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The Fundamentals of Radioactive Waste Management

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RADIOACTIVE WASTE MANAGEMENT: AN OVERVIEW

12th August 2011

ICTP School, Trieste, Italy

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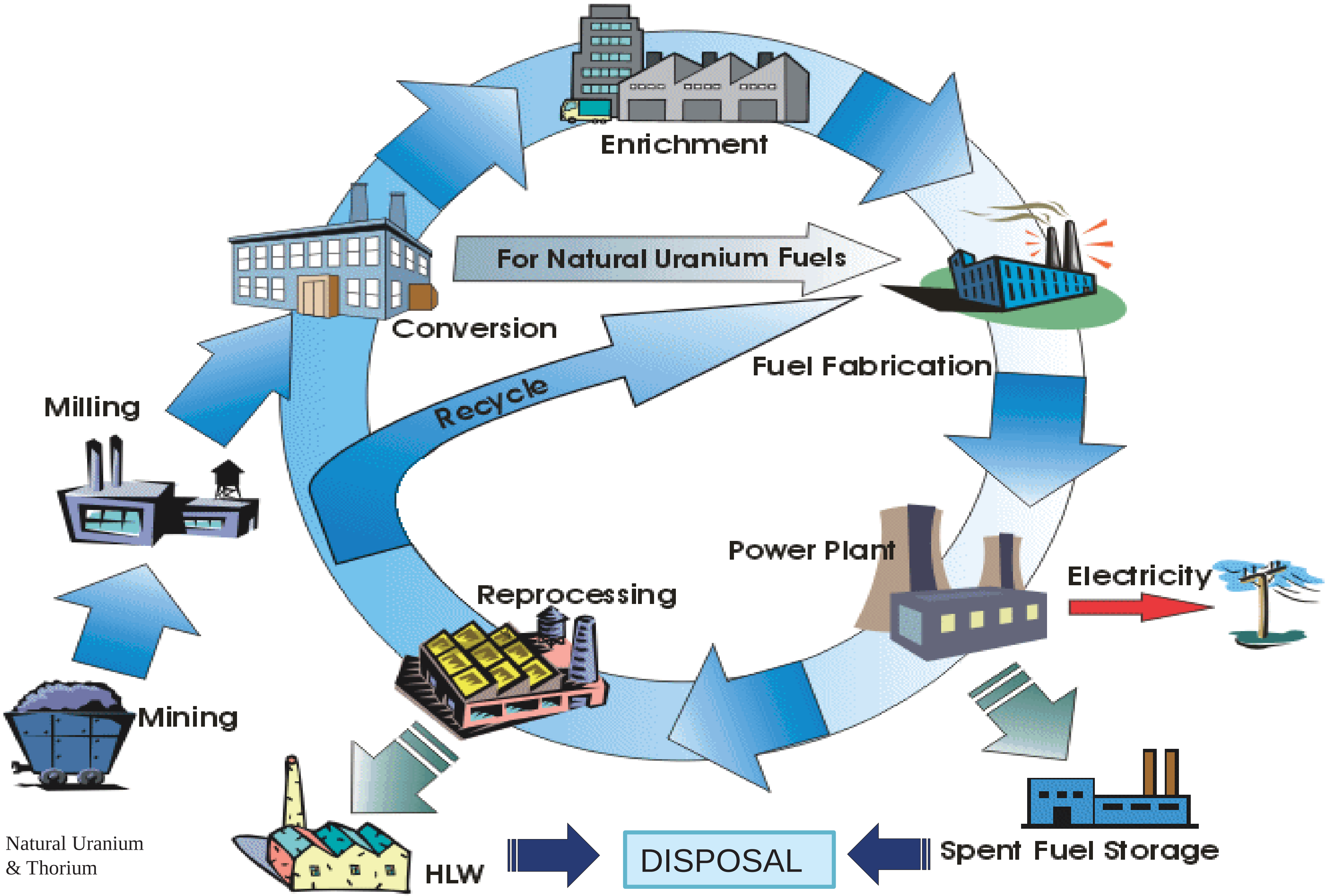
NEFW, IAEA


DANGER!
NUCLEAR
WASTE
ROUTE
STOP WIPP!
Accidents

Presentation Outline

- What is radioactive waste and how does it arise?
- The Goal and Principles of Radioactive Waste Management
- The IAEA Radioactive Waste Classification Scheme
- Pre-Disposal Activities
- Disposal Concepts
- Examples of Repositories

The Nuclear Fuel Cycle



What is radioactive waste?

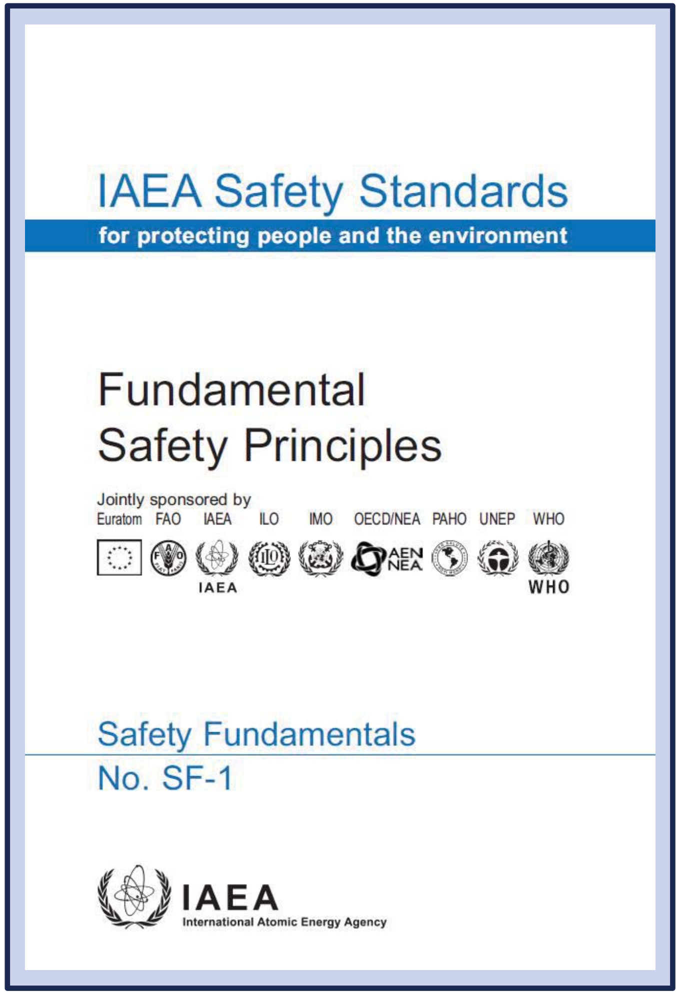
- A radioactive waste is any material that contains or is contaminated with *radionuclides* and for which no use, including recycling, is foreseen. The waste can be in gaseous, liquid or solid form.

- For legal and regulatory purposes, a material can be considered a waste if it contains radioisotopes in activity concentrations above a prescribed regulatory limit (clearance level).

SAFETY is always, at all steps, in each activity, for all parties, the first concern.

The primary **Goal** of radioactive waste management is to protect people and the environment from the harmful effects of ionizing radiation, now and in the future and without an undue burden on following generations.

IAEA Fundamental Safety Principles Document


IAEA Safety Standards
for protecting people and the environment

Fundamental
Safety Principles

Jointly sponsored by
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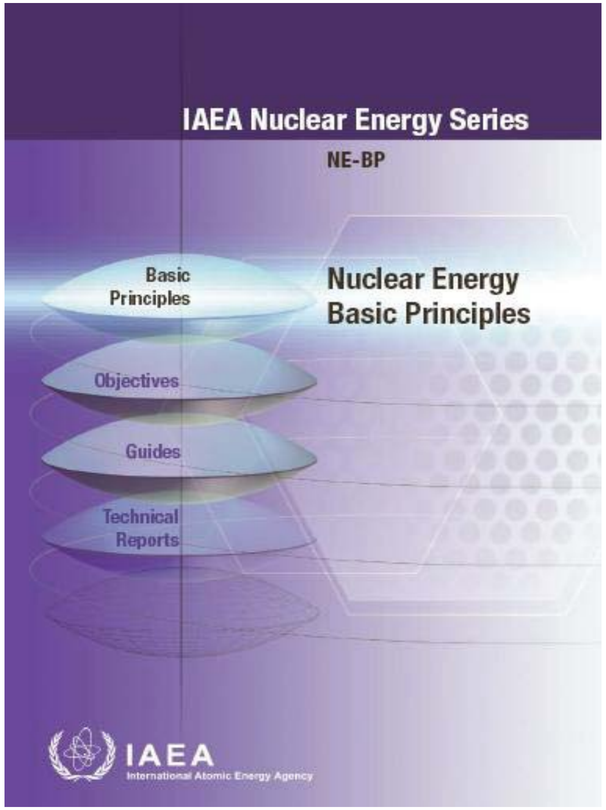
Safety Fundamentals
No. SF-1

IAEA
International Atomic Energy Agency

Other Radioactive Waste Management Principles & Objectives

- The IAEA *Nuclear Energy Basic Principles* document presents the fundamental tenets on which nuclear energy systems should be based to fulfil nuclear energy's potential to help meet growing global energy needs.

- This document and others in the Nuclear Energy Series are intended to complement the IAEA's safety documents by providing guidance on strategies, methods and technologies that will ensure safety (radiological and non-radiological) and efficiency.



Waste Arisings (The sources of radioactive waste)

- Radioactive waste is generated during all stages of the nuclear fuel cycle for nuclear power generation e.g. during uranium mining & milling, nuclear fuel production, reactor operation, reactor decommissioning and the reprocessing of spent fuel

- It also arises during the operation and decommissioning of nuclear research reactors and in operations involving the production of radioisotopes and their application in medicine, industry, agriculture and research.

- The types and volumes of waste produced depend upon the particular operation being conducted, and can vary extensively in radiochemical, chemical and physical content.

Radioactive Waste Classification Schemes

Various classification (categorization) systems exist in Member States and are based on e.g. :

- **Radiological characteristics**
- **Physical and chemical properties**
- **Origin and Technological (processing) aspects**
- **Selected specific features**

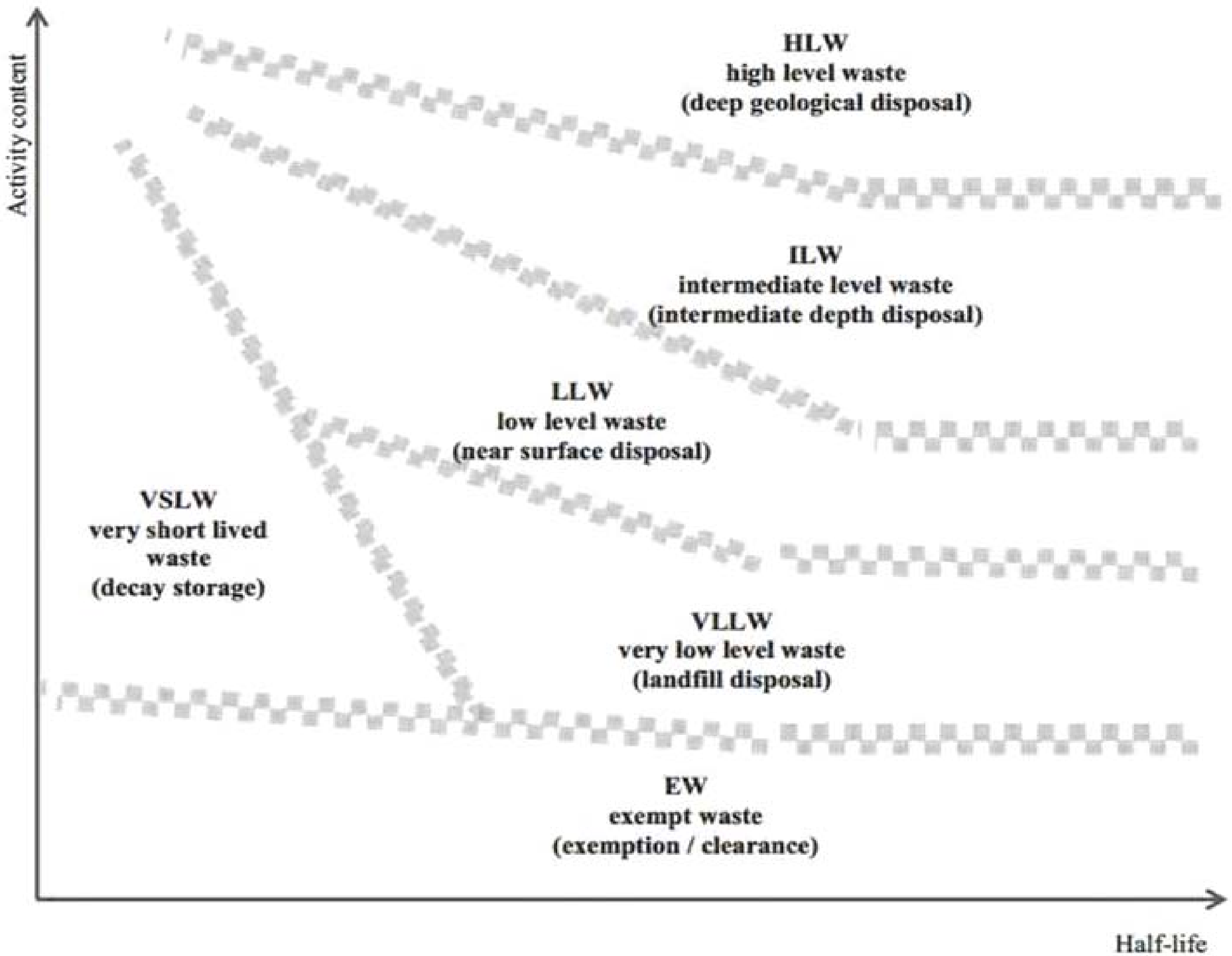
Examples of LLW, ILW & HLW

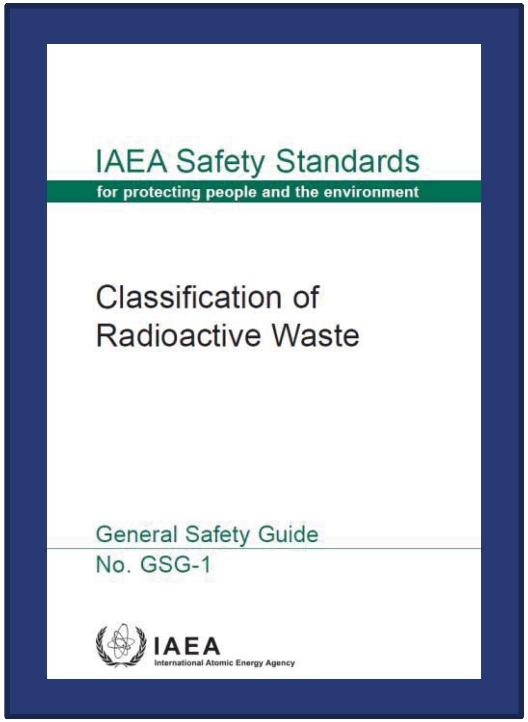
LLW includes loosely contaminated materials (e.g. paper, rags, tools, clothing, filters). Generally the waste does not require significant shielding during handling and interim storage

ILW includes e.g. resins, chemical sludges and metal fuel cladding, as well as contaminated materials from reactor decommissioning. The waste has levels of penetrating radiation sufficient enough to require shielding during handling and interim storage.

SNF/HLW includes the fission products and transuranic elements in the fuel itself or arising from reprocessing (e.g. spent fuel bundles, liquors). It generates significant heat and requires substantial shielding

IAEA RW Classification & Appropriate End Points





General Radioactive Waste Management Options

1. **Dilute and disperse**
    - **Exemption**
    - **Delay and decay (leading to Clearance)**
2. **Contain and disposal**
    - **Conditioning**
    - **Storage**
    - **Disposal**
3. **Return to supplier**

Selection of Waste Management Options

Key Technical and technological criteria

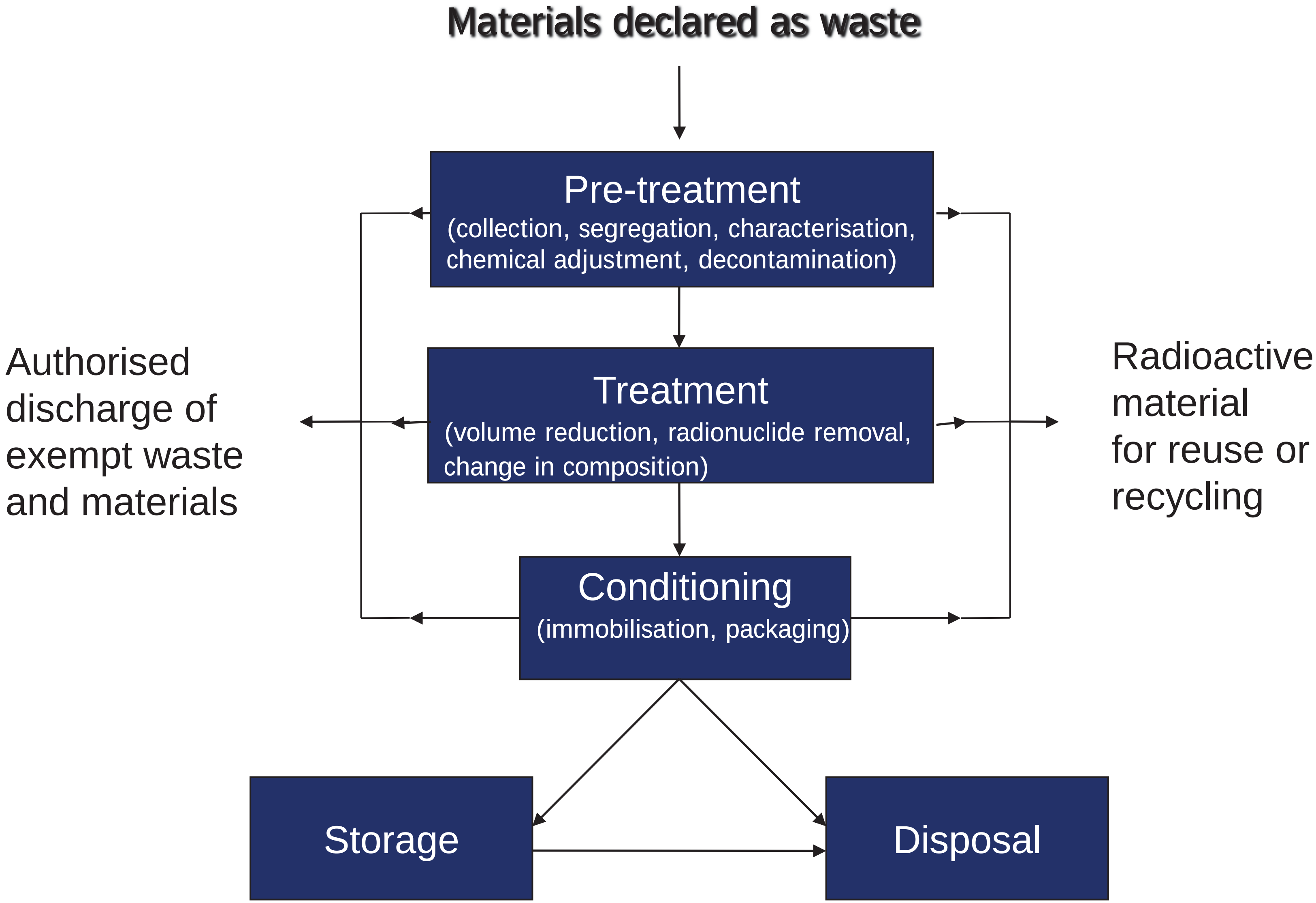
- Waste characteristics
- Scale of technology application (now and in the future)
- Availability of technology, flexibility
- Robustness of technology
- Treated and conditioned product properties
- Volume reduction
- Complexity; maintenance
- Compatibility with existing processes
- Site availability, geological conditions

Selection of Waste Management Options

Key Non-technical factors

- Adequacy of the national waste management system
- National policy and strategy
- Compliance with regulations
- Available infrastructure, interrelations of WM steps
- Manpower and competency
- Resources
- Socio-political situation
- Potential international co-operation
- Financial and practical feasibility
- Cost efficiency

The Basic Steps in RWM



AN IMPORTANT CONCEPT FOR RWM

- Waste minimization – it encompasses three main areas:
  - Source reduction, which includes any activity that reduces or eliminates the generation of radioactive waste within a process (including segregation of waste and prevention of contamination spreading)
  - Recycling and reuse of valuable materials produced as by-products of the process;
  - Actions to reduce the volume (e.g. compaction or incineration)

PRE-DISPOSAL

The Goal of Pre-Disposal

Pre-disposal of radioactive waste includes all activities in the management of radioactive waste from its generation to its reuse and recycling, its discharge within authorised limits or leading up to its ultimate disposal.

The GOAL of Pre-disposal is the disposal,

discharge or reuse and recycling of radioactive waste

In seeking to achieve this goal a primary objective of pre-disposal is to minimize the integrated detriment from the handling, processing and storage of radioactive waste.

Meanings: Pre-treatment

- Characterisation - Determination of the physical, chemical and radiological properties of the *waste* to establish the need for further adjustment, *treatment*, *conditioning*,or its suitability for further handling,
- Segregation – Where materials are separated or are kept separate according to radiological, chemical and/or physical properties. The collection of waste should especially provide for segregation according to half-life and chemical composition in order to facilitate subsequent storage for decay, or treatment, conditioning and disposal.

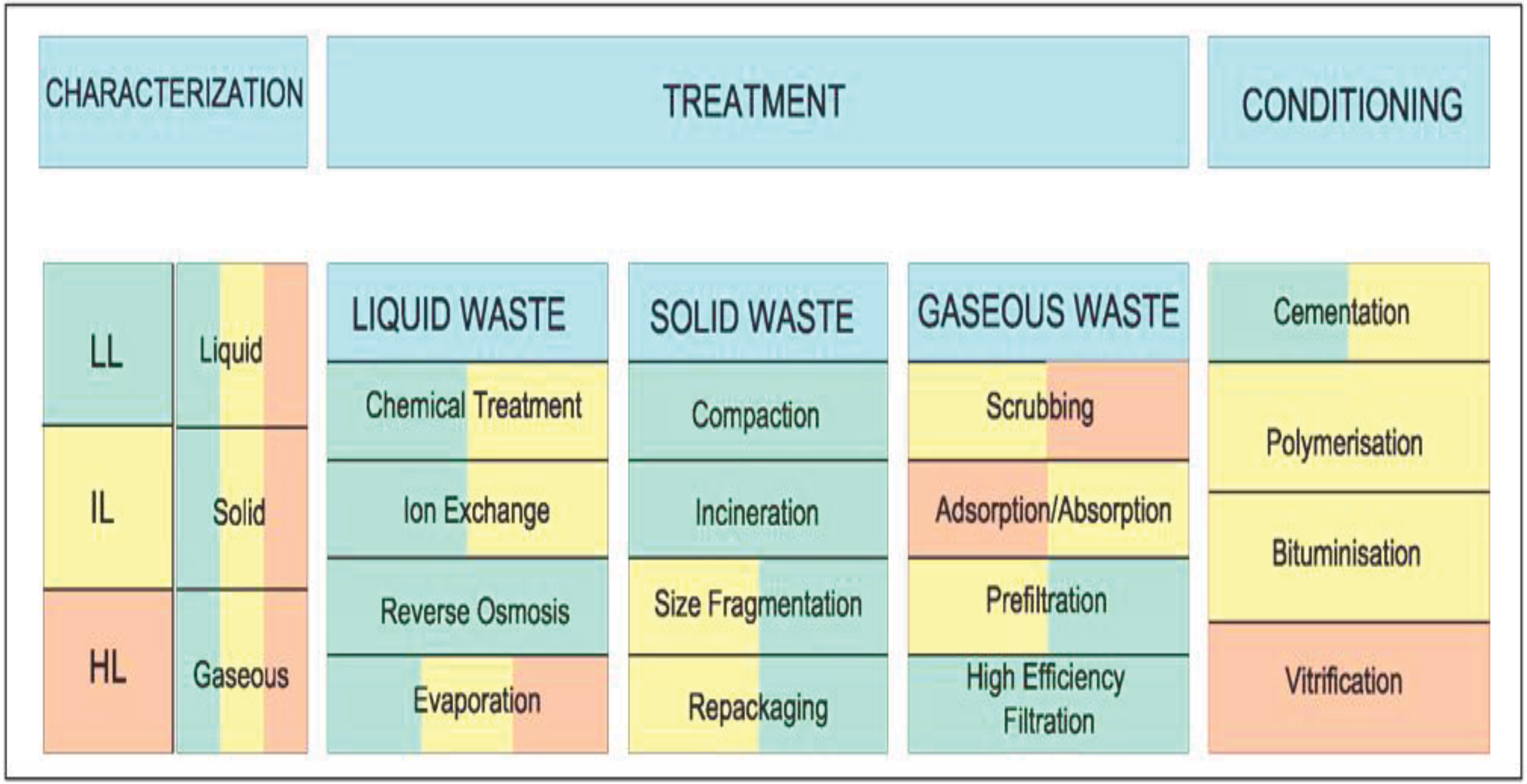
Meanings – Treatment

- Treatment - Operations intended to benefit safety and/or economy by changing the characteristics of the *waste*. Three basic treatment objectives are: *volume reduction,* removal of *radionuclide*s from the *waste* and change of composition.
- Solid waste may be treated by e.g. compaction or incineration, and liquid waste concentrated by means of chemical precipitation, evaporation or ion exchange techniques.

Meanings - Conditioning

- Conditioning of waste is defined as those operations that produce a waste package suitable for handling, transportation, storage and/or disposal. Conditioning may include the conversion of the waste into a solid waste form, enclosure of the waste in containers and, if necessary, providing an overpack. An important component of the conditioning process is the choice of matrix material (e.g. Various kinds of cement, Bitumen, Polymers, Glass or glass-like materials)

PRE-DISPOSAL MANAGEMENT



In most cases packaging will be required for shielding, confinement and/or for handling purposes

Examples of Compactors (Treatment)

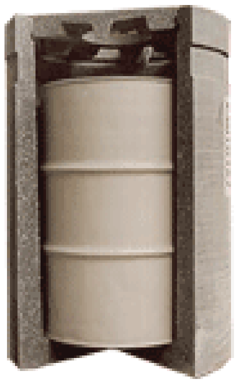
Low pressure in-drum compactor

High pressure drum compactor (super-compactor)

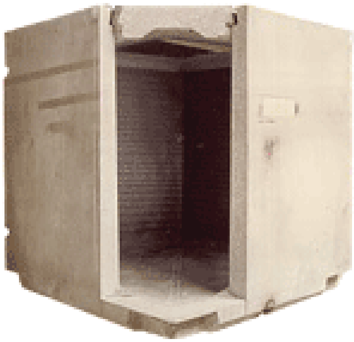
Example of Conditioning Equipment

In-drum cementation facility

Examples of Waste Packaging



CYLINDRICAL
CONTAINERS



CUBICAL
CONTAINERS

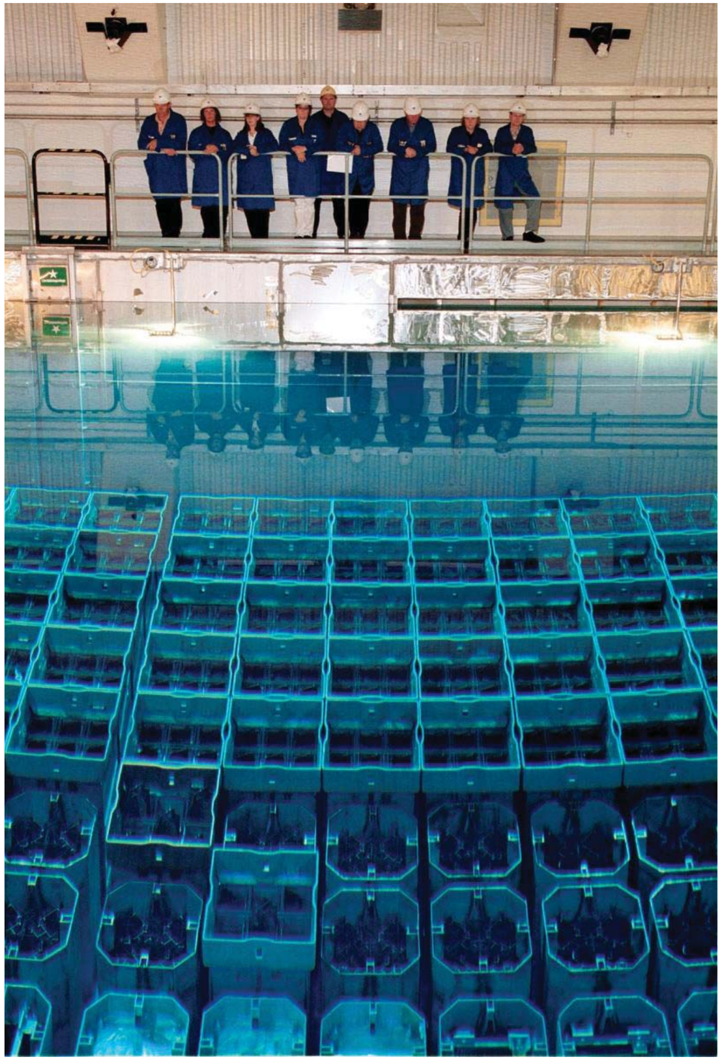
Transport of concrete container

Storage

- Two types of waste storage may be required:
  - For raw waste awaiting treatment and/or conditioning or decay for release.
  - For conditioned waste awaiting disposal.

Interim LLW Storage

SNF STORAGE



Is Prolonged Storage an Option?

Prolonged storage is generally considered to be longer than ‘usual’ design life, but not unlimited ~ 100 years or longer. The benefits may include:

- Waiting for public acceptance
- Waiting for first-movers to prove concepts
- Extended solution for decay of some wastes
- Wait & see what new technologies arise as an alternative to disposal
- No repository available or possible

But, bear in mind:

- A next step is required to provide for an end-point. This option is ultimately not sustainable.
- The option entails transferring responsibility to a future generation (issues of inter-generational equity)

Storage *“Holding of SNF or RW in a facility that provides for its containment, with the intention of retrieval”*

(article 2 of the IAEA Joint Convention)

TRANSPORT OF SNF

DISPOSAL

The Goal of Disposal

The disposal of radioactive waste includes all activities focussed on the emplacement of radioactive waste in a facility with no intention of retrieving it in the future.

The GOAL of disposal is the limitation of radiological impacts of radioactive waste to acceptable levels that ensure the protection of man and the environment, to be achieved through the effective and efficient use of resources

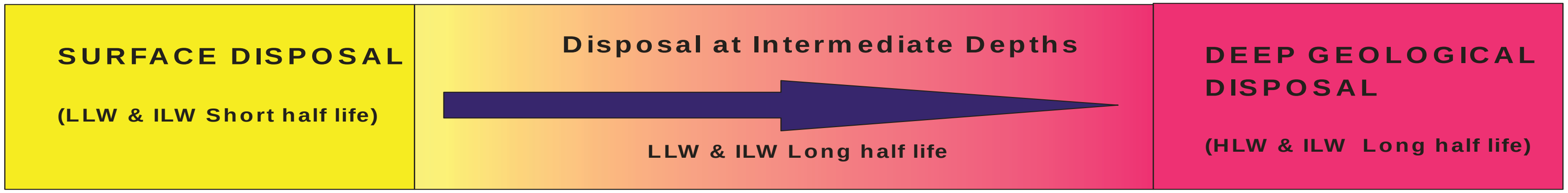
In seeking to achieve this goal an objective of disposal is to minimize the integrated detriment from the handling of radioactive waste during disposal operations and the effects of any releases that may occur during post-closure phase.

Broad Disposal Options

- Surface and near-surface disposal (with and without engineered barriers) including underground cavities (natural or engineered) at relatively shallow depths
- Geological disposal (a mined facility)
- Borehole disposal
- Other "Exotic" disposal options (either not considered credible or legal)

Near-Surface & Geological Disposal

RADIOACTIVE WASTE DISPOSAL OPTIONS



HIGH RELIANCE ON ENGINEERED BARRIERS supported by natural site characteristics

Characterisation & post-closure safety assessment relatively straightforward - limited time scale and near-surface characterisation

Long-term institutional control may continue after emplacement and closure to ensure managed safety

HIGH RELIANCE ON NATURAL BARRIERS supported by engineered and chemical barriers

Characterisation & post-closure safety assessment relatively complex - very long time scales and detailed understanding of the sub-surface necessary

Possible post-closure monitoring but concept relies on passive safety

Factors Affecting Choice of Disposal Option

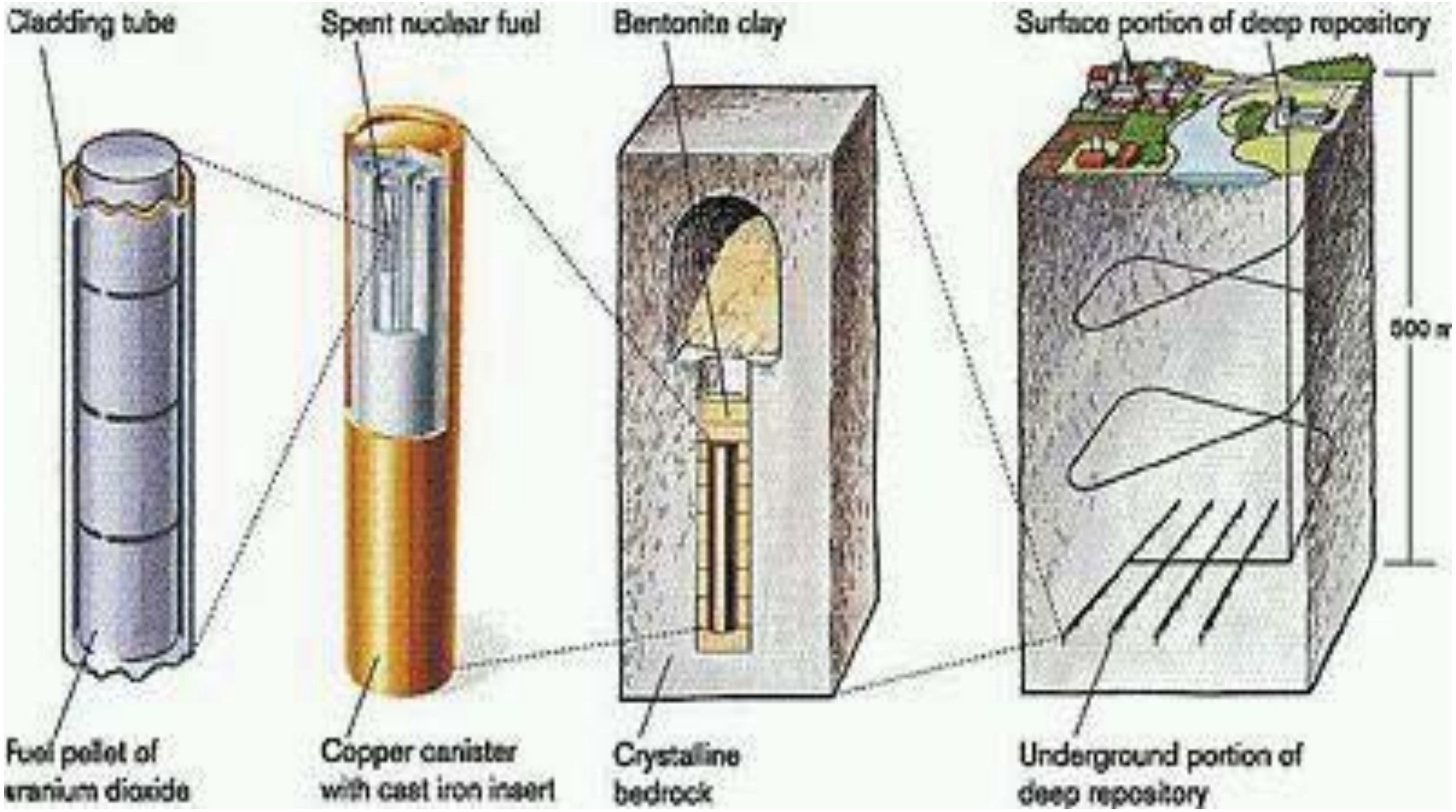
- The choice of an appropriate disposal concept will depend on:
  - Nature of the waste (e.g. activity, half-life, toxicity)
  - Quantity and location of waste (e.g. volume, where is it?)
  - Site Characteristics (e.g. nature of the rock, water flow & chemistry, stability)
  - The repository design and construction
  - Other Factors (e.g. national policy and strategy, stakeholder consensus)

- Disposal is intended to be permanent, but a programme can be designed to include the option of retrievability (reversing the action of waste emplacement before or after closure) and/or reversibility (reverse one or more steps in a repository development at any stage) – but if these are built into the overall concept they must not detract from the basic safety function

Barriers and Safety Functions

- Natural Barriers, i.e. the host rock and surrounding geosphere, provide:
  - Isolation (To keep the waste and its associated hazard apart from people and the accessible biosphere)
  - Containment (Methods or physical structures designed to prevent the dispersion of *radioactive substances)*
    - Factors and processes that contribute to Isolation and Containment e.g. Depth, Barrier Integrity, Dispersion, Dilution, Retardation
- Engineered Barriers – i.e. waste form, container, backfill and repository system
  - Containment
  - Structural stability
  - Limit surface water and groundwater intrusion
  - Gas control
  - Limit intrusion

Multi-Barrier Concept for Geological Disposal



Pathways

- Groundwater Transport (solution and advection/dispersion, colloids, diffusion)
- Surface Water Transport
- Gas (sub-surface and atmospheric)
- Human Intrusion (intentional and inadvertent)
- Microbial processes and Food Chains

Property	Salt	Shale	Granite	Deep boreholes
Thermal conductivity	High	Low	Medium	Medium
Permeability	Practically impermeable	Very low to low	Very low (unfractured) to permeable (fractured)	Very low
Strength	Medium	Low to medium	High	High
Deformation behavior	Visco-plastic (creep)	Plastic to brittle	Brittle	Brittle
Stability of cavities	Self-supporting on decade scale	Artificial reinforcement required	High (unfractured) to low (highly fractured)	Medium at great depth
In situ stress	Isotropic	Anisotropic	Anisotropic	Anisotropic
Dissolution behavior	High	Very low	Very low	Very low
Sorption behavior	Very low	Very high	Medium to high	Medium to high
Chemical	Reducing	Reducing	Reducing	Reducing
Heat resistance	High	Low	High	High
Mining experience	High	Low	High	Low
Available geology*	Wide	Wide	Medium	Wide
Geologic stability	High	High	High	High
Engineered barriers	Minimal	Minimal	Needed	Minimal

Favorable property (blue) | Average (green) | Unfavorable property (orange)

Activity Decreases with Time

10 half lives => 10^3 fold decrease

20 half lives => 10^6 fold decrease

Half Life	10 Half Lives	20 Half Lives
1 Y	10 Y	20 Y => delay/decay
30 Y	300 Y	600 Y => near surface disposal
>30 Y	>300 Y	>600 Y => geological disposal

But, remember:

- **RW is often contaminated by a mixture of RN's**
- **Even after 20 half lives the waste will still be radioactive => case by case evaluation needed**

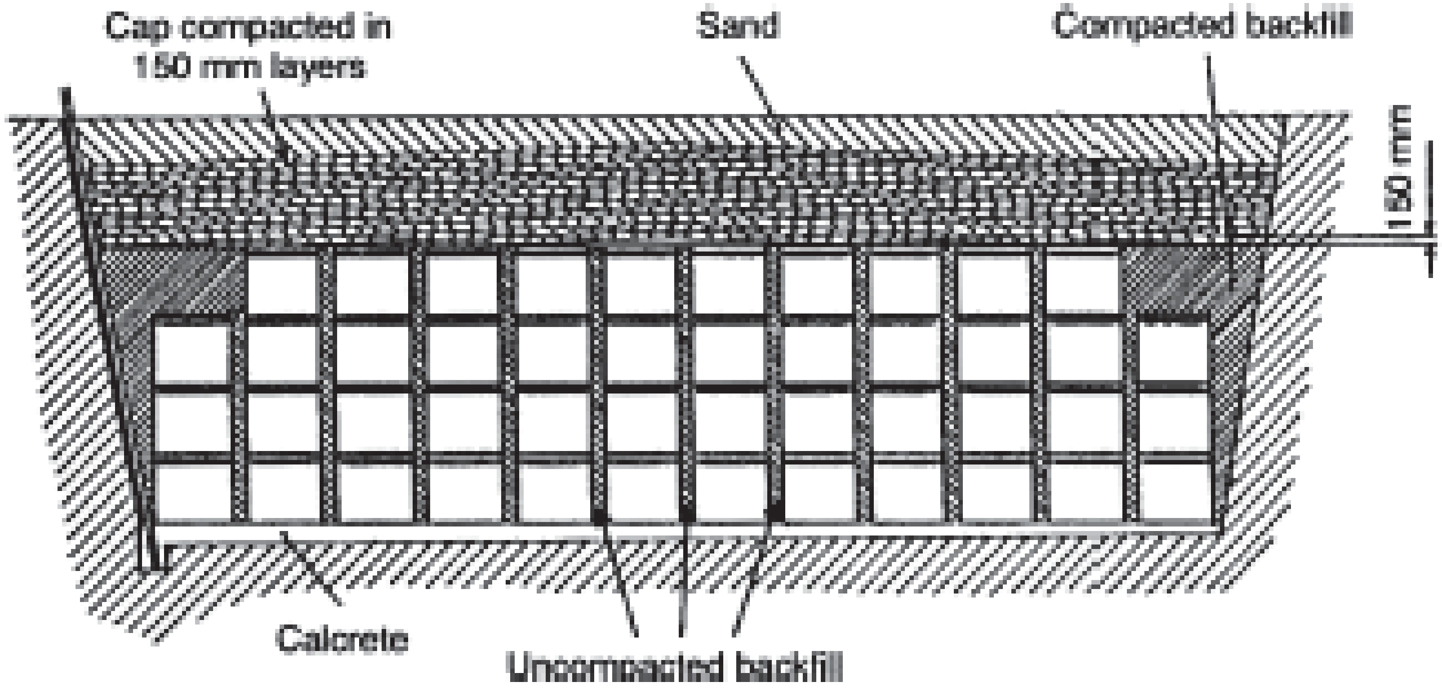
Examples of Repositories

TYPES OF DISPOSAL FACILITIES 1

- Surface trenches (US Ecology Richland)

VAALPUTS (South Africa)

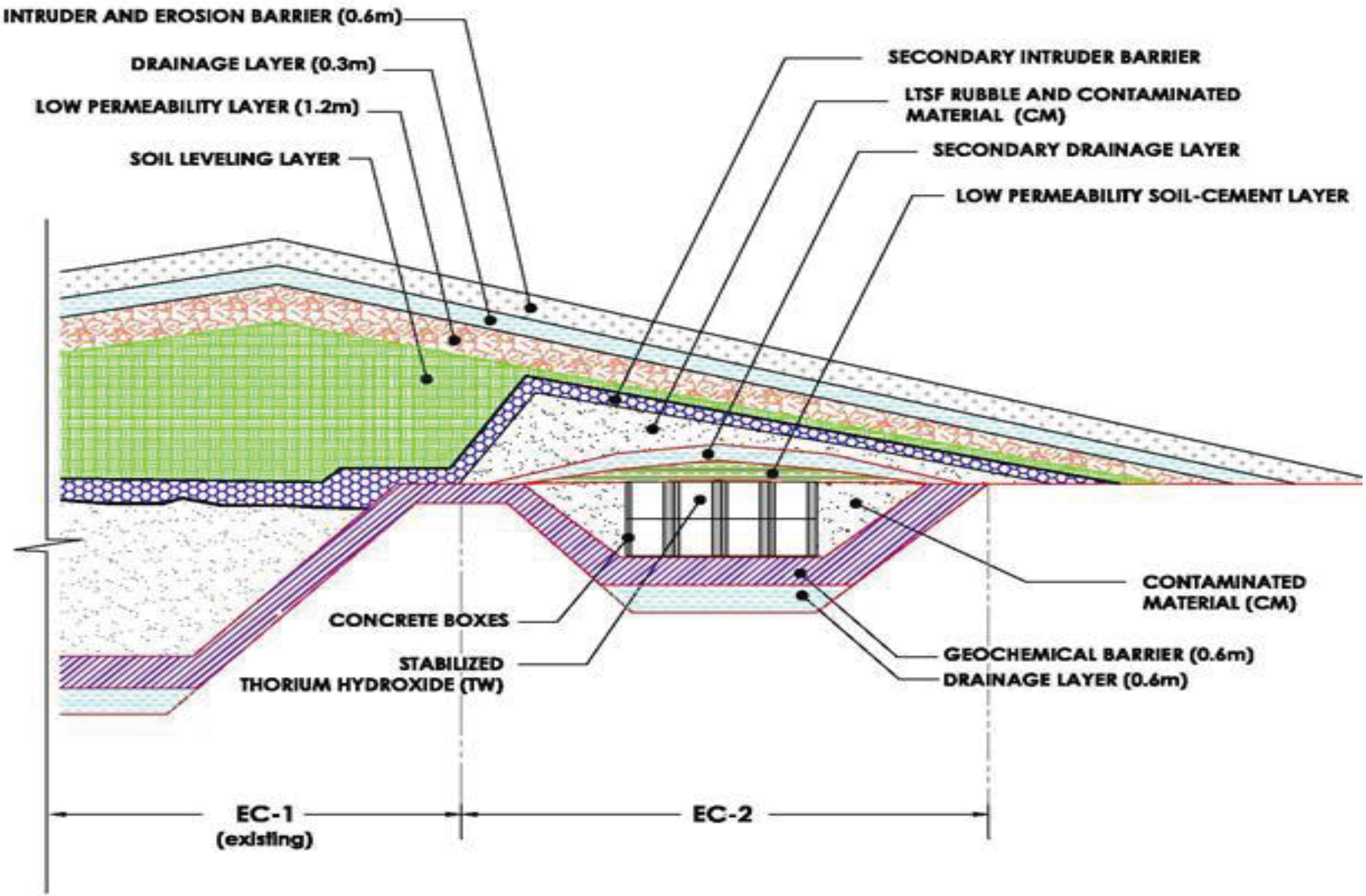
TRENCH - VAALPUTS



VLLW – TRENCHES

- High volume of very low activity waste
- Decommissioning waste (rubble)
- NORM/TENORM

MORVILLIERS – DESIGN SCHEME



TYPES OF DISPOSAL FACILITIES 2

Surface and Near surface engineered vaults
(Mochovce, Slovakia)

TYPES OF DISPOSAL FACILITIES 3

Subsurface caverns (Loviisa, Finland)

TYPES OF DISPOSAL FACILITIES 4

Geological repositories (Morsleben, Germany)

Waste Package Emplacement at Morsleben

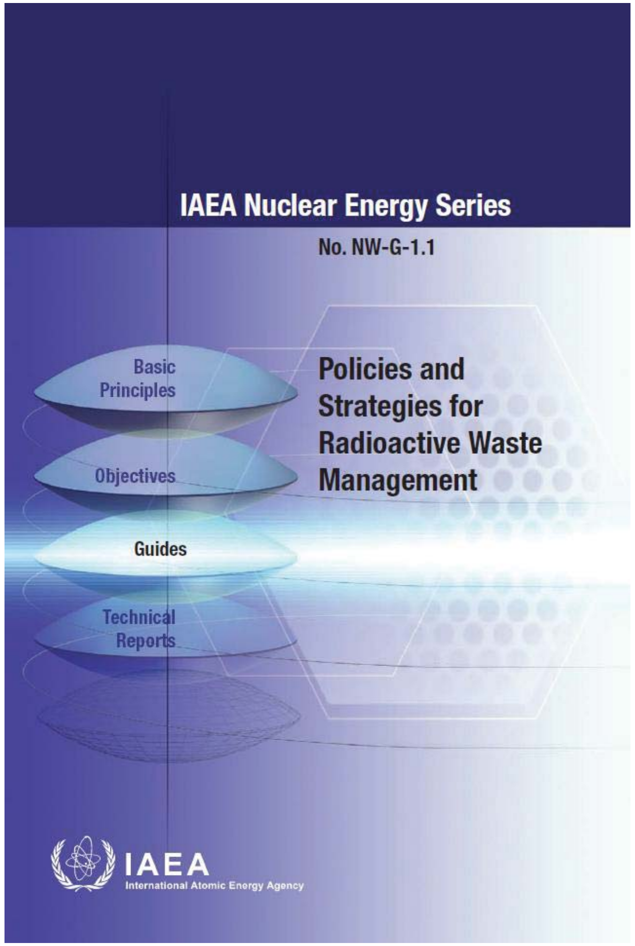
Key RWM Infrastructure Areas to be Considered by Newcomer Member States

- Clear national Policy & Strategy
- Legislative environment providing rules
- Responsibility allocation among regulators, waste generators and waste disposer
- Adequate financing scheme
- Human capability and technological ability to manage waste
- Transparent & open stakeholder communication system

A starting point:

National policy & appropriate technical strategies

Policies and Strategies for Radioactive Waste Management, IAEA NES No. NW-G-1.1 (2009)



Thank you for your attention