INVESTIGATION OF POSSIBLE BASIS FOR A COMMON APPROACH WITH REGARD TO RESTORATION OF AREAS AFFECTED BY LASTING RADIATION EXPOSURE AS A RESULT OF PAST OR OLD PRACTICE OR WORK ACTIVITY - CARE

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1 ABSTRACT

The objective of the CARE project is to develop a basis for a common approach to restoring areas affected by lasting radiation exposure from naturally occurring radionuclides (NOR), arising from past, or old, practices or work activities.
Industries handling NOR-containing material were identified (9 categories) and described. The most contaminating industries are uranium mining and milling, metal mining and smelting and the phosphate industry.
An appropriate assessment methodology was elaborated for existing conditions and with extrapolation to future normal evolution and intrusion scenarios. For the phosphate gypsum dumps of the phosphate industry at Tessenderlo, Belgium, the major exposure pathways and the radionuclides of major concern were indicated. The dominant dose to almost all exposure groups arises from inhalation of radon gas. Doses in excess of 1 mSv a^{-1} were obtained for external radiation and food ingestion pathways for the intrusion scenario only. Doses obtained from these pathways were always more than two orders of magnitude lower that that from the radon inhalation dose.
The impact of different restoration options was also predicted. The remediation options considered were characterised and evaluated in terms of performance, costs and social implications using a cost-benefit (CB) and multi-attribute utility (MAU) decision aiding framework. Since it was indicated that the main exposure pathway arises from radon emanation, actions which reduce the emanation represent the most likely cost effective approaches in site remediation measures.
The optimum remediation option was determined for one specific contamination situation, the waste dumps of the phosphate processing plant in Tessenderlo, with CB and MAU-analysis. For the MAU-analysis health, cost and social attributes were considered. Based on site specific data and some generic parameters, none of the 14 remediation options screened were justified on cost-benefit grounds. Following the MAU-analysis, capping, sub-surface barriers, or a combination of both technologies could not be distinguished from the do-nothing option.

2 INTRODUCTION

The objective of the CARE project (Common Approach for REstoration of contaminated sites) [1] was to develop a basis for a common approach to restoring areas affected by lasting radiation exposure from naturally occurring radionuclides (NOR). The sites considered were areas contaminated as a result of past practices or work activities. These may include activities which may not have been classified as 'of radiological concern' or which should be subject to site licensing for disposal of radioactive materials based on contemporary criteria. The objective was met through considering, in detail, four principal areas of work:

- The identification of areas of concern
- The development of an assessment model
- Inventory and methodology for selecting remedial options
- Derivation of criteria and action levels

2.1 Identification of areas of concern

Nine important categories of industries involving the extraction and processing of materials which contain enhanced levels of NORs were identified: uranium mining and milling, metal mining and smelting, phosphate industry, coal mining and power production from coal, oil and gas drilling, rare earth and titanium oxide industry, zirconium and ceramics industry, building materials, application of radium and thorium

To determine the extent of the radiological problems related to these industrial activities, information has been collated on the industrial processes and the resulting levels of NORs in feedstock, waste and (by)-products. More information in this area is given at this conference [2].

2.2 Assessment of the existing and prospective radiological situation

The impact of waste from the extraction and processing of NOR-containing material, the consequential public concern and the need for decisions on restoration and remediation of radioactively contaminated sites, require systematic investigation and objective evaluation of the existing (and prospective) radiological situation.

A substantial site characterisation, including radiological and physico-chemical characterisation of waste and surroundings, site geology and hydrology, demography, etc., has to be performed before any assessment can be initiated.

A model, AMCARE, has been developed under CARE to assess the individual doses to an average member of the critical group for current conditions and to assess the maximal dose occurring in a period of 10000 years. A local collective dose to the population living within a 20 km radius from the site is assessed for

100 and 500 years. Both 'normal evolution' and 'intrusion' scenarios are considered. The important exposure pathways for the radionuclides of major concern are identified (Fig. 1) and dose conversion factors calculated for the different scenarios.
To illustrate the AMCARE model, the abandoned phosphogypsum dumps at Tessenderlo (Belgium) was selected. The phosphate industry is one of the most important contaminating industries, due to relatively high NOR-levels in the ore and wastes and its spreading in Europe. Although for the different categories discussed the wastes originate from a number of different industrial processes, many of the features of these wastes are common, allowing for a generic modelling approach applicable on a site-by-site basis.

At the Tessenderlo phosphate processing site a volume of about $9x10^6$ m^3 of sludge was disposed off and the waste disposal area was capped with a layer of soil. The waste contains primarily ^{226}Ra and ^{232}Th, which by decay also gives rise to radon gas, lead and polonium daughters.

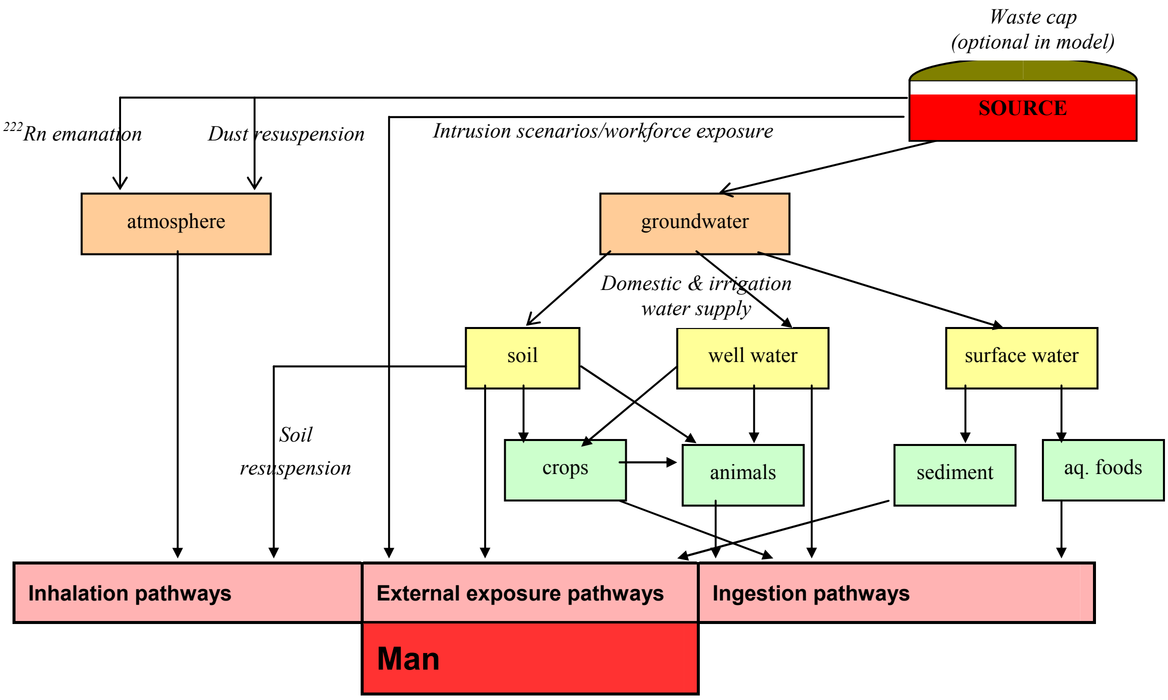

Fig. 1 Exposure pathways from contaminated waste to man incorporated in AMCARE

The dominant dose to almost all exposure groups arises from inhalation of radon gas arising from the parent inventory of ^{226}Ra (Table 1). To be able to compare the dose estimates for the different sites, doses incurred per unit concentration of the dominant radionuclides were calculated. Doses in excess of 1 mSv a^{-1} were obtained for external radiation and food ingestion pathways for the intrusion scenario only. However, the doses obtained from these pathways were always more than two orders of magnitude lower than that from the radon inhalation dose.

The main factors determining the uncertainty in the dose estimates, other than the waste inventory itself, related to the rate of emission of radon gas to the atmosphere (emanation factor and surface layer thickness) and, to a lesser extent, to the shielding from external radiation. Radon exhalation in turn was very sensitive to changes in soil moisture and structure.

Table 1: Peak dose to local residents from phosphate processing sludge at Tessenderlo, Belgium (mSv a^{-1})

Radionuclide	Inventory (Bq kg^{-1})	External irradiation	Inhalation (dust + radon)	Ingestion	Total
^{226}Ra &	3500	5.30 10^{-7}	0.5	4.79 10^{-7}	0.5
^{232}Th &	40	1.88 10^{-18}	1.85 10^{-18}	3.20 10^{-14}	3.2 10^{-14}

2.3 Effect of remediation options on dose

Remediation technologies are techniques (or measures) which prevent (or reduce) the radiological impact (or risk) to the population from a contaminant source. A wide variety of remediation technologies are available. However, techniques considered for the CARE project were limited to those that are well-established and require little maintenance.

Table 2: Dose reduction factors and costs for different remediation technologies applied to the Tessenderlo phosphate processing site

Remediation Technology	**Dose reduction factor**	**Cost, 10^6 ECU**
No remediation (A)	1	0
Removal of source (B)	4□5 - 10	4050 - 13455
Capping (C)	480 - 1080	16 - 24
Sub-surface barrier (grout curtain) (D)	1 - 1□1	18 - 24
Cement-based solidification (*in-situ*) (E)	4□8 - 11	405 - 3069
Cement-based solidification (*ex-situ*) (F)	4□8 - 11	608 - 2970
Chemical-based solidification (*in-situ*) (G)	1□5 - 3□4	486 - 4158
Chemical-based solidification (*ex-situ*) (H)	1□5 - 3□4	891 - 5643
Soil washing (I)	8□8 - 20	1620 - 6435
Flotation (J)	8□8 - 20	533 - 3899
Chemical extraction (K)	5 - 12	1458 - 8118
Flotation + Capping (L)	3300 - 7400	539 - 3923
Cement-based solidification (*in-situ*) + Capping (M)	3300 - 7400	421 - 3093
Chemical extraction + Cement-based solidification (*ex-*	33 - 75	1616 - 9738
Sub-surface barrier + Capping (O)	480 - 1080	34 - 48

The remediation technologies considered were discussed in terms of their impact on the emission of radon, the mobility of radionuclides and radiation effects. With the AMCARE model the impact of different remediation strategies on the radiation exposure (including the dose to the workforce) for the different scenarios considered was calculated. Each technology was further assessed in terms of the cost of implementation, performance, service life and workforce exposure during remediation. The uncertainties, associated with such countermeasures were included in the model.

Since the main exposure pathway arises from radon emanation, actions which reduce the rate of emanation may thus supposed, *a priori*, to represent the most likely cost-effective approaches in site remediation measures. Capping and combinations herewith are the most cost-effective remedial options. This is clear from the results presented in Table 2.

2.4 Optimisation of the remedial measures

In the context of remediation of contaminated sites, remediation actions should be justified and, hence, subjected to an optimisation process for selecting the best strategy of remedial measures.

A specific remediation option is justified when there is a positive net benefit between the total cost of the remediation, including the equivalent cost of the collective dose to the workers implementing the measure, and the equivalent monetary value of the dose reduction to the affected population. For the selected site, operational remediation criteria in terms of Action Levels (AL), e.g. the activity concentration within the contaminated media, have been derived from justification calculations in which site-specific parameters, such as cost, efficiency of the remedial measure and averted dose to the affected population, play an important role. An Action Level is the level of dose rate or activity concentration above which remedial or protective actions should be considered. An Action Level is not a limit but can be used as a screening tool to determine if a remediation is justified on economic grounds. In this study the Action Level concept has been restricted to a pure cost-benefit expression. Calculated Action Levels for remediation options at the Tessenderlo site are shown in Figure 2. The Action Levels are all above the actual ^{226}Ra concentration on the site, which means that none of the remedial options would be justified from a pure economic point of view.

The optimum remediation option was selected by means of multi-attribute utility analysis (MAUA), which allows for the inclusion of factors, which are not easy to quantify in monetary terms. The attributes, which have been considered by CARE, were:

- health attributes (collective radiation dose to members of the public)
- cost attributes (cost of remedial actions, including disposal costs of generated waste) and equivalent monitory costs of collective dose to contractual workers
- social attributes (reassurance of the public)

The MAUA required the selection of appropriate weighing factors for the different attributes. These weighing factors were used in the derivation of scores for the different attributes for the different remediation options. The option with the highest score was considered the optimal option. The outcome of any MAUA should, however, be judged carefully in the light of the attributes selected and the values assigned to the corresponding weighing factors before any firm conclusions can be drawn.

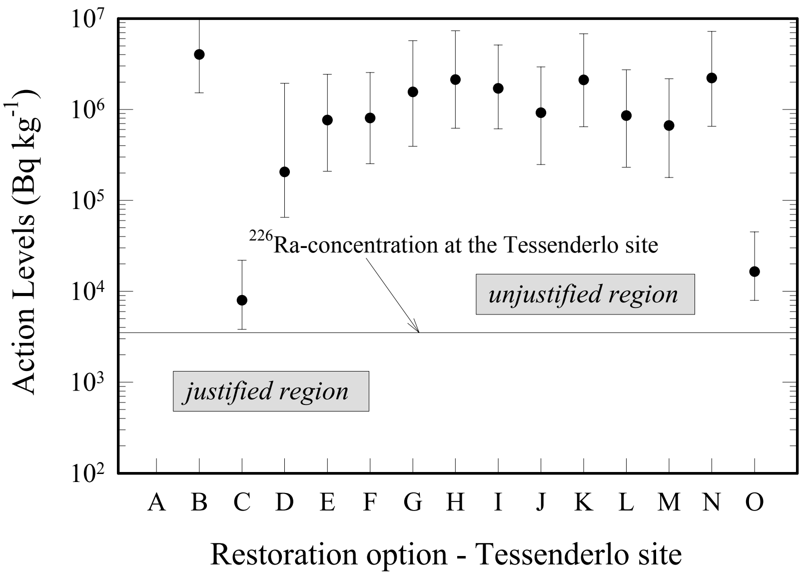

Figure 2: Calculated Action Levels for remediation options at the Tessenderlo site

An example of a MAUA for the Tessenderlo site is given in Figure 3. Capping or combinations herewith could not be distinguished from the do-nothing option.

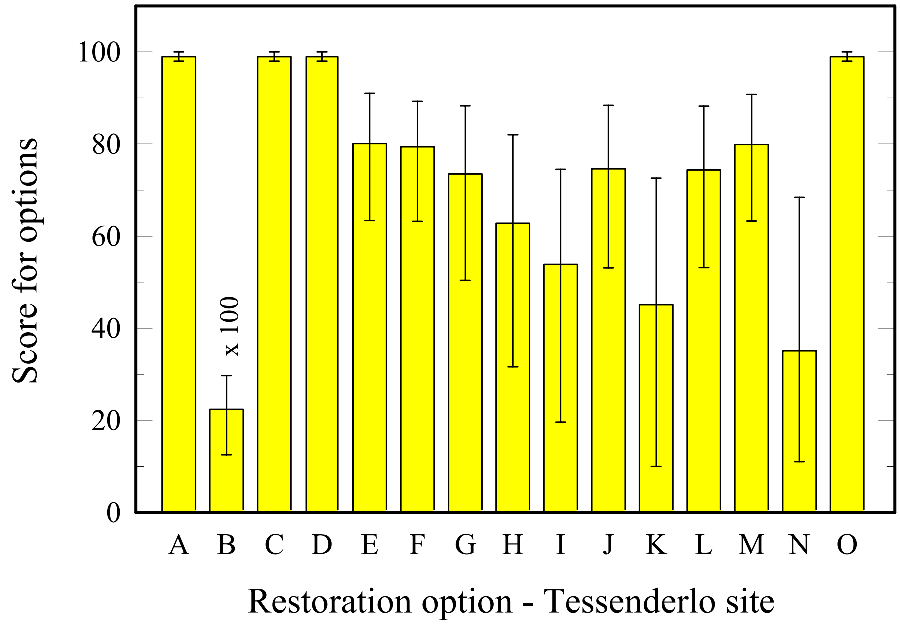

Figure 3: Overall evaluation of scores for remediation strategies at the Tessenderlo site

3 REFERENCES

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