Radioactive Waste Arising, Management Options and Waste Classification

name of presenter (e-mail)
training event title
dates
location, host organization, host country
This lecture provides:

- An overview of radioactive waste arising from various practices, and the rationale for waste classification systems.
- A summary of management approaches used for different types of waste
- Examples of final disposal choices
Radioactive waste arises from many different activities, for example:

• Operation and decommissioning of nuclear facilities (e.g. nuclear power plants);
• Application of radionuclides in industry, medicine, and research;
• Cleanup of contaminated sites; and
• Processing of raw materials containing naturally occurring radionuclides.
Sources of Radioactive Waste (1)

Nuclear fuel cycle - Power generation

- **Operational waste**
  - Ion exchange resins, evaporation and filtering residues
  - Metal scrap, thermal insulation material, protective clothing
  - Very low to medium level concentrations of RN

- **Spent nuclear fuel**
  - Large inventory, large number of radionuclides

- **Decommissioning waste**
  - Large amounts
  - Very low to high concentrations - mainly activation products
# Activity Levels in LILW from Reactors

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>BWR Activity, TBq/GW(e)-y</th>
<th>BWR Percent of Total Activity</th>
<th>PWR Activity, TBq/GW(e)-y</th>
<th>PWR Percent of Total Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>6.33</td>
<td>1.15</td>
<td>0.662</td>
<td>0.0594</td>
</tr>
<tr>
<td>C-14</td>
<td>0.161</td>
<td>0.0294</td>
<td>0.0352</td>
<td>0.0315</td>
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<tr>
<td>Cr-51</td>
<td>7.35</td>
<td>1.34</td>
<td>0.850</td>
<td>0.762</td>
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<tr>
<td>Mn-54</td>
<td>24.0</td>
<td>4.38</td>
<td>3.56</td>
<td>3.19</td>
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<tr>
<td>Fe-55</td>
<td>189.1</td>
<td>34.5</td>
<td>29.34</td>
<td>26.3</td>
</tr>
<tr>
<td>Co-58</td>
<td>5.55</td>
<td>1.01</td>
<td>10.14</td>
<td>9.09</td>
</tr>
<tr>
<td>Fe-59</td>
<td>0.618</td>
<td>0.113</td>
<td>0.0684</td>
<td>0.0613</td>
</tr>
<tr>
<td>Ni-59</td>
<td>1.19</td>
<td>0.216</td>
<td>0.0271</td>
<td>0.0243</td>
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<tr>
<td>Co-60</td>
<td>269.0</td>
<td>49.1</td>
<td>46.41</td>
<td>41.60</td>
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<tr>
<td>Ni-63</td>
<td>19.2</td>
<td>3.51</td>
<td>7.55</td>
<td>6.76</td>
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<tr>
<td>Zn-65</td>
<td>11.1</td>
<td>2.02</td>
<td>0.0025</td>
<td>0.00227</td>
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<td>Sr-90</td>
<td>0.0259</td>
<td>0.0047</td>
<td>0.841</td>
<td>0.754</td>
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<tr>
<td>Y-90</td>
<td>0.0259</td>
<td>0.0047</td>
<td>0.841</td>
<td>0.754</td>
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<tr>
<td>Nb-94</td>
<td>0.000334</td>
<td>0.00006</td>
<td>0.00005</td>
<td>0.00004</td>
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<tr>
<td>Te-99</td>
<td>0.00560</td>
<td>0.0010</td>
<td>0.00146</td>
<td>0.0013</td>
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<tr>
<td>I-129</td>
<td>0.0164</td>
<td>0.0030</td>
<td>0.00032</td>
<td>0.0003</td>
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<tr>
<td>Cs-134</td>
<td>2.80</td>
<td>0.510</td>
<td>2.98</td>
<td>2.67</td>
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<tr>
<td>Cs-137</td>
<td>6.02</td>
<td>1.10</td>
<td>4.22</td>
<td>3.78</td>
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<tr>
<td>Ba-137m</td>
<td>5.70</td>
<td>1.04</td>
<td>3.99</td>
<td>3.58</td>
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<tr>
<td>Ce-144</td>
<td>0.0136</td>
<td>0.0025</td>
<td>0.0118</td>
<td>0.0106</td>
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<tr>
<td>Pr-144</td>
<td>0.0136</td>
<td>0.0025</td>
<td>0.0118</td>
<td>0.0106</td>
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<tr>
<td>Pu-241</td>
<td>0.0291</td>
<td>0.0053</td>
<td>0.0147</td>
<td>0.0132</td>
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<tr>
<td>Cm-242</td>
<td>0.00445</td>
<td>0.0008</td>
<td>0.0228</td>
<td>0.0204</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>548.24</strong></td>
<td>---</td>
<td><strong>111.57</strong></td>
<td>---</td>
</tr>
</tbody>
</table>
Sources of Radioactive Waste (2)

Nuclear fuel cycle - Various

• Mining and milling and U ore extraction
  — Large quantities
  — Enhanced levels naturally occurring radionuclides
  — Radium-226, radon-222

• Chemical refining
  — small amounts of waste

• Enrichment
  — depleted uranium a waste?

• Reprocessing of spent fuel.
## Typical tailings properties

<table>
<thead>
<tr>
<th>Mine</th>
<th>Ore Grade (%)</th>
<th>Uranium Production (t)</th>
<th>Volume of Tailings (t)</th>
<th>Uranium / Tailings Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaverlodge</td>
<td>0.21</td>
<td>21,236</td>
<td>10,100,000</td>
<td>475</td>
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<tr>
<td>Key Lake</td>
<td>1.95</td>
<td>71,611</td>
<td>4,400,000</td>
<td>61</td>
</tr>
<tr>
<td>McArthur</td>
<td>12.75</td>
<td>160,200</td>
<td>4,400,000</td>
<td>27</td>
</tr>
</tbody>
</table>
Sources of Radioactive Waste (3)

Industrial applications

- Production of radioactive sources
- Use of radioactive sources
  - Sealed sources
    - Thickness, level and density gauges
    - Industrial radiography, sterilization facilities
    - Large number of potentially hazardous sources
  - Unsealed sources
    - Tracers, monitoring
    - Mostly short-lived radionuclides
- Co-60, Cs-137, Ir-192, Am-241,…
Sources of Radioactive Waste (4)

Medical applications

• Diagnosis and treatment
• Large number of administrations and operations
• Short-lived liquid and solid waste
• Large activity administrations
• High-activity sealed sources
• Tc-99m, I-131, P-32, Y-90, Sr-89
• Co-60, Ir-192, Cs-137
Sources of Radioactive Waste (5)

Research and development
- Wide variety of uses
- Wide variety of techniques

Other:
- historical sources - radium processing
- defense programs – legacy wastes
Sources of Radioactive Waste (6)

Wastes containing naturally occurring radioactivity (NORM)

- Phosphate industry
- Production of metals
- Refractory materials
- Energy Production (Oil and Gas, Coal, Biomass, Geothermal)
- Usually large volumes, Ra-226, Rn-222
Radioactivity in NORM

<table>
<thead>
<tr>
<th>Material</th>
<th>Radionuclide Concentrations (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale in pipes and equipment for oil/gas production</td>
<td>0 - 15,000,000 (average one thousand to hundreds of thousand)</td>
</tr>
<tr>
<td>Sludges in natural gas supply equipment</td>
<td>up to ~40,000</td>
</tr>
<tr>
<td>Sludges from ponds of produced water</td>
<td>10,000 to greater than 40,000</td>
</tr>
<tr>
<td>Scales from geothermal energy production</td>
<td>4,000 - 40,000</td>
</tr>
<tr>
<td>Uranium mining overburden</td>
<td>100 - 20,000 (only Radium reported) (average ~5,000 total radionuclide concentration)</td>
</tr>
<tr>
<td>Coal fired power plants</td>
<td>100 - 25,000</td>
</tr>
<tr>
<td>Drinking water treatment waste</td>
<td>Sludges - ~600 (only $^{226}$ Ra reported)</td>
</tr>
<tr>
<td></td>
<td>Resins - ~1,300,000 (only $^{226}$ Ra reported)</td>
</tr>
<tr>
<td>Phosphate fertilizer</td>
<td>1,000 - 25,000</td>
</tr>
<tr>
<td>Phosphate processing waste</td>
<td>Phosphogypsum - 1,000 - 4,000</td>
</tr>
<tr>
<td></td>
<td>Slag - 2,000 - 7,000</td>
</tr>
<tr>
<td>Other mineral processing waste</td>
<td>Scale - ~40,000 (only $^{226}$ Ra reported)</td>
</tr>
<tr>
<td></td>
<td>up to 40,000 (generally 100 - 5,000)</td>
</tr>
</tbody>
</table>

These data should only be used as rough indicators of the levels of radioactivity.
Waste Properties

- Origin/Source
- Criticality
- Radiological Properties
  - half-life
  - heat generation
  - intensity of radiation
  - nuclide conc.
  - surface contamination
  - dose factors
- Biological properties:
  - potential biological hazards

- Chemical Properties
  - potential chemical hazard
  - combustible, corrosive
  - organic content
  - reactivity
  - gas generation
  - sorption of radionuclides

- Other Physical Properties
  - compactability, incinerability
  - dispersability, volatility
  - solubility, miscibility
  - physical state (solid, liquid, gas)
  - size and weight
Waste Management Approaches

Waste and materials

Pre-treatment

Treatment

Conditioning

Disposal

Effluent discharge

Clearance

Recycling and re-use
‘Delay and Decay’ – hold waste in storage until sufficient decay has occurred for desired management approach.
Waste Management Approaches (2)

- ‘Concentrate and Contain’ – reduce volume and condition and/or containerize waste to limit dispersion in the environment
• ‘Dilute and Disperse’ – discharge waste in a manner that environmental conditions reduce concentrations to acceptable levels
Spent Fuel Management Options

- Two main alternatives to manage spent fuel (reprocessing and direct disposal)
  - Spent fuel may also be stored for use at a later date (not considered a waste);
- All predisposal options involve a period of storage of the spent fuel.
Purpose - for safety, engineering, operational and regulatory aspects:

- Devising radioactive waste management strategies, planning, designing and operating waste management facilities;

- Facilitating record keeping and giving a broad indication of the potential hazards involved in the various types of waste at the operational level;

- Communication between interested parties by providing well understood terminology (e.g., Joint Convention)
Difference between waste acceptance criteria (WAC) and a waste classification system?

- **WAC** – are specific to a particular predisposal management activity, storage or disposal facility.

- **Waste classification systems** – provide a national system of classification for managing all types of radioactive waste. Do not specify criteria for individual facilities.
Difference between waste acceptance criteria (WAC) and a waste classification system?

- WAC provide detailed specifications as per waste properties on earlier slide for waste to meet before it can be accepted at a predisposal management activity, storage or disposal facility.

- WAC is defined as part of the safety assessment and safety case of any radioactive waste management facility or activity while the classification system depends on the policy and strategy for the safe management of radioactive waste.
Some of the possible ways to classify waste:

- **Classification by origin**
  Nuclear fuel cycle, isotope production,..

- **Classification by physical state**
  Solid, liquid, gaseous

- **Classification by activity concentration**
  Very Low Level waste (VLLW), Low Level Waste (LLW), Intermediate Level Waste (ILW), High level Waste (HLW)

- **Classification by half-life**
  Short-lived waste, long-lived waste
Ideal classification system should:

Cover all RW types

- Address all stages of RW management
- Relate RW classes to potential hazard
- Be flexible
- Not change accepted terminology
- Be simple, easy to understand
- Be universally applicable

No such system exists!
Need for a classification system?

• Permits appropriate decisions to be made at each step of lifecycle management of wastes.

• Provides a systematic foundation for waste segregation programmes.

• Efficient management system for operators (otherwise decisions are ad hoc or made on case by case basis).

• Provides essential input for national WM policy & strategy.
New IAEA Waste Classification

IAEA Safety Standards
for protecting people and the environment

Classification of Radioactive Waste

General Safety Guide
No. GSG-1

IAEA
International Atomic Energy Agency

2010

supersedes

1994
Objectives

• To set out a general scheme for classifying radioactive waste that is based primarily on considerations of long term safety, and thus, by implication, disposal of the waste.

• To identify the conceptual boundaries between different classes of waste and provides guidance on their definition on the basis of long term safety considerations.
Scope:

• from spent nuclear fuel, when it is considered radioactive waste, to

• waste having such low levels of activity concentration that it is not required to be managed or regulated as radioactive waste,

• disused sealed sources, when they are considered waste, and

• waste containing radionuclides of natural origin.
Summary of IAEA System GSG - 1

Waste types

Safety Principles and Requirements

- Regulatory Aspects
- Technological Aspects
- Economical Aspects
- Social Aspects
The IAEA system

(1) Exempt waste

(2) Very short lived waste (VSLW)

(3) Very low level waste (VLLW)

(4) Low level waste (LLW)

(5) Intermediate level waste (ILW)

(6) High level waste (HLW)

The term ‘exempt waste’ has been retained from the previous classification scheme for consistency; however, once such waste has been cleared from regulatory control, it is not considered radioactive waste.

Quantitative values of allowable activity content for each significant radionuclide should be specified on the basis of safety assessments for individual disposal sites (which is outside the scope of this Safety Guide).
In the classification scheme, the following options for management of radioactive waste are considered, with an increasing degree of containment and isolation in the long term:

— Exemption or clearance;
— Storage for decay;
— Disposal in engineered surface landfill type facilities;
— Disposal in engineered facilities such as trenches, vaults or shallow boreholes, at the surface or at depths down to a few tens of metres;
— Disposal in engineered facilities at intermediate depths between a few tens of metres and several hundred metres (including existing caverns) and disposal in boreholes of small diameter;
— Disposal in engineered facilities located in deep stable geological formations at depths of a few hundred metres or more.
Exempt Waste (EW)

Waste that has been cleared, exempted or excluded from regulation as described in Safety Guide RS-G-1.7 “Application of the Concepts of Exclusion, Exemption and Clearance” (2004)
Waste containing material that can be slightly above the exempt region. Disposal facilities for such waste do not need a high level of containment and isolation and near surface landfill is generally suitable. Typical waste would include soil and rubble with activity low enough not to require shielding.
Very Short Lived Waste (VSLW)

Waste that can be stored for decay over a limited period of up to a few years and subsequently cleared for uncontrolled disposal or discharge after a suitable period of storage. This would include radioactive waste containing short half life radionuclides typically used for research and medical purposes.
Waste that contains material with radionuclide content above clearance levels, but with limited amounts of long lived activity. It requires robust isolation and containing for periods of up to a few hundred years typically 300. It includes a very broad band of materials that includes very high activity waste with short half life that requires shielding and some long lived material at relatively low activity levels. .............
Cont.

Such waste would require up to around 300 years of control but would not be hazardous beyond that period of time. The radionuclides within the waste will decay to activity levels that are acceptably low from a radiological safety viewpoint, within a time period during which institutional controls can be relied upon.
Intermediate level waste (ILW)

Waste which, because of its high radionuclide content and the potential mobility of the materials involved requires a higher level of containment and isolation than is provided by near surface disposal. However, needs little or no provision for heat dissipation during its handling, transportation and disposal. It may include long lived waste that will not decay to an acceptable activity level during the time which institutional controls can be relied upon.
High Level Waste (HLW)

Waste with radioactivity levels intense enough to generate significant quantities of heat by the radioactive decay process or with large amounts of long lived activity which need to be considered in the design of a disposal facility for the waste. Disposal in deep, stable geological formations is the preferred option for its disposal. It includes spent reactor fuel which has been declared as waste, vitrified waste from the processing of reactor fuel and any other waste requiring the degree of containment and isolation provided by geological disposal.
The IAEA Waste Classification System (2009) categorizes waste into different levels based on their activity content and half-life. Here are the classifications:

- **High Level Waste (HLW)**: High level waste is disposed of in deep geologic disposal sites.
- **Intermediate Level Waste (ILW)**: Intermediate level waste is disposed of at intermediate depth disposal sites.
- **Low Level Waste (LLW)**: Low level waste is disposed of near surface disposal sites.
- **Very Short Lived Waste (VSLW)**: Very short lived waste is stored in decay storage.
- **Very Low Level Waste (VLLW)**: Very low level waste is disposed of at landfill disposal sites.
- **Exempt Waste (EW)**: Exempt waste is allowed under exemption or clearance processes.

The diagram illustrates the relationship between the activity content and half-life of waste, showcasing how different types of waste are classified based on these characteristics.
Classification as Practised

- Many member states still use their own system, customized to fit local needs.
- Disposal endpoint is what is most commonly used to define waste classes.
- As part of Joint Convention, each country reports on national system of waste classification and reports a national inventory of radioactive waste.
Waste Disposal Options

Surface Disposal

Geological Disposal

Near-Surface Disposal

Well injection

Surface Discharge
Waste Disposal Options (cont.)

Geological Disposal

- Ventilation shaft
- Access tunnel
- Characterisation tunnel, main investigation level
- Lower investigation level
## Waste Types and Disposal Options (cont.)

<table>
<thead>
<tr>
<th>NORM</th>
<th>DSS</th>
<th>LILW</th>
<th>HLW</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXC</td>
<td>LO W</td>
<td>ENH</td>
<td>ENH</td>
</tr>
<tr>
<td>LANDFILL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEAR SURFACE &lt; 30 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INTERMEDIATE &lt; 200 m</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>GEOLOGICAL &gt; 200 m</td>
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</tr>
</tbody>
</table>

### Colors

- **ACCEPTABLE**
- **NOT APPROPRIATE**
- **UNACCEPTABLE**
Selection of Management Options

• Selected options must be consistent with National policies for waste management;
• Need to consider interdependencies with other predisposal and final disposal options;
• Adequate characterization of waste is critical.
Summary

• Permits appropriate decisions to be made at each step of lifecycle management of wastes

• Provides a systematic foundation for waste segregation programmes

• Efficient management system for operators (otherwise decisions are ad hoc or made on case by case basis)

• Provides essential input for national waste management policy and strategy
Many member states still use their own system, customized to fit local needs.

Disposal endpoint is what is most commonly used to define waste classes.

As part of Joint Convention, each country reports on national system of waste classification and reports a national inventory of radioactive waste.
Thank you!