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METHODOLOGY FOR RISK ASSESSMENT FOR WORKERS HANDLING UNSEALED RADIOACTIVE SOURCES

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INTRODUCTION

Occupational handling of unsealed radioactive substances may result in internal or external contamination of the worker or in releases to the environment.

We developed a methodology for risk assessment for workers who handle unsealed sources and for the estimation of releases to the environment. Results of risk assessments are helpful to establish derived limits regarding the quantities of radioactive substances that can be handled within defined dose constraints, appropriate for the actual working scenarios.

This study is supported by the Dutch Department of Labour, with the special objective to develop constraints on the source activities in laboratory work and other fields of application. In this paper, we give some highlights of the study, focussed on the dose consequences for the worker.

MODEL ANALYSIS

In essence our study is concerned with the model analysis of the relationship between the quantities of the unsealed radioactive substances that are handled in a particular practice and the potential dose consequences for the workers. A major factor in this modelling is the description of the characteristics of these scenarios, in particular the working techniques, the physical and chemical properties of the material and the protective measures that are taken.

As regards the working conditions we distinguish regular working conditions, which indicate that the progress of work is as it was planned, and incidents that are perceived as small mishaps which can occur and for which it is reasonable to assume that they will occur every now and then.

The model analysis that we developed also provides the option to calculate dose consequences in accident situations. In accident situations, however, the dose consequences for the worker are not the only factor that should be considered. The probability of accidental events plays an important role as well. Therefore, the risk assessment for accidents is beyond the scope of this paper.

The dose consequence for the worker in terms of committed effective dose can be described as a function of the activity intake and the dose coefficient DC for the pathway under consideration. The intake can be described as the product of the source activity ACT and the fraction of this activity, which is transferred to the worker – the transfer fraction to the worker – TFW:

$$\text{DOSE CONSEQUENCES} = \text{INTAKE} \times \text{DC} = \text{TFW} \times \text{ACT} \times \text{DC}$$

From this expression, it is clear that the transfer fraction for the worker TFW is an unambiguous measure for the consequences for the worker. In principle, this transfer fraction should be determined for all relevant pathways. However, some pathways cannot be described in a simple way with a mathematical model. Furthermore, the practical importance of the various pathways is different. Exposure of the worker due to the air pathway can happen under normal working conditions and as a result of incidents or accidents. Exposure of the worker due to contamination of the skin, ingestion or injection is always an incident or accident.

Therefore, we developed a mathematical model for the air pathway. This mathematical model is based on a general algorithm that solves first order compartment models, including recycling. Our model makes calculations of transfer fractions possible, not only under regular working conditions but for incident and accident scenarios as well. After calculating the transfer fractions for the air pathway, the other relevant pathways are judged retrospectively.

Restrictions to the activity of radioactive substances can be described in terms of restrictions to the product of activity and dose coefficient. In actual situations, an upper bound for this product (ACT × DC) can be derived from the dose constraint for a certain kind of practice.

$$\mathrm{TFW} \times (\mathrm{ACT} \times \mathrm{DC}) \leq \mathrm{DOSE\ CONSTRAINT}$$

The product (ACT × DC) is a very elegant way of describing the upper bound for the activity, because it is a measure for the 'radiotoxicity' of the activity handled. When the transfer fraction and the dose constaint are known, the product (ACT × DC) is the same for all radionuclides.

The transfer fraction and the dose constraint are different for regular working conditions and for incidents. If we want to derive guidelines for constraints of activity, it is necessary to choose a dose constraint for regular working conditions and for incidents. Developing dose constraints was not the objective of this study. However, the study can provide insight into the meaning of dose constraints.

The mutual difference in consequences for the worker in different scenarios can be expressed by the ratio of respective transfer fractions. Assuming that the consequences in a certain actual scenario A and in a so-called *reference scenario* R are identical, it follows that:

$$\mathrm{TFW}_R \times (\mathrm{ACT} \times \mathrm{DC})_R = \mathrm{TFW}_A \times (\mathrm{ACT} \times \mathrm{DC})_A$$

Once an upper bound of (ACT × DC) for the refence scenario has been derived (or chosen), the upper bound of (ACT × DC) in the actual scenario can be derived, assuming identical consequences for the reference scenario and the actual scenario:

$$(\mathrm{ACT} \times \mathrm{DC})_A = \frac{(\mathrm{ACT} \times \mathrm{DC})_R}{\mathrm{TFW}_A / \mathrm{TFW}_R}$$

The ratio of the transfer fractions $\mathrm{TFW}_A/\mathrm{TFW}_R$ can be regarded as the correction factor needed to derive the upper bound of (ACT × DC) for the actual scenario.

RESULTS: ABSOLUTE MEANING OF TRANSFER FRACTIONS

We calculated transfer fractions for a variety of scenarios. In this paper, we present a summary of the results for a 'standard' laboratory. The results are given for working in a fume hood, for one month of regular working conditions and for the 'maximum reasonable incident', respectively.

The maximum reasonable incident is failure of the fume hood. The transfer fraction for one month of regular working conditions is calculated by multiplying the transfer fraction for a full working day by 20. The transfer fraction for the incident is calculated over a period of one hour after the incident.

From this summary of results it can be shown that the transfer fraction for the worker during one month of regular working conditions is always less than the transfer fraction for the maximum incident. Furthermore, it may be expected that the dose constraints for regular working conditions and for incidents, although numerically unequal, are in the same order of magnitude. Taking into account that it is prudent to assume that an incident will occur once a month for planning purposes, this means that the transfer fraction for the incident situation is dominant in the risk evaluation. Therefore, derived limits should be based on the incident circumstances. An adequate level of protection under regular working conditions then is implicitly guaranteed.

A very important conclusion from this study is that it is not effective to improve the ventilation qualities of a fume hood beyond a certain level. Provided that a certain level of protection by the fume hood is guaranteed, the upper bound of (ACT × DC) is determined by the incident situation, in which the fume hood is not working at all. On the other hand, it is advantageous to improve the operational safety of the fume hood in order to prevent incidents.

RESULTS: RELATIVE MEANING OF TRANSFER FRACTIONS

We compared the calculated transfer fractions for a number of actual scenarios (for working in a fume hood) to the transfer fraction in a chosen reference scenario. This ratio of transfer fractions can be taken as the correction factor TFW_A/TFW_R for determining the upper level of $(ACT \times DC)_A$ in the actual scenario, once the upper level of $(ACT \times DC)_R$ for the reference scenario is known.

The comparison refers to incidents, because the incident circumstances determine the maximum activity that can be handled in a certain scenario.

We have chosen the *handling of an aqueous solution in a fume hood in a standard laboratory* as the reference scenario.

SUMMARY OF RESULTS FOR WORKING IN A FUME HOOD IN A STANDARD LABORATORY

TFW – one month regular working conditions	*TFW – maximum incident*	*SCENARIO*	*TFW_A / TFW_R for incidents (rounded)*
4,6 E-3	1,4 E-1	Boiling of a volatile or an aqueous solution*	2000
4,4 E-3	8,1 E-2	Boiling of a moderately volatile solution*	1000
1,7 E-3	1,1 E-2	Working with very fine dust	150
4,4 E-5	1,4 E-3	Spattering processing of a volatile solution*	15
2,2 E-4	1,2 E-3	Gas or vapour in a holder or working with dust	15
4,4 E-5	8,1 E-4	Spattering processing of an aqueous solution*	10
4,4 E-6	1,4 E-4	Working with a volatile solution*	2
1,7 E-5	1,2 E-4	Spattering processing of a moderately volatile solution*	2
4,4 E-6	8,1 E-5	Working with an aqueous solution* (reference scenario)	1 (by definition)
1,7 E-6	1,2 E-5	Working with a moderately volatile solution*	0,2
4,4 E-7	8,1 E-6	Preparation of syringes with an aqueous solution*	0,1
2,2 E-9	1,2 E-8	Solution of a non-volatile material	0,0002

*It is assumed that the radionuclide in the solution is equally volatile as the solvent

OTHER IMPORTANT RESULTS

The methodology for calculating transfer fractions allows us to derive upper bounds for the activity handled, and not only for working in laboratories, but for other situations as well (nuclear medicine, working with animals, radionuclide production and other industrial applications).

The method provides an insight into the differences between the consequences of different working conditions, different physical properties of the material handled and different protective measures.

The methodology is also a useful tool in optimisation studies, because it can provide insight into the effect of additional protective measures (e.g. an extra containment).

The method also gives us an opportunity to derive transfer fractions to the environment for the air pathway. This makes it possible to derive upper levels of activity for unsealed radioactive sources, based on upper bounds for the emissions of activity.