The Optimization of Radioactive Waste Management in the Nuclear Installation Decommissioning Process

Matej Zachar, Vladimír Nečas
Slovak University of Technology in Bratislava
Faculty of Electrical Engineering and Information Technology
Department of Nuclear Physics and Technology
Ilkovičova 3, 812 19 Bratislava, Slovakia
matej.zachar@stuba.sk

ABSTRACT

The paper presents a basic characterization of nuclear installation decommissioning process especially in the term of radioactive materials management. A large amount of solid materials and secondary waste created after implementation of decommissioning activities have to be managed considering their physical, chemical, toxic and radiological characteristics.

Radioactive materials should be, after fulfilling all the conditions defined by the authorities, released to the environment for the further use. Non-releasable materials are considered to be a radioactive waste. Their management includes various procedures starting with pre-treatment activities, continuing with storage, treatment and conditioning procedures. Finally, they are disposed in the near surface or deep geological repositories.

Considering the advantages and disadvantages of all possible ways of releasing the material from nuclear installation area, optimization of the material management process should be done. Emphasis is placed on the radiological parameters of materials, availability of waste management technologies, waste repositories and on the radiological limits and conditions for materials release or waste disposal. Appropriate optimization of material flow should lead to the significant savings of money, disposal capacities or raw material resources.

Using a suitable calculation code e.g. OMEGA, the evaluation of the various material management scenarios and selection of the best one, based on the multi-criterion analysis, should be done.

1 INTRODUCTION

Decommissioning of nuclear installation (NI) becomes an important branch of nuclear power engineering because of the increasing number of nuclear power plants with terminated operation. A dominant feature of the decommissioning process is a large diversity of involved activities, demanding various technological equipment and technological procedures, a large amount of finance and usually long term duration (10-100 years). The final aim of decommissioning is to release the site of former nuclear installation from radiation control and then achieve an unrestricted use of the former NI area. To reach this status of nuclear installation, following decommissioning activities have to be done:

- Pre-dismantling decontamination of technological equipment is applied to lower the exposure of personnel during following dismantling.
- Dismantling of technological equipment. All contaminated, activated and also non-contaminated technological equipment are removed, using a large variety of technological procedures.
Post-dismantling decontamination of technological equipment is applied to decrease the contamination of equipment. That results to reduction of the amount and level of radioactive waste (RAW).

Decontamination of building surface is used to removal of the contamination from buildings. Then the buildings are ready for demolition or further use.

Dosimetric survey and monitoring of materials, buildings surfaces and area.

Demolition of buildings, site restoration. Only non-radioactive buildings could be demolished and removed from the site. Then the site is released for unrestricted further use.

Management of radioactive and non-radioactive material. All usable materials and waste should be managed in an appropriate way (see next chapters).

Non technological activities and procedures like project preparation, administrative activities, procurement of material and equipment, personnel training, research, management of decommissioning process etc [1].

2 MATERIALS AND WASTE PRODUCED IN NUCLEAR INSTALLATION DECOMMISSIONING

One of the characteristic feature of decommissioning process that was not mentioned in the introductory chapter is a production of large amount of radioactive materials (waste) created during performance of decommissioning activities described in the previous text. Compared with operational waste, the decommissioning waste is different in the term of their characteristics, and in many cases it is specific only for NI decommissioning process. Decommissioning radioactive waste is characterised by:

- Large amount (volume, mass).
- Variety of kinds and categories (state, material composition and structure).
- Different radiological characteristics (level, nuclide specification).

The main sources of the primary radioactive waste from decommissioning are:

- Activated construction materials of the reactor and reactor systems (steel) that contain more than 90% of total activity of materials arising from the decommissioning process (except spent nuclear fuel).
- Activated building structures in immediate vicinity of the reactor e.g. biological shielding or reactor shaft concrete (including steel reinforcement).
- Contaminated construction materials of primary circuit and auxiliary systems components (mainly steel, non-ferrous metals, thermal insulation). Considering good fuel cladding tightness, the activation products are represented by the main contaminants e.g. $^{60}$Co.
- Contaminated building parts, surfaces and structures including build-in parts e.g. sewage parts build-in building segments.

Apart from mentioned primary RAW, secondary RAW also arising during decommissioning process. Their activity is strongly depended on the primary RAW activity. The examples of secondary RAW are following:

- Liquid RAW from chemical or electro-chemical decontamination (decontamination dilutions, electrolytes, decontamination foams or gels).
- Abrasives from mechanical decontamination of building structures.
- Air conditioning filters that captured majority of activity of generated aerosols before air discharging to the environment (ENV).
- Ion exchangers using for purification and activity reduction of liquid RAW.
• Waste from treatment and conditioning of RAW (metal melting sludge, ash from incineration, laundry solutions, evaporation concentrates etc.).
• Contaminated tools and equipment having been used for dismantling.
• Waters from sanitary locks.

In specific cases (type of reactor, operational accidents) special forms and types of RAW have to be managed in decommissioning process:

• Activated or contaminated graphite is typical for older type of reactors where graphite is used as a moderator (RBMK, MAGNOX) or biological shielding (GCR - A1 in Slovakia). Total mass of graphite in these reactors is around thousands tons and due to occurrence of long lived activated products e.g. $^{14}$C, $^{36}$Cl there are serious problems with the graphite final disposal.
• Radioactive toxic and hazardous materials are additional risk because of their chemical or toxic characteristics. The examples are beryllium (moderator or reflector in research reactors), cadmium (absorbing rods), asbestos (insulation material in building constructions), sodium (fast reactor coolant).
• Contaminated soils, concrete (internal structures) should be generated as a product of non-standard operational situations like RAW leakage and infiltration into the soil or concrete structures.
• Contaminated sludge or sediments are liquid RAW, polluted with solid particles.

Except of RAW also non-radioactive waste is generated during dismantling of technological equipment outside controlled area (steel, non-ferrous metals, plastic, insulations etc.) or demolition of building structures (reinforced concrete, concrete, masonry, steel constructions etc.). The amount of non-radioactive waste from decommissioning is much higher than the amount of RAW (see Table 1.) [2],[3]. However, these materials are considered to be and managed as a standard industrial waste.

Table 1: Comparison of estimated amount of waste from decommissioning

<table>
<thead>
<tr>
<th>Nuclear Installation (country)</th>
<th>Reactor type</th>
<th>Output power [MW$_{e}$]</th>
<th>Radioactive waste amount [t]</th>
<th>Non-radioactive waste amount [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barseback 1 (Sweden)</td>
<td>BWR</td>
<td>600</td>
<td>5 370</td>
<td>177 310</td>
</tr>
<tr>
<td>Ringhals 3 (Sweden)</td>
<td>PWR</td>
<td>1000</td>
<td>5 260</td>
<td>207 860</td>
</tr>
<tr>
<td>Tokai 1 (Japan)</td>
<td>GCR</td>
<td>160</td>
<td>18 200</td>
<td>174 000</td>
</tr>
</tbody>
</table>

3 RADIOACTIVE MATERIALS MANAGEMENT ARISING FROM NUCLEAR INSTALLATION DECOMMISSIONING

Radioactive materials management covers several phases and it involves various technological operations (Figure 1). The final goal is to transform the materials arising from decommissioning process to the form assuring that an influence on the environment will be within the limits after their releasing outside nuclear installation site [4].

Pre-treatment of radioactive materials is used to make the following steps easier and more effective. The main purpose of pre-treatment is to maximize the amount of materials releasable to the ENV and to reduce the amount of produced RAW. The main activities of pre-treatment are following:

• Collection, segregation, sorting and characterization of materials, following radioactivity analysis.
• Decontamination of solid RAW (chemical, electrochemical, melting) is usually used to reach the clearance (release) levels of the materials or to re-categorize the RAW.
• Size reduction, fragmentation.
• Packaging of RAW and transport to a treatment facility or to a storage area.
3.1 **Management of materials releasable to the environment**

Large amount of materials from decommissioning inside the controlled area have such a low activity of radionuclides that allows them to be released to the environment (Figure 2) [5]:

- Just after dismantling or after decontamination in pre-treatment operations.
- After storage period by applying radioactive decay of nuclides ("time decontamination" principle).

Following the requirements of the released materials, further application should be considered (Figure 2):

**A. Unconditionally release of materials to the environment**

The mass activity ($\text{Bq.kg}^{-1}$) and surface contamination ($\text{Bq.m}^{-2}$) of unconditionally released materials is lower than clearance values for unrestricted release set up by the authorities. Following
the recommendations of International Atomic Energy Agency (IAEA), clearance levels are usually derived from the value of maximum annual allowed individual dose for the member of critical group of public (10µSv.year\(^{-1}\)) and from the total collective public dose of (1manSv.year\(^{-1}\)) caused by released material [6]. Unconditionally released materials should be used in all areas of industry without any restriction and could be divided into (Figure 2):

- Usable materials are after recycling, suitable for using in any industrial area.
- Non-usable materials representing industrial waste. No practical or economical reasons for their further use exist. They are disposed on municipal or special (toxic) dumps.

B. Conditionally release of materials to the environment

Materials which activity levels exceed the limits for unconditional release, could be released to the environment conditionally. The recommendations for conditional release could also be derived from the above mentioned principle 10 µSv.year\(^{-1}\)/1 manSv.year\(^{-1}\). However, following principles have to be met:

- Materials are contaminated mainly with short lived radionuclides.
- Long term placement of materials at one place where also restricted occurrence of population is assured.
- Materials are used in conformity with beforehand developed scenario ensuring that the population dose rates will not be exceeded.

The further use of conditionally released materials may be following [5]:

- Usage within nuclear industry, no release of materials from radiation control. Recycling (melting) is performed inside the nuclear locality. After recycling, materials could be used for RAW packages fabrication or RAW treatment facility construction (high-pressure compactor).
- Usage in non-nuclear industry assumes releasing the materials from NI area and their use following above special defined conditions (rails, metal bars for reinforced concrete).

3.2 Management of RAW determined to be disposed in RAW repositories

Materials that cannot be released into the environment due to their level of radioactivity are considered to be a RAW that has to be safely isolated from the environment within the repository barriers. RAW management includes following steps (Figure 3.) [4],[7]:

![Figure 3: Management of RAW non-releasable to the environment](image)
RAW interim storage

Interim storage is placement of RAW within barriers, which can be checked and protect the ENV with the intention of RAW retrieval in the future. Interim storage should be included into the RAW management process for the following reasons:

- RAW re-categorization by applying “time decontamination” principle. It means that less difficult technologies for treatment, conditioning and disposal can be used.
- Treatment or conditioning technologies may not be accessible at the time, missing disposal facilities at the time.
- Absence of legislative regulations for RAW management, lack of financial resources.

RAW treatment

RAW treatment is presented as a complex of operations and activities leading to the increase of safety by reduction of the RAW volume, removal of radionuclides from the RAW, changing characteristics and composition of the waste. The most commonly used treatment technologies are:

- Evaporation, ion exchange, chemical precipitation for liquid RAW.
- High-pressure compaction, incineration, melting for solid RAW.

RAW conditioning

RAW conditioning is presented as a complex of operations and activities leading to creation such chemical and physical form that is suitable for transport and final disposal. Conditioning also includes the immobilization of the liquid RAW to a solid form. The most frequently used conditioning technologies are bituminization, cementation, vitrification, calcination and polymerization.

RAW disposal

RAW disposal represents the final phase of RAW management and is defined as a placing of RAW package into the suitable disposal facility (repository) without intention of retrieval. The RAW repository allows the long term isolation of nuclides from environment applying multi-barriers principle:

- Waste form (fixing matrix) depends on the used conditioning technology.
- Waste package isolates the immobilized waste from surrounding (concrete container, metal drum).
- Engineered barriers involve structural walls of disposal system, roof construction, backfill materials above the waste packages, drainage layers etc.
- Natural barriers are created by the host rock and surrounding geological formation.

In general, two types of repositories are considered:

- Near surface repository (NSR) is designed for short lived (half life lower than 30 years) low and intermediate level waste disposal (majority of decommissioning waste). Long lived nuclides have to be disposed only within the limit concentrations. Two kinds of NSR are distinguished: surface (trench, vaults, bunkers), and subsurface in about 100 meters depth (caverns, cavities, deep boreholes) [8].
- Deep geological repository (DGR) is appointed for disposal of RAW that does not fulfill the limits and conditions for NSR; it means long lived intermediate and high level waste. However, currently no DGR is built. So the RAW not disposable in the NSR (e.g. activated reactor components) has to be safely stored in the special nuclear storage facilities until the DGR is operated.
4 CHARACTERIZATION OF THE CALCULATION CODE OMEGA

OMEGA code (Oracle Multicriterial General Assessment of Decommissioning) is a calculation code developed in the DECOM company and used for quantification of basic decommissioning parameters e.g. costs, manpower, exposure, consumptions, duration of the process, effluents volume and activity, amount of released or disposed materials etc.

For the evaluation of decommissioning parameters in the OMEGA code, it is necessary to break down the decommissioning process into single groups and sub-groups of activities, up to unambiguous elementary decommissioning activities.

Basic structure, which systematizes these activities, is PSL (Proposed Standardized List) structure approved by IAEA, OECD/NEA and EC as a tool systemizing the costs items. Moreover, it is also used for other decommissioning parameters systematization. In the OMEGA code the basic PSL structure for NI is developed in a structure of buildings, floors, rooms, down to technological equipment. This format is used also in the inventory database part of the OMEGA code [9].

Computing structure is generated automatically in dependence on input parameters, physical and radiological parameters of the inventory database items. This structure can be modified before the calculation run [1].

4.1 Calculation methods of decommissioning material parameters using the OMEGA code

Analysis of material parameters in the decommissioning process in the OMEGA code is performed by using integrated material flow tool. The tool combines the material flow in decommissioning process with radiological parameters of these materials. The tool of integrated material flow takes into consideration [1]:

- Physical parameters of materials from the inventory database (mass, volume, surface).
- Radiological parameters of materials (inner and outer surface contamination, induced or mass activity, dose rates, nuclide vectors).
- Impacts of all decommissioning activities on the materials and radioactivity distribution and on the secondary waste and effluents generation.
- Limits and conditions of technological facilities for treatment and conditioning of RAW, for materials to be released to the environment, for RAW disposal in the near surface repository.
- Radioactive decay of nuclides.

Using the integrated material flow tool it is possible to monitor materials mass and activity on the elementary material item level during the decommissioning process from the dismantling up to their release to the environment or disposal in the repository.

5 RADIOACTIVE MATERIALS MANAGEMENT OPTIMIZATION

It is mentioned in the text above that a large amount of various material types with different characteristics results from the decommissioning process. Another fact that makes the materials management more difficult is the time aspect. From the one point of view different material types with different characteristics has to be managed at the same time. But long duration is also a characteristic feature of decommissioning and special technologies for treatment of specific material type usually have to be ready at any moment of the process e.g. high-pressure compactor or facility for liquid RAW immobilizing. For all these reasons the material management in the NI decommissioning process is a great challenge that has to be elaborated in detail, already in the phase of decommissioning project preparation. To optimize this process, it is necessary to know and consider following facts about NI and infrastructure and conditions of material management:
• Technological and radiological inventory of NI at the end of operational period. The inventory is mainly dependent on the type of reactor, output power, construction materials and characteristics of the operational period (duration of operation, number and seriousness of accidents).
• Decommissioning strategy - immediate (just after NI final shutdown) or deferred dismantling after appropriate time period (application of radioactive decay to achieve radioactivity level reduction).
• Accessibility, availability and serviceability of decontamination and dismantling technologies and technologies for RAW treatment and conditioning.
• Accessibility and capacity of storage rooms and disposal facilities for different categories of RAW.
• Limits and conditions for material release, disposal of RAW to repositories, discharge of gaseous and liquid effluents to the environment (ENV) set up by the authorities.
• Other legislative or public restrictions, budget.

Considering above mentioned input parameters, it is possible to develop various radioactive material management scenarios. Using the calculation code OMEGA, the computational analysis and main output parameters evaluation (costs, number of waste packages for different types of repositories, amount of released materials, personnel exposure, manpower etc.) for the selected scenarios can be done.

6 CONCLUSIONS AND FUTURE CHALLANGES

The paper analyses the material management in the process of nuclear installation decommissioning. A brief description of decommissioning and characterization of radioactive waste produced in this process are presented. Individual options of material release outside nuclear site such as unconditional and conditional release to the environment or disposal in radioactive waste repositories are defined in the main part of the paper. Finally, the calculation code OMEGA, its integrated material flow tool and the parameters mainly influencing the waste management optimization are described.

Further work will focus on developing a complex methodology of decommissioning material flow optimization with emphasis on radiological characteristics and material management scenarios. Detailed diagrams of material flow for basic types of materials (steel, non-ferrous metals, non-metal materials, concrete, liquids) arising from decommissioning will be developed. All possible ways how to release the material from nuclear installation area, considering their characteristics and defined limits, will be reflected in diagrams. Then the methodology will be implemented into the existing and functioning calculation code OMEGA. The calculations of model waste management scenarios will be performed to check the correctness of suggested methodology. Finally, the selection of the best scenario, based on the multi-criterion analysis, will be done.

REFERENCES


