PERSPECTIVES IN FOREST RADIOECOLOGY

Report of the Working Group on Measurement and Data[1]

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1. Introduction

During the NATO Advanced Research Workshop on "Contaminated Forests: Recent Developments in Risk Identification and Future Perspectives" a Working Group (WG) entitled "Measurements and Data" was conducted. At the end of the first session the participants of the Working Group selected three topics from a list to be discussed in more detail. The Working Group decided:

- to work out recommendations for environmental sampling,
- to work out recommendations on how to share data, and
- to rank radioecological processes in forest ecosystems by using a matrix method and applying the expert knowledge of the WG participants.

The limited time available allowed only a very general consideration of the three topics.

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2. Recommendations for environmental sampling

The result of the working group discussion clearly showed that in the future a **"new philosophy"** has to be followed for field sampling in view of the fact that radioecological research in Western countries is cut back and financial support is decreasing. Three measures are recommended:

1. **Conduct environmental sampling under a more general view.** This means that sampling should not be restricted to the act of simply taking the sample for radio-ecological purposes, but should include a description of the environment around the sample. The forest or landscape around the sample should be characterized and environmental conditions described in as much detail as possible. When planning a sampling campaign other fields of science should be considered, e.g. ecotoxicology, geobotany, air pollution research, etc. because samples could be shared. By this measure
   - the value of samples will improve and
   - the spectrum of radioecology becomes broader which will help this discipline to survive.

2. **Report your data** in a way which makes them accessible and applicable across disciplines and to other research programs. This measure helps to combine research programs and avoids double track sampling.

3. **Don't throw samples away.** As a consequence of points one and two, it is recommended to keep samples (or portions) after they have been collected. "Historical" samples can be used by other research groups for other purposes at a future date. New analytical techniques might be developed which then are applicable to these samples.

The Working Group was aware of certain constraints which can limit compliance with its recommendations:

1. The Working Group has no authority to require compliance
2. Sampling time and finances to follow the above recommendations are restricted
3. New samples have to be comparable to old ones (backward compatibility).

For more detailed information concerning sampling we refer to a not yet published report about a recent workshop on "Measuring Radionuclides in the Environment: Radiological Quantities and Sampling Designs" jointly organized by ICRU, EC and GSF in November 1997.

3. Recommendations how to share present and future data

The Working Group was convinced that a huge number of samples and data exist which could be exchanged and used in other projects. By communicating the existence of these samples and data we would improve their value and initiate new collaboration and joint publications within the field of radioecology and other disciplines. Four possibilities were proposed to improve the present situation:

1. To indicate the existence of samples and data sets in the web on the home page of institutes and scientists with cross links to other sites.
2. To set up a database within an international program or organization which supports the idea (EC, IAEA, NATO). Especially the EC could be interested to have a database of the data collected in the frame of their programs. It is suggested to submit a proposal for the 5^{th} programme.
3. To strive for collaboration with UIR (International Union of Radioecologists) which already runs a database in one of their Task Forces.
4. To establish a News Group to share activities.

4. Ranking of radioecological processes in forest ecosystems

During the presentations of this NATO-ARW it became very obvious that most investigations are restricted to more or less one specific forest type. It was also shown that it is very unlikely that a single model can describe all radionuclide fluxes and a tendency was seen to develop a framework of sub-models. Therefore it is important to identify key processes and get an insight into them. This knowledge would help to define which data are needed in the future.

In a first step, the Working Group members were asked to rank 11 factors (given by one participant), in order of their importance. Members were asked to use a scale from 1 (not important) to 20 (very important). Table 1 shows the importance of forest type, soil type and type of landscape on radionuclide migration which primarily depends on the type of the radionuclide and its mobility. This result also reflects the fact that most radioecological forest models are very site specific and confirms the findings of the Working Group in section one to do environmental sampling under a more general view.

In a second step, the importance of radioecological processes in forest ecosystems was ranked by using an interaction matrix previously applied by Avila and Moberg [1] for the development of a conceptual model of the migration of ^{137}Cs in forest ecosystems. The heterogeneous composition of the Working Group with chemists, physicists, soil scientists, biologists, geochemists, ecotoxicologists, health physicists and ecologists gave a sound basis for ranking the processes given in the matrix (Figure 1). The starting point of the evaluation was a pulse contamination with ^{137}Cs.

TABLE 1. Ranking of factors influencing radionuclide migration in forest ecosystem on a landscape level. Scale: 1 (not important) - 20 (very important).

Factor	Mean ranking (n=7)	Standard deviation
Mobility of radionuclides	15.6	3.5
Type of forest	15.7	4.6
Type of soil	15.4	3.7
Type of landscape	15.6	4.7
Climatic conditions	12.1	5.6
Humidity of forests	10.7	4.0
Forest Fires	9.9	4.1
Geobotanical variety in forest	7.7	4.7
Biological effects of dose, factors on migration process	7.3	4.8
Removing of forest products	5.7	5.0
Pastures in forest	4.4	3.4

Participants were asked to rank the importance of single processes which are specified in the off diagonal boxes of the matrix. Rankings were from 4 to 0 (critical- 4, strong- 3, medium- 2, weak- 1, no interaction 0) for ^{137}Cs cycling and to specify the forest type for which they were doing the evaluation. The ranking had to be done process-related and independent of the question if such a flux is measurable in practice. Figure 2 gives the results of the evaluation by indicating the mean value, standard deviation and relative deviation for each process.

Based on Figure 2 the following 10 interactions between compartments were found to be most important in forest ecosystems in decreasing order (mean value = 3.0):

1. Root uptake (soil organic-fungi)
2. Root uptake (soil organic-understorey)
3. Root uptake (Soil organic-tree)
4. Decomposition (litter-soil organic)
5. Leaf fall (tree-litter)
6. Root uptake (fungi-tree)
7. Ingestion (fungi-wild animals)
8. Ingestion (understorey-wild animals)
9. Diffusion (soil organic- mineral)
10. Root uptake (fungi-understorey)

The above list clearly shows that processes at the soil - plant interface are rated to be most important for radiocaesium cycling in forests followed by ingestion of fungi and understorey vegetation by animals. Decomposition of litter, leaf fall and fixation of ^{137}Cs to mineral soil are other important processes. By adding the process ranked 11th, the translocation from tree to leaves, the cycle of radiocaesium in forests can be closed. It is astonishing that the ^{137}Cs transfer from understorey to litter was not ranked higher compared to litter fall from trees. Another very obvious result is that fungi and especially mycorrhizae keep a most important position in the whole cycle of radiocaesium which is exactly the opposite of the knowledge of understanding we have.

By adding the numbers in each row we obtain an indication of the way a certain component affects ^{137}Cs cycling. Table 2 gives the corresponding values.

Atmosph. (Air)	Inter-ception, Rainfall Snowfall	Inter-ception	Inter-ception, Rainfall, Snowfall			Inter-ception,	Inter-ception, Rainfall, Snowfall	Inter-ception, Inhalation
Transpir. Burning	**Tree leaves**	Translo-cation	Leaf fall, weather-ing			Weather-ing, Inter-ception	Weather-ing, Inter-ception	Ingestion
Burning	Translo-cation	**Tree other**	Weather-ing, Inter-ception	Fertili-sation	Fertili-sation	My-corrhizae	Weather-ing, Inter-ception	Ingestion
Resus-pension		Rain splash	**Litter**	Decom-position, Percola-tion	Percola-tion	Root upake	Rain splash	Ingestion
		Root Upake	upward transport, Meso-fauna	**Soil oganic**	Percola-tion, Diffusion, Advect.	Root upake	Root uptake	Soil Ingestion
		Root Uptake			**Soil mineral**	Uptake	Uptake	Soil Ingestion
		Root uptake (My-corrhizae)	Fertili-sation	Fertili-sation	Fertili-sation	**Fungi**	Root uptake, My-corrhizae	Ingestion
Transpir. Burning			Leaf fall, Weather. Intercept.	Fertili-sation	Fertili-sation		**Under-storey**	Ingestion
			Fertili-sation			Con-sumption	Con-sumption	**Wild animals**

Fig. 1. Interaction matrix with 9 diagonal elements to describe migration of ^{137}Cs in a forest ecosystem. The matrix is read clockwise. After Avila and Moberg [1].

Atmosph. (Air)	*1.2* **2** 1.5 1.0	*1.3* **1** 1.1 1.0	*1.4* **1** 1.4 1.0	*1.5* **0** 0.3 3.9	*1.6* **0** 0.3 3.9	*1.7* **0** 0.5 1.5	*1.8* **1** 1.0 1.1	*1.9* **0** 0.5 1.5
2.1 **2** 1.2 0.8	**Tree leaves**	*2.3* **2** 1.2 0.6	*2.4* **3** 0.8 0.2	*2.5* **0**	*2.6* **0**	*2.7* **1** 0.8 1.6	*2.8* **1** 1.1 0.9	*2.9* **2** 1.0 0.5
3.1 **2** 1.1 0.7	*3.2* **3** 1.0 0.4	**Tree other**	*3.4* **1** 0.7 0.5	*3.5* **1** 1.2 1.0	*3.6* **1** 0.7 1.4	*3.7* **2** 1.4 0.9	*3.8* **1** 0.9 1.2	*3.9* **1** 1.1 1.4
4.1 **0** 0.5 1.3	4.2 **0** 0.8 3.9	*4.3* **0** 0.8 2.1	**Litter**	*4.5* **4** 1.1 0.3	*4.6* **1** 1.3 1.1	*4.7* **3** 1.2 0.4	*4.8* **1** 0.9 1.7	*4.9* **1** 1.1 0.9
5.1 **0**	*5.2* **1** 1.4 2.6	*5.3* **4** 0.6 0.2	*5.4* **1** 1.0 1.5	**Soil oganic**	*5.6* **3** 1.3 0.4	*5.7* **4** 0.8 0.2	*5.8* **4** 0.9 0.3	*5.9* **1** 1.1 1.7
6.1 **0**	*6.2* **0** 0.4 2.6	*6.3* **2** 1.1 0.6	*6.4* **0**	*6.5* **0** 0.7 1.8	**Soil Mineral**	*6.7* **1** 1.1 1.1	*6.8* **1** 1.1 0.7	*6.9* **0** 0.6 1.9
7.1 **0**	*7.2* **0** 1.2 2.7	*7.3* **3** 1.3 0.4	*7.4* **2** 0.9 0.4	*7.5* **3** 0.7 0.3	*7.6* **1** 0.9 1.1	**Fungi**	*7.8* **3** 0.8 0.3	*7.9* **3** 0.8 0.2
8.1 **1** 0.7 0.5	*8.2* **0**	*8.3* **0**	*8.4* **2** 0.9 0.4	*8.5* **1** 1.0 0.8	*8.6* **1** 0.7 1.1	*8.7* **0** 0.6 2.2	**Under-storey**	*8.9* **3** 0.7 0.2
9.1 **0**	*9.2* **0**	*9.3* **0**	*9.4* **1** 1.0 0.8	*9.5* **0** 1.0 3.9	*9.6* **0**	*9.7* **1** 1.2 1.1	*9.8* **1** 1.1 1.3	**Wild animals**

Fig. 2. Coded matrix of the long-term migration of ^{137}Cs in a forest ecosystem. Meaning of the numbers within fields from top: numeric identification of the process; interaction index of process (critical- 4, strong- 3, medium- 2, weak- 1, no interaction 0); standard deviation; relative deviation. n=15, values were rounded.

TABLE 2. Interaction matrix from Figure 2. The sum of columns indicates how high the effect of the system onto a component is, the sum of rows indicates how high the effect of a component onto the system is

4.9	5.7	12.3	12.5	9.3	6.5	11.3	12.4	11.6	
at-mosph	*1.2* 1.5	*1.3* 1.2	*1.4* 1.5	*1.5* 0.1	*1.6* 0.1	*1.7* 0.3	*1.8* 0.9	*1.9* 0.3	5.9
2.1 1.6	leaves	1.9	3.4	0.0	0.0	0.5	1.2	2.0	10.5
3.1 1.5	2.9	Tree	1.3	1.2	0.5	1.6	0.8	0.8	10.6
4.1 0.4	0.2	0.4	litter	3.5	1.3	2.9	0.5	1.1	10.4
5.1 0.0	0.5	3.6	0.7	soil org.	3.1	3.6	3.6	0.7	15.7
6.1 0.0	0.1	1.9	0.0	0.4	soil min.	1.0	1.5	0.3	5.3
7.1 0.0	0.5	3.3	2.1	2.5	0.9	fungi	3.0	3.3	15.6
8.1 1.4	0.0	0.0	2.3	1.3	0.7	0.3	under-storey	3.1	9.0
9.1 0.0	0.0	0.0	1.3	0.3	0.0	1.1	0.9	animals	3.5

The highest effects on ^{137}Cs cycling have the soil organic compartment and the fungi compartment. The effect of the tree and litter compartment are intermediate while the role of the mineral soil compartment is very small.

During the evaluation additional processes have been identified by single participants which were not contained in the original matrix of Avila and Moberg [1], e.g., bioturbation (compartment 9.4 and 9.5, Figure 1), deposition and percolation (compartment 1.5 and 1.6, Figure 1) and the transfer of ^{137}Cs from understorey to fungi by mycorrhizae (compartment 8.7, Figure 1).

5. Conclusions

Discussions within the Working Group on "Data and Measurement" are concluded as follows:

- On an ecosystem level future data collection and measurements have to be done under a more general view. Collaboration with projects of other disciplines of science have to be considered. By this measure the value of samples will be improved and costs reduced. The extension of the activities will also help this discipline to survive.
- On a process level, key processes were identified by a matrix method. Future research in forest ecosystems has to be directed towards a better understanding of processes where fungi and mycorrhiza are involved in, such as root uptake, especially in the organic soil horizon, and decomposition of litter.

- It is essential that we find a method to share data by initiating the creation of a *widely accessible database.*

6. References

1. Avila, R. and Moberg, L. A systematic approach to the migration of Cs-137 in forest ecosystems using interaction matrices, accepted for publication in J. Environ. Radioactivity.