AN INTERNATIONAL PERSPECTIVE ON DEEP BOREHOLE DISPOSAL

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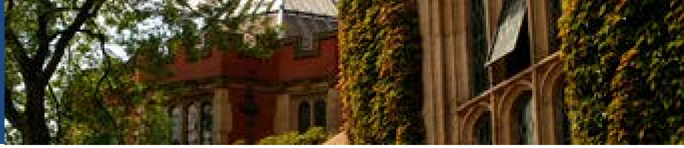

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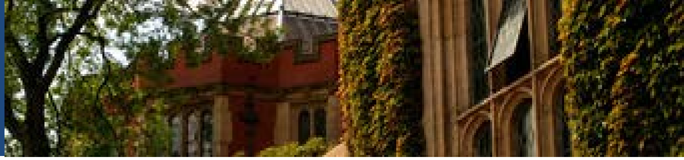
Differences - - → Technical issues, Options & Challenges for implementation

History of DBD

(a.k.a. VDH & VDD)



Key Milestones

1950's Early ideas in USA & USSR

1957 US National Academy of Sciences - Rejected

1983 Woodward Clyde Consultants - *"Very Deep Holes Systems Engineering"*

20 inch (50 cm) hole to 6 km

1989 Juhlin & Sandstedt - *"Storage of Nuclear Waste in Very Deep Boreholes: Feasibility Study and Assessment of Economic Potential"* 80 cm (32 inch) hole to 4 km

1990's Gibb (2000) - *"A New Scheme for the Very Deep Geological Disposal of High-Level Radioactive Waste"*

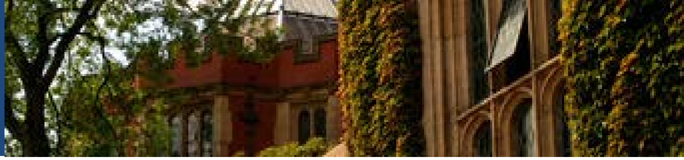
2003 Chapman & Gibb - *"A Truly Final Waste Management Solution – Is Very Deep Borehole Disposal a Realistic Option for HLW or Fissile Material?"*

2003 Ansolabhere et al. - *"The Future of Nuclear Power: An Interdisciplinary MIT Study"*

"The DOE should broaden its long-term waste R&D program to include .... deep borehole disposal".

History of DBD

(a.k.a. VDH & VDD)



Key Milestones

2008 Beswick - *"Status of Technology for Deep Borehole Disposal"*

To a depth of 4 km, boreholes with a diameter up to –
50 cm could be successfully designed & implemented now,
75 cm may be practical with some technology development,
100 cm are outside the envelope of experience.

2009 Brady et al. - *"Deep Borehole Disposal of High-Level Radioactive Waste"*

Confirmed the exceptional degree of safety afforded by DBD

2011 Arnold et al. - *"Reference Design and Operations for Deep Borehole Disposal of High-Level Radioactive Waste"*

17 inch (43 cm) hole to 5 km

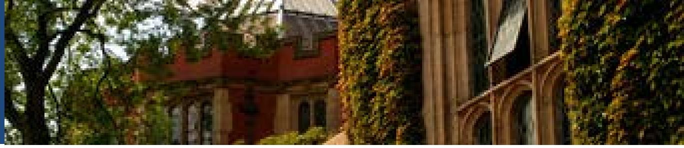
2012 Blue Ribbon Commission - *"America's Nuclear Future: Report to the Secretary of Energy"*

"… identified deep boreholes as a potentially promising technology for geologic disposal that could increase the flexibility of the overall waste management system and therefore merits further research, development, and demonstration."

2012 Gibb et al. - *"Deep Borehole Disposal of High Burn-up Spent Nuclear Fuels"* *Could eliminate the need for 100+ years of pre-disposal cooling.*

2014 Beswick et al. - *"Deep Borehole Disposal of Nuclear Waste: Engineering Challenges"*

Potential Benefits of DBD



1. SAFETY
2. COST- EFFECTIVE — <20% of disposal in SKB repository/tHM
3. ENVIRONMENTAL IMPACT — Transient ~ 3 years
4. EASIER SITING
5. DISPERSED DISPOSAL — Reduce/eliminate transportation
6. SECURITY
7. INSENSITIVE (to Composition & Heat Output)
8. EARLY IMPLEMENTATION
9. FLEXIBILITY — "Pay as you go"
10. LONGEVITY
11. SMALL 'FOOTPRINT'
12. EARTHQUAKE 'PROOF' — No threat to overall safety

UK

2004 UK Nirex Report *"A review of the Deep Borehole Disposal Concept for Radioactive Waste"*

2006 CoRWM (Committee on Radioactive Waste Management**) *"Managing our Radioactive Waste Safely"*** *Recommendation 5 –*
"… decision making should leave open the possibility that other long term management options (for example borehole disposal) could emerge as practical alternatives"

2008 Government White Paper "*Managing Radioactive Waste Safely*"
" The NDA will also keep options such as borehole disposal .... …. .... under review"

2011 NDA (Nuclear Decommissioning Authority**) Report *"Review of Options for Accelerating Implementation of the Geological Disposal Programme"***
***Included the use of deep boreholes to bring the first disposal of HLW forward from 2075 to 2040*.**

2014 Government White Paper "Implementing Geological Disposal"
No change in UK commitment to a mined repository.

SWEDEN

1989 SKB Report (*Juhlin & Sandsted*) *"Storage of nuclear waste in very deep boreholes: Feasibility study and assessment of economic potential."*

1992 SKB Report *"Project Alternative Systems Study – PASS. Analysis of performance and long-term safety of repository concepts."*

"long-term safety of … VDH is potentially as good as the long-term safety of a KBS-3 repository" ……
….. but was more difficult to demonstrate

Deep boreholes ranked last. *[KBS-3 ranked top!]*

2000 SKB Report (*Harrison*) *"Very deep borehole. Deutag's opinion on boring, canister emplacement and retrievability."*

"it is possible to drill the well with currently existing technology, although it represents one of the biggest challenges to be presented to the drilling industry."

SWEDEN

2006 SKB Report *(Marsic et al.)* *"Very deep borehole concept: Thermal effects on groundwater flow."*

The heat output from SF would not jeopardise the stability of the saline groundwater.

Swedish environmental law requires consideration of alternatives & justification of choice of disposal concept

2010 SKB Report *(Grundfelt)* *"Comparison of the KBS-3 method and deposition in deep boreholes for the final disposition of spent nuclear fuel."*

2011 SKB Application to Environmental Court for construction of SF repository.

2012 Application challenged *Swedish Regulators (SSM)*
Swedish NGO Office for Nuclear Waste Review (MKG)
Swedish Council for Nuclear Waste
Swedish Nature Conservancy

2014 SKB Submitted a revised and reduced case against deep boreholes to the Environmental Court.

Decision of Environmental Court pending.

DBD in International Programs

GERMANY

10,500 Tonnes of SF + 300 Canisters of Vitrified HLW

2013 Commission on Final Disposal Site Selection set up by Government

2014 DBD Group formed – Individuals (Academe, Industry, Government)

2015 Deep Borehole Conference (Berlin)

? ? ?

Others

1995 RUSSIA Proposal from VNIPIPT (Institute of Industrial Technologies)
[Kedrovsky] To dispose of spent RBMK fuel in deep boreholes at or near NPPs

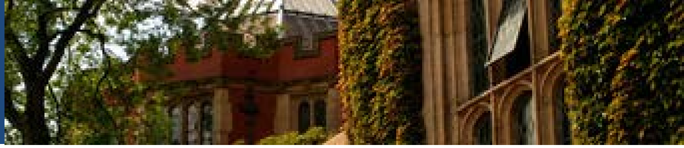
199? CZECH REPUBLIC Approach to the University of Sheffield

2012 SOUTH KOREA Involvement with US DOE Program through Sandia NL

2014 CHINA Involvement with US DOE Program through Sandia NL

Potential market for a successful DBD technology is large

Issues, Options & Challenges



Many different versions of the DBD concept have been proposed (mostly for SNF disposal)

1. **Waste Package Deployment**

2. **Near-field Safety Case**

3. **Borehole Sealing**

! ! !

! ! !

Drilling & casing the borehole and construction of any well-head facilities is just a large engineering project like any other

….. with only normal operational safety requirements.

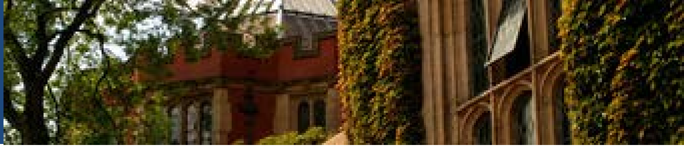
Arrival of first active waste package

….. the site becomes a "Nuclear Facility" so success of all subsequent operations and procedures must be virtually guaranteed.

Criteria for selection of options: -

1. Simplicity
2. Minimal Risk
3. Reliability (Failsafe)

Waste Package Deployment



Deployment method? Single or Multiple?

METHODS

Method	*Round trip times*	*Comments*
1. Free Fall	1-2 hours (one way)	*Lack of control*
2. Drill Pipe	18 - 24 hours	*Slow. Needs rig kept on site.*
3. Wireline	~ 6 hours	*Load limits. Stretching. Entanglement.*
4. Coiled Tubing	4 - 6 hours	*Fast. Reliable. Conductors. Cost-effective.*

Coiled Tubing Rig

Multi-Package Emplacement

Woodward – Clyde (1983) ***Package assembly into strings (rigid coupled)***

↓

M.I.T. Work **-** *E.g., Hoag (2006)*
Sapiie & Driscoll (2009)

↓

Sandia " Reference design" **-** *Arnold et al. (2011)*
200 m long string of 40 spent fuel packages weighing 69.5 tonnes

Issues

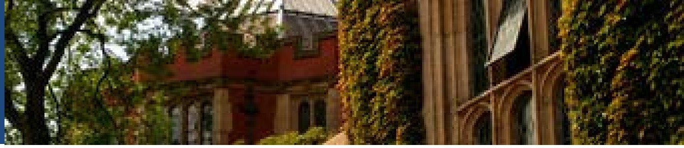
Weight – deployment only by drill pipe (requiring 300+ ton rig).
Well tortuosity & clearance
Complex well head engineering below shielded transfer facility
Increased package time at well head
High heat generation ?

Rationale = *Time saved on individual round trips.*

Fast, reliable CT deployment could negate this!

Re-examine justification ?

'Near Field' Safety Case



The emphasis is on the geological barrier but DBD is still a multi-barrier disposal concept.

1. **Wasteform**
2. **Infill**
3. **Container**
4. **Package / / Casing / / Rock annuli**

(a) Once the DZ is sealed off, radionuclide escape from the near-field becomes irrelevant as isolation is ensured by the geological barrier for well over 1Ma

(b) The Safety Case should be maximised by making the near-field barriers as strong as reasonably achievable.

'Near Field' Safety Case

1. Wasteform

UO_2, MOX, HLW Glass, Cs/Sr Capsules, etc.

Can the risks & costs of further processing be justified ?
Volume reduction, e.g. fuel rod consolidation ?

2. Infill

Sand, Cement, Silicon carbide, Glass, Lead, Iron, etc.

Essential – What are the best options ?

3. Container

C-Steel, Stainless, Copper, Titanium, Ni-alloy, (Cu-plating)

Depends on – (i) Mechanical properties required,
(ii) Corrosion resistance needed.

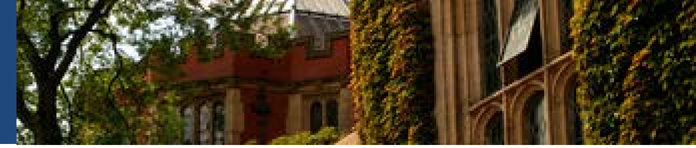
4. Package / / Rock annuli

Water, Drilling mud, Deployment fluid, Well cement, Sands, Various sealing & support matrices (SSM).

(i) High-density support matrix (HDSM) – [*Gibb et al. (2008)*]
(ii) Cement SSM – [*Collier et al. (2014)*]

Assess these & other options!

Borehole Sealing



It is imperative that the borehole itself does not provide an easier route back to the human environment for any radionuclide bearing fluids than does the enclosing geology.

- **Disposal Zone must be sealed off 'permanently' (> 100,000 years).**

- **Disposal Zone need only be sealed off long enough for salinity gradients to become re-established in the borehole and the decay thermal high (with a possibilty of convection) to have passed.**
  This could be as little as a few hundred years!

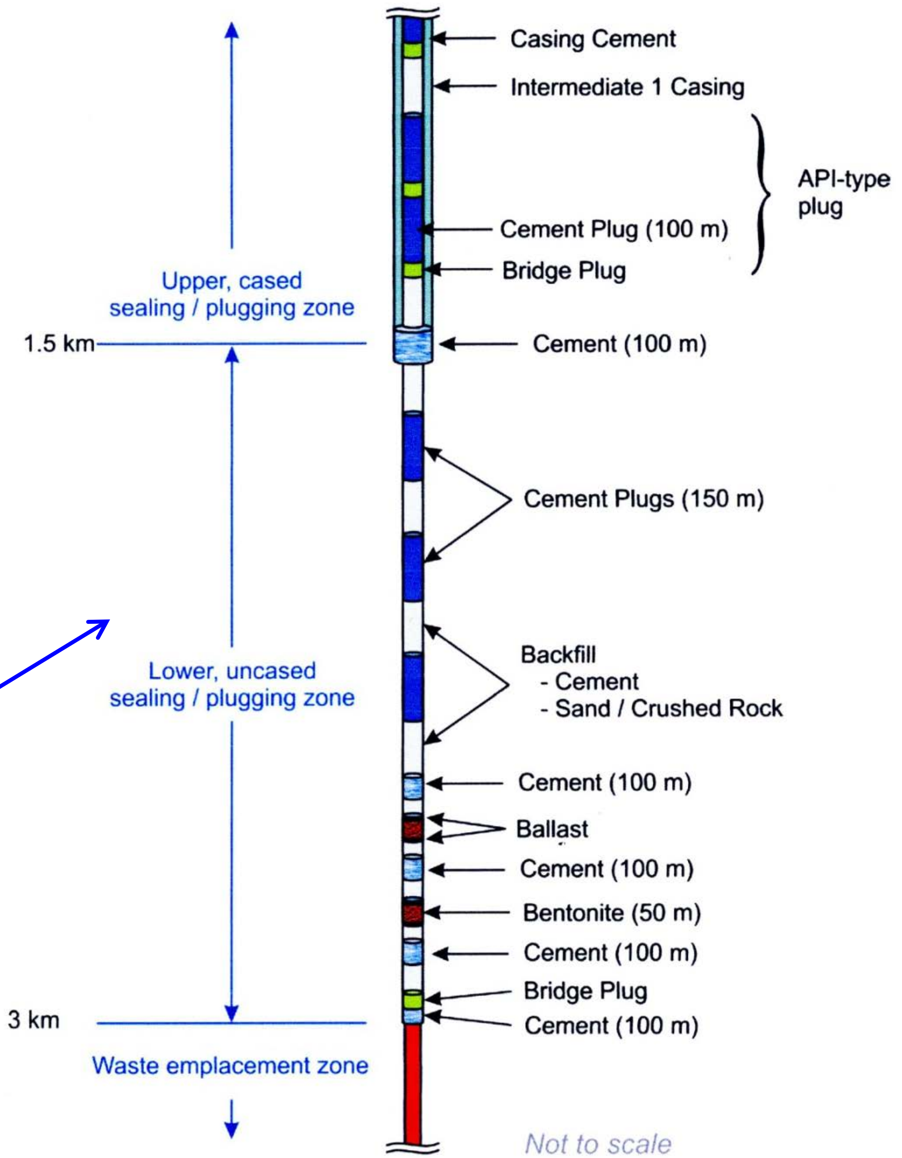
?

Site - specific

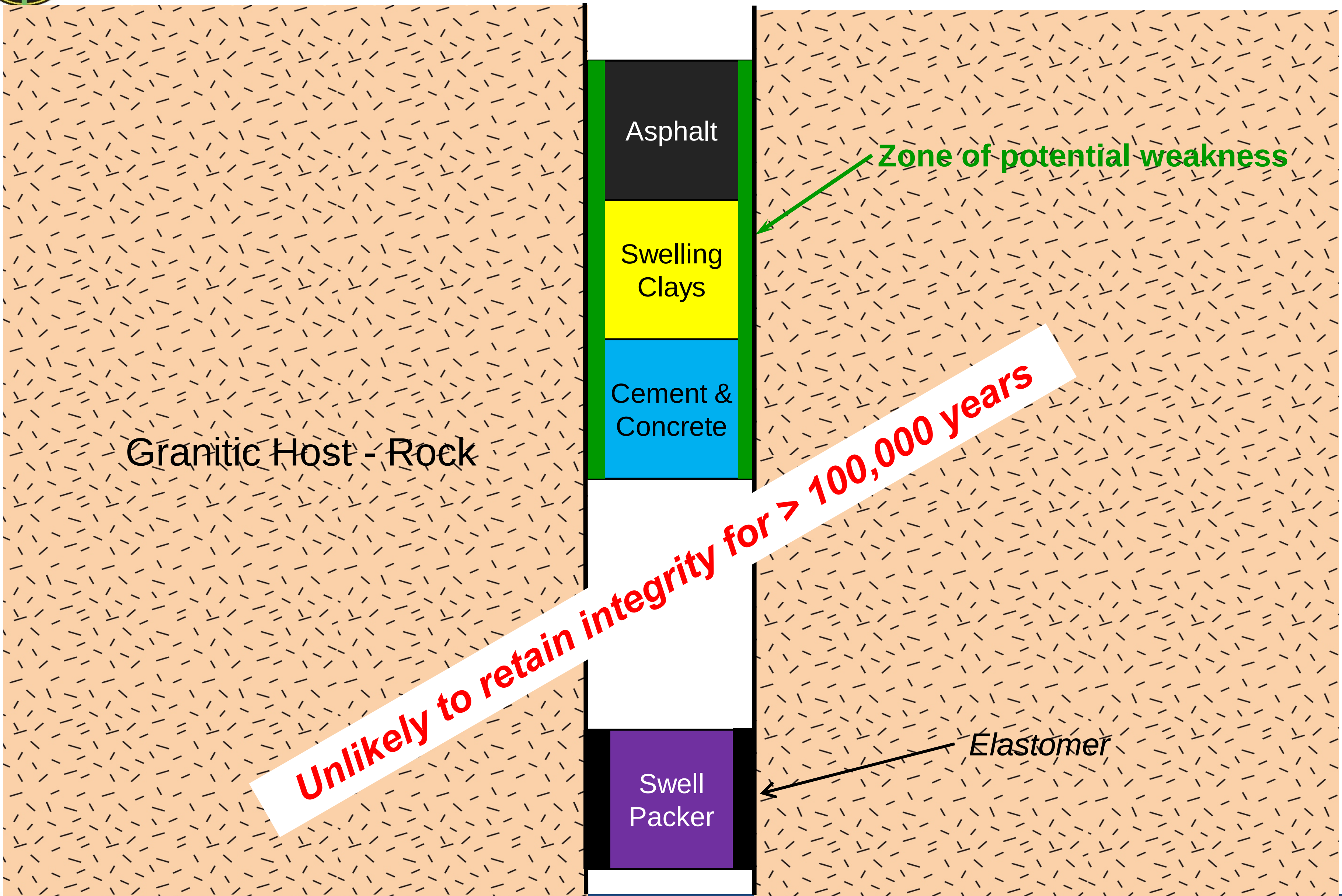
MUST RESOLVE

Conventional methods

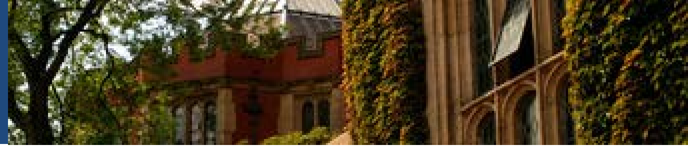
Sandia "Reference Design"
(Arnold et al., 2011)

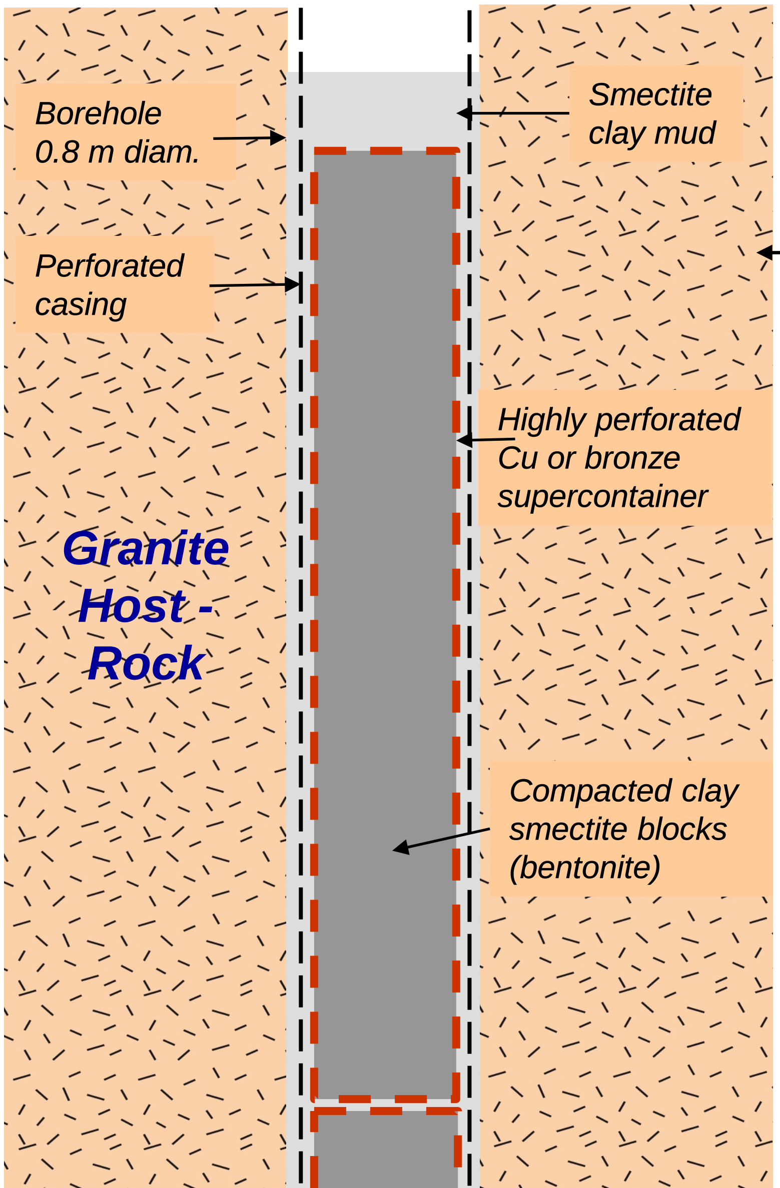


Conventional Seals



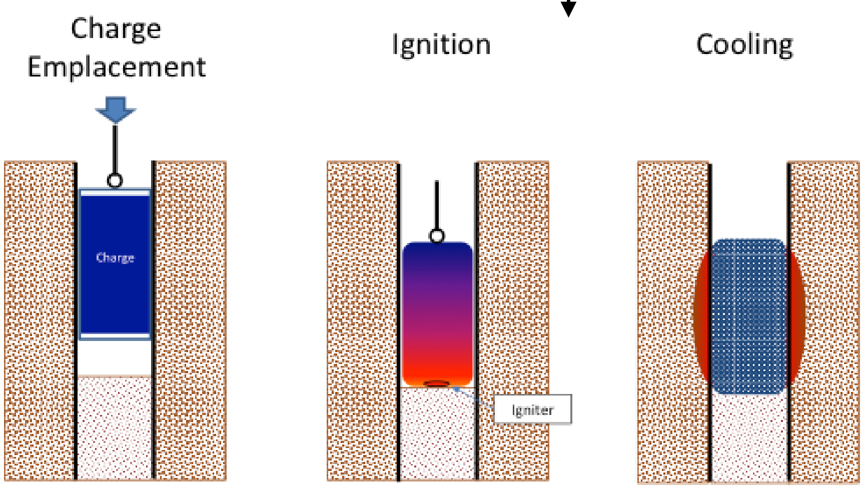
Advanced Sealing Concepts



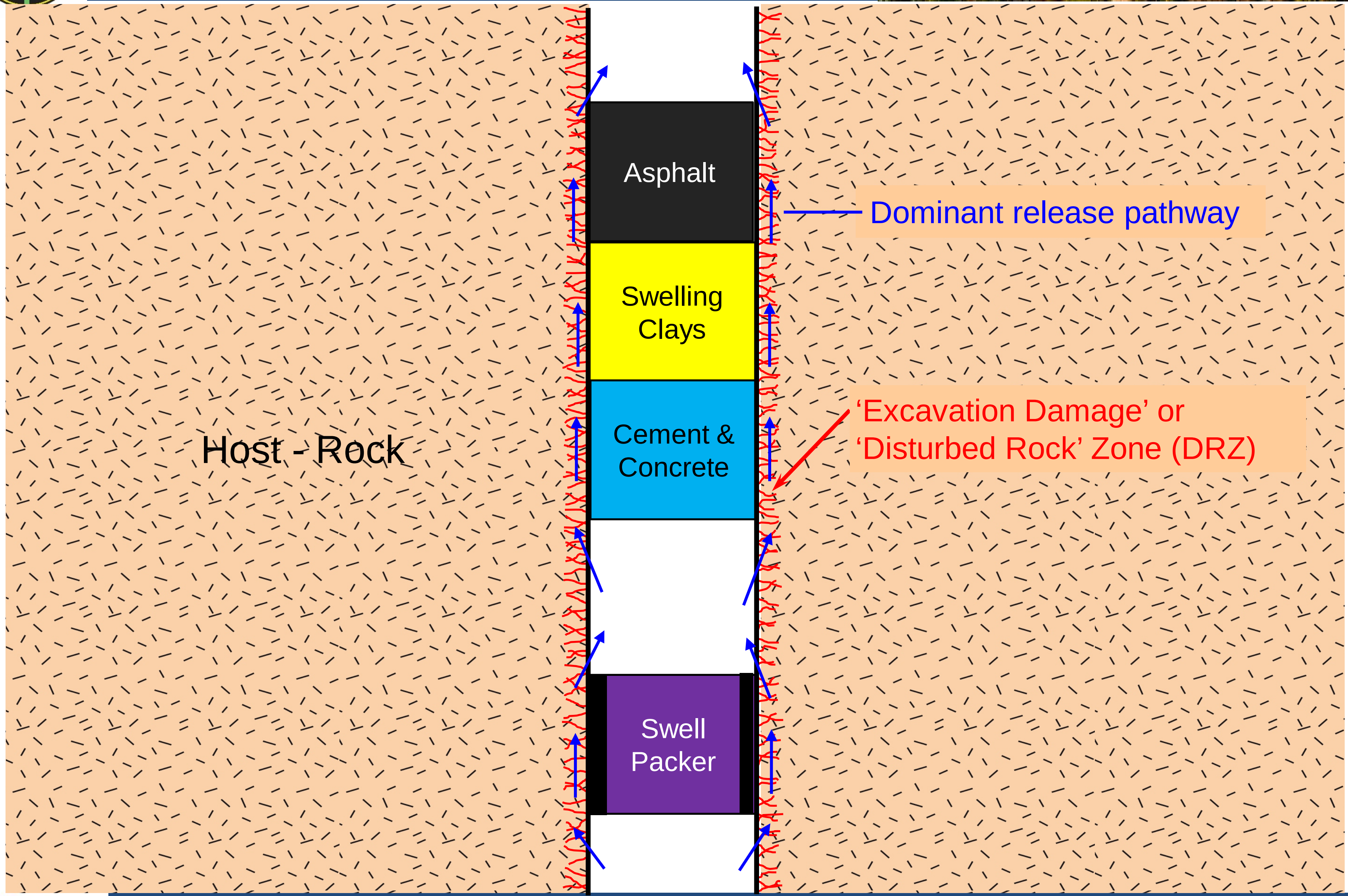


Supercontainer Clay Seal
(After Pusch et al., 2012)

Self-sintering Ceramic Plug
(Lowrey, 2015)



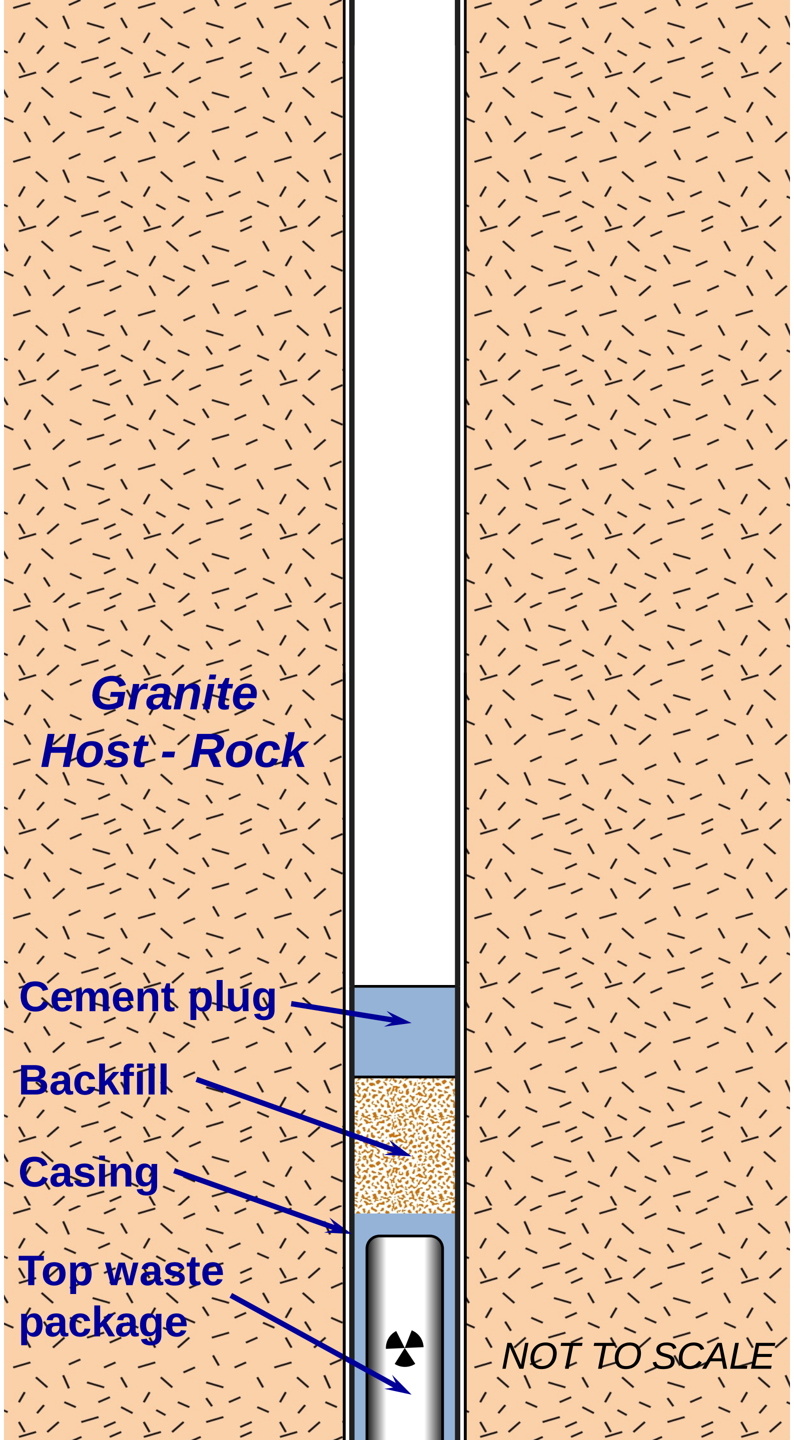
EDZ / DRZ



Asphalt
Swelling Clays
Cement & Concrete
Swell Packer
Host - Rock
Dominant release pathway
'Excavation Damage' or 'Disturbed Rock' Zone (DRZ)

Rock-welding Engineering Concept

(Under development at The University of Sheffield)



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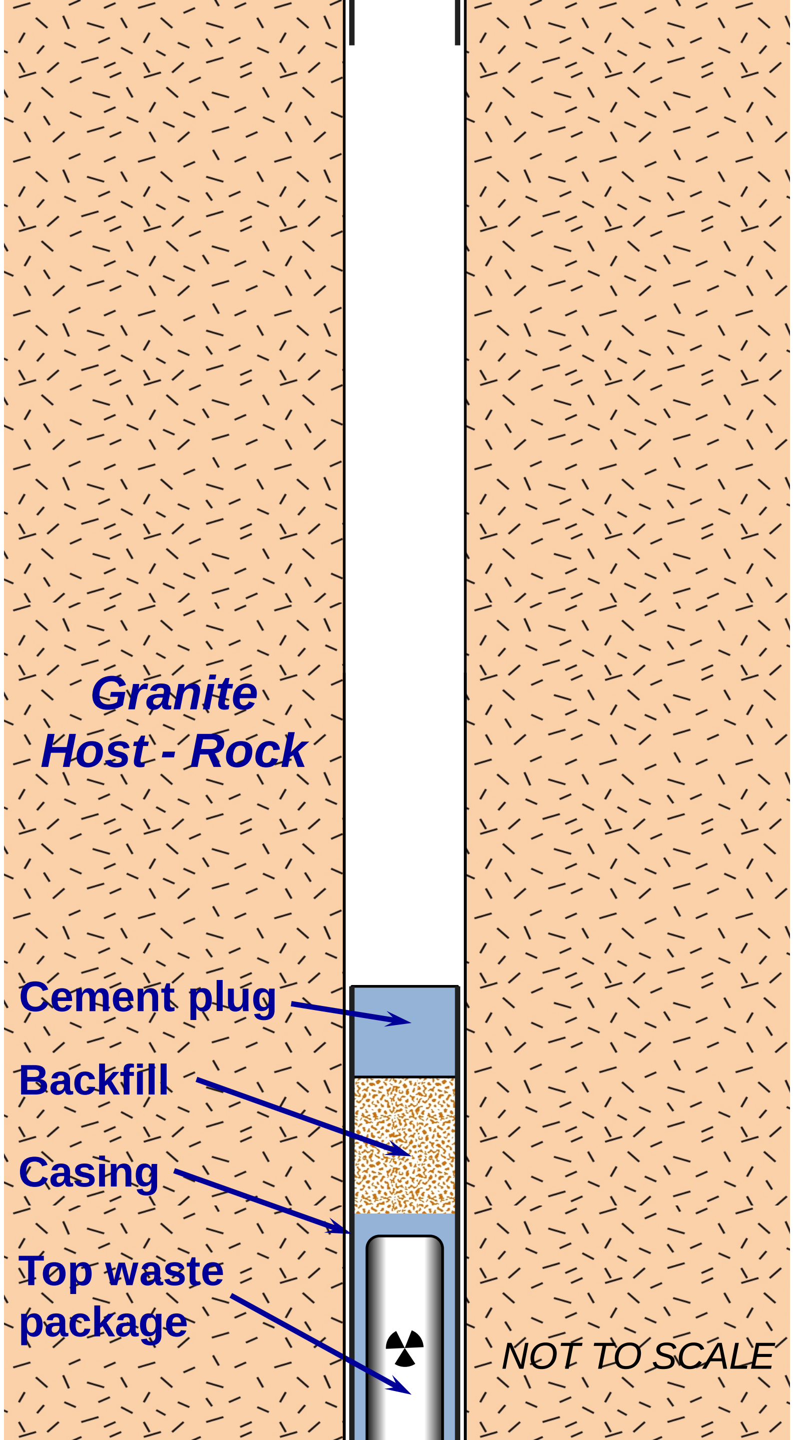

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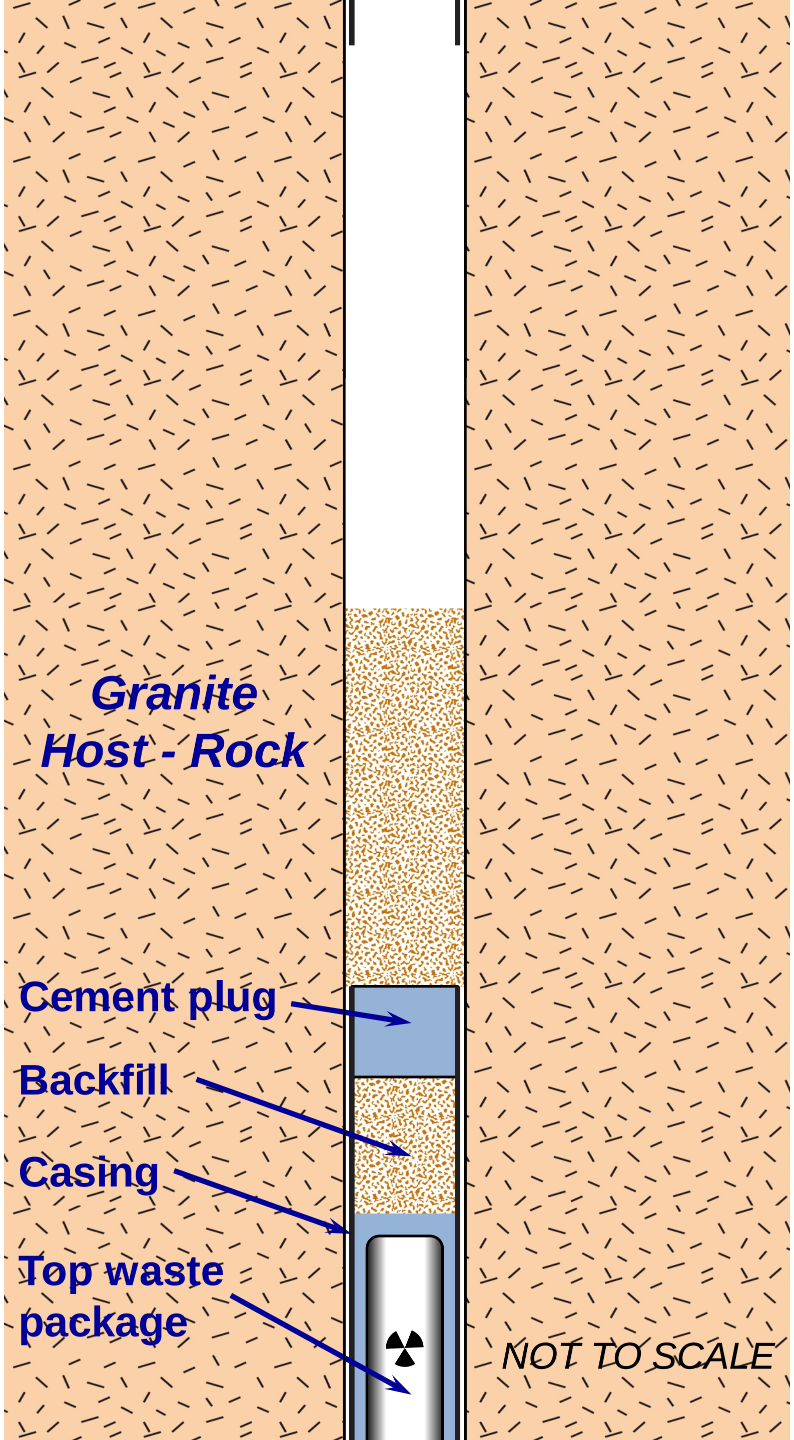

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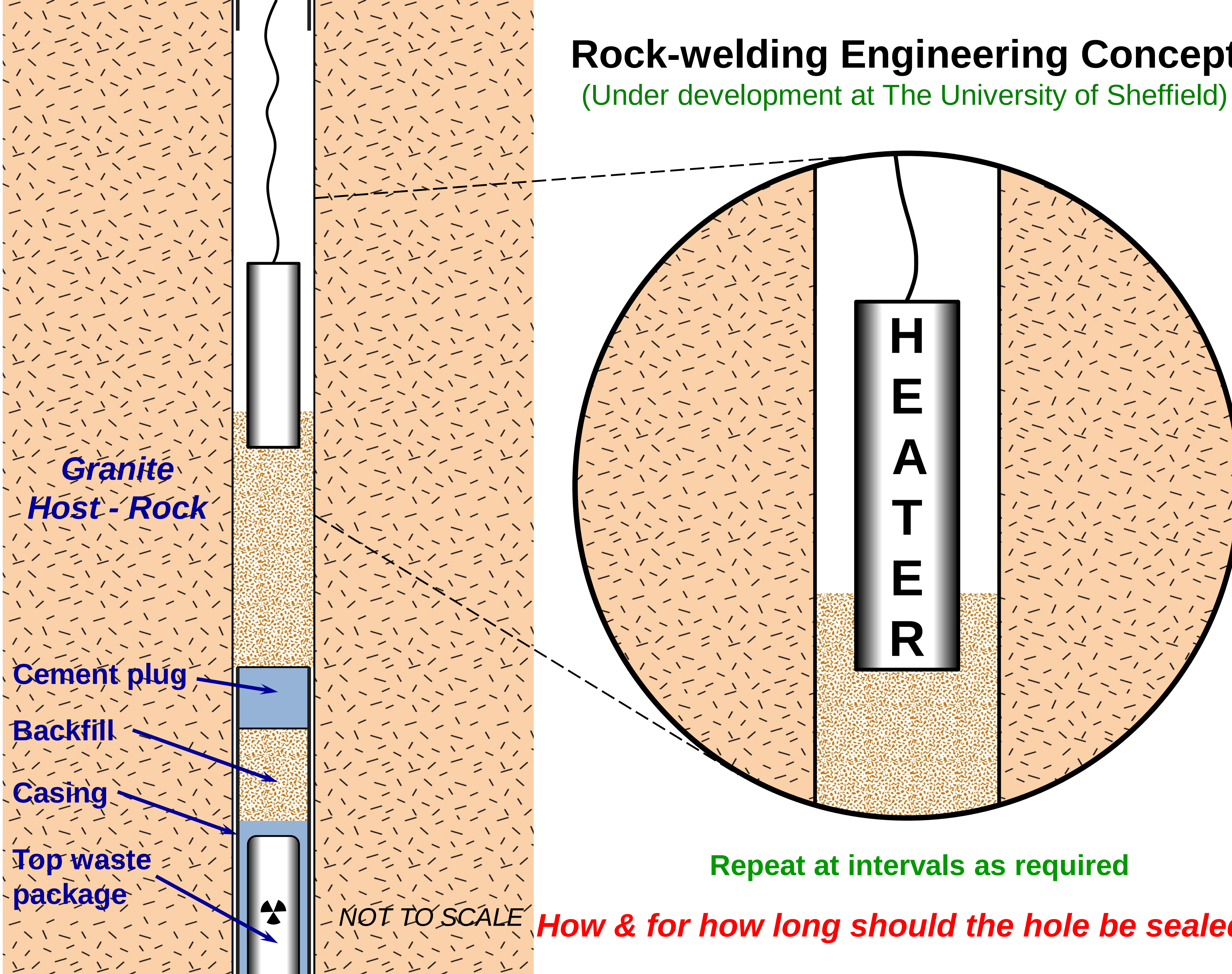

Repeat at intervals as required

How & for how long should the hole be sealed?

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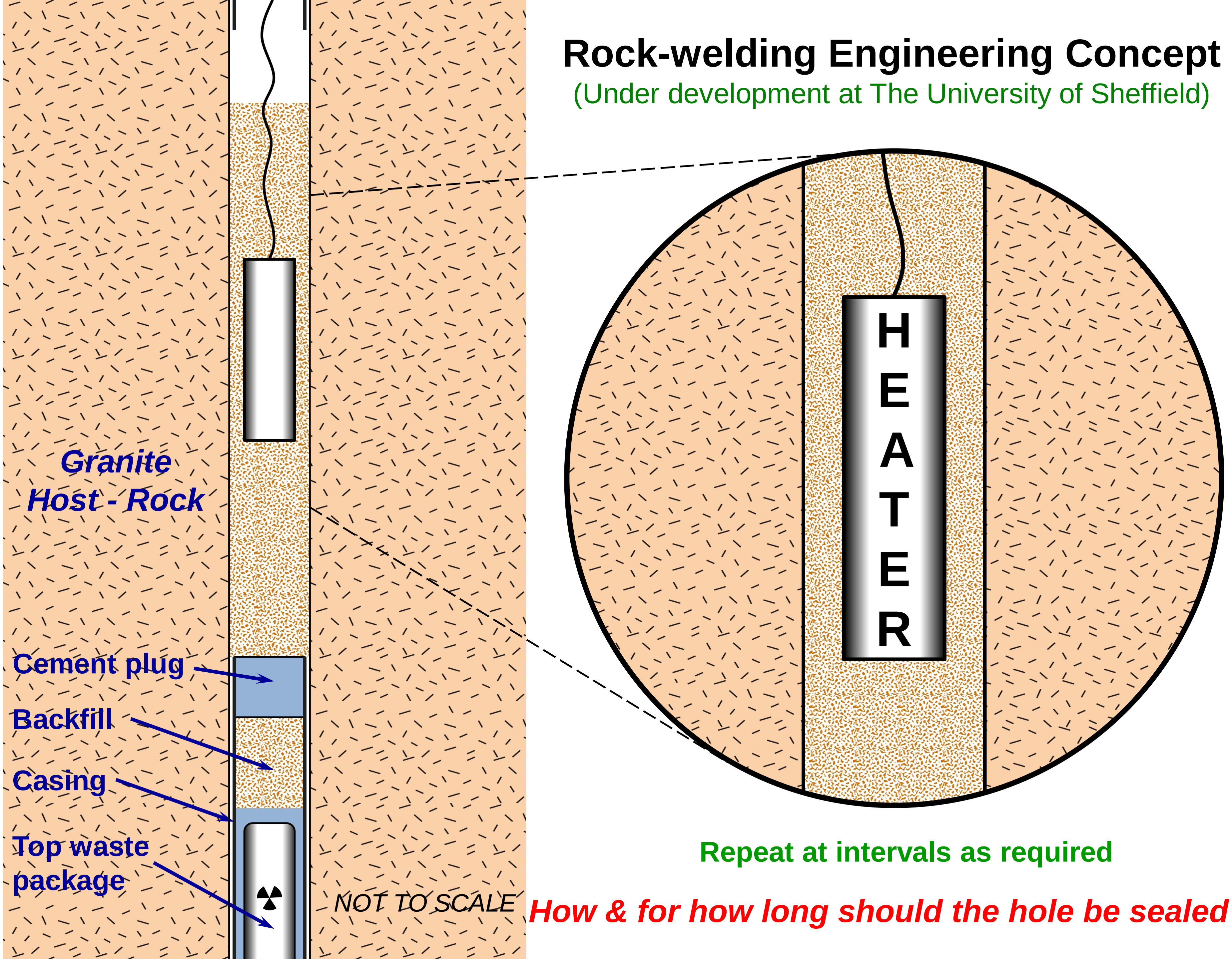

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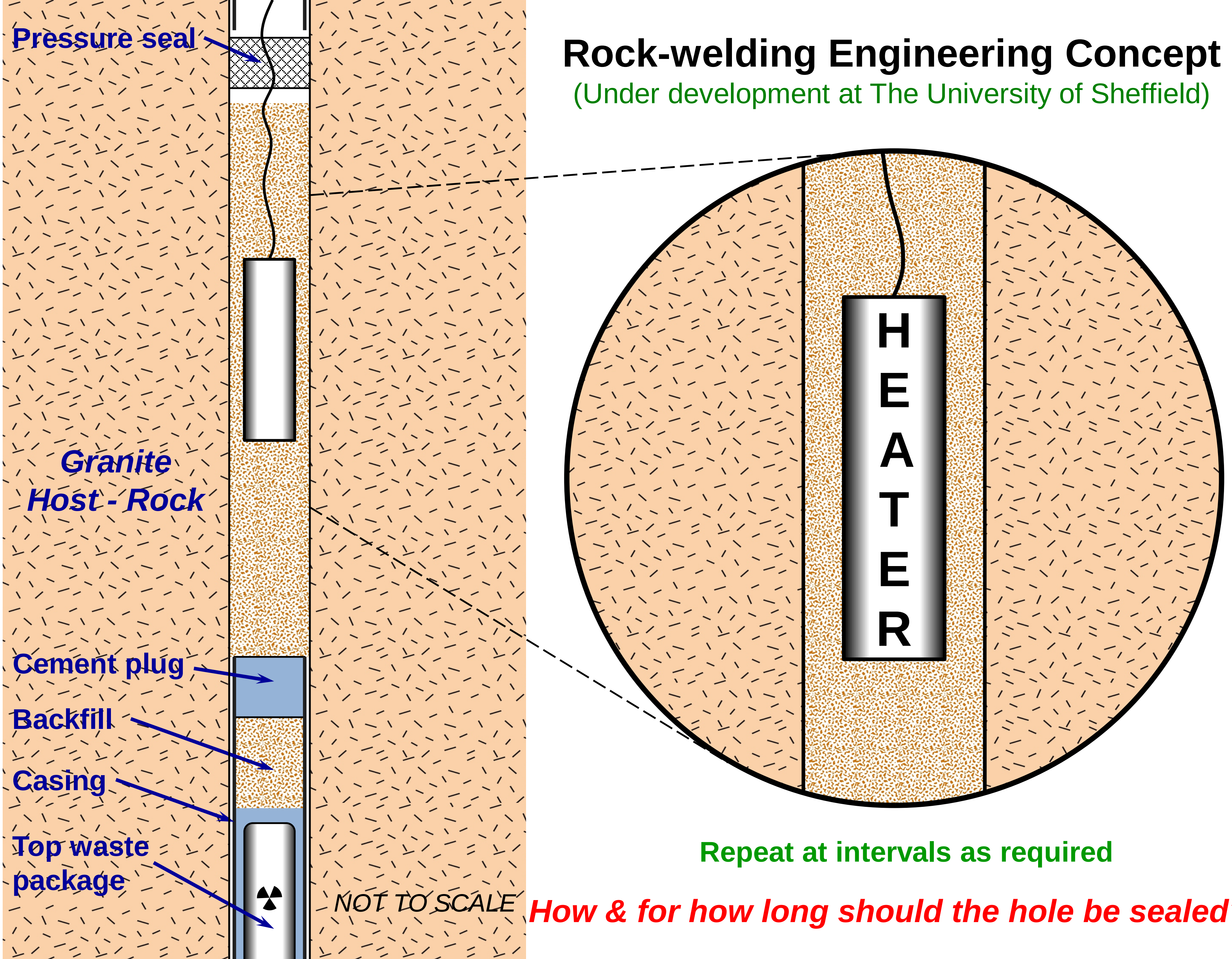

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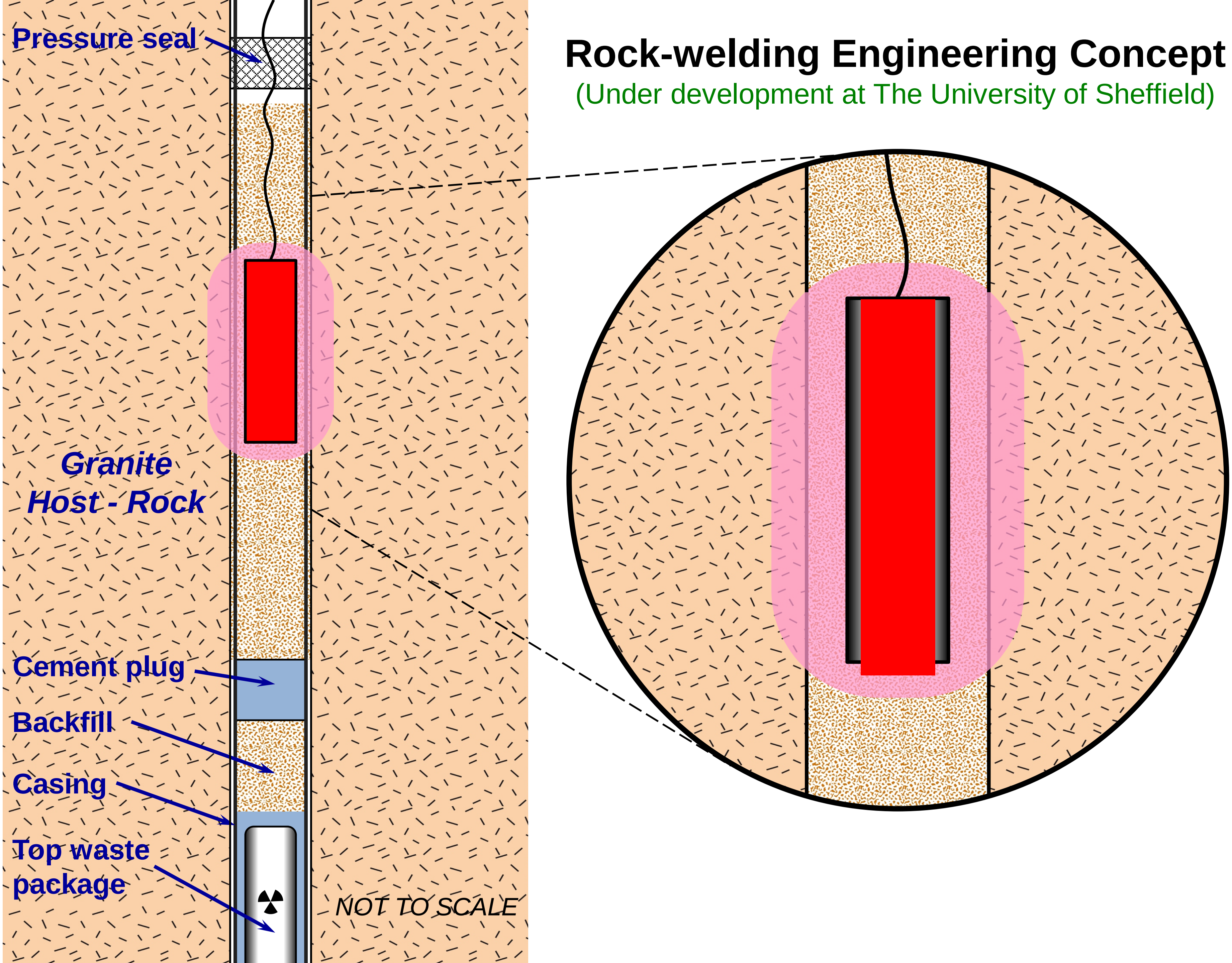

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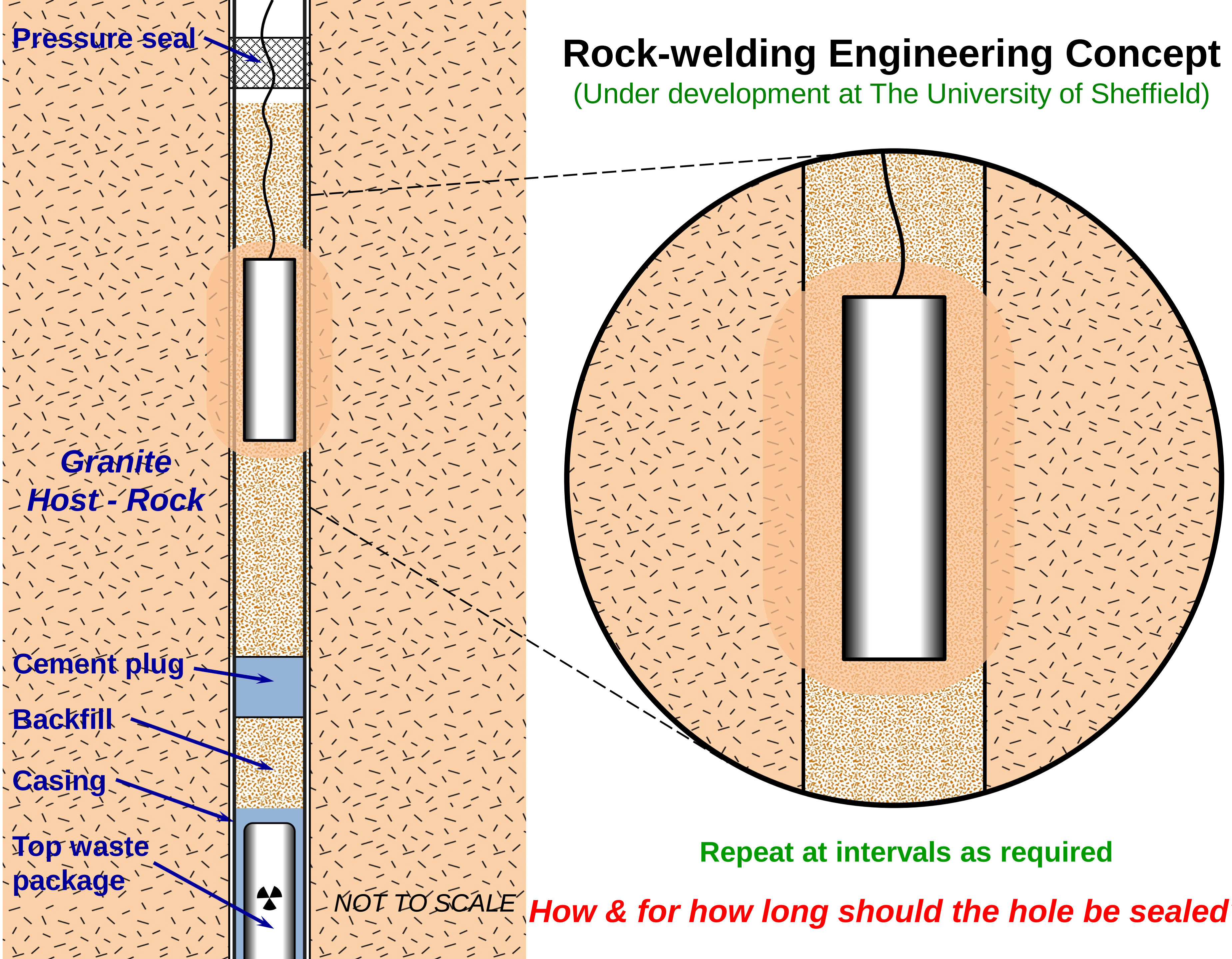

Repeat at intervals as required

How & for how long should the hole be sealed?

"When you hear about a new idea don't ask yourself what is wrong with it … ask what can we do to make it work."

(David Balmforth, President, Institution of Civil Engineers, Oct. 9th, 2015)