CHALLENGES IN ESTIMATING PUBLIC RADIATION DOSE RESULTING FROM LAND APPLICATION OF WATERS OF ELEVATED NATURAL RADIOACTIVITY

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Abstract

Ranger Uranium Mine is located in the northern wet/dry tropical region of Australia. The mine implements a comprehensive water management programme and land application of water from its retention pond 2 (RP2) is a part of that programme. The land application areas are located in common woodlands within the mine lease boundary — the combined area is about 336 ha. RP2 contains runoff from the waste rock and low grade ore stock piles and the water is therefore elevated in natural radionuclide activity concentration. When the water is applied to the land, the radionuclides are adsorbed within a few centimetres of the surface. A comprehensive project is underway to estimate the radiation dose likely to be received by the critical group during occupancy of these areas after rehabilitation. The distribution of radionuclides and the traditional use of the land are such that direct application of commonly used parameters in dose estimates through pathway analysis may not be adequate. This paper describes the site, identifies the special aspects of the distribution of radioactivity on the ground and their influence on radiation dose estimation through the different exposure pathways.

1. INTRODUCTION

Ranger Uranium Mine is located in the Alligator Rivers uranium province in the northern tropical region of Australia. Mining at Ranger commenced in 1980 and is still continuing. The main uranium deposits at Ranger are hosted in altered schists and silicified carbonates. Acid leaching is used to extract uranium.

The total lease area of Ranger Uranium Mine is 7908 ha. It is located near the township of Jabiru. The lease area is surrounded by Kakadu National Park which is World Heritage listed both for its natural value and for its cultural significance due to ancient Aboriginal habitation of the area.

The climate in the Alligator Rivers Region is monsoon-like with distinct wet and dry seasons. Almost all of the rain falls during November to March and the dry season lasts from about May to September. The mean average rainfall for the past 32 years at Jabiru Airport was 1579 mm and the mean annual evaporation (2628 mm) exceeds the rainfall [1]. The region is subject to severe weather events such as cyclones and floods. Seasonality adds to distinctive features in the physiography of the land.The seasonal and often unpredictable rainfall patterns pose water management challenges for Ranger Uranium Mine. Runoff water from areas of above background natural radioactivity is collected in retention ponds. Retention Pond 2 (RP2, Fig. 1) catches water mainly from the waste rock and low grade ore stock pile areas at Ranger and, consequently, it exhibits elevated activity concentrations of naturally occurring radionuclides. The pond is about 12 m deep and 24.86 ha in surface area. The water volume retained at any time in the pond varies — from nearly empty to its full capacity of 1 100 000 m^3. Some water from the pond is used to sustain mining and milling operations, but since 1985, large volumes have been disposed of through a technique of land application to common woodland within the mine lease.

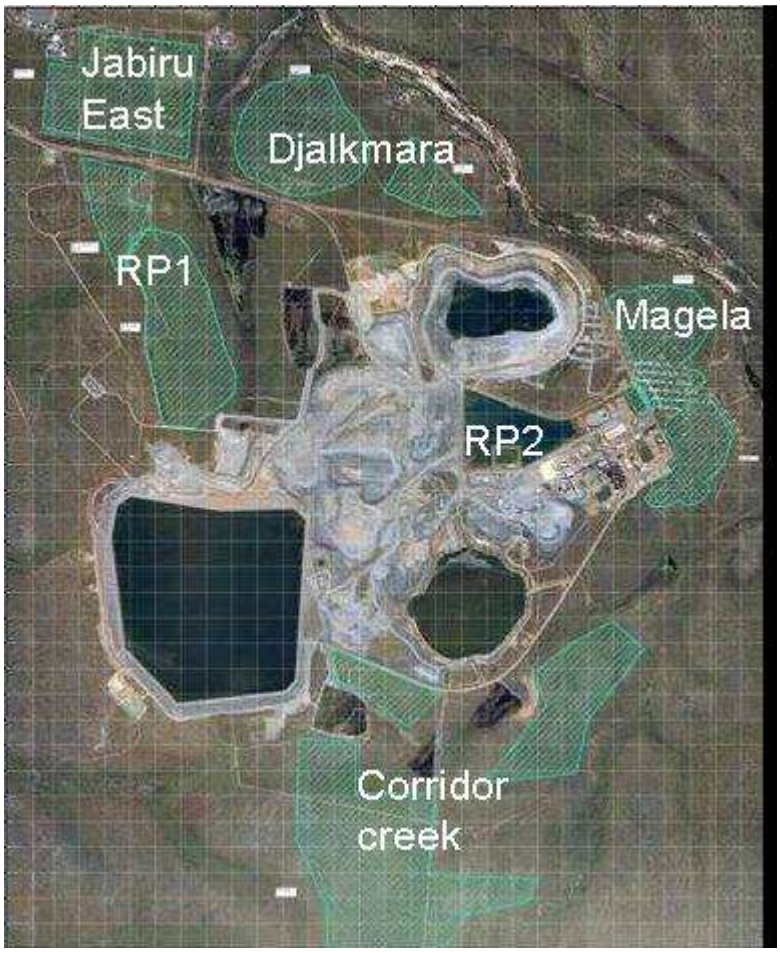

FIG. 1. Locations of land application areas (hatched) and Retention Pond 2 (RP2).

2. LAND APPLICATION

Land application technology relies on the ability of soil and plant systems within the application area to retain radionuclides, metals and some major ions from the applied water volumes. As the land can be more appropriately monitored, managed and rehabilitated than water, an advantage of successful land application of effluent waters is the transfer of the constituents from a less manageable aqueous phase to a more containable solid phase. If immobilized by adsorption in the soil system, the radionuclides will not reach the aquatic ecosystems through runoff and subsurface flow during subsequent wet seasons.

TABLE 1. LAND APPLICATION AREAS AT RANGER URANIUM MINE

Location	Section	Size (ha)	Year commissioned	Water quality
Magela	Original	33	1985	Unpolished
	Extension	20	1994	Unpolished
RP1	Original	46	1995	Polished
	Extension	8	2006	Unpolished
Djalkmara	Original	18	1997	Polished
	Extension	20	1999	Polished
Jabiru East		52	2006	Unpolished
Corridor Creek		141	2007	Unpolished

The area of land application at Ranger has gradually increased (Table 1). Overall, 336 ha of land is now set aside for this purpose. Raw RP2 water is applied to most land application areas. In some areas, polished (wetland filtered) RP2 water is applied; this has a lower concentration of radionuclides than the raw RP2 water. Water is applied through a grid of sprinklers with a 6–10 m radius. The application rate is controlled such that no runoff occurs. Total applied volumes have varied from year to year, ranging from 6.3×10^4 to 1.3×10^6 m^3 between 1985 and 2008 (no water was applied to the land in 1990 or 1999). When compared to natural waters, RP2 water contains elevated concentrations of ^{238}U, ^{226}Ra and ^{210}Pb with values around 12, 0.3 and 0.15 Bq/L, respectively.

3. DISTINCTIVE FEATURES OF NORM DISTRIBUTION IN LAND APPLICATION AREAS

Soils from different land application areas have been investigated for their ability to retain RP2 water solutes [2, 3]. In particular, the original Magela land application area has been extensively investigated. The studies based on batch and column experiments showed that the soils have a strong adsorption capacity for radionuclides such that during land application they are likely to be retained within a few centimetres of the ground surface. Gamma spectrometry analyses of sections of soil cores from the land application area demonstrate this. The signal decreases rapidly with depth and, typically, below 10 cm it reduces to natural background levels. Water and a number of other, less reactive, chemical species infiltrate to the subsurface [2, 3]. Land application of RP2 water has therefore created areas of relatively high radioactivity in a surface zone (a few centimetres in depth) over 336 ha of common woodland. The spatial distribution of radioactivity is non-uniform; higher values occur closer to the sprinklers.

The mine operators are committed to rehabilitate the land application areas such that future occupancy does not lead to radiation doses exceeding the regulatory limits. Special consideration is required for the traditional local lifestyles which are based on a strong relationship with the land, some food gathering and hunting activities.

4. IMPLICATIONS FOR DOSE ESTIMATES

To determine above background radiation doses to members of the public that may enter the lease area after rehabilitation of the mine, Ranger Uranium Mine has developed a project to assess the radiological condition of the land application areas so that appropriate rehabilitation plans can be developed and remediation actions taken if required. Exposure pathways that must be considered are direct irradiation, inhalation of radon and its progeny, inhalation of resuspended long lived radionuclides in dust and direct ingestion of radionuclides in soils or through the consumption of bush foods collected from the land application areas.

This project has identified that standard values of a number of different parameters that are commonly used in models for estimating radiation doses in areas in which mining and milling of radioactive ores is carried out may not be strictly applicable to the special case of land application — the discrepancies in some cases may be up to several orders of magnitude. The differences arise mainly due to the fact that adsorbed radionuclides are likely to be present at the mineral grain surface, rather than being distributed throughout the mineral matrix. The radionuclides are also retained within the surface zone of the soil. By contrast, naturally occurring radionuclides are likely to be more or less evenly distributed in the bulk of the soil grains and throughout the deeper soil layers. In addition, the traditional use of bush foods is an important factor to be considered [4, 5]. Due to their significance for radiological assessments, the differences are identified in this paper:

In traditional lifestyles, the bare skin may be exposed to ground surfaces. For this reason external radiation dose measurements will ideally take into account both the non-penetrating $H_p(0.07)$ and penetrating $H_p(10)$ radiation;

With regards to the ^{222}Rn source term, ^{226}Ra presence near the surface of grains will lead to higher ^{222}Rn emanation rates than expected from bulk soil ^{226}Ra distribution. In addition, as the applied ^{226}Ra is retained close to the soil surface, ^{222}Rn is likely to diffuse more readily;

Atmospheric radon concentration is typically measured at a height of 1–2 m, but the traditional Aboriginal lifestyle may involve sitting and sleeping on the ground. Radon concentration above ground may vary as a function of height, wind speed and due to the presence or absence of perennial vegetation [6].

Resuspension factors are commonly used to estimate the expected concentration of airborne radioactivity in dust relative to that on the surface of the ground (to a few centimetres depth). These factors have been developed for the wet–dry tropical areas in northern Australia [2, 7]. Corrections are required to determine the contribution of suspended dust in land application areas. This is because a strong gradient exists in the soil activity concentration as a function of depth and also because of the larger surface area to volume ratios (as smaller particles tend to have higher adsorbed activity concentrations). Additionally, preliminary observations show differences in the dust loading values as a function of heights representative for a person lying down or sitting, a juvenile standing and an adult standing;

Conventionally determined concentration factors for edible fruit and forage may also not be valid for the land application areas. During the operational phase, foliage and fruit in the land application area may be sprayed directly by the water derived from the mine areas. Following rehabilitation, the uptake is likely to be through root system only. For larger fruit bearing trees, roots may be distributed underground to depths of greater than a few centimetres and may not be influenced by the applied radionuclides which are retained near the surface.

Taking account of these issues, a comprehensive programme of direct measurements has been established. This programme is now one of cleanup and the results will become available in due course.

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EXPERIENCE OF THE CONSTRAINTS AFFECTING THE IMPLEMENTATION OF DECOMMISSIONING/REMEDIATION PROGRAMMES AT URANIUM MINING SITES

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Abstract

It is well known that the need for extensive remediation programmes derives from the lack of appropriate planning at the beginning of mining operations, i.e. remediation is not adequately taken into consideration in the overall mining development. As a consequence of this, the implementation of remediation work generally faces several constraints that prevent the adoption of the necessary cleanup procedures. These constraints can be of an economic, technical, regulatory or social nature. In Brazil, the remediation of the uranium mining site of Poços de Caldas constitutes a very significant challenge for the mine operator and regulatory organizations. Many research/technical projects have been carried out by different institutions but the integration of the results of these works into a coordinated framework has never been achieved. There is also a lack of synergism between the environmental and nuclear regulatory authorities, and the mine operator does not seem to have a clear plan of action to deal with the problem. As a result of this situation, the expertise existing in the country is not being properly utilized to facilitate the development of the necessary actions. Also, members of the public have not yet been properly involved in the decision making process and this will constitute a serious problem in the near future. The paper discusses potential actions to overcome these constraints based on international experience.

1. INTRODUCTION

In Brazil, activities related to the exploration, production and processing of uranium ores are implemented by the State owned company Indústrias Nucleares do Brasil (INB). Uranium is produced to supply the domestic demand, presently represented by two PWR type nuclear reactors. As a result of the decision not to depend on the external supply of uranium, the exploration of the available and known low grade ore bodies in Brazil has been undertaken.

The first deposit to be exploited was the one located at the municipality of Poços de Caldas. This deposit was discovered in the 1970s. The ore grade was of about 0.1% uranium, which occurred as pitchblende, associated with pyrite (FeS_2), fluorite (CaF_2) and zirconium and molybdenum minerals. The Uranium Mining and Milling Facility of Poços de Caldas (UMMFPC) started operations in 1982. After 13 years of non-continuous operations, the mining activities were finally suspended. The total uranium production was 1242 tonnes of U_3O_8 [1].

At the present time, the UMMFPC is in the first phase of a decommissioning/remediation process and a general project for the mine closure is cleanup. Several scientific and technical projects have been developed by different organizations dealing with the closure and remediation of this installation. However, a well defined plan of action has not yet been conceived.

This paper discusses the reasons for this situation, i.e. why there are problems in implementing the UMMFPC remediation works. The Brazilian situation is used as the basis for this analysis but it is expected that some of the lessons learned may serve to aid the implementation of remediation programmes at other sites that share similar problems.

2. DESCRIPTION OF THE MINE SITE — ACID MINE DRAINAGE PROBLEM

The uranium production centre of Poços de Caldas is located on the Poços de Caldas plateau, in the south-east region of Brazil. This alkaline complex corresponds to a circular volcanic structure whose formation began in the upper Cretaceous period (87 ma (million years ago)) and evolved in successive steps until 60 ma. The uranium enrichment in the Poços de Caldas mine is related to hydrothermal events (primary mineralization) and to later weathering processes (secondary mineralization). The uranium in this mine was extracted by open pit operations. About 45×106 m^3 of ores were processed and this gave rise to approximately 12×10^6 m^3 of waste rock, while the mill process generated a volume of approximately 2.4×10^6 m^3 of tailings [2].

The main sources of pollutants to the environment are the tailings dam (TD), the waste rock piles (WRPs) and the open pit (OP). Pyrite oxidation was found to be the driving force in leaching metals and radionuclides into the environment. It has been estimated that acid drainage generation will last for 600 and 200 years from the

waste rock piles and the tailings dam respectively [2]. The long timescale involved in the oxidation of sulphidic materials implies a need to adopt permanent remedial solutions.

It was also estimated that the release of untreated effluent from the tailings dam and waste rock piles into the environment, without any treatment, would result in radiation doses as high as 8.0 mSv/a to members of the public. These values are higher than the primary dose limit for members of the public established by the Brazilian regulatory authority, i.e. 1.0 mSv/a [2, 3].

3. REGULATORY CONSTRAINTS

One of the first issues to constrain the implementation of remediation works in Brazil, especially at uranium mining sites, is concerned with the regulatory framework. Uranium mining operations are regulated both by the Federal Environmental Agency (IBAMA) and by the Nuclear Regulatory Authority (CNEN). However, when the mine was developed, the environmental legislation, now available, was not in place. As such, the mining developer did not have to present an Environmental Impact Statement (EIS) prior to the operation of the mining and milling facilities. The licensing process was mainly dictated by the CNEN because uranium mining and milling facilities are considered to be nuclear installations in Brazil. From the point of view of the CNEN, the decommissioning/environmental remediation of a mining facility is treated as 'abandonment of the installation'**.** The requirements are rather generic in nature and the actions to be implemented regarding the post-operational phase of facilities were not prescribed. The requirements include the following actions to be implemented by the operator:

- Backfilling of the open pit with mine debris and sealing of all wells, holes, galleries or any other excavation for research or ore removal, in the surface or subsurface, to prevent the occurrence of accidents.
- Actions to limit the potential risks to human health and safety.
- Classification of areas in the mine to avoid the release of toxic substances to the environment.
- Implementation of an abandonment and area restoration plan, to be approved by the regulatory authority. This plan will ideally contain, to the extent possible, predictions of possible future uses of the area.

These criteria are contained in the regulatory document CNEN–NE–1.13 (1989) (www.cnen.gov.br) which also contains the regulatory requirements to be applied in the licensing of uranium and thorium mining and milling facilities. Numerical standards, however, are not provided, but it seems to be implicit that the releases to the environment will ideally not exceed those authorized for the operational phase of the installation.

More specific requirements are available for the management of tailings dams (Standard CNEN–NE–1.10 (1980) (www.cnen.gov.br)). It is required that waste be stabilized physically and chemically in order to ensure that effluents leaving the system comply with the appropriate regulatory levels. Stabilization will ideally begin immediately after the termination of waste disposal. The systems will ideally be provided with means to seal or eliminate contaminated drainage sources in order to avoid, as much as possible, the collecting and treatment of the drainage. The system will ideally also be protected against natural drainage by means of engineering works, such as dykes and embankments. It will ideally also be controlled and marked in order to restrict intrusion by members of the public and to prevent non-authorized use of the waste. The stabilization, control and maintenance of the system in the long term will ideally be documented and this record must be part of any commercial transaction involving the area. CNEN will ideally also be informed promptly about any new landowner.

After 1986, EISs began to be required for any operation in Brazil that could cause significant impacts in the environment. The EIS document has to be presented to the IBAMA for approval. In addition, every project involving mineral extraction in the country has to make available an Area Restoration Plan, based on the decree No. 97623 of 10 April 1989 linked with the Brazilian Constitution (Article 225, paragraph 2). The decree also establishes that, in the case of a new project, the plan must be presented during the environmental licensing of the project. Economic aspects of the environment restoration are also to be taken into account and the costs related to this activity must be part of the overall project cash flow.

As the uranium mining and milling operations in Poços de Caldas began before the above dates, the Environmental Agency (IBAMA), in July 2002, made use of a mechanism known as 'Terms of Environmental Commitment (TEC)'**.** By signing this, the operator commits himself/herself to present a Degraded Area Restoration Plan (DARP) to be inserted in the Decommissioning Project of the installation. In the Terms of Reference (ToR) that have been elaborated to guide the operator in complying with the safety requirements established in the DARP, different elements related to the appropriate and definitive remediation of the tailings disposal area, open pit and waste rock dumps are clearly defined.

The resulting situation is that if the operator does not wish to declare the mine as abandoned, i.e. if it is intended to continue water treatment operations indefinitely, no constraint will be made by the Nuclear Regulatory Authority as long as the emissions level is below that leading to radiation doses to members of the public of 0.3 mSv/a. On the other hand, the environmental agency requires the adoption of a remediation plan as soon as possible, but as long as radiological issues are involved and while the IBAMA does not have the necessary expertise to deal with them, a grey area exists and this can only be solved by means of proper negotiations and mutual understanding between the relevant parties. It is important to mention that other stakeholders must also be involved in this process in an appropriate way.

4. MANAGERIAL CONSTRAINTS AND TECHNICAL ISSUES

Unlike some other mining sites in the world (that are located in dry areas) the mining site of Poços de Caldas is located in an area characterized by high precipitation rates, i.e. 1800 mm/a, meaning that if the water treatment is not functioning undue emissions of radionuclides and heavy metals into the environment will occur. On the other hand, when the water is being treated, large amounts of material (sludge) — containing significant levels of radionuclides and heavy metals — have to be disposed of. Because of this, disposal areas at the mining site have to be made available. As the tailings dam is not capable of containing any more waste, the material resulting from water treatment is disposed of in the mine pit (an operation that was not predicted in the mining operation plan).

Because of this, it seems to be clear that the starting point for any remediation plan for the site will ideally be the abatement of acid drainage generation. Unfortunately, the mine operator, despite several studies already carried out at the site, has not understood and drawn the proper conclusions from the results of these studies. Instead of channelling resources to pursue solutions for the problem of acid drainage, efforts have been directed towards the implementation of ineffective solutions. For example, resources have been wasted: in the re-vegetation of the waste rock piles; in trying to decrease the amount of water infiltrating these systems, in applying — without appropriate understanding and calculations — a clay layer on the top of the waste rock piles; and in enhancing the disposal volume of the tailings dam.

Another important managerial flaw is the lack of effort in trying to collect and organize the relevant information about the site. This includes, for example, descriptions of the mining operations, environmental monitoring data, publications related to the site, etc. This situation is aggravated by the fact that a large part of the work force has left the company or has been relocated to other productions centres or has retired. As a result, the memory of the site will soon be lost to a very large extent.

Finally, the full dismantling of the industrial area and site remediation do not constitute priorities for the company. Since these operations are resource consuming and no funding mechanism (e.g. trust fund) has been created to support them, the company prefers to invest the available resources in the development of the mining and processing operations of the new production centre in Caetité in the north-east region of the country. The problem is that acid drainage has been estimated to last for at least 600 years and, in the long term, it will require a very significant amount of resources. In other words, procrastination of the implementation of effective solutions for the remediation of the site is not a wise managerial decision. Instead, the operator will ideally seek appropriate support from experienced professionals in the pursuit of the design and implementation of an adequate remediation plan.

5. LEGAL CONSTRAINTS

In December 2002, to attend to the requirements embodied in the Terms of Environmental Commitment (TEC), the operator started an international bidding process to contract specialized consulting services for the development of the necessary studies for the elaboration of the DARP. The type of bidding was based on the lowest price and was open to contractors from outside Brazil, as long as the technical requirements (based on the terms of reference) were fulfilled. This process was not concluded because of problems in complying with Brazilian legislation (mainly problems related to the exchange rate variation). At the end of 2004, another bidding process was opened, but reduced to a national outreach while allowing for the possibility of establishing partnerships between Brazilian and international companies. A consortium between a European consulting company and a Brazilian one won the bidding. However, the contract was cancelled in June of 2006 by INB due to technical problems. At the end of 2006, a third bidding attempt was opened by INB. Once again the process was not concluded. This time no proposal could comply with the requirements established in the bidding process. According to information obtained from INB (personal communication) it is foreseen that another bidding process will be started in 2009.

The main problems that the operator faces in the bidding process relate to the legal/bureaucratic constraints resulting from the legal status of the company, i.e. a State owned company. This prevents flexibility

and imposes serious constraints in the setting up of good contracts. Another factor that contributes to the inefficiency of the process is the lack of experienced companies in the country dealing with the remediation of radioactively contaminated/nuclear sites. While a considerable amount of research work has been carried out dealing with the decommissioning and remediation of the site [4–10] practical remediation experience is still lacking in the country. To make things worse, there is no contact (or synergism) among the different research projects and the results are not being assimilated by the regulatory authorities or the operator.

6. CONCLUSIONS

The uranium production centre of Poços de Caldas is the first uranium production centre to be decommissioned and remediated in Brazil. Due to the lack of experience in developing uranium mining operations and also due to the lack of an appropriate regulatory framework, significant environmental liabilities have been generated. Eleven years after the termination of the mining and milling operations at the site, a well defined site remediation plan has not yet been designed. As demonstrated in this paper, this situation results from three main issues: regulatory, managerial and legal constraints. Lack of financial resources certainly plays a role, but overcoming the first steps may contribute to reducing the costs associated with site remediation. It would also avoid the waste of financial resources in the implementation of inappropriate and/or ineffective solutions.

Individual measures to improve the overall situation can be suggested. They would include:

- Commitment of the upper hierarchies of the company and regulatory authorities to the implementation of a remediation programme;
- Coordination of actions amongst the different regulatory authorities;
- Integration of the results arising from the technical and scientific work;
- Greater autonomy of the operator to conduct the bidding process;
- Involvement of all relevant stakeholders;
- Allocation of appropriate financial, material and human resources

The adoption of any one of the above elements in isolation would not be enough to improve the overall situation. Lessons learned from other countries that have had to face similar challenges reveal that it is essential to establish administrative arrangements that lead to the formation of a working group that can discuss and propose a road map for the design and implementation of the remediation plan. This group will ideally be made up of representatives of the operator (and its consultant company), the regulators (at the federal and state level), relevant technical and scientific institutions and other relevant stakeholders.

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LESSONS LEARNED FROM THE REMEDIATION AT VILLA ALDAMA URANIUM EXTRACTION PLANT

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Abstract

From 1969 to 1971, a uranium extraction plant operated in close proximity to Villa Aldama city in Chihuahua state; the plant ceased operations in 1971 leaving 30 000 t of uranium tailings, 1735 t of uranium ore and contaminated equipment and buildings. The whole facility and the radioactive material remained almost unattended for more than 20 years. During this time the tailings and ore contaminated the soil around them. At the same time, the city of Villa Aldama expanded and its houses began to approach the site boundary. Because of this and other factors, such as the potential contamination of groundwater, remediation actions were required by the Nuclear Safety and Safeguards National Commission. These actions were, basically, the decontamination of the site and the disposal of the radioactive waste generated in the process. This paper describes the remediation efforts that brought the facility to a safe status.

1. INTRODUCTION

In 1967, the Mexican Mining Development Commission, which was a decentralized entity of the federal government, set up a project for the operation of a uranium and molybdenum ore processing facility in Chihuahua State in the north of the country. For this purpose, a small city called Villa Aldama (the name was later changed to Ciudad Aldama) was selected, because of favourable factors for the siting and operation of the facility — such as its relative proximity to the uranium mining sites (located 50 km north of the city) and the easy access to urban services such as electric power and water supplies and also the availability of a workforce.

Then, in June 1969, the plant was transferred to URAMEX (short for Mexican Uranium), which also was a federal entity (now extinct). The purpose of this transfer was that URAMEX would use the facility as an experimental plant focusing only on the extraction of uranium. The operation of the experimental uranium extraction plant started in 1969 and ended two years later due to its demonstrated low profitability. The plant ceased operations in 1971 but remained under the responsibility of URAMEX until 1985, the year in which URAMEX was liquidated. The facility was returned to the Mining Development Commission along with approximately 35 000 t of uranium tailings generated during the two years of plant operation and around 1735 t of non-processed uranium ore.

The tailings were deposited on a non-stabilized provisional impoundment located on the site — west of the main building in an area called zone 1 (see Fig. 1). The ore was deposited in an area to the east of the main building in zone 2. Zone 3 included the grinding section, the processing building, the machine room, the laboratory and transit areas between buildings. (This layout and nomenclature were adopted for the remediation and dismantling activities.)

In September 1992, the Mining Development Commission was also liquidated and the facility and the radioactive material were transferred to the Mining Development Trust (FIFOMI). This transference also included rights, obligations and non-fulfilled commitments.

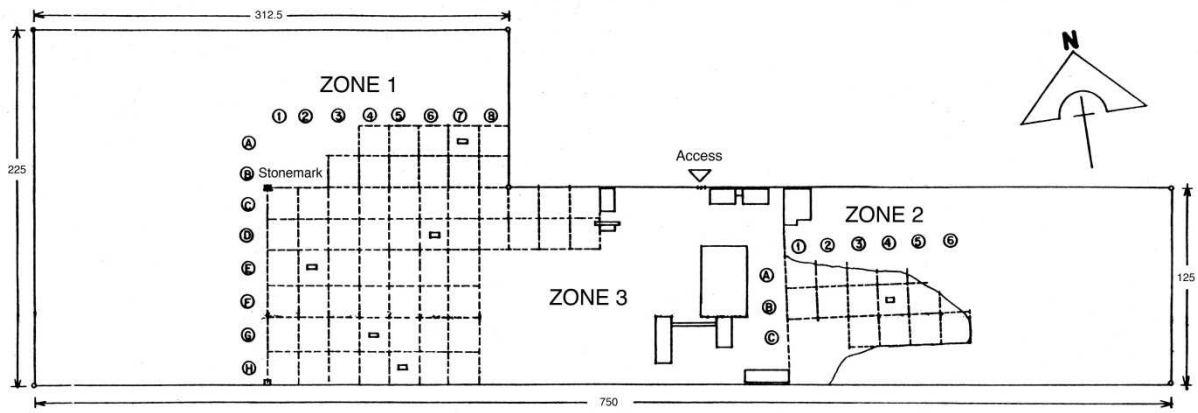

FIG. 1. Villa Aldama plant layout.

2. NEED FOR REMEDIATION MEASURES

The facility, the tailings and the ore were given little attention for more than 20 years until 1991, the year in which the Nuclear Safety and Safeguards National Commission (CNSNS) identified the need for remediation actions due to the following facts:

(a) The growth of Ciudad Aldama. The plant and the onsite impoundment for the tailings were located only a few hundred metres from houses and other inhabited buildings. Projections suggested that the population of the city would continue growing at an increasing rate, raising the risk of direct exposure to radiation and the risk of intake of radioactive material by members of the public.

(b) The original impoundment and the ore were located over a groundwater body from which water is extracted to be used as a part of the city's urban services. (Groundwater is approximately 20–30 m beneath the surface at the site.)

(c) The original impoundment and the ore were located on the slope of a hill which is part of a rainwater basin.

(d) The edges of the original impoundment were made of non-stabilized filling soil, and therefore the material was not properly immobilized and the integrity of the impoundment was not assured.

3. REMEDIAL ACTIONS

In order to decide how to proceed for the remediation of the site, several meetings involving the main entities were held in 1991. Those involved were: CNSNS as the regulatory body, FIFOMI as the owner of the site, Ciudad Aldama Government as the affected party (but also in a role of supporting party), and the Nuclear Research National Institute (ININ) as FIFOMI's technical support organization. As a result of these meetings, it was decided to carry out the following actions (to be performed by the ININ):

(1) The removal of the tailings from the site (zone 1).

These activities were divided into two stages. The first stage started in July 1994. During the first stage, 35 000 t of uranium tailings and 1735 t of uranium ore were removed from the site. The tailings were taken to the Peña Blanca uranium mining site, which is the place where the uranium mineral came from. It was necessary to construct a new impoundment at Peña Blanca for the disposal of the uranium tailings removed from the Villa Aldama facility. However, due to the long period that the tailings had remained at the Villa Aldama site in an impoundment without impermeable layers, the soil beneath the tailings was contaminated by the uranium tailings. This soil did not meet the criteria established by the CNSNS, so it was determined that a second removal stage was necessary. The second stage started in 1996 and ended in 1997. During this period, an additional 30 000 t of contaminated soil were taken to the Peña Blanca disposal site, making a total amount of 65 000 t of waste disposed.

(2) The removal of uranium ore (zone 2).

The 1735 t of uranium ore were also moved to the Peña Blanca site and deposited in the amortizing zone of the impoundment facility.

(3) The decontamination of the buildings and the equipment (zone 3).

Mineral, tailings and other material with high concentrations of uranium were removed from the process buildings. Walls, floors and process equipment were decontaminated using

aggressive methods such as high pressure water (hydro-laser), mechanical brushing and the use of strong solvents (fuel oil and mixed acids). The decontamination of zone 3 spanned the time period December 1993 until March 1994.

The goal of the decontamination of buildings and equipment was to take the contamination to levels below the criteria given by the CNSNS. However, some components could not be decontaminated as required by the authority and they had to be dismantled and removed. The destination for this radioactive material was a mine gallery called Las Margaritas at the Peña Blanca mining site. The amount that had to be moved was about 30 t. After that, the mine gallery entrance was sealed with concrete.

4. CRITERIA APPLIED FOR CLEARANCE

At the time that the remediation actions were required by the regulatory body (1991), the regulation involving soil and buildings clearance had not yet been established. The CNSNS had therefore to issue provisional specific clearance criteria for the release of soil, buildings and equipment. These criteria were issued specifically for application to the remediation activities at the Villa Aldama Uranium Extraction Plant, and were not to be used elsewhere. The criteria and requirements established by the CNSNS [1] were as follows:

(1) The average concentration of radium-226 in 100 m^2 of land shall not be above the background levels by more than:
- 0.185 Bq/g (5 pCi/g) averaged over the first 0.15 m of the soil;
- 0.555 Bq/g (15 pCi/g) averaged over 0.15 m thick layers of soil more than 0.15 m below the surface;

(2) For occupied or habitable buildings:
- The average annual concentrations of radon-222 short lived decay products (including the background) shall not exceed 0.02 WL;
- The exposure rate shall be reduced to as low as reasonable achievable, but shall not be above the radioactive background by more than 20 μR/h;

(3) In order to release the facility, equipment and any other components for unrestricted use, they shall comply with the following requirements:
- No paint or any other cover shall be applied to contaminated surfaces of equipment or structures unless a reasonable effort has been made to reduce contamination below the applicable limits stated in Table I of the Regulatory Guide 1.86 of the US Atomic Energy Commission; this shall be determined by direct measurements, and appropriate records shall be generated;
- Reasonable efforts for the removal of the residual contamination shall be carried out;
- Contamination levels shall be determined on the internal surfaces of process piping, drain lines or ducts; this determination shall be carried out by direct measurements in appropriate accessible points representative of the contamination levels inside such pipes lines or ducts.

5. RESULTS OF THE REMEDIATION ACTIONS

Despite the efforts applied in the removal of uranium ore, tailings and contaminated soil, the contamination in the land area of the facility (zones 2 and 3) still persisted, although at lesser concentrations than previously. The options considered to address this situation were:

- To take even more contaminated soil to the disposal facility at Peña Blanca site; or
- To cover the soil with a 0.15 m thick layer of alluvium, establishing restrictions for the use of the land.

The involved parties CNSN, ININ, FIFOMI, and the Local Government, discarded the first option and agreed to proceed according to the second one. The results obtained from applying this option were quite good in terms of the resulting exposure rate [2]. However, in terms of contamination, a few persistent spots remained with concentrations of radium-226 slightly above the given criteria. Therefore, the CNSNS established the following conditions [3] for the restricted use of the land and buildings on the site:

- Agricultural activities and shepherding of cattle will not be allowed;
- The construction of habitation buildings will not be allowed;
- Drilling for water wells will not be allowed;

- The minerals yard (zone 2) can be used only as a transit zone as long as the radiation levels remain slightly above the background levels;
- For any activity carried out in the property, it shall be guaranteed that the personnel will not stay more than 40 hours a week, averaged on an annual basis.

The above restrictions are still in force and the CNSNS periodically carries out visits to the site to verify that these conditions are met. At the present time, the local government of Ciudad Aldama is responsible for the former facility including the land and buildings. The main processing building of the plant is now used as a warehouse for several types of construction materials that will be used in public works; the yards of the property are now used as parking areas and a service station for local government vehicles (zone 2) and as a depository for plastic residues that will be recycled (zone 3).

6. LESSONS LEARNED

The remediation actions at the former Villa Aldama Uranium Extraction plant prevented a potential risk situation for the population of Ciudad Aldama. However, remediation could have been avoided if a proper and timely decommissioning of the facility had been carried out. Because responsibilities for the site passed from one entity to another, there was a delay in concluding the decommissioning activities. This delay was enough to allow the migration of contaminants to the underlying soil with the resulting potential for groundwater contamination. The delay also allowed the expanding city of Ciudad Aldama to approach too close to the site. Additionally, the site selection process for the plant was performed in the late 1960s when no regulation or recommendations existed at national, or even at international, level and so more priority was granted in the siting process to having easy access to urban services, and less to issues with potential safety impacts such as projections of future activities and populations in the region or the proximity of the facility to groundwater.

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OCCUPATIONAL EXPOSURE DURING REMEDIATION WORK AT A URANIUM TAILINGS PILE

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Abstract

The aim of the study is to assess the occupational exposure at an abandoned uranium mining site due to work activities involving tailings pile remediation. A hypothetical scenario has been created in which the workers involved in the remediation activities are exposed to radiation through internal and external pathways. The results indicate that occupational radiation doses may reach a significant fraction of occupational radiation protection limits. For future tailing site remediation projects which are planned in Portugal, individual dose levels will ideally therefore be carefully measured, controlled and registered. Also, optimization techniques to reduce individual and collective doses in the remediation work activities will ideally be implemented.

1. INTRODUCTION

The exploitation of uranium ore in Portugal took place from 1913 to 2000. There were mining activities at 61 sites, mostly at small open pits, although there were also some underground mines. The great majority of the mining sites are located in the districts of Guarda and Viseu (central-east Portugal). In this region, the country's most important mine, the Urgeiriça mine, is located. From 1913 to 1944, it was only mined for radium. After World War II, its purpose changed and in 1951 a chemical treatment plant for the production of low grade uranium concentrates was built. Later, the plant was modified for the production of high grade uranium concentrates. The ores from the Urgeiriça mine, as well as from other Portuguese uranium mines, were processed in the uranium mill facility built near to Urgeiriça. Tailings from this facility include most of the radionuclides contained in the processed ores (those of the uranium decay chains), as well as some minor amounts of residual chemicals [1].

Since 1996, the Portuguese government has had to deal with the decommissioning of the mines, mills and other facilities and the rehabilitation of the mining sites. In particular, for the remediation of the Urgeiriça uranium site, a reclamation programme was instituted on 20 July 2005. At this site, the rehabilitation of the Old Dam was considered to be a key element of the overall environmental remediation programme. The programme at the Urgeiriça site also included remediation of the industrial area, where the remains of the former milling and processing plants were located, as well as two former stockpile areas, one for ore and another for waste rock. Some of the waste arising from the industrial area had to be transferred to the tailings pile. After remediation, the tailings were to be fenced off to prohibit public access [1]. These works were planned for completion before the end of 2007. In fact, the tailings pile rehabilitation was concluded in April 2008.

This paper focuses on the potential occupational exposure during the Old Dam remediation. The tailings at this site were a source of external radiation and also a significant source of radon gas and airborne dusts. During the remediation, only external radiation doses were monitored. In fact, the workforce could have been exposed to radiation through three main exposure pathways: (a) inhalation of radon decay products, (b) inhalation of dust-borne long lived alpha emitters, and (c) external radiation. This paper describes a preliminary assessment with limited data and focuses, in particular, on radon inhalation and external (gamma) radiation exposures.

2. METHODS AND MATERIALS

2.1. Occupational exposure in remediation/rehabilitation activities

Occupational exposure is defined by the International Commission on Radiological Protection (ICRP) as all exposures incurred at work as a result of situations that can reasonably be regarded as being the responsibility of the operating management [2]. The European Council Directive 96/29 EURATOM stipulates a limit on exposed workers of 100 mSv in a consecutive 5 year period subject to a maximum effective dose of 50 mSv in any single year. Below this dose limit, the principle of optimization requires that any radiation exposure be kept as low as reasonably achievable (ALARA). When the annual dose limit is exceeded, the regulatory body can permit this exposure by considering the individual case and/or imposing work conditions and dose restrictions for the successive years.

The exposure scenario adopted in this study considers both internal and external radiation exposures. The critical group is represented by an average adult worker, involved in the remediation of the tailings, assumed to be exposed during an 8 hour work day, 5 days per week, 48 weeks per year (assuming that he/she is away on vacation for 4 weeks per year), for 3 years. It was also assumed that all of the working time is spent outdoors. It is recognized that these assumptions are conservative and are likely to result in dose estimates at the upper end of the likely range. The relevant pathways considered for the workers exposure are radon inhalation and gamma radiation from the tailings.

2.2. Sampling

A radon survey over a 13.3 ha area of the tailings pile was carried out during two field campaigns: in March 2001 (45 sampling points) and in August of 2002 (22 sampling points). The radon concentrations in the atmospheric air measured at 1 m above the soil ranged from 195 to 1205 Bq/m^3, with an average value of 557 Bq/m^3 [3].

To assess the external dose, in the absence of direct measurements of external radiation, the doses were estimated based on radionuclide concentrations in the soil determined for individual radionuclides by gamma spectrometry (Table 1 [4, 5]).

TABLE 1. ESTIMATED RADIONUCLIDE CONCENTRATIONS IN SOIL AND DOSE COEFFICIENTS

Radionuclide	Average soil concentration ($C_{soil,i}$) (Bq/kg) ± □	Dose coefficients (DC_{ext}) (Sv/s)/(Bq/m^2)
^{235}U	483 ± 975	1.48×10^{-16}
^{234}Th	6506 ± 14 262	8.32×10^{-18}
^{226}Ra	3004 ± 5692	6.44×10^{-18}
^{210}Pb	3046 ± 5541	2.48×10^{-18}
^{137}Cs	9.9 ± 10.1	2.85×10^{-19}
^{40}K	1738 ± 871	1.46×10^{-16}

3. RESULTS

3.1. Effective dose assessment

The effective dose received by a worker depends on many factors including the radon concentration, the exposure time, the exposure frequency and the characteristics of the radon decay products. It is given by Eq. (1):

$$D_{Rn} = C_{Rn} \times DC_{inh} \times E_f \times f_{eq} \quad (1)$$

where

D_{Rn} is the annual dose resulting from radon inhalation (mSv/a),
C_{Rn} is the average radon concentration in air breathed at the tailings pile (Bq/m^3),
DC_{inh} is the radon effective dose equivalent factor (mSv/(Bq.h/m^3)),
E_f is the outdoor exposure frequency (hours/year),
f_{eq} is the equilibrium factor for radon decay products.

The recommendations of the United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR) for the conversion of potential alpha energy exposure (Bq. h/m^3) to effective dose equivalent (nSv) have been adopted [6]. A value of 9 nSv per Bq.h/m^3 was adopted for the radon effective dose equivalent factor. This conversion factor incorporates an adult average breathing rate of 19.2 m^3/d. An outdoor exposure frequency of 1920 hours per year and an equilibrium factor for radon decay products of 0.4 were assumed.

For external exposure due to contaminated ground surfaces ($D_{ext,i}$), the dose coefficients (Table I) were converted into the appropriate units by assuming a soil density of 1600 kg/m^3 (ρ) and a soil depth contamination of 1 m (T_s) [5].

$$D_{ext,i} = C_{soil,i} \times DC_{ext} \times E_f \times 3600 \times \rho \times T_s \quad (2)$$

The dose estimates obtained from the assessment of exposure from external radiation and from intake of radon were combined for the assessment of the value of total effective dose for comparison with dose limits.

3.2. Summary results

For the hypothetical exposure scenario, the effective dose for one year's radon exposure at 557 Bq/m^3 is 3.85 mSv while, for external exposure, the estimated gamma radiation dose is 4.5 mSv/year. The total effective dose is obtained by summing the doses resulting from internal and external exposure. The value for the total effective dose is 8.35 mSv/year.

4. CONCLUSIONS

This assessment, because of limited data and the associated uncertainties, ought to be regarded as only indicative of the likely exposures received by workers. Nevertheless, it is clear that the workers involved in the Old Dam remediation could have been exposed to significant radiation doses via both internal and external pathways. In addition, radiation doses due to the inhalation of dust containing radionuclides, which were not considered in the assessment, may also contribute significantly. External exposure to gamma radiation (54%) and internal exposure due to the inhalation of radon (46%) were both found to contribute significantly to the total dose.

The results show that occupational radiation doses for this assumed exposure scenario reach a significant fraction of the protection limits. If it is assumed that the exposure to work activities is for three years, the dose would be about 25% of the 100 mSv limit for the consecutive five years of exposure. These calculations were done assuming that no radiation protection precautions were applied during work activities.

Further remediation actions are planned for other former uranium tailings sites in the vicinity of the Old Dam. This preliminary assessment indicates that, for these planned remediation projects, improved radiation protection procedures and surveillance of workers will ideally be implemented. The individual worker dose levels, therefore, will ideally be carefully measured, controlled and registered. Optimization techniques to reduce individual and collective doses will ideally be established. Radiation exposure of the workers will ideally be reduced by proper planning and use of protective equipment in order to keep doses as low as reasonably achievable (ALARA). Implementing some simple precautions, such as the wearing of appropriate work clothes and dust masks, would contribute to this objective. Additionally, workers will ideally be monitored and controlled periodically in order to assess the exposure being received.

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BASELINE RADIOLOGICAL SURVEY OF THE URANIUM BEARING REGION OF POLI (NORTHERN CAMEROON)

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Abstract

The paper describes a baseline study of the uranium bearing region of Poli where it is expected that the uranium deposit of Kitongo will be exploited in the near future. Soil, water and foodstuffs were sampled. The results show that activity concentrations of natural radionuclides in soil and water samples are low and comparable with global averages, but higher in foodstuffs (vegetables) (^{210}Po and ^{210}Pb). Further elaborated studies of this type will ideally be undertaken by the company that develops the mine, prior to the beginning of operations.

1. INTRODUCTION

Many reported studies reveal the impact of uranium mining and milling in the environment [1–9]. Prior to any uranium mining and milling, a baseline radiological study is necessary. Thus, measurements of naturally occurring radioactive materials (NORM) carried out within the framework of this study will be helpful to assess the environmental impact of the mining and milling of the Kitongo uranium deposit in the Poli region of Cameroon and, later, to the site remediation after these processes are completed [9].

Since 1950, many geological studies for assessing the uranium potential of the Kitongo deposit have been carried out [10–12]. This deposit may be exploited in the near future by the Government of Cameroon [13]. To date, no radiological study in the area of this deposit has been undertaken. The main objective of the present work is to carry out the first part of a baseline study of the uranium bearing region of Poli. This study has involved the sampling of soil, water and foodstuffs. Indoor radon concentrations were also measured in some dwellings as radon can contribute significantly to the radiation dose to the public.

2. MATERIALS AND METHODS

2.1. Sampling

The uranium bearing area zoned during uranium prospecting corresponds to a surface of 6710 km^2 as illustrated in Fig. 1 [10–12]. In the present work, a surface of 144 km^2 was sampled. The sampling plan comprises a square grid on which soil samples were collected at points separated by distances of 4 km. Each sampling point corresponds to a square surface area of 1 m^2. At each point, a sample to 0–5 cm depth was taken, giving an average sample whose dry mass is around 500 g. At Gata, a soil profile was sampled (0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm and 20–25 cm of depth) to study the vertical distribution of the radioactivity. In total, 20 soil samples were taken. In addition, 10 water samples and 10 foodstuff samples were collected in the small town of Poli and its neighbourhood. The water samples were taken from rivers, wells and drinking fountains. All of the soil and foodstuff samples collected were dried, sieved (2 mm) and homogenized.

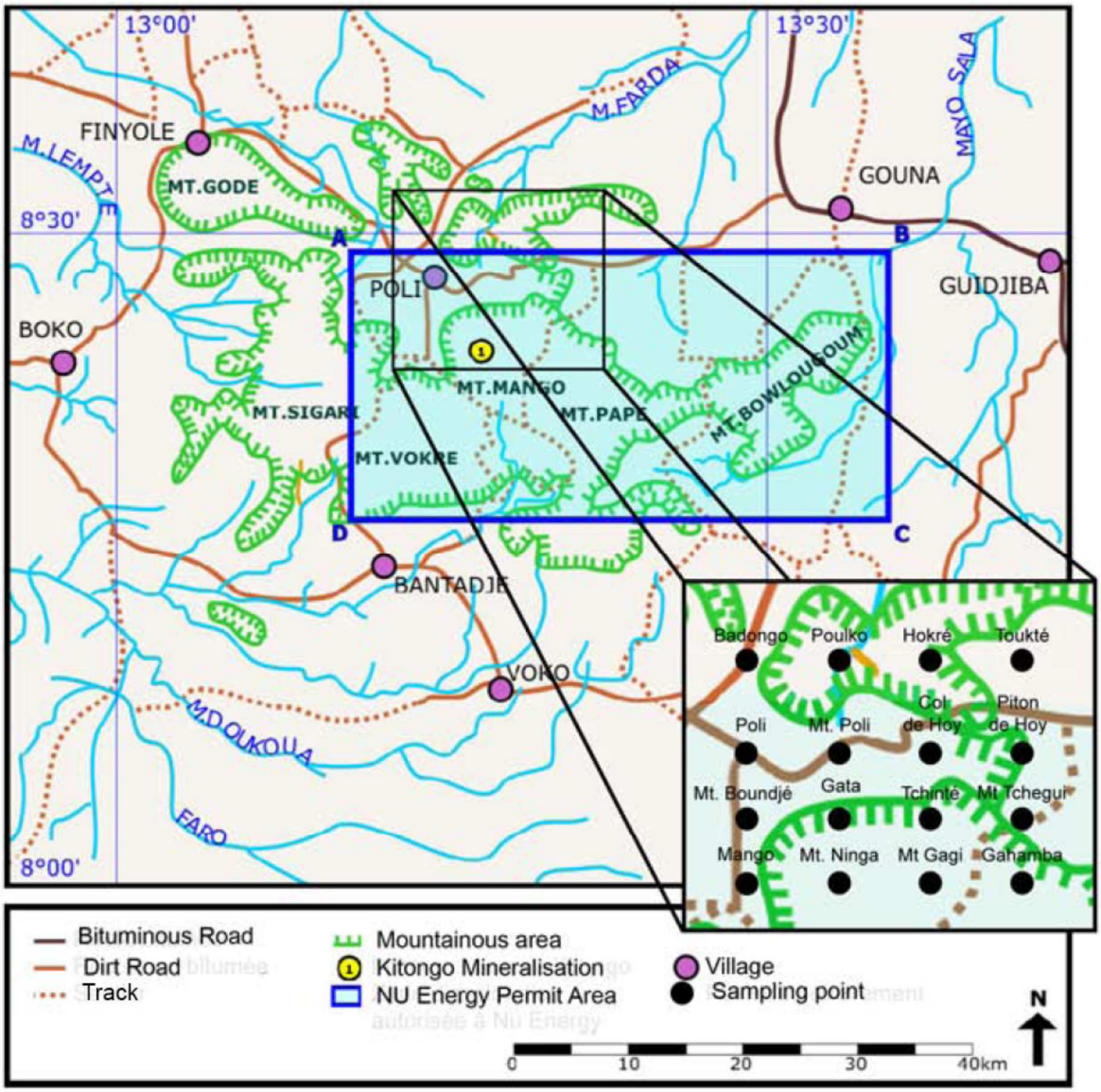

FIG. 1: Strategy of sampling for the uranium bearing region of Poli including the town of Poli and the Kitongo deposit. The points A, B, C and D circumscribe the area (6710 km^2) over which a German institute undertook an airborne survey [10–12].

2.2. Methods for radioactivity measurement

The measurement procedure for uranium and thorium isotopes used in this study has been described in Ref. [14] and the procedure for ^{210}Po determination is fully described in Ref. [15].

Uranium measurements were performed using thin films containing diphosphonate and sulphonate groups that have been shown to have the required selectivity for uranium [16]. For ^{226}Ra measurement, a thin film containing MnO_2 in 100 mL of water sample was used [16]. After exposure, the thin films were dried at ambient temperatures and measured using alpha spectrometry.

For ^{210}Po measurements, a silver disc coated on one face with plastic rubber was put into weakly acidified water containing 50 mBq of the ^{209}Po tracer. ^{210}Po and ^{209}Po were spontaneously deposited onto the disc. The silver disc, dried at ambient temperatures, was measured using alpha spectrometry.

Gamma spectrometry measurements were performed using a Canberra p-type HPGe well detector (GCW4523) with a total active volume of 206 cm^3, a relative photopeak efficiency of 45%, and a resolution at 122 and 1332 keV of 1.24 and 1.93 keV, respectively. Treatment of the data was carried out using GENIE 2000 software. The spectrometer was calibrated using a liquid solution of ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{137}Cs, ^{88}Y and ^{60}Co traceable to international standards and emitting gamma rays in the energy range 59–1836 keV. Coincidence-summing corrections for ^{88}Y and ^{60}Co were determined by Monte Carlo calculations [17]. The self-absorption correction factors were also calculated by Monte Carlo simulation [18].

2.3. Measurements of radon in dwellings

Indoor radon concentrations were measured in five dwellings in the uranium bearing region of Poli by using electret detectors (E-perm) [19]. These detectors were exposed in dwellings (bedrooms, classrooms and offices) for a three month period.

3. RESULTS AND DISCUSSION

3.1. Radioactivity in soil

The measurements in 20 soil samples are summarized in Fig. 2. The activities of ^{210}Po and ^{210}Pb are higher compared to other members of the ^{238}U series. The results presented in Fig. 3 show an exponential decrease of the ^{210}Po and ^{210}Pb activity concentrations with sampling depth. The enrichment of soil surface (0–5 cm) in ^{210}Po and ^{210}Pb is explained by the deposition of radon progeny coming from the disintegration of radon in the atmosphere after emanation. A similar result was observed for ^{210}Po and ^{210}Pb around closed uranium mines in Portugal [8]. ^{208}Tl activity is lower than the equilibrium value due to the branching ratio (36%) of its mother product, ^{212}Bi.

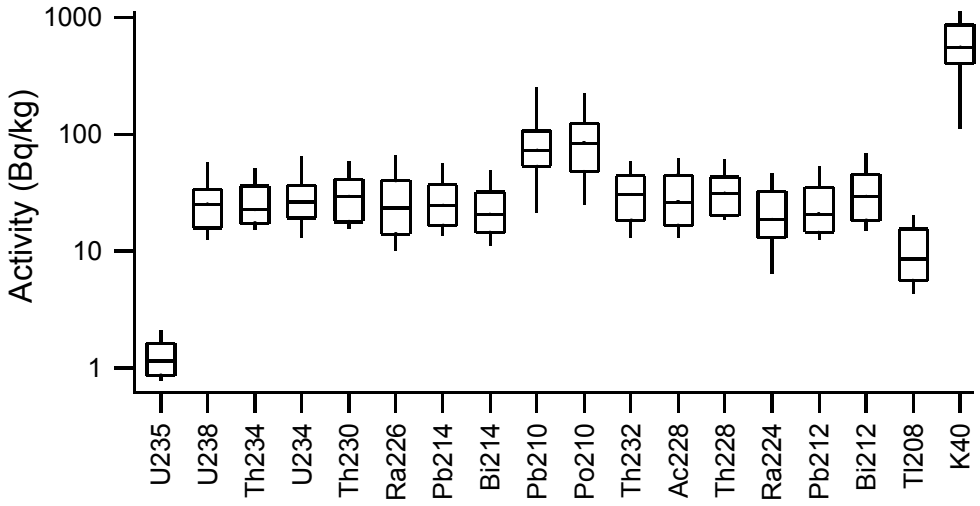

FIG. 2. Box plot of the activity (Bq/kg) distribution of ^{40}K and natural series ^{235}U, ^{238}U and ^{232}Th in 16 soil samples from the uranium bearing region of Poli.

The average activities observed in the world are 420 Bq/kg for ^{40}K, 38 Bq/kg for ^{238}U and 45 Bq/kg for ^{232}Th [20]. Activities of ^{40}K measured in 20 soil samples, as illustrated in Fig. 2, show a median activity of 552 ± 10 Bq/kg, a mean activity of 506 ± 3 Bq/kg and a maximal value of 1124 ± 27 Bq/kg (Mont Tchegui sampling point). Figure 2 shows median activities of 25 ± 2 Bq/kg for ^{238}U, 23.3 ± 6.3 Bq/kg for ^{226}Ra and 30.5 ± 1.7 Bq/kg for ^{232}Th. Radioactivity levels in the region of Poli are comparable to global averages and, as might be expected, lower than reported results from measurements [8–9] undertaken in the environments of closed uranium mines.

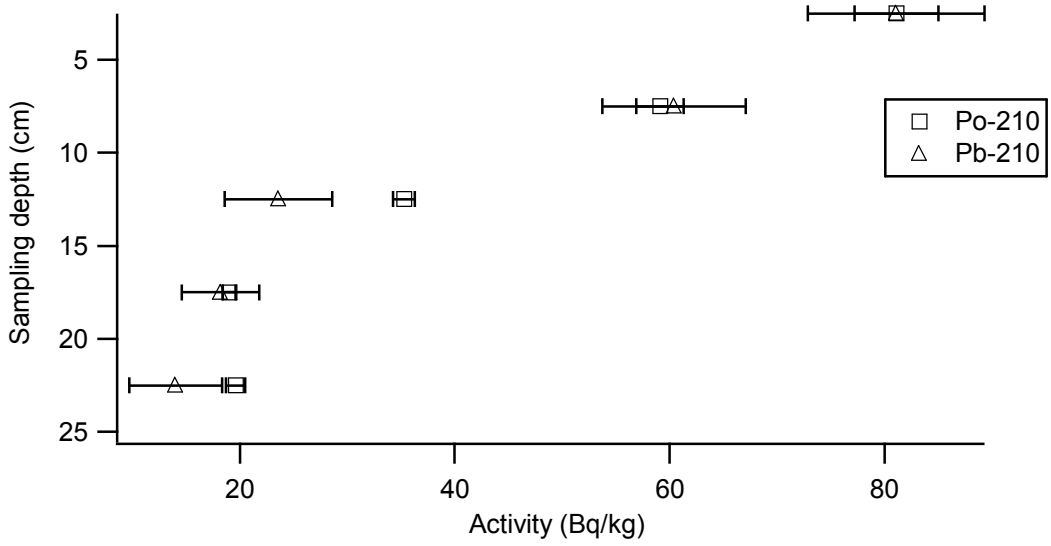

FIG. 3. Vertical distribution of ^{210}Po and ^{210}Pb in materials sampled at the Gata sampling point.

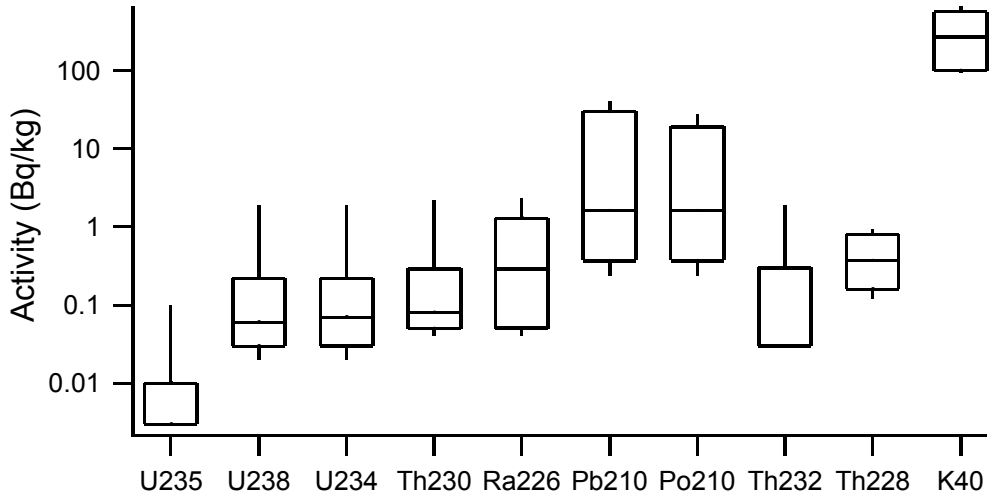

FIG. 4. Box plot of the activity concentration (Bq/kg) distribution in foodstuffs frequently consumed in the region of Poli.

3.2. Radioactivity in foodstuffs

From Fig. 4, it can be observed that activity concentrations of ^{40}K are high compared to the values observed for the other radionuclides. This is not of great concern from the standpoint of radiation protection due to the homeostatic regulation of ^{40}K in the human body. The activities of ^{210}Po and ^{210}Pb are higher in vegetables due to the deposition of radon progeny. The activities measured in beef are 5 ± 0.5 Bq/kg for ^{210}Po and 5 ± 1 Bq/kg for ^{210}Pb; this can also be explained by the deposition of radon progeny in pasture land as well as the ingestion of soil by cattle.

3.3. Radioactivity in water

All measurements of ^{226}Ra in water were under the limit of detection of alpha spectrometry (10 mBq/L). Figure 5 presents activities of ^{238}U, ^{234}U and ^{210}Po. All the reported results show that radioactivity in water of the region of Poli is low compared, for instance, with radioactivity around the closed uranium mine of Rayrock [7].

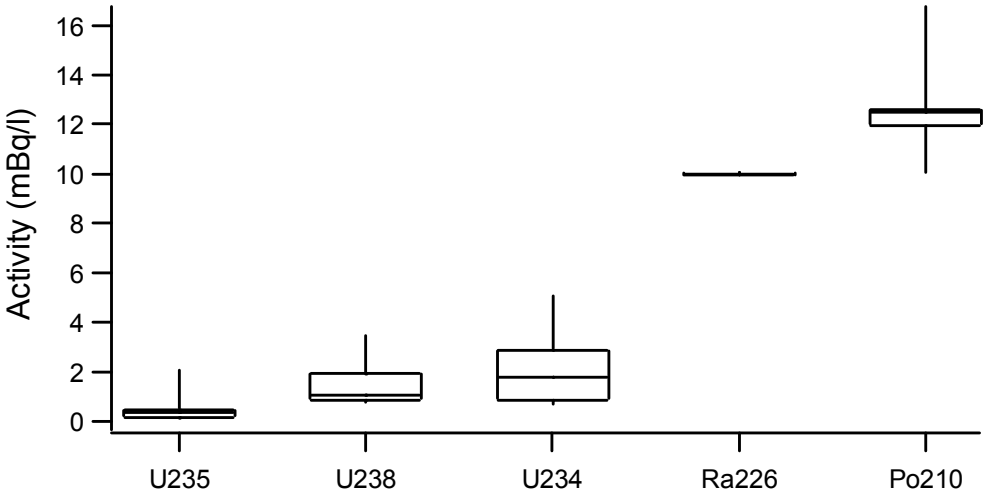

FIG. 5. Box plot of activity distribution in water (river, well and drinking fountain) of the uranium bearing region of Poli. ^{226}Ra is represented by its limit of detection in water.

3.4. Radon in dwellings

Table 1 presents the results of ^{222}Rn measurements in dwellings in the Poli region. The average indoor concentration (without values obtained for the office) is 120 ± 21 Bq/m^3. The value obtained for the office is 2000 ± 100 Bq/m^3, which is very high compared to the world average value of 40 Bq/m^3 and this value was identified as being in need of further investigation.

Many studies have been reported on measurements of radon in dwellings [4, 21–25]. The reported results reveal the large variation in the radon level in houses. It has been recognized that in most houses with high radon levels, the main source is not the building material but the convective radon influx from the soil. The radon level depends also on geological and meteorological factors, ventilation conditions and other factors [26].

TABLE 1. CONCENTRATION OF ^{222}RN IN 5 DWELLINGS OF THE URANIUM-BEARING REGION OF POLI

Exposure area	Concentration (Bq/m^3)
Inn	115 ± 19
Room	113 ± 18
Classroom	106 ± 19
Parlour	137 ± 18
Office	2000 ± 100

4. CONCLUSION

In this environmental baseline study of the uranium bearing region of Poli, it has been found that soil, drinking water and food do not contain high levels of radioactivity, although the leaves of vegetables contain relatively higher levels of ^{210}Pb and ^{210}Po.

Any changes in environmental radioactivity due to mining activities will be evident by comparison with the results of this study and further studies of this kind. Once uranium ore is brought from depth to the surface, ^{222}Rn emanation and ^{210}Pb and ^{210}Po deposition might lead to an increase in the radiation dose to the population of the Poli area. Thus, no mining licence will ideally be given by national authorities without the mining company being required to undertake an adequate monitoring programme. Well water may also be an interesting component in which to assess any damage from mining to the environment because of the very low levels of uranium and radium radioisotopes in water at the present time.

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ROMANIAN EXPERIENCE IN THE REMEDIATION OF NORM CONTAMINATED SITES — A CASE STUDY

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Abstract

In January 2006, the National Commission for Nuclear Activities Control (CNCAN) received an official letter from the mayor of a village claiming that an area of the local environment was radioactively contaminated due to some past liquid discharges from gas exploitation in the area. The paper describes the steps taken by CNCAN to investigate the situation and to resolve it by a programme of remediation which involved the polluter, the local community, the radiological assessment organization and local and national regulatory authorities.

1. INTRODUCTION

In Romania, naturally occurring radioactive materials (NORM) have been produced as a result of various industries, such as uranium and non-uranium mining and milling facilities, chemical fertilizer production and oil and gas extraction and exploitation. These industrial facilities are at different stages in their life cycles: some are still operating but many of them have ceased operations and are, at present, at an advanced stage of decommissioning.

The nuclear field in Romania is governed by Law No. 111/1996, on the safe deployment, regulation, licensing and control of nuclear activities. The general radiation protection requirements stipulated by this law are detailed by the Fundamental Norms on Radiological Safety, approved by the National Commission for Nuclear Activities Control (CNCAN) Presidential Order No. 14/2000. Chapter VII of these Norms is dedicated to situations of significantly increased exposure due to natural sources and Chapter X to radiation protection in the case of interventions. More detailed requirements on radiological safety during working activities involving NORM were issued in November 2008 as a result of the European Community's Phare project No. 017-519-03.03, 'Development of CNCAN capabilities regarding the regulatory aspects of Naturally Occurring Radioactive Materials (NORM) and Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) related activities'. However, these regulations do not address past activities. There are no specific requirements for intervention in the case of chronic exposure to radiation or to environmental radioactive contamination.

The principles and general requirements for environmental protection in Romania are established under the Romanian Government Urgent Ordinance No. 195/2005, approved with modifications and completions by the Law No. 265/2006. Specific requirements for the investigation and assessment of soil and subsoil pollution, as well as for the remediation of affected areas are established by the Romanian Government Decisions Nos 1408/2007 and 1403/2007, but they do not address radioactive contamination. In 2008, the Ministry of Environment and Sustainable Development initiated a process of developing similar Government Decisions for radioactively contaminated sites; a first meeting of the working group was held in order to justify the need to develop such decisions.

2. CASE PRESENTATION

2.1. Identification of radioactively contaminated land

In January 2006, CNCAN received an official letter from the mayor of a village situated in the west of the country, claiming that an area of the local environment was radioactively contaminated due to some past liquid discharges from gas exploitation in the area. CNCAN investigated the area in February 2006, performing measurements and environmental sampling for laboratory analysis.

Figure 1 shows the investigated area, located to the north-easterly limit of the forest in the vicinity of the village and comprising a drainage channel (2 m wide, 475 m long) and a woodless area with a meandering water flow (4 m wide, 80 m long) linked to a drainage ditch (1 m wide, 155 m long). The drainage channel is almost covered with bushes and small trees. At the time of the investigation, both the drainage channel and ditch were partly covered with ice.

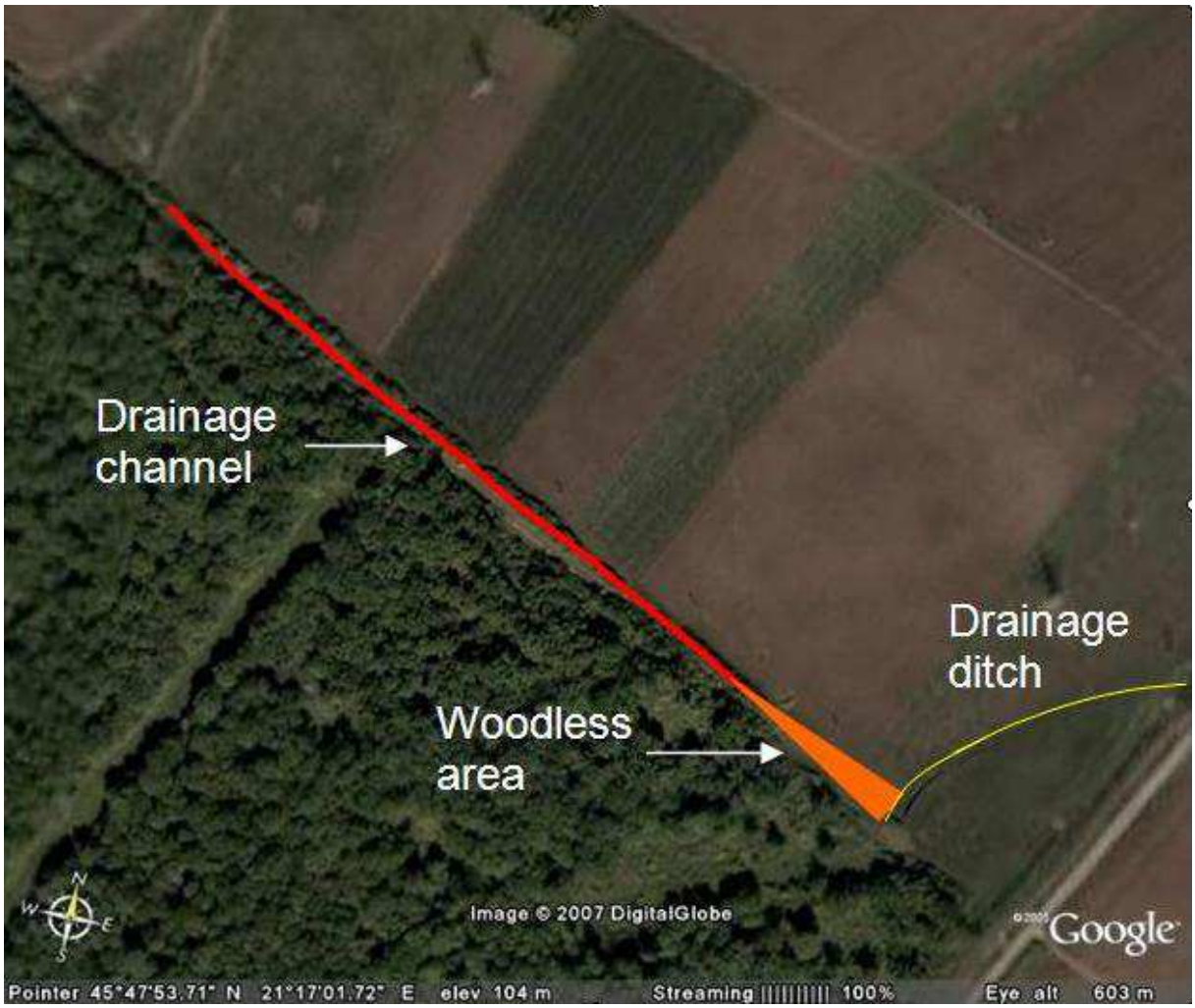

FIG. 1. The contaminated site.

The ambient gamma radiation dose rate values measured in the area are generally within the typical range of natural background, except for the drainage channel, where values two to three times higher than background were measured on the banks. The middle of the channel showed the highest values (up to 6 times higher than natural background).

Four samples of water, soil and sediment were collected from the hotspots for subsequent gamma spectrometric analyses. The water sample showed a ^{40}K activity concentration equivalent to natural background levels. In the soil and sediment samples, radionuclides from the ^{238}U and ^{232}Th series were identified at concentrations one order of magnitude higher than the average concentrations in undisturbed soil of Romania.

Consequently, CNCAN confirmed the presence of the radioactive contamination on the land but noted that it did not represent a significant radiological risk for the local population. However, it also noted that due to the fact that the neighbouring land has been sold and that houses are being built in the vicinity of the contaminated area, the presence of the enhanced NORM might become a real radiological risk in the near future.

2.2.1. Regulatory dispositions

The polluter company was identified and, based on the provisions of CNCAN's Fundamental Norms on Radiological Safety, it was asked:

(a) To mark the perimeter of the contaminated area and to limit the access of the public inside the perimeter;
(b) To assess the level of radioactive pollution of the contaminated area;
(c) To send the results to CNCAN, in order for it to establish the appropriate remediation actions.

2.2.2. Immediate actions

Warning signs were posted in March 2006. The building of a fence around the contaminated area took more than 6 months, due to all of the authorizations and approvals necessary from different public authorities (local public administration, land administration, forest administration, gas transport company) but also because of the time taken to identify all the owners of the land (including one private person).

2.2.3. First assessment of the radioactive pollution of the contaminated area

In order to assess the level of radioactive pollution of the contaminated area, the polluter company contracted the Pitesti Nuclear Research Branch (Radiation Protection Laboratory), which is approved by CNCAN, to perform radioactivity measurements in environmental samples. It was led by a qualified radiation protection expert. The radiological investigation was performed in 2007, while both the drainage channel and the drainage ditch were flooded, and it consisted of:

- Radiological mapping, performed by systematic measurements of the radiation count rate 10 cm above the ground at different steps along three mapping elements;
- Measurement of the ambient equivalent dose rate 1 m above ground;
- Field sampling and laboratory spectrometry analysis: 8 soil samples were collected from hot spots by core drilling down to 80 cm. In order to determine the depth migration profile of the radionuclides, the cores were divided into 5 segments representing different depths (0–20 cm, 20–35 cm, 35–50 cm, 50–65 cm, 65–80 cm). Five background soil samples were collected, including one depth profile; the others were taken from the 20 cm top layer of soil. Ten samples of vegetation were collected (one background), to assess the radionuclide transfer from soil to plants. Four surface water samples were collected from the contaminated area and one sample of well water from the Gas Separators Station. All samples were prepared following laboratory procedures and were analysed by high resolution gamma spectrometry.

The count rate values obtained by direct measurement were converted in units of ambient equivalent radiation dose rate and processed via a bivariate interpolation method following grid generation by a linear kriging method. In Fig. 2, these values are presented as dose rate maps for each of the radiological mapping regions.

Areas were considered to be contaminated when the background ambient dose rate was exceeded by at least two times. On this basis it was concluded that the extent of the contamination was approximately 1500 m^2.

The ratios between ^{238}U and ^{232}Th progeny concentrations in soil samples from the area and in the background sample are generally higher than 1 in the 0–20 cm and 20–35 cm layers, with higher values in the first layer. Maximum values of the ratios are registered for ^{226}Ra in the first layer and they vary between 7 and 47. For each sample, excepting one, the radionuclide concentrations decrease to the average concentrations of the background depth profile within 20 to 35 cm. One soil core shows a greater depth migration of radionuclides, probably because it was collected from near the discharge point.

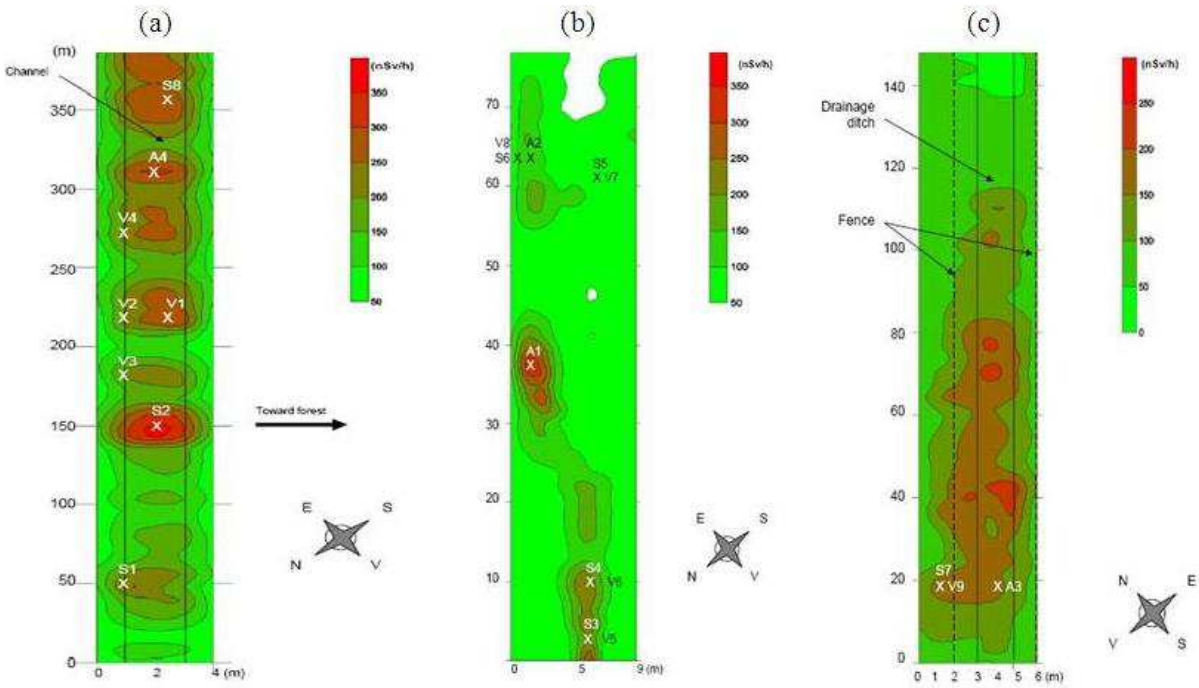

FIG. 2. Radiological mapping of: (a) drainage channel, (b) woodless area, (c) drainage ditch.

The radionuclide concentrations in the water samples from the area are similar to that of the background sample. The contaminant transfer factors from soil to vegetation are in good agreement with the ranges of values indicated in the literature for the radionuclides under consideration.

Taking into account the extent and the depth of the contaminated soil layer, it is estimated that there is a maximum of 550 m^3 of contaminated material.

The assessment of the radiation doses to the public was done using the RESRAD 6 computer code, developed by Argonne National Laboratory in the USA. The source term was derived from the soil measurement results. A contaminated surface of 1500 m^2 was assumed and, for conservative reasons, the recipient was placed directly above the contaminated area. A 35 cm thick layer of contaminated soil was assumed — without a covering layer. The following additional assumptions were made: density of soil 1.7 g/cm^3, average wind velocity 1 m/s, annual precipitation rate 1000 L/m^2 and the annual rate for soil irrigation 200 L/m^2. The dose conversion factors were taken from the US Environmental Protection Agency's (EPA) Federal Guidance Reports Nos 11 and 12. The consumption data for the public are the default values contained in the RESRAD code. On this basis, the additional dose to the population was calculated to be 25.4 mSv/a, of which 24.3 mSv/a is due to radon in homes built directly above the contaminated soil and inhabited for 24h/day. If the contaminated area is not used for building houses, the additional dose to population will be less than 1.1 mSv/a, representing about half of the dose received due to natural background radiation, but slightly exceeding the public dose limit of 1 mSv/a.

2.2.4. Proposals for remedial actions

The results of the study were presented to CNCAN in July 2007, together with the following proposals for further actions:

(a) Removal of vegetation and drainage of water from the contaminated area;
(b) Removal of a soil layer up to 35 cm thick in areas in which the radiation dose rate exceeds twice the natural background, under radiological supervision;
(c) Final disposal of the removed material by one of the following methods: dispose of it in the National Low and Intermediate Level Radioactive Waste (LILW) Repository or in a sludge pile of the National Uranium Company; make a slurry of the soil and inject it into an oil extraction well or dilute the contaminant concentration by mixing the contaminated soil with uncontaminated soil at the same location.

In August 2008, during a meeting involving all stakeholders (the polluter company, the local environmental protection agency, the mayor of the commune, CNCAN and the team responsible for the study), these proposals were discussed, with the following conclusions:

(a) The removal of the vegetation and water from the contaminated land must be followed by another set of measurements, in order to check that there are no other hot spots;
(b) The precise volume of the soil to be removed must be decided after this second study is completed;
(c) The final disposal of the removed material in the National LILW Repository is not acceptable;
(d) The National Uranium Company did not accept such material for disposal in its sludge piles;
(e) The injection of the sludge into an extraction well is not feasible;
(f) The dilution of the contaminated soil with uncontaminated soil was not agreed to by the mayor of the commune, nor by CNCAN.

2.2.5. Second assessment of the radioactive pollution of the contaminated land

In 2008, the same laboratory was contracted to perform new measurements and analyses in the same area, after the vegetation and water had been removed. All of the water and vegetal material removed was checked for radioactivity. It showed natural background values. The new study was performed in July 2008 using the same methods with slightly different approaches:

- The radiological mapping was performed in smaller steps along the drainage channel;
- The value of 300 nSv/h of ambient dose rate measured in contact was selected as a criterion for deciding if land is contaminated. Using this criterion, eight hot spots were identified and marked on the field;
- From each hot spot, soil samples were collected by core drilling down to 60 cm; the cores were scanned by in situ gamma spectrometry and then divided into 4 segments of 15 cm each; 1 soil background sample was collected, representing one depth profile.

Using the 300 nSv/h operational intervention level, the extent of the contamination was reduced to 560 m^2. It was also calculated that removing the 35 cm top layer of soil from the hot spot areas would ensure the removal of 50% of the radioactive inventory. Taking into account the extent and the depth of the contaminated soil layer, a maximum of 200 m^3 of contaminated material is estimated to be present.

New calculations of the additional dose to the public resulted in similar values to those previously estimated, that is: 23 mSv/a, of which 21.8 mSv/a is due to radon in a house built on the contaminated land and inhabited for 24 h/d. If the area is not used for house building, then the dose would be 1.2 mSv/a.

3. REMEDIAL PROPOSALS

These new results were presented to CNCAN in November 2008, together with the following proposals:

(a) Removal of the 35 cm top layer of soil from the hot spot areas, under radiological supervision;
(b) Intermediate storage of the removed material, in one of the polluter's facilities, located near to the contaminated site;
(c) Disposal of the contaminated soil in one of the future disposal facilities designed for hydrocarbon contaminated soil.

CNCAN accepted these solutions, with the following conditions:

(a) The removal of the contaminated soil will be approved only if the operations are assisted by radiologically qualified staff and performed under such conditions that the workers will not receive radiation doses higher than the public dose limit (1 mSv/a);
(b) The intermediate storage of the contaminated soil will be approved only if the polluter company can demonstrate that it has the capacity to store it in a safe condition;
(c) The site will be released from regulatory control only if, after the removal of the contaminated material, it can be demonstrated by measurements that the doses to the public will not exceed the legal dose limit (1 mSv/a);
(d) If agreed by the environmental protection authorities, the disposal of the contaminated soil in one of the disposal facilities for hydrocarbon contaminated soil will be approved provided that the results of a radiological safety assessment of the disposal facility are acceptable.

Due to weather constraints, the removal of the material cannot be carried out until March 2009. By the end of March, the polluter company must present to CNCAN its practical solutions for removing and storing the contaminated soil documented in such a manner as to demonstrate the observance of the previously stated conditions.

4. CONCLUSIONS

From this example, several lessons can be learned. The remediation of a land area contaminated with radioactive material requires, first of all, an understanding of the physical processes taking place in the local environment. Unexpected delays must always be expected, starting with those involved in the search for persons owning the land and finishing with the problems caused by the different (technical) languages spoken by the authorities and companies involved in the process. The perception of the radiological risk by the public has also to be taken into consideration. Finally, it is a matter of finding the proper balance between the need for an intervention, public concern, regulatory requirements, the capabilities (and financial resources) of the polluter and the actual possibilities for effective remediation.

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RADIOECOLOGICAL ASSESSMENT AND REMEDIATION PLANNING OF URANIUM MILLING FACILITIES AT THE PRIDNEPROVSKY CHEMICAL PLANT IN UKRAINE

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Abstract

During the last 3 years, comprehensive radiological studies at the largest uranium production legacy site in Ukraine, the Pridneprovsky Chemical Plant, have been carried out. The studies included gamma dose mapping, radon-222 indoor and outdoor measurements, characterization of the dump sites and other hazardous facilities in this territory, as well as the preliminary dose assessment for people working at the industrial site. The paper describes the current status of remediation planning and the development of a new concept for the decontamination of the former uranium extraction facilities.

1. DESCRIPTION OF THE CURRENT STATUS OF THE LEGACY SITE

Uranium mining was carried out intensively in Ukraine from the end of the 1940s to the beginning of the 1990s [1]. The former State Industrial Enterprise, the Pridneprovsky Chemical Plant (PChP), was one of the largest metallurgical facilities in the former Soviet Union. Uranium ores were processed there from 1948 until 1991. During that time, uranium extraction was carried out on raw ore products delivered from Central Asia, the Czech Republic and Germany.

In addition to imported ores, the PChP processed uranium bearing sludge obtained from the smelting of iron ore from the uranium mines of Ukraine. In the early 1990s, due to disintegration of the former Soviet Union and consequently the uranium industry, the PChP was split into several separate enterprises and the processing of uranium was stopped.

Nine tailings impoundments were created in an area containing about 42 million tonnes of uranium extraction residues with a total activity of 3.2×10^{15} Bq (86 000 Ci) [1]. Some of the highly contaminated equipment and metals used at the facilities were deposited at storage sites within the area of the industrial zone of Dnieprodzerzhinsk and other residues were disposed of about 14 km to the south-east of the site. Each tailing impoundment has been inventoried based on information obtained from limited studies carried out during the past decade under a programme initiated by the Ministry of Fuel and Energy of Ukraine. However, the quality of the information available for each particular facility is not always reliable and more specific studies are required.

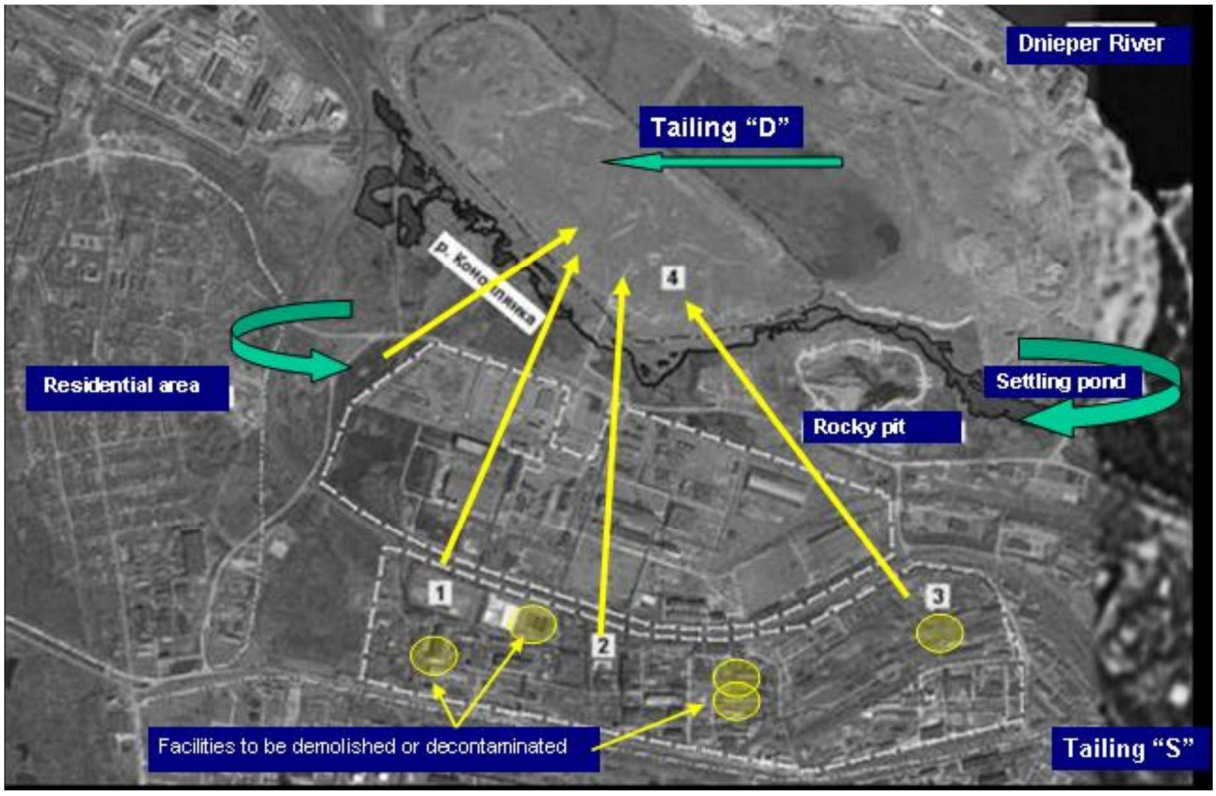

FIG. 1. The PChP uranium production legacy site. 1—Tailing Zapadnoe, 2 — Tailing Centralny Yar, 3 — Tailing Yugo-Vostochnoe, 4 — Tailing D (Dnieprovskoe).

The PChP territory is demarcated by a concrete fence. The area of the former PChP is divided by a railway into two large areas — the upper and lower parts. The main former uranium extraction facilities of PChP are situated in the upper part of the territory, and the largest tailings dump, Dnieprovskoe, is in the lower part, south of the Konoplyanka River — also referred to as the drainage canal (see Fig. 1). The upper part of the PChP territory, where the facilities are located, is much more contaminated with uranium–thorium series radionuclides than the lower part, due to the influence of the former uranium extraction facilities. No proper engineered barriers were provided for most of the tailings. After full capacity was reached, each tailing impoundment was usually covered with local soils, debris and other industrial waste.

The distinctive feature of this site and its uranium residue tailings is that it is located within the populated area of Dnieprodzerzhinsk town (about 276 thousand citizens). The residential area is situated close to the industrial zone at a distance of 1–2 km from the nearest tailings (see Fig. 1). Therefore, the planning of the remediation of the former uranium production facilities is very sensitive to the opinions of the local population.

2. CURRENT ACTIVITIES IN AND AROUND THE PChP TERRITORY

In 2008, about 20 enterprises were still in operation in the PChP area. Most of the enterprises are not related to the former uranium processing activities. However, the workplaces of these enterprises are situated close to the highly contaminated tailings dumps and former buildings used for ore milling and extraction. The presence of contamination from these facilities may expose workers externally due to gamma radiation and internally due to radon-222 emanations and alpha-aerosol dispersion [2]. Some small enterprises make use of facilities which were not decontaminated in a proper way. The regulatory constraints for enterprises within this territory are still not well developed and require improvement.

In addition to the enterprises already operating on this territory, there is significant interest in the further exploitation of the empty buildings on the site. For example, some workshops of the former hydrometallurgical plants that were used in the past for the extraction of the uranium concentrate have been sold to a new owner who intends to use these workshops for the processing of raw materials containing gold. It is clear that such 're-profiling' of the former uranium facilities requires the complete decontamination of the facilities.

Assessments have shown that there is an environmental impact at most sites where there are uranium tailings and waste. The impact is mainly due to releases of radionuclides from the uranium decay series (^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po) to surface waters and to the groundwater table, as well as to radon emissions and dust dispersion into the air.

Typical external gamma dose rates in the territory are generally rather low: 0.15–0.30 μSv/h. However, in some places, for example at the tailings surface, external gamma dose rates may reach 1–3 μSv/h and even 30–60 μSv/h. In such local 'hotspots' (e.g. the Central Yar tailings), ^{226}Ra activity in soils at the surface of tailings reaches 0.1–0.2 kBq/g. The radon exhalation at such hot spots was measured to be 2–6 Bq/m^2.s. Surveillance studies showed that the surface cover on such tailings is not sufficient to reduce the exhalation rates [2, 3].

Surface contamination on machinery, equipment, metal scrap, etc. from the period of uranium production still exists and these items are kept in close proximity to the former uranium production workshops. Some of the most contaminated debris and metal were dumped together with uranium residues at the tailings sites. This material contains, among other nuclides, ^{226}Ra and the long lived radon daughter nuclides ^{210}Pb and ^{210}Po on the surfaces of contaminated equipment and scrap. Monitoring has shown that the activity concentration of ^{238}U and ^{226}Ra within the territory of PChP varies from hundreds to several thousands of Bq/kg; this may be compared with local soils which contain only 15–30 Bq/kg. The main long lived radionuclides in the tailings are ^{234}U, ^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb/ ^{210}Po with activities of up to 10^5 Bq/kg. Aerosol pollution is also relatively high at the legacy site in comparison to naturally occurring background levels in the vicinity and is the result of wind driven resuspension and the dispersion of radon progeny radionuclides over this area.

The main contributor to radiation exposure in this territory is indoor radon. Concentrations of radon in some buildings used by workers in the industrial premises were found to be between 10^3 and 10^5 Bq/m^3. The highest concentrations were found at some indoor working areas where highly contaminated facilities are still in place (uranium extraction facilities, transport tubes etc.). Maximum measured outdoor concentrations of radon are (2–4) $\times 10^2$ Bq/m^3.

Preliminary dose and risk assessments carried out recently have shown that the current levels of alpha activity in surface water are rather low and lead to doses less than the permissible levels in Ukraine [1]. However, according to Ref. [3], the pore water in aquifers around tailing dumps is highly contaminated (the highest concentrations of alpha emitting radionuclides were 10^5 Bq/m^3) and can pose a potential risk in the event of the protective dyke becoming damaged. This could result in the spillage of the highly polluted tailings pore water into the drainage canal and on to the Dnieper River. Under natural conditions, the pore water moves in the aquifer towards the Dnieper River very slowly. At present, the water in the drainage canal (Konoplyanka River) has gross alpha activity levels of between 0.3 and 0.6 Bq/L; this is 10 to 20 times higher than the background levels that have been found in the Dnieper River upstream of the drainage water inlet to the reservoir. The most significant source of Dnieper River pollution is tailings pile D, the closest pile to the Konoplyanka River.

3. PRELIMINARY DOSE ASSESSMENT AND CONCLUSIONS BASED ON MONITORING DATA ANALYSES

Radiation exposures due to external radiation, inhalation of contaminated aerosols and radon, and soil ingestion were calculated [2]. The results showed that external exposure and radon inhalation make the highest contribution to the total dose. Depending on the scenarios chosen, annual dose rates may exceed the dose limits for both Worker Categories A and B, i.e. 20 and 5 mSv per year, respectively.

The radiation doses to people living in the vicinity of the PChP site are estimated to be less than 1 mSv per year for any potential scenario. However, an accidental situation which affected the tailing dams and removed the tailings cover could lead to significant radiological consequences which would still require long term surveillance for periods of 100–1000 years, or longer.

For most workers whose workplaces are in buildings which are not contaminated or who are mainly working in non-contaminated areas of the site, annual doses are estimated to be in the range 0.1–0.5 mSv per year. The annual doses to workers whose workplaces are located near to tailing dumps or near to the contaminated buildings or who are regularly inspecting/monitoring the tailing dumps may vary from 1 to 12 mSv per year depending on their specific duties and the time spent in the contaminated areas or contaminated premises. The highest doses (30–45 mSv/a) will be received by those who have regular access to the contaminated premises and are involved in remediation activities involving the removal and utilization of the tailing materials and/or of the most contaminated equipment.

The preliminary assessment concluded that the main priorities of the remediation plan will ideally be the cleanup of the former uranium extraction facilities, proper surface coverage of the tailings or removal of the tailings to specially prepared tailing sites (with engineering barriers). Predictions based on the radionuclide migration model incorporated into the radiological assessment tool 'Ecolego' showed that proper soil coverage and removal of the tailing materials from the largest tailing site D would decelerate radionuclide transport into the Dnieper River for the next 500 years [4].

A new concept for remediation has been developed; it involves establishing the following pre-feasibility actions in further remediation planning:

- To re-consider some of the legislative and regulatory norms — as a basis for safe management of the former uranium facilities (the new rules to be improved according to the principles of the International Basic Safety Standards [5]);

- To extend the tailing dump characterization and inspection programmes taking into account the recommendations of the IAEA;
- To consider retreatment (reprocessing) options for some tailings materials as a part of the remediation process.

The pre-feasibility studies are to be implemented by 2010 and will help in the selection of the most appropriate and economically justified options for remediation at the PChP industrial site. The experience gained from global best uranium facility remediation practices will be applied [6, 7].

Among the most pressing remediation problems still awaiting attention are: the highly contaminated buildings at the industrial sites; the phospogypsum cover, the integration of the largest tailing pile, Dnieprovskoe (tailing D), with other tailing materials; and the wet uranium Sukhachevskoe tailing pile (tailing S), which is still partly covered with water. One option to be considered is the deepening of the Konoplyanka creek to serve as a natural drainage canal for both the industrial site and the tailings pile D.

The new concept considers, as the most preferable action, the removal of the relatively small tailing dumps over the territory and their transportation to the surface of the largest tailing D (about 1 km) with further conservation of the tailings pile using a multilayer soil cover. The State Programme of 2003 suggested removing all tailing dumps and contaminated materials to the tailing S — a distance of about 14 km. This would dramatically increase the project costs. However, both options are still to be finally evaluated taking into consideration social and long term ecological considerations by using multi-attribute assessment procedures.

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EXPERIENCE GAINED IN TRANSFERRING WISMUT RADIATION PROTECTION KNOW-HOW TO INTERNATIONAL PROJECTS IN URANIUM MINING REMEDIATION

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Abstract

Since 1990, the federally owned corporation Wismut GmbH has been rehabilitating the legacies left behind by some 40 years of intensive uranium ore mining and processing operations in Eastern Germany. Starting in 1996, Wismut has been involved in transferring the know-how gained in the rehabilitation of the Wismut sites to projects outside of Germany. As a rule, radiation protection management and radioecological issues are key elements of these activities. In this work, benefits have been obtained both from the substantial similarities prevailing in the countries of the former Soviet Union and in Eastern Germany after termination of uranium production and from the commonality of the problems to be resolved. This paper describes the possibilities and limits of transferring radiation protection know-how to countries where the rehabilitation of uranium mining liabilities is often to be carried out under circumstances of limited financial, material and human resources. It also describes some lessons learnt. Conclusions for application to future projects are derived.

1. INTRODUCTION

Forty years of intensive mining and processing of uranium ores in the heart of densely populated areas in Eastern Germany left behind considerable liabilities. They are being cleaned up by the federally owned corporation Wismut GmbH under an environmental restoration project which is unique in terms of complexity and size. Since 1996, the corporation has also been involved in transferring the know-how gained in the rehabilitation of Wismut sites to projects outside of Germany. These projects have been funded by the European Community, the World Bank and other international organizations. In 2002, the Wismut subsidiary WISUTEC (Wismut Umwelttechnik GmbH) was established with a view to marketing the know-how gained during the rehabilitation of uranium mining sites in Eastern Germany. So far, more than 25 projects have been successfully implemented outside Germany. The know-how transfer has been primarily targeted at the Russian Federation and countries of the Commonwealth of Independent States (CIS) in Central Asia, but also to countries in Africa and North America. As a rule, consulting activities focus on key elements such as radiation protection management and radioecological issues.

Given the commonality of the inherited histories, the similarity of environmental problems to be resolved, and, last but not least, the former working level contacts between the experts of Wismut and their counterparts in countries in Eastern Europe and the former Soviet Union, Wismut was (and still is) well positioned for the task of transferring know-how to Eastern European and CIS countries. Examples of recent or ongoing projects are listed in Table 1.

TABLE 1. EXAMPLES OF TRANSFER OF KNOW-HOW BY WISMUT/WISUTEC

Project/beneficiary country	Task	From–to	Funded by
Phare Project PH4.2 / Bulgaria, Czech Republic, Estonia, Hungary, Poland, Romania, Slovakia, Ukraine	Provision of means to assess radiological risks	1997–1999	EC
Sillamäe Tailings Pond Remediation Project, Estonia	Environmental Impact Assessment (EIA), conceptual design, supervision	1999–2008	NEFCO
EUROPAID Project Lermontov, Russian Federation	EIA, identification of remedial measures, stakeholder involvement	2004–2005	EC
Disaster Hazard Mitigation Project Mailuu Suu, Kyrgyzstan	EIA, optimization of remedial measures, supervision of implementation	2005–	World Bank

2. CHARACTERISTICS OF PRE-REMEDIAL CONDITIONS IN BENEFICIARY COUNTRIES AND PROBLEM DEFINITION

The termination of uranium production in the beneficiary countries (and at Wismut) was marked by the following features:

(1) Uranium production was often carried out in complete disregard for the most elementary rules of occupational health and safety and of environmental protection. As a consequence, an existing long term radiological situation was left behind which requires the application of radiological protection principles for intervention situations.

(2) Operations were mostly terminated in a very abrupt way: no preparations had been made for closure, knowledge of remediation concepts and know-how on techniques were almost non-existent, regulations and methodology for rehabilitation design were usually absent, in general few expert personnel were available and the technical equipment necessary for conducting remediation (including the means for radiological data acquisition and for radiological assessment) was lacking.

(3) During the production operations, no financial provisions had been made for rehabilitation. Due to the economic situation prevailing in the countries, the State owned corporations were unable to carry out remediation according to international standards. Remediation had to be implemented under the conditions of constrained resources.

(4) The old culture of secrecy prevailed. Arrangements for communicating with the local population and the culture of ‘stakeholder involvement’ were barely developed.

The following is a typical list of issues which the experts from Wismut/WISUTEC have had to deal with:

- Definition of evaluation criteria, in collaboration with national authorities;
- Radiological impact assessment as an integral part of an Environmental Impact Assessment (EIA);
- Introduction of appropriate measurement techniques for the determination of contamination levels as well as procedures for measuring releases, including QA/QC procedures;
- Development of a radiological monitoring system, including individual monitoring;
- Optimization of remediation measures;
- Introduction of procedures to document the progress of the remediation effort;
- Ensuring practical radiation protection of employees and minimization of remediation related radiological exposure of the population;
- Management of radioactive waste and residues;
- Licensing management;
- Training and further education of employees involved, capacity building;
- Public relations, stakeholder involvement.

3. EXPERIENCE WITH MEANS OF KNOW-HOW TRANSFER

3.1. Body of rules and regulations and licensing management

There was a tendency in CIS countries for authorities to wish to retain the standards of the former Soviet Union. This phenomenon made it difficult to develop country , site and object specific solutions and to assign pertinent priorities. As an example, in the case of a geo-mechanically unstable waste dump located far from residential areas and in conditions of limited national financial resources, it seemed to be justified to limit remediation efforts to regrading (in order to eliminate immediate hazards), while refraining from capping (which

is required by national standards). In this particular case, the idea was somewhat difficult to transmit to national authorities. In matters like these, Wismut has been successful when presenting arguments based on international documents. The Safety Standards, Technical Reports and Technical Documents of the IAEA [1–5] as well as the recommendations of the International Commission on Radiological Protection (ICRP) [6] and of other international agencies provided a sound basis. In addition, case studies of remediation actions conducted in Germany proved helpful in overcoming a reluctance to move from previous approaches.

3.2. Provision of means

From the 1990s through to the present time, various programmes have provided countries with instrumentation and software for radiological measurements, modelling and interpretation. There have been shortcomings in coordinating such provisions both in the donor organizations and within beneficiary countries. Also, issues related to providing practical training in the use of hardware and software, to providing for quality assurance/quality control (QA/QC) (e.g. in radiation metrology), and to long term funding of operating costs, did not always receive due attention. In implementing the European Union Phare Project PH4.2, under the terms of which technical equipment designed to establish the radiological situation at uranium mining sites was provided to seven Eastern European countries from 1997 to 1999, Wismut contributed, in almost the same proportion, to the purchase of hardware, on the one hand, and to efforts for training, QA/QC, and the continuation of operations, on the other.

3.3. Training

Workshops and training courses are essential elements of assistance, irrespective of whether they are conducted in a beneficiary country or in the country of the project consultant. Choosing appropriate candidates is a key to success. Training courses will ideally put a great deal of emphasis on imparting practical skills. Wismut/WISUTEC's project experience shows that the best results are achieved by on-the-job training schemes. Funded by the IAEA, the European Union and other organizations, more than ten experts have completed study visits at Wismut on radiological aspects of uranium mining site remediation in recent years. Accompanied by Wismut specialist staff, these experts went on field trips to perform joint measurements, carried out laboratory work or worked together on modelling, etc.

3.4. Joint project work

As a rule, projects begin with the acquisition of data and the subsequent radiological evaluation of that data. Rather than distinguishing between consultant and beneficiary, the emphasis is again on joint efforts for concept building, acquisition and evaluation of data. Seeking and finding common ground and learning from each other — this approach has also provided benefits to Wismut. In 2001 and 2002, for instance, Wismut and the DIAMO Corporation (from the Czech Republic) initiated a project located in the German–Czech border region which was designed to adjust the methods used to acquire and evaluate radiological data. The project was conducted in the two neighbouring towns of Johanngeorgenstadt (on the German side) and Potucky (on the Czech side) along the common border in the Ore Mountains. Jointly performed measurements, modelling, exposure assessments and the exchange of results brought about harmonization in dealing with radiological issues in adjacent former uranium mining regions.

3.5. Radiation protection management under conditions of constrained resources

A performance based regulatory framework is better suited than a prescriptive regulatory framework for supporting radiation protection management under conditions of constrained resources. State of the art of science and technology are not always implementable under these conditions. Focusing on essentials, assigning priorities and selecting the proper degree of required accuracy can help to provide sufficient radiological data for the justification and optimization of radiation protection measures, irrespective of the scarcity of available means. An example of such an approach is Wismut's combination of field and laboratory measurement methods by making use of statistical evaluation procedures and of problem orientated follow-up calibration (see the flow chart in Fig. 1). Under such a scheme, the calibration and the laboratory measurement programme is reduced to a minimum while local experts on-site perform field measurements with a limited but sufficient degree of accuracy.

3.6. Stakeholder involvement

After forty years of uranium production in Eastern Germany, conducted to some extent under severe secrecy regulations, finding ways of dispelling mistrust and building bridges with the local population was the only possible way for Wismut to implement its environmental restoration project. This was achieved by active public relations work, by disclosing the whole range of environmental data and integrating the public concerned into the process of identifying optimized remedial options. Area rehabilitation was and is being carried out with the goal of returning reclaimed land to productive reuse (for example, the integration of rehabilitated mine dumps into the park landscape of the Schlema spa centre). In the framework of consulting projects performed in Eastern Europe, experience gained in stakeholder involvement was actively described and illustrated (for example, by inviting political and societal decision makers to attend site visits at Wismut). As a result, diverging stakeholder interests in identifying remedial solutions have been overcome.

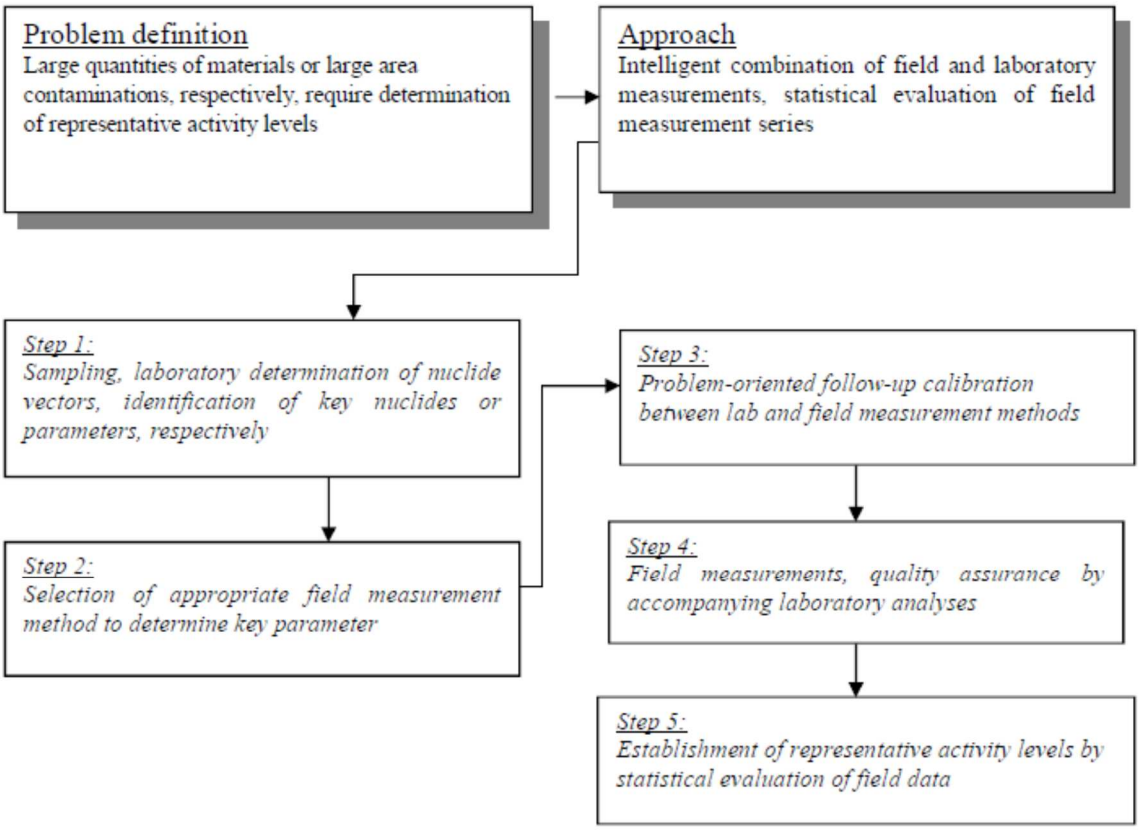

FIG 1. Flow chart of the combination of field and laboratory measurement methods for release measurements of materials and areas.

4. LESSONS LEARNED AND CONCLUSIONS

Key elements in successfully transferring radiation protection know-how in the framework of international projects designed to remediate the legacies of uranium mining and processing operations are:

- The application of international standards and technical documentation, in particular those published by the IAEA and ICRP;
- Transferring personal experience gained, with due regard to country specific conditions;
- Development of site and object specific solutions;
- Imparting practical skills through learning on the job schemes;
- Ensuring stakeholder involvement;
- Implementation of process orientated solutions consistent with conditions of limited resources.

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EXPERIENCE IN THE REMEDIATION OF CONTAMINATED LAND

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Abstract

This paper provides details of a series of projects related to the remediation of contaminated land. Sites with different contamination issues have been selected to show the extent of the problems that may be encountered. The sites described include a nuclear bomb testing range, a radium luminizing site, an old nuclear experimental facility and a tritium factory. Relevant aspects of legislation, assay and safety issues are considered for each site.

1. INTRODUCTION

The paper describes the remediation of four sites contaminated with radioactive materials and, in some cases, chemicals. The sites represent a range of contamination situations resulting from various nuclear processes. The sites considered are:

(a) The Maralinga Nuclear Weapons Test Site in Australia;
(b) The former Admiralty Research Centre at Ditton Park, United Kingdom;
(c) The Southern Storage Area at UK Atomic Energy Authority, Harwell;
(d) A tritium contaminated site at Hayes in London.

2. CASE STUDIES

2.1. Maralinga

The Maralinga test site occupies some 3200 km^2 and is located on the northern edge of the Nullabor Plain in South Australia, approximately 900 km north-west of Adelaide. Between 1953 and 1963, the British Government carried out seven atmospheric nuclear weapons tests and approximately 550 small scale experiments ('minor trials') using nuclear materials at the site. These latter trials resulted in the dispersal of over 23 kg of plutonium, 22 kg of enriched uranium, 8447 kg of natural and depleted uranium and 102 kg of beryllium, as well as smaller amounts of other materials at various locations over the range. During the operation of the test site, various 'housekeeping' radiation surveys and cleanup operations were undertaken. Some of the materials used in the trials were gathered up and buried in various numbered and unnumbered pits throughout the range.

As part of the work, an initial helicopter based aerial survey was undertaken of all the significant sites to map the distributions of the significant gamma ray emitters: ^{241}Am, ^{60}Co and ^{137}Cs.

The rehabilitation programme for the site was specified as a 'risk reduction exercise', not as a 'cleanup'. The underlying assumption was that the site would be returned to its former Aboriginal owners, the Maralinga Tjarutja. They would return to live in their semi-traditional lifestyle, albeit supplemented by certain modern accompaniments, such as imported foodstuffs, motor vehicles and health care. This semi-traditional lifestyle is associated with the intake of much higher levels of dust than is characteristic in the life patterns of western societies. Hence, the inhalation of plutonium contaminated dust has been identified as the dominant pathway for radiation dose accumulation. The critical group was identified as Aboriginal children and the rehabilitation strategy was devised to ensure that the annual dose to individuals did not exceed 5 mSv. This dose limit was translated by the Australian Radiation Laboratory (ARL) into acceptable residual contamination levels for various parts of the site. These levels ranged from 1.8 to 4 kBq/m^2 of ^{241}Am; this radionuclide was used as a marker for the plutonium present.

The key components of the risk reduction works were:

(a) The construction of three large, 15 m deep, burial trenches at Taranaki, TM100/101 and Wewak;
(b) The removal of contaminated soil to an average depth of 150 mm from approximately 2.2 km^2 at Taranaki, TM100/101 and Wewak and its placement into the corresponding disposal trenches;
(c) The removal of the concrete caps from the 21 numbered pits in central Taranaki, followed by in situ vitrification of their contents, using the Geosafe process, and replacement of the concrete caps and restoration of the surfaces to their natural levels;

(d) The excavation of various other pits containing plutonium contaminated debris and placement of the contents in the burial trenches;
(e) The restoration of various other numbered and unnumbered pits by collection and burial of surface debris, compaction, importation of clean soil, recontouring and the re-introduction of vegetation;
(f) The installation of 100 km of marker posts at 50 m intervals throughout the outer plume areas to warn the Aboriginal population that they may hunt and traverse the area, but should not camp there permanently;
(g) The removal of access routes to certain areas by destroying roads;
(h) The re-vegetation of selected areas.

The bulk of the soil was removed using scrapers; an excavator was used to remove small areas requiring further treatment. In some areas the soil cover was very limited, and vacuum and rotary brush attachments were used to clean rock surfaces. The major hazard to the operators arose from the generation of plutonium bearing dusts. The dust also caused recontamination during the rehabilitation process. A variety of measures were undertaken to minimize such dust generation. These included modifying facilities to reduce dust generation, for example, by covering loads, restricting plant operating spreads and spraying areas with water prior to working them.

In order to minimize risks to workers, operations were designed to keep the number of personnel present during the removal of active materials as low as possible. All vehicles were modified to have positively pressurized, sealed cabins with absolute filtered air supplies.

Contaminated areas were surveyed at the end of each day and material was removed in sequence during the following day. This enabled a 'survey — removal' process to be adopted and allowed the process of personnel surveying during dust generation processes during the day to be dispensed with. Areas were remonitored after clearance of active material and reworked if found to be still contaminated. All treated areas were independently surveyed by ARL, using a specially modified vehicle with a boom mounted, high purity germanium detector, to certify that all clearance criteria had been met. Finally, areas to be revegetated were treated to return the site to a condition close to its original state.

2.2. UK admiralty research centre at Ditton Park

Ditton Manor Park is a 68 ha site located adjacent to the M4 motorway some 2 km to the south-east of the town of Slough in the United Kingdom. The site was formerly used by the UK Admiralty for the development, manufacture and testing of compasses. These activities involved the use of radium based luminizing paints.

In March 1998, Ditton Manor Park was purchased from the UK Ministry of Defence (MoD) to become part of the corporate headquarters of a major computer software company. It comprised a listed moated manor house with various outbuildings, which had been extended and used as workshops and laboratories. Investigations had revealed widespread localized radioactive contamination of the ground over much of the site. In addition, many of the buildings were contaminated with radium and mercury. A site waste tip had been used and this was contaminated with radium, heavy metals and polyaromatic hydrocarbons.

A remediation programme was developed to remove all significant historic contamination from the ground and fabric of buildings and to leave the site suitable for redevelopment without the need for any future special precautions. The current and future risks to the environment were to be eliminated. The remediation criteria were set on the basis of a quantitative risk assessment in close consultation with the prime regulator, the Environment Agency, and also with the Local Authority. The criteria were established, based upon the proposed uses of the site and with public access to all areas outside the moat. They were also compatible with sensitive multifunctional use, for example for housing.

A novel feature was the extensive use of the Groundhog gamma area surveying system in the characterization, remediation and validation of all land clearance. The Groundhog system comprises a highly sensitive NaI scintillation radiation detector linked to a GPS detector for position location and a data logger. A plot of a Groundhog survey showing regions of contamination is shown in Fig. 1.

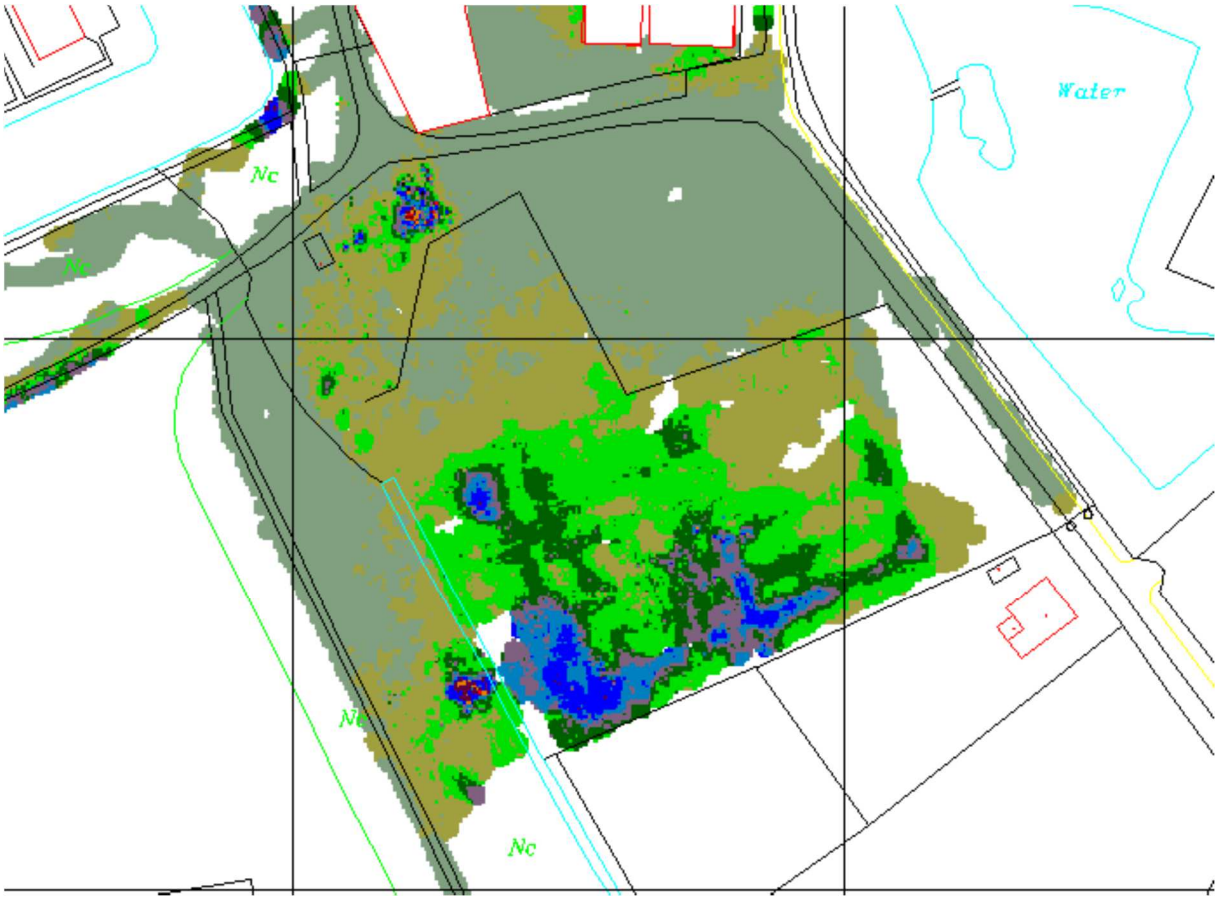

FIG. 1. Regions of contamination at Ditton Manor Park.

At the onset of the works, comprehensive surveys were undertaken to further characterize the contamination present. Surveys were either conducted manually with a portable Groundhog system, or with four detectors mounted on a vehicle. These surveys set the scope for the remedial works and helped to finalize the areas requiring excavation and backfilling. In addition, the advanced surveys identified contamination of the building structures and defined the areas requiring remediation.

The remedial works involved:

(a) Advance surveys;
(b) Remediation of ground contamination — both chemical and radioactive;
(c) Remediation of non-listed buildings prior to demolition;
(d) Remediation of ground after demolition of non-listed buildings;
(e) Remediation of radioactive (radium) contamination of listed buildings;
(f) Remediation of chemical (mercury) contamination of listed buildings;
(g) Investigation of moat sediments and their subsequent remediation;
(h) Remediation of the cottage gardens along the estate edge;
(i) Extensive consultation with all key stakeholders.

Regular liaison was established with the prime regulator, the Environment Agency, in order to ensure that remediation criteria, waste handling and disposal methods met with their approval.

This was the largest remediation project which had been undertaken in the United Kingdom of a site contaminated with ^{226}Ra from luminizing operations — in terms of both scale and cost. The works were successfully completed within a period of nine months. All identified contamination was removed to below levels of concern.

2.3. Remediation of the Southern Storage Area at UK Atomic Energy Authority, Harwell

The Southern Storage Area (SSA) is a separate, security fenced site, which is located approximately 1 km south of the main Harwell nuclear licensed site in the UK. It is approximately 7.3 ha in area. The site was the main munitions storage area for RAF Harwell, which was a Second World War bomber and training aerodrome. It was subsequently used for radioactive waste storage, treatment and disposal operations by UKAEA during the early UK nuclear research programmes. A cleanup of the site was carried out during 1988–1990 in order to eliminate the need for the site to be licensed under the Nuclear Installations Act; this was also required for the main Harwell site. As a result of the historical operations on the site, there were three main liabilities. They were the chemical pits, the beryllium pits and the common land, which is the remainder of the site. It was known that radioactive and chemical contamination was present due to past storage in the various pits.

The waste segregation strategy was a key component of the programme. It was based on the following key steps:

(a) Use of previous characterization results plus in situ and excavation bucket monitoring for radioactive and chemical contamination by gamma, beta surface, volatile organic compound and mercury probes to provide initial segregation into exempt/special/controlled and low level waste streams.
(b) Packaging of the bulk of waste, excepting large artefacts, etc., into 1 m^3 cube bags, which became the standard packaging volume.
(c) Sampling of the waste during the filling of the 1 m^3 bags and other waste containers;
(d) Gamma and contamination monitoring of the faces of each bag. The former provided evidence of any significant gamma sources in each bag.
(e) Gross α/β analysis of the homogenized sample from each bag.
(f) High resolution gamma spectroscopy of every bag of the potentially exempt waste.

All waste arising from the site was consigned as low level, exempt, controlled and/or special waste. The latter was dependent upon the levels of chemical contaminants present.

Finally, in order to facilitate the remedial works, two authorizations were granted by the Environment Agency. The first authorization was to accumulate and dispose of radioactive waste on the site. The second authorization was granted for a gaseous discharge from the SSA. Special sampling arrangements were made to comply with these authorizations.

2.4. Tritium contamination on a storage site at Hayes

An industrial unit at Hayes near London was vacated after a 25 year lease had expired. It had been used by a company which collected redundant gaseous tritium light devices (GTLD). It was found that low level tritium contamination was left after the removal of these devices.

Nuvia Limited was initially contracted to undertake a detailed survey of the buildings. In this first stage of the survey, a limited number of building samples were taken to gauge the spread and penetration of the tritium into the building fabric. This showed the contamination to be much greater and more widespread than previously thought and resulted in a further extensive survey, which included concrete cores from the floor slab together with soil samples from below the slab. The outbuildings were found to have widespread contamination in the range of thousands of Bq/g of tritium on the concrete base. Tritium had also migrated into the soil below the concrete slab. The main building slab and subsoil were also contaminated with tritium up to levels of hundreds of Bq/g.

Nuvia led negotiations with the Environment Agency on behalf of the landlord to establish and agree a remediation plan and an end-point. The landlord wished to reuse the contaminated site and also to enable the use of the large adjacent area of industrial and commercial buildings that he leased to other tenants. Although the environmental impact of the contamination was not excessive, the definition of radioactive waste in the UK means that any material with anthropogenic radiological contamination above 0.4 Bq/g is radioactive waste. The amount of building materials and soil contaminated above 0.4 Bq/g was estimated to be 1500 t. Disposal of this amount of material would cost several million pounds.

Some investigations and trials were undertaken to establish whether soil and concrete washing would remove the tritium to acceptable levels. However, it was soon established that the cost and commercial risk of soil washing did not make this an attractive option. The only disposal site available in the UK for this material is the National Low Level Waste Depository at Drigg in Cumbria. This site is both costly for disposal and represents a limited national resource so it was not the ideal disposal solution. Nuvia established that a commercially operated active incinerator was prepared to accept the waste for treatment. This process would drive off the tritium contamination from both concrete and soil and it could then be either collected from the flue gas as a liquid or dispersed to atmosphere with acceptably low environmental impact.

Further negotiation with the Environment Agency resulted in agreement that the incineration method of waste treatment for the concrete and soil contaminated with higher levels of tritium was acceptable. It was also agreed that soils at greater depth and contaminated to a level slightly above 0.4 Bq/g could be left in place without conditions being imposed on the development of the site. It was shown that this would not influence the site development work and that after redevelopment, the tritium would disperse and decay from these areas over time with minimal environmental impact. Nuvia undertook all of the demolition work and remediated the site to the agreed standards.

3. SUMMARY

Four completed projects which required the identification, assessment and removal of a variety of radioactive contaminants in land and buildings have been briefly described. All of the work was conducted to prescribed safety standards and within relevant legal environmental requirements.

ASSESSMENT OF CURRENT DOSES FROM URANIUM TAILINGS

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Abstract

Assessments of radiation doses have been carried out in and around existing uranium tailings in Tajikistan, Ukraine and Uzbekistan. Radioactive contamination at these sites can potentially impact human health as nearby areas are often heavily populated. As an example, the current doses to humans were assessed in detail for one site. These first assessments will ideally help in building more realistic scenarios and dose estimates. This work may be used as part of decision making on the most suitable remediation options based on the long term intended uses of the sites.

1. INTRODUCTION

This paper summarises studies carried out around existing uranium tailings in Tajikistan, Ukraine and Uzbekistan in 2008. Specific assessments were carried out in Ukraine as part of a collaborative project between Swedish and Ukrainian authorities [1] and as part of expert missions on behalf of the IAEA to Tajikistan and Uzbekistan [2] to define scenarios for dose assessments for the uranium mill tailings disposal sites.

1.1. Brief description of sites

The following is a brief overview of the sites studied; more details are included in Refs [1, 2]. In general, contamination at all sites is not spatially homogeneous; large variations exist in radionuclide levels in different parts of a given site.

- Dniprodzerzhyns'k (Ukraine). Nine tailing impoundments were created in the area; they contain about 42 million tonnes of radioactive waste with a total activity of 3.2×10^{15} Bq. Some of the waste was deposited within the territory of the industrial zone of Dniprodzerzhyns'k, and some at about 14 km to the south-east of the site. The sites are located in and near to the Pridneprovsky Chemical Plant (PChP) in the town of Dniprodzerzhyns'k (about 280 000 inhabitants).
- Taboshar (Tajikistan). Tailings occupy a 54 ha area and contain about 7.6 million tonnes of waste. They are located a few kilometres away from the town (12 000 inhabitants). Some of the tailings are without any cover and represent a source of highly contaminated drainage and seepage water, which is migrating into surface water and to the shallow groundwater table. Due to hot climatic conditions, the drainage waters evaporate, resulting in the precipitation of carbonate, sodium and sulphate complexes of uranium. This creates a salt cover of white colour with yellow uranile crystals, containing concentrations around 10–20 Bq/g of ^{238}U.
- Degmay (Tajikistan). This is the largest single uranium mill tailings site in Central Asia. It extends over 90 ha and contains about 20 million tonnes of uranium residue waste. The estimated total activity is about 1.6×10^{13} Bq. It is located 2 km from the Chkalovsk settlement (22 000 people) and 10 km from the town of Khujand (164 000 inhabitants). Due to hot climatic conditions, the water from the tailings' surface has evaporated, and the tailings pile has cracked, leading to high ^{222}Rn exhalation (36–65 Bq/m^2.s). The ^{222}Rn ambient concentration in air at the site varied from 200 to 1000 Bq.m^{-3}.
- Charkesar in (Uzbekistan). This is a uranium legacy site located in the suburb of the village of Charkesar (2500 people). The site extends over 20.6 ha and contains 482 thousand m^3 radioactive waste with a total activity of 3 x10^{13} Bq. The ventilation shaft currently discharges contaminated water containing ^{238}U at concentrations ranging from 26 to 36 Bq/L.

2. METHODOLOGY

The assessments to derive current radiation doses to humans living in the vicinity of these sites were performed using the same approach for each site:

- First, monitoring data was used to identify the hazardous areas.

- For each hazard, exposure pathways, and associated models, were determined.
- The hazards were then quantified in term of radiation dose rates from each pathway per unit time or for a given use of contaminated media, such as water and food.

Once the exposed groups had been identified it was then possible to assess the existing radiation doses to the particular exposed population groups based on defined scenarios.

This approach produces results which are only indicative of the current situation. In order to quantify the actual risks to individuals, further analyses are needed based on both current and future scenarios. These steps are not described in this paper.

3. IDENTIFICATION OF HAZARDS

In this study, a hazardous area is defined as an area with elevated radionuclide or radiation levels, as compared with background levels. These areas pose an additional radiological hazard, as their occupancy by the population can result in radiation doses above those due to natural background radiation. Radiological hazards can also be caused by elevated radionuclide levels in water bodies, such as underground and surface waters.

Monitoring data were used for each site to identify the hazardous areas, using information such as:

- Gamma radiation dose rates outside and inside of buildings;
- Radionuclide concentrations in aerosols, soils and tailing materials;
- Radon concentrations outside and inside of buildings;
- Radionuclide concentrations in water and food products, such as milk and meat (not yet obtained at the Ukraine site).

3.1. Dniprodzerzhyns'k — Ukraine

The monitoring data helped to identify a number of contaminated locations: inside and outside contaminated buildings (closed to the public and due to be demolished); the PChP north part; hot spots in the forest; tailing Zapadnoe; tailing Central Yar; tailing Yugovoctochnoye; tailing Dniprovskoye; ponds near tailing Central Yar.

From the description of the current activities on the PChP territory, it is clear that workers on the site receive the highest radiation doses if they spend part of their working hours near the hot spots, in the contaminated buildings or working at the tailings surface where the cover is not sufficient. The development and analysis of scenarios has been focused on critical groups of workers. Expansion of the scenarios to address risks to members of the public is scheduled for 2009.

3.2. Taboshar — Tajikistan

The following radiological hazards in terms of elevated radionuclide and radiation levels were identified at the Taboshar site: (a) outdoors at the Taboshar settlement; (b) indoors at the Taboshar settlement; (c) at the uranium tailings piles, which may affect the population which have free access to the tailing sites and use the tailings surface for the grazing of domestic animals; (d) at the uranium pits (waste rock piles), where some local citizens spend part of their time visiting the waste rock piles and former uranium pits for swimming and for other private needs; (d) in waters contaminated by the uranium tailings; and (e) in waters contaminated by the uranium pits.

3.3. Degmay — Tajikistan

The main exposure pathways for persons visiting this site are external exposure to gamma radiation and inhalation of radon and particulate bearing dusts. The following radiological hazards in terms of elevated radionuclide and radiation levels were identified at the Degmay site: (a) in the Degmay settlement; (b) at the uranium tailings; and (c) in groundwaters (water from local wells).

3.4. Charkesar — Uzbekistan

It was found that the main radiological problem at Charkesar is that local citizens, in many cases, use tailing materials for the construction of their houses. The following radiological hazards in terms of elevated radionuclide and radiation levels were identified in the Charkesar site: (a) in areas of the Charkesar settlement that are close to the industrial site ('near settlement'); (b) in areas of the Charkesar settlement that are far from

the industrial site ('far settlement'); (c) at the industrial site; (d) in spring waters; (e) in the mine waters; and (f) in the river waters.

4. CURRENT RADIATION DOSE RATES

4.1. Derivation of doses

To provide a basis for exposure assessments at sites of this type, the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety has published a document containing appropriate models and parameters [3]. This document provides equations for estimating radiation exposures through all pathways that can be relevant at uranium mining and processing sites, namely:

- External exposure caused by soil contamination for reference persons inside and outside buildings;
- Exposure through contaminated aerosols inside and outside buildings;
- Radiation exposure from locally grown foodstuffs;
- Exposure through the direct ingestion of soil;
- Determination of activity concentration in foodstuff;
- Exposure from the inhalation of ^{222}Rn and its short lived progeny.

According to this methodology [3], the radionuclides to be considered for calculating doses are included in the following three decay chains:

(1) ^{238}U > ^{234}U > ^{230}Th > ^{226}Ra > ^{210}Po > ^{210}Pb;
(2) ^{235}U > ^{231}Pa > ^{227}Ac;
(3) ^{232}Th > ^{228}Ra > ^{228}Th.

In the present study, dose calculations were only performed for the seven radionuclides: ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Po, ^{210}Pb and ^{228}Th, due to limitations in the availability of data. This may lead to a slight underestimation of doses. The equations for dose calculations from the German report [3] were implemented in the software package Ecolego [4].

4.2. Predicted dose rates

Table 1 summarizes the estimated radiation dose rates for the exposure pathways used in the model calculations. The results [1, 2] showed that external exposure and radon inhalation contributed the most to the total doses.

Figure 1 compares the four sites. Similar results are found at the sites, except for Dniprodzerzhyns'k, Ukraine, where the measurements were taken in highly contaminated locations for at worker dose estimation rather than in areas occupied by the local population.

TABLE 1. DERIVED DOSE RATE RANGES IN µSV/H FOR THE FOUR STUDIED SITES

Site	Hazard	Total dose rates µSv/h	
		Minimum	Maximum
Taboshar, Tajikistan	Settlement outdoors	0.10	0.53
	Settlement indoors	0.11	0.53
	Tailings	0.11	0.77
	Uranium pit	0.15	2.40
Degmay, Tajikistan	Settlement	0.04	0.31
	Tailings	2.70	13.00
Charkesar, Uzbekistan	Far outdoors	0.22	1.20
	Far indoors	0.22	2.70
	Near outdoors	0.28	1.30
	Near indoors	0.56	4.40
	Industrial site	0.22	1.90
Dniprodzerzhyns'k, Ukraine *	Outside polluted building	0.56	7.17
	Inside polluted building	5.70	21.80
	PChP north part	0.15	0.49
	Hot spots	4.93	18.40
	Tailing Yugovoctochnoye	1.30	30.60
	Tailing Zapadnoe	0.09	2.65
	Tailing Dniprovskoye	0.15	0.49
	Tailing Central Yar	0.52	3.29
	Ponds (near tailing Central Yar)	0.53	2.35

* Results based on experimental data.

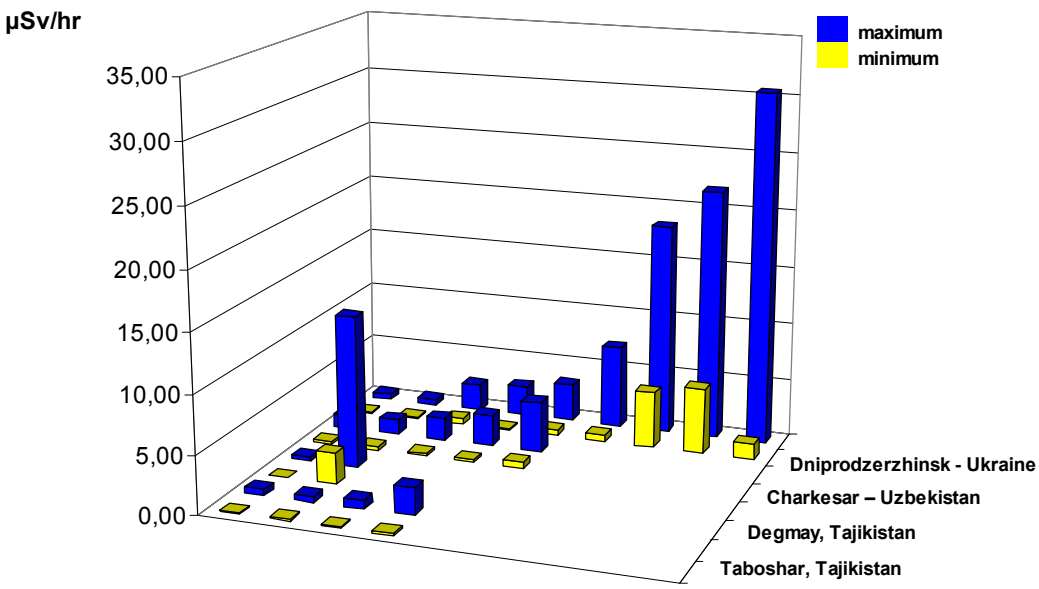

FIG. 1. Minimum and maximum dose rates (µSv/h) in and around the four studied uranium tailings sites in Ukraine, Tajikistan and Uzbekistan.

4.3. Current doses to exposure groups

Once the radiation doses from the exposure pathways have been evaluated it is possible to assess the doses that different groups of individuals may receive based on their lifestyles. Both studies [1, 2] present such results, but here one example is provided. At the Taboshar site, five groups were identified:

- Group 1. People that live in Taboshar, relatively far from the tailing dump site, and stay most of the time in houses. The houses are not contaminated because materials from the tailing have not been used for house construction. They obtain all their drinking water from the non-contaminated river Utken-Suu;
- Group 2. People from this group have the same occupancy of the hazardous areas as Group 1, but they use water from the mine for drinking and for irrigation of vegetables;
- Group 3. People from this group use water from the mine for drinking and irrigation (as for Group 2). They also live in Taboshar, relatively far from the tailing dump site, and stay most of the time in houses, but they regularly visit the areas in the vicinity of town where the uranium waste rock piles are situated;
- Group 4. People from this group make the same use of the water from the mine as people from Group 3. They differ from the other group in that spend some time at the tailings pasturing their cows and sheep and in that they obtain 30% of their meat and milk from cows that drink tailing waters;
- Group 5. People from this group work 30 hours per week during 46 of the weeks of the year in areas near the uranium pit. Like the other groups, they live in Taboshar, relatively far from the tailings dump site, and stay most of the time in their houses.

Table 2 presents the assumptions used and the derived annual radiation dose rates for the five groups.

TABLE 2. ESTIMATED RADIATION DOSE RATES (mSv/a) TO VARIOUS GROUPS OF THE POPULATION AT THE TABOSHAR SITE

Group	Exposure (h/a) to different hazards				Percentage of annual consumption %		
	Outdoor at tailings	Outdoor at waste rock piles	Indoor in houses	Outdoor at the town	Meat and milk (water from tailings)	Irrigation of vegetables (water from mine)	Drinking water from mine
1	0	0	5 840	2 920	0	0	0
2	0	0	5 840	2 920	0	30	30
3	0	730	5 110	2 920	0	30	30
4	1 460	730	5 110	1 460	30	30	30
5	0	1 380	5110	2 270	0	0	0

Group	Dose mSv/a		Contribution %		
	Minimum	Maximum	External	Radon	Others
1	0.93	4.70	12	88	0
2	1.20	5.10	11	80	9
3	1.20	6.50	32	59	8
4	1.30	6.80	39	49	12
5	1.00	7.20	48	50	2

5. SUMMARY

A consistent approach for deriving radiation doses to groups of people exposed to uranium tailings contaminants has been applied at four locations. By identifying the hazards and quantifying them based on exposure pathways, radiation dose rates can be calculated and form the basis for quantifying the exposure to given groups of the population. As stated in the main report [2] "… the data generated will support prioritization of the legacy sites for remediation and preparation of the necessary remedial feasibility assessments". Further work is being pursued at all four sites.

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