Research Reactor Spent Fuel DISPOSAL OPTIONS

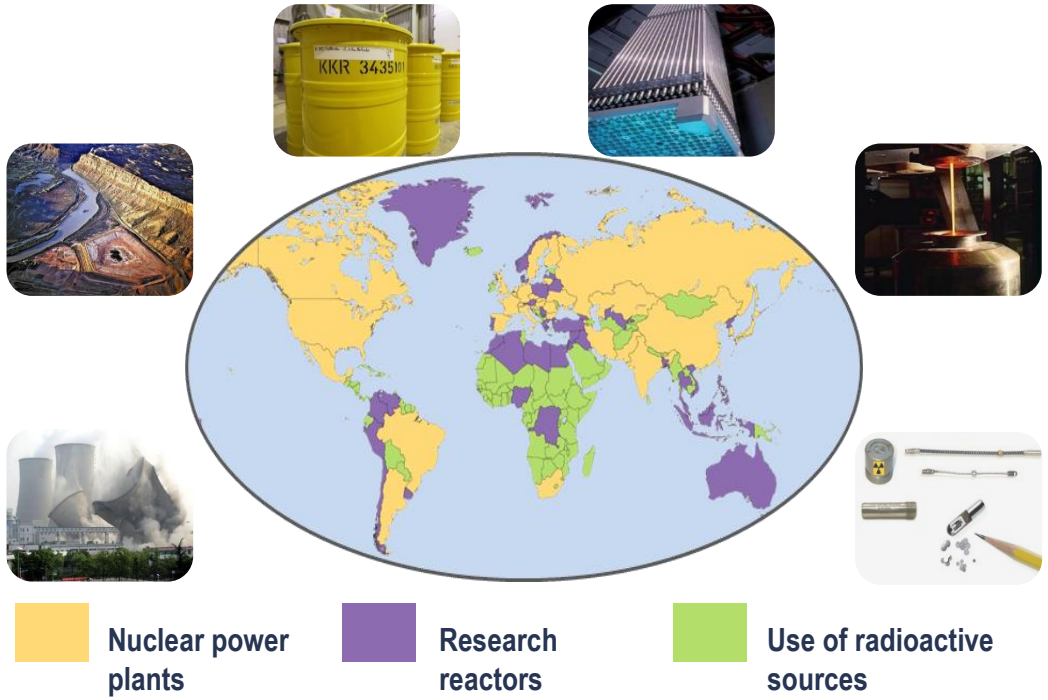
Managing Non-Standard Legacy Power and Research Reactor Spent Fuels

Stefan Mayer
IAEA Department of Nuclear Energy

19 February 2025

“The Waste issue”

RadWaste in every country



Volumes are small – if operating NPPs…

VLLW and LLW
~ 35 Mio m^3 globally
~80% in disposal ~20% in storage

Discharged Spent Nuclear Fuel
~ 400.000 tHM globally
~1/3 reprocessed ~ 2/3 in storage

HLW (vitrified)
ILW (e.g. assembly components)
LLW

… and considerably smaller if only operating a Research Reactor

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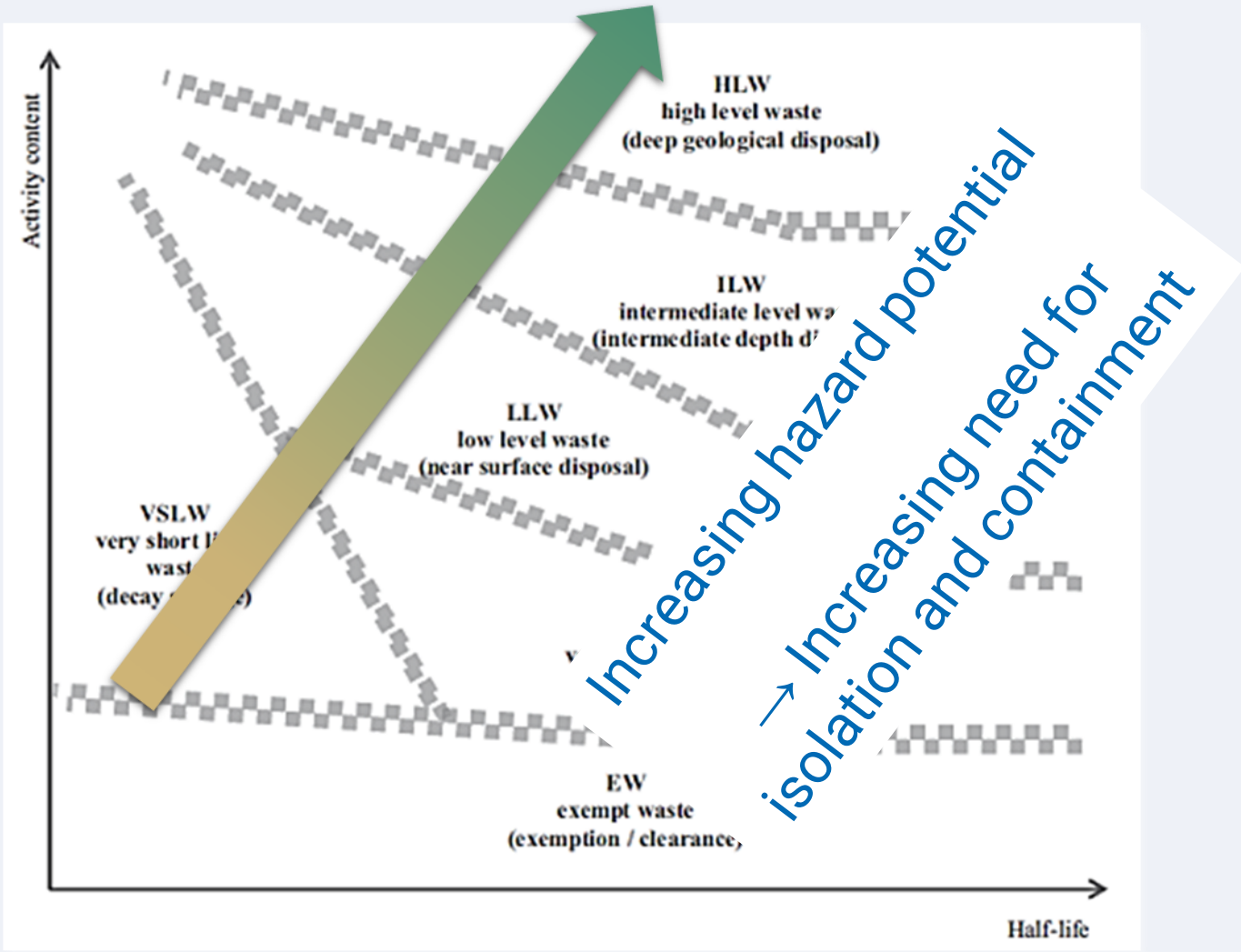
High Level Waste	HLW
Intermediate Level Waste	ILW
Low Level Waste	LLW
Very Low Level Waste	VLLW
Very Short Lived Waste	VSLW
Exempt Waste	EW



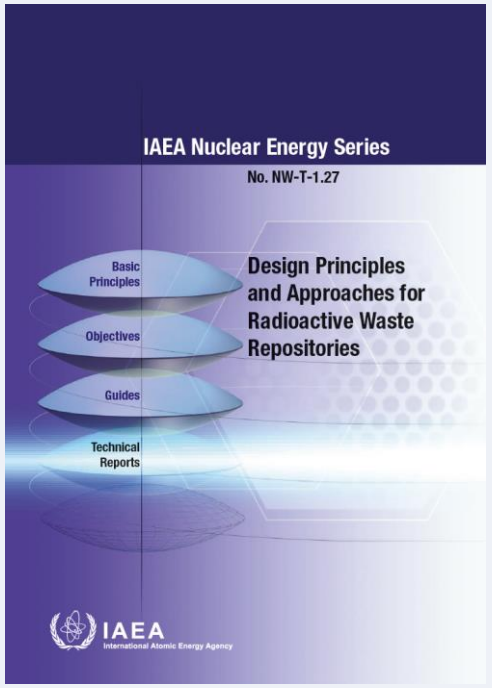
IAEA Safety Standards
for protecting people and the environment

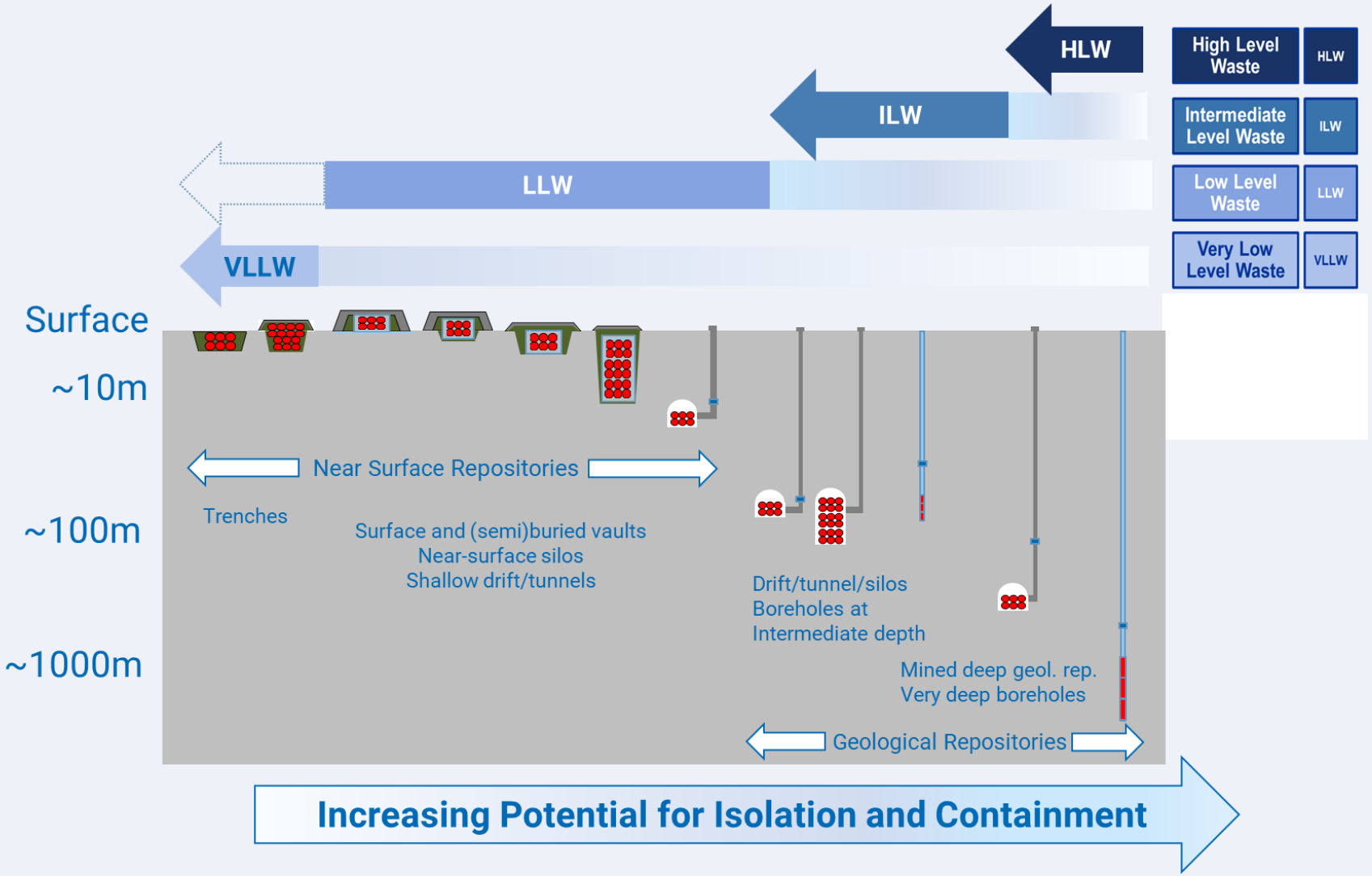
Classification of Radioactive Waste

General Safety Guide
No. GSG-1

IAEA International Atomic Energy Agency

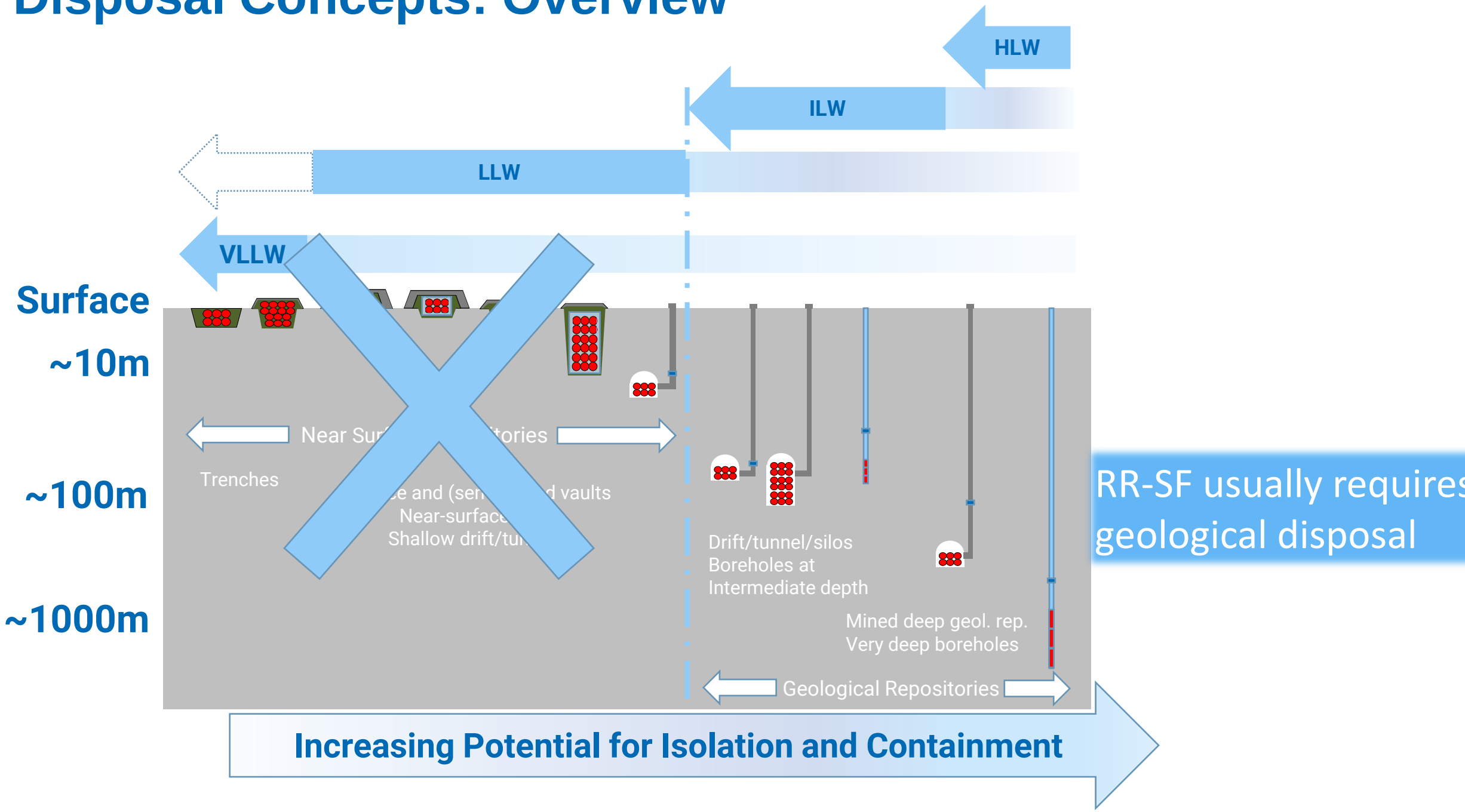
Waste Classification & Disposal





Disposal Concepts & Waste Classes

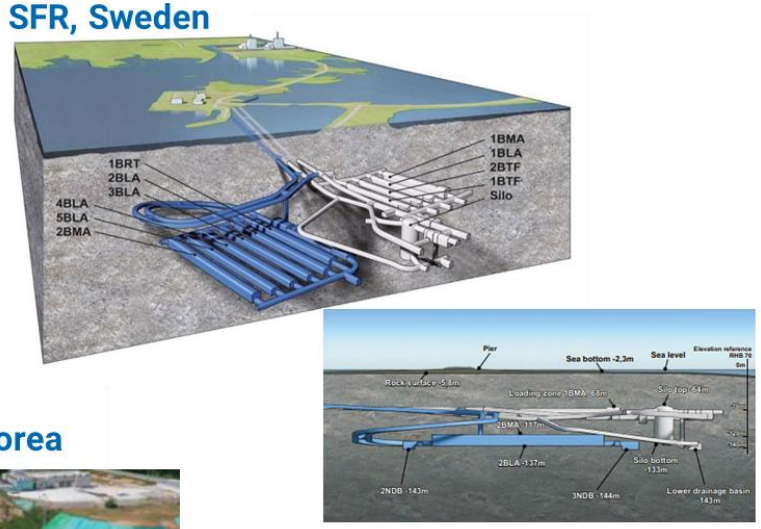
Disposal Concepts: Overview



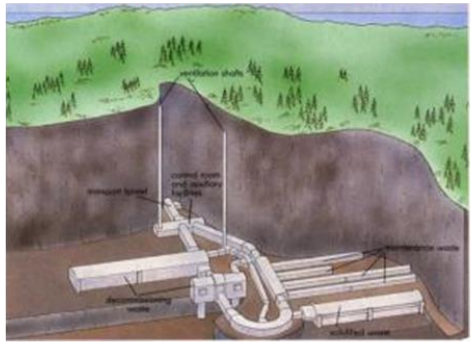
RR-SF usually requires geological disposal

Examples: Disposal in geological formations “at intermediate depths”

SFR, Sweden



Loviisa, Finland



Wolsong, Korea

Richards, Czech Republic

Bátaapáti - Hungary

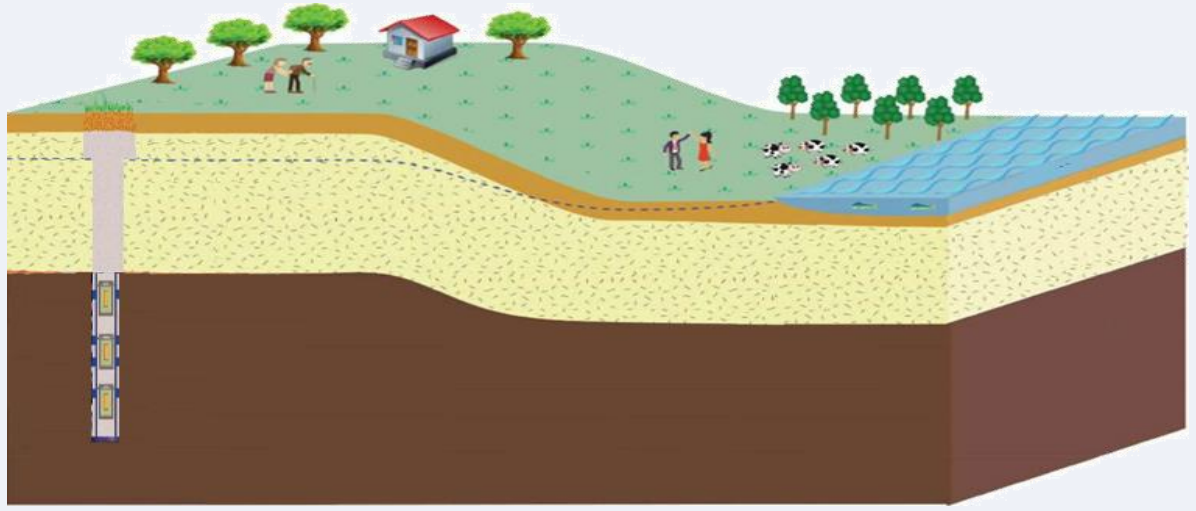
The natural barrier of the disposal system at intermediate depths contributes to a higher potential to contain and isolate the radionuclides in the ILW.

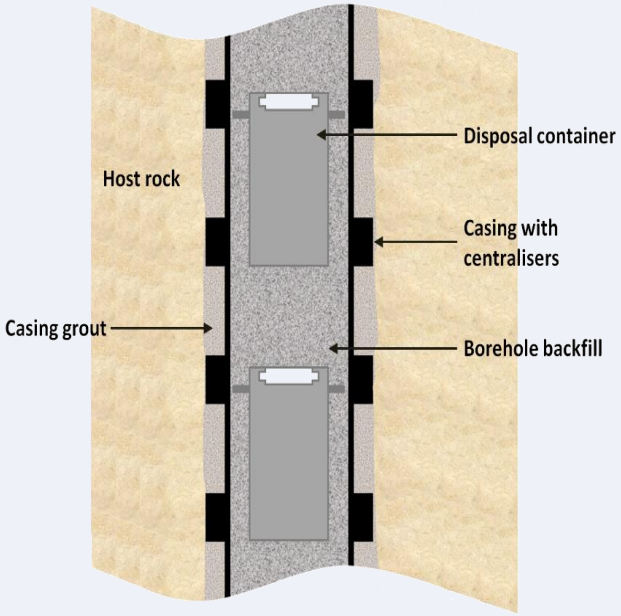
Underground cavern or silo

Pros	Cons
▪ Relatively wide applicability for range of waste types and forms ▪ Very flexible for range of waste size or volume	▪ Current examples of concept at intermediate depth (~100-200 m) - thus potentially vulnerable to surface perturbation from erosion, glaciation or uplift ▪ Not suitable for high-level wastes and spent fuel

Suitability for RR-SF requires assessment, i.e. depends on radiological inventory, detailed design and site properties

“Small Diameter” DSRS Borehole Disposal





- ✓ Could be sited and designed to accept the entire “small” DSRS inventory
- ✓ Tentative project time scale is a decade or less until disposal
- ✓ Comparatively low cost overall
- ✓ Site specific studies can build on prior generic studies
- ➢ Will not accommodate “small – but larger” volumes of VLLW and LLW

Geological Disposal Facilities

Sweden (SKB) - Osthammar
Construction start 01/2025

Finland (Posiva) - Onkalo
2024 Cold-Commissioning

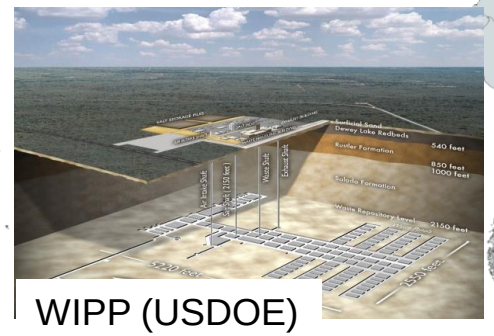
France (ANDRA) - Cigéo
Construction licence application
01/2023

Canada (NWMO)
“Positive” from finalist communities

Switzerland (NAGRA) - Nördlich Lägern
11/2024 License application

USA (DOE) - Carlsbad
WIPP emplacing TRU waste since 1999

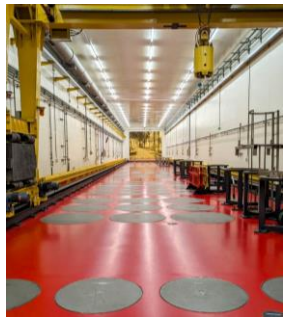
Germany (BGE) - KONRAD
Preparing for commissioning (~2030)

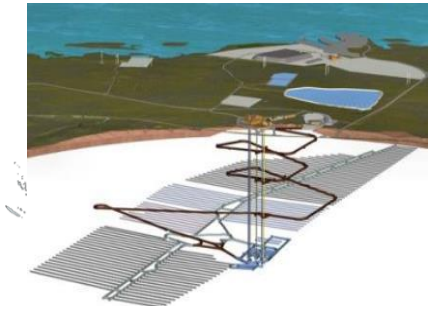


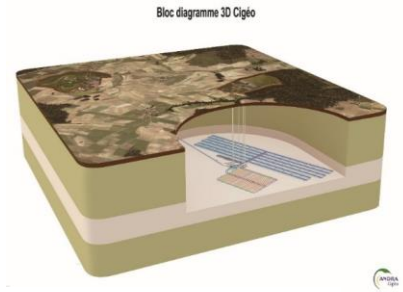
WIPP (USDOE)

SF Dry Storage
(USA)

HLW Storage
(Netherlands)




Spent Fuel Repository
at Olkiluoto (Posiva)

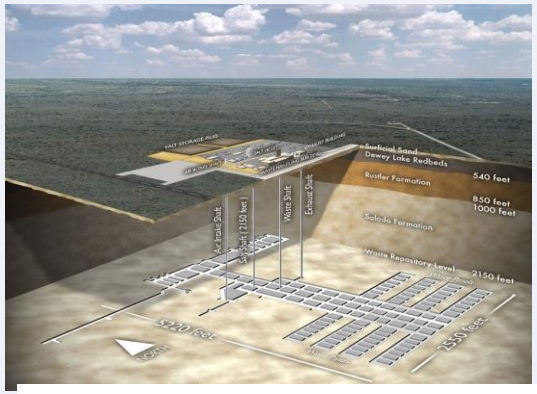


Cigeo Project at
Bure (Andra)

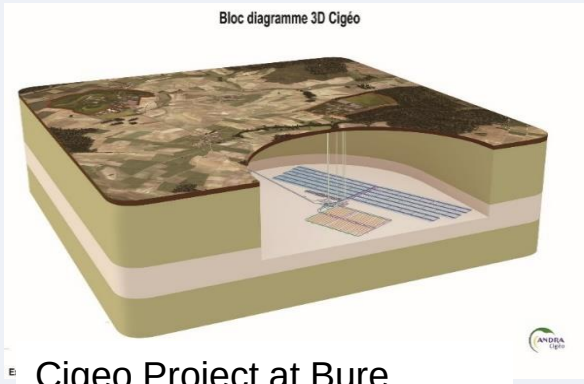
- ✓ Significant international experience with siting, licensing, construction.
- ✓ Operation for ILW disposal.
- ✓ Cold-commissioning for SNF disposal.

Geological Disposal Facilities

- ✓ Could be sited and designed to accept the entire ILW/HLW inventory
- ✓ Multiple host formations and sites have been found as suitable
- ✓ Only needed after SF/HLW has sufficiently cooled down
- ➢ Takes a long time until licensed for disposal of waste
- ➢ Has a significant, uncompressible up-front cost
- ➢ Requires extensive studies and expertise from a broad range of disciplines



WIPP (Courtesy of USDOE)



Cigeo Project at Bure (Courtesy of Andra)

Spent Fuel Repository at Osthammar (Courtesy of SKB)

Converted mine

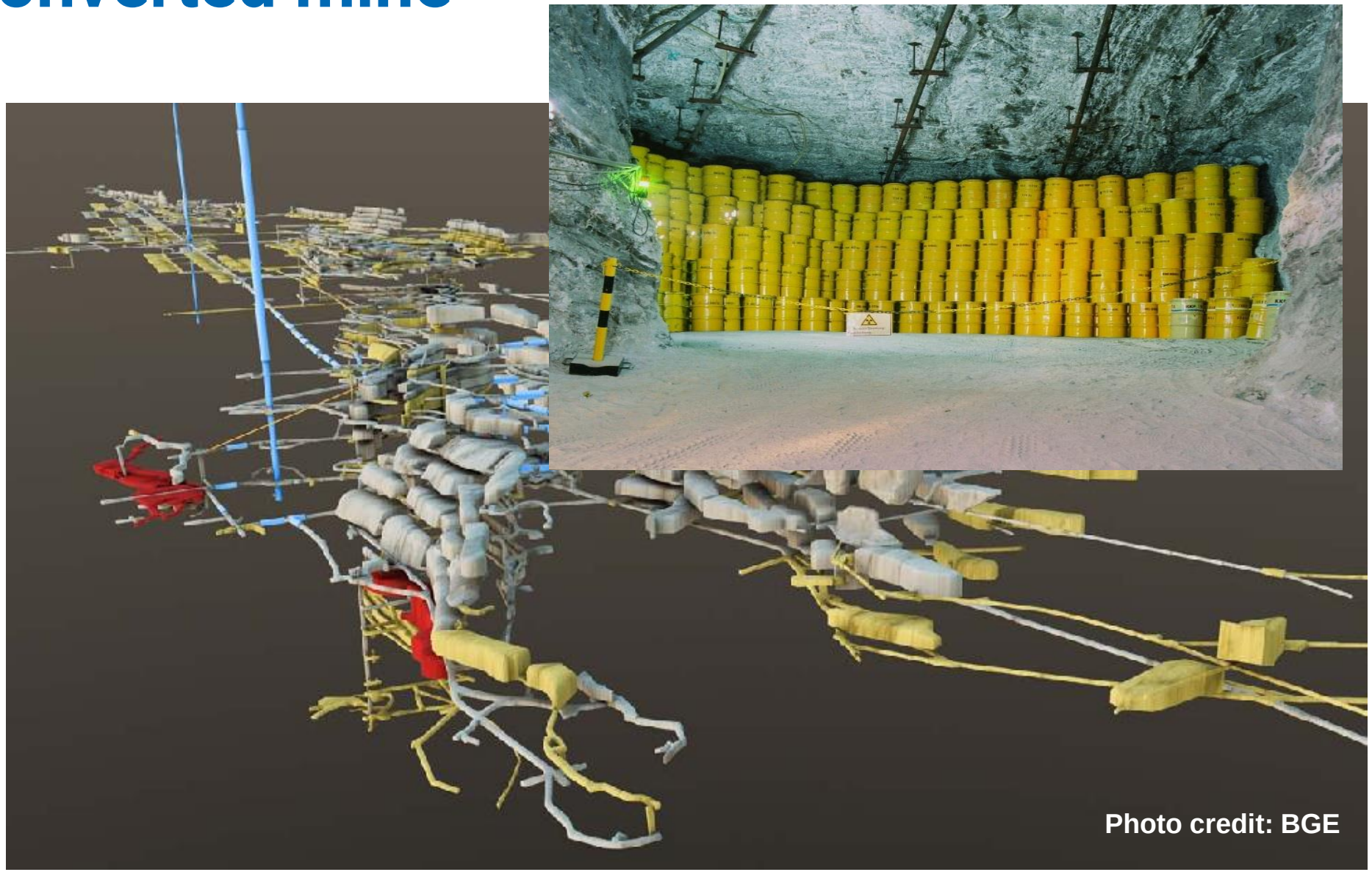


Photo credit: BGE

Converted mine

Pros	Cons
▪ The underground galleries or cavities and the access routes are already (partly) constructed ▪ Potentially large cavities which could accommodate large waste packages and volumes. ▪ It could offer a solution for all waste types.	▪ Refurbishment and closure of the mined repository can be challenging and can become very costly. ▪ Demonstrating post-closure safety may be more challenging than for a purpose-built repository.

Suitability for RR-SF requires assessment, i.e. depends on radiological inventory, site properties, specific mine conditions and closure concept

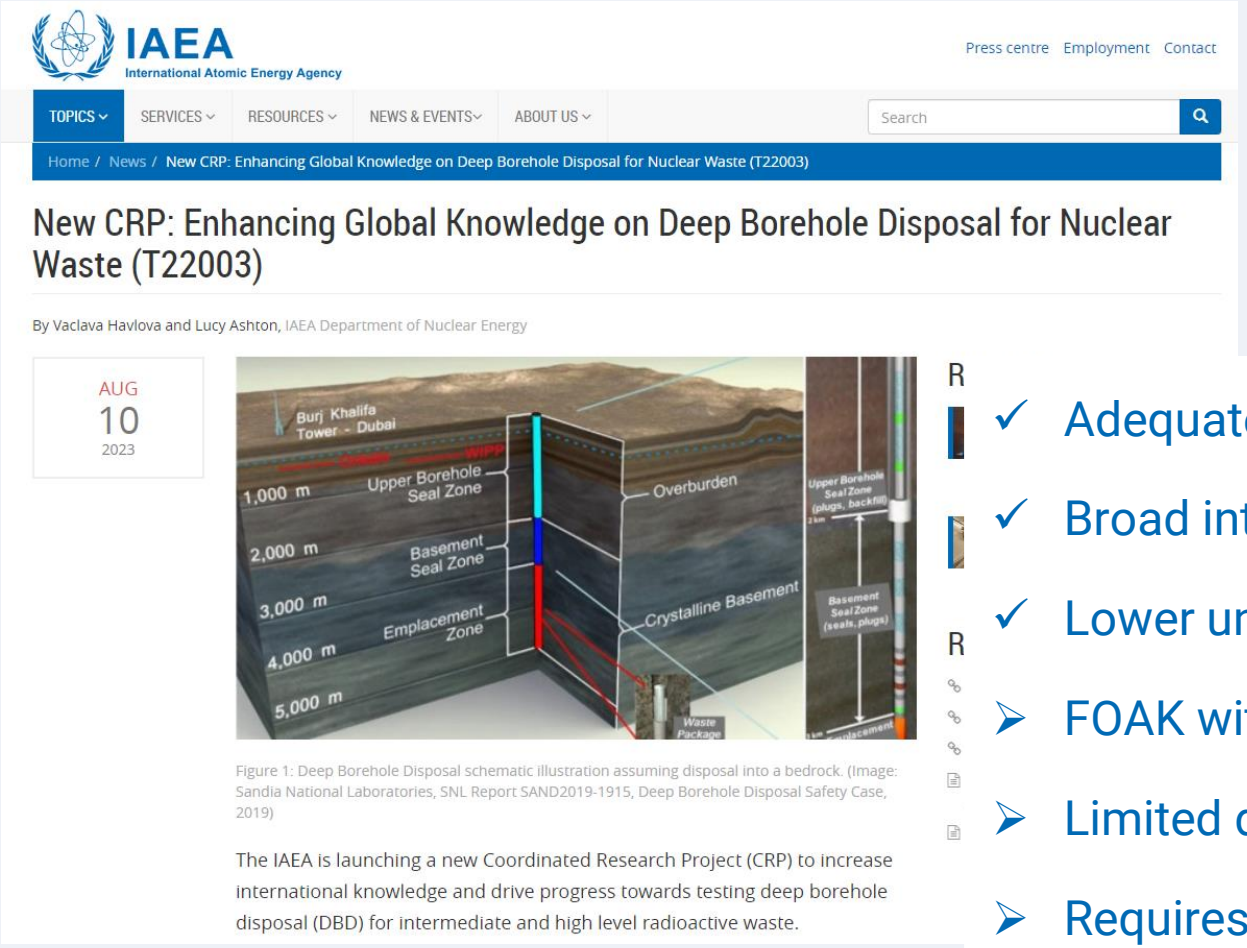
Further Disposal Developments & Considerations

- Deep Borehole Disposal – a “Technical” Dual-track approach
- Multinational Disposal – a “Societal/Political” Dual-track approach

Deep Borehole Disposal Concept – Considerations for National RWM P&S

+ Recognized potential
+ Extensive generic studies

- FOAK
- No field demonstration yet



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New CRP: Enhancing Global Knowledge on Deep Borehole Disposal for Nuclear Waste (T22003)

By Vaclava Havlova and Lucy Ashton, IAEA Department of Nuclear Energy

AUG
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2023

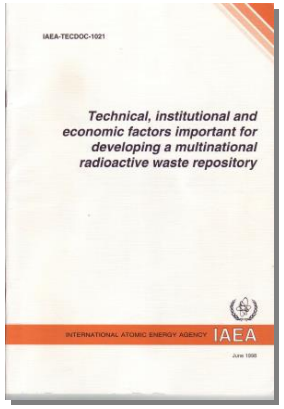
Figure 1: Deep Borehole Disposal schematic illustration assuming disposal into a bedrock. (Image: Sandia National Laboratories, SNL Report SAND2019-1915, Deep Borehole Disposal Safety Case, 2019)

The IAEA is launching a new Coordinated Research Project (CRP) to increase international knowledge and drive progress towards testing deep borehole disposal (DBD) for intermediate and high level radioactive waste.

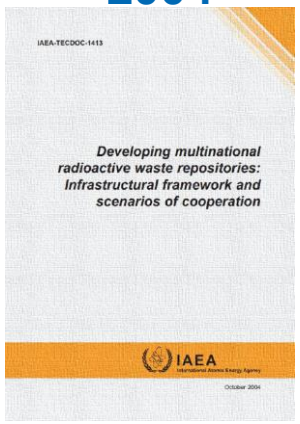
- ✓ Adequate disposal capacity for “small” inventory, including SF
- ✓ Broad international cooperation (IAEA CRP; EURAD 2-WP ASTRA)
- ✓ Lower uncompressible up-front cost than mined DGR
- ➢ FOAK with extensive ongoing generic studies (Project Risk!)
- ➢ Limited diameter for disposal container
- ➢ Requires regulatory framework

Multinational Disposal – Considerations for National RWM P&S

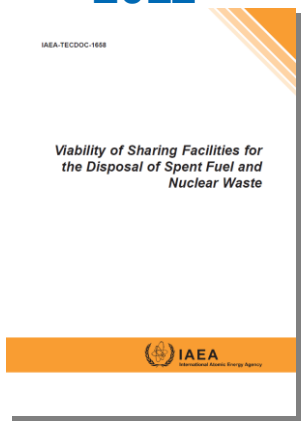
1998



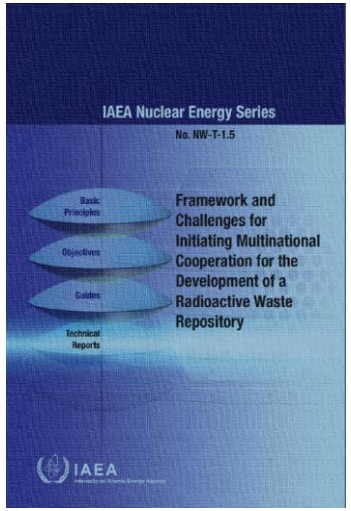
2004



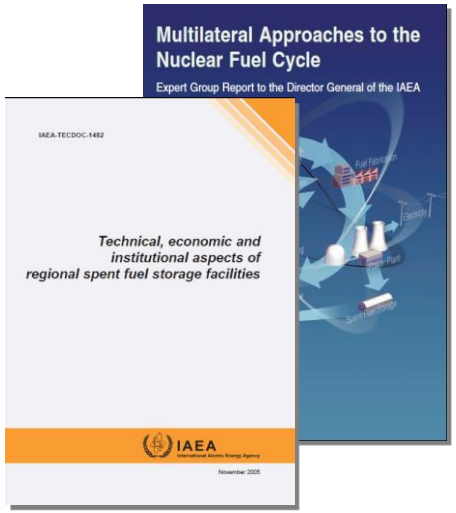
2011



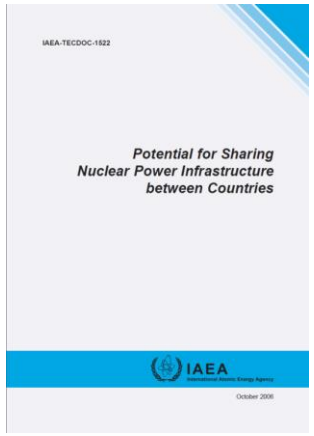
2016



2005



2006



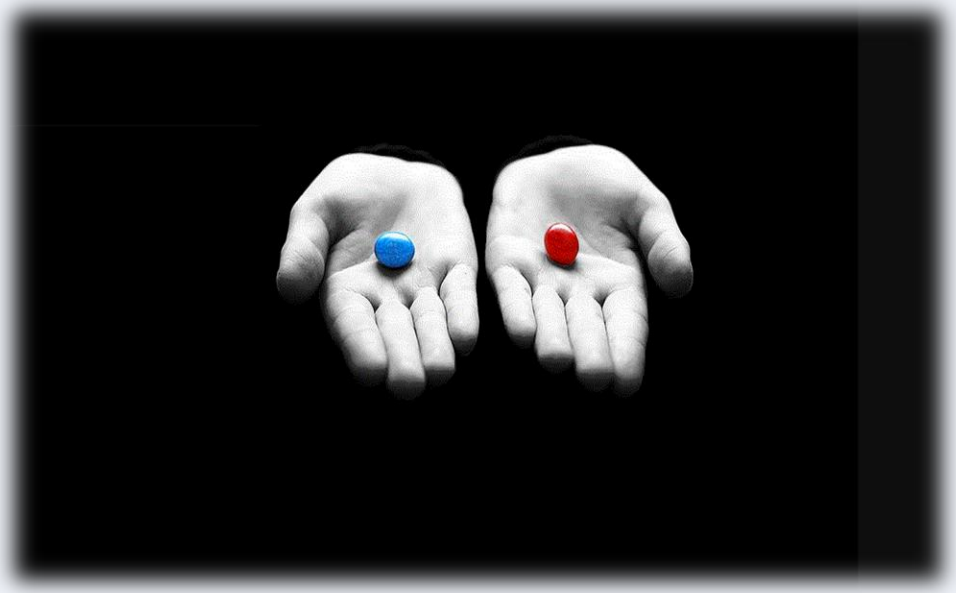
~2026

Participation in a multinational repository project:

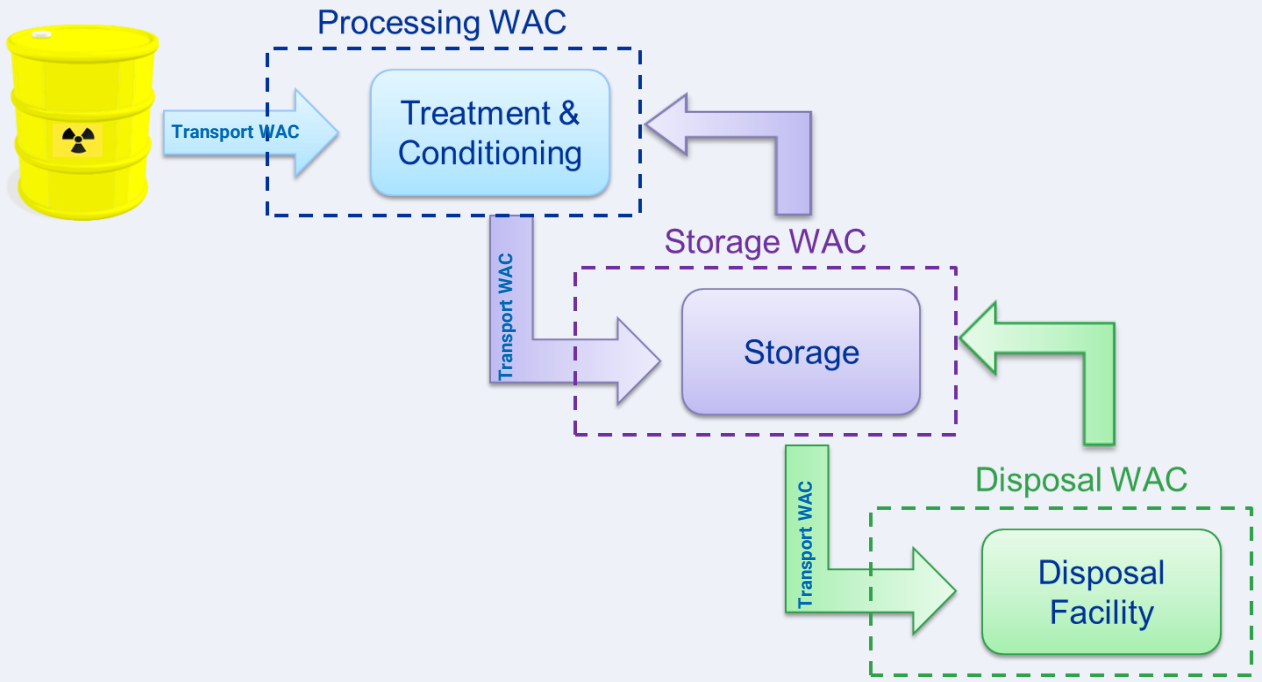
- ✓ Needs political and societal acceptance
- ✓ Needs a legal framework open to RW import/export
- ✓ Needs a framework in the national RWM policies
- ✓ Needs a decision process in the national RWM strategies/programmes
- ✓ Needs clarity on how to license for RW from various countries
- ✓ Needs agreements on cost sharing and on local compensation/benefits
- ✓ ….

Historical Note: Managing RW from foreign origin was not always difficult.

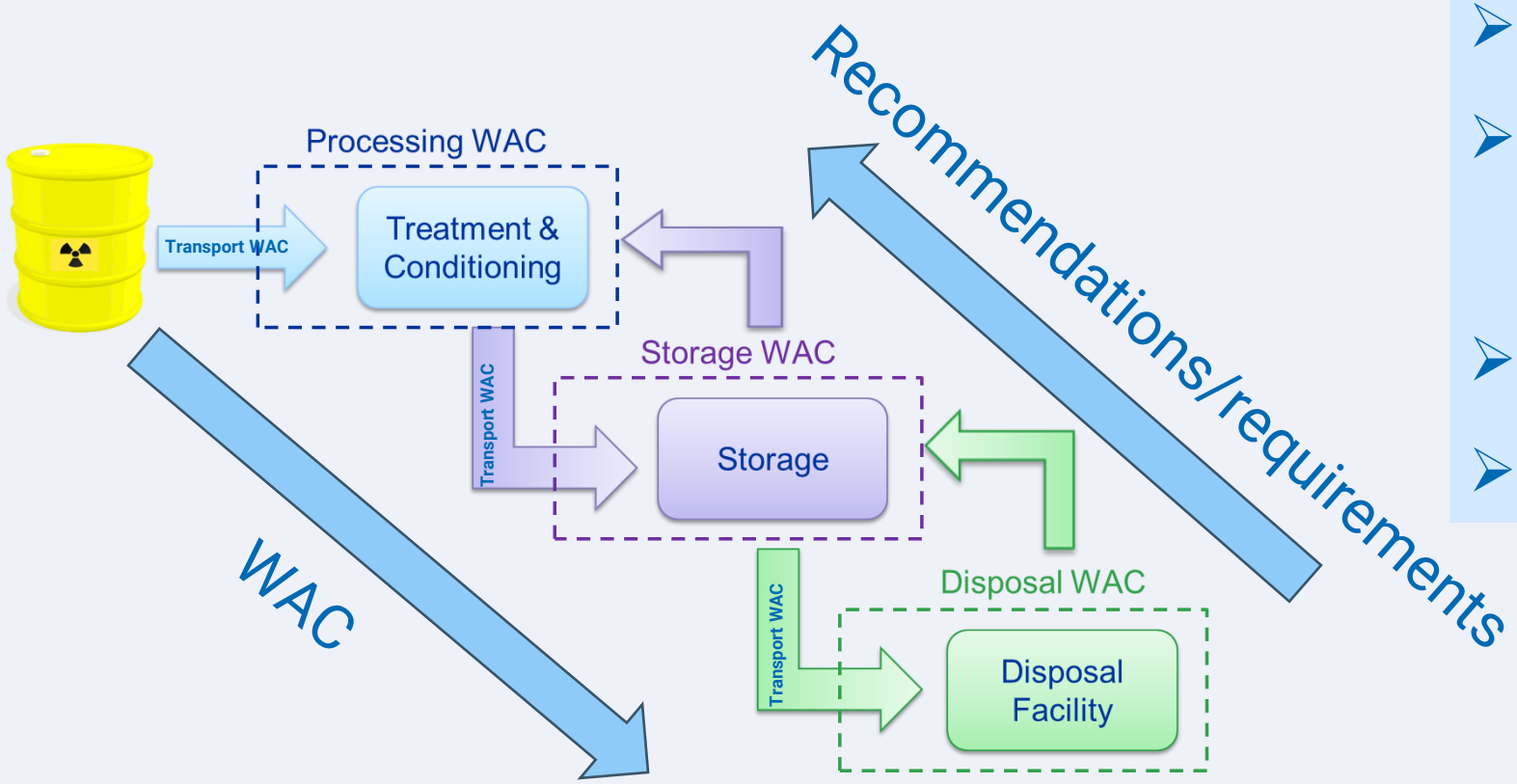
Endpoint – informed RWM Strategy



- ✓ Which concept or combination of disposal concepts to chose?
- ✓ …to begin disposal of RR-SF, and possibly other RW?
- ✓ …to inform needed / preferred “upstream” RWM steps?



Endpoints informing “upstream” RWM steps



- Minimization objectives
- Segregation objectives
- Characterization objectives (Incl.: chemical content)
- Waste form properties
- Container/overpack properties

WAC as an Iterative Process: Needed/Preferred Waste Disposal Container properties both input and output from iterative Disposal System safety assessment

Factors affecting disposal strategy

National radioactive waste inventory

- Comprehensive?
- Capacity to determine radiological and chemical properties?
- Prior treatment and conditioning steps?
- DSRS?
- Volumes (and transport) needed for VLLW/LLW?
- Volumes (and transport) needed for ILW?
- RR spent fuel? – NPP spent fuel? – SMR spent fuel?

Policy/Framework options for Endpoints

- Options for repatriation?
- Options for Spent fuel reprocessing?
- Options for multinational disposal (dual track)?
- Capacity to innovate ("technical" dual track)?
- Keeping options open (i.e. defer disposal decision)?

Human and financial resources

- Defined mandates
- Funding mechanisms
- Available professional expertise

➢ Scheduling and realism of disposal planning

Stakeholder expectations

- National, regional, local
- Neighbouring countries
- Waste owners
- …

"Endpoint – informed RWM" ≠ Urgency to provide disposal capacity

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Thank you

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