MANAGEMENT OF LARGE AMOUNTS OF WASTE ARISING FROM A NUCLEAR/RADIOLOGICAL EMERGENCY AND LEGACY SITES

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International Workshop on the Safe Disposal of Low Level Radioactive Waste 03 to 05 February 2015, Montrouge, France
Overview

- Waste management requirements and approaches for large volumes of waste arising from
  - Nuclear accidents
  - Legacy sites
- Example of waste management approaches at uranium mining legacy sites
- Current IAEA activities (development of TECDOC)
Normal Situation

- Nuclear facility, e.g., nuclear power plant
  - Implementation of a system of legal regulations
  - High levels of safety, safe operation predominantly required
  - Licensing process well established
  - Clear allocation of responsibilities
  - Supervision by competent authority

- Well-established radioactive waste management system
  - Handling, treatment, and processing of operational, decommissioning and dismantling waste
  - Engineered storage
  - Disposal in near-surface and/or geological repositories
Emergency Situation

- Emergency situation after a nuclear accident is totally different from the normal situation
- Unexpected event (beyond design basis) including many uncertainties and unforeseen issues
- Essential features:
  - Destruction (at least of parts) of the nuclear facility
  - Release of radionuclides, high radiation exposures
  - Contamination of large areas of land (mainly off-site)
  - Huge amounts of radioactive residues, i.e., radioactive waste and contaminated material (mainly onsite)
  - Urgent clean-up measures in severe radiation fields
Nuclear Accident Phases

- Initial phase of a nuclear accident
  - Period of threat resulting from the facility failures
  - Period of possible radioactive releases from the facility until the operator is able to bring the plant in a safe state.
  - Main activities aiming at mitigation of accident
  - Period after the emergency phase, with the return of the facility in a safe state, the end of significant radioactive discharges
Nuclear Accident Phases

- Phase subsequent to the actual accident
  - Transition period - uncertainty as to the actual contamination of the environment and about the future of the affected territories
  - Long-term period - contamination of the territories, and the risk of human exposure to a lower but sustainable level (up to several years after the accident)
  - Activities on waste management more and more important
  - Development of a waste management strategy:
    - Guidance for effective waste-related emergency response
    - Perspectives for reasonable clean-up measures
    - Advice for decision making
Post-Accident Remediation and Waste Management (1)

- Radiological characterization of environment and foodstuff and delineation of the contaminated area
- Actions to reduce population exposure:
  - Relocation of population
  - Restrictions on access of certain areas and on consumption of food and water
  - Prioritized clean-up of residential areas, schools etc.
- Utilization of temporary waste storage areas for
  - Waste arising from clean-up activities
  - Potential large volumes of very low activity waste from non-marketable agricultural production.
Planning and preparation of sustainable management solutions for large quantities of waste which gradually substitute the temporary solutions taken before.

Public information about waste management arrangements:
- To avoid activities which could lead to a further spread of radioactive substances.
- For reassurance of public.
Waste Management Strategy

- Development of a waste management strategy for application in an emergency situation to be based on available experience and knowledge in a step-by-step procedure

- Analysis of lessons learnt from, e.g.
  - Decommissioning of nuclear facilities
  - Safe enclosure of nuclear power plants
  - Environmental remediation (e.g. large nuclear legacy sites and clean-up of uranium ore mining and processing sites)
  - Emergency preparedness and response actions
  - Past nuclear accidents and emergency situations
Legacy Sites

- Site was not operated according to modern standards resulting in:
  - Contamination of buildings, soil, surface and ground water on-site and off-site from normal operation and from incidents and accidents during operation or after
  - Planning, construction, operation and closure of waste management facilities not according to current standards

- Incomplete or no longer available records lead to many uncertainties and unforeseen issues
Waste from Accidents vs. Legacy Waste

- Large volumes of radioactive residues from remediation of sites contaminated by accidents as well as from legacy sites leading to similar challenges for the waste management
- Radiation fields at legacy sites usually are lower and measures less urgent as compared to emergency situations
Remediation of Uranium Mining Legacy Sites
Mining (Ore Mountains) since Middle Ages (e.g. silver)

Uranium Mining since 1946 by Soviet, later Soviet-German, company WISMUT

Total production: 220,000 t U

Low activity concentrations:
- U mill tailings: typically between 10 and 100 Bq/g ($^{238}$U decay chain)
- Waste rock < 3 Bq/g

<table>
<thead>
<tr>
<th>Site</th>
<th>Area [ha]</th>
<th>Volume [million m$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tailings Crossen</td>
<td>250</td>
<td>45</td>
</tr>
<tr>
<td>Tailings Seelingstädt</td>
<td>335</td>
<td>107</td>
</tr>
<tr>
<td>Heaps Seelingstädt</td>
<td>520</td>
<td>60</td>
</tr>
<tr>
<td>Heaps Ronneburg</td>
<td>620</td>
<td>188</td>
</tr>
<tr>
<td>Heaps Aue</td>
<td>311</td>
<td>45</td>
</tr>
<tr>
<td>Heaps Königstein</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td>total</td>
<td>2085</td>
<td>450</td>
</tr>
</tbody>
</table>
Doses are real (often high population densities and existing exposure pathways)

- Assessments must avoid to be overly conservative

German approach - risk based:

- Additional exposure to reference person (public)

- Additional requirements:
  - Justification (do more good than harm)
  - Optimization (maximize net benefit by balancing possible risk reduction and costs incurred)

Doses and risks from natural events and processes affecting barriers to be considered in optimization

1 mSv/a
Safety Assessment (1)

- Highly variable parameters
  - Adequate treatment of uncertainties essential
  - Use of probabilistic assessments for complex facilities

- Natural events and processes
  - Consider extreme conditions (e.g. floods, earthquakes)
  - Take into account series of events and processes

- Time scales for assessments limited by
  - Uncertainties of models and parameters
  - Unknowns of future developments
  - Technical durability of barriers

→ Period of 200 to 1000 years appears reasonable
Safety Assessment (2)

- Optimization to assist in deciding how much passive safety is warranted (i.e. cost effective)
  - Distinguish between high and low maintenance options
  - Consider passively safe (more durable) safety features

- Integrated risk assessments including all relevant risk and damage components (including costs)
  - Carcinogenic and toxic substances
  - Damages to ecosystems
  - Damage to natural resources (e.g. groundwater)
  - Direct physical risks (e.g. dam failures)

→ Decision-making to include all relevant risks
Decision Making

Comparison of Options
Overview: Decision-Making

- **site characterisation**
  - radioactive and other contaminants in soil, water, air
  - site factors: hydrogeology, topography, land use, population density, etc.

- **contaminant migration in soil and groundwater**
- **atmospheric contaminant dispersion**

- **analysis of exposure pathways**
  - current risk, long-term evolution, uncertainties

- **cost/benefit of intervention**

- **optimisation and decision-making**
  - analysis of technical aspects (CBA, MAUA, ...)
  - social and political aspects
Optimization

Carrying out optimization considerations

<table>
<thead>
<tr>
<th>simple situation</th>
<th>difficult situation (normal case)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option A</td>
<td>Option A</td>
</tr>
<tr>
<td></td>
<td>Option A</td>
</tr>
<tr>
<td>Option B</td>
<td>Option B</td>
</tr>
<tr>
<td></td>
<td>Option B</td>
</tr>
</tbody>
</table>

residual dose | costs

IAEA Workshop Paris - February 2015
Optimization - General Aspects

- Comparison of options through qualitative comparison
  - Difficult for many factors of influence
  - Subjective
  - Difficult to communicate and to defend

- Alternative: quantitative optimization
  - Risks (mSv/a) and costs: different units
  - Individual dose not represents radiological detriment
    → number of exposed persons relevant
  - Methodology for optimization required
Principle of Cost-Benefit Analysis (CBA)

Quantitative optimization requires integrated measure of detriment $D$:

- collective radiological risks
- financial expenditures
- non-radiological risks
- possibly ecological risks
- other factors

Common measure for detriment: monetary equivalent

Goal: Basis for decision-making
Quantification of Risks

- Radiological risks:
  - Maximum individual dose
  - Collective dose

- Risks through chemically cancerogenic substances:
  - Individual and collective risks
  - Risk coefficients (i.e. US EPA)

- Common unit: Loss of Life Expectancy (LLE)

\[ 1 \text{ Sv} \approx 1 \text{ year LLE} \]
Application of CBA

<table>
<thead>
<tr>
<th>Monetary equivalent of risk reduction (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>justified expenditures</td>
</tr>
<tr>
<td>for a risk reduction (years LLE)</td>
</tr>
<tr>
<td>considering available resources and other</td>
</tr>
<tr>
<td>requirements of society</td>
</tr>
</tbody>
</table>

| range for $\alpha$: | 50.000 - 150.000 €/a LLE |
| mean value:         | 100.000 €/a LLE          |

| total detriment = financial expenditures + $\alpha \cdot$ collective risk |
Assessment of Options

- Modelling of exposures – contaminant release and migration (atmospheric, groundwater) and potential for intrusion:
  - Development and calibration of site specific models
  - Identification of relevant exposure mechanisms
- Identification and assessment of options for risk reduction
- Scenarios:
  - Reference scenarios
  - Alternative scenarios
- Assessment of uncertainties
EXAMPLE

REMEDICATION OF TAILINGS IMPOUNDMENT
Reclamation Options Considered

- Primary reclamation options considered
  - Wet recl. low water table - small lake (Option 1)
  - Wet recl., high water table - large lake (Option 2)
  - Dry reclamation with simple cover (Option 3)
  - Dry reclamation with complex cover (Option 4)

- Targets of probabilistic simulation for each option:
  - Total risk (radiological and non-radiological)
  - Financial expenditures
  - Target quantity of cost-benefit analysis:

\[
\text{total detriment} = \text{financial expenditures} + \alpha \times \text{total risk}
\]
Financial Expenditure (incl. failure scenarios)
Total Risk
(incl. failure scenarios)
Total Detriment (incl. failure scenarios)

The graph shows the total detriment in million DM for wet and dry conditions. The y-axis represents the total detriment in million DM, ranging from 0 to 3000. The x-axis represents the years from 10 to 41. The columns and lines indicate the variation in detriment over time under different scenarios.
Tailings Impoundment Culmitzsch 1991
Tailings Impoundment Culmitzsch 2010
Conclusions from Example

- Probabilistic simulation allows for keeping track of uncertainties and assessing their consequences.
- Inclusion of failure scenarios reveals that passive safety of wet option is not satisfactory.
- Quantitative optimization necessary in order to arrive at conclusion (higher financial expenditures yield lower risks, but how safe is safe enough?)
- Safety assessments have to
  - Avoid to be overly conservative
  - Be limited to meaningful time periods
  - Put emphasis on the optimization principle
  - Include non-radiological risks
IAEA ACTIVITIES

ON MANAGEMENT OF LARGE VOLUMES
OF RADIOACTIVE WASTE
ARISING FROM NUCLEAR OR
RADIOLOGICAL EMERGENCIES
New Direction: Improve Preparedness

- Post-accident recovery is an complex situation, and many aspects cannot be planned in detail since post-accident conditions strongly depend on the accident.
- Nevertheless:
  - Some preliminary planning could be done for the cleanup of large areas and the related RWM in the event of an accident holding the potential to release large amounts of radioactive material in countries having nuclear facilities.
  - Being prepared may significantly contribute to a sound management of post-accident conditions, including those implemented later on.
Safety Standards under development

- GSR Part 7: Emergency preparedness and response
- DS474: Arrangements for the termination of a nuclear or radiological emergency
- DS468: Remediation process for areas with residual radioactive material

Safety-related document under development

- Management of large volumes of RW arising from nuclear or radiological emergencies
  - assignment of roles & responsibilities, development of generic design for different types of WM facilities, ease licensing procedure
Technical Documents under Development in Relation to Advance Planning (2)

Technology-oriented document under development

- Predisposal Management of Radioactive Waste in the Aftermath of Severe Nuclear Accident: Challenges, Issues and Lessons Learned
  → waste characterisation, monitoring and sampling strategy, treatment, conditioning options, identification of temporary and permanent storage sites

- Disposal of radioactive waste resulting from a nuclear accident
  → anticipated disposal routes, identification of potential sites for disposal of VLLW and LLW
THANK YOU