DEEP ISOLATION™

Fuel cycle innovations

The potential for borehole disposal of spent nuclear fuel in Estonia

What I will cover today

1 The challenge

If Estonia chooses nuclear as part of its low carbon future, how will it dispose of the resulting spent fuel?

2 A potential solution

Deep borehole disposal, enabled by innovation in directional drilling technology

3 Initial feasibility results

Findings from our initial study of this technology's suitability within Estonia's crystalline basement geology

4 Implications for Estonia

Integrating these innovations into the policy and regulatory process

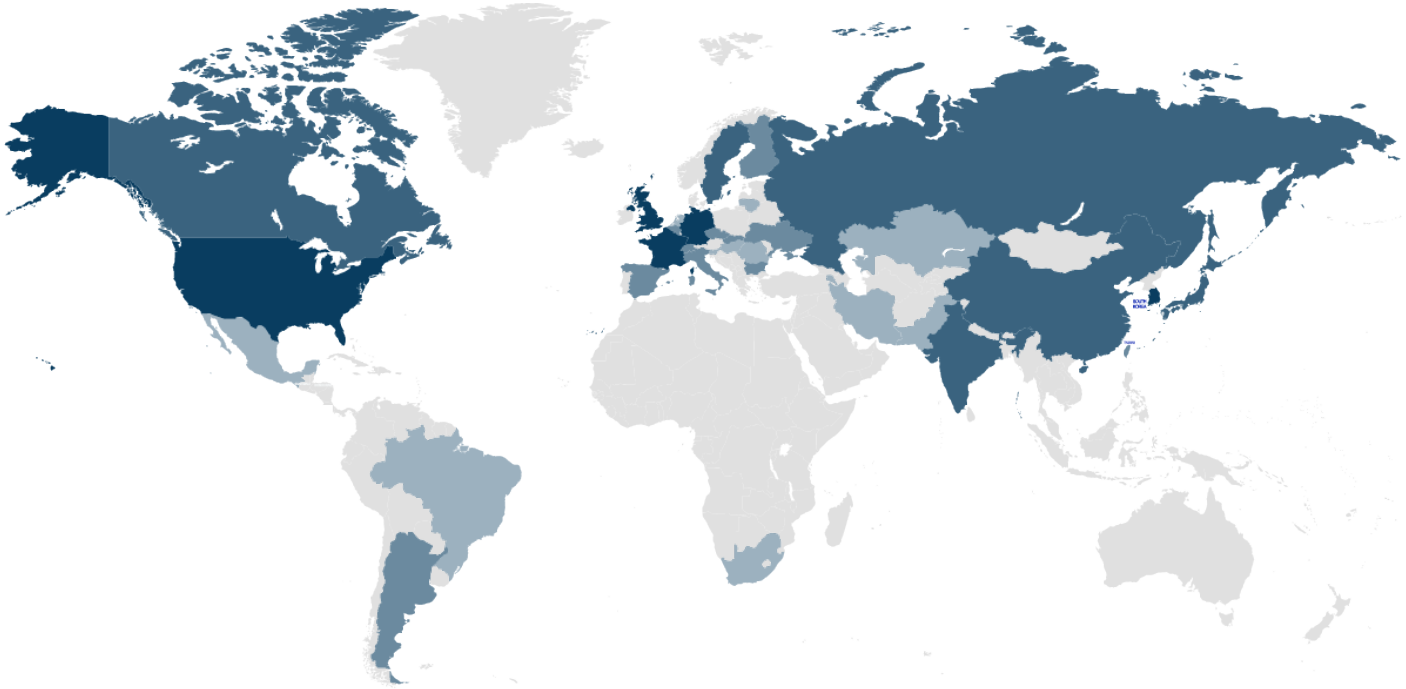
The challenge

- The world has not yet disposed any of the spent fuel it has created over the last seventy years

Estimated size of spent fuel inventories

- Less than 3,000 tHM
- 3,000 - 10,000 tHM
- 10,000 - 30,000 tHM
- Greater than 30,000 tHM

Sources: Deep Isolation analysis of country-level and regional-level data in IAEA 2018 and ANS: Nuclear News (March 2018)



…. and the current model for geological disposal is simply not scalable

The challenge

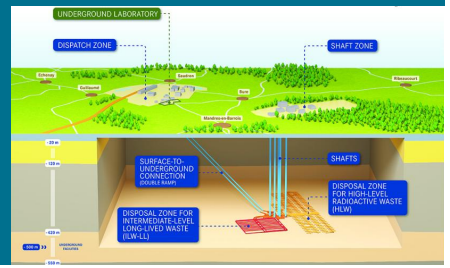
- In Europe, for example, only a few nuclear countries have advanced plans for disposal of spent fuel

Planned Geological Disposal Facility

UK
€16 billion

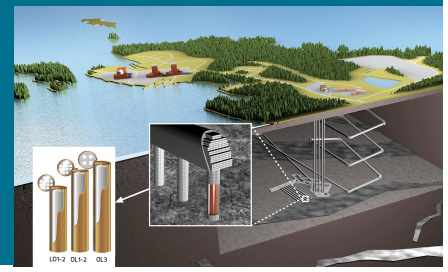
CIGEO facility in in Meuse/Haute-Marne

France
€20-35 billion



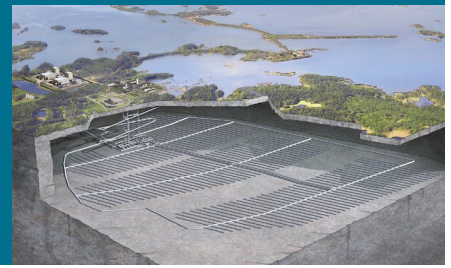
The Onkalo spent fuel repository

Finland
€1.8 billion



The Forsmark spent fuel repository

Sweden
€3.7 billion

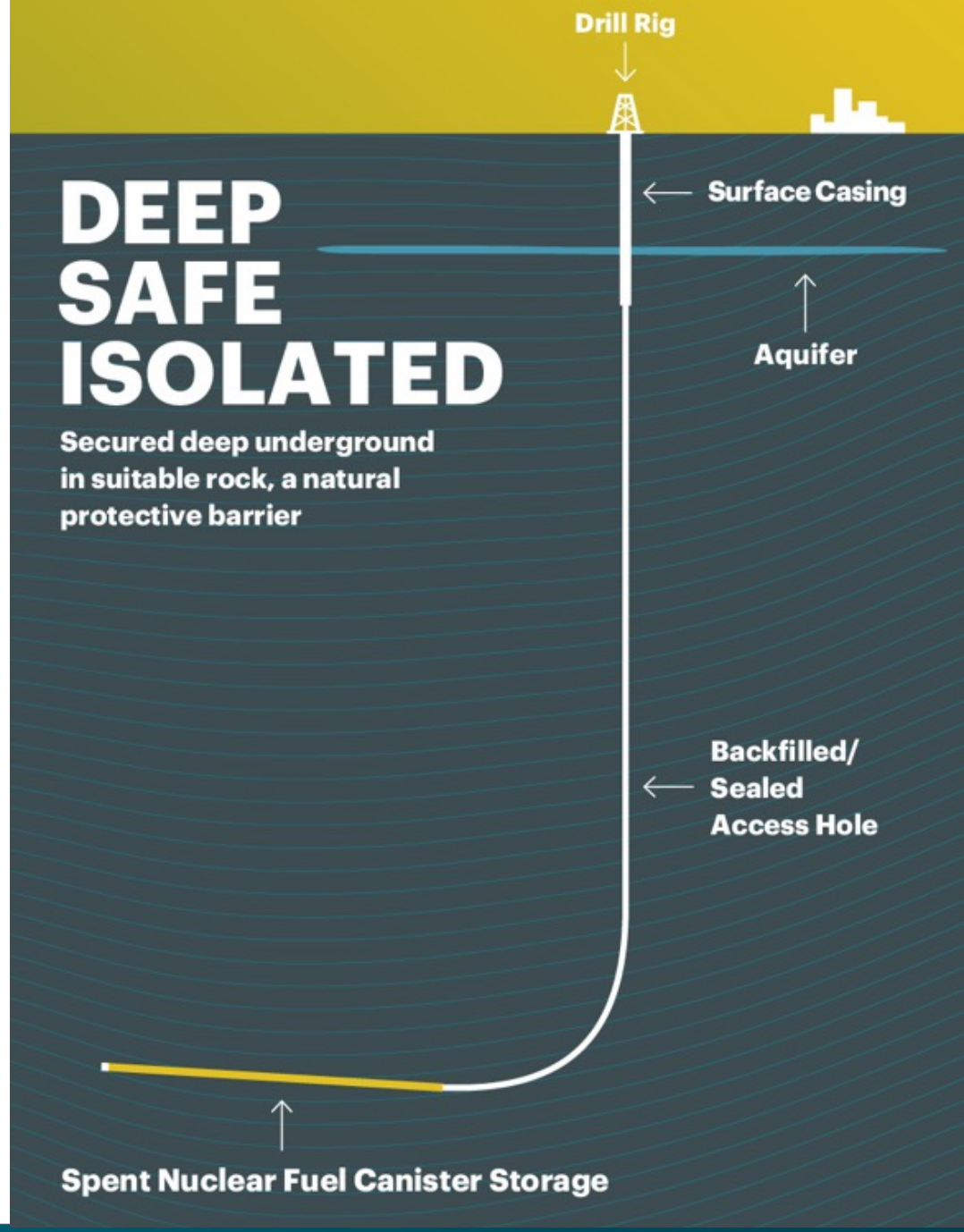


….. and these are projects that take decades to plan and deliver, and cost billions of Euros

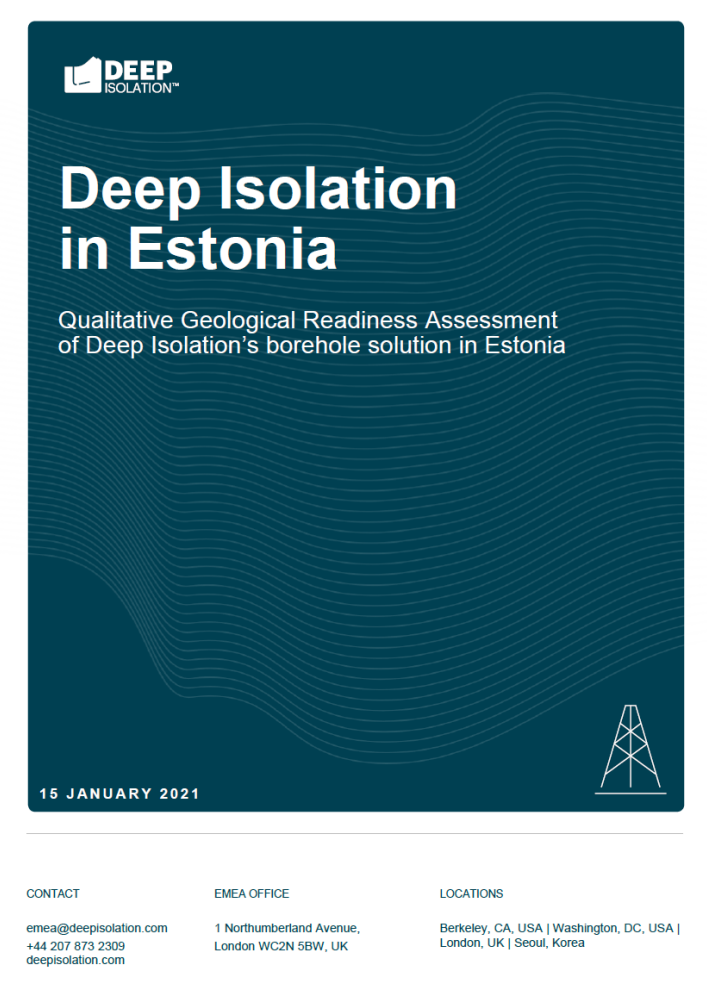
Source for cost estimates: The costs of geological disposal, Professor Neil Chapman ERDO Working Group and Arius Association, IFNEC Workshop, Paris 11th December 2018

Overview of Deep Isolation

- Deep Isolation offers safe, equitable and affordable disposal of nuclear waste
- Founded in US in 2016; Deep Isolation EMEA Limited launched in 2020, based in London
- Our solution:
  - Uses state-of-the-art directional drilling technology to create a drilled repository in suitable host rocks that have remained isolated from the environment for millions of years
  - Lowers corrosion-resistant canisters containing spent fuel into boreholes repositories deep underground (far deeper than feasible with a mined repository) and seals the access hole
  - Leverages mature technologies that are widely used in industry and that we have integrated and enhanced with our own patented innovations



Today we are publishing a preliminary study on deep borehole disposal in Estonia



- An international group of industry partners have assessed the potential of this technology in Estonia

- A preliminary study analyzing existing data, with no site-specific research at this stage
- We have addressed two key research questions:

1

Safety

Does Estonian geology provide suitable host rocks in which a borehole repository could be safely sited?

2

Deliverability

Can a borehole repository be constructed on a cost-effective basis in Estonian geology?

Methodology

We screened the 15 counties of Estonia against four Assessment Criteria, aligned with the requirements for geologic disposal sites set out in the IAEA Safety Standard *"SSG-14: Geological Disposal Facilities for Radioactive Waste"*

Seismicity	Is the deep geosphere historically stable from disruptive seismic events?

- Tectonic history and framework of the geological setting at a local and regional scale and its historical seismicity
- Evidence of active (Quaternary and possibly late Tertiary) neotectonic processes, such as uplift, subsidence, tilting, folding and faulting
- Presence of faults in the geological setting (e.g. their location, length, depth and information on the age of latest movement)
- Estimates of the characteristics and maximum intensity of earthquake that would be possible at the site on the basis of its seismotectonic context;
- The in situ regional stress field

Geothermal heat flux / volcanism	Are there risks of the deep repository being disturbed by volcanic activity?

- Estimates of the geothermal gradient and evidence of thermal springs
- Evidence of active (Quaternary and possibly late Tertiary) volcanism

Climate change	Does past glaciation and expected long-term future trends suggest risk of contact with the biosphere?

- Climatic history (local and regional) and expected long term future trends at regional and more global scales
- Impact of isostatic rebound from glaciation
- Penetration of freshwater into deep rock formations

Paleohydrology	Has the hydrological environment at depth remained isolated from surface waters for millions of years?

- What is the regional paleo-hydrologic setting
- Depth of aquifers
- Regional flow regime, recharge time
- Interaction of aquifers with deeper water sources

…. and summarised our findings by assessing each county on a 0-3 scale

3: Highly suitable

No significant risks throughout region; high probability of many locations that are suitable

2: Suitable

No significant risks at region-wide scale, but there may be localised problem areas that will need to be avoided

1: Potentially suitable

Significant risks at region-wide scale, but there may be some suitable host geologies at a more localised level

0: Unsuitable

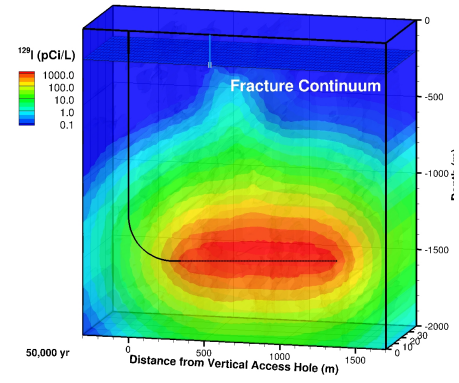
Significant risks at region-wide scale: region should be ruled out for repository siting

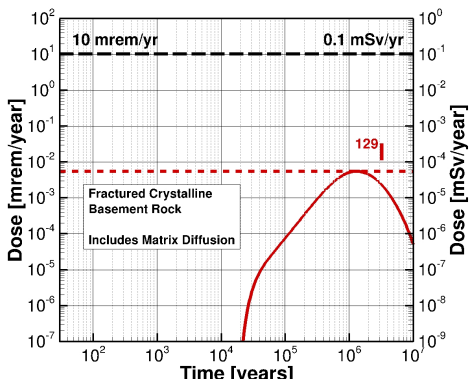
Key findings

1. A deep borehole repository would be both a **safe** and **affordable** option for Estonia

Safety at depth in crystalline basement rocks

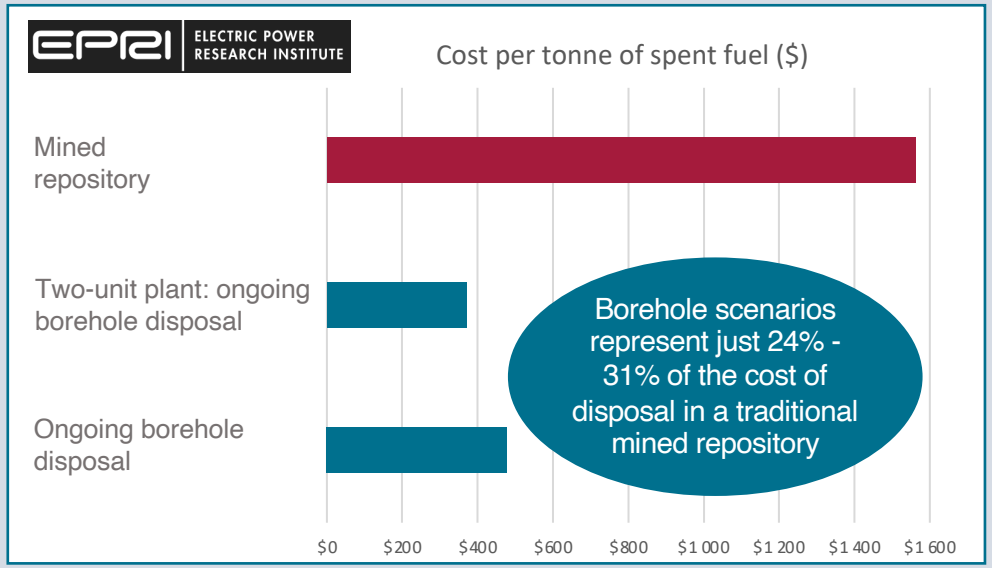
- Preliminary modelling of a generic repository disposing of spent nuclear fuel in crystalline basement geology similar to Estonia's indicates that it will provide robust safety:
  - ✓ Peak dose at the surface arrives after 1.3 million years ….
  - ✓ …..and at a level approximately three orders of magnitude below regulatory requirements





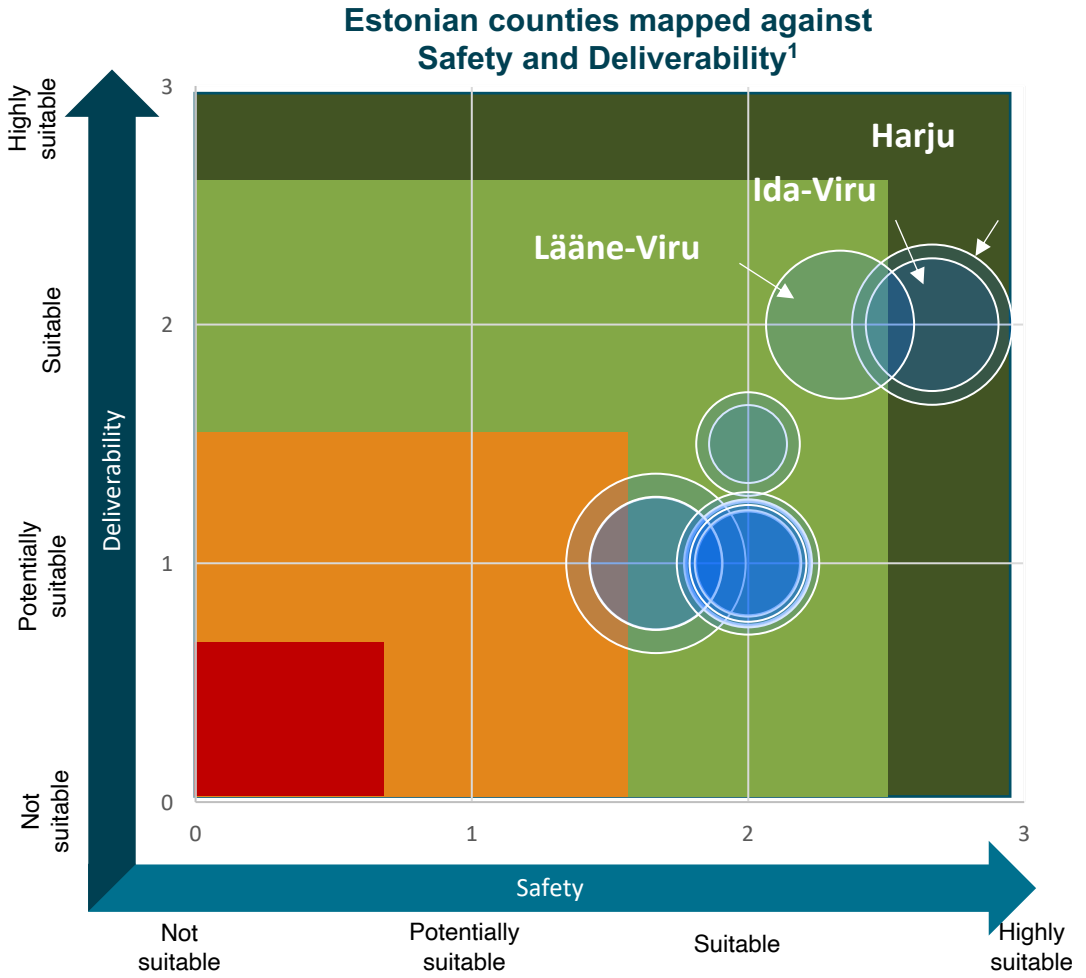
The benefits of geologic disposal, at a fraction of the cost

- Research by the Electric Power Research Institute suggests that the cost of disposing spent nuclear fuel from advanced reactors (such as the Small Modular Reactor under consideration in Estonia) is significantly less expensive in a borehole repository (*see report for assumptions*)



Key findings

2. There are no fundamental geologic limitations to siting of nuclear waste in deep horizontal boreholes in Estonia, and a wide range of siting options are available

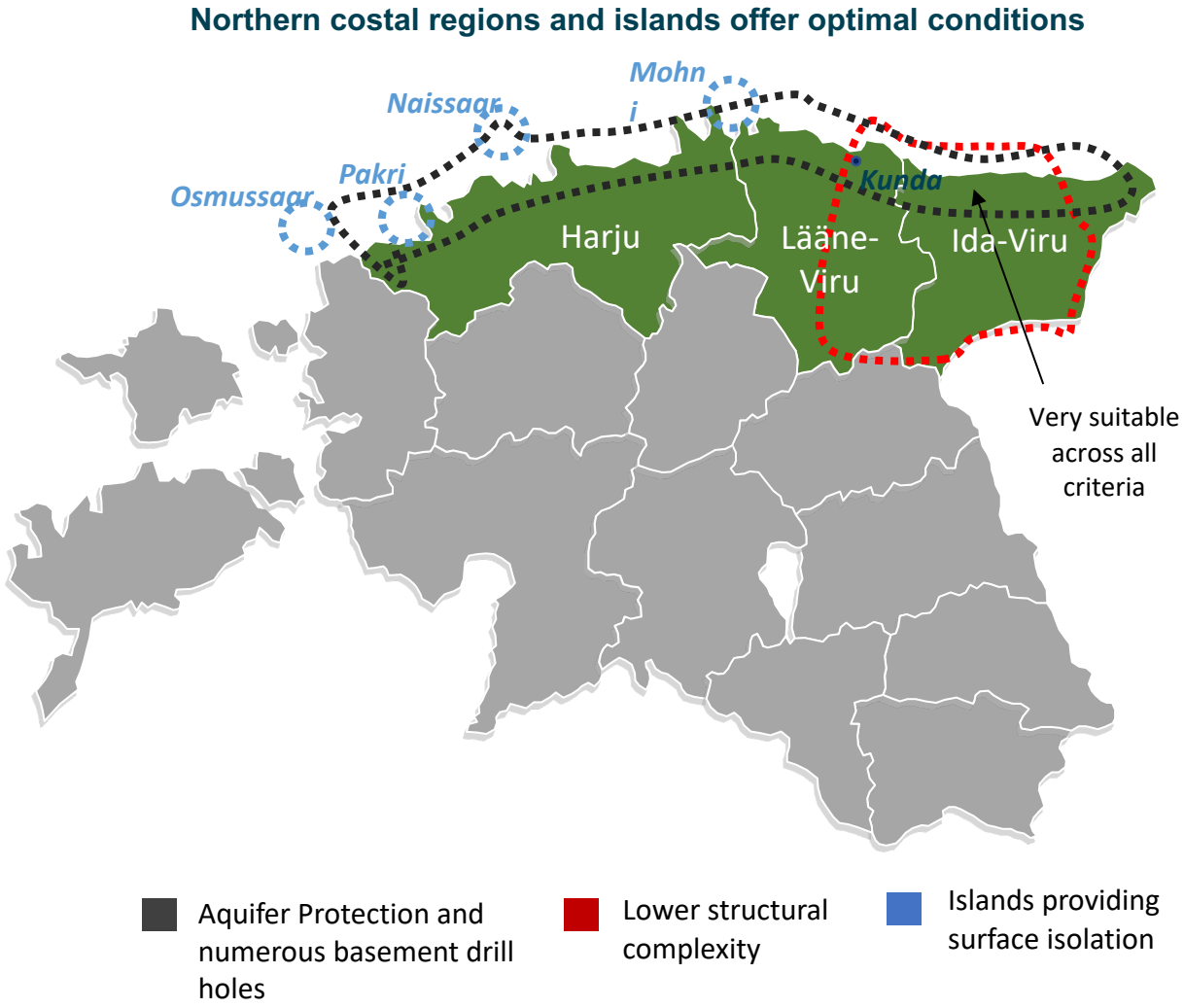


[1]This chart is qualitative and illustrative. It presents an equally-weighted average of the different criteria we have assessed for both Safety and Deliverability, using a 0-3 scale that represents a simplified summary of qualitative judgments, not empirical data points. Size of bubble indicates relative area.

Key findings

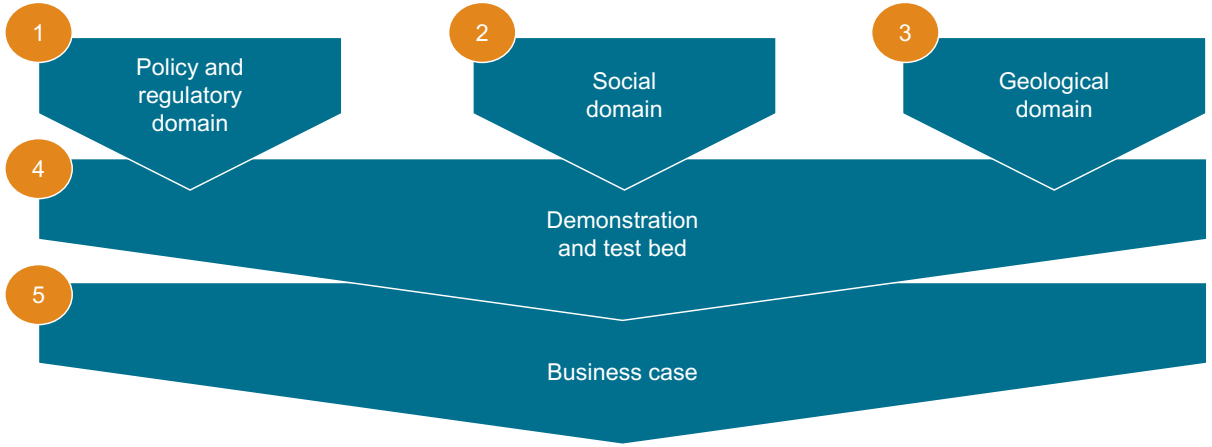
3. The areas with the greatest likelihood of providing appropriate host rock formations from both a safety perspective and an operational are:
   - Harju County and Ida-Viru County, and to a slightly lesser extent Lääne-Viru, on the north coast of Estonia
   - The islands off that coastline

   These areas combine optimal conditions including:
   - Aquifer isolation
   - Coastal sites that will facilitate seismic surveys for site characterization
   - Numerous crystalline basement drill holes with cores



Implications and recommendations for Estonia

- **This has been a preliminary study only:** Extensive further work will be needed to identify and characterize specific potential sites, and to engage with potential host communities. Our recommendations on how this might best be taken forward in Estonia are set out in the report, across five key domains



- **One over-arching recommendation:**

"The Estonian Government should, in parallel with its consideration of the SMR option, also develop a strategy for managing the resulting spent fuel. This strategy should:

- *Be based on deep borehole disposal*
- *Aim to establish a clear implementation plan at or before grant of the operating license for the nuclear power plant."*

This will establish Estonia as a world-leader:

The only country in the world to have established a clear disposal route for nuclear waste before it starts to produce that waste

Thank you

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