THE EXTENT OF ENVIRONMENTAL CONTAMINATION BY NATURALLY OCCURRING RADIOACTIVE MATERIALS (NORMS) AND APPLICABLE REMEDIATION MEASURES - AN IAEA PROJECT.

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1 ABSTRACT

NORM occur in a variety of industrial processes, including mining and milling of ores, fossil fuel production and use, and groundwater utilisation. In many cases the NORMs are separated out into the waste streams and disposed of or released into the environment. This IAEA project assesses the resulting environmental contamination and applicable methods for reduction either at the source, by e.g. changing the respective processes, or retrospectively by remediation. Novel remediation technologies may be required to deal with the often low-level and diffuse contamination. Particular attention is also given to the socio-economic implications of abatement and remediation measures.

2 INTRODUCTION

Elevated concentrations of Naturally Occurring Radioactive Materials (NORMs) are found in many geological materials, namely igneous rocks and various ores. Human activities that exploit these resources may lead to enhanced concentrations of NORM and/or enhanced potential for exposure to NORM in products, by-products and wastes. Such activities may include, for instance, the mining and processing of ores, the combustion of fossil fuels, or the production of natural gas and oil.

These radioactive wastes from outside of the nuclear fuel cycle have developed over the past two decades from a little known issue to an issue that is receiving a considerable amount of global attention. Two important reasons for the increasing levels of concern are

— the large amount of such NORM containing wastes and other materials, and
— the potential long-term hazards resulting from the fact that NORM is comprised of long-lived radionuclides with relatively high radiotoxicities.

An important first step for industry and regulatory bodies is to understand when and where NORM can occur and also to identify the locations where concentrations of NORM can be greatest within a given process. This document is intended to both identify the industries that may involve NORM and to provide perspectives on the amounts, characteristics, and radionuclide concentrations that can be found in products, by-products, residues and at respective sites.

The assessment of the radiological relevance of environmental contamination is complicated by the fact that the exposure scenarios depend very much on local or regional circumstances and behavioural patterns. For example, contamination from an oil well or a mine located in an unpopulated, remote area pose less of a risk for potential exposures than similar facilities located in a populated area. Likewise, rural populations in tropical, developing countries will face different potential for exposure than a rural family in Europe (different types of homes, amount of time spent at home, etc., see below). Adequate exposure scenarios must be considered when determining the concentration levels at which a given NORM contaminated area becomes a concern.

NORM is becoming an international problem, since not only do Member States' industries grapple with it, but also increased globalisation of business leads to cross-border transport of contaminated commodities.

3 PROJECT OBJECTIVES AND SCOPE

The amenability of NORM wastes and NORM contaminated sites to regulatory control and the mode for the implementation of such control are still subject to scientific and technical debate. Introducing new regulations or extending existing controls to such situations is likely to have a significant technological and socio-economic impact.

Very little appears to be known about the actual and potential environmental contamination due to the inadvertant release and the disposal of NORM containing wastes. In order to identify suitable remediation strategies and technologies, an assessment of NORM sources, the typical processes leading to their concentration enhancement and dispersal in the environment and resulting exposure patterns is required (Fig. 1).

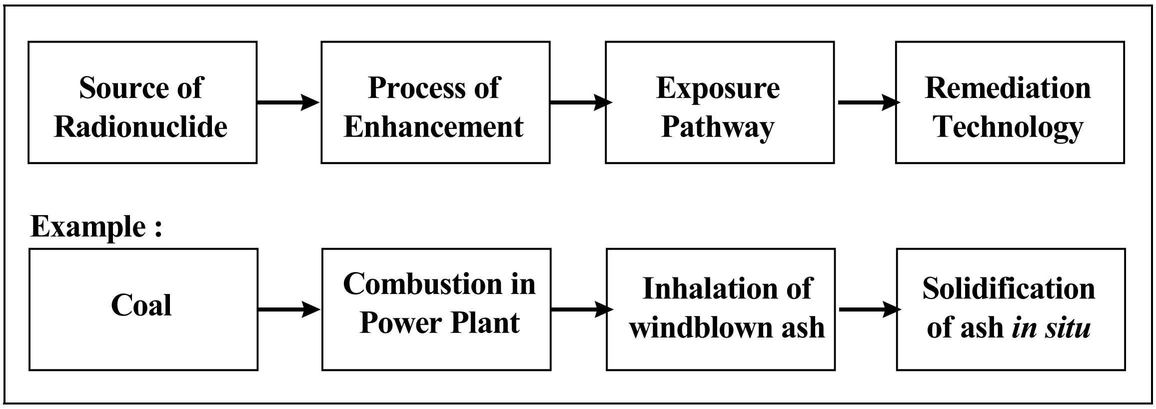

Figure 1. Logic for the development of remediation technologies for NORM contamination in the environment.

Understanding these processes is the basis for understanding the waste arisings, waste forms produced and related modes of disposal. Understanding the processes will also help to identify potential contamination situations.

Possible changes in production and waste management technologies will be investigated in order to assess the scope for reduction of waste arisings, their radioactivity, or to change their form into one more manageable or less harmful. Technological options for abatement applicable to current operations include changes in raw materials, processes, and waste handling and management procedures. It should be noted that certain NORM wastes have a potential for re-cycling and re-use, provided the potential accumulation of NORM is properly addressed.

Given the occurrence of NORMs in common industrial and domestic circumstances, the applicability of any proposed change in technologies has to be evaluated very carefully, as it may entail significant costs and/or commercial and economic disruptions.

The main objective of this project is to create, as a basis for further evaluating the potential size of the problem, a world-wide knowledge base on the occurrence and characteristics of technically enhanced NORM concentrations in a wide variety of industrial and domestic activities, in feed-stocks, products, by-products, wastes, and environmental compartments. The database is intended to provide the first step in an effort to assess the technological implications from applying any forthcoming safety criteria to NORMs containing wastes and environmental contamination, in the context of both, remediation of existing contamination, and prevention of further contamination at current operations.

Specific criteria related to the issues of clearance, exemption and transborder movement of radioactive materials, however, will not be discussed. Not covered are the sources, the impact and abatement technologies concerning indoor radon from geological sources in residential or other buildings. Similarly, issues of radiation protection at the workplace and of direct exposure to NORMs in consumer products etc. are not subject of this project. Such issues have already been discussed extensively, e.g. (1,2) for the European context, and are subject to a variety of Agency guidelines in draft.

While it is understood that exposure of the public and workers can be kept low under normal operation conditions for most industries, absence or loss of institutional control over lands on which large amounts of NORM containing wastes have been placed, resulting in redevelopment, intrusion and re-use of materials, can be a major concern.

4 OCCURENCE OF NORM

NORM comprises radionuclides associated with the ^{238}U and ^{232}Th decay chains as well as ^{40}K, all of which are primordial. These radionuclides are very long-lived, have progeny that are long-lived, such as ^{226}Ra, and have a relatively high radiotoxicity. While the specific problems arising from ^{222}Rn accumulation in buildings will not be covered in this project, it should be noted that radiogenic radon typically is a major source of exposure in many NORMs-related exposure cases.

The key to understanding the occurrence of NORM, is to understand the distribution of the respective source-rocks and the physical and geochemical processes that lead to the release of radionuclides. Certain radionuclides exhibit a high geochemical mobility in some types of environments. Uranium, for instance, is easily mobilised in circumneutral and not too highly mineralised surface and groundwaters. As a result, uranium and its decay product, radium, can enter the food chain through irrigation and drinking waters.

Other release and transport mechanisms include airborne releases in form of suspended solids from burning fossil fuel or waste material storage or disposal facilities.

It is worth noting that the NORM problem often goes in hand with elevated concentrations of other elements that are considered toxic or hazardous, such as arsenic or heavy metals.

5 PROCESSES ENHANCING CONCENTRATIONS

The mobility of radionuclides, like any other chemical element, is controlled by their physico-chemical properties in relation to the ambient conditions. Human activities change these ambient conditions intentionally, e.g. *in situ* leaching of uranium ore, or inadvertantly. The physico-chemical properties are responsible for the enrichment of radionuclides in certain fractions of wastes, or in particular products. A range of principal processes can be identified:

- chemical changes (pH, redox potential, gas partial pressures, mixing) of groundwater following its abstraction can lead to the precipitation of scales, which scavenge, for instance, radium;
- combustion processes volatise certain nuclides, such as lead and polonium, and concentrates others in residues such as bottom slags;
- sedimentation, both in nature and in waste management facilities can lead to accumulation of NORM;
- (preferential) adsorption on clays or organic sedimentary fractions can lead to enhanced concentrations in these fractions;
- size fractionation (sieving, floatation, etc.) leads to concentration enhancement;
- physical disaggregation enhances dissolution and dispersal owing to increased mineral surface areas, allowing one of the above processes to concentrate NORMs;

6 INDUSTRIAL AND OTHER ACTIVITIES OF RELEVANCE

The projects aims at elucidating the material flows for selected (industrial) processes, types of primary feed materials, particular end-products, and the ensuing waste, in order to identify the potential for environmental contamination and, hence, the need for remediation. The intention was originally to achieve a comprehensive geographical coverage, but the necessary data on waste arisings and disposal techniques, in particular with respect to historical wastes are difficult to collect. Instead, the focus is on describing the various processes, product and waste streams in detail, in order to raise the awareness for the potential occurrence of NORMs.

To date, a range of industrial and other processes have been identified that typically lead to enhanced concentrations of NORMs in products, by-products, or wastes, and their material streams have been described in some detail for selected examples, including:

- Mining, milling and raw materials processing
- Metals such as iron, copper, aluminium, gold, niobium, tin, uranium and thorium
- Oil and gas recovery
- Coal mining and combustion
- Phosphate mining and fertilizer production
- Heavy minerals extraction and processing
- Rare-earth elements processing
- Clay, ceramics and building materials
- Abstraction and use of groundwaters as drinking, process and irrigation water, and for geothermal energy generation;
- Radionuclide applications outside the nuclear industry;
- Various wastes from, e.g.
- Dredging rivers and harbours;
- Decommissioning wastes.

7 MINING, MILLING AND RAW MATERIALS PROCESSING

The mining and processing of ores, notably of uranium and phosphate, generates large quantities of NORM wastes. These wastes include mill tailings and smelter slags, some of which contain elevated concentrations of uranium, thorium, radium, and their decay products that were originally part of the process feed ore. Tailings are the solid materials remaining after physical or chemical beneficiation (washing, flotation, grinding, and drying) removes the valuable metal constituents from the ore. Slag is the vitreous residue left from the smelting (blast furnace melting and conversion) of ore for extraction and purification. The mining technique and its selectivity can be an important variable that controls the NORM content in wastes. For instance, the NORM content of adjacent ore veins or other deposits might vary considerable and selecting the appropriate portion can reduce the NORMs in the waste stream.

Depending on the mineralogy of the ore and the host rocks, generation of acid mine and spoil heap drainage from pyrites and ensuing release of radionuclides and other toxic constituents is a problem. This concerns also landfilled mining residues and below commercial-grade ores.

The systematic analysis of certain industrial processes and their waste streams is complicated by often complex and interlinked materials streams. A typical example are the heavy mineral, rare earth and ceramics industries. The primary feed material may be in all cases placer deposits, the heavy mineral content of which is split into different processing streams that may become reunited further on as waste streams of one industry join the feed streams of another. A discussion based on individual radionuclides may also not be appropriate, as frequently several occur together.

During most smelting processes, the majority of any radionuclides present are accumulated in slags and filter dusts, if efficient flue gas scrubbing is performed. These residues may be landfilled, but slags are also a commercially viable by-product, being used as aggregate for a variety of house and road construction purposes. Owing to their glass-like nature, slags release only very small amounts of their radionuclide loading due to leaching, but radon emissions may be problem in domestic environments. Although also of a glassy nature, the release of radionuclides from landfilled filter dust may be more of a problem, owing to the large surface area presented to leaching fluids.

Historic mining wastes are processed at various places for elements different from those for which the material was mined originally. In more recent projects, such as e.g. Olympic Dam in Australia, separation of copper from other valuable accessories is integrated into the overall milling process, thus enhancing the commercial value of the operation and reducing the radionuclide contents in the waste stream.

If uranium is extracted as a by-product in precious and other metal mining operations, this reduces potential adverse impacts from this nuclide. As is the case, for certain other metals, spoil and waste heaps are reworked at some places with more efficient extraction techniques or for different target elements. In many such cases, and in dedicated uranium ore processing, however, thorium and radium may be left behind in the tailings. Improved disposal techniques and environmental conscience are likely to result in less legacy wastes.

The major environmental problem associated with many industries is the disposal of tailings. The typical disposal procedure is pumping the material into mined-out ore bodies and dammed-up valleys. However, such tailings 'lakes' can release leachates and process solutions into underlying aquifers. When not properly closed-out, i.e. capped, the drying out of the surfaces can give rise to the dispersal of dusts.

It appears that in most cases the radioactive residues have been collected and stored on the site of the processing plants, e.g. in drums, awaiting disposal. Some ground contamination is found around the plants and waste treatment facilities.

Certain radionuclides, such as uranium, may be bound by sorption to clay mineral surfaces. Hence, processing of clays into a variety of ceramic and similar products can lead to environmental contamination. Technical processes, such as grain-size separation, floatation and other purification steps etc. can lead to the accumulation of radioactivity in residues, certain fractions of the feedstocks, or in products. Firing and other types of heat treatment typically lead to the volatisation of e.g. ^{210}Po, which then accumulates in dust extraction systems, precipitates on chimney walls or is dispersed around the facilities. Otherwise, concentrations in products and wastes do not differ significantly from feed materials.

8 ABSTRACTION AND USE OF WATERS

Five main areas of relevance have been identified: geothermal energy use, drinking water, process water and waste water treatment, and irrigation.

Geothermal energy is heat produced by and stored in the earth. The heat carrier typically is either groundwater or water injected into the system with direct contact to, and hence reacting with, the host rock. Concentrations of NORM are found in the solid wastes generated by the exploration and exploitation of geothermal systems. These wastes include scales or sludge formed on the inside surfaces of the drilling and production equipment (e.g. heat exchangers, process lines, valves, turbines, and fluid-handling equipment). Such wastes contain calcium, barium, and strontium carbonates, sulfates, and silicates with significant concentrations of radium and radium decay products. The scales have to removed periodically to ensure free flow of solutions and the safe operation of equipment, such as valves.

Similar considerations apply to drinking water, where NORMs are removed during treatment processes such as hardness or iron removal, or for organic contamination. The residues, such as carbonate and ferric hydroxide sludges, spent granular activated carbon etc. are often disposed of on-site without consideration for NORMs. Exposure to radon of water works staff in aeration plants may be a concern.

It has been noticed that waste water treatment sludges and ashes from incinerated sludges sometimes have elevated levels of radionuclides. The sources are either elevated levels of NORMs in groundwaters or (authorised) discharges into the sewerage system by various industries. The organic solids in the sewage concentrate radionuclides and incineration of the sludge further concentrates the radionuclides. The common practice of dispersing sewage sludges or incinerator ashes onto agricultural land can lead to the accumulation of radionuclides - and heavy metals - in the soils and eventually their uptake into crops. For this reason various countries have regulated this practice over the last few years.

Several industries, notably the paper industry, are heavy users of process water. Owing to the substances involved, significant radionuclide concentrations can accumulate in various products, intermediates and wastes. Paper pulp, for instance, is capable of scavenging heavy metals and radionuclides. Certain chemical processes may lead to the precipation of scales inside tubes and other vessels, which have to be removed and require special treatment when radioactively contaminated.

As with drinking water, (ground)waters used for irrigation may contain NORM that may then accumulate in certain soil fractions and eventually transfer into plant material.

9 USE OF RN OUTSIDE THE NUCLEAR INDUSTRY

Some radionuclides, radium and thorium in particular, have been used for non-nuclear applications and outside the nuclear industry. Wellknown cases include the application of radium paints as luminiser on watch and instrument dials and thorium in incandescent mantles and welding rods.

The Agency has as a large-scale programme to condition spent sealed sources from radiotherapy and radiography units, an almost discontinued use of radium.

Environmental contamination may arise from the improper use and disposal of such materials. For instance, radium contamination was found at sites where watch and instrument dials were manufactured or dismantled in larger numbers, e.g. at national defence establishments.

The use of radium-bearing waters in spas can result also in a waste management problem, having to deal with scales and down-stream contamination below the discharge point of spent waters.

10 VARIOUS WASTES

Wastes with secondary contamination by NORMs may arise from various industrial and other activities. For instance, sediments dredged from inland water ways and harbours may contain significant amounts of NORM plus heavy metals. Decommissioning of mining and milling, and other industrial facilities handling materials containing NORM may have given rise to contaminated wastes not adequately conditioned and disposed off, if the radiation problem had not been recognised.

11 NORM CONTAMINATION AND THE IAEA DIRECTORY OF RADIOACTIVELY CONTAMINATED SITES (DRCS)

The Agency is currently developing a directory of sites radioactively contaminated by past practices and accidents. The objective of this directory is not so much to provide a comprehensive listing of sites, but rather to provide the user with examples of contamination situations and the remediation measures taken. It is the intention to include also uranium mining and milling sites and other sites contaminated with NORM. In this sense, the DRCS complements the Agency’s Net Enabled Waste Management Database (NEWMDB) and the Nuclear Fuel Cycle Information System (NFCIS), providing information on possible origins of radioactive wastes not declared as such.

12 REMEDIATION OF NORM CONTAMINATED SITES

Once waste arisings, waste management practices and associated contamination problems have been identified, the project will address the remediation options.

The project will provide an overview over technologies and strategies (3) available for the remediation of NORM contaminated sites and their respective applicability. In many cases the same techniques as for the characterisation (4,5) and remediation (6,7) of other radioactively contaminated sites will be applicable. Frequently, however, large volumes of residues and/or low concentration levels are involved. Typically, the relative efficiency of (removal) techniques decreases with decreasing concentration levels. Special and novel techniques, such as bioremediation, may need to be employed.

When assessing the remediation and abatement options, particular consideration must be given to the socio-economic context and unwanted side-effects of the remediation activities. Such non-technical factors influencing the decision making processes in environmental restoration are currently studied in detail and the results will be published in a forthcoming report (8). Applicable techniques, methods and strategies will depend very much on the special circumstances in the Member State. Exposure pathways and effectiveness of measures, such as institutional controls, can be quite different in industrial countries and developing countries. In response to this, the remediation has to be tailored to the specific exposure scenarios (see Table 1), situations and feasibilities in the Member States.

Table 1: Examples of lifestyle differences and resulting exposure, if home is built on NORM wastes.

Urban/Suburban, Temperate Developed Country	**Rural, Tropical Developing Country**
• Less time at home (work away from home) results in reduced external radiation exposure • More robust home which provides some shielding while inside the home, however less air circulation, radon can accumulate • Purchase food away from home, only a fraction may be contaminated with NORM	• Majority of time near the home which maximises external exposure • Home constructed of soil (may actually enhance external exposure rather than providing shielding) • Open air design of home, so indoor radon concentrations are not significantly enhanced • Subsistence farmer could obtain essentially all food and milk from around the home

13 SUMMARY

This paper briefly describes the activities currently undertaken at the IAEA to identify environmental contamination with anthropogenic enhanced concentrations of NORM. This is based on an identification of relevant (industrial) processes and their associated waste streams. Methods to reduce environmental impacts from such wastes, both for current operations and in a remediation context are investigated.

The readers are invited to provide to the IAEA information on their experience.

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