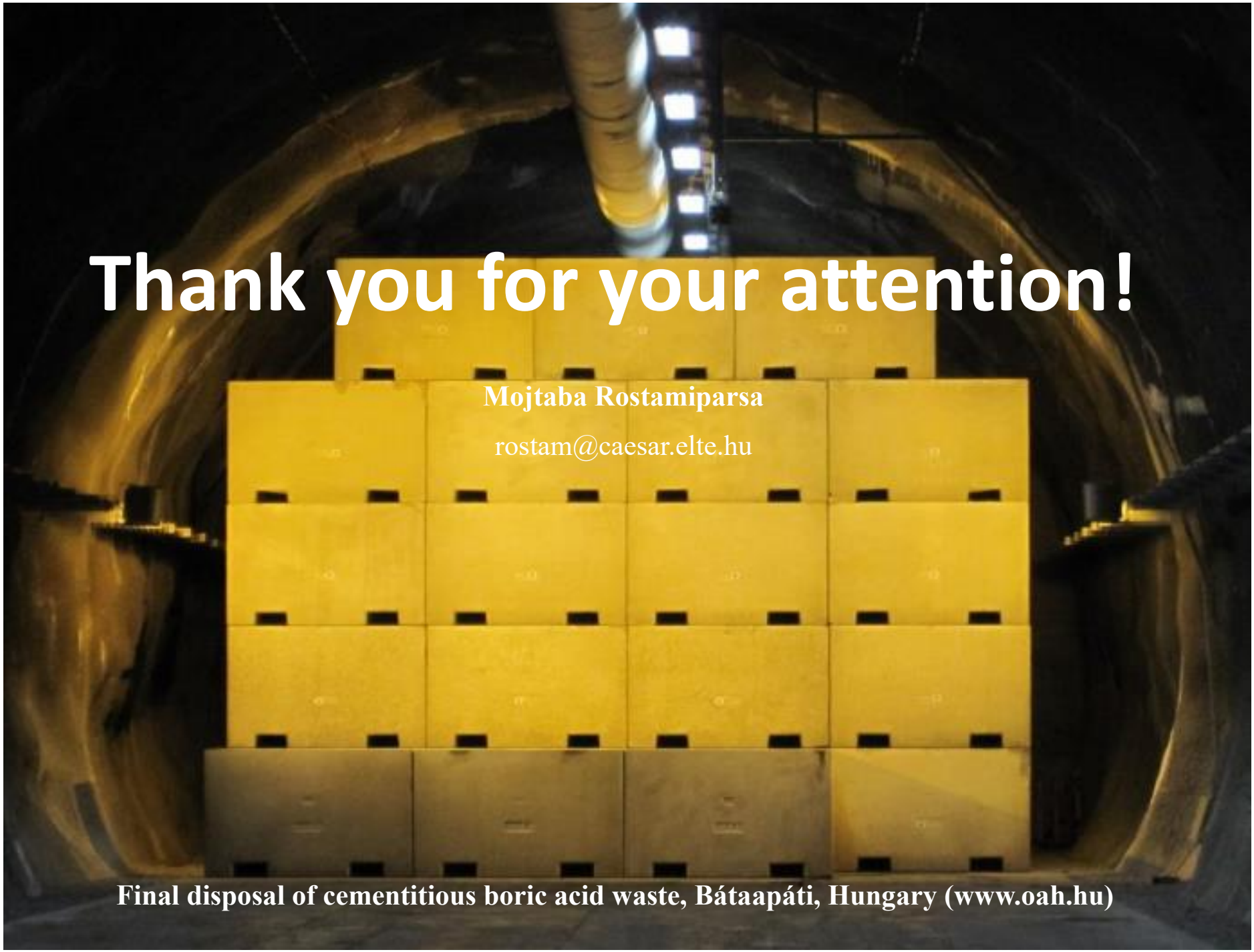

Final disposal of cementitious boric acid waste, Bátaapáti, Hungary (www.oah.hu)

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