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ICONDE – INNOVATION IN CONCRETE DESIGN FOR HAZARDOUS WASTE MANAGEMENT APPLICATIONS

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The ICONDE project

Iceland Liechtenstein Norway grants | Norway grants

Innovation In Concrete Design for Hazardous Waste Management Applications

Aim: develop innovative concrete mixtures for safe disposal of hazardous waste, including radioactive waste.

- **Promoting circular economy** by using ***oil shale ash***, an industrial waste product created in energy production in Estonia, ***as supplementary cementitious material in concrete production***.
- **Improving the mechanical properties** of concrete by adding ***dispersed fibres***.
  - **Increasing the material's ability to shield neutrons** by using ***basalt fibres infused with boron oxide***.

- A Baltic Research Programme's project, financially supported by the EEA Grants of Iceland, Liechtenstein and Norway.
- Timeframe: 2021 – 2024
- Four partners:
  - Latvia – Riga Technical University
  - Lithuania – Lithuanian Energy Institute
  - Estonia – University of Tartu
  - Norway – Arctic University of Norway

Outline of the presentation

- Oil shale ash
  - Usability of oil shale ash in concrete production
- Fiber-reinforced concrete
  - Basalt and basalt-boron fibers
- Radioactive waste management by cementation
- Outline of the ICONDE project

Oil shale and oil shale ash

- Oil shale has been used for energy production in Estonia over half a century.
- Calorific value 8.4 MJ/kg
  - *Comparison:* coal 9–27 MJ/kg
- High content of mineral matter
  - Burning 1 tonne →
    more than 0.5 tonnes of ash.
- Oil shale ash has found very little use.
  - Between 2014 and 2020, *ca.* 55 million tonnes of oil shale processing residues was created in Estonia.
  - Only 1-2 % of the residues have been utilized.

Fig.: Oil shale (Photo by Oil Shale Competence Center, Taltech https://taltech.ee/en/oil-shale-competence-center/about-oil-shale)

Fig.: Oil shale ash sample (Photo by S.Salupere)

Oil shale and oil shale ash – radionuclide content

- Radionuclide content in oil shale is similar to Estonian soils.
- Up to 4-5 fold enrichment in ash, especially for K-40 and Pb-210.
- Activity concentrations of naturally occurring radionuclides stay below exemption levels by EU BSS.

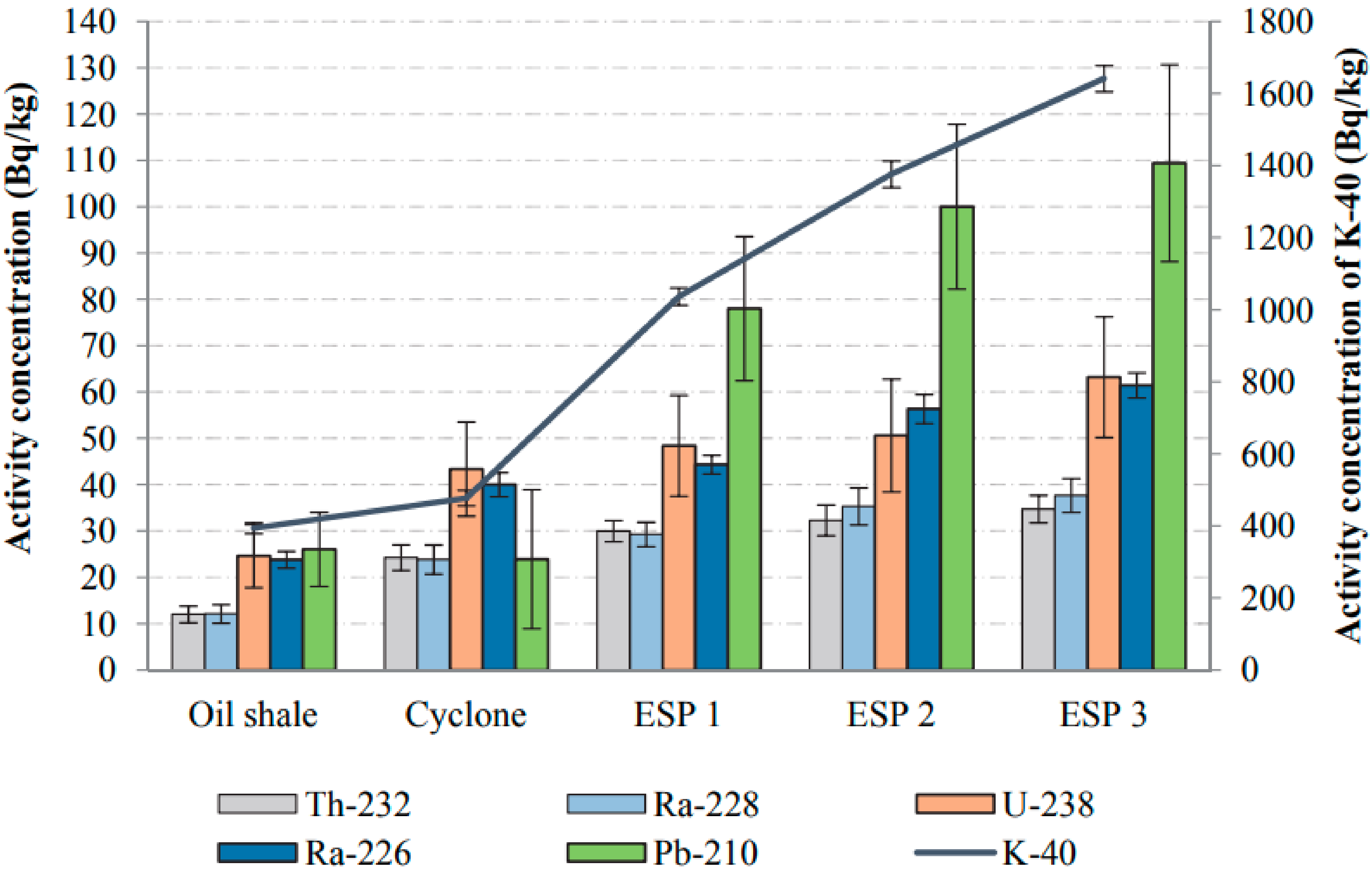

Fig.: Radionuclide activity concentrations (Bq/kg) in different ash fractions of a pulverized fuel boiler (Vaasma, 2017. PhD thesis. University of Tartu).

Oil shale ash – chemical composition

Table: Five most abundant components (weight %) in oil shale ash samples and ordinary portland cement (XRF measurement results) with the comparison to coal fly ash (Bhatt *et al.*, 2019).

Component	**OIL SHALE ASH, sample 1** (XRF result)	**OIL SHALE ASH, sample 2** (XRF result)	**Ordinary portland cement sample** (XRF result)	**Coal fly ash, worldwide min and max** (Bhatt *et al.*, 2019)
CaO	37.06	32.59	61.69	0.1 – 52.0
SiO_2	33.20	32.87	19.11	20.0 – 80.0
Al_2O_3	8.09	7.79	4.79	1.0 – 55.0
SO_3	5.45	9.50	2.02	0.0 – 15.0
Fe_2O_3	4.44	4.53	2.85	1.0 – 44.7

Reference: Bhatt *et al.*, 2019. Physical, chemical, and geotechnical properties of coal fly ash: A global review. Case Studies in Construction Materials 11 (2019) e00263

Oil shale ash – usability in concrete production

- ISO standard EN 197-1:2011 allows up to 55% of clincer replacement by puzzolans (siliceous and aluminous materials).
- Oil shale ash – a promising material to be used as ***a barrier material to immobilize hazardous material***, incl. radioactive waste.
  - Incorporation of heavy metals into hydration products, such as calcium-silicate-hydrate gel, ettringite and monosulfate (Leben *et al.*, 2019).
    - Layered structure provides several potential positions that can be occupied by heavy metals (Vespa *et al.*, 2014).
    - Incorporation of heavy metal ions in channel and columnar sections of the crystal structure.

References:

Leben *et al.*, 2019. Long-term mineral transformation of Ca-rich oil shale ash waste. Science of The Total Environment, 658 (2019), pp 1404-1415.

Vespa *et al.*, 2014. Competition behaviour of metal uptake in cementitious systems: An XRD and EXAFS investigation of Nd- and Zn-loaded 11A tobermorite. Physics and Chemistry of the Earth, 70-71 (2014), 32-38.

Fiber-reinforced concrete – advantages

- Reduction of early age shrinkage causing crack formation during the hardening process.
- Increase of flexural tensile strength for mechanical purposes.
- Enhancement of fire resistance.
- Replacement of traditionally used steel rebars by structural dispersed fibers.

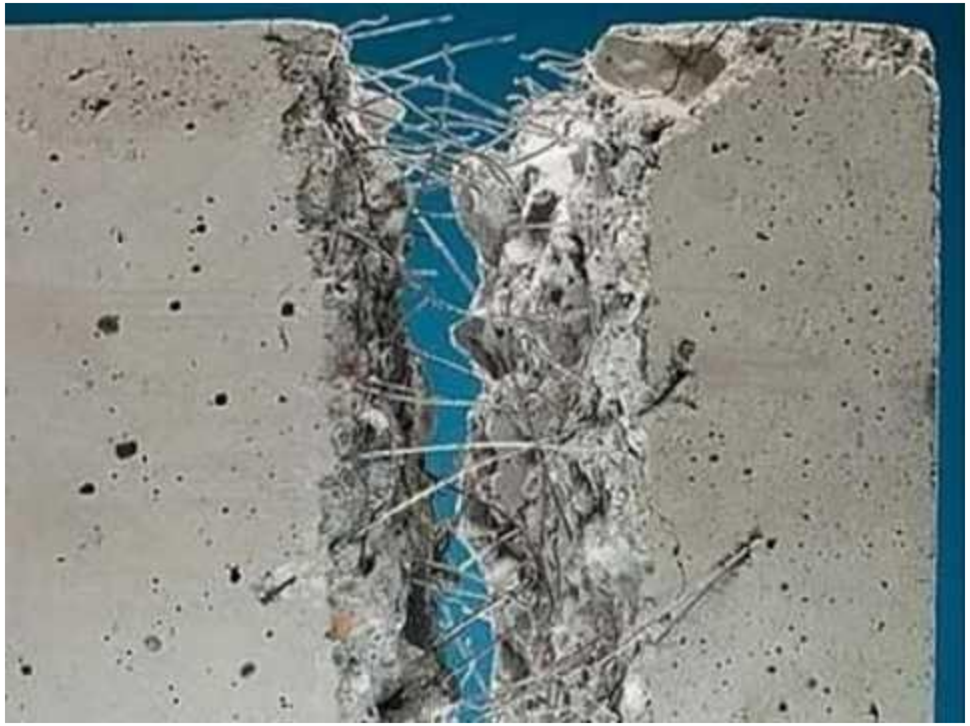

Fig.: fiber-reinforced concrete
(Illustration by Ischenko & Borisova, 2020. Application of fiber-reinforced concrete in high-rise construction. E3S Web of Conferences. 164:02005.
DOI: 10.1051/e3sconf/202016402005)

Basalt and basalt-boron microfibers

Basalt microfibers improve:

- impact and fracture toughness, deformation capacity;
- tensile and flexural strength;
- resistance to a high range of temperatures;
- chemical and corrosion resistance.

Basalt fibers have similar specific gravity as the basic components of concrete → **uniformly distributed over concrete volume** (unlike steel polymer fibers).

Basalt-boron microfibers:

- Infused with boron oxide B_2O_5.
- Improve material's neutron radiation shielding properties.

Fig.: Basalt fiber (Photo by S.Salupere)

Radioactive waste management by cementation

Cementation is a standard technique in radioactive waste management.

+ Suitable for a variety of waste.
+ Simple, flexible, reliable and cost effective.
+ Usually accepted for storage.
+ Inherent properties of cemented products:
    + radiation resistance,
    + compatibility with many types of environmental conditions,
    + good actinide retention.

– Increase of the volume of final product.

Innovative concrete design

Today's main requirements of concrete for radioactive waste storage: ***density*** and ***fragility***.

Advanced performance of concrete is not taken into account.

The ICONDE project sees an opportunity to ***improve other properties*** of concrete for hazardous, incl. radioactive, waste storage in order **to reduce its environmental impact**.

The ICONDE Project – work plan (1)

I. Input material characterisation

Chemical, mineralogical and radiological analysis of input materials for concrete production.

II. Selection of fibres

For testing in the concrete mixtures.

III. Modelling

Mechanical and radiation shielding (gamma and neutron) properties of different concrete mixtures where (i) ordinary portland cement has been partially replaced by oil shale ash, (ii) fibers have been added.

Objective – development of concrete mixtures for:

- low and intermediate level waste;
- storage casks for spent nuclear fuel.

The ICONDE Project – work plan (2)
Source term for radiation modelling

Radioactive waste from the decomissioning of the Ignalina NPP, Lithuania.

- Low and intermediate level wastes.
- Spent nuclear fuel – RBMK-1500 fuel assemblies.

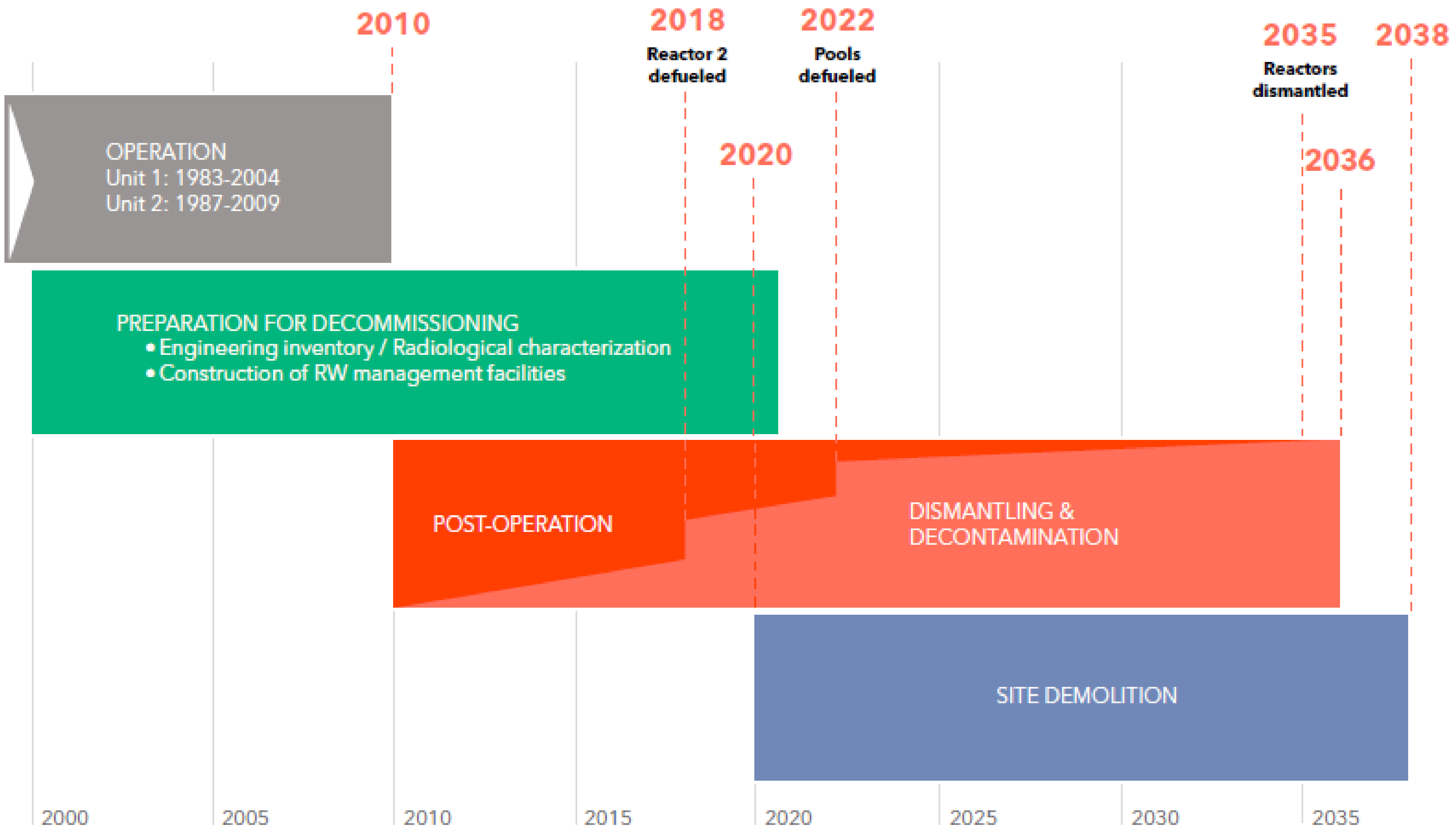

Fig.: Ignalina NPP decommissioning schedule
(Source: VATESI, 2020. Nuclear Power Safety In Lithuania Annual Report)

The ICONDE Project – work plan (3)

IV. Preparation of concrete sample specimens

Recipies chosen based on modelling results.

V. Experimental analyses

Mechanical tests, chemical and mineralogical analysis, radiation shielding measurements (gamma and neutron).

IV. Comparison

Modelling results *versus* experimental results.

The performance of the novel materials will be compared with currently used standard materials in radioactive waste management.

Conclusions

Objective: development of innovative concrete mixtures for safe disposal of hazardous waste, including radioactive waste.

How to get there?

- Addition of oil shale ash
  - Reduction of cement dose
  - Utilization of problematic waste (oil shale ash) in the circular material flow.
  - Enhancement the immobilization properties of concrete for heavy elements, incl. radionuclides.
- Addition of dispersed fibers
  - Improving the mechanical properties of concrete
  - The use of basalt-boron fibers will increase the material’s ability to shield neutrons.
- High optimization through the implementation of modelling.

Thank you for your attention!

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Acknowledgment

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Working together for a green, competitive and inclusive Europe