Geological Disposal Colloquium

Integrated management of TRU waste

Ian McKinley, Ellie Scourse & Susie Fawley

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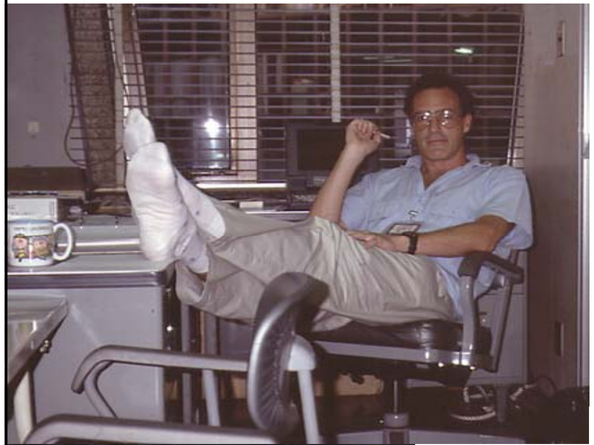
Tokai, Japan

Introduction: Ian McKinley

- Working in radwaste since 1975 (initial work on radio-Cs in the environment now relevant to Fukushima)
- Main involvement in UK & Swiss geological disposal programmes
- Special links to Japan
  - Coordinated collaboration / attachments to Switzerland
  - Attached to PNC for H3 preparation
  - Reviews of ENTRY, QUALITY, H12, 1st & 2nd TRU reports
  - Visiting professor at Nagoya, Okayama
  - Supporting Fukushima cleanup



Contents

- What is TRU and why is it a concern?
- What is the current status in Japan?
- What is going on with such waste in a similar programme (UK: co-disposal of HLW & reprocessing waste, volunteer approach to siting)?
- What advances are expected in TRU management?
- Key areas to be considered in Japan in the future.

‘TRU’ waste definition(s)

- Long-lived intermediate level wastes: wide range of possible sources
- Major volume from reprocessing (often claimed that lower volume and better performance of HLW is a benefit compared to SF - ignores TRU!!!)
- May contain significant quantities of transuranics (→ "TRU”: definition rigorously applied only at WIPP)
- Sometimes classified on basis of concentration of α-emitting radionuclides
- Most problematic nuclides from the point of view of post-closure PA may, however, be C-14, Cl-36, I-129, etc. (highly soluble, long-lived and weakly sorbing)

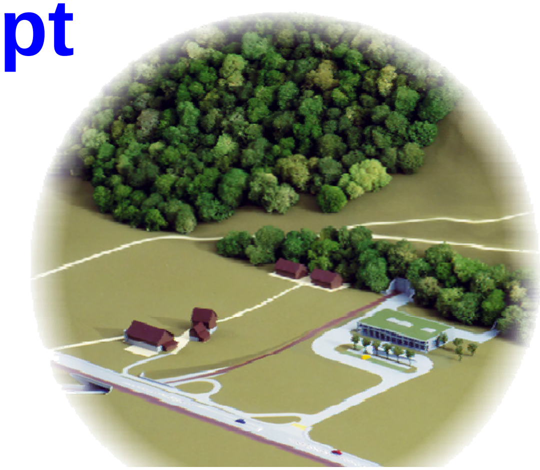
What's so special about TRU?

- Compared to HLW, quantities are large, radionuclide content variable and properties heterogeneous
  - sophisticated EBS limited by cost constraints
  - generally sub-divided into different groups to further simplify analysis
  - simple performance assessment aimed at demonstrating conservatism

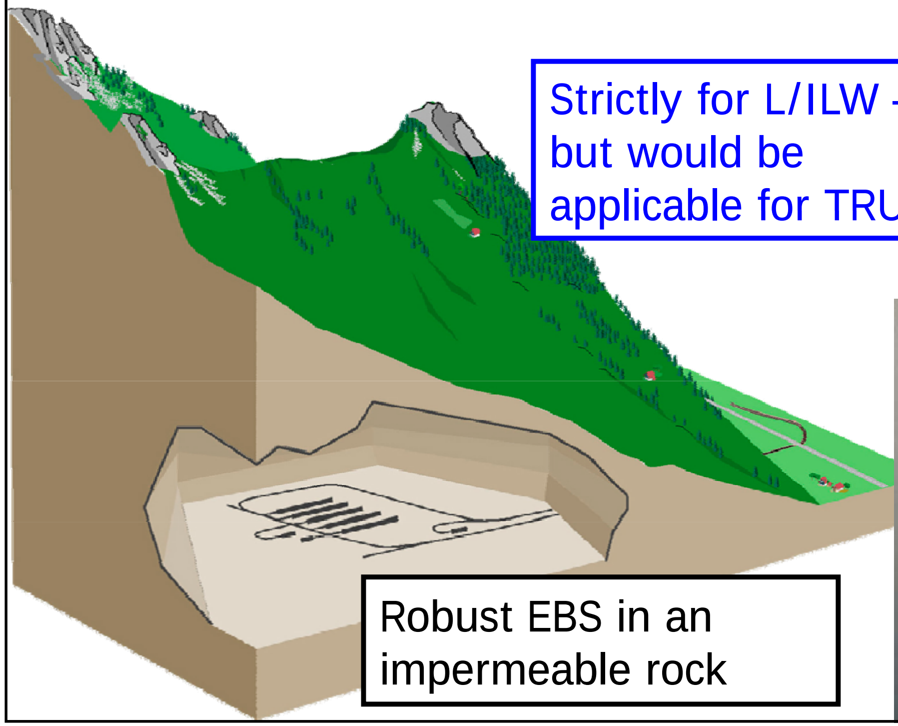
Geological disposal concept

Deep disposal (~350m below surface): Swiss example

- mountain area but good rail & road links
- most infrastructure underground
- horizontal access
- standard emplacement packages for solidified waste
- layout to minimise risk of short circuits
- monitored disposal region

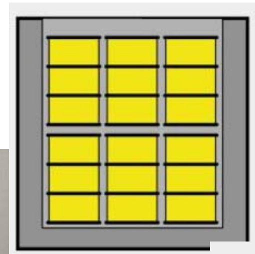


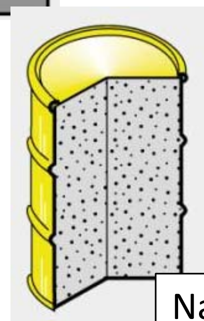
Surface facilities with minimum visual impact



Strictly for L/ILW – but would be applicable for TRU

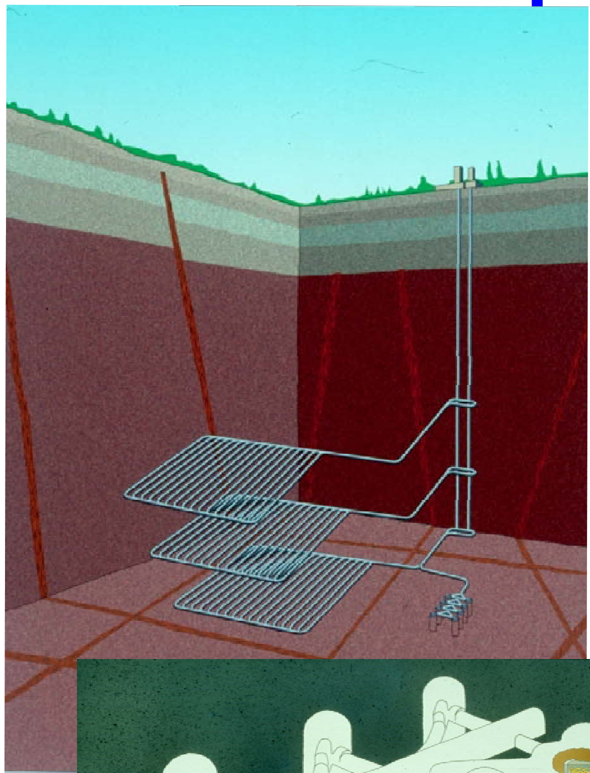
Robust EBS in an impermeable rock

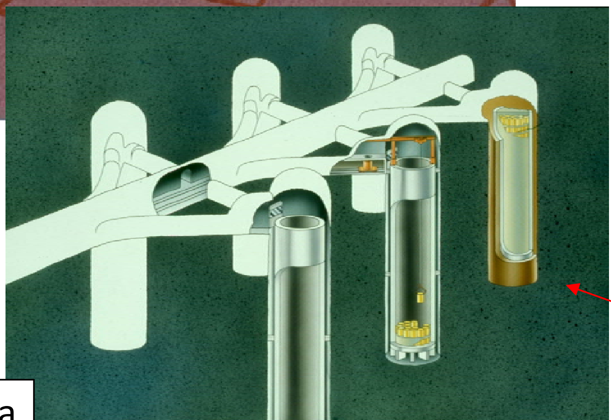


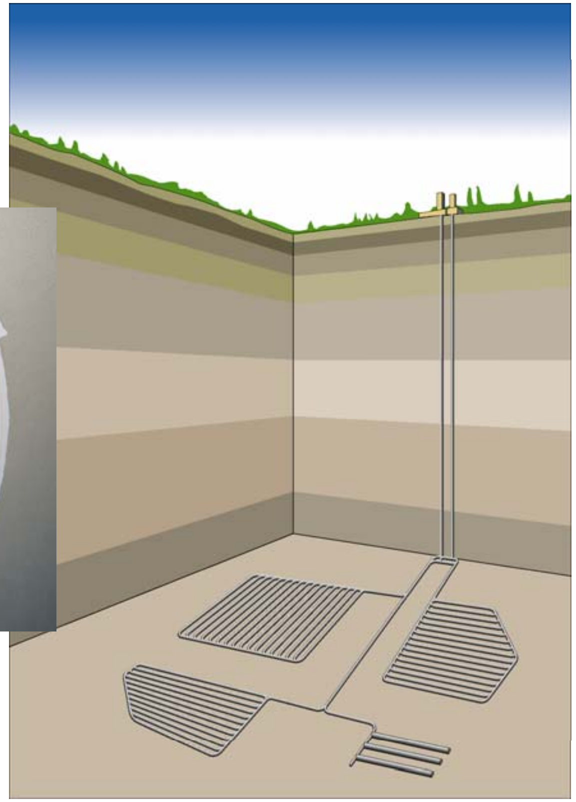


Nagra

TRU co-disposal concepts - crystalline







Alternative cavern variant

Silo design for Gewähr and Kristallin-1

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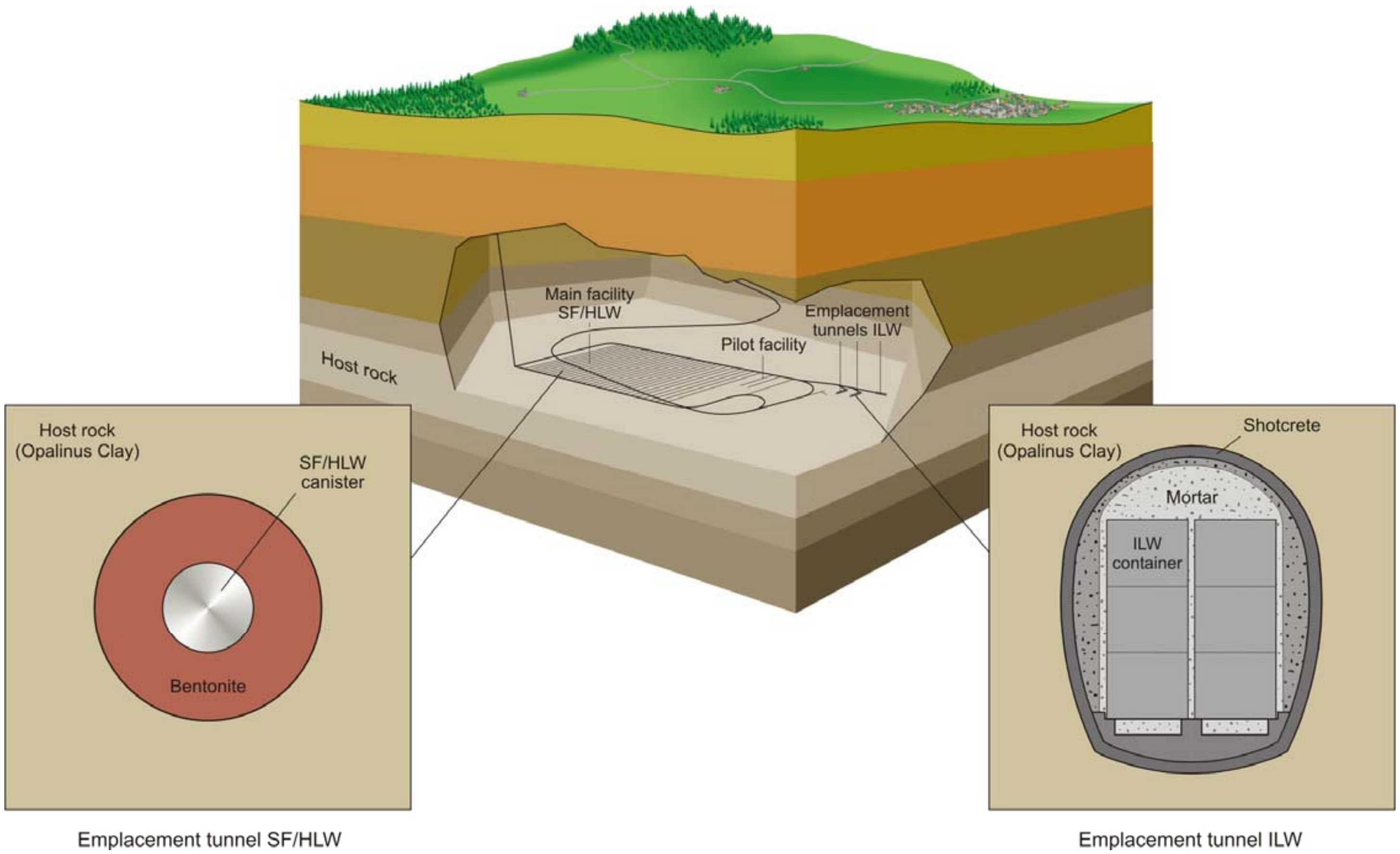
HLW/SF/TRU co-disposal: Opalinus Clay



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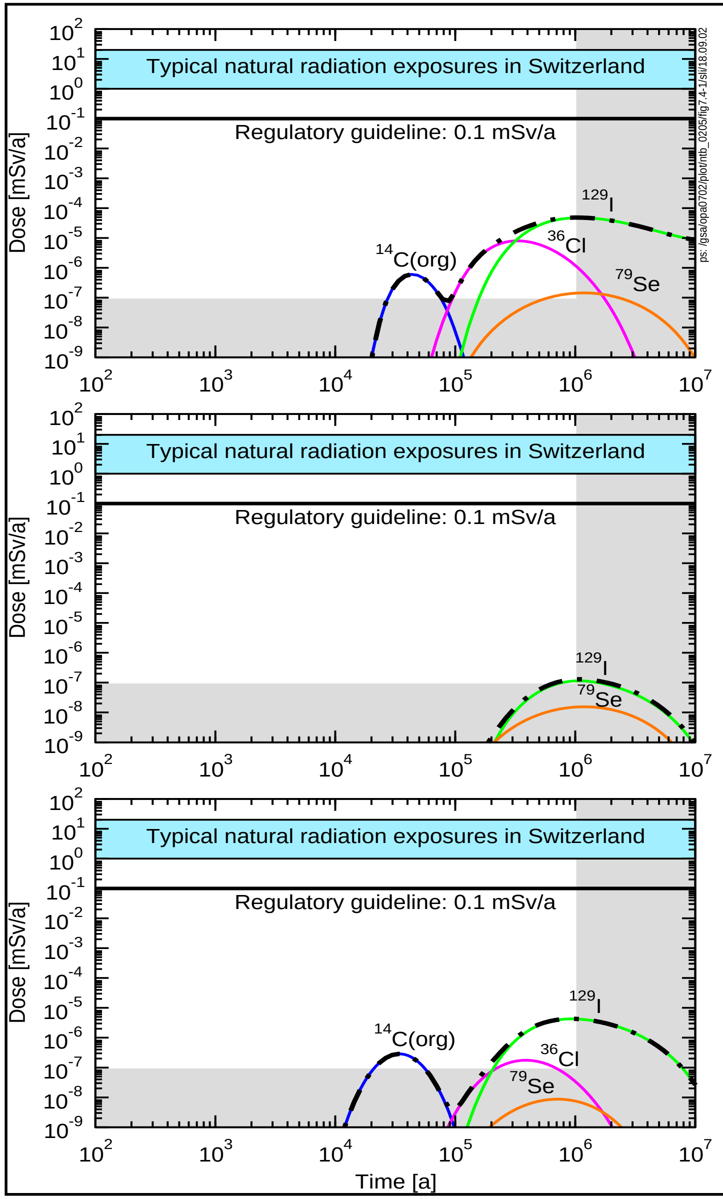
The TRU Safety Case

- Overall safety case weaker than HLW and, possibly, SF (for particular scenarios)
- Calculated doses dominated by a small fraction of the total waste inventory
- Safety case can be strengthened by:
  - enhanced engineered barriers or special location for specific waste groups
  - consideration of special treatment or conditioning

Safety Analysis: Results

(Nagra NTB 02-05)



Spent Fuel

Vitrified HLW

Long-lived ILW = TRU

NB special case for the high performance Opalinus Clay host rock studied by Nagra: differences may be larger for less powerful geological barriers

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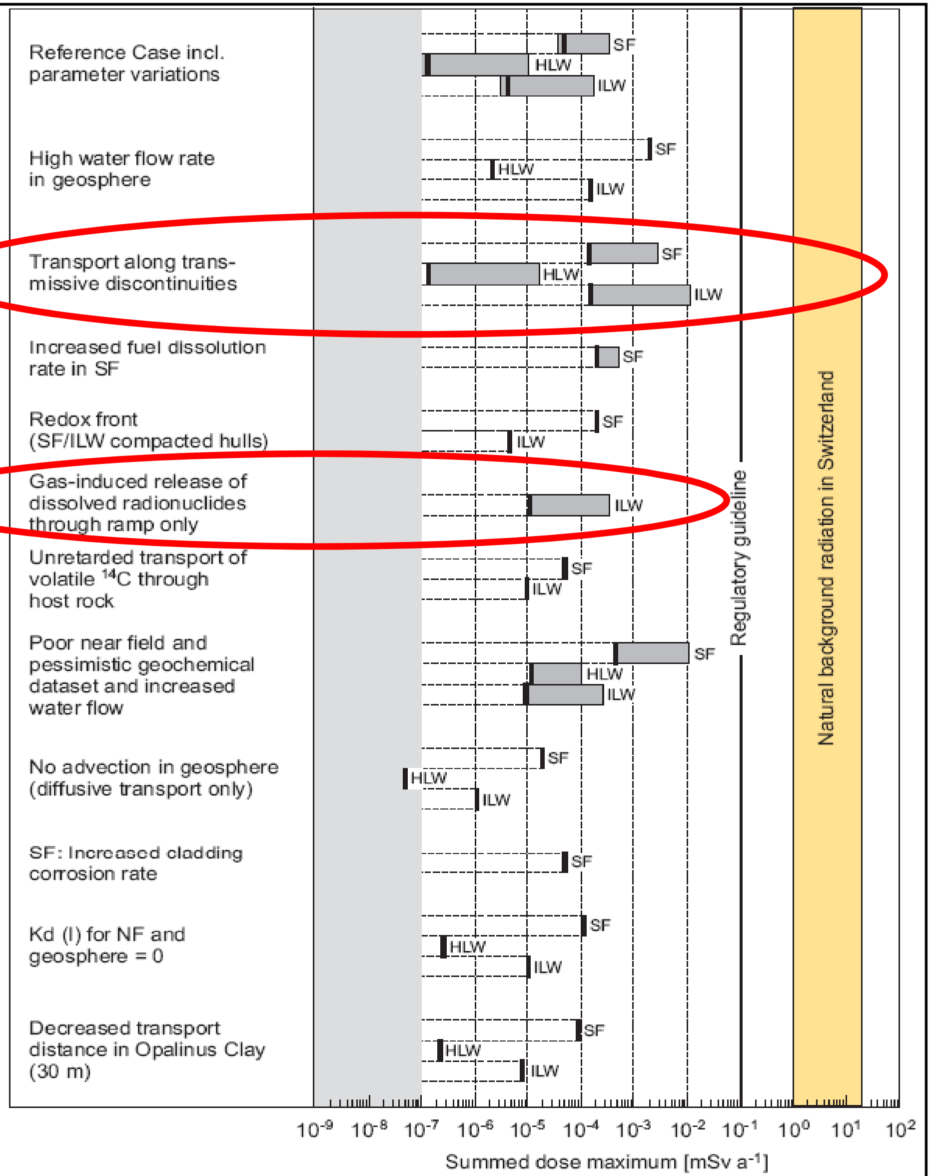
Alternative scenarios

- Even for an extremely good host rock, some pessimistic scenarios reduce safety margins
- For a few such scenarios, TRU doses dominate



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International status: TRU deep disposal

- Dedicated facilities: WIPP operational
- L/ILW facilities including higher activity wastes: Morsleben closed (remediation), Konrad coming on line, Bruce in final planning stages
- Co-disposal with HLW/SF: planned in Sweden, Finland, Switzerland, UK, Belgium, France,…

Sources of waste in "TRU-type" inventories

Programme	Reprocessing	Reactor operations	Reactor Decommissioning	Military	MIR	NORM	Other
Belgium	X	X	X		X		MOX fabrication, other fuel cycle activities
Canada		X	?				
France	X	X	X	X	X		MOX fabrication , other fuel cycle activities
Germany	X	X	X		X		
Japan	X						MOX fabrication
Sweden / Finland		X	X				
Switzerland	X	X	X		X		Core meltdown waste
UK	X	X	X	X			MOX fabrication , other fuel cycle activities
USA (WIPP)	X	X	X	X	X		All military wastes

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What is TRU waste?

- Low level radioactive waste arising from spent fuel reprocessing plant and mixed oxide fuel (MOX) fabrication facilities that contains artificial radionuclides of atomic number larger than uranium
- TRU waste consists of fission products and actinides containing relatively large concentration of α emitters.
- Some ... heir α nuclid ... urface or at concr...

Definition is not consistent with international use and is often confusing in practice:

- Some "TRU" is below regulatory concern or goes for surface disposal
- Key waste streams contain negligible α activity

TRU（Trans-...

R... plutonium and americium.

FP（Fission Product）

Nuclides generated as result of nuclear fission of uranium and plutonium, most with half lives in the range of several seconds to several million years.

NB Some key nuclides are activation products

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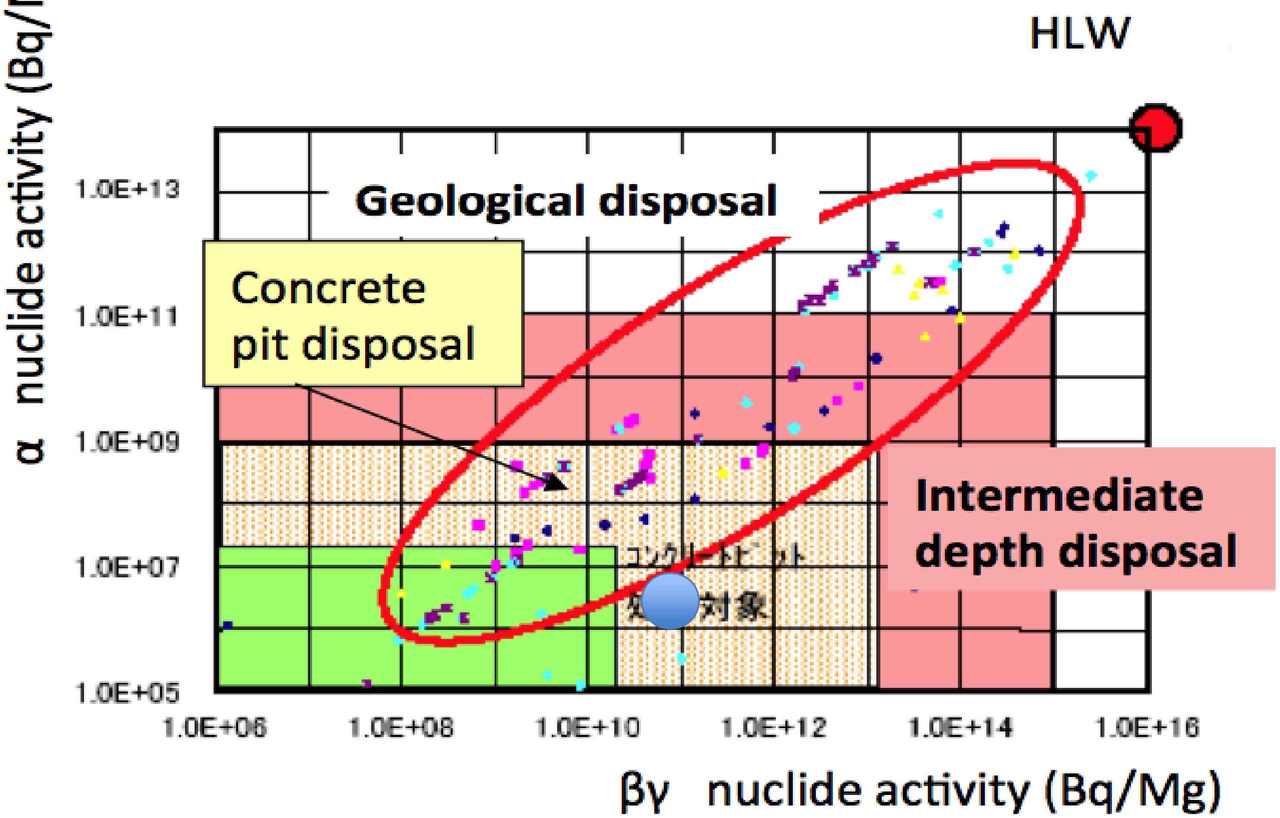
TRU Waste Definition in Japan

...beware of simple classifications: AgI filters shown by blue circle



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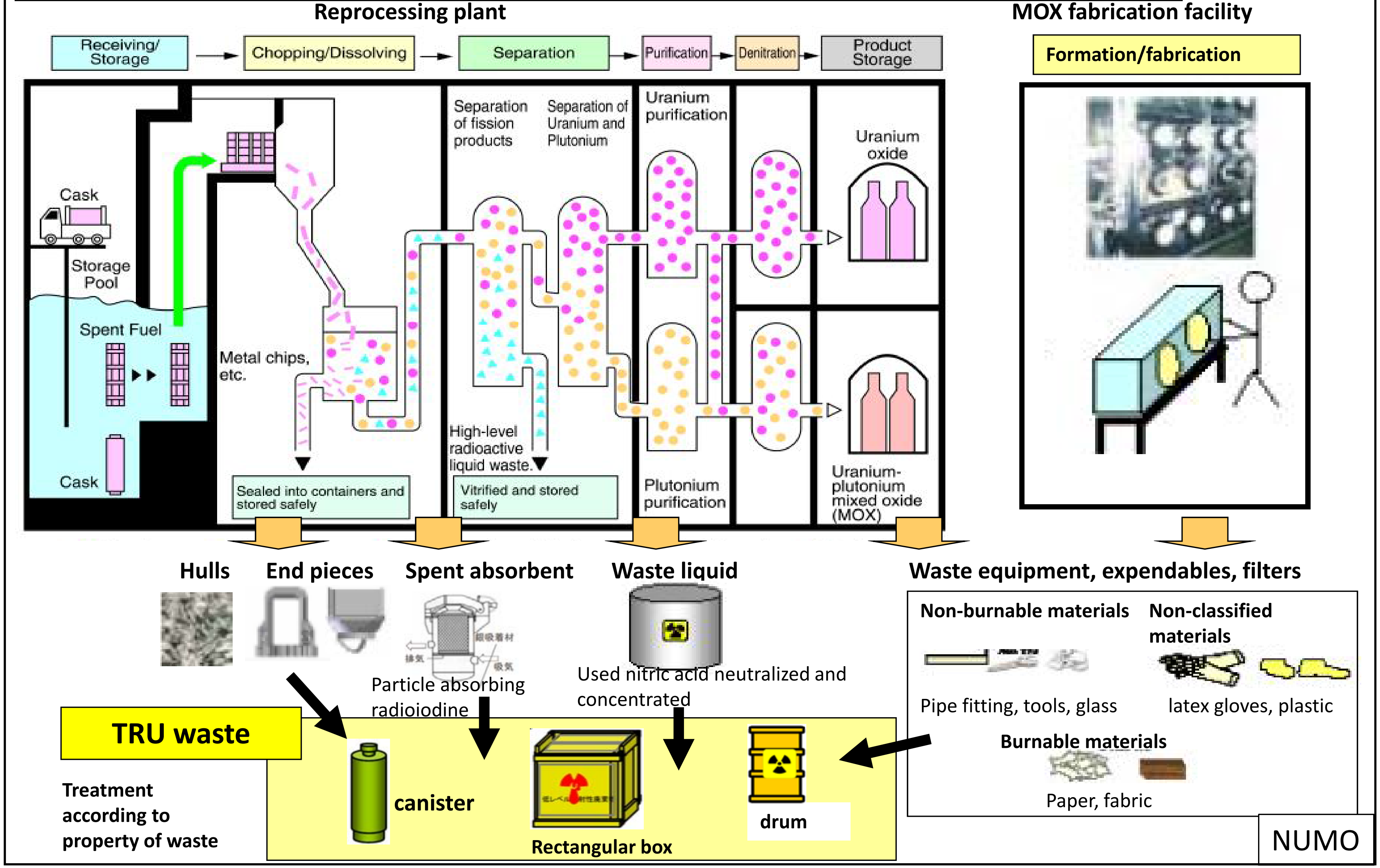
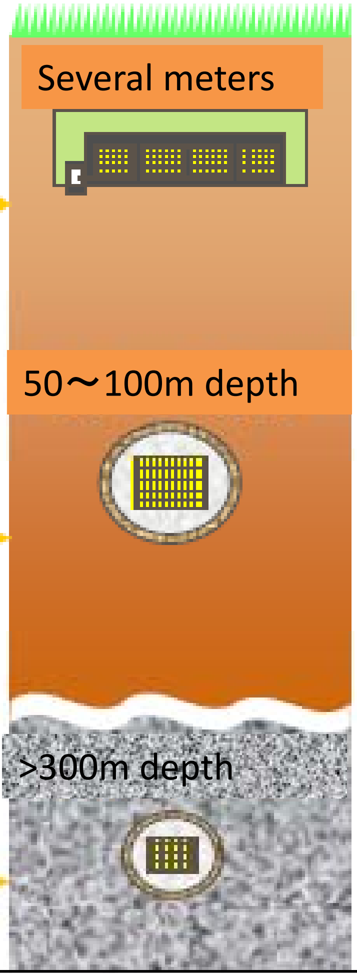
Origin and Form of TRU waste in Japan



Disposal concept for TRU waste



Near surface concrete pit disposal

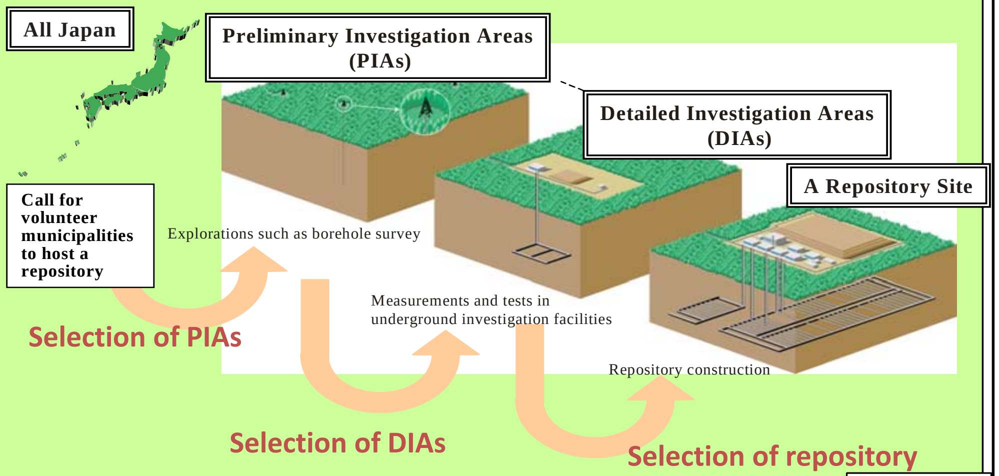
Intermediate depth disposal

This would not be termed "TRU" in other national programmes

Geological disposal

Same site-selection concept as HLW repository

Site selection process of HLW repository



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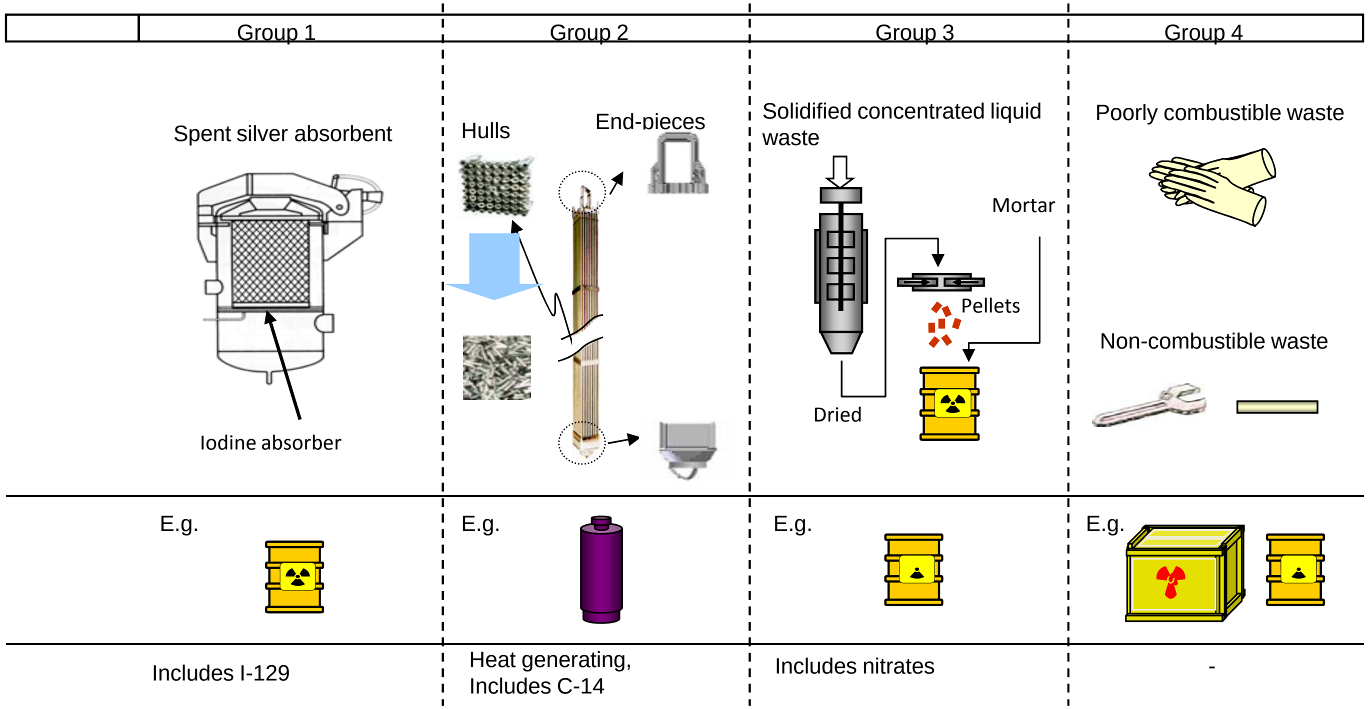
Japanese TRU for geological disposal: waste grouping

Groups on the basis of:

1. I-129 content
2. Heat output
3. Nitrate content
4. Rest

Equivalent to "TRU" in other countries with reprocessing



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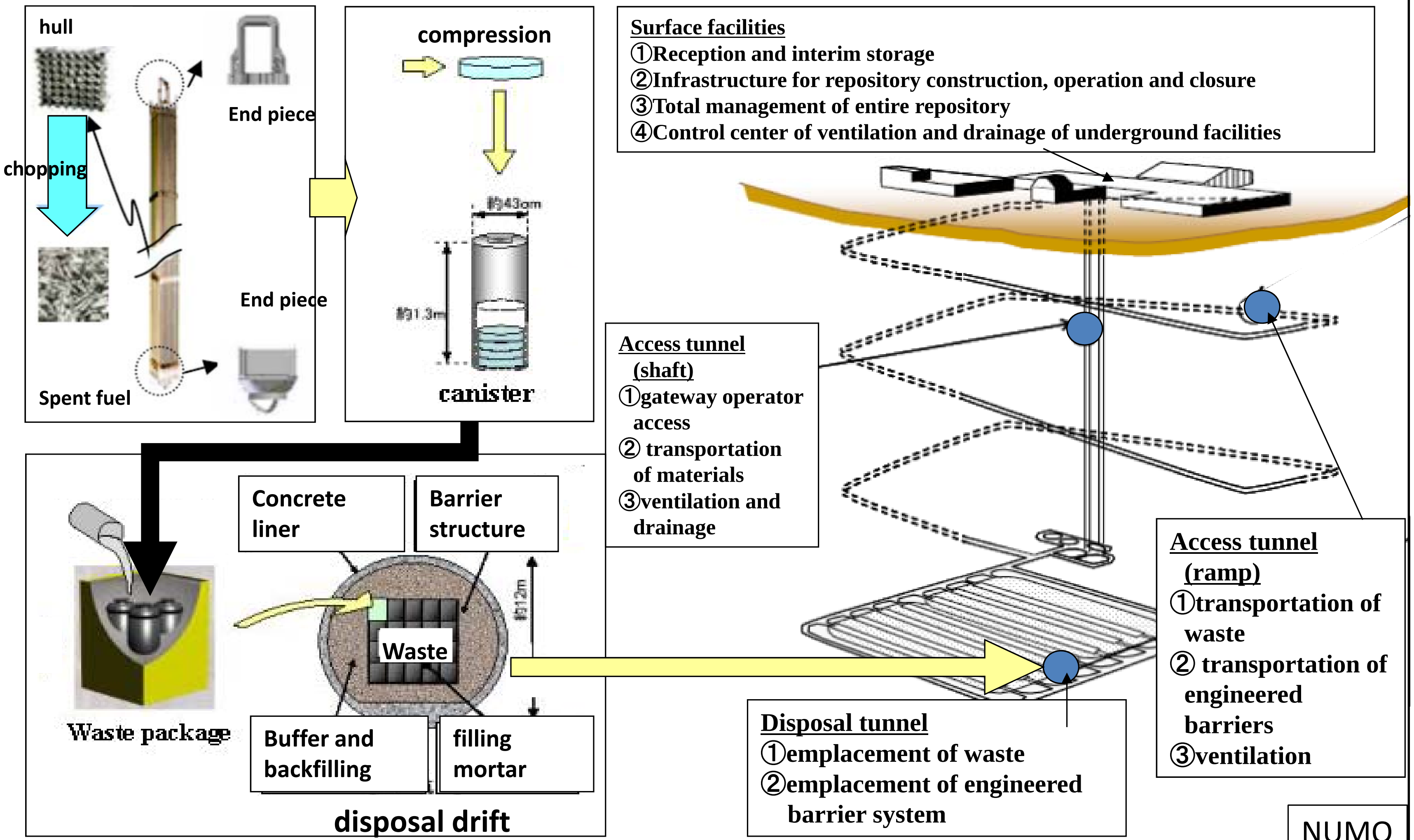
Repository Concept (engineered barrier system)



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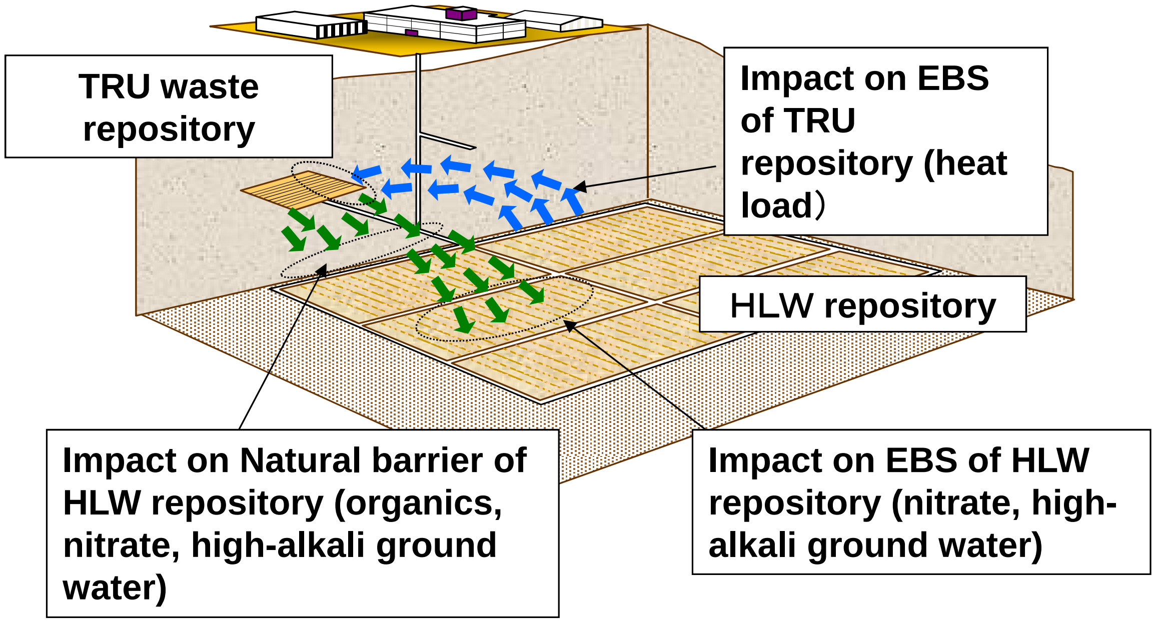
Co-disposal of HLW and TRU waste

- Shared repository site for HLW and TRU waste
（TRU waste repository located near the HLW repository）
- Reduce the number of repository sites and rationalization by sharing investigation for site selection and part of facilities
- Minimize interactions by taking appropriate measures, such as keeping sufficient offset distance



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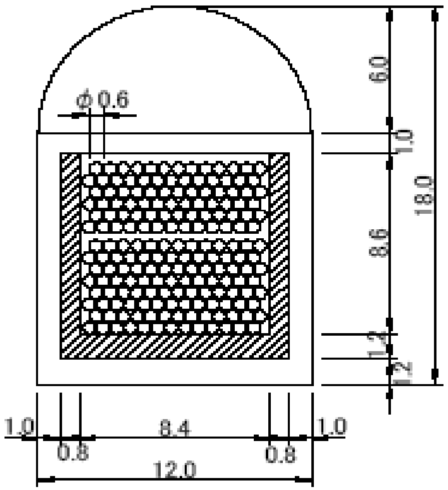
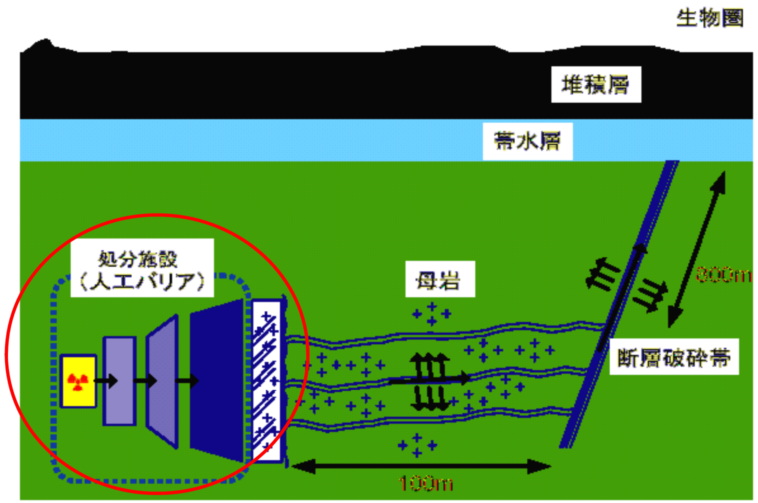
Simplistic assessment (1)

- Simplistic near-field model, which is over-conservative in terms of transport, but greatly simplifies chemical complexity of system (and its variation with time)

Complex diffusion system
- very sensitive to loss of buffer (Gps 1&2)



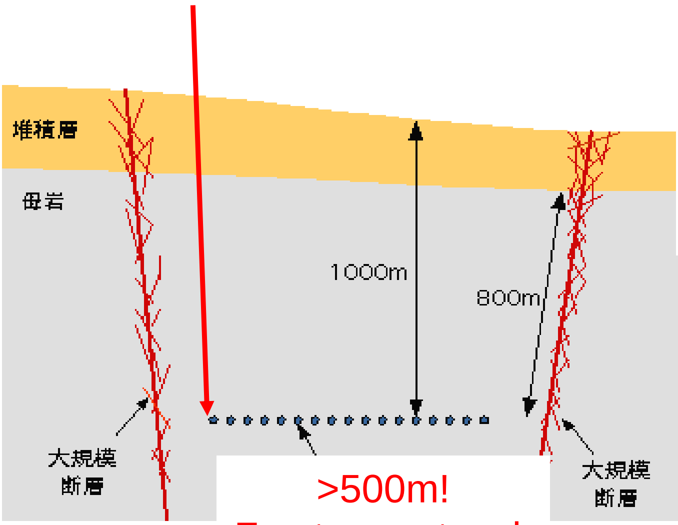


Inner mixing tank!
Simple diffusion barriers

Simplistic assessment (2)

- Simplistic far-field model, which is over-conservative but extremely sensitive to assumed hydro properties and cannot realistically represent a high pH plume

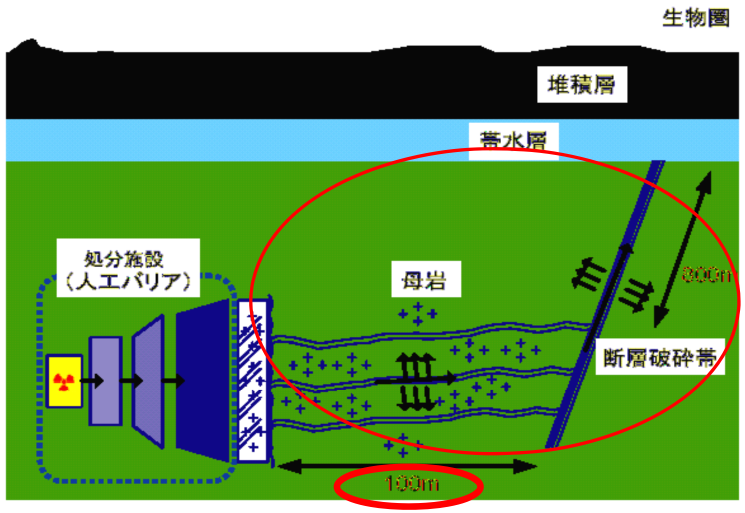
Dominant waste



>500m!
Fracture network

Hydraulic gradient

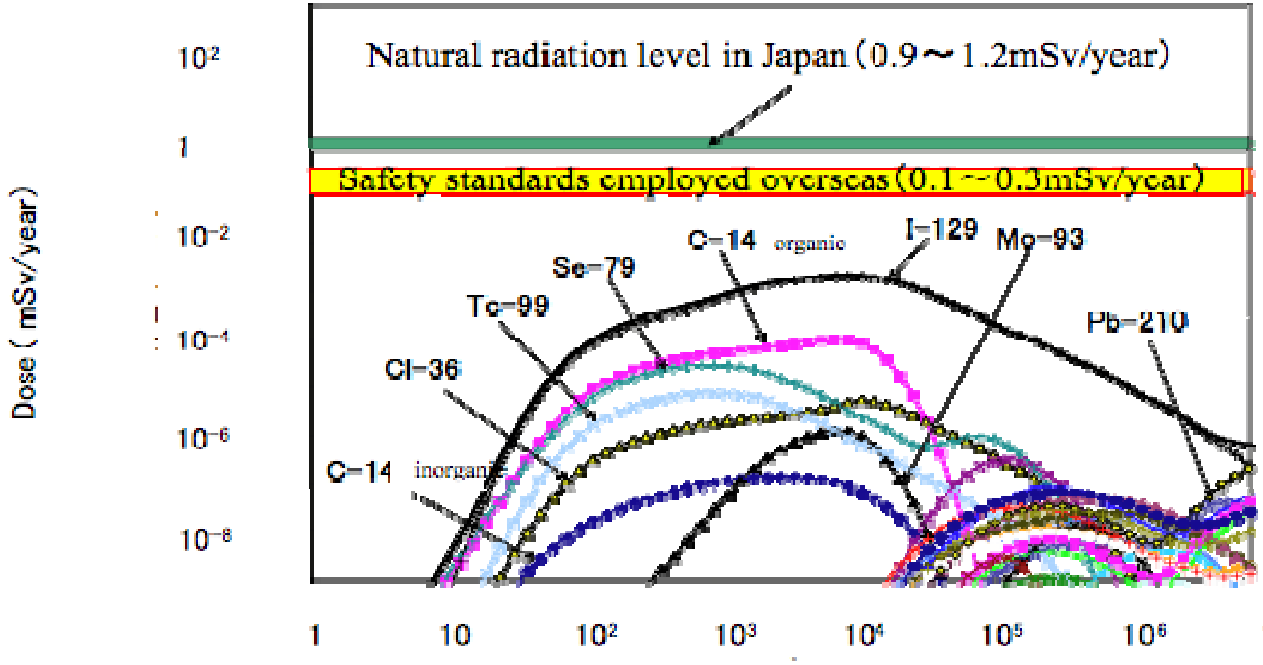
Hard rock, 1000m



100m!
Parallel plate

Generic safety assessment results

Doses over 100ka dominated by I-129 from Gp1 and C-14, predominantly from Gp2



Quoted from radioactive Waste Safety Subcommittee of Nuclear Safety Commission

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Current status in Japan

- Impact can be reduced if I-129 concentration diluted in space or time (too long-lived for decay to play a role): main source is Gp1, so this is the focus for improvement. Difficult to ensure chemical constraints (solubility, sorption) will play a role for the existing waste packages.
- Next key nuclide is C-14, predominantly from Gp2. Again dilution can help but, as half life is not too long, decay can also play a role if release is delayed.
- Improved conditioning / waste packaging could provide benefits but:
  - could give doses to workers
  - could be problematic to implement on a commercial scale with full QA (NB Sellafield & Rokkasho glass production experience) and will produce secondary wastes
  - will be very expensive
  - proposed solutions are not demonstrated for long timescales under relevant conditions

UK TRU overview

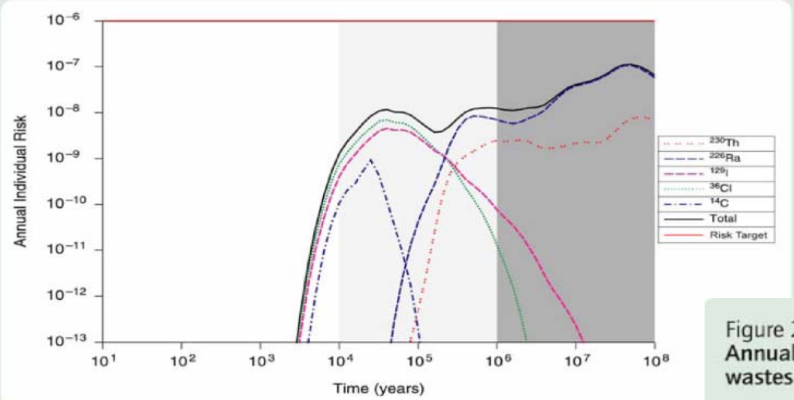
- Similar program to Japan – prefer co-disposal of HLW & reprocessing waste, volunteer approach to siting, island with coastal sites,…
- UK TRU inventory larger and more complex than Japan, including sources from poorly-defined legacy wastes, NPP operations, military activities, fuel fabrication, reprocessing, decommissioning (including fuel & reprocessing facilities)
- UK co-disposal may also include SF, Pu/U wastes,…

UK background

- Early L/ILW repository studies considered a range of design configurations including caverns, silos, boreholes, shafts, vaults and tunnels, both under the sea or under land.
- In 1991 Sellafield was announced as the preferred site for a repository and a design of an array of long vaults excavated at 900m depth in Borrowdale Volcanic Group was selected.
- Following refusal of the Sellafield RCF planning application in 1997, Nirex concentrated on the description of a generic repository concept assuming a reference repository depth of 650m in a site with high permeability sedimentary rock overlying low-permeability sedimentary or hard rock at repository depth.

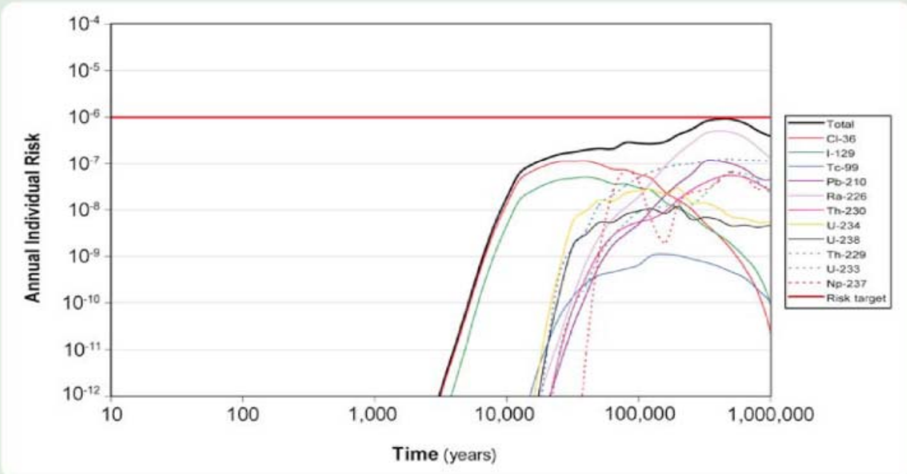
UK – Nirex 97 / GPA

Figure 28
Annual Individual Risk vs Time for the Nirex 97 Reference Assessment Model



Nirex 97 - geo-data from Longlands Farm site.
Restricted inventory (due to expected operations duration) without large decommissioning waste volumes (inc. graphite)

Figure 27
Annual individual risk vs time for final stage decommissioning wastes added to GPA reference case



GPA - generic UK data (somewhat more "conservative" than Nx-97)

Full inventory incl. ~80,000t graphite from reactor cores

RWMD concept basics

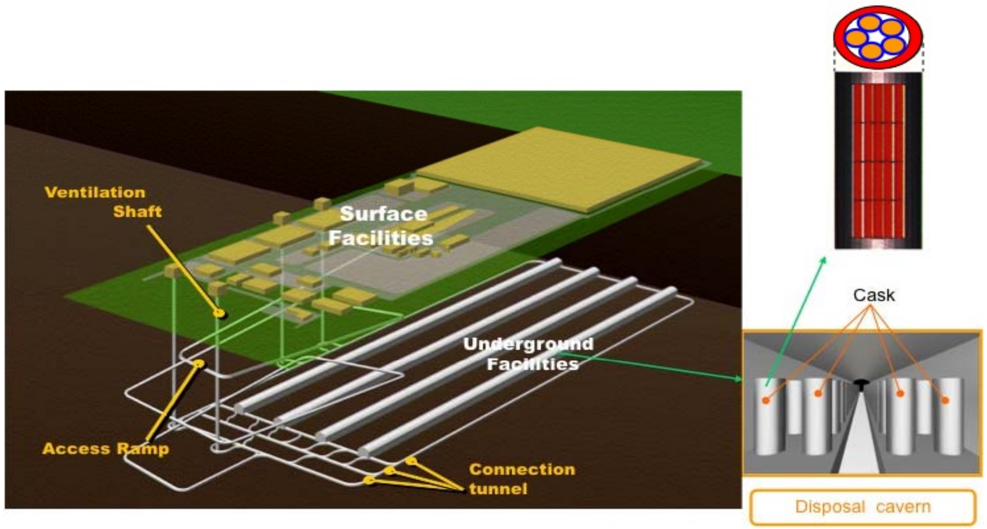
- A PGRC (Phased Geological Repository Concept) has been derived for the disposal (/co-disposal) of ILW/LLW, which incorporates a period of monitored retrievable storage.
- Previous concept for waste in self-shielding packages deemed unfavourable due to package size /weight, increase in repository volume and costs.
- New option with re-usable shielded transport containers for unshielded packages / remote-handling equipment to emplace them.
- R&D has focused on developing a range of standard waste packages to simplify quality control procedures, waste package transport / handling and allow operations to be optimised around a limited number of variants.

Issues

- Improving the inventory: developing better models for new build waste arisings
- Developing improved concepts for cost-effective tailoring to volunteer sites
- Examination of wide range of options for co-disposal / waste mixing
- Studies of advanced waste conditioning / volume reduction for some waste streams focus on various vitrification methods)
- Development of “optioneering” approach to examine impact of wide range of requirements on variants

Trends: co-disposal

- Focus on cavern disposal options for all types of waste due to:
  - High emplacement density / small footprint / low cost
  - Practical and safe to construct and operate using existing technology
  - Considerable flexibility to mix waste to manage thermal loading (including co-disposal of HLW / SF / some TRU within a single cavern)
- Acknowledged problems
  - Novelty – need to build acceptance
  - Complexity of EBS – need for improved models, databases and validation cases (e.g. URL projects, natural analogues)



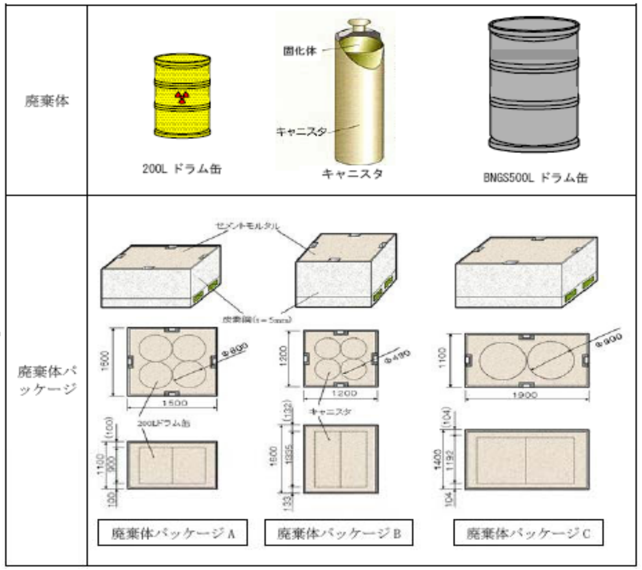
Future challenges

- Develop a design that will strengthen the Safety Case:
  - reduce I-129 (and C-14?) releases by a large factor
  - be insensitive to the complexity of near-field chemistry
  - have low sensitivity to site hydrogeological properties
  - be robust in terms of provision of multiple barriers and depending on well-established principles
- Additionally, the design should be:
  - easy to implement to required QA levels
  - reduce (or be neutral with regard to) operational risks
  - reduce (or be neutral with regard to) costs
  - easy to present to the general public

➡ There are possibly many solutions to this problem, but some generic options could focus studies until specific sites need to be examined

Disposal packaging

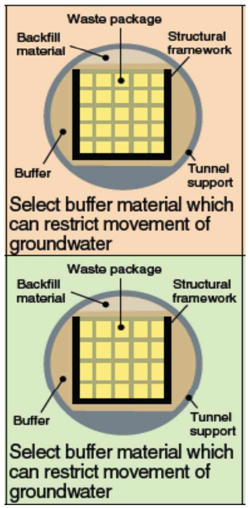
- For existing, conditioned waste, this may already be defined; for future waste arisings the option of optimisation should be explicitly considered (area for negotiation between waste producer and NUMO)
- Standard sizes of emplacement container greatly aid operational flexibility: choices of container material and grout should be made iteratively, with feedback from safety assessment
- Inventories need to include full specs of containers (e.g. metal SA / vol ratio, organic content of grout, etc.)

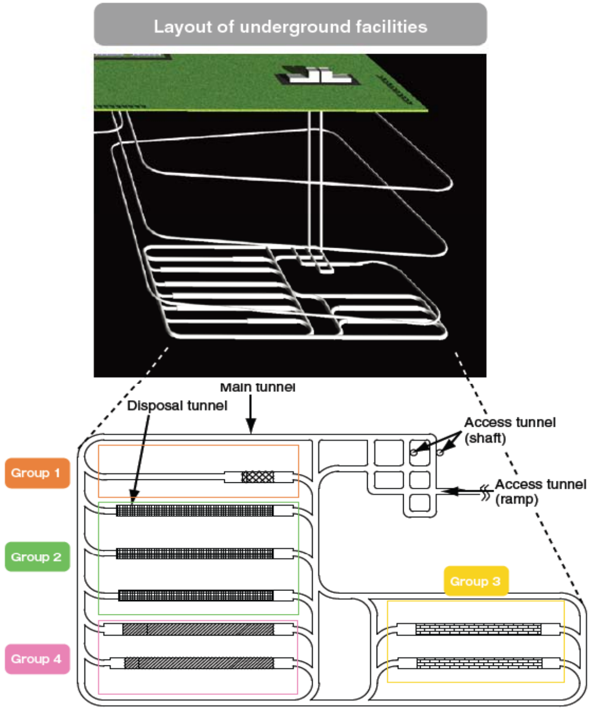


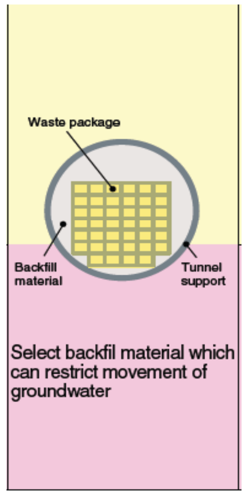
EBS design and layout

TRU-2 simplistic

- no consideration of optimisation in the distribution of waste packages within groups / between groups
- detailed design components introduced without discussion of requirements or consideration of barrier







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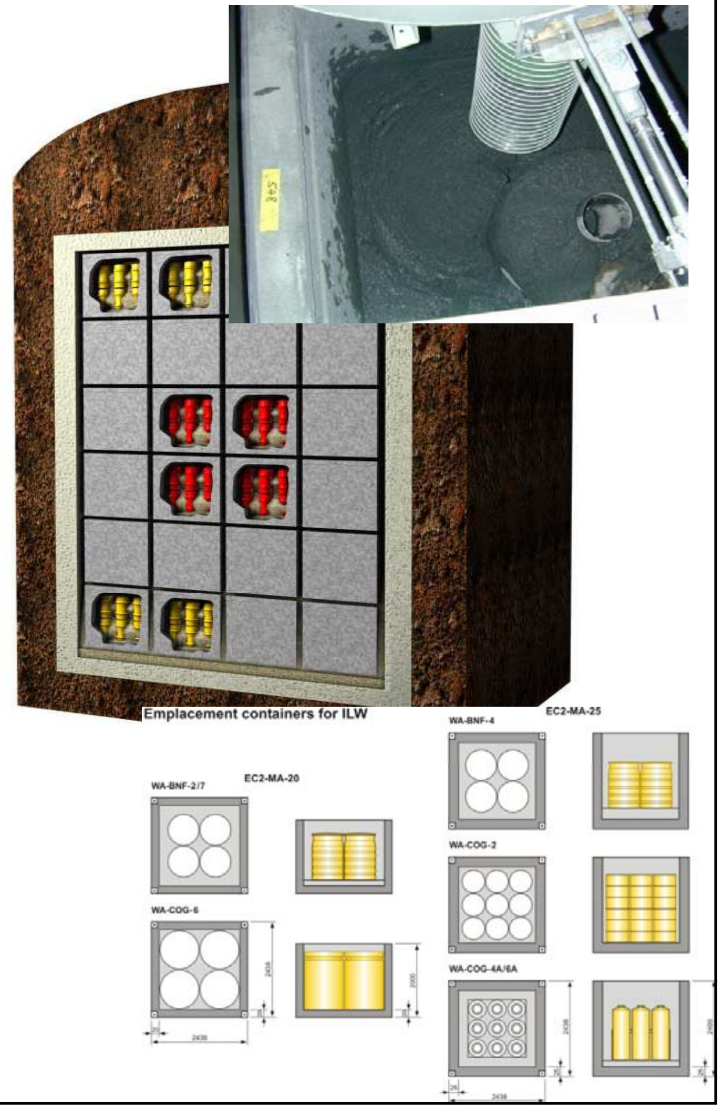
Approaches to optimisation

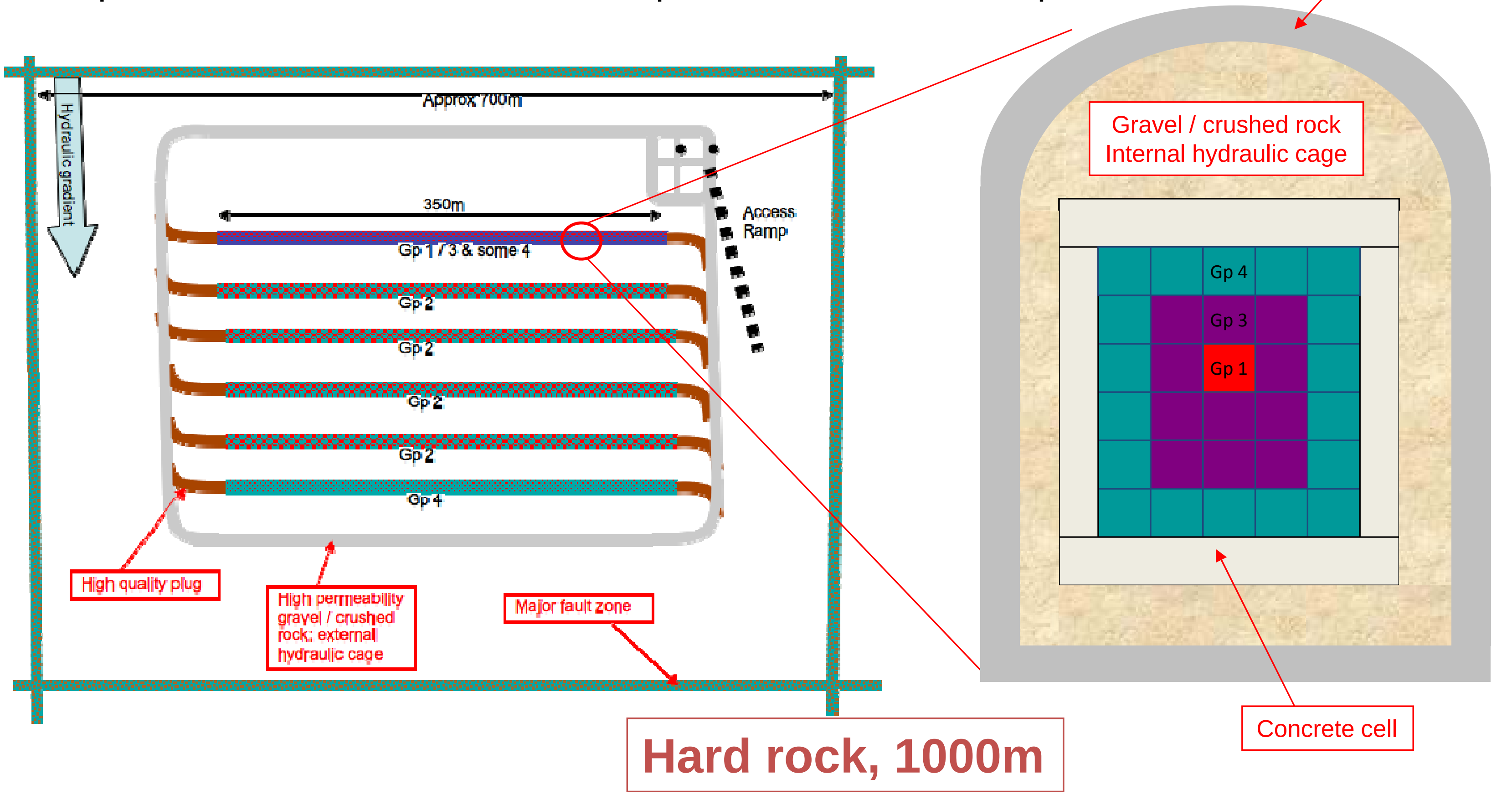
Lateral thinking:

- Overall design:
  - replace expensive barriers that are difficult to assess with cheaper, simpler options
- Integrated management of waste:
  - overview from production / conditioning to final disposal
- Flexible design:
  - use less problematic wastes as barriers around the smaller volumes of tricky materials, tailored to arisings
- Ensure ability to respond to changing boundary conditions (especially with regard to future power generation)



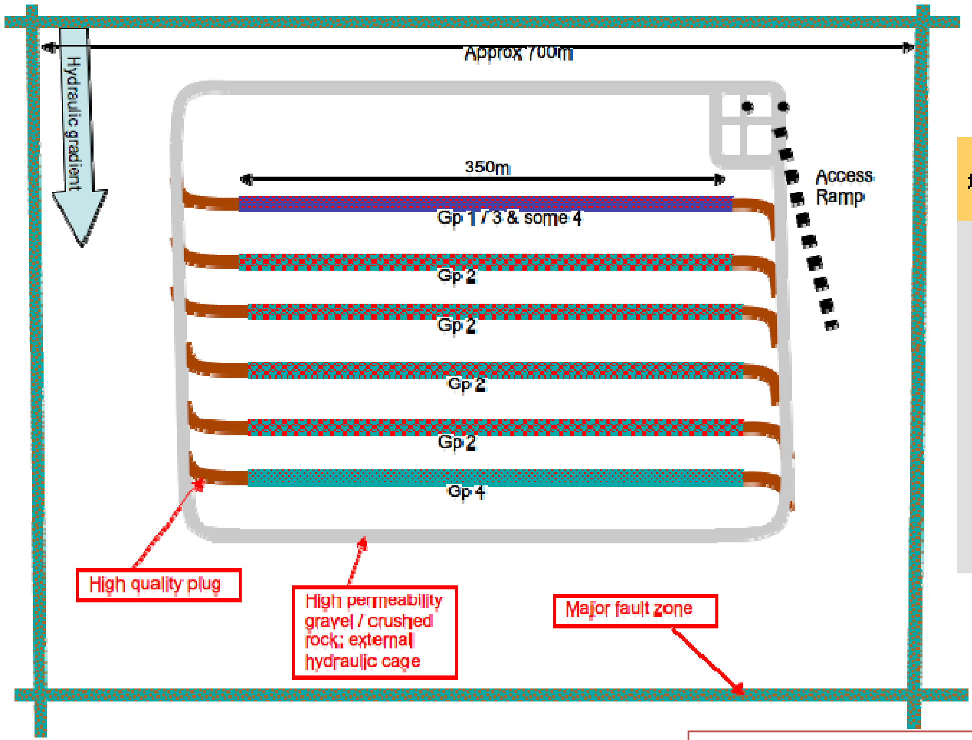
Nested Hydraulic Cage (NHC): concept

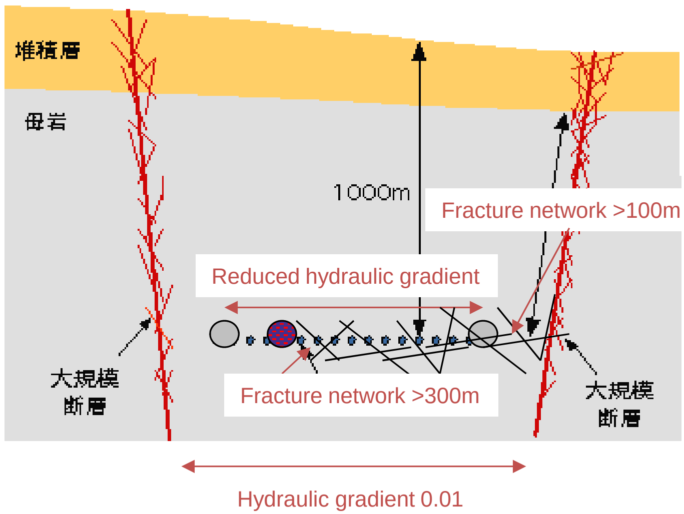
- External hydraulic cage reduces internal gradient
- Internal cage ensures diffusion inside primary EBS
- Gp 3 & 4 wastes act as barrier to spread releases from Gp1



NHC: I-129 far-field

- External hydraulic cage reduces internal gradient
- Transport distance within cage >300m in fracture network
- Outside cage, further 150m transport in fracture network (NB more compact layout)





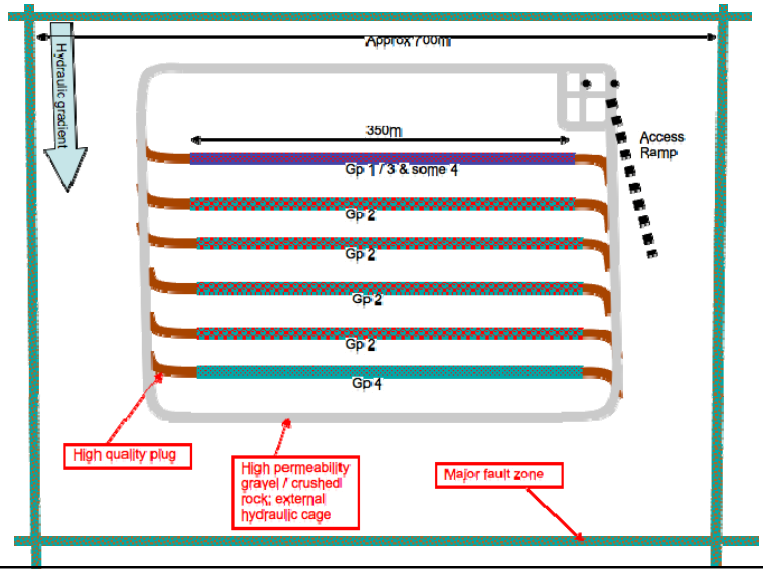
Hard rock, 1000m

NHC: I-129 safety case summary

- Dose is reduced by:
  - Spatial dilution in the near-field
  - Temporal dilution due to slow diffusive release from the EBS
  - Spatial dilution in spread of releases into a large volume of rock
  - Temporal dilution due to matrix diffusion within the hydraulic cage and along the external flow path from the cage to the nearest fault zone
- Supporting arguments:
  - Safety case made without assuming sorption: any such retardation (far-field) acts as a reserve FEP
  - Performance insensitive to chemical conditions in the NF, gas, etc.
  - If nitrate in Gp3 wastes acts to produce locally oxidising conditions, this will reduce release of I from AgI (reserve FEP)

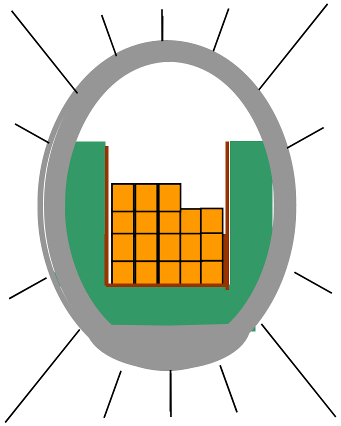
NHC: practicality (1)

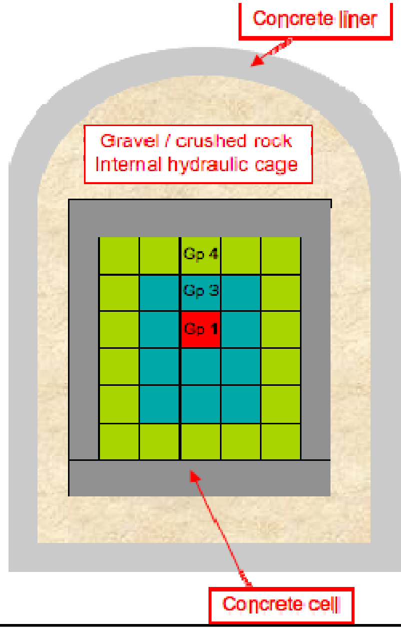
- External hydraulic cage must only ensure high permeability and would be easier (and cheaper) to construct than a high-quality backfilled tunnel. Outer concrete liner can be perforated as part of the closure process. Note that if crushed host rock suitable, this also minimises resultant spoil (can also be used for much of the access ramp)
- The emplacement tunnels have all same cross-section (largest practical) and approx same length - although this would be tailored to volume of good rock. Simplifies construction and maximises flexibility



NHC: practicality (2)

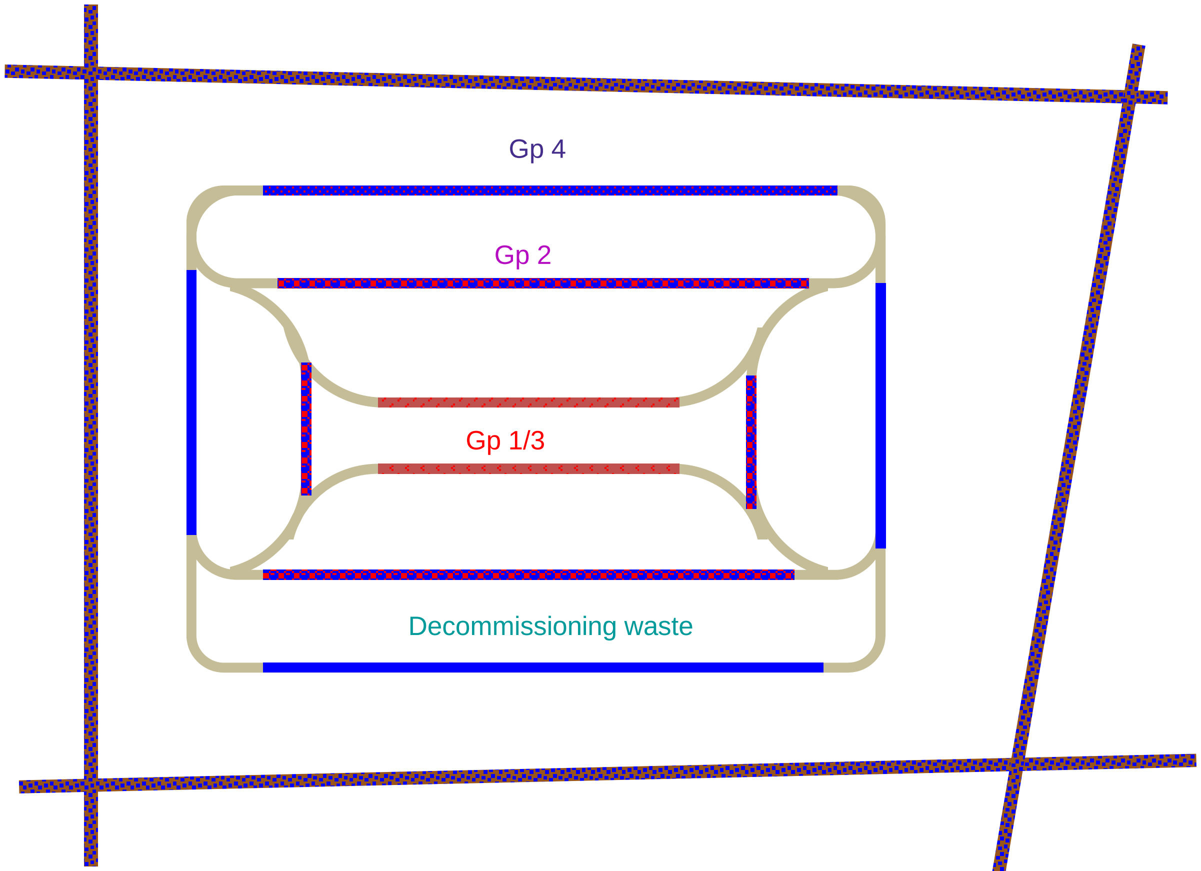
- Original Gp1 design includes bentonite buffer, which plays a critical role in ensuring long-term diffusive release:
  - difficult to construct to high quality levels
  - vulnerable to water inflow / high humidity / high pH
- Hydraulic cage may be easier to construct and assure robust performance
- NB reference TRU-2 design without drainage, so very good liner / ventilation needed: in accident cases vulnerable to flooding, whereas NHC design easy to drain to sump during the operational phase



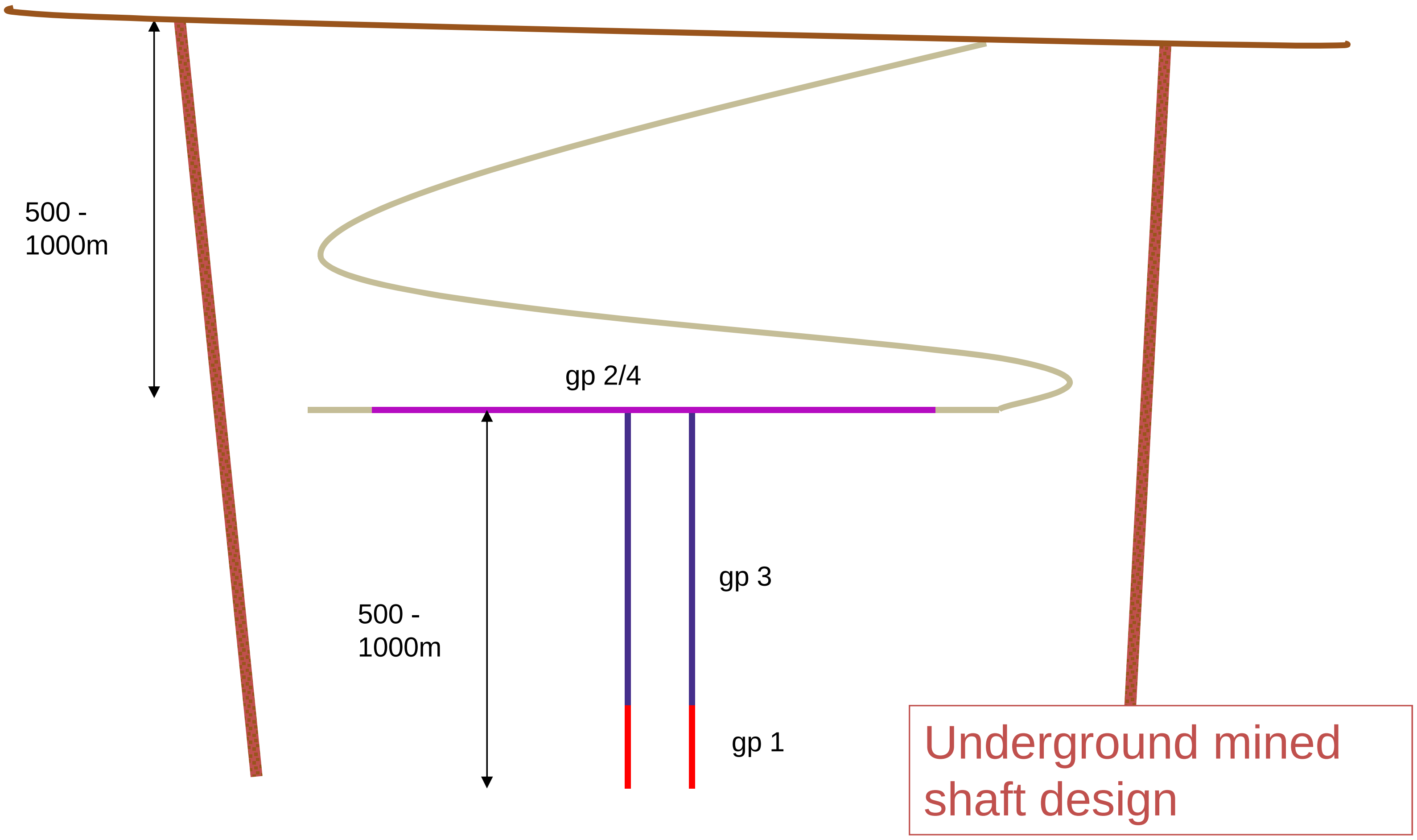


Further tailoring options

What if the direction of the hydraulic gradient cannot be assured over relevant timespans (e.g. coastal site)



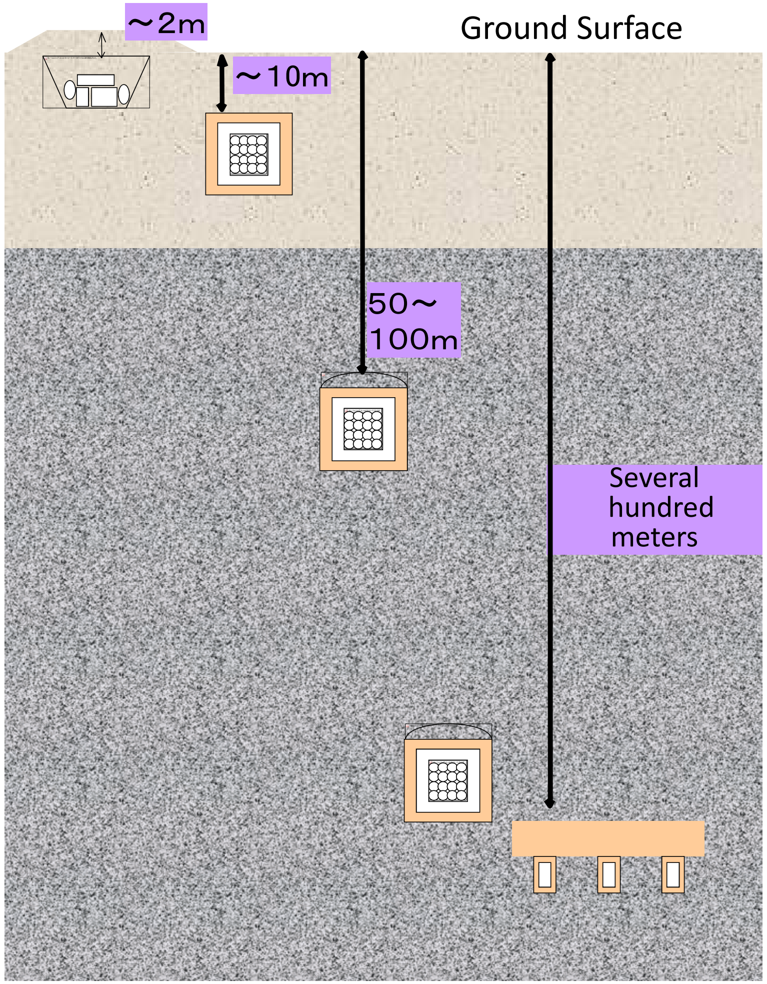
What if deep brines present?



Situation in Japan: personal observations

Planning focuses of fuel cycle wastes from existing facilities:

- ➢ No fully integrated national inventory of all wastes (even from fuel cycle)
- ➢ Existing sources of medicine, industry and research wastes poorly defined (but huge!): NORM wastes a grey area
- ➢ No detailed development of future power scenarios and resulting wastes (which can also allow for optimisation)
- ➢ No detailed consideration of future socio-political or environmental context (NB long institutional control of coastal sites)
- ➢ Insufficient consideration of potential problems with Rokkasho L1
- ➢**Little (or no) integration as yet with Fukushima wastes**

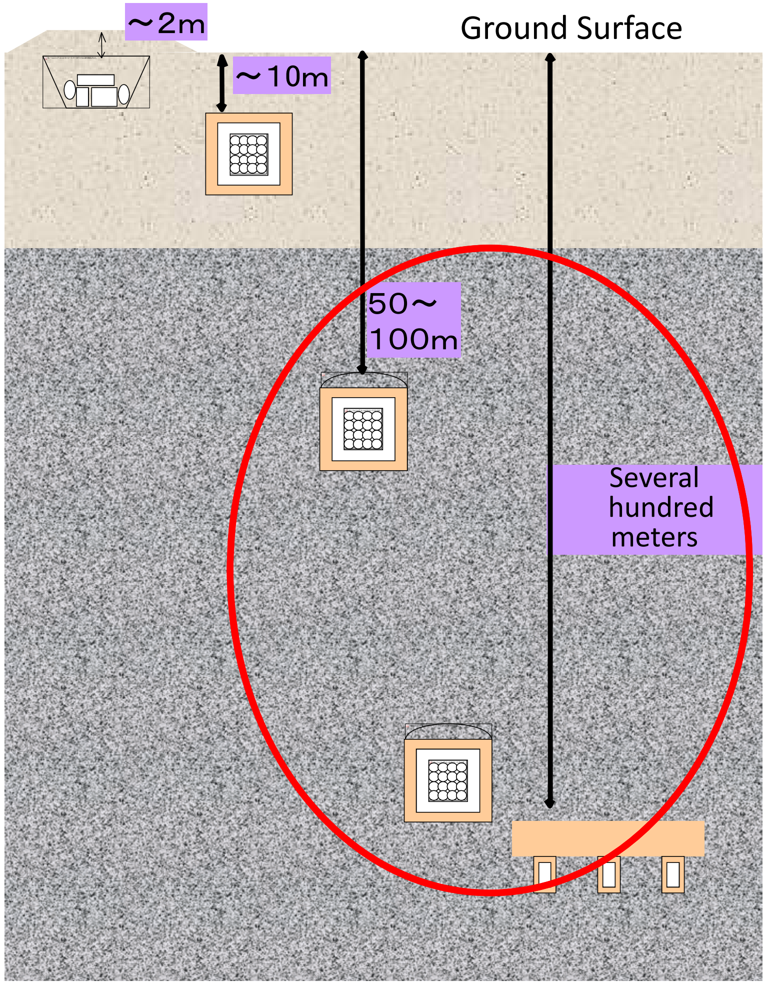


Credibility of the long-term safety case

For all deep disposal of "LLW" there are a number of concerns:

- ➢ Quality and long-term performance of EBS (bentonite & concrete)
- ➢ Radionuclide release and transport model assuming constant boundary conditions
- ➢ Biosphere with release into swamp or marsh (effect of sea level change!)
- ➢ Coastal erosion or similar perturbation scenarios

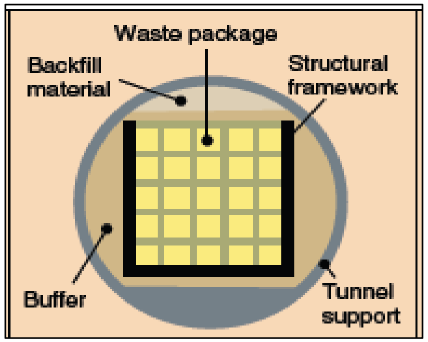
➔ Should be considered for robust safety case development

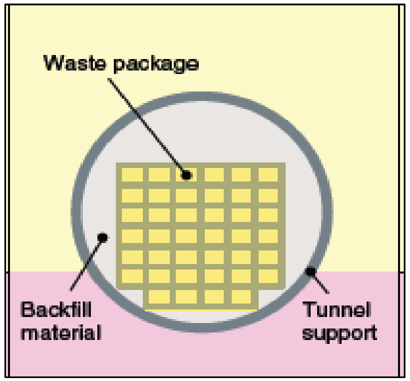


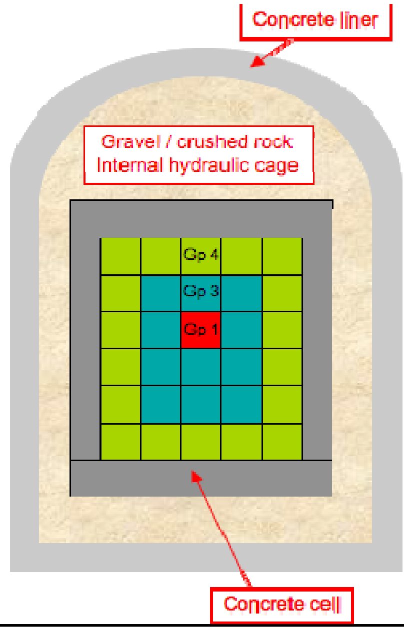
Model Improvement – EBS scale

Model requires to be realistic to distinguish between design options:

- Representation of all barrier components in 3D
- Representation of time evolution of physical, chemical and hydrogeological conditions
- RN release constrained by solubility / sorption on different barriers
- Explicit representation of gas, microbiology, colloids, oeganics,...



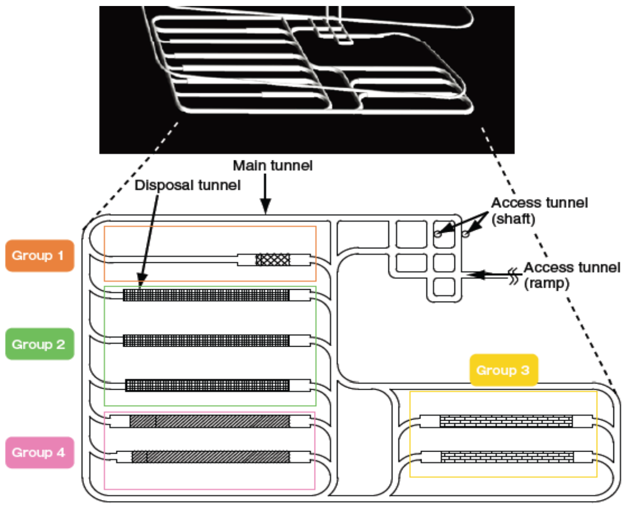


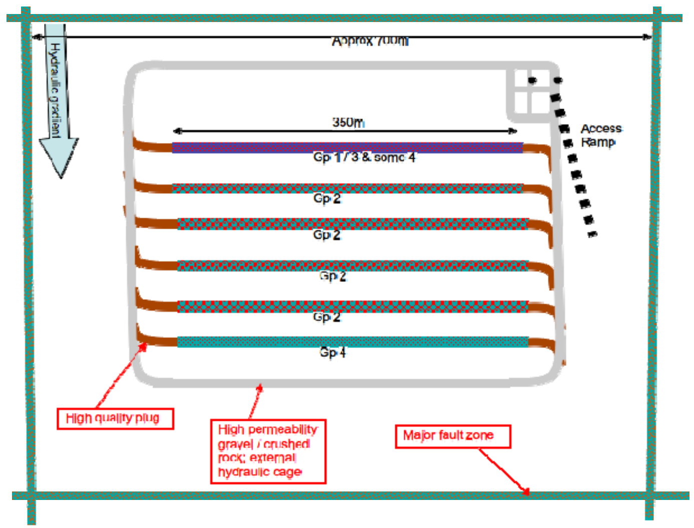


Model Improvement – Repository scale

Model requires to be realistic to distinguish between layout options:

- Representation of waste package distributions in 3D
- Representation of time evolution of physical, chemical and hydrogeological conditions
- RN transport within the repository zone modelled explicitly (with all potential short circuits)
- Explicit representation of gas, microbiology, colloids, organics,...

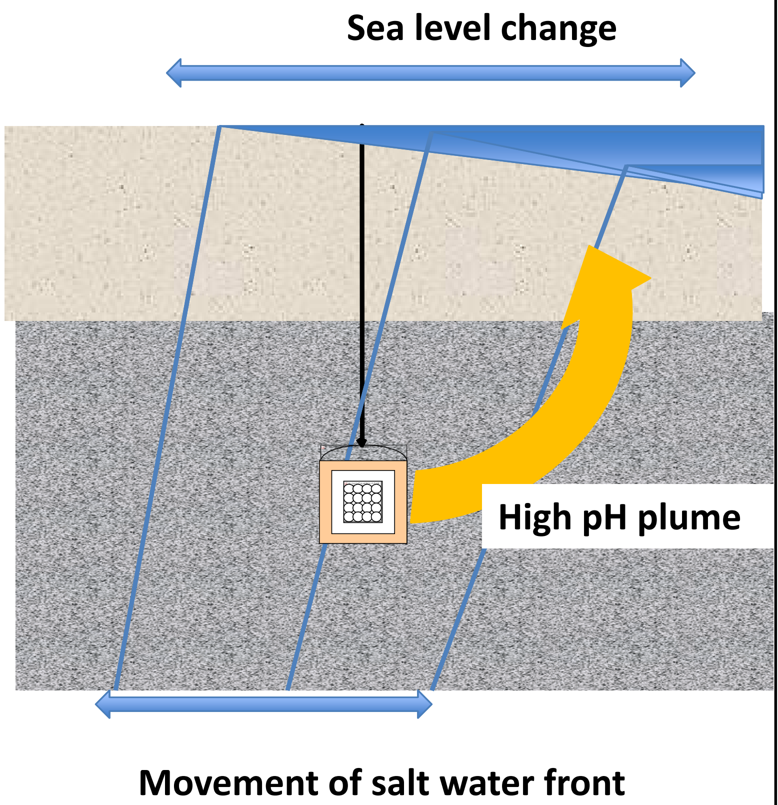




Model Improvement – Regional scale

Model requires to be realistic to distinguish between sites – e.g. for coastal site:

- Realistic flow paths from repository to biosphere (length, flow & RN retention characteristics)
- Cyclic marine transgressions (coupled evolution of geosphere & biosphere)
- High pH plume (with other components such as nitrate, organics)
- Ecplicit representation of any other site-specific features (e.g. uplift & erosion)



Fukushima Dai-ichi waste

Rubble removed from top of the R/B

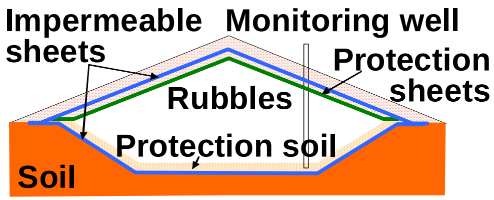
Top of the R/B (Unit 3)

Top of the R/B (Unit 4)

< 0.1mSv/h*1 → Open air storage

0.1mSv/h ～ 10mSv/h → Temporary storage facility

10mSv/h ～ 1Sv/h → Temporary storage facility



1Sv/h < → Temporary storage area with shielding ability

Temporary storage area with shielding ability
Container
Container storage in building

*1 Dose rate at the surface

*2 R/B : Reactor Building

TEPCO

Fukushima Dai-ichi – open issues

- Waste storage based on pragmatic separation according to surface dose
- Disposal optimisation would require
  - Re-grouping in terms of radionuclide contents / materials
  - Material-specific conditioning / volume reduction and packaging
  - Holistic treatment in disposal concepts, potentially including wastes from decontamination on- and off-site, decommissioning wastes, wastes from other locations
- Significant overlap in required knowledge / experience with the established TRU programme

Conclusions

- Disposal of TRU is particularly challenging, especially for the case of volunteer siting (as in Japan, the UK, ...)
- Improvements can be made to conditioning and packaging of problematic waste **but** improvement of the concept / layout may be more robust, more practical to implement & much more cost-effective
- Some examples of improved concepts have been illustrated, but it would be useful to do this in a more systematic manner
- Because some aspects are quite novel, demonstration projects are needed along with improvement of supporting PA models & databases (with testing using analogues)
- The experience in the TRU programme may help develop a more integrated approach to waste management, especially taking into account wastes expected from Fukushima Dai-ichi

Acknowledgements

- Invitation from JAEA
- Images from JAEA, NUMO, TEPCO, Nirex/NDA & Nagra
- Novel concepts developed with colleagues from JAEA, NUMO, Obayashi, Quintessa & the “MCM family”

Reserve

What is TRU waste?

- Low level radioactive waste arising from spent fuel reprocessing plant and mixed oxide fuel (MOX) fabrication facilities that contains artificial radionuclides of atomic number larger than uranium
- TRU waste consist of fission products and actinides containing relatively large concentration of α emitters.
- Some kinds of TRU waste should be disposed of geologically, because their α nuclide concentration is so high that they cannot be disposed of near surface or at concrete disposal and intermediate depth disposal.

TRU（Trans-uranic）

Radionuclides of atomic number larger than uranium, such as neptunium, plutonium and americium.

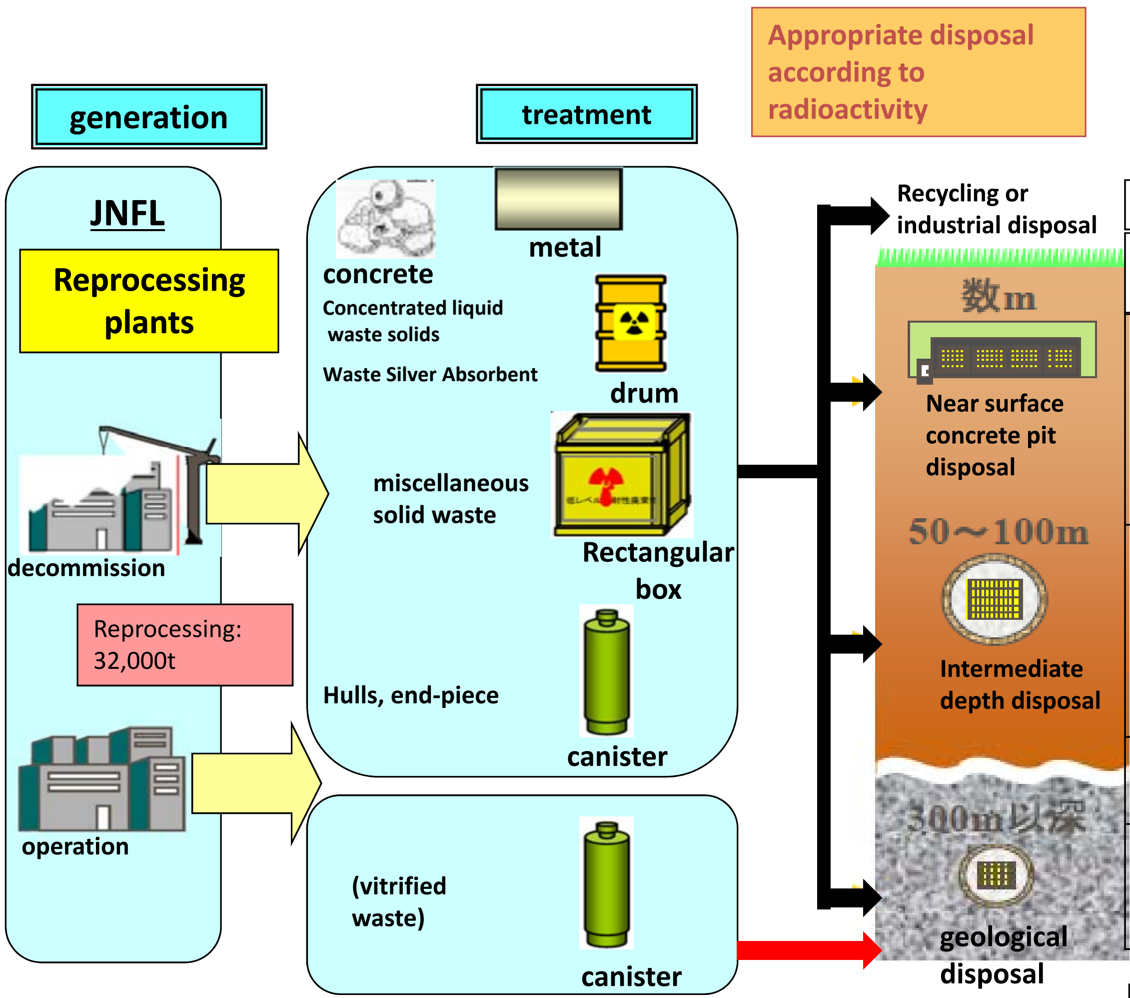
FP（Fission Product）

Nuclides generated as result of nuclear fission of uranium and plutonium, most with half lives in the range of several seconds to several million years.

NB Some key nuclides are activation products

NUMO

Total amount of TRU waste



JNFL		project area (km^2)
Total amount of waste(m^3)	Total Radioactiviy (Bq)	
About 61,000	5E+15	
About 21,000	5E+18	
About 14,000	2E+19	0.2
About 7,600	2E+20	6

Black:TRU waste, Red: HLW

NUMO