Problems in optimization of radiation protection concerning site remediation: case study

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Summary

The problem of optimization of radiation protection measures in site remediation is discussed. The basis was the case when sludge slightly contaminated with Co-60 from nuclear power plant had to be dealt with. The sludge is stored at the water cleaning station. The decision of the site remediation was taken and recommendations on what to do with sludge had to be given.

Measurements of concentrations of gamma radionuclides in sludge and tritium in water have been performed and dose assessment using different scenarios done. A conservative approach and parameters recommended by the IAEA were used for the assessment. Some site specific parameters were also used. On the basis of these assessments the appropriate recommendations including radiation protection measures of workers involved in remediation were given. The most complicated stage in solving of this problem was connected with giving the recommendations. Uncertainties are connected not only with assessment of doses but mainly with the approach in optimization, dose constraints, possible public reaction to decision taken and, in general, the effectiveness of the approach used.

Introduction

Remediation of sites contaminated with radionuclides is a problematic area. One of the most complicated stages is assessment of radiological situation in the site under consideration and presenting the advice on the optimized ways of solving the problem. The present paper was prepared on results received after investigation of situation in the sludge storage place of Visaginas sewage cleaning system. The approximate square of the storage area was 10 000 m^2, thickness of sludge layer – 1-1.5 m. In 2002 it was decided to remediate the site. Previous investigations showed that the sludge was contaminated with artificial radionuclides. The task of this study was assessment of situation and prognosis of doses which might be received by workers and members of public.

Investigation of the situation

The first stage of study was measurements with the aim of assessment of concentrations of radionuclides in the sludge.

The necessary amount of samples has been calculated by Environ-Calc software (Larry Keith et. al., American Chemical Society) which calculates the number of samples necessary to estimate an average analyte concentration within a specified error with a specified confidence. Such an estimation of extent of sampling is needed according to [1].

The estimated number of samples needed was 38 for the assumed variability of the population - 150%, maximum tolerable error of the average - 50% and confidence in estimating the average equal to 95%.

40 samples of sludge 2 kg each were taken at 5 to 90 cm depths (down to the bottom of the layer of sludge). Additionally 10 samples of water were taken for tritium analysis.

Measurements of concentrations of gamma radionuclides were performed with HPGe spectrometers, tritium concentrations – with liquid scintillation counter. Samples for gamma spectrometry were dried before the measurements. Water samples for tritium measurements were distilled.

It was found that tritium concentrations in water had been below the minimum detectable concentration (2.6 Bq/l). Concentrations of gamma radionuclides in the sludge were the following (in Bq/kg): Ra-226 - 8 to 45, the average (24±3), Th-232 - 8 to 45, the average (19±2), K-40 - 11 to 397, the average (103±47), Cs-137 - 2.6 to 72, the average (10±4), Co-60 - 1.4 to 135, the average (42±8). It is evident that only concentrations of Co-60 exceed its background levels and should be taken into account when assessing the doses caused by sludge. No variations of concentrations of Co-60 with depth and no correlation of concentrations of Cs-137 and Co-60 were observed.

Dose assessment

In calculations of possible doses the following concentrations of artificial radionuclides were used (in Bq/kg): Cs-137 - 10, Co-60 – 42. Though concentrations of Cs-137 are similar to its background concentrations, on the basis of the principle of conservatyvism of radiation protection the exposure due to Cs-137 has been also taken into account.

The following scenarios and target groups were considered during assessment:

- the sludge used for fertilization of cultivated land and pastures; target groups - members of public (due to drinking water and agriculture products) and workers of sludge factory,
- the sludge covered with soil; target groups - members of public (due to drinking water and workers).

Doses to adults and babies of up to one year have been taken into account when public exposure was assessed.

In the fertilizers scenario the conservative presumption was made according to which a part of sludge is transferred to the lake and accumulated in fish which is eaten by members of critical group. He/she also consumes the food (vegetables, meat of animals and milk of cows fed with forage from the contaminated field). Other exposure pathways are inhalation of resuspended particles and external radiation from the contaminated field.

The following parameters have been accepted: the amount of sludge used for fertilization in area of 10,000 m^2 - 5,000 kilograms of dry weight (25,000 kg of fresh weight) [2], intake of radionuclides into vegetation takes place only through the roots (small amounts of soil is ingested together with vegetables), duration of fertilization - short in comparison with half lives of Cs-137 and Co-60, depth of roots of grass - 10 cm, vegetables and corns - 20 cm. Transfer coefficients (from soil) were the following: cobalt to grass - 2, to vegetables and corns - 0.08, cesium to grass - 1, to vegetables and corns - 0.04 [3]. Radioactive decay of Cs-137 and Co-60 in forage during its storage has not been taken into account.

In calculations of concentrations in meat and milk the following parameters were used: coefficients of transfer of cobalt - 0.01 day/l (to milk) and 0.07 day/kg (to meat), cesium - 0.01 day/l (to milk) and 0.05 day/kg (to meat). Consumption of forage by cow - 16 kg per day, by beef cattle - 12 kg per day.

In calculations of concentrations in fish it was presumed that during spreading of fertilizers 1000 kg of sludge is transferred to the lake of medium size (square - 10^5 m^2 and depth 3 m), radionuclides are distributed in the lake homogenously. Bioaccumulation coefficients were the following (Bq kg^{-1}/(Bq l^{-1}): of Co – 300, of Cs - 10 000 (maximum values - sand and organic sediments on the bottom).

The following concentrations were received on the basis of these presumptions and parameters (in Bq/kg): Co-60 - 0.032 in vegetables and corns (fresh weight), 1.62 in grass (dry weight), 0.26 in milk, 1.36 in meat, 0.042 in fish (fresh weight); Cs-137 - 0.004 Bq/kg in vegetables and corns (fresh weight), 0.19 Bq/kg in grass (dry weight), 0.03 Bq/l in milk, 0.11 Bq/kg in meat, 0.3 Bq/kg in fish (fresh weight).

Annual effective doses according to estimations were: to members of public due to external radiation - 8.3 μSv, due to radionuclides in meat, milk, vegetables and fish - 4.4 μSv (to babies) and 1.1 μSv (to adults), due to resuspended radionuclides – less than 0.001 μSv. The last exposure pathway might be neglected.

The total dose to babies (12.7 μSv) exceeds the clearance level (10 μSv). However, the presumption that babies stay in the contaminated field for 24 hours each day is too conservative. Taking into account this fact the conclusion that the fertilizer scenario would cause annual effective doses lower than 10 μSv might be made. Assessment gives 6 μSv if 5 hours per day are spent by babies in the contaminated field.

Annual effective doses to workers of sludge factory due to external radiation of Co-60 are 0,72 mSv, due to Cs-137 - 0,041 mSv, due to resuspended radionuclides - up to 2.5 10^{-4} μSv (neglected). The total dose (0.74 mSv) might be important from the point of view of radiation protection. More realistic dose assessment is needed (e.g., hardly workers will be working for the whole year). This kind of dose assessment might be done only if the real conditions of work are taken into account. It should be performed if the decision to use the sludge according to the above mentioned scenario is taken.

Collective dose has been calculated on the basis of presumptions that the sludge might be used for $6\ 10^6\ m^2$ of cultivated land ($1.7\ 10^{-4}$ of Lithuanian land used for agriculture) and population of Lithuania - 3.49 mln. In such a case the collective dose is $6.6\ 10^{-3}$ man Sv. It is lower than 1 man Sv [1] used as clearance level.

In scenario of covering of sludge with soil the public exposure will be incurred with drinking water. Neither decay nor dilution of radionuclides are taken into account.

Sludge factory workers are receiving the same exposure as in the above mentioned case.

By measurements of concentrations of radionuclides in water contained in the sludge it was determined that the concentrations of both radionuclides were lower than minimum detectable concentrations - Cs-137 - 1 Bq/l, Co-60 - 1.3 Bq/l. If water with such concentrations of artificial radionuclides is used for drinking the annual dose due to radionuclides in drinking water would be 12 μSv (for babies) and 11 μSv (for adults). These doses exceed 10 μSv, though assessment seems to be too conservative.

Discussion

Though the fertilizer scenario gives slightly lower doses the covering of sludge with soil seems to be an optimised way. Such recommendation was given also taking into account the facts that covering of sludge might be cheaper and cleaner way because other contaminants are contained in the sludge. Measurements of concentrations of, e.g, heavy metals in the sludge have not been performed.

Advice was also given that radiation protection measures of workers might be considered necessary.

This example shows that sometimes even by relatively simple means an assessment of possible doses for decision making might be performed. However, such an evaluation might be not acceptable by, e.g., public unless sound basis is used for it. For this reason in the present study rather detailed measurements have been made, Cs-137 has been taken into account, both site specific and global parameters used. Though availability of site specific parameters might be rather problematic the problem might be resolved by use of generic global parameters.

The scenario of use of sludge as a fertilizer might be not realistic. However, it might be acceptable because it gives a chance to illustrate the fact that even under the non realistic but unfavourable exposure conditions the exposure level which might be used for decision making would not be exceeded. This fact and possibility to compare results received for such a scenario with the ones from more realistic scenario increases the reliability of assessment.

Such a conservative approach might cause problems if it results in exposures which are close to levels used for decision making. Then additional more specific parameters are to be used however it might undermine the trust in assessment of persons which are not aware about conservative approaches used in radiation protection.

The detailed report with the appropriate references has been prepared about results of this study. The report is supposed to be not only for persons with education or background in radiation protection and radioecology. Such a user friendly report increases confidence in results received and advice given.

References

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3. International Atomic Energy Agency. Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment, Safety Reports Series No. 19. Vienna, 2001.