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CONSIDERATION FOR MODELING STUDIES OF MIGRATION OF ACCIDENTALLY RELEASED RADIONUCLIDES IN A RIVER WATERSHED

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Consideration for Modeling Studies of Migration of Accidentally Released Radionuclides in a River Watershed

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Concerning radionuclides that might be released in an event of an accident from a nuclear facility, much attention has been paid to the migration pathways including the atmospheric deposition and subsequent inflow to surface water bodies since the Chernobyl nuclear accident in 1986. In European countries, computer-coded systems for predicting the migration including those pathways and providing scientific supports for decision makers to manage the contamination have been developed. This report is a summary of presentations and discussion made at the occasion of the visit of Dr. Monte in order to have directions related to the current subject of research, development of a mathematical model of the behavior of radionuclides in a river watershed. Those presentations and discussions were made at JAERI and also at prominent universities and institutes of Japan involved in this study field. As a result of these discussions, distinct advantages and key issues in use of a mathematical model for prediction of the migration of radionuclides in a river watershed have been identified and analyzed. It was confirmed that the use of mathematical modeling has distinct advantages. Re-arrangement of the existing experimental knowledge on the environment in an ordered way according to a theory (a mathematical model) will lead to a new angle to consider a problem in that environment, despite several partial gaps in the data array. A model to assess the radionuclide behaviour in contaminated aquatic ecosystems is a basis of decision analysis tools for helping decision-makers to select the most appropriate intervention strategies for the ecosystems. Practical use of a mathematical model and continuous effort in its validation were recognized as crucial.

Keywords: Nuclear Accident, Radionuclides, Migration, River Watershed, Mathematical Model

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事故時放出放射性核種の河川流域移行予測モデル研究に関わる考察

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(2003 年 11 月 11 日受理)

原子力施設の事故時に放出され得る放射性核種については、大気からの地表への沈着と、これにつづく表面水系の移行経路に対して 1986 年のチェルノブイリ事故以来大きな関心が払われてきた。欧州の国々ではそれらの経路を含んだ放射性核種の移行予測と汚染対策に関わる意志決定支援のための計算コードシステムが開発されている。本報告は、河川流域における放射性核種の移行挙動についての数学モデルの構築に関して、この種の数学モデルの専門家であるイタリアの Luigi Monte 氏の滞在の期間に日本原子力研究所ならびに当該分野に関わる日本国内の大学・研究機関において行われた報告と議論を要約したものである。この報告・議論の中で、河川流域における放射性核種の移行挙動を表す数学モデルの優位性が強調された。すなわち、実環境に関する実験的研究からの知見を１つの理論（数学モデル）にしたがって「再配列」することは、その環境で着目する問題の考え方に新たな角度を与える。汚染を受けた河川流域における放射性核種の挙動を評価するモデルは、その流域に対する最も適切な対策を選択するための意志決定支援ツールの基盤となる。移行挙動モデルの優位性と同時にモデル利用上の留意点も議論された。モデルを応用する場を増やすこと、モデル検証を継続することが、実際の課題でモデルを有効に活用するために必須であることが認識された。

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※原研リサーチフェロー（新技術・エネルギー・環境開発機関（ENEA,Italy）から招へい）

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執 筆 分 担

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PREFACE

In many countries, the majority of freshwater resources are taken from surface waters of rivers, natural lakes, and artificial reservoirs. For instance, the latest statistics for Japan show that the percentage of the water demand for agriculture, industry, and daily life of people supplied by surface waters is 94 %, 70 % and 77 %, respectively (Ministry of Land, Infrastructure and Transport, 1998). The conservation of water quality is a very important subject, especially for countries such as Japan where the dependency on surface waters is high.

Among various substances that can affect the quality of surface freshwater, atmospheric deposits are difficult to control. An affected area can include a wide variety of land in terms of natural and social conditions. Field research alone cannot capture all those variations. Further, the influences of a substance can last long after deposition. These considerations indicate that a kind of research which make space and time projections using mathematical modeling is crucial.

Concerning radionuclides that might be released in an event of an accident from a nuclear facility, much attention has been paid to the migration pathway from the atmospheric deposition to subsequent inflow to surface water body after the Chernobyl nuclear accident in 1986. In European countries, computer-coded systems making projections of such pathways have been developed (EU, 2002; MOIRA). In this context, a mathematical modeling approach used together with experimental studies to describe the fate of atmospherically derived radionuclides in a river catchment has also been explored at the Japan Atomic Energy Research Institute (JAERI). This research theme has been pursued at the Research Group for Terrestrial Environment of the Department of Environmental Sciences of JAERI since 2001.

JAERI invited a guest scientist on mathematical modeling of radioecology, Luigi Monte of Italian National Agency for New Technologies Energy and the Environment (ENEA: Ente per le Nuove tecnologie,L'Energia e l'Ambiente) of Italy, from May 22 to June 20 of 2003. This was done in order to obtain constructive comments and to have discussions related to the current subject of research of a development of a mathematical model of the behavior of radionuclides in a river watershed. The visit was financially supported by the Japan Society for the Promotion of Science. This report is a summary of presentations and discussion made at the occasion of the visit of Dr. Monte. Those presentations and discussions were made at JAERI and also at prominent universities and institutes of Japan involved in this study field.

In the following, the scientific background of the invitation of the guest scientist is described in Chapter 1. Aims of discussion with the guest, that were made during the stay of the guest, are explained in Chapter 2. Presentations on the current progress of experimental and modeling studies in JAERI are given in Chapters 3 and 4, respectively. Discussion of those presentations is also included in both Chapters. Chapter 5 provides presentations given by the guest scientist at JAERI. Chapter 6 summarizes presentations of the guest and discussions during visits to Japanese institutions, which have special relevance to a question of the migration of harmful substances and accidentally released radionuclides in a river watershed. Main texts of those presentations, which contain advance reports of a computer-coded simulation systems in European countries, are also described in Chapter 6. Finally, problems and realistic solutions that associate with the mathematical modeling approach are summarized in Chapter 7 with possible future works. The editors believe that this report will serve as a useful working document for currently evolving development of a mathematical tool for management of catchment systems of fresh water bodies.

1. Background of the invitation of the guest scientist

1.1 Objectives of the invitation

The Research Group for Terrestrial Environment of JAERI has conducted field studies on i) physico-chemical forms of radionuclides and ii) characteristics of their fluvial transport since 1987. Based on those studies, JAERI has started to construct a model that predicts the migration of artificial radionuclides and trace toxic elements in a river watershed. In order to execute the modeling work adequately, the group needs to collaborate with experienced researchers in the study field of solute modeling in catchment systems. Luigi Monte is a researcher of the modeling mentioned above. He has been engaged in developing models of i) migration of radionuclides and toxic substances in the environment and ii) prediction of effectiveness of countermeasures for those contaminants. Although the linkage between conditions on the ground and the surface aquatic system is complicated, he has found methodologies to decrease uncertainties in predicting the behavior of contaminants by introducing a method to treat related natural processes collectively. He has tested his approach in many instances of environmental contamination such as that caused by nuclear weapon tests and the Chernobyl accident. As a result, it has been shown that his models are generally applicable to various catchments of rivers and lakes. Currently, his group has applied their research to develop strategies to restore contaminated environments. This is the direction, which the present research sub-group of JAERI is aiming at. Thus, the studies he has developed are very useful for the river sub-group of JAERI.

Owing to repeated participation in research projects conducted by international organizations (e.g. EU, IAEA), he has knowledge of the model and validations of this kind carried out in Europe, which experienced a severe radioactive contamination due to the Chernobyl accident. Accordingly, his stay was also considered to make it possible to access the accumulated intelligence of European researchers.

This invitation was set up in order to promote a construction and a validation of a migration model at JAERI through intensive discussions with him. Further, this visit was intended to have mutual benefits for European and Japanese scientists through exchange of professional opinions and information on the latest relevant studies.

1.2 Realization of the invitation

The visit was made possible by the sponsorship of the Japan Society for the Promotion of Science (JSPS). JSPS granted Luigi Monte one of its "invitation fellowships for research in Japan (Short term)". Owing to the support, Monte Luigi stayed in Japan from May 22 2003 to June 20 2003. The subject of this research has been defined as "Modeling study on migration of accidentally released radionuclides in a river watershed"

2. Aims of discussion

2.1 Expected issues for discussion

At the beginning of the visit, issues expected to be discussed during the visit were presented (Appendix A). Firstly, they are:

- Appropriateness of the model structure under development.
- Applicability to the environment in Japan.
- Experimental data needed for the validation of the model
- Capability of the model to utilize the experimental dataset obtained in the Chernobyl or other contaminated watershed in foreign countries.

It was stressed that it is necessary to take into consideration the characteristic features of Japanese watersheds such as i) hilly, steep, well-vegetated surfaces, ii) a large, sudden increase in water flux in a precipitation event, and further iii) importance of river water for agriculture, industry, and potable water use.

Secondly, it was also expected to discuss about approaches for further applications of the experimental findings and the results from a mathematical model. This issue was subdivided into i) application to the fate of toxic elements, chemicals, ii) application as a tool to evaluate effectiveness of countermeasures for an event of radioactive contamination, iii) application as a tool to evaluate a non-point source pollution in a watershed from agricultural, industrial, and populated areas.

2.2 A brief history on past and present activities of the river sub-group of JAERI

A brief history of the river sub-group's study of radionuclides and trace elements in a river watershed was given in Fig. 2.2-1. The research began in 1987. At that time, we found that studies on the behavior of artificial radionuclides in river water were sparse

Thus, it was necessary to investigate that behavior, in order to i) increase the understanding of behavior of the radionuclides in various circumstances in the environment, and ii) consider the migration of the radionuclides over different environmental media. Consideration of the link between different media (the atmosphere, the terrain, the waters) in a study of environmental radionuclides was sparse, at least domestically. During 1987-1993, several apparent rules regulating the discharge of radionuclides were clarified in the Kuji river watershed. In Chernobyl of Ukraine (1995-1999), physico-chemical form of radionuclides in river was deeply investigated in the watershed of the Pripyat River, where a detailed, comparative study of important radionuclides was possible.

Presently, expanded investigations to relevant reaction processes and to mathematical modeling are in progress as follows:

i) Long-term investigation on atmospheric deposition of radionuclides and stable elements (1993 -);

ii) Study on migration behavior of trace elements from soil layers of forested and arable plots (2002 -);

iii) Study on spatial and conditional variations of behavior of trace elements in dissolved and particulate forms (Migration behavior of uranium and toxic element) (2000 -):

iv) Development of a mathematical model to describe the transport of artificial radionuclides and trace elements in a river watershed (2001-).

These studies aim at both generalization (e.g. inclusion of toxic elements, various pathways other than atmospheric depositions) and practical use of experimental findings (e.g. prediction of the fate of accidentally released radionuclides).

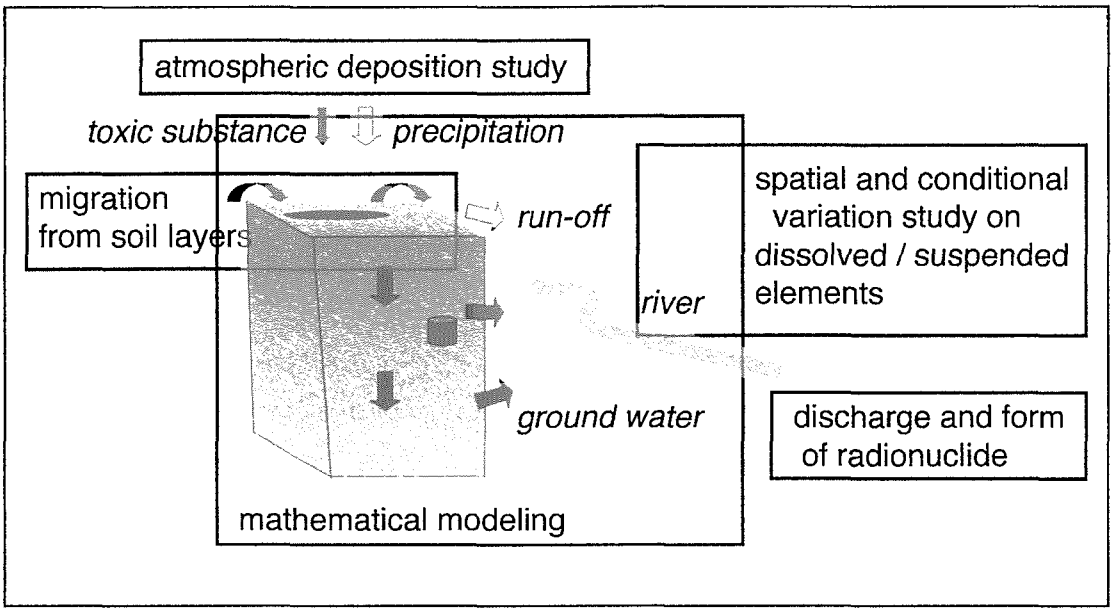

Fig.2.2-1 Study of radionuclides and trace elements in a river watershed by the river research sub-group.

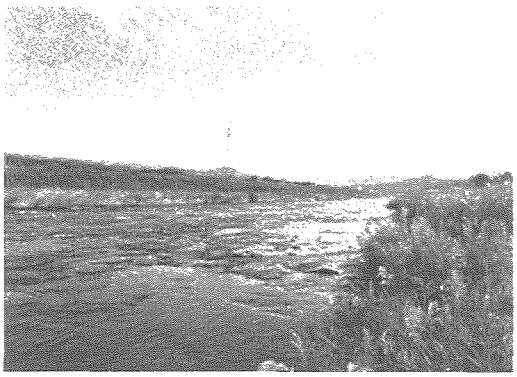

Fig.2.2-2 Kuji river watershed, Japan. (A typical view in its upstream, Hanawa, Fukushima)

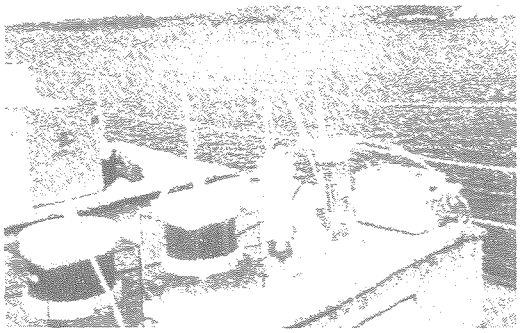

Fig.2.2-3 Sampling appratus for river water (Pripyat river in the Chernobyl accident area, Ukraine)

3. Experimental studies by the river sub-group of JAERI

3.1 Long-term investigation of atmospheric deposition

Takashi UENO

3.1.1 Objectives

In environmental monitoring, many numbers of evaluations of monthly atmospheric deposition using a basin have been carried out [1)-12)]. These studies, however, have dealt with a limited number of γ-emitting radionuclides such as ^{7}Be, ^{137}Cs and ^{210}Pb. From a viewpoint of radioecological and environmental aspects, ^{137}Cs has drawn attention of researchers[1)-5)]. In recent years, the amount of fallout deposition of ^{137}Cs has been much decreased. As a consequence, the ratio of resuspension of ^{137}Cs to total deposition of ^{137}Cs was relatively increased and resuspension has become an important issue of research [1), 3)]. As for ^{7}Be, it was shown that its amount of deposition and its concentration in the air had a good correlation with precipitation in 1970s' [6)]. Moreover, the seasonal and regional variation in the amount of deposition of ^{7}Be in Japan has been clarified[7)]. Sakashita et al.[8)] have attempted Simulation of atmospheric deposition of those radionuclides with a mathematical model. The residence time of ^{210}Pb and ^{7}Be after atmospheric deposition in a watershed was investigated by Matsunaga and others including the present author[9)]. Other researchers attempted to clarify seasonal variation of atmospheric deposition of ^{210}Pb [10)] and to evaluate deposition velocity (dry deposition) of airborne ^{210}Pb [11)].

Atmospheric deposition of ^{7}Be, ^{40}K, ^{137}Cs and ^{210}Pb during 1993 Sep.-2001 June was studied at Tokai-mura, Japan. This was in order to illustrate the characteristics of radionuclide deposition for long-term at Tokai-mura. Thus, in particular we performed: 1) Evaluation of atmospheric deposition of radionuclides. 2) Analysis of the deposition data with respect to characteristics of seasonal variations and possible controlling factors.

3.1.2 Methods

In this study, monthly deposition samples were collected with a basin with the surface area of 0.5 m^2. It was set up inside the JAERI in Tokai-mura. The basin was regularly monitored so that it contained ample amount of water to collect both wet and dry depositions. Water in the basin was collected every month and evaporated without ebullition to dryness to obtain residual samples. Its dry (residual) weight, and radioactivities of ^{7}Be, ^{40}K, ^{137}Cs and ^{210}Pb therein were measured with a germanium detector. The typical measurement time was 200,000s. Meteorological data were provided by the Department of Health Physics of JAERI. They included precipitation, wind speed and wind direction as hourly averaged values. Also, estimation of deposition of stable elements for a part of the samples was done by instrumental neutron activation analysis using JRR-4.

3.1.3 Results

Deposition of ^{40}K and ^{137}Cs

The obtained results have clarified following features of the atmospheric depositions of radionuclides in the studied area. First, Fig. 3.1-1 shows variation of monthly deposition of ^{40}K in the basin sample at Tokai-mura. The deposition of ^{40}K has seasonal variations with peaks in the spring. Next, Fig. 3.1-2 shows variation of monthly deposition of ^{137}Cs in the basin sample at Tokai-mura. Depositions less than the detection limit are depicted by white bars. White bars itself indicate the detection limit. The deposition of ^{137}Cs shows temporal variations similar to ^{40}K.

Deposition of ^{210}Pb and ^{7}Be

Variations of monthly deposition of ^{210}Pb and ^{7}Be are shown in Fig. 3.1-3 and Fig. 3.1-4, respectively. The deposition of ^{210}Pb as well as that of ^{7}Be, shows peaks in the springs and autumns.

Deposition weight

Variation weight of the dried sample of monthly deposition (hereafter, deposition weight) is shown in Fig. 3.1-5. The deposition weight has very clear seasonal variations with peaks in springs from February to April, and also in May in some years. These peaks seem to be caused by the yellow sand ("Kosa" in Japanese). Frequent occurrence of the Kosa events has been reported for March and April 2000, for instance, at which times the deposition weight shows the highest peaks.

Monthly precipitation

Fig. 3.1-6 shows monthly precipitation at Tokai-mura. Monthly precipitation is much at rainy (June) and typhoon (Sep.-Oct.) seasons, and little at dry (Dec.-Feb.) season in winter.

Dependency of monthly deposition weight on precipitation

Fig. 3.1-7 shows dependency of monthly deposition weight on precipitation. Similar figures can be drawn for ^{40}K and ^{137}Cs. Fig. 3.1-8 and Fig. 3.1-9 show monthly depositions of ^{210}Pb and ^{7}Be, respectively, plotted against monthly precipitation. The gradient of regression line for spring is the largest, implying that the air concentration is also the highest in the spring.

3.1.4 Discussion by the presenter

Correlation between monthly depositions of radionuclides and other conditions

Correlation coefficients of first correlation between deposition weight, precipitation and deposition of radionuclides with each other were shown in Table 3.1-1. Both of the depositions of ^{40}K and ^{137}Cs have high correlation with the deposition weights and with each other. The depositions of ^{40}K and ^{137}Cs have a low dependency on the monthly precipitation. But, depositions of ^{7}Be and ^{210}Pb have only weak correlation with the deposition weight, and relatively high correlation with monthly precipitation.

Controlling factors of deposition of radionuclides

The level of ^{210}Pb deposition observed on the Pacific side of eastern Japan in this study is much lower than that measured on the Japan sea side. The deposition of ^{210}Pb measured on the Japan sea side has sharp peaks often around 200 Bq m^{-2} month^{-1} in the winter [12], which is about one order of magnitude larger than the above-mentioned spring peaks of the Pacific side.

Monthly deposition of ^{7}Be and ^{210}Pb have only weak correlation with the deposition weight, implying that these two nuclides are carried not mainly by larger particles. Smaller particles have negligible contribution to the deposition weight. The depositions of ^{7}Be and ^{210}Pb have relatively high correlation with monthly precipitation. Therefore, it can be said that the depositions of ^{7}Be and ^{210}Pb are mainly caused by wet deposition.

It is clear that the large winter peaks are due to the strong winter monsoon directly from the Siberian continent to the Japan sea side and due to the heavy snowfall there. This scavenging process in addition to the dry weather of Tokai-mura during winter accounts for the present result that the ^{210}Pb deposition at Tokai-mura does not have peaks in winters. It can also be said that spring is the season when the Pacific side of eastern Japan is most directly affected by continental air mass

with less scavenging during advection.

Both of the depositions of ^{40}K and ^{137}Cs have high correlation with the deposition weights and with each other. The depositions of ^{40}K and ^{137}Cs have a low dependency on the monthly precipitation. This implies that dry deposition of larger particles, whose deposition is not substantially depend on the precipitation, is a dominant factor for the deposition weight, the deposition of ^{40}K and ^{137}Cs.

Therefore, the data indicate that ^{40}K and ^{137}Cs are born by larger particles which dryly deposit and contribute the deposition weight, while ^{7}Be and ^{210}Pb are born by smaller particles which wetly deposit.

Stable elements

Fig. 3.1-10 shows deposition of stable elements at Tokai-mura during 1993 Sep.-1995 Oct. According to result of correlation analysis, stable elements in deposition are divided soil origin elements (Al, Sc, Cs etc.) and sea origin elements (Na, Br etc.). Deposition of these group elements is related to prevailing wind direction in Tokai-mura.

3.1.5 Conclusion

(1) A pair of long-term monthly atmospheric deposition samples and radionuclide data were obtained.
(2) Clear seasonal variations of deposition of radionuclides, which can be attributed to the meteorological conditions, especially precipitation was found in the atmospheric data.
(3) The data indicate that ^{40}K and ^{137}Cs are born by larger particles which dryly deposit and contribute the deposition weight, while ^{7}Be and ^{210}Pb are born by smaller particles which wetly deposit.
(4) Stable elements in deposition are divided soil origin elements (Al, Sc, and Cs etc.) and sea origin elements (Na, Br etc.). Deposition of these group elements is related to prevailing wind direction in Tokai-mura.

3.1.6 Discussion of the guest scientist

This is very interesting and well-collected set of data. First, I have a comment. There are two important groups of elements studied here. Most of these probably have originated from resuspension of soil particles, for instance ^{137}Cs. However ^{7}Be has a very different, cosmogenic origin. This difference surely influences the behavior of the elements in precipitation and in deposition.

For instance, there is a positive correlation between ^{7}Be and the precipitation. It can reasonably occur, because ^{7}Be is cosmogenic and is produce in the atmosphere where the produced radionuclide will be incorporated to rain drops. On the other hand, ^{137}Cs has showed very poor, or even negative correlation with the precipitation.

In case heavy raining, the ^{137}Cs in the atmosphere which can be deposited will be trapped by the initial part of precipitation. The following precipitation will be very clean with respect to ^{137}Cs. Accordingly, the correlation between the precipitation and ^{137}Cs will get worse as the amount of rain in a single precipitation event increases.

It is very complicated task to analyze this dataset. For instance, if one looked at the deposition of ^{137}Cs and ^{134}Cs during an accident like the Chernobyl accident, one will have a very strong correlation between the amount of deposition of the radionuclides and the amount of the

precipitation.

However, such strong correlation cannot be found in this dataset because ^{137}Cs this dataset have a terrestrial origin mainly. Table 3.1-1 has summarized the relationship between the precipitation and the radionuclide deposition. At a glance, relationships are very complicated. However, the Table seems reasonable upon closer examination. Though ^{137}Cs has no correlation with precipitation, it has a good correlation with the weight of deposit. This is a demonstration that ^{137}Cs has a resuspension origin in the present observation. However, this is not the case with ^{7}Be. What we have to consider is how much these data and findings can be applied to an accident, and in which way that application will be possible.

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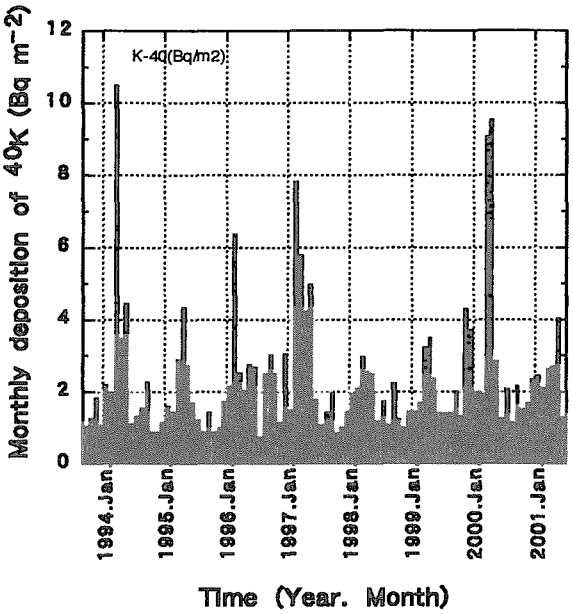

Fig. 3.1-1 Variation of monthly deposition of ^{40}K in basin sample at Tokai-mura

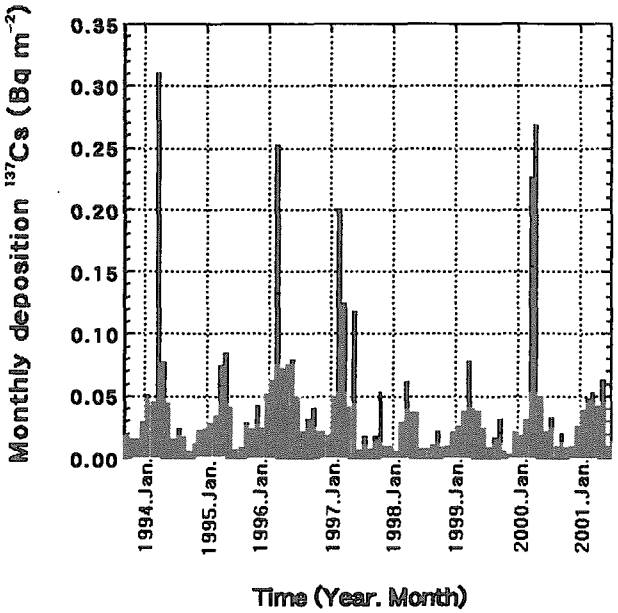

Fig.3.1-2 Variation of monthly deposition of ^{137}Cs in basin sample at Tokai-mura

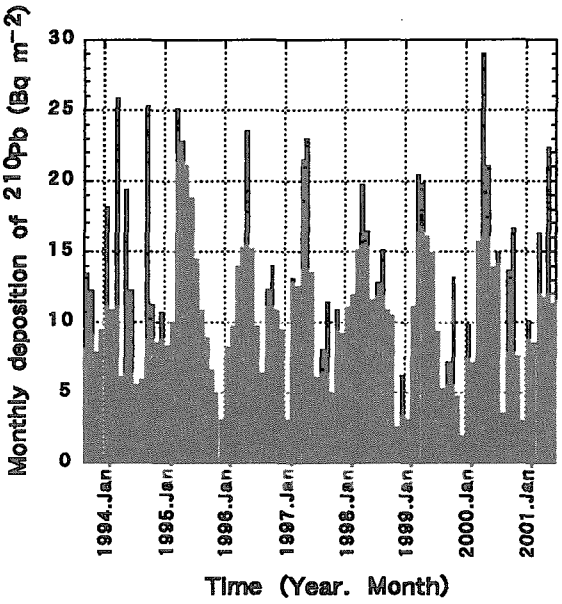

Fig. 3.1-3 Variation of monthly deposition of ^{210}Pb in basin sample at Tokai-mura

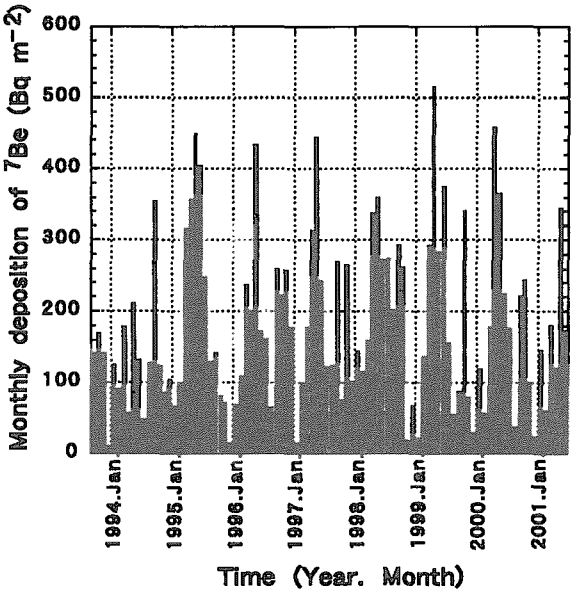

Fig.3.1-4 Variation of monthly deposition of ^{7}Be in basin sample at Tokai-mura

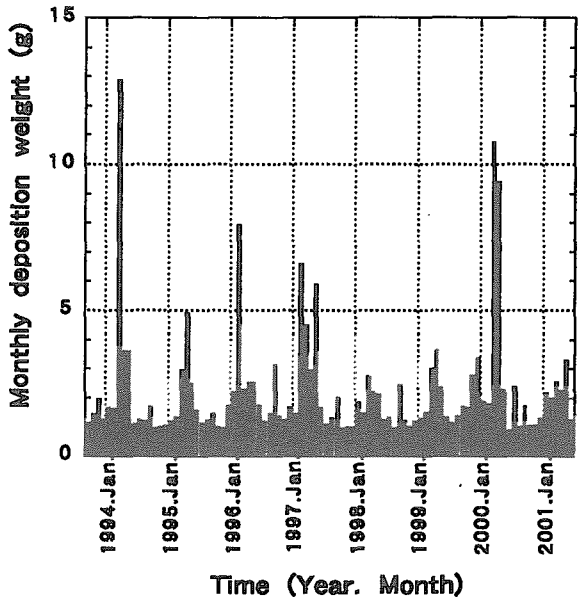

Fig.3.1-5 Variation of monthly deposition weight of dried basin sample at Tokai-mura

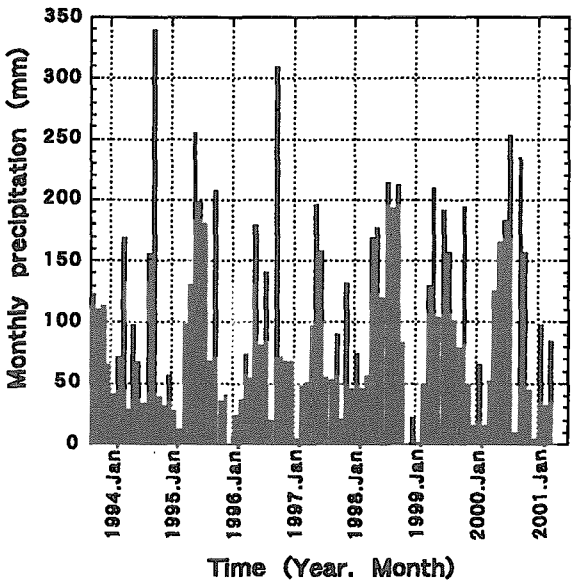

Fig. 3.1-6 Variation of monthly precipitation at Tokai-mura

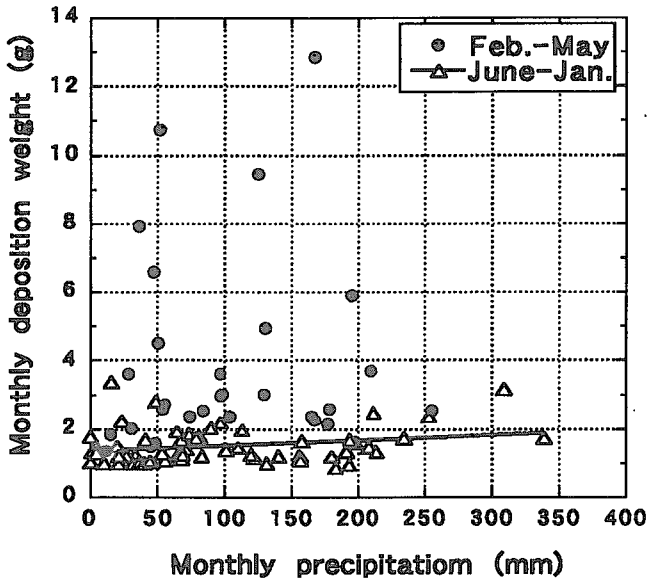

Fig. 3.1-7 Dependency of monthly deposition weight on precipitation

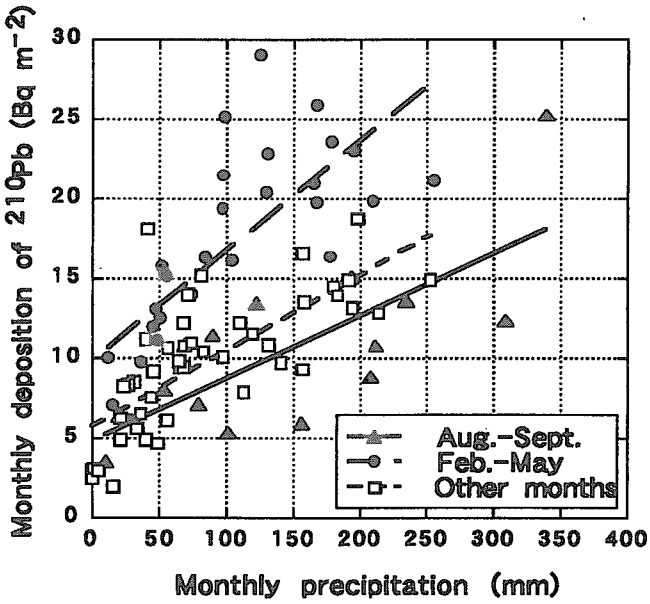

Fig. 3.1-8 Dependency of monthly deposition of ^{210}Pb on precipitation

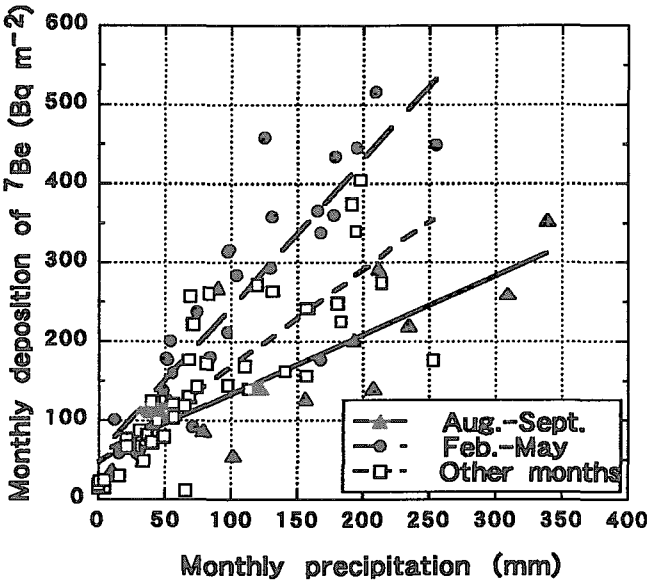

Fig.3.1-9 Dependency of monthly deposition of ^{7}Be on precipitation

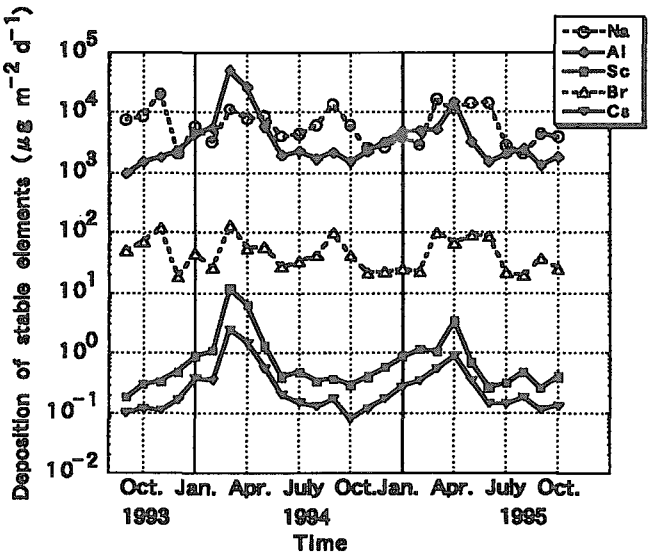

Fig.3.1-10 Deposition of stable elements at Tokai-mura

Grouping can be possible based on the result of correlation analysis for
1)Soil origin elements: Al, Sc, Cs etc., 2)Sea origin elements: Na, Br etc.
Not that prevailing wind direction at Tokai-mura is as follows:
Apr.-Aug.: NE(From sea); Dec.-Feb.: NW(From land)

Table 3.1-1 Correlation coefficients among monthly deposition of radionuclides and some environmental factors

	Weight	Precipitation	^{7}Be	^{40}K	^{137}Cs	^{210}Pb
Weight	1.000	0.088	0.246	0.961	0.935	0.472
Precipitation	0.088	1.000	0.734	0.059	−0.054	0.599
^{7}Be	0.246	0.734	1.000	0.253	0.135	0.825
^{40}K	0.961	0.059	0.253	1.000	0.897	0.485
^{137}Cs	0.935	−0.054	0.135	0.897	1.000	0.408
^{210}Pb	0.472	0.599	0.825	0.485	0.408	1.000

3.2 Migration behavior of elements from a soil system to a river

Yukiko HANZAWA

3.2.1 Introduction

As a part of the study on migration behavior of radionuclides (e.g. ^{137}Cs and ^{90}Sr) and trace elements (e.g. Cd and Pb) in river watershed, migration of those elements from a soil system to a river is especially important, because a soil system is one of the major sources for materials found in a river. To investigate dissolution behavior of elements from soil into water would provide basic information on their migration from a soil system to a river. Therefore, in this study, an extraction experiment using soils collected along the Kuji River was carried out to determine dissolution characteristics of elements from these soils to water.

In order to correlate the dissolved amounts to total amounts of elements in a soil, an extraction coefficient (EC) was introduced. The EC is a ratio defined as follows[1].

$$EC = \frac{\text{Amount of the element concerned dissolved in the soil (g/g)}}{\text{Total amount of the element concerned in the soil (g/g)}}$$

Considering the development of a mathematical model, it would be helpful that one could estimate amounts of elements dissolved in soil in a river watershed (i.e. information on migration of elements) from total concentrations of the elements in the soil, on which data would be more readily available.

In this study, the EC values of several elements were compared and discussed with regard to land use, because the information of land use is available widely, not only in the Kuji River watershed. This is an attempt at general description of dissolution characteristics and migration behavior of elements from a soil system to a river.

3.2.2 Experimental

Soil samples were collected along the Kuji River. The sampling sites are shown in Fig. 3.2-1. Reflecting the land use of this area, five rice fields (R1 – R5); two forests (F1, F2), an orchard (K1) and a field for other crops (H1) were selected. At each site topsoil (0 – 10 cm in depth) was collected, dried at 50°C and sieved (ca. 1 mm mesh). Using these samples, a batch type extraction experiment using purified water was carried out. Figure 3.2-2 shows the procedure of the extraction. The extracts were analyzed for amounts of elements, amounts of total organic carbon (TOC) and ultra violet (UV) absorption. Soil samples were also analyzed for amounts of elements and TOC. The procedure of elemental analysis of the soil samples is given in Fig. 3.2-3.

The amounts of 20 elements in the soil samples and these extracts were determined by inductively-coupled mass spectrometry (ICP-MS, HP-4500 by Agilent Technologies). The elements evaluated were major elements (Na, Ca, etc.), toxic minor elements (Cd, Pb, etc.), radioactive elements (U, Th) and stable elements of radionuclides released by nuclear accidents (Sr, Cs) that can be regarded to have similar behavior.

TOC measurement was carried out using a carbon analyzer TOC-5000 (Shimadzu co. Ltd.) and UV absorption was measured by a spectrophotometer U-3300 (Hitachi co. Ltd.).

3.2 3 Results and discussion

Figure 3.2-4 shows the amounts of several elements in the soil samples and their EC values. The EC values showed larger differences from sample to sample compared to the amounts of elements.

In some elements, the EC values showed typical dependence on the land use. Namely, the EC values of Cd, Pb (and Th) were especially large in case of forest soils. This means dissolution amounts of these elements in forest soils could be larger than those in other soils even if their amounts in these forest soils were less. Possible causes of the large EC values of these heavy metals in forest soils are accumulation of atmospheric depositions of these elements in topsoil of forests. A contribution of existence of soil colloids as carriers in forest soils will be also not excluded. Some past studies indicated that low pH in forest soils causes a high trace metal solution concentration[2]. It would not be an appropriate explanation in this study, however, because the extract from the forest soil "F1" showed slightly higher pH value than the rice field soil "R1" (5.6 and 5.3, respectively), while "F1" indicated larger EC values of Cd and Pb than "R1".

In case of U (and Cu), similar trend were observed, though large EC values were also found in some fields and an orchard. The reason for these large EC values in the fields could be anthropogenic additions (e.g. fertilizers, pesticides, etc.).

On the other hand, in case of Ca, (Sr and Na), no clear difference of the EC values was found among different land uses. These elements are basically originated from weathering of rocks (i.e. not anthropogenic sources) and have low absorption property generally. These characteristics could be the reason why the EC values of these elements are not dependent on the land use.

In past studies on dissolution of heavy metal elements[3)- 6)], it is pointed out that dissolved organic matters (DOM), especially humic substances can be carriers of these elements. In order to investigate in this study whether DOM plays a role as a carrier of elements or not, characteristics of DOM in the extracts were examined. Amounts of TOC in the soil and the extracts were determined and an extraction coefficient was also introduced for TOC.

$$EC_{TOC} = \frac{\text{Amount of TOC dissolved in the soil (mgC/g)}}{\text{Total amount of TOC in the soil (mgC/g)}}$$

The amount of TOC in the soil samples and their EC values are given in Fig. 3.2-5.

As an indicator of existence of humic substances in the extracts, UV absorbance at 280nm divided by TOC concentration was evaluated, the result given in Fig. 3.2-6.

As shown in Fig. 3.2-5, the EC values for TOC were almost constant among the samples, though amount of TOC in the soils was quite different. Amount of TOC in the forest soils and consequently in their extracts were more than other land uses. This fact might be related to the larger dissolution of heavy metals in the forest soils. However, the results shown in Fig. 3.2-6 implied the quality of DOM in the extracts were different from soil to soil and humic substances which are considered to play an important role as a carrier of heavy metal elements were not necessarily poorer in the rice fields, orchard and other field soils than the forest soils.

Therefore, it has not been made clear that DOM (or humic substances) promote the dissolution of metal elements in soils in this study. Further investigation is necessary on this point.

3.2.4 Summary

In this study, it was found that the land use could influence dissolution behavior of some heavy elements from soils. It means that in evaluation of migration of elements from a soil system to a river, not only the abundance of the elements in the soil but also the land use should be taken into account. A tentative evaluation to elucidate the role of DOM on dissolution of metal elements was carried out, but clear finding was not obtained in this study

In further investigations, soil properties, depth profiles of a soil, effects of percolation, chemical

forms of dissolved elements, etc. should be the subjects, in addition to the role of DOM.

3.2.5 Discussion by the guest scientist

The presentation is also important research that clearly shows the essential points of modeling of environmental processes. This presentation deals with issues that have been commonly experienced. The migration of elements in the environment are strongly influenced and controlled by a large number of different processes. This is really a challenge for modelers, because to account for everything is extremely difficult. One should keep it in mind that it is also difficult to find a univocal and strict relationship between migration parameters such as 'Extraction Coefficient' and specific characteristics of the environment to be assessed. This is one of the main reasons for the approach in which a limited number of processes or behavior fashions that can be very clearly identified are selected.

Related to this point, the presented investigation deals with the land use to express the spatial variations in characteristics of the environment, rather than to deal with specific chemical, geochemical characteristics of soil. For instance, the investigators are trying to correlate apparent, significant processes to the land use. This is definitely a wise way to approaching the problem of the migration of trace substances in river watershed that is affected by a number of intertwined parameters.

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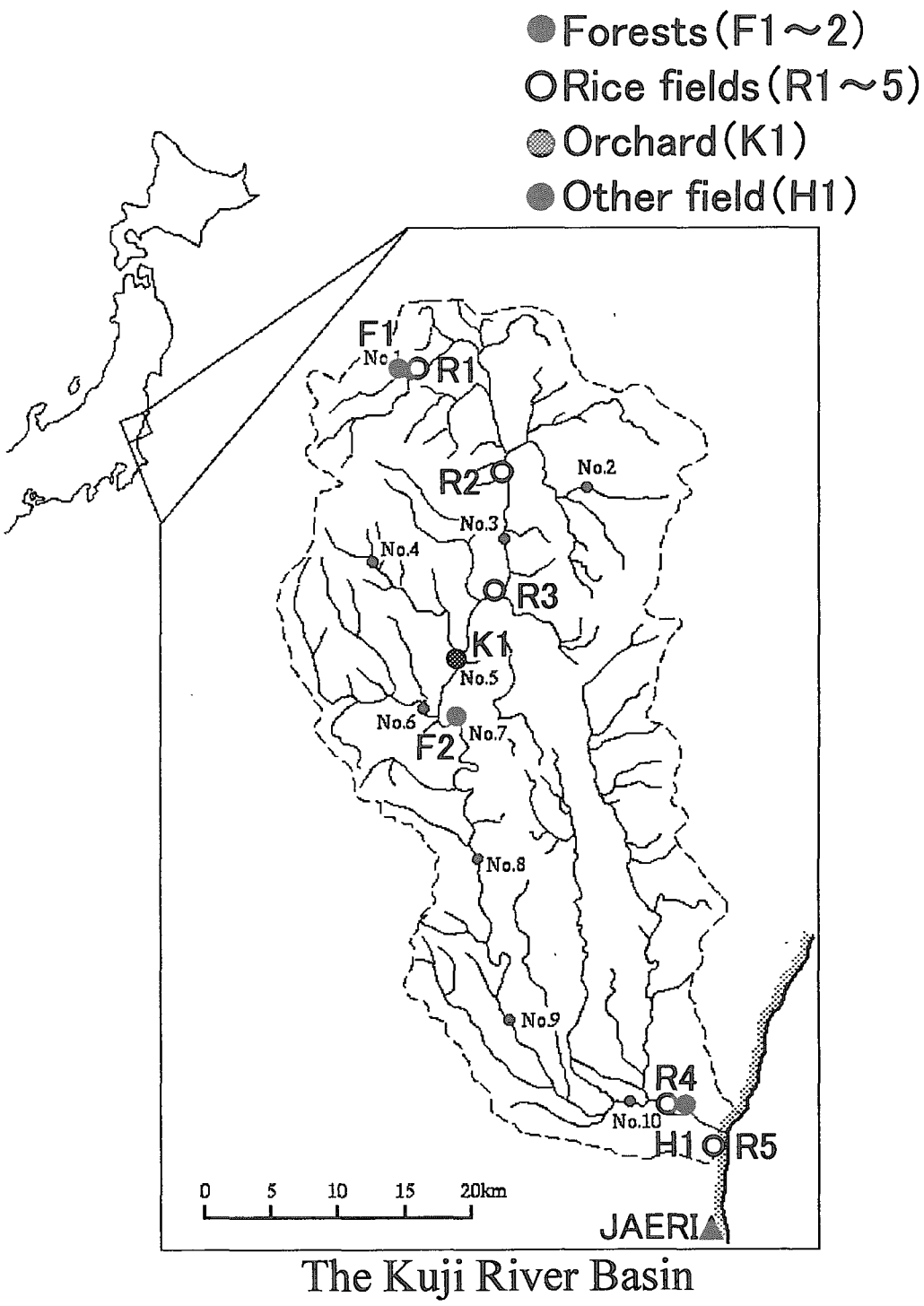

Fig. 3.2-1 The sampling sites for soils for the extraction experiment

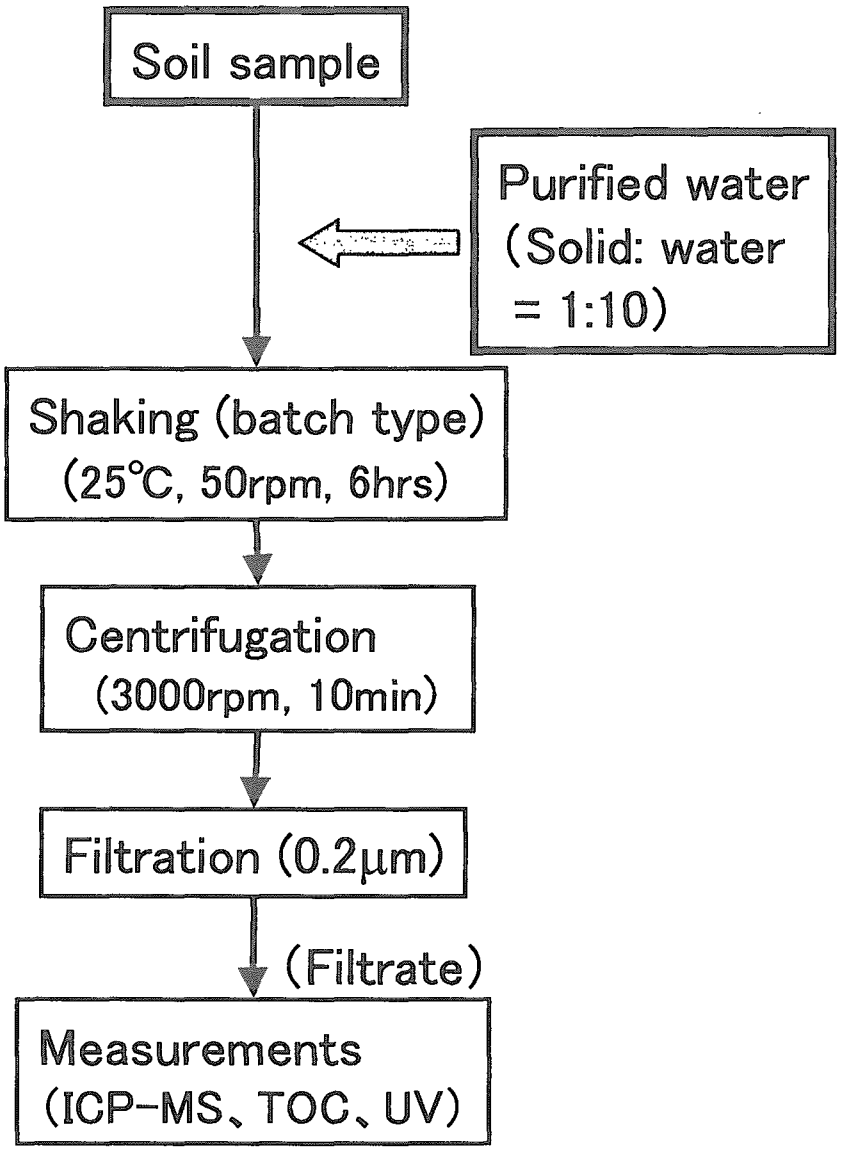

Fig. 3.2-2 Procedure of the extraction experiment

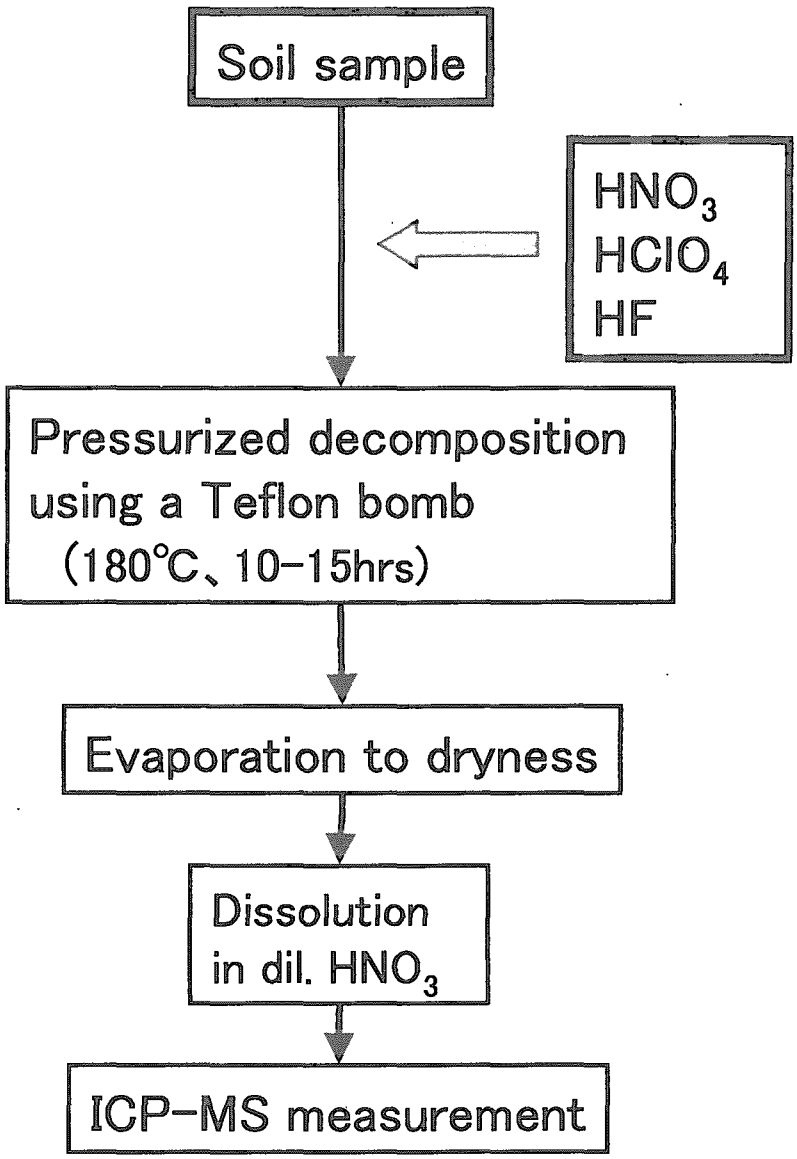

Fig. 3.2-3 Procedure of elemental analysis of soil samples

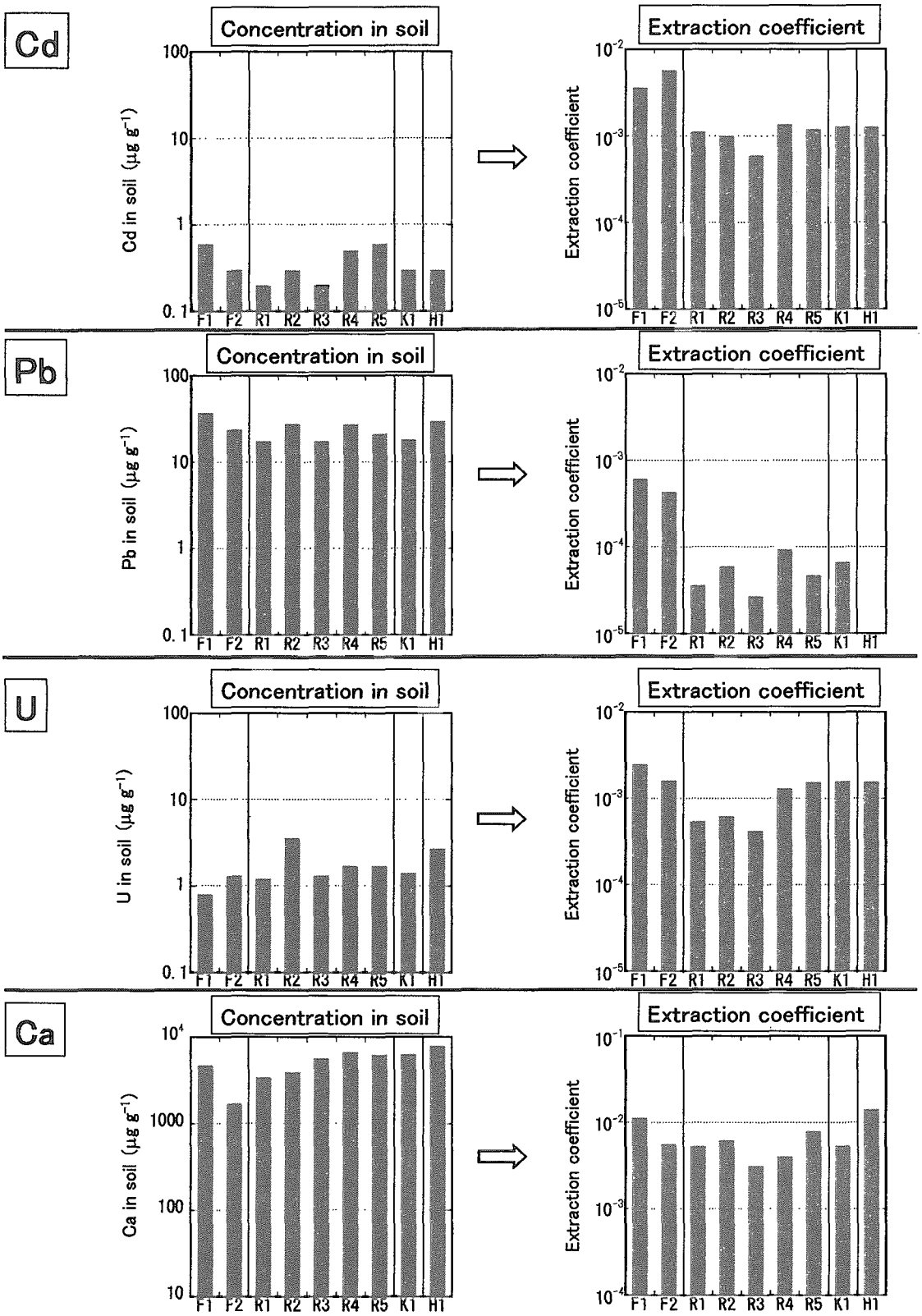

Fig. 3.2-4 Concentration of elements in soils and extraction coefficient

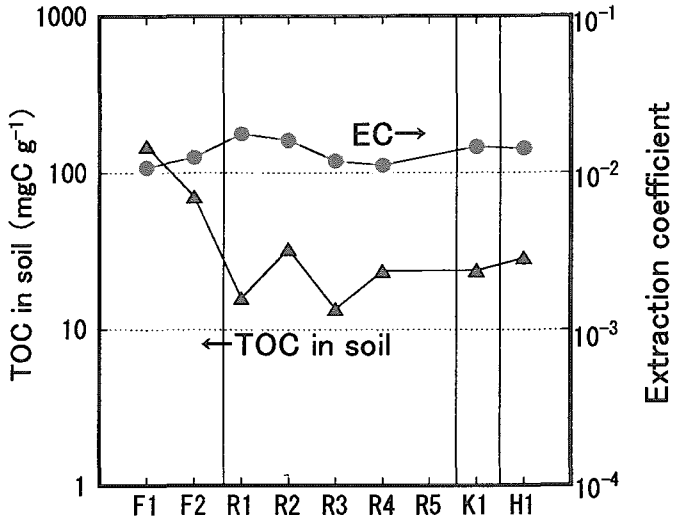

Fig. 3.2-5 Concentration of TOC in soils and extraction coefficient

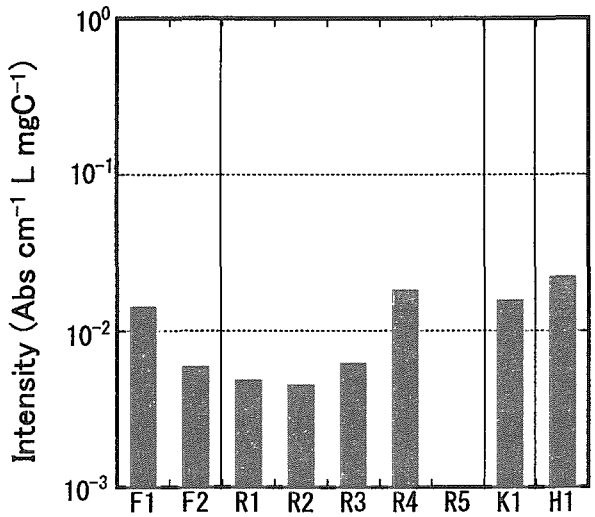

Fig. 3.2-6 UV absorbance at 280nm / TOC concentration in the extracts

3.3 Migration behavior of uranium and toxic elements in the Kuji River watershed - The proportion of dissolved and particulate forms -

Nobuyuki YANASE

3.3.1. Introduction

River water is used for irrigation, drinking, etc. in Japan. The concentration of toxic elements including radioactive elements in the river water is primary concern for the people living by the river. However, transport mechanisms of toxic elements in a river watershed are not well understood. Therefore, understanding of migration behavior of toxic elements and development of prediction models are needed.

Since the behaviors of dissolved and particulate elements are different in the river watershed, partition coefficient of element between river water and suspended matter is important parameter for a river transport model. In situ partition coefficients have been determined by the previous studies (e.g. Vesely et al.[1] ; Miller et al. [2]). The element having relatively high partition coefficient (e.g. around 10^3-10^4) is considered to be immobile in a river watershed. However, chemical form of such elements transported by the river water is predominately in dissolved form at the baseflow condition and in particulate form at the stormflow condition (e.g. Miller et al.[2]). The proportion of dissolved and particulate form of element is correlated with a partition coefficient, which depends on hydrological and chemical condition of river water. In this study, proportions of dissolved and particulate form of toxic elements were determined at a precipitation event and during a drought in the Kuji River watershed.

3.3.2. Experimental

River water samples were collected at No.8 in upper middle small tributary of the Kuji river watershed during a small precipitation event (1 mm for 1 hour) in Nov. 7-9, 2002 and No.10 in mainstream, 9 km from the mouth, during drought (17 mm from Mar. 27 till Apr. 27) in Apr. 4-26, 2001 (Fig. 3.3-4).

The river water samples were filtered using 0.2 μm PTFE membrane filter (VH020P, ADVANTEC) (Fig. 3.3-3). Unfiltered and filtered river water were collected and acidified with Suprapur HNO_3 to make up 1.4 % HNO_3 solution for the determination of element concentration by ICP-MS (HP-4500, Agilent Technologies). The element concentration of particulate fraction was calculated from the difference between the concentration of unfiltered and filtered samples. River water qualities (electrical conductivity, temperature, turbidity, pH) were measured using a water quality checker (WQC-22A, DKK-TOA). By the measurement of hydrological parameters (water flow rate and the depth of water) , water discharge was estimated based. The flow rate was measured around one third of the total depth with an electromagnetic current meter (VP-1000, KENEK).

3.3.3. Results and discussions

The difference of hydrological and chemical conditions of river water, concentration of trace elements, and proportion of dissolved and particulate form of trace elements is discussed in the two distinctly different river flow conditions, i.e. drought and precipitation event, hereafter.

After the precipitation event, hydrological and chemical conditions of river water changed. Flow rate and conductivity increased, and pH, turbidity, and temperature decreased. The unexpected decrease of turbidity may be due to a direct inflow of transparent rainwater. During drought, conductivity and turbidity increased and pH was constant (Fig. 3.3-5).

For all the samples, U and As was almost dissolved form before the precipitation event (Fig. 3.3-6, -7). However, the proportions of particulate U and As increased up to 18% and 10 % after the precipitation event, respectively. During the drought, concentrations of particulate U and As increased more rapidly than dissolved U and As concentration. The proportions of particulate U and As increased from 15% and 18 % to 35% and 40 %, respectively.

For Al and Pb, the proportions of dissolved and particulate form changed quite differently compared with U and As. Aluminum in particulate form was dominant in all cases (Fig. 3.3-8). The proportions of particulate Al were about 60-80% and 90% before and after the precipitation event, respectively. During the drought, the proportion of particulate Al was more than 90% everyday except in the first day. After the precipitation event, Pb concentration increased remarkably and the proportion of particulate Pb increased from about 30% up to 80% (Fig. 3.3-9). During the latter half of the drought, the concentrations and proportions of particulate Pb increased rapidly. The proportions of particulate Pb increased up to 70%.

Copper and Ni showed similar change of proportion to U and As. Copper was almost entirely in dissolved form before the precipitation event, and the proportion of particulate Cu increased up to 20 % after the precipitation event (Fig. 3.3-10). During the latter half of the drought, concentration and proportion of particulate Cu increased rapidly. The proportion of particulate Cu increased up to 30%. The proportion of particulate Ni was about 5-10% and 30-10% before and after the precipitation event, respectively (Fig. 3.3-11). During the drought, the proportion of particulate Ni was about 30%-50% except the day of 24 Apr.

It was concluded that for uranium and toxic elements, the concentration and proportion of particulate form increased after the precipitation event and during the drought in the Kuji River watershed.

3.3.4. Summary

Uranium, As, Cu, and Ni were predominately in dissolved form before and after the precipitation event, and during the drought. This may be due to the nature of these elements in their basic soluble form or in a soluble complex with an organic or inorganic ligand[1]. However, the proportion of particulate form during the drought was slightly higher than that at the precipitation event, although the difference of sampling point and time was neglected.

Aluminum was always predominately in particulate form due to its low solubility in neutral pH[1]. On the other hand, Lead changes its form depending on individual conditions and the particulate form increased remarkably after the precipitation event due to an increase of suspended particulate matter with which Pb may be associated. From these data, apparent partition coefficients for these elements can be deduced (Fig. 3.3-12).

3.3.5. Other works in progress (Fig. 3.3-13)

For understanding of migration behavior of toxic elements and development of a prediction model in the Kuji River watershed, 3-stage ultrafiltration has been carried out to determine the proportion of colloidal forms of element. Determination of radionuclide concentrations of soil has been carried out to investigate transport mechanisms of radionuclides from surface soil to the river. Furthermore, discharge behavior of toxic elements has been studied at an acid mine drainage site.

3.3.6 Discussion by the guest scientist

In this survey, no particulate copper was present before a rain. However, in the drought

condition, there was much more particulate copper. This means a significantly different behavior of copper in those two conditions. A very small particulate percentage of Ni was observed before a rain event. During the drought, there was a higher level of its particulate form. It is advisable to execute a comparison of the concentration levels and the forms of trace elements under various conditions at a certain identical observation point. It has been also confirmed that it is very necessary to discriminate radionuclides and trace elements in their dissolved, particulate, and also colloidal forms to be able to apply the findings from the field study to modeling research activities.

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Migration behavior of uranium and toxic elements in the Kuji River watershed

- The proportion of dissolved and particulate forms -

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Fig.3.3-1 Research theme

Which form is dominant, dissolved or particulate?

- River water is used for irrigation, drinking, etc.
- The concentration of toxic element in the river water is primary concern for the people living in the river side.
- Understanding of migration behavior of toxic element and development of prediction model are needed.
- The behaviors of dissolved and particulate elements are different in the watershed.
- Filtration of the river water using 0.2 μm membrane filter was carried out to determine the proportion of dissolved and particulate form of toxic element.

Fig.3.3-2 Research subjects

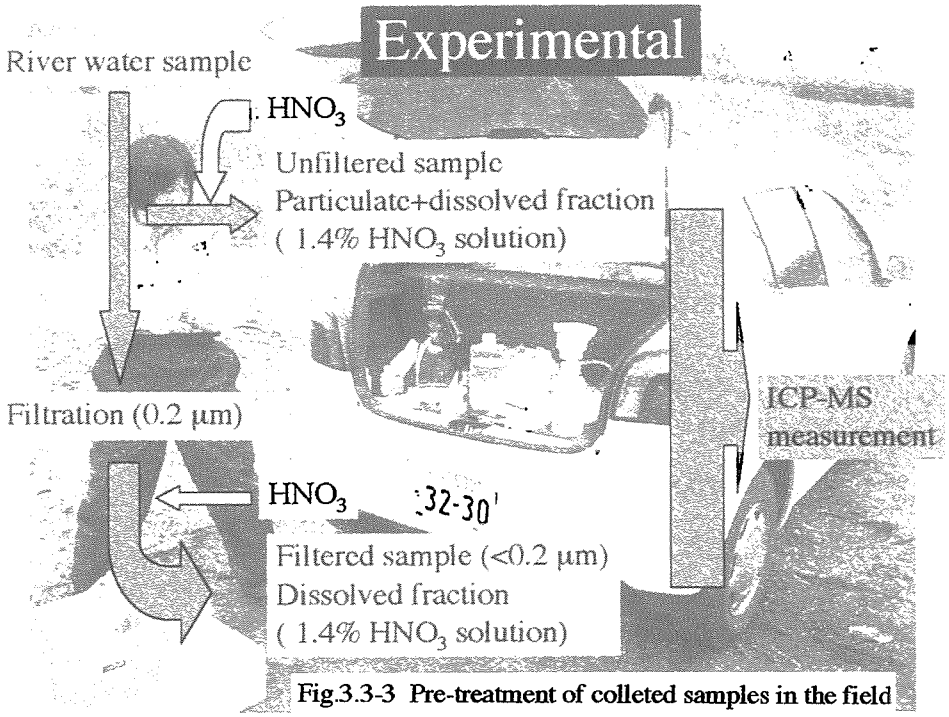


Fig.3.3-3 Pre-treatment of colleted samples in the field

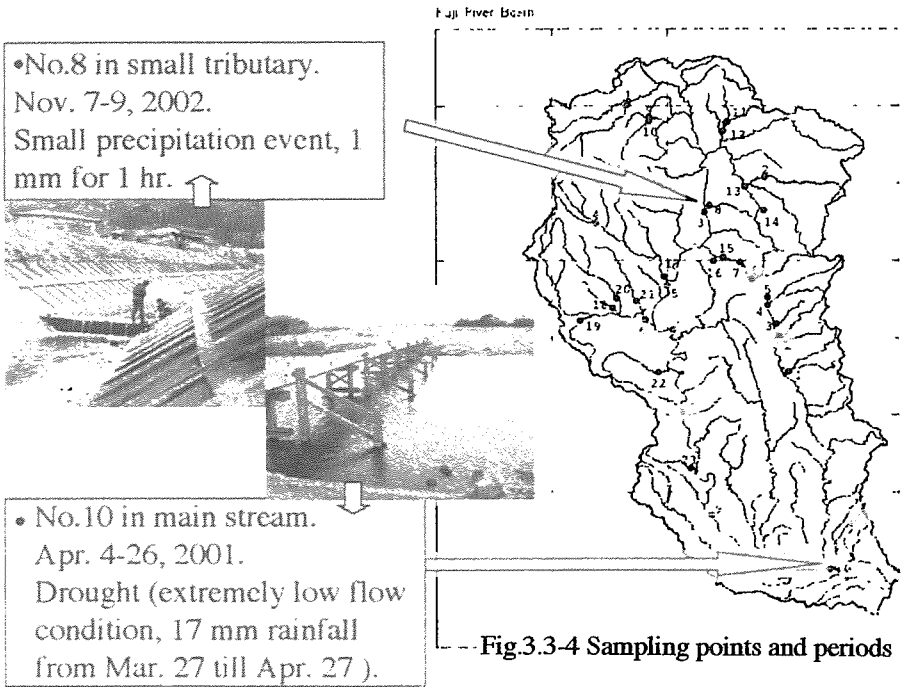


Fig.3.3-4 Sampling points and periods

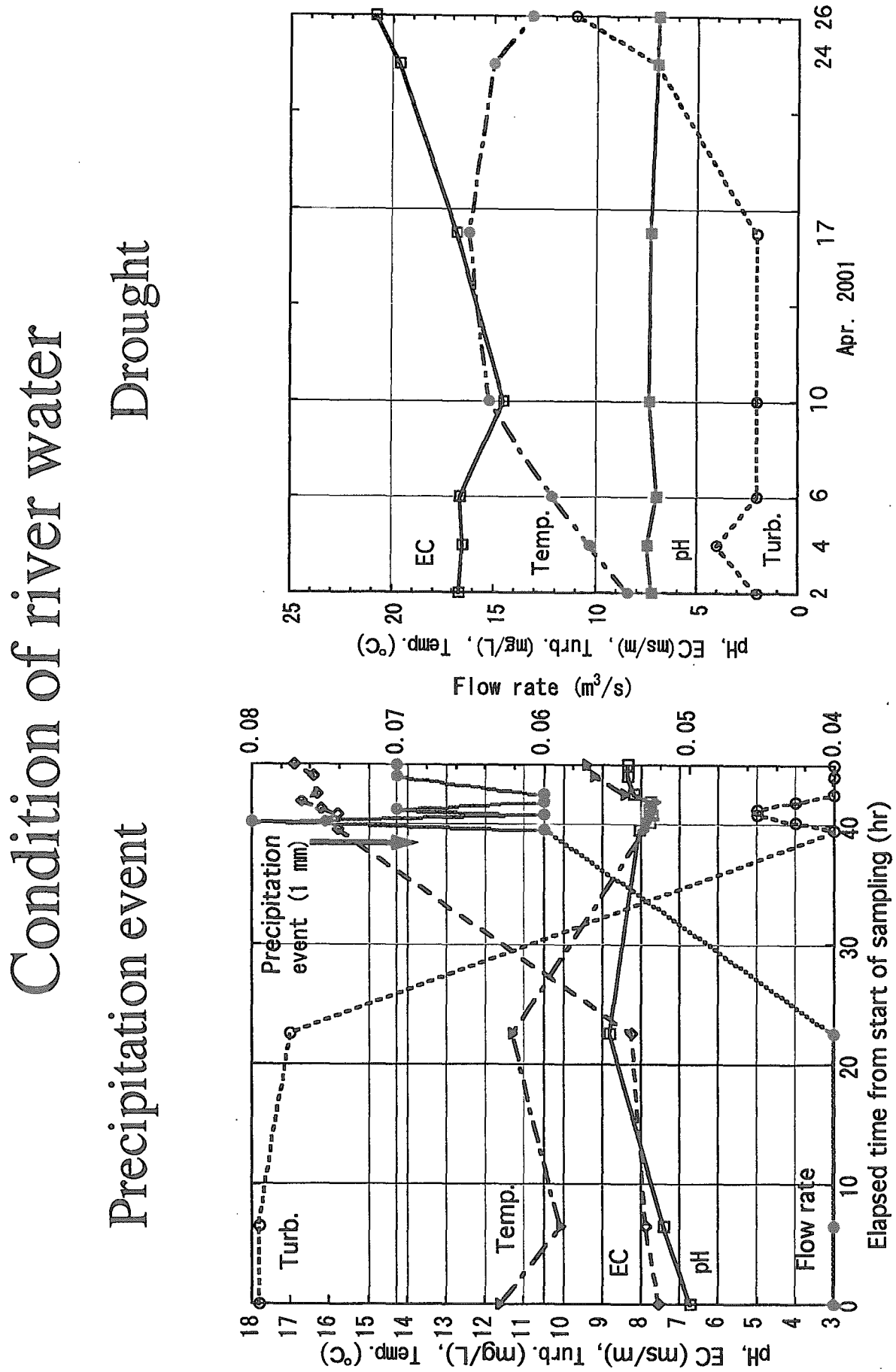
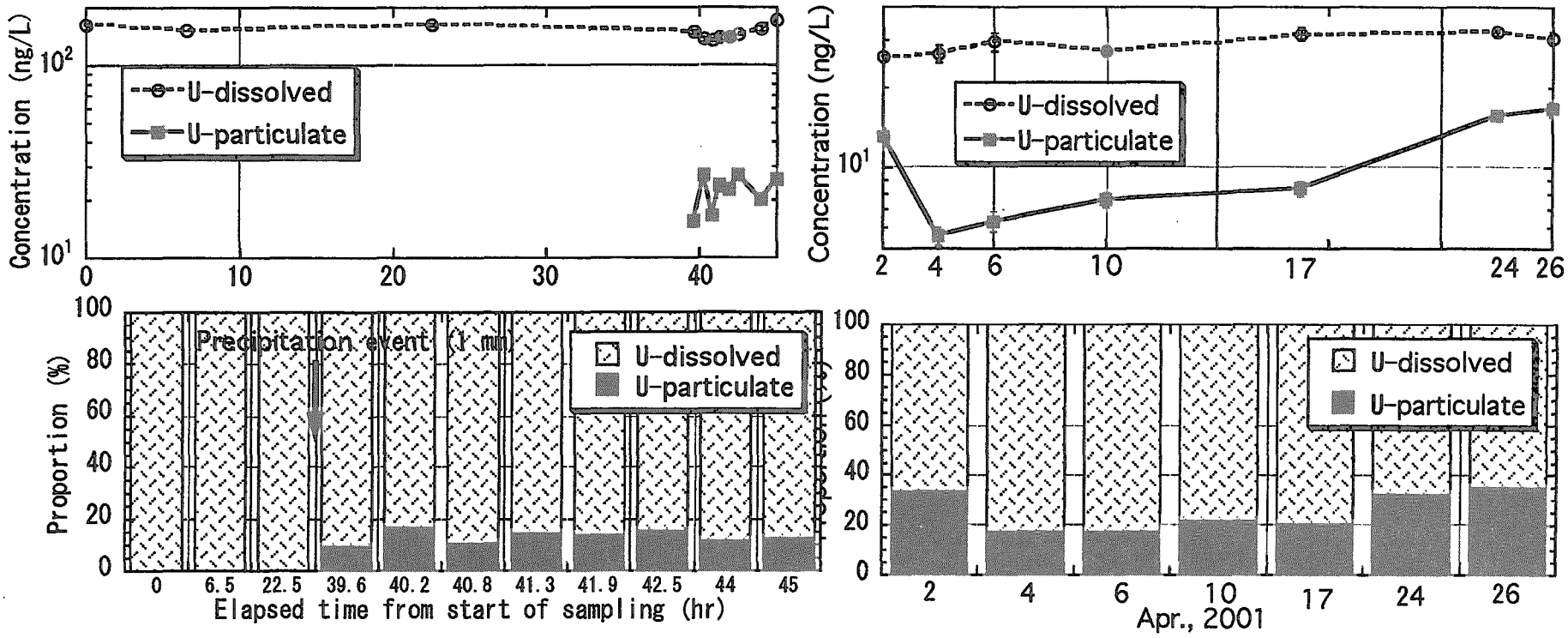


Fig.3.3-5 Condition of river water in different hydrological conditions

Uranium

Precipitation event (pH : alkaline)

Drought (pH : neutral)



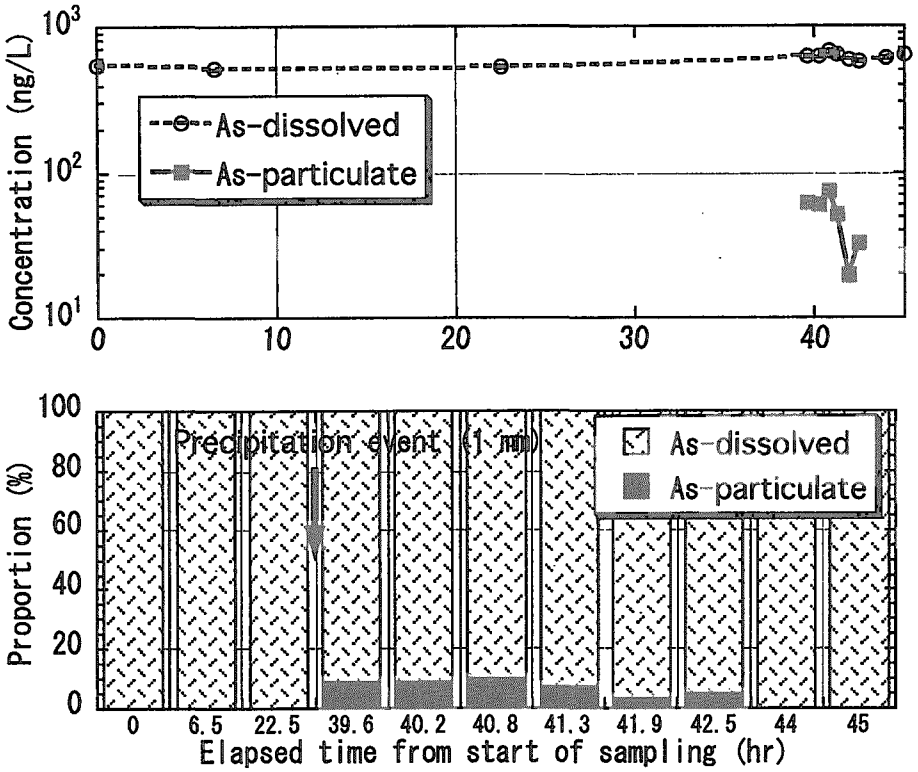
- Before rain event, U was almost all dissolved.
- After rain event, particulate U increased as high as 18%.

- Particulate U concentration increased more rapidly than dissolved U concentration.
- Particulate U increased from 15% to 35%.

Fig.3.3-6 Concentration and distribution of uranium in dissolved and particulate forms

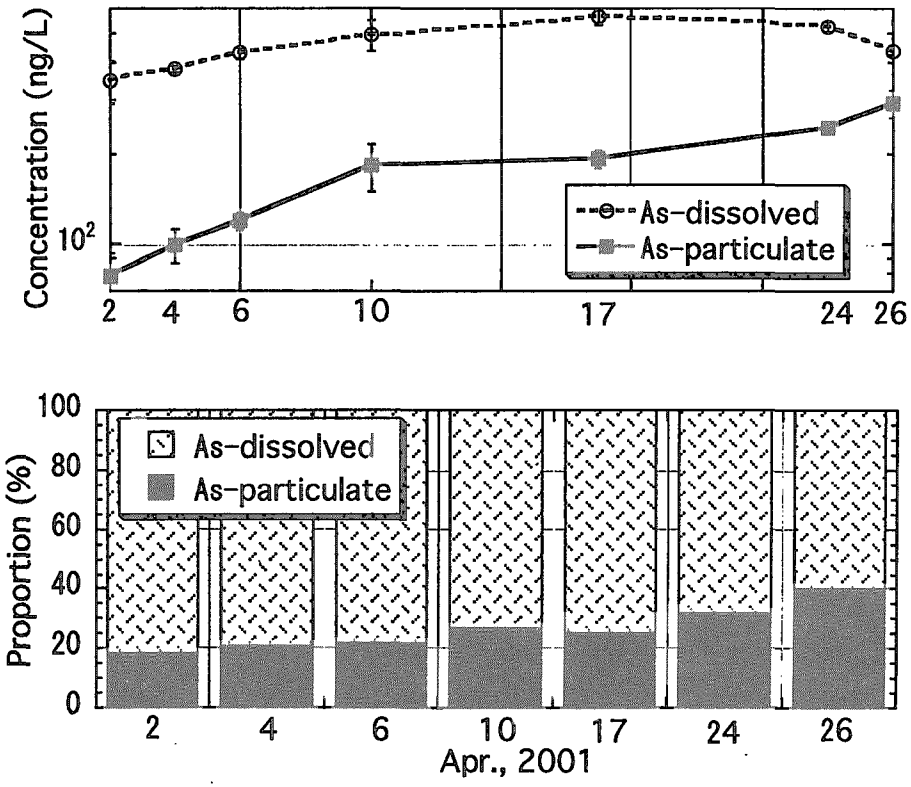
Arsenic

Precipitation event



- Before rain event, As was almost all dissolved.
- After rain event, particulate form of As increased as high as 10%.

Drought

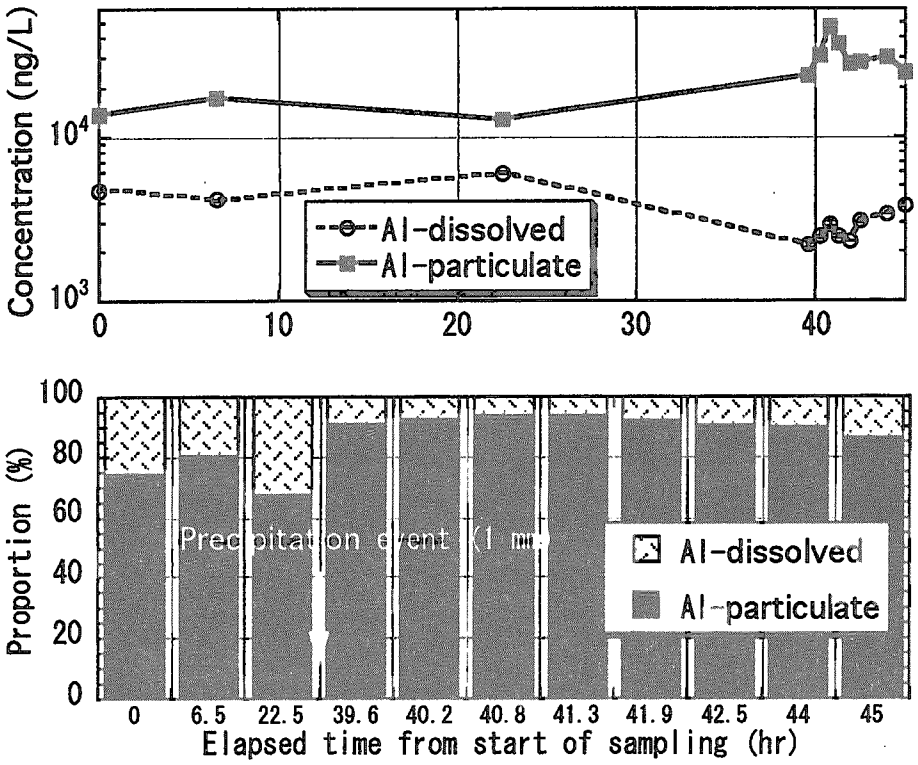


- Particulate As concentration increased more rapidly than dissolved As concentration.
- Particulate As increased from 18% to 40%.

Fig.3.3-7 Concentration and distribution of arsenic in dissolved and particulate forms

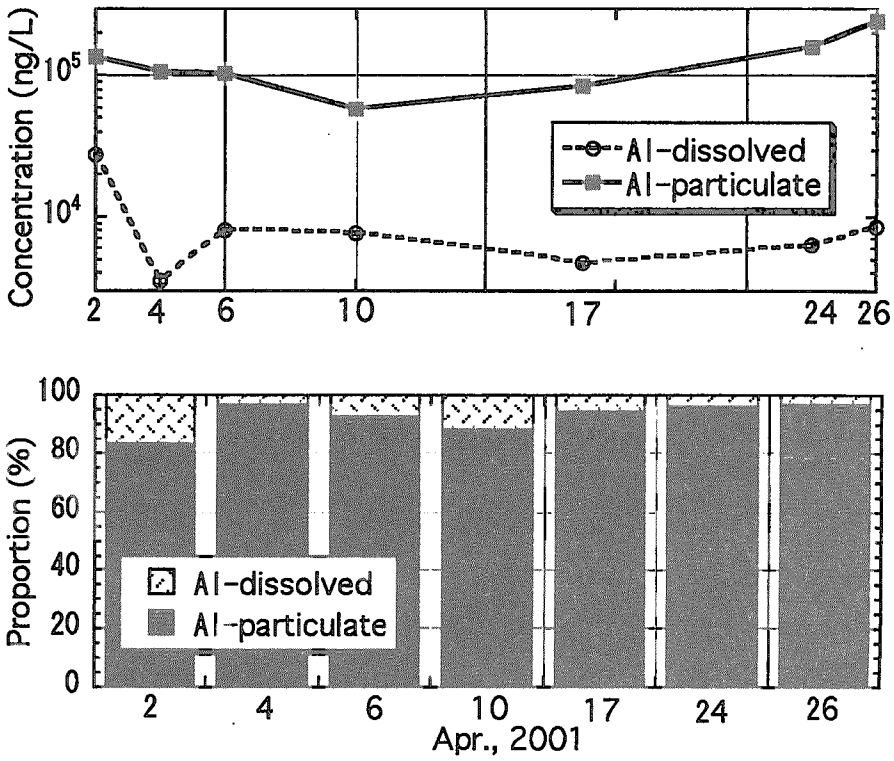
Aluminum

Rain event



- Al was predominately in particulate form in all cases.
- Proportion of particulate Al was about 60-80% and 90% before and after rain event, respectively.

Drought

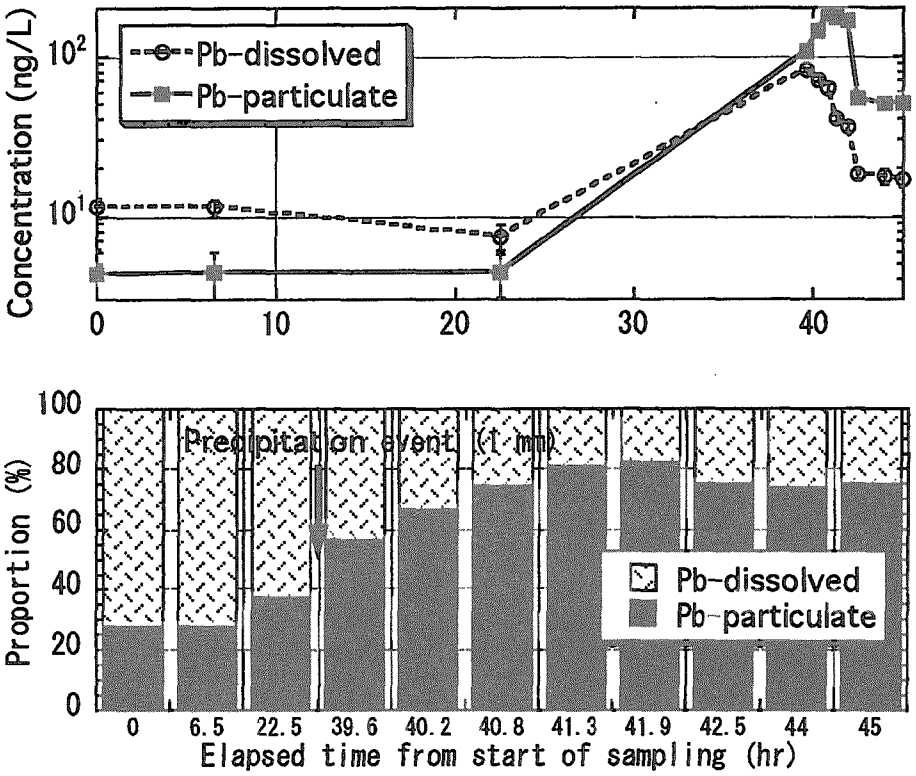


- Proportion of particulate Al was more than 90% except the first day.

Fig.3.3-8 Concentration and distribution of aluminum in dissolved and particulate forms

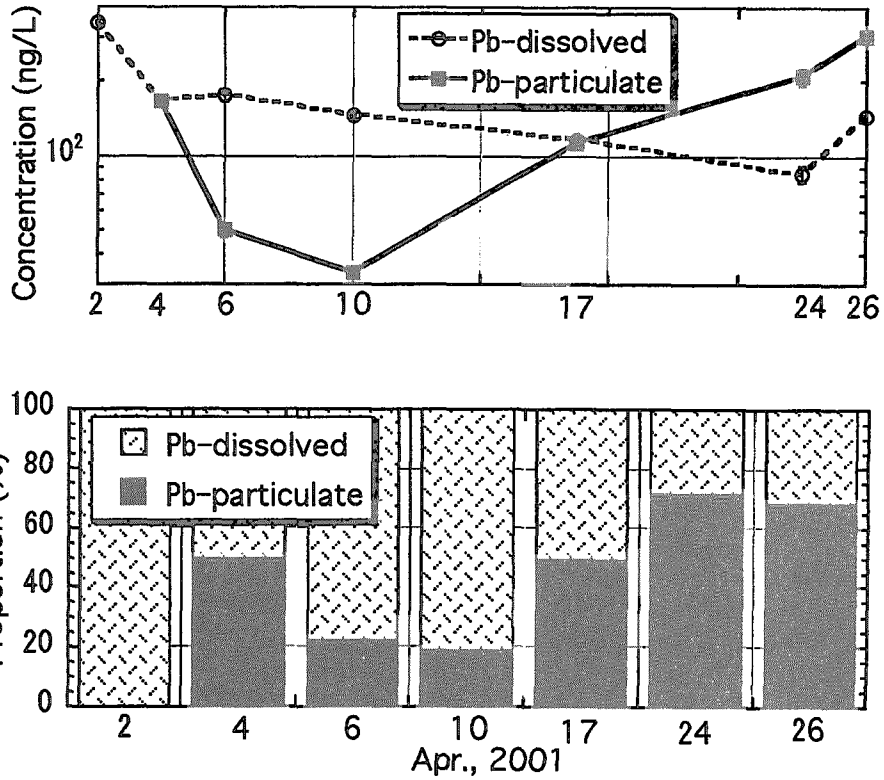
Lead

Precipitation event



- After rain event, Pb concentration increased remarkably and particulate form of Pb increased from about 30% up to 80%.

Drought

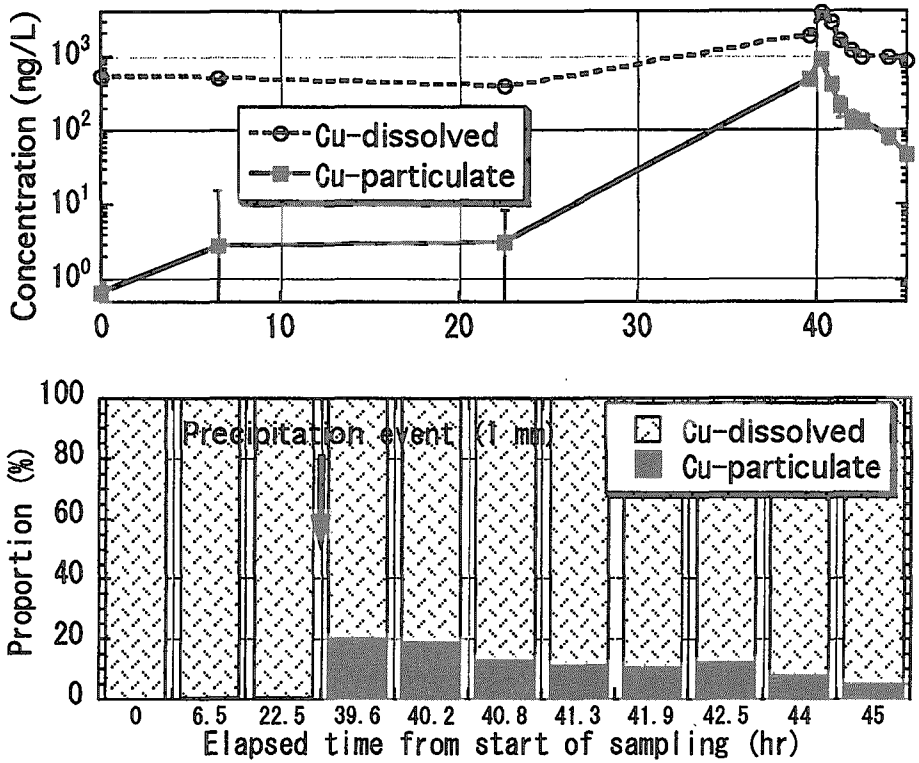


- During the latter half of drought, concentration and proportion of particulate Pb increased rapidly.
- Particulate Pb increased up to 70%.

Fig.3.3-9 Concentration and distribution of uranium in dissolved and particulate forms

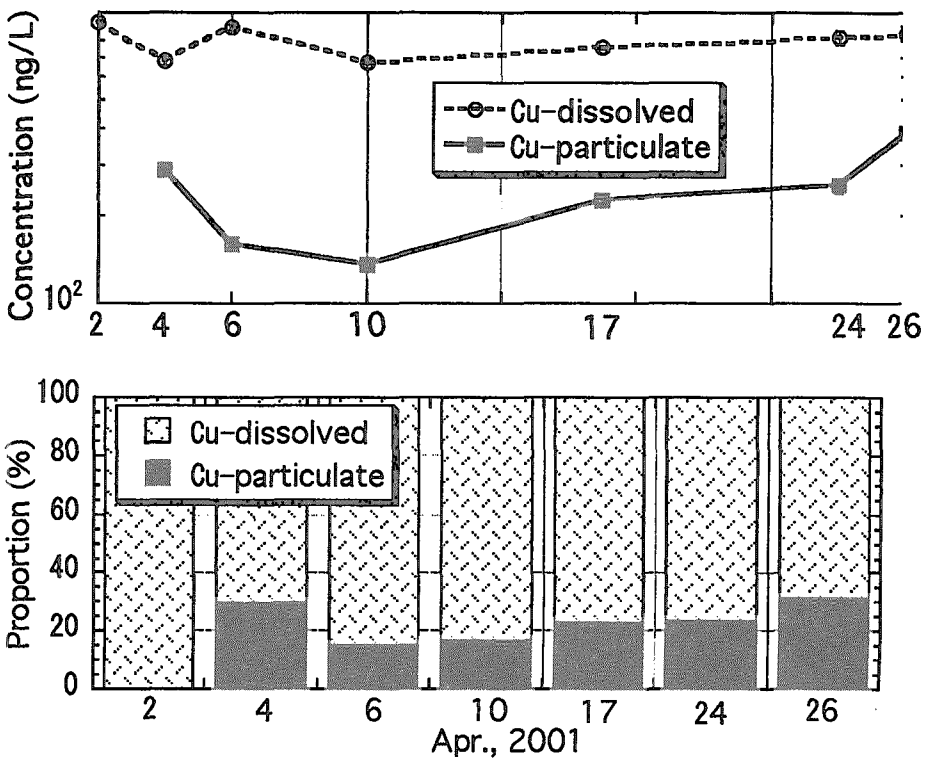
Copper

Precipitation event



- Before rain event, Cu was almost all dissolved.
- After rain event, Cu concentration increased remarkably and particulate form of Cu increased as high as 20%.

Drought

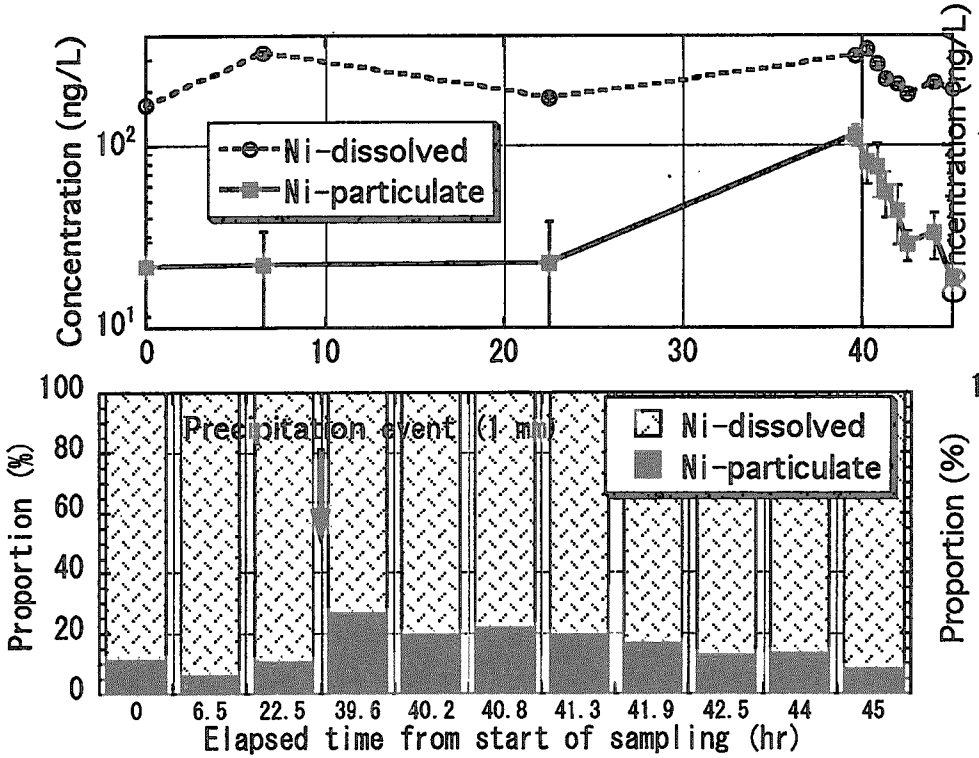


- During the latter half of drought, concentration and proportion of particulate Cu increased rapidly.
- Particulate Cu increased as high as 30%.

Fig.3.3-10 Concentration and distribution of copper in dissolved and particulate forms

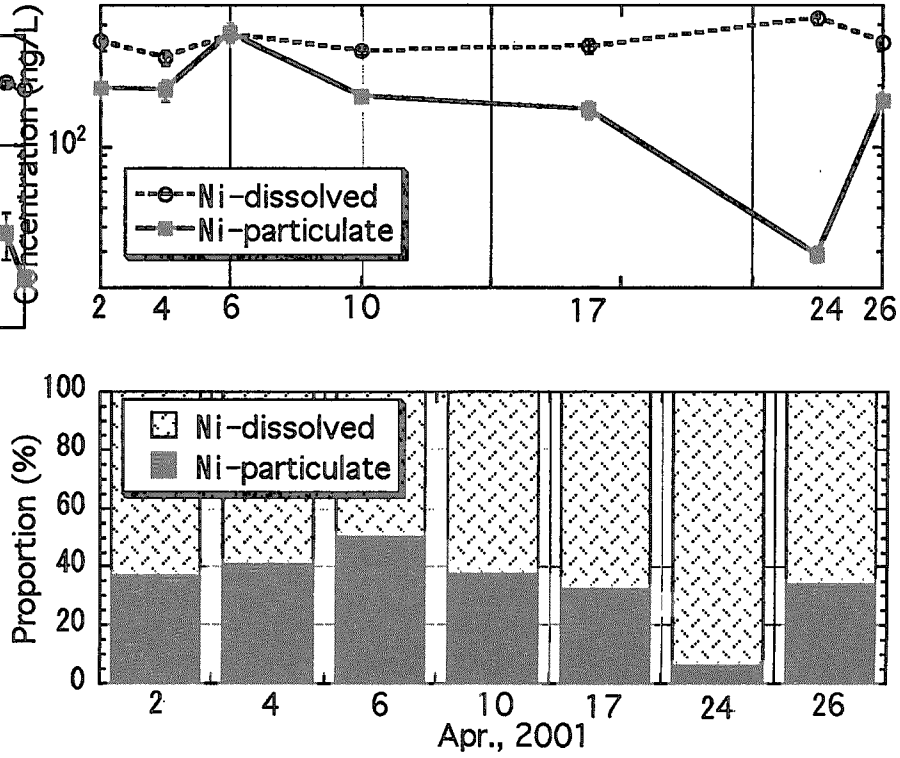
Nickel

Precipitation event



- Proportion of particulate Ni was about 5-10% and 30-10% before and after rain event , respectively.

Drought



- Proportion of particulate Ni was about 30%-50% except the day of 24 Apr.

Fig.3.3-11 Concentration and distribution of nickel in dissolved and particulate forms

Summary

	Precipitation event		Drought
	Before	After	
U	Dissolved (100%)	Dissolved (82-90%)	Dissolved (85→65%)
As	Dissolved (100%)	Dissolved (90→100%)	Dissolved (82→60%)
Al	Particulate (60-80%)	Particulate (>90%)	Particulate (>90%)
Pb	Dissolved (60-70%)	Particulate (60 →80%)	Dissolved →Particulate (100% (70%)
Cu	Dissolved (100%)	Dissolved (80 →90%)	Dissolved (70-100%)
Ni	Dissolved (90-95%)	Dissolved (60 →90%)	Dissolved (50-95%)

Fig.3.3-12 Summarized characteristics of the proportion of dissolved and particulate forms of uranium and toxic elements in the Kuji river water

The other works

- 3 stage ultrafiltration (200, 50, 10 k Da or 100, 10, 1 k Da)
- Radionuclide concentrations of soil ($^{239,240}Pu$, ^{137}Cs, ^{210}Pb, ^{226}Ra, ^{40}K)
- Acid mine drainage (As, Pb, Al, etc.)

Fig.3.3-13 Other related researches

3.4 Fluvial discharge and form of radionuclides in river water

Takeshi MATSUNAGA

3.4.1 Field study revealing several regularities in discharge of radionuclides in the Kuji River watershed

(1) Objectives

There are several pathways in the secondary migration of atmospherically derived radionuclides on the ground: infiltration to deeper soil layers and groundwater; resuspension to the atmosphere; turnover through means including vegetation; and redistribution to surface water bodies.

Among the secondary migration pathways, redistribution from the ground soil to the downstream region of a river is of special importance [1]. It has an influence on man via contamination of water bodies and bottom sediments, especially in the downstream region. We have carried out the study on the secondary migration pathway through a river since 1987. Radionuclides that have been used in the study are ^{137}Cs of global fallout origin, and subsidiary ^{210}Pb and ^{7}Be of natural origins. Besides the well-known good traceability of ^{137}Cs for this pathway[2], the choice of this radionuclide was rational for us because it is a major radionuclide which might be released in a nuclear accident because of its inventory in nuclear reactors and its volatility. In Japanese watersheds, ^{137}Cs is mainly derived from the radioactive fallout of nuclear fission during the weapon tests in the atmosphere. The Chernobyl accident in 1986 resulted in several times greater fallout of ^{137}Cs in European countries than the weapon fallout [3]. However, it increased the integrated deposition density of ^{137}Cs in Japan at the time of accident, 1986 by only about 4 % (Matsunaga, unpublished data).

(2) Methods

The Kuji River is located in the northern part of the Kanto Plains, Japan (Fig. 3.4-2) . It originates from the Yamizo mountain area in the centre of Japan, which is a 1490 km^2 (hills: 80.6%; plains: 16.9%; streams: 2.5%) area characterized by afforested hills and numerous agricultural fields(Fig. 3.4-3). The mean annual precipitation of the watershed is 1360 mm. There are no nuclear facilities along the river except at its mouth. All sampling was performed at the downstream end of the river, 10 km from the sea (Fig. 3.4-4). Field experiments were done under both low (10-20 m^3/s) and high (up to 80 m^3/s) water flow conditions. River water samples of 500-2000 l were pumped at 2-5 l/min. using an *in-situ* sampling system for particulate forms of ^{137}Cs, ^{210}Pb, and ^{7}Be; and for the dissolved form of ^{137}Cs. All the radioactivity concentrations of the samples were determined by gamma-ray spectrometry.

(3) Results

Radioactivity of ^{137}Cs in Kuji River water

The results of measurements of ^{137}Cs in the Kuji River water are shown in Fig. 3.4-5 (left). Under low flow conditions, after there had been little precipitation during several preceding days, the concentrations of the dissolved ^{137}Cs ranged from 0.07 to 0.12 mBq/l, while those of particulate ^{137}Cs ranged from 0.02 to 0.09 mBq/l. The ratios of particulate to dissolved ^{137}Cs were therefore 0.14 to 0.87 with an average of 0.64. A large increase in particulate ^{137}Cs was observed after precipitation. In case of a 40 mm precipitation event in the middle of April 1988 on the Kuji River watershed, that provided high flow conditions, and there was a large increase in the particulate ^{137}Cs up to 0.77 mBq/l [4].

Empirical relationship for the daily load of radionuclides

A data set of measured concentrations of the radionuclides and the flow rate of river water was used to derive a relationship between the load of the radionuclides in fluvial discharge and the water flow rate. The load equals the concentration of radionuclides in each form (dissolved or particulate) multiplied by the flow rate. Results showed that the load conforms empirically to the following relationship (Fig.3.4-5, right):

$$L=aQ^b \qquad (3.4.1)$$

where L is the load of fluvial discharge of the dissolved form of ^{137}Cs and the particulate form of ^{137}Cs, ^{210}Pb, and ^{7}Be (Bq/km^2/d); Q is the flow rate (m^3/s) at the sampling site; and a and b are the constants determined for each of the radioactive species in the watershed. It was found that the load of suspended solids also follows Eq.3.4-1. This type of relationship is common in the fluvial discharge of dissolved materials[5] and of nutrients[6]. The similarity in the graph slopes (variable b) for suspended solids and particulate radioactivities is noteworthy, and is due to the fact that the concentrations of the particulate radionuclides per unit mass of suspended solids was relatively independent of the flow rate, while the concentrations of suspended solids were more dependent on changes in the flow rate.

The similarity in particulate radioactivities may have occurred by chance, because the characteristics of suspended solids were different under high- and low-flow conditions. We applied Eq.3.4-1 to estimate the annual load of radionuclide discharge in the watershed. Estimated mean loads in 1979-1988 were 1.6 and 0.14 MBq/km^2/y for particulate and dissolved forms of ^{137}Cs, respectively. In the Kuji River watershed, the contribution of the particulate ^{137}Cs was estimated ~ 90 % of the total annual discharge of ^{137}Cs. It should be noted that this result was substantially derived from a large discharge of particulate ^{137}Cs under high water flow conditions following a precipitation event [4), 7)].

(4) Summary

To summarize, followings were found as characteristic features in the secondary migration pathway of atmospherically derived ^{137}Cs, ^{210}Pb and ^{7}Be through a river: a) particulate form is dominant, b) a storm event is decisive for the total discharge; c) a rating curve can be applied to approximate a discharge load of the radionuclides. It should be noted that those studied radionuclides have high affinity to soil constituents, and further ^{137}Cs in this study is of the global fallout origin, which means that it has stayed long in the watershed since it was introduced to that terrestrial environment.

3.4.2 Investigations on the form of radionuclides in river

(1) Objectives

Transport of radionuclides in river water is mainly in two forms, in dissolved form in water and in adsorbed form in particulate materials. Since the mobility of the two forms are quite different depending on the movement of the "carriers", the water and the particulate materials themselves, understanding on the partitioning between the two forms is important in order to describe the fate of the radionuclides in river water over intervals of space and time. The area in the vicinity of Chernobyl Nuclear Power Plants (ChNPP) has been heavily contaminated by ^{90}Sr and ^{137}Cs due to the nuclear accident in 1986 (Fig. 3.4-7) [8) -10)]. Transuranic elements such as $^{239,240}Pu$ and ^{241}Am also exist at detectable levels in this area. Therefore, it is possible to compare the partitioning of different

radionuclides under identical environmental conditions. In order to predict remobilization of radionuclides in the fluvial environment, it is necessary to perform a chemical speciation study, in addition to the analysis of total radioactivity. However, studies of radionuclide speciation in the natural environment have been limited because of the low level of radioactivity so far. Accordingly, it is required to take advantage of results of speciation in a high-level environment such as the Chernobyl accident area.

(2) Methods

Partitioning

Samples from the selected rivers and lakes in the Exclusion zone of ChNPP (Fig. 3.4-8) were collected in following way(Fig. 3.4-9). Particulate solids from 100-150 liters of river water were collected on sequentially-connected cartridge filters of three pore sizes (1, 0.45 and 0.20 μm). After the filtration, "dissolved" ^{137}Cs (finer than 0.20 μm fraction) was collected on an acrylic fiber impregnated with potassium hexacobalt(II) ferrate(II). Dissolved ^{90}Sr and dissolved transuranic radionuclides of ^{238}Pu, ^{239,240}Pu, ^{241}Pu, ^{241}Am and ^{244}Cm were collected by a co-precipitation. The radioactivity concentration of ^{137}Cs in the filter ash was determined by gamma-ray spectrometry. Then the ash was chemically decomposed and this was followed by radiochemical determination of ^{90}Sr and the transuranic radionuclides. Dissolved ^{137}Cs on KCFC was measured by gamma-ray spectrometry after incineration of the acrylic fiber. Dissolved and particulate forms of radionuclides other than ^{137}Cs were analyzed in a similar manner.

Chemical form

To further understand the partitioning of radionuclides in the river(s)/ lake between the suspended solid (particles) and the ambient water, it was considered that an investigation of their chemical form was necessary. Particulate radionuclides collected by a cartridge filter were investigated for the partitioning coefficient. However, because the filter was incinerated to ash, it was not possible to deduce any chemical information about the nature of radionuclides on the suspended solid and geochemical information of the suspended solid. Thus, instead the suspended solid was collected by a method using a centrifuge at the second stage. This method, called here the centrifugation method called here, concentrates the suspended solid to a form of mud, which makes various (geo)chemical analyses possible such as XRD, observation by electron microscopy of the matrices, and sequential extraction of radionuclides. Suspended solid was collected by using a cartridge filter from the Glubokoye Lake and other bodies of water in the Exclusion Zone around the ChNPP. The lake is located in the left bank of the river Pripyat, 6 km north of Pripyat Town. It lies in one the most contaminated area in the Exclusion zone.

Bottom sediment

Investigations by other researchers for the Dnieper-Pripyat river system contaminated by the Chernobyl accident in 1986 revealed that the bottom sediments of its reservoirs act as a trap for the accident-derived radionuclides [9]. This finding posed a question about the mobility of the radionuclides accumulated in the sediments. In the present study, the chemical forms and the vertical distribution of the radionuclides (^{137}Cs, ^{134}Cs, ^{90}Sr, ^{238}Pu, ^{239,240}Pu, ^{241}Pu, ^{241}Am) have been studied for the river bottom sediments. Bottom sediment samples were collected from Pripyat River near Chernobyl City in the Zone (Fig. 3.4-10). A gravity sampler of 8-cm diameter was used for collection of a cylindrical core.

(3) Results

Partitioning

Distribution ratios between particulate and dissolved radionuclides in river/lake water around ChNPP were found as in Fig. 3.4-11 (Right). To summarize the result, the ranges of the ratios (ml/g) are : ^{90}Sr, 1.4x10^3 - 8.5x10^3 ; ^{137}Cs, 6x10^3 - 4.5x10^4 ; ^{239,240}Pu, 8.2x10^4 - 1.1x10^6; ^{241}Am, 5.9x10^4 - 8.8x10^5 ; and ^{244}Cm, 3.8x10^4 - 5.1x10^5. This study showed that particulate /dissolved ratio of TRU , ^{137}Cs and ^{90}Sr each exhibit distinct ranges. Further, when the ratios in this study are compared to the values (called "Distribution Coefficients" in some literature's) reported by other researchers, it was found that the range of the ratios falls within approximately one-order of magnitude for each of the radionuclides with an exception of ^{90}Sr. This closeness of the ratios of each of the radionuclides implies the effectiveness of the ratios in modelling the environmental conditions of fresh water systems usually encountered [11].

Chemical form

Fig.3.4-11 (Left) shows the result of sequential extraction of radionuclides of the suspended solid from the water column of the Glubokoye Lake. More than 80% of ^{137}Cs was found in the residue fraction (the least extractable fraction) in the sample. It was considered that clay minerals are responsible for that distribution, although the result of XRD did not clearly indicate the presence of the clay minerals. Such unclearness can occur when the minerals are poorly crystallized. Strontium-90 in the sample was mainly present in the first extract, the acid soluble fraction. A phenomena of incorporation of dissolved ^{90}Sr into the suspended solid was suggested by comparison of the concentration ratios of soil samples and suspended sediment at the lake. The present result is compatible with the suggestion. ^{239,240}Pu was mainly found in the third and fourth extracts, the oxidizable and residue fractions. Both fractions are considered to have low extractability in surface, fresh water. These results of the chemical investigation on radionuclides in the suspended solid agree well with the results of apparent partitioning shown earlier. For instance, ^{239,240}Pu exhibited a large distribution ratio 10^5-10^6 ml/g. In the chemical investigation, it was clarified that ^{239,240}Pu in the suspended solid were present in phases of low extractability[12].

Bottom sediment

As shown in Fig. 3.4-10, concentration peaks of radionuclides were found at a depth of around 25-30 cm in the core. Therefore it was supposed that this layer had been the surface at the time of the accident. Close examination of the vertical profile showed that the profile of various radionuclides differed slightly from each other, suggesting the difference in their post- or pre-sedimentation behavior. The results of sequential extraction showed that more than 90% of ^{137}Cs and Pu isotopes were extracted in the residual fraction. The residual fraction of ^{90}Sr, by contrast, had a small contribution with an average of 37% (17-62%). The acid soluble fractions of ^{90}Sr, ^{137}Cs and ^{239,240}Pu were 3-26%, 0-1% and 0.1-7%, respectively. It is concluded that the possibility of release of ^{137}Cs and ^{239,240}Pu from the bottom sediment is low compared with ^{90}Sr, even after the dissolution of fuel particles. The bottom sediment acts as a sink for ^{137}Cs and ^{239,240}Pu, and consequently, their long-term impact will be minimal. On the other hand, the potential dissolution of ^{90}Sr from the river bottom sediment should be taken into account with respect to the long-term radiological influence on the aquatic environment [13].

(4) Summary

Investigations on the physical forms of radionuclides in the aquatic circumstance of the Chernobyl accident area showed that the partitioning of dissolved and suspended particulate radionuclides is highly dependent on their chemical forms. Radionuclides such as ^{137}Cs and Pu isotopes, which were preferentially present in suspended solids with high distribution coefficients, were found to be present in least dissolving phase in the solids. The opposite was the case for ^{90}Sr. Although the apparent partitioning between dissolved and particulate phases of radionuclides in river water are directly related to their fluvial transport, investigations on their chemistry in the environment will afford reasons for the partitioning. The relations found can be applied to other specific locations.

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Field study of several apparent regularities
in discharge of radionuclides
in the Kuji River watershed

Summarized by
Takeshi MATSUNAGA

Fig.3.4-1 Research theme of the discharge of fluvial radionuclides

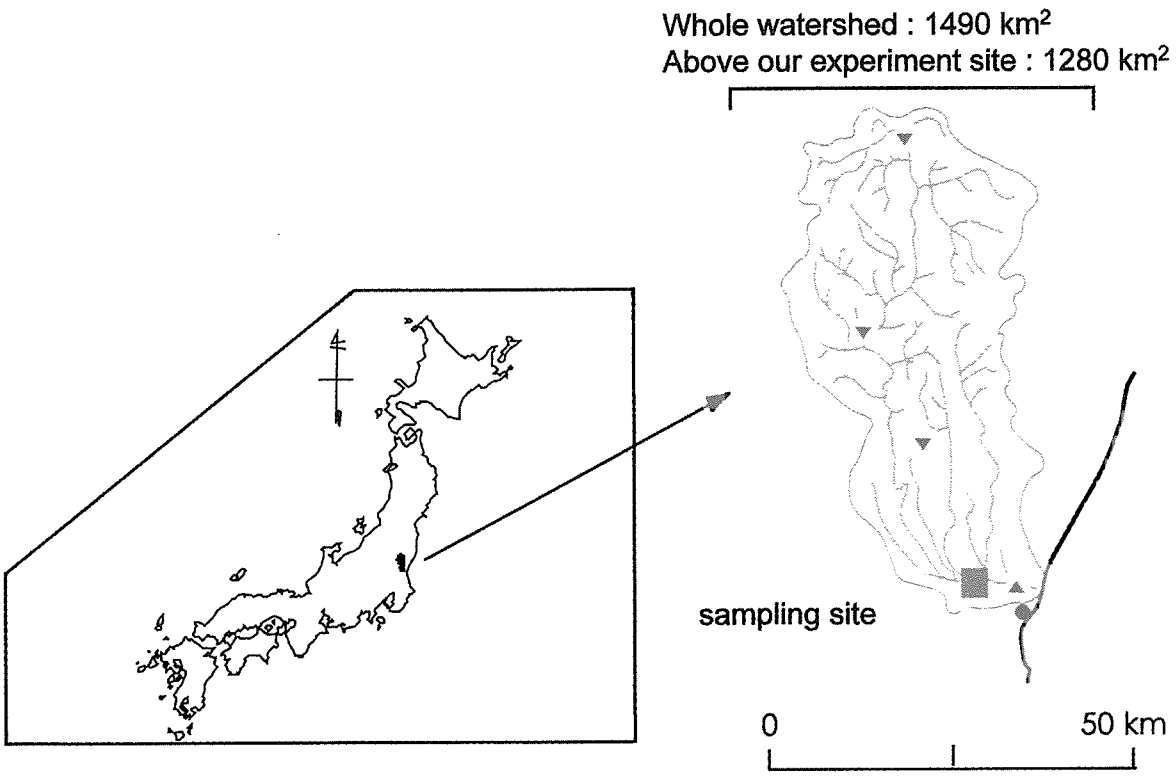

Fig.3.4-2 Location of the Kuji river watershed

Fig.3.4-3 Well-vegetated midstream of the Kuji river watershed
(Shimo-no-miya, between No.5 and No7 in Fig.3.3-4)

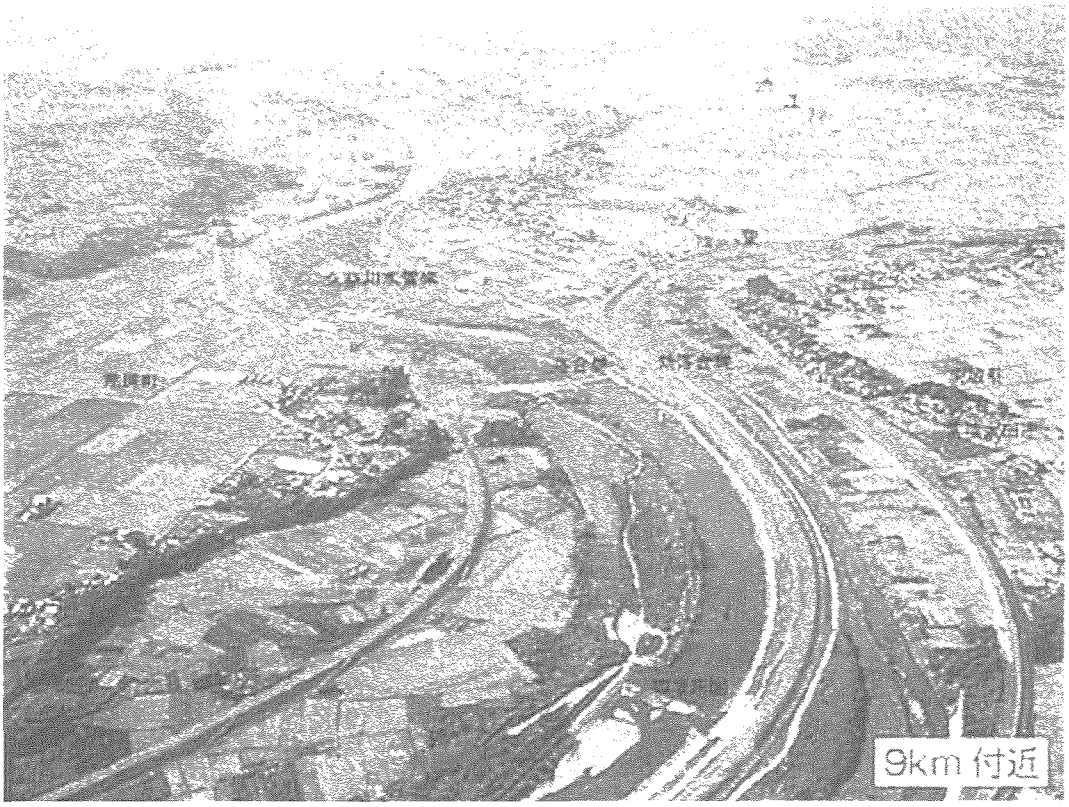

Fig.3.4-4 Location of the experiment site (No.10, □) of this study
in the downstream of the Kuji river

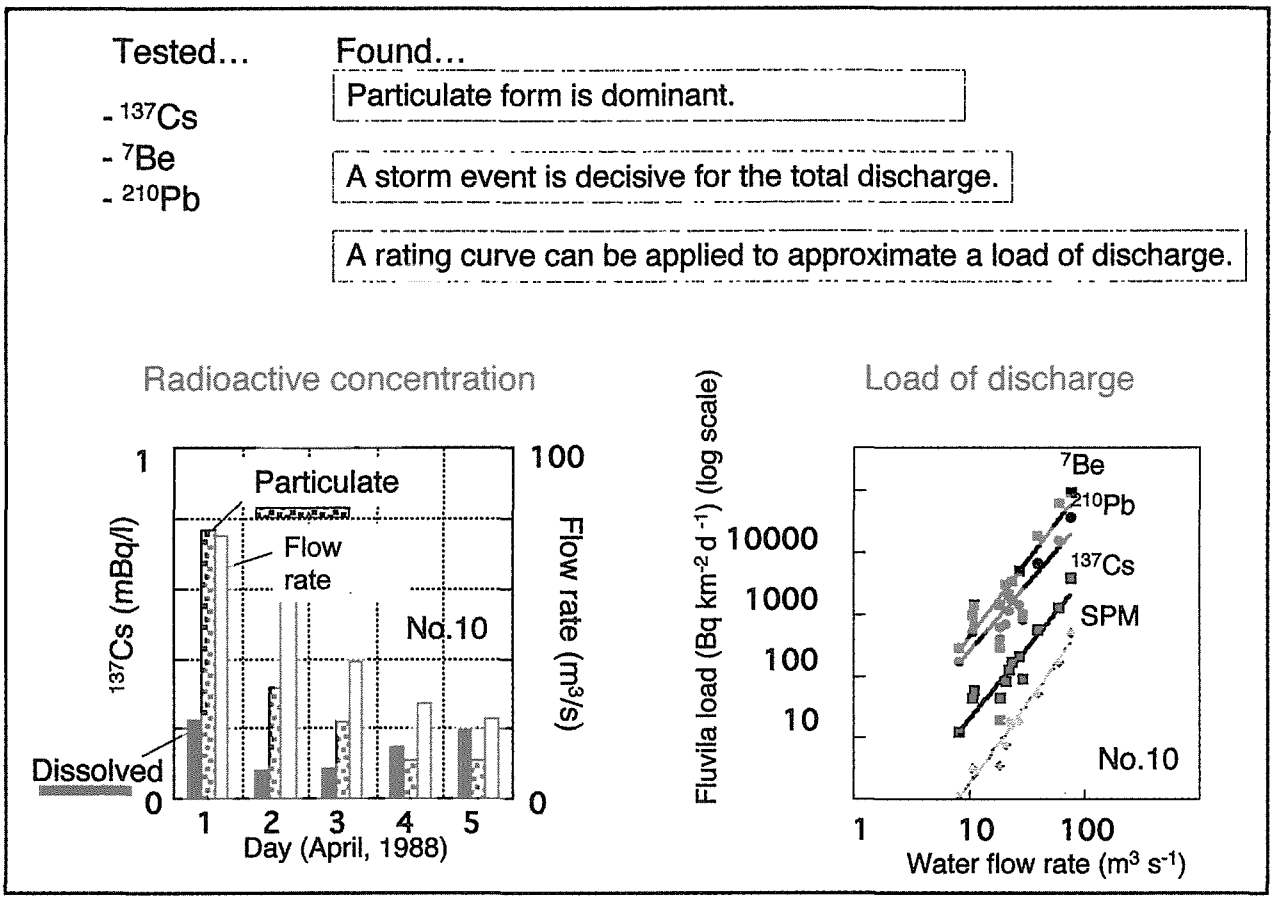

Fig.3.4-5 Apparent regularities in discharge of radionuclides found in this stud

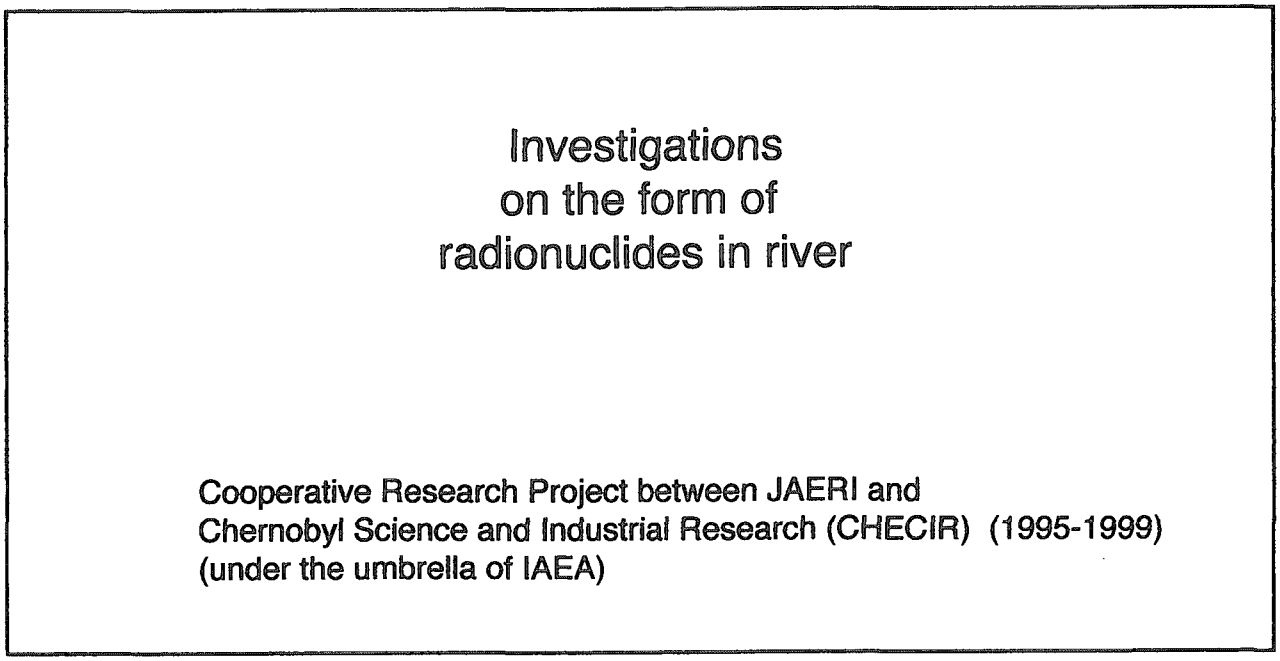

Fig.3.4-6 Research theme of the form of fluvial radionuclides

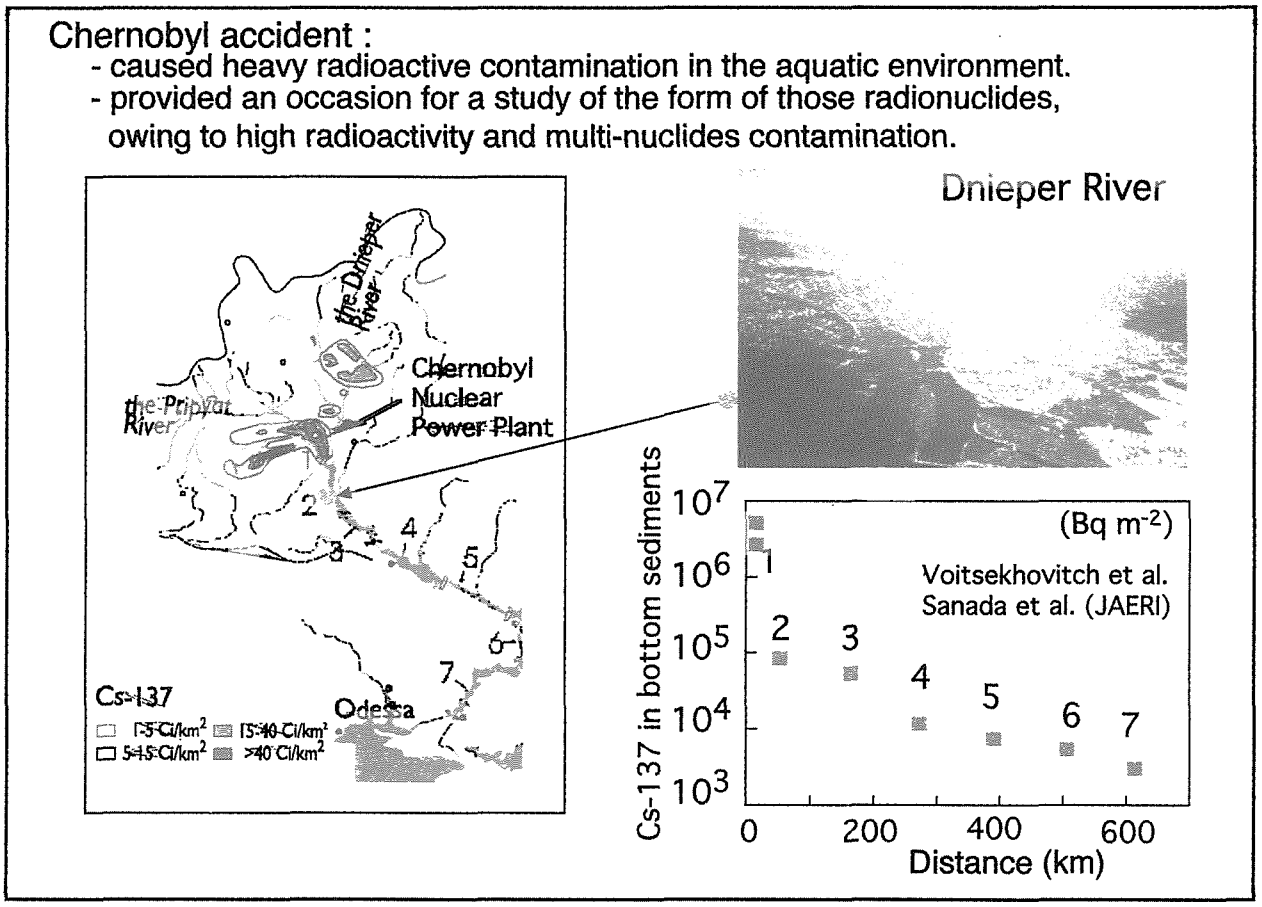

Fig.3.4-7 Contamination in the Dnieper river system

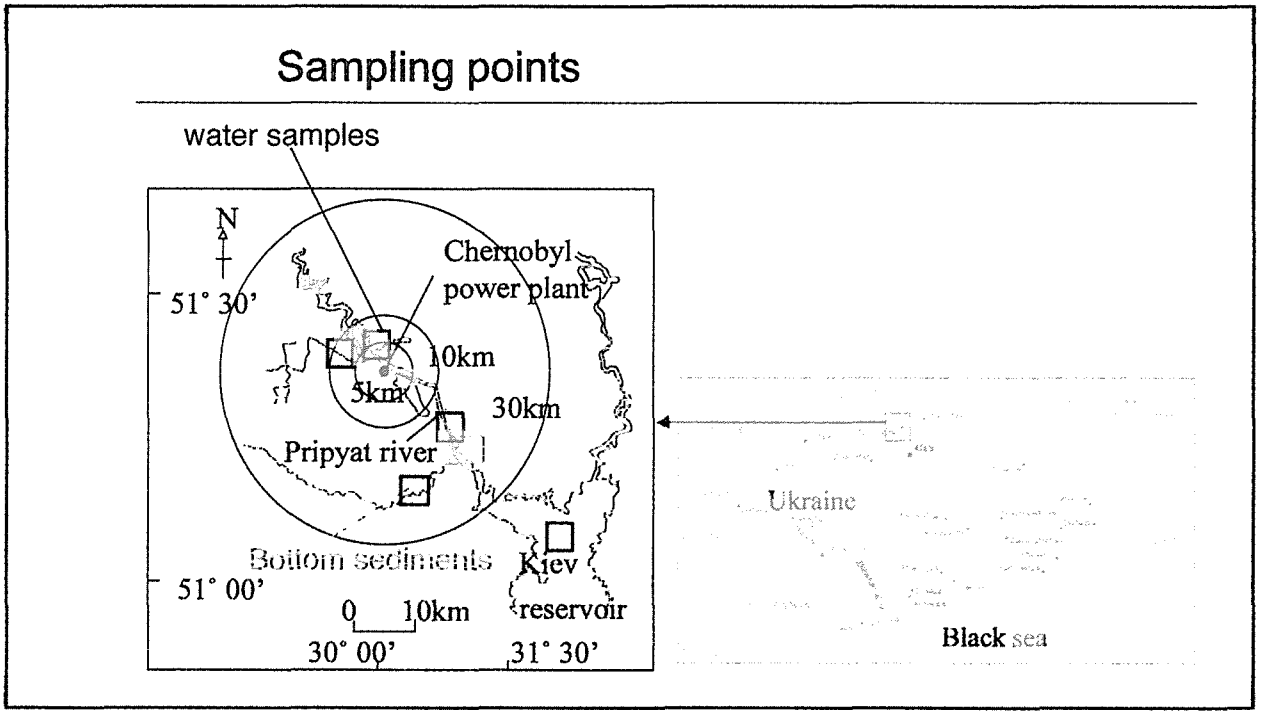

Fig.3.4-8 Sampling points in the Chernobyl area for fluvial radionuclides

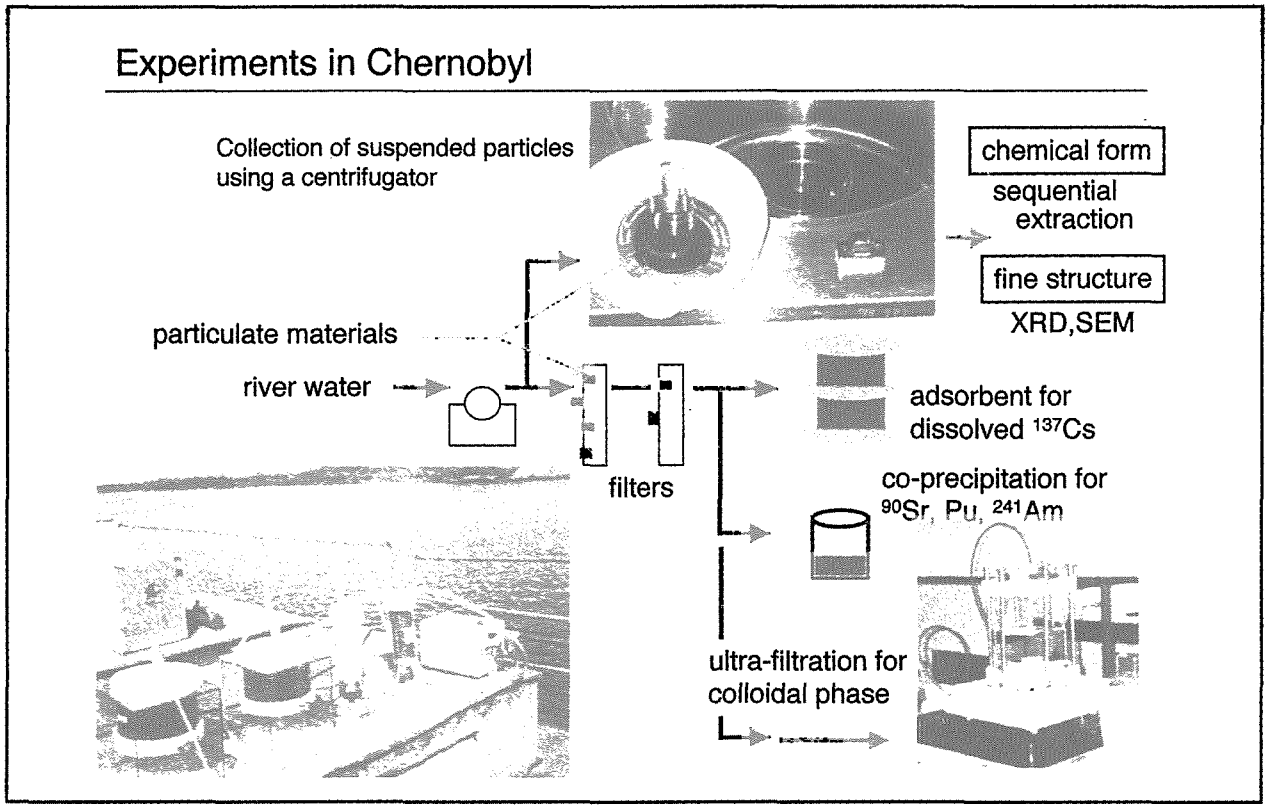

Fig.3.4-9 Experimental set up in the field and in the laboratory

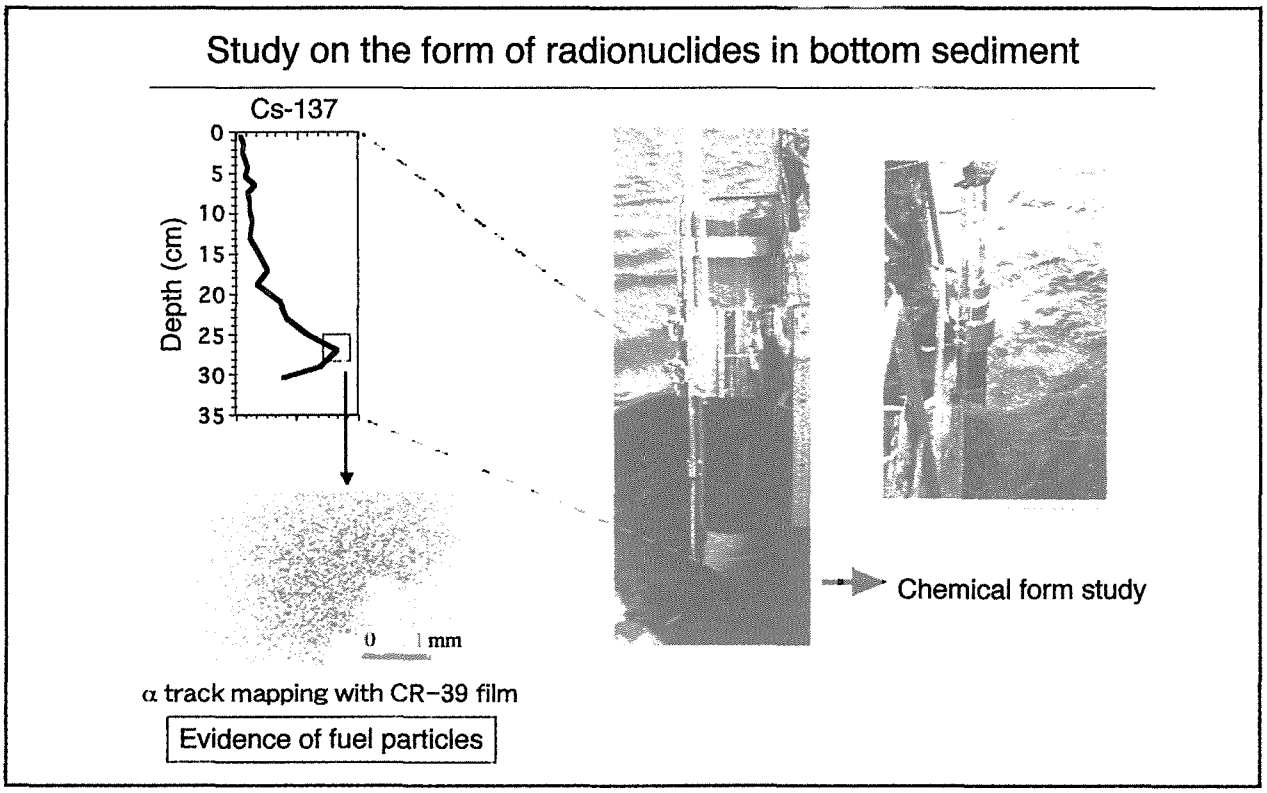

Fig.3.4-10 Vertical profile of ^{137}Cs in a river bottom sediment collected fror the Pripyat river near Chernobyl

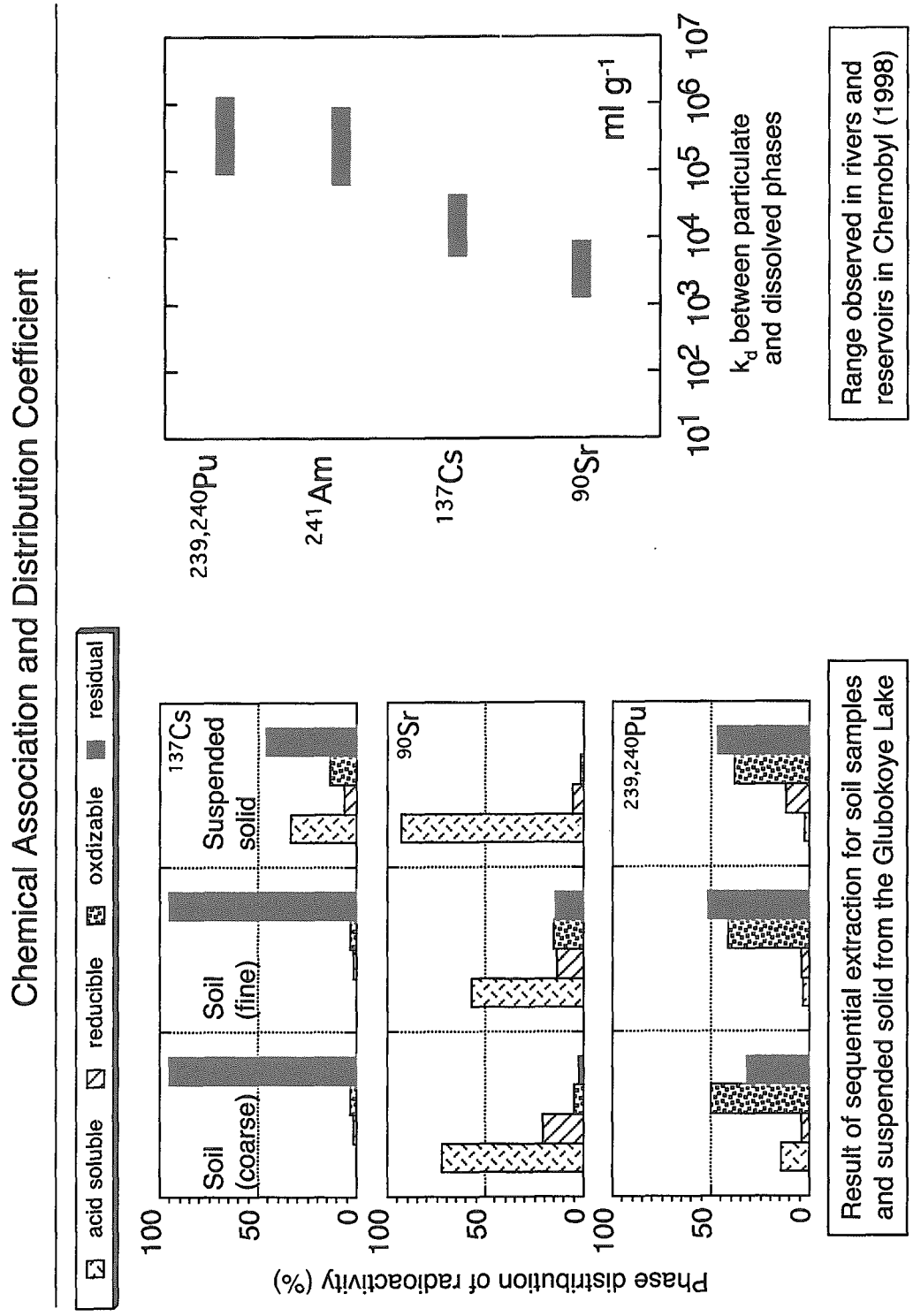

Fig.3.4-11 Chemical association and distribution coefficient of radionuclides in surface water bodies of Chernobyl

4 Modeling works by the river sub-group of JAERI

4.1 Development of a mathematical model to describe the transport of artificial radionuclides and trace elements in a river watershed

Katsunori TSUDUKI

4.1.1 Introduction

The majority of models to describe the pollution transport in watersheds of wide area have been developed as so-called concentrated type models up to the present, which models compute the averaged value of the outflow of contamination from an objective watershed. Models of this type allows the simplified calculation and the calculation of a long period of time (hundreds of years or more). But, the pollution distribution in the objective watershed is not calculated. The following reason lies in the background of the situation that the concentrated type model have been popular. Until several years ago, it had been hard to acquire the information, which is required for calculation such as the weather data, the precipitation and the geographic information, in a form of distribution information. Besides, the power of a computer was low But now, the weather data and the geographic information can be easily obtained in a form of distribution information. And the power of a computer also has been improved rapidly. Owing to these recent improvements, it has recently become possible to develop a distribution type model to estimate the migration of environmental materials including pollutants in a terrestrial environment so as to calculate the pollution distribution successfully.

Generally speaking, the radionuclides emitted into the environment by the accident have a possibility to pollute the land surface of heterogeneous terrains and to spread to a wide area. Moreover, land use, soil distribution, and rainfall conditions are also uneven. So, the behavior of the radionuclides in the polluted earth surface can not be considered as uniform. Therefore, where the behavior of the polluted materials in heterogeneous terrestrial environment is estimated, a distribution type model that can describe their spatial distribution is needed. The model which describes the detailed behavior of the radionuclides in the terrestrial environment is under development by the present research sub-group of JAERI. The aim of this model is the detailed estimate of a pollution conditions, and enabling an application at all watersheds in Japan. Accordingly, a model needs to have the feature that it is the model of a distribution type, and that flexibility is in a model parameter. A model under development is taking the following things into consideration, in order to give such a feature.

- Parameter varying with specific river watershed are not used.
- Various distribution information (land use distribution, soil distribution, etc.) relevant to the model and which can be obtained easily are used.

This model is applicable to a watershed where land use distribution, soil distribution, etc. are improved.

The mathematical model under development consists of two sub-models.

a) The hydrological model which describes the behavior of water.

b) The materials runoff model which simulates the behavior of materials.

The analysis universe of discourse makes a river basin a basic unit, and aims at an early outflow estimate when a wide area is contaminated. In the following, the hydrological model for materials transfer estimation is described.

4.1.2 Hydrological model

(1) Structure of Model

The model under development is a grid type distribution runoff model. A transfer route between grids is determined by the following approaches .

i. Polygon type river basin information is changed into grid type data.
ii. Flow direction of a river channel is decided from river channel location data.
iii. Transfer route of a land segment is set up from elevation data. Among the grid cells of the four sides which contact one grid cell in question, transfer to the grid cell of the same watershed with the lowest elevation is set.

The structure of a unit grid consists of a five-layer compartment and a river compartment in the perpendicular direction. Layer 0 and layer 1 model land use, layer 2 and layer 3 model soil, layer 4 model geology, and layer 5 model the river channel. Land use is classified into five types, a building land, a paddy field, a forest, upland field, and others, in the model. The relationship between the structure of the model and the distribution information to be used is shown in Fig. 4.1-1. Distribution data is described in Table 4.1-1.

(2) Transfer equations

In this model, the approach of solving the mass balance equation of the moisture for every compartment was used. The formula of the outflow of a horizontal and a vertical direction in each layer is shown below.

Layer 0

In this layer, the storage effect of land coverage is described. The outflow from this layer (q_O) is

$$q_O = \begin{cases} (h_0 - H_0)A/dt & (h_0 > H_0) \\ 0 & (h_0 \le H_0) \end{cases}, \tag{4.1.1}$$

where h_0 (m) is water level of this layer, H_0 (m) is thickness of this layer, A (m^2)is area of base. The value of H_0 has a different value for each land use type.

Layer 1,2,3,4

The basic equation of these layers is based on Darcy's Law[1]. Through flow (q_S) is

$$q_S = KILH\,, \tag{4.1.2}$$

where K (m/s) is Coefficient permeability, I (m/m) is slope, L (m) is width of layer, and H (m) is thickness of layer. Further, infiltration flow (q_I) is

$$q_I = KA\,. \tag{4.1.3}$$

The coefficient permeability (K) was calculated as follows:

$$K = Ks\left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\beta}, \theta = h/H, \theta_r = \theta_s - \theta_e\,. \tag{4.1.4}$$

K_s (m/s) is saturated hydraulic conductivity, h (m) is water level, q_s (m^3/m^3) is saturated water content, q_e (m^3/m^3) is effective porosity, and b (-) is a parameter.

Layer 5

The basic equation of this layer is based on Manning's formula1[2]. Water outflow (q_O) is

$$q_O = vBh, v = \frac{1}{n} I^{1/2} R^{2/3}, R = \frac{hB}{2h + B}, \tag{4.1.5}$$

where B (m) is width of river channel, n (s/m$^{1/3}$) is Manning roughness, and R (m) is hydraulic radius.

(3) Parameters in this model

The value of B and n were calculated as follows:

$$B = B_0 (A / A_0)^{0.5}, n = n_0 (A / A_0)^{-0.2}. \tag{4.1.6}$$

A_0 (m^2) is drainage basin area at a reference point, B_0 (m) is width of river channel at a reference point, and n_0 (s/m$^{1/3}$) is Manning roughness at a reference point. The values of other parameters are given by past research or experiment.

4.1.3 Discussion by the guest scientist

One concern for the presented model under development is that it includes so many parameters. It will be hard to obtain specific experimental data in a given watershed for each parameter. A key issue is how much one could combine those parameters, even partly of course, into a smaller number of parameters. For instance, it is easy to provide a "representative" value of water content to each of segregated boxes with a fine increment of 100 m mesh at this moment. What must be examined is the difference in the calculated outputs between a case when the 100 m mesh used and another case where the mesh scale is increased. One must know much these complex processes can be combined. It is understandable that this fine mesh structure has been used in order to imitate the finely devided land use in this country. However, this is not evaluation of the output, but of the input. One should look at the output that one wants. One should carefully examine the fineness of the model so as to satisfy a required certainty for the output. In making this examination, it is recommended to check the output of the model in response to a single, pulse deposition.

References (4.1)

(1) Darcy, H., , *Les Publiques de la Ville De Dijon*, Dalmont, Paris (1856).

(2) Manning, R., On the flow of water in open channels and pipes, *Transactions of the Institution of Civil engineers of Ireland* (1891)

Table 4.1-1 Information about distribution data

Digital national land information (created by Geographical Survey of Japan)

	Data type	Acquisition place
Land use	100 m grid data	Ministry of Land, Infrastructure and Transport Web site (URL : http://www.mlit.go.jp/)
Soil and Geology	1 km grid data	
River channel location	Line data	
Watershed	Polygon and 100 m grid data	
Elevation	50 m grid data	Atlas

Weather data (observed by JAPAN METEOROLOGICAL AGENCY)

	Data type	Recorded data
Radar-AMeDAS Precipitation	5km grid data	Precipitation
AMeDAS ANNUAL REPORT	Point data	Temperature, precipitation, wind direction, wind velocity, sunshine hours, snow accumulation
ANNUAL PREPORT JAPAN METEOROLOGICAL AGENCY	Point data	Air pressure, temperature, vapor pressure, relative humidity, wind direction, wind velocity, cloud amount, sunshine hours, insolation from the whole sky, evaporation, precipitation, snow accumulation

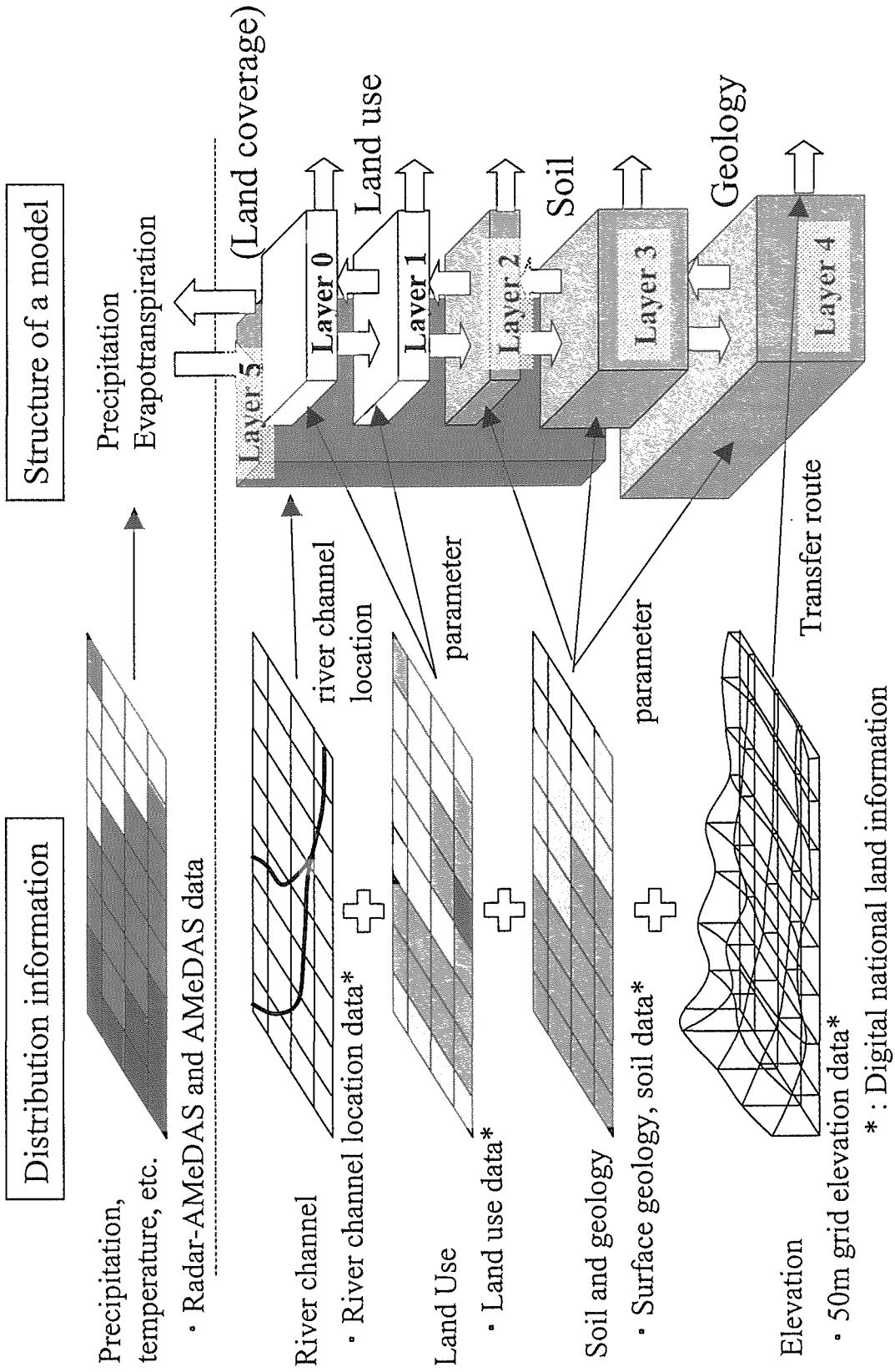

Fig.4.1-1 The relationship between the structure of a model and the distribution information to be used

Table 4.1-2 Information about distribution data

Digital national land information (created by Geographical Survey of Japan)

	Data type	Acquisition place
Land use	100 m grid data	Ministry of Land, Infrastructure and Transport Web site
Soil and Geology	1 km grid data	
River channel location	Line data	
Watershed	Polygon and 100 m grid data	
Elevation	50 m grid data	Bookstore

Weather data (observed by JAPAN METEOROLOGICAL AGENCY)

	Data type	Recorded data
Radar-AMeDAS Precipitation	5km grid data	Precipitation
AMeDAS ANNUAL PREPORT	Point data	Temperature, precipitation, wind direction, wind velocity, sunshine hours, snow accumulation
ANNUAL PREPORT JAPAN METEOROLOGICAL AGENCY	Point data	Air pressure, temperature, vapor pressure, relative humidity, wind direction, wind velocity, cloud amount, sunshine hours, insolation from the whole sky, evaporation, precipitation, snow accumulation

Table 4.1-2 List of model parameters

H	Height of layer [m]	Layer 0 : It has a different value for each land use type Others: Constant for each layer
Ks	Saturated hydraulic conductivity [m/s]	It has a different value for each land use, soil, and geology type
θs	Saturated water content [m^3/m^3]	
θe	Effective porosity [m^3/m^3]	
β	Parameter [-]	Constant(b=3.5)
B	Width of river channel [m]	It has a different value for each grid.
n	Manning roughness [$m^{-1/3}s$]	

4.2 Sensitivity analysis of a migration model of radionuclides derived from atmospheric deposition in a river watershed

Takeshi MATSUNAGA

4.2.1 Summary

A sensitivity analysis was performed for a preparatory model to simulate transport of atmospherically-derived radionuclides from a watershed to a river system during a short period after a release incident. The analysis was executed in order to evaluate the importance of each possible pathway in the transport as a step in construction of a migration model of radionuclides in a river watershed. The model MARTE[1)] was selected as a preliminary model. It consists of two components: i) a direct discharge channel to river water, with no interaction with the ground soil except one-way transport through; ii) reversible/irreversible adsorption to soil particles. The model was simplified by making that hydrological conditions static in this analysis. Sensitivity analyses for instances of ^{137}Cs and ^{90}Sr both showed a great influence of the depositional fraction on the first component, and a conditional influence of the distribution coefficient in the soil system in the second component.

4.2.2 Objectives

In case of a nuclear accident, there exists a probability that radionuclides are released to the environment out of a facility. That release can cause environmental contamination by the radionuclides in the short-term and in the long-term in some cases. To be prepared for such a situation, a practical system to assess the physiological influence on the public due to that contamination is necessary. This system must evaluate effectiveness of countermeasures when the contamination is serious. When the contamination is limited, it must provide adequate information to the public to ease psychological stress. The system for assessing the physiological influence on the public will consist of the prediction of the migration of radionuclides in the environment and the evaluation of the radiation risk.

Among various cases of environmental contamination by released radionuclides, this work deals with the contamination of a river watershed following atmospheric deposition on the ground and the subsequent transport to river water. This is because of the significance of a river as a freshwater resource and as an agent of transport of contaminants. Other contaminations such as in air plumes that would be inhaled, arable lands, urban areas and the marine environment will be also important.

This paper describes our first step in construction of a model of migration of radionuclides in a river watershed. The model consists of i) a hydrology sub-model for the water discharge and ii) a sub-model for discharge of radionuclides in which the water discharge is reflected. The details of the hydrology model will be given separately. In the following, a sensitivity analysis is given for a preparatory model of radionuclides behavior. It is intended to simulate transport of atmospherically-derived radionuclides from the ground to river water during a short period after a release incident. The analysis was executed in order to identify the importance of each possible pathway in the discharge of radionuclides.

4.2.3 Procedure of analysis

(1)Migration model

The preliminary model is composed of two components of the deposited radionuclide (Fig. 4.2-1). The model has been proposed by Monte[1)]. The two-component model was chosen based on

research of Monte[2]. He studied dissolved fluxes of ^{137}Cs and ^{90}Sr in several European rivers, whose watersheds received a pulse deposition of radionuclides from the Chernobyl nuclear accident. The fluxes were well simulated by two discharges with exponential decay. Their effective half-lives were found to be 10-30 days and a few years for "short-term" and "long-term" discharges, respectively. In reality, the short-term discharge may come from vegetation surface, roofs, and pavements which limit contact of the radioactive fallout with the ground soil. The long-term discharge may come from the ground soil where a close interaction of radionuclides with soil constituents is expected to cause retarded migration.

In the model, it was assumed that the first component of radioactive discharge to river water occurs by direct migration in dissolved form in surface run-off water. Migration of the second components will indirectly contribute to discharge to river water via the soil. Radionuclides in the second component were assumed to react with the ground soil in the modes of reversible sorption/desorption and irreversible fixation. The second component of radioactive discharge river water occurs in dissolved form in soil solution and in particulate form in eroded soil. The model was simplified, and hydrological conditions were taken static in this analysis. The hydrological conditions will be made dynamic when the model is incorporated in a grand model that has a detailed hydrology.

(2) Selected parameters for sensitivity analysis and model watersheds

Parameters tested in the sensitivity analysis were as follows: a) intensity of precipitation; b) soil erosion rate; c) fractional distribution of the components; d) rate of irreversible fixation; e) apparent distribution coefficient of radionuclides between i) soil particles in soil solution, and ii) suspended particulate materials in ambient river water. These are denoted in Fig. 4.2-1.

A model system of river watersheds was considered as shown in Fig. 4.2-2. It consists of a contaminated watershed (CC) and a non-contaminated watershed (NC). Following a pulse deposition of a radionuclide on CC, the radioactivity discharge will join the main stream that runs from NC. The radioactivity will inflow at the confluence both in dissolved (from the first and second component) and particulate forms (from the second component). It was assumed that the radioactivity re-distributes between the water phase and the suspended particulate materials at the confluence.

(3) Values of selected parameters

The Kuji River watershed of Japan was used to determine values of those parameters in the analysis. The Kuji River is located in the central Japan, and is originated from the Yamizo mountainous area. The length of its main stream and the area of its watershed are about 120 km and about 1280 km^2, respectively. Each value is close to a corresponding median of major Japanese rivers. The water flow rate ranges from about 10 m^3/s in winter to more than 100 m^3/s after a storm event.

The soil erosion rate

The load of suspended solid in river water is composed of a load of scoured bank-bed materials and a load of eroded surface soil (Eq. 4.2.1).

$$ML1 = ML2 + ML3 \qquad (4.2.1)$$

where,

ML1: load of suspended particulate materials, kg day^{-1} km^{-2};

ML2: load of scoured bank and bed materials, kg day $^{-1}$ km $^{-2}$;

ML3: load of eroded surface soil particles, kg day $^{-1}$ km $^{-2}$.

In Eq.1, the loads are expressed for unit area of a watershed (km^2) and unit time (day). ML1 can be determined for various river water flow rates using a rating curve obtained by filed observations in the Kuji River (Fig. 4.2-3). ML3 is the soil erosion rate to be determined. ML2 can be determined by subtracting ML3 from ML1.

The suspended load of ^{137}Cs in river water can be determined similarly using another rating curve for ^{137}Cs (Fig. 4.2-3). On the other hand, the radioactivity load is related to the soil erosion rate and the radioactivity concentration of eroded soil particles (Eq.4.2-2). In Eq. 4.2-2, we assumed that the surface soil is tagged with the bomb-derived ^{137}Cs and the bank-bed materials are not.

$$RL = ML3 \times RC \qquad (4.2\text{-}2)$$

where,

RL: load of radioactivity of ^{137}Cs in suspended particulate material, Bq day $^{-1}$ km $^{-2}$

ML3: load of eroded surface soil particles, kg day $^{-1}$ km $^{-2}$.

RC: radioactivity concentration of ^{137}Cs, Bq kg $^{-1}$

or,

$$ML3 = RL/RC. \qquad (4.2\text{-}3)$$

At a given flow rate (i.e. at a determined value of RL), ML3 becomes minimum when RC is maximum. This is the case where previously undisturbed top soil is eroded. Field observations in the Kuji River watershed showed that such concentration of ^{137}Cs in undisturbed surface soil is about 200 Bq/kg. Thus, we get

$$ML3, \text{minimum} = RL / 200 \qquad (4.2\text{-}4)$$

In turn, ML3 becomes maximum when RC is minimum. The proportion of eroded soil in ML1 will be lowered without limit by addition of scoured bank-bed materials. This addition will be smaller with lower flow rate. Therefore, the minimum value of RC that is undiluted by scoured bank-bed materials can be estimated by extrapolation of the observed concentration of ^{137}Cs in suspended particulate materials to a zero flow rate where no scouring occurs. The estimated value was 10 Bq/kg. Thus, we get

$$ML3, \text{maximum} = RL / 10 \qquad (4.2\text{-}5)$$

This is the case where the surface soil that is eroded is already a mixture of undisturbed top soil (Highest in ^{137}Cs) with deeper soil that contains little ^{137}Cs. Estimated maximum and minimum values of the surface soil load in case of the Kuji River watershed are listed in Table 4.2-1 for various water flow rates that are generally encountered in the Kuji River.

Precipitation Intensity

In this paper, precipitation intensity means the effective precipitation intensity. Because the erosion rate of the surface soil depends on precipitation conditions, different levels of precipitation intensity were set. Here, three levels - weak, middle, strong - were chosen. They respectively caused

water rates of 20, 50, and 100 $m^3 s^{-1}$ at the lowest reach of the Kuji River. Its watershed area is 1280 km^2 at the lowest reach. Assuming that the discharge coefficient (a ratio of the amount of fluvial discharge to the amount of effective precipitation) is 0.6, precipitation intensities to be used in this simulation were estimated as in Table 4.2-2. It was estimated that 0.0015, 0.005, and 0.015 m d^{-1} , labelled here for weak, medium, and strong precipitation intensity, caused the above low, medium, and high flow rates, respectively. In this analysis, model watersheds different from the 1280 km^2 of Kuji River watershed were defined (Fig. 4.2-2):

Contaminated area : 100 km^2;

Uncontaminated area : 400 km^2.

Still, the estimated intensities in Table 4.2-1 were used because they were expressed in terms of unit area. Namely, averaged characteristics of fluvial discharge for the whole Kuji River watershed was adopted for the model watersheds. Anyway, the intensities used in the model were rounded off from those based on the assumptions. Therefore, precision of estimates is limited.

Fractional distribution of the first and the second component

Although the two-component model seems reasonable (its reasonability will be discussed elsewhere), fractional distribution of the first and the second components can be determined only by an actual deposition incident or by an assumption. In this work, two extreme cases were assumed, i) a case dominated by the second component, ii) a case dominated by the first component. The fraction of the first component was selected as 0.2 and 0.8 respectively.

Fixation rate of a radionuclide in the soil

As a result of literature survey of studies on kinetic sorption of ^{137}Cs to soil particles[3)], the lowest fixation rate was determined as $1x10^{-4}$ (d^{-1}) and the fastest one as $1x10^{-1}$. Concerning ^{90}Sr, no such study was found. General knowledge on the behavior of ^{90}Sr in soil implies that the fixation is very limited. Therefore, no fixation was assumed for the lowest fixation case for ^{90}Sr. A value of $1x10^{-4}$ (d^{-1}), that is the lowest limit in case of ^{137}Cs , was chosen arbitrary for the fastest case of ^{90}Sr.

Infiltration of a radionuclide (Vertical transfer from the surface soil layer to deeper layer)

This process was neglected in the present simulation. The literature has found that the vertical transfer rate is in a range of 0.1 to 1 cm y^{-1} (Table 4.2-3). This analysis focused on the initial discharge in a month following a pulse deposition of a radionuclide. It was considered that the vertical distribution of a radionuclides does not vary largely in the first month with the found rate.

Distribution coefficients of radionuclides in soil and in river system

The term "distribution coefficient" may not be an appropriate concept in the field, because no equilibrium is attained in the field. Still, it is used here in a broad sense. The distribution coefficient for ^{137}Cs in soil was determined as $1x10^3$ or $1x0^4$ (ml g^{-1}) based on generally reported values. In a river system, the ratio of concentration of ^{137}Cs in the suspended particulate material to that in the water column was found to be larger than in soil systems investigated in several reports (Table 4.2-4).

4.2.4 Sensitivity analysis

The performed analysis should be called an uncertainty analysis or a variation analysis rather

than a sensitivity analysis. The target value was selected as the radionuclide discharge integrated over the first 30 days following the end of a pulse deposition. The pulse deposition was set to be a five-day deposition at a constant deposition rate. The radionuclide discharge per day per unit area of the modeled contaminated watershed was also monitored in order to analyze its temporal change.

Analyzed was the variation of the target value corresponding to change of each parameter value. Table 4.2-5 lists the levels of those changes. The precipitation intensity and the soil erosion rate were changed concurrently in three levels. An even intensity over both contaminated and non-contaminated watersheds was set. Other selected parameters were changed by two levels (the maximum, the minimum). The changes were intertwined to result in 48 different cases for ^{137}Cs and ^{90}Sr each. Constant parameter values are listed in Table 4.2-6. Tested cases with varied parameter values are listed in Table 4.2-7.

4.2.5 Results

(1)Typical temporal variations of contamination and discharge

For the sake of the understanding of the main result described later, typical temporal variations of contamination and discharge are depicted in Fig. 4.2-4. They are the result of the case No. 25 (Table 4.2-7). The inventory of radioactivity in the first component exhibits a sharp, exponential decrease with time (Fig. 4.2-4a, Fig. 4.2-4d). The exponent x is a constant value given by Eq. 4.2-6.

$$x = (a+b)/[c*d] \qquad (4.2\text{-}6)$$

where,

a: water run-off flux in the first layer as a fraction of total water flux (-);

b: water infiltration from the first layer to the second layer as a fraction of total water flux in the watershed (-);

c: saturation thickness of the first layer (m);

d: amount of water in the first layer expressed as a fraction water flux in the watershed (-).

There is no difference is in the first component between ^{137}Cs and ^{90}Sr. This is natural because the characteristics of radionuclides influence only the radioactive decay and the distribution coefficient. A decrease by radioactive decay is negligible in case of ^{137}Cs (half life 30 .0 y) and ^{90}Sr (28 y) during the term of present interest (30 days). The distribution coefficient is not involved in the description of the first component.

Fig. 4.2-4b shows the amount of the second component for ^{137}Cs. It is characterized by i) a small decrease with time, and ii) a large association to soil particles. The discharge of ^{137}Cs to river is presented in Fig. 4.2-4c. It is dominated by the flux from the first component. Contributions of i) ^{137}Cs associated with eroded soil and ii) ^{137}Cs dissolved in surface runoff water derived from the soil solution are negligibly small in the early discharge.

In contrast to ^{137}Cs, ^{90}Sr has an appreciable decrease with time in the amount of the second component (Fig. 4.2-4e). By referring to the fluvial discharge (Fig. 4.2-4f), it can be understood that the decrease is due to a discharge of dissolved ^{90}Sr in surface runoff water. The loss of radionuclides from the soil solution is compensated by dissolution of radionuclides from soil particles based on a exchangeable equilibrium between the compartment X and Y (Fig. 4.2-1). The low distribution coefficient of ^{90}Sr makes the compensation significant quantitatively. That is not the case with ^{137}Cs.

(2) Results of sensitivity analysis

^{137}Cs

The results of the sensitivity analysis are shown in Fig. 4.2-5 (^{137}Cs) and Fig. 4.2-6 (^{90}Sr).They give the total discharge from the contaminated watershed to a river during the first 30 days after deposition. The results are subdivided into three sub-illustrations with different precipitation intensity (weak-0.0015 m d^{-1}, middle-0.005 m d^{-1}, strong-0.015 mm d^{-1}). Further, in each sub-illustration, cases are categorized by a fraction of the first component (small-0.2 and large-0.8). The eminent feature in the initial total discharge of ^{137}Cs is that the discharge is always low when the fraction of the first component is small and vice versa. The discharge is most sensitive to the fraction. A reason for these responses can be seen from a typical fashion of the discharge of ^{137}Cs. As already mentioned, the discharge comprises mainly the first component (Fig. 4.2-4c). Naturally, differences in parameters involved in the behavior of the second component have little influence on the discharge, as seen in cases where there are differences in the distribution coefficient (e.g. Case 1 vs. Case 2) and in fixation rate to soil particles (e.g. Case 1 vs. Case 3).

^{90}Sr

In case of ^{90}Sr, a situation is somewhat complicated (Fig. 4.2-6). Although it is similar to ^{137}Cs in that the cases where the first component is large have larger discharges, the discharge is decreased when the distribution coefficient is at larger values. Results of Case 33 (k_d, ground = 10 ml g^{-1}) and of Case 34 (500 mg l^{-1}) show this pattern, for instance. It was found that this complexity is related to the extent of the dissolved portion of the second component. An instance of that dissolved portion is seen in Fig. 4.2-4f (a black line). It is large or small depending on whether the distribution coefficient of ^{90}Sr in soil system is low (10 ml g^{-1}) or high (500 ml g^{-1}).

On the one hand, the discharge of ^{90}Sr in case of low k_d is always larger than that of ^{137}Cs when the parameter values are identical other than k_d. On the other hand, the discharge of ^{90}Sr in case of high k_d is almost the same as that of the corresponding ^{137}Cs cases.

4.2.6 Conclusion

It was found that the total discharge of a radionuclide (^{137}Cs or ^{90}Sr) after its pulse deposition is highly sensitive to the fractional distribution of the first component and the second component. The total discharge is large when the fraction of the first component is large. In this simulation, the first component has been defined as a component which does not interact with a solid phase.

The sub-discharge of ^{90}Sr from the second component in dissolved form was found to be highly sensitive to its distribution coefficient (k_d). At low k_d (10 ml g^{-1}),_the sub-discharge is increased. When k_d of ^{90}Sr is as high as 500 ml g^{-1}, the sub-discharge is largely suppressed, the amount of discharge being almost same as that of ^{137}Cs. This finding suggests that an identification of the distribution coefficient would be important for a radionuclide such as ^{90}Sr that exhibits generally low absorpidity, with respect to a fluvial discharge.

A radionuclide of high absorptivity will show a low sensitivity for the following reason. With a distribution coefficient 500 ml g^{-1} or larger (as in the present simulation), the discharge of a radionuclide from the second component in dissolved form is largely prevented. Further, the discharge of a radionuclide from the second component in particulate form is always much smaller than the discharge from the first component during early days after deposition. As a result, the influence of the distribution coefficient and the fixation rate on the total discharge of a high absorptivity radionuclide is minimal.

References (4.2)

(1) Monte, L., Analysis of Models Assessing the Radionuclide Migration from Catchments to Water Bodies. *Health Physics*, 70, 227-237 (1996).

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(3) Absalom, J. P., Crout, N. M. J., and Young, S. D., Modeling radiocesium fixation in upland organic soils of northwest England, *Environ, Sci. Technol.* 30, 2735-2741(1996).

Table 4.2-1 Determination of soil erosion rate based on an empirical rating curves for material and ^{137}Cs load in the Kuji River watershed.

river water flow rate	Cs-137 load	SPM load	Assumption 1* Surface soil load (min-case)	Bank-bed load (max-case)	Assumption 2** Surface soil load (max-case)	Bank-bed load (min-case)	SPM conc.
$m^3 s^{-1}$	$Bq\ km^{-2}\ d^{-1}$	$kg\ km^{-2}\ d^{-1}$	$kg\ km^{-2}\ d^{-1}$	$kg\ km^{-2}\ d^{-1}$	$kg\ km^{-2}\ d^{-1}$	$kg\ km^{-2}\ d^{-1}$	$mg\ l^{-1}$
10	20	2	0.1	1.9	2.0	0.0	3
20	98	10	0.5	9.5	9.8	0.2	7.4
30	250	29	1.3	27.7	25.0	4.0	14.3
40	484	63	2.4	60.6	48.4	14.6	23.3
50	808	113	4.0	109.0	81	32.2	33
60	1230	185	6	178.8	123	62.0	46
70	1753	279	9	270.2	175	103.7	59
80	2383	398	12	386.1	238	159.7	74
90	3124	545	16	529.4	312	232.6	90
100	3981	722	20	702.1	398	323.9	107

SPM: Suspended particluate materials

* ^{137}Cs in SPM was assumed to be 200 $Bq\ kg^{-1}$ ($mBq\ g^{-1}$)

** ^{137}Cs in SPM was assumed to be10 $Bq\ kg^{-1}$ ($mBq\ g^{-1}$)

Table 4.2-2 Precipitation intensities adopted in the sensitivity analysis

River water flow rate	specific discharge per unit area of a catchment	precipitation intensity		
		needed for the specific discharge*	increment to base flow**	adopted***
$m^3 s^{-1}$	$[m^3 d^{-1}] m^{-2}$	$m d^{-1}$	$m d^{-1}$	$m d^{-1}$
10	0.000675	0.001125		0.001
20	0.00135	0.00225	0.001125	0.0015
50	0.003375	0.005625	0.0045	0.005
100	0.00675	0.01125	0.010125	0.015

* discharge coefficient 0.6 was assumed

** A value, 0.001125 ($m d^{-1}$) corresponding to 10 $m^3 s^{-1}$ was regarded as the base flow. The flow rate, 10 $m^3 s^{-1}$ is the lowest flow rate at the downstream of the Kuji River observed in winter when precipitation is sparse.

*** rounded increment.

Table 4.2-3 Vertical transfer rate in surface soil for ^{137}Cs

vertical transfer rate	origin of ^{137}Cs	reference
about 1 cm y^{-1} at 1980, for 0-2 cm depth	Chernobyl ^{137}Cs	Bunzl et al. (1994)
about 0.2 cm y^{-1} at 1986-1988, for 0-1 cm depth	Chernobyl ^{137}Cs	Bonaazzola et al. (1993)
0.4 - 1 cm y^{-1}	Weapon fallout ^{137}Cs	Schimmack & Bunzl (1989)
0.2 - 0.3 cm h^{-1} (initial infiltration for a few% of the total deposition)	Chernobyl ^{137}Cs	Schimmack & Bunzl (1989)

Table 4.2-4 Several reported distribution coefficients for ^{137}Cs and ^{90}Sr in the fluvial environment

Location	Particulate fraction (%)	Particulate material (mg l^{-1})	Distribution Coefficient (ml g^{-1})	Reference
^{137}Cs				
Kuji River	24-80	2.1 -96		Matsunaga et al. (1992)
Clinch River	8-92	25-185		Struxness et al.(1967)
Tennessee	19-30	9-22		Struxness et al.(1967)
Cattaraugus Creek		225		Schell et al. (1981)
Chernobyl Rivers				Matsunaga et al. (1998)
Japanese Rivers				Hirose (1988)
^{90}Sr				
Clinch River			$1.24x10^2$	Struxness et al.(1967)
Lake Michigan			$8.2x10^1$	
Cattaraugus Creek			$6.22x10^1$	Schell et al. (1981)
Chernobyl Rivers			$1.4x10^3$ - $8.5x10^3$	Matsunaga et al. (1998)
Japanese Rivers			not reported	

Table 4.2-5 Varied parameter values in the sensitivity analysis

Process ID*	Parameter	Number of levels	Parameter values		
			weak	medium	strong
a	Precipitation intensity ($m\ d^{-1}$)	3	0.0015	0.005	0.015
b	Soil erosion rate ($kg\ km^{-2}\ d^{-1}$)	2 for each precipitation intensity	level 1) 0.5 level 2) 10.0	level 1) 4 level 2) 80	level 1) 20 level 2) 400
			level 1)	level 2)	
c	Fractional distribution of the two components**	2	First: Second 0.2 : 0.8	First: Second 0.8 : 0.2	
d	Fixation rate to soil particles	2	^{137}Cs $1x10^{-4}$ ^{90}Sr 0	^{37}Cs $1x10^{-1}$ ^{90}Sr $1x10^{-4}$	
e	Distribution coefficient	2	For soil system : ^{137}Cs $1x10^{3}$ ^{90}Sr $1x10^{1}$ For river system : ^{137}Cs $1x10^{4}$ ^{90}Sr $1x10^{1}$	For soil system : ^{137}Cs $1x10^{4}$ ^{90}Sr $5x10^{2}$ For river system : ^{137}Cs $3x10^{5}$ ^{90}Sr $5x10^{2}$	

* ID in Fig. 4.2-1

** Two components: the first and the second component in Fig. 4.2-1.

Table 4.2-6 Constant parameter values used in the sensitivity analysis

Parameter	Value
Area of contaminated catchment	100 km^2
Area of non-contaminated catchment	400 km^2
Amount of water in the first layer expressed as a fraction of the saturation thickness	1 (dimensionless)
Water run-off flux from the first layer as a fraction of water flux	0.2
Water run-off flux from the second layer as a fraction of water flux	0.3
Saturation thickness of the first layer	0.05 m
Saturation thickness of the second layer	0.025 m
Soil density	1000, kg m^{-3}
Thickness of the second layer	0.05 m
Water infiltration from the first layer to the second layer as a fraction of water flux in catchments	0.8 (dimensionless)
Water infiltration from the second layer to the third layer as a fraction of water flux in catchments	0.5 (dimensionless)

Table 4.2-7 A whole list of tested cases and varied parameter values

Precipiattion and soil erosion						Deposition			Distribution coefficient				Fixation	
Precipitation intensity [$m^3\ m^{-2}\ d^{-1}$]						Fractional distribution by components [-]			k_d [$(Bq\ g^{-1}) / (Bq\ ml^{-1})$]				Fixation rate to soil particles [d^{-1}]	
0.0015		0.005		0.015			[1st]	[2nd]	Cs-137 in soil	Cs-137 in river	Sr-90 in soil	Sr-90 in river	Cs-137	Sr-90
Case1	0.5	*Case17*	4	*Case33*	20	⇨	0.8	0.2	$1x10^3$	$1x10^4$	$1x10^1$	$1x10^1$	$1x10^{-4}$	0
Case2	0.5	*Case18*	4	*Case34*	20	⇨	0.8	0.2	$1x10^4$	$3x10^5$	$5x10^2$	$5x10^2$	$1x10^{-4}$	0
Case3	0.5	*Case19*	4	*Case35*	20	⇨	0.8	0.2	$1x10^3$	$1x10^4$	$1x10^1$	$1x10^1$	$1x10^{-1}$	$1x10^{-4}$
Case4	0.5	*Case20*	4	*Case36*	20	⇨	0.8	0.2	$1x10^4$	$3x10^5$	$5x10^2$	$5x10^2$	$1x10^{-1}$	$1x10^{-4}$
Case5	0.5	*Case21*	4	*Case37*	20	⇨	0.2	0.8	$1x10^3$	$1x10^4$	$1x10^1$	$1x10^1$	$1x10^{-4}$	0
Case6	0.5	*Case22*	4	*Case38*	20	⇨	0.2	0.8	$1x10^4$	$3x10^5$	$5x10^2$	$5x10^2$	$1x10^{-4}$	0
Case7	0.5	*Case23*	4	*Case39*	20	⇨	0.2	0.8	$1x10^3$	$1x10^4$	$1x10^1$	$1x10^1$	$1x10^{-1}$	$1x10^{-4}$
Case8	0.5	*Case24*	4	*Case40*	20	⇨	0.2	0.8	$1x10^4$	$3x10^5$	$5x10^2$	$5x10^2$	$1x10^{-1}$	$1x10^{-4}$
Case9	10	*Case25*	80	*Case41*	400	⇨	0.8	0.2	$1x10^3$	$1x10^4$	$1x10^1$	$1x10^1$	$1x10^{-4}$	0
Case10	10	*Case26*	80	*Case42*	400	⇨	0.8	0.2	$1x10^4$	$3x10^5$	$5x10^2$	$5x10^2$	$1x10^{-4}$	0
Case11	10	*Case27*	80	*Case43*	400	⇨	0.8	0.2	$1x10^3$	$1x10^4$	$1x10^1$	$1x10^1$	$1x10^{-1}$	$1x10^{-4}$
Case12	10	*Case28*	80	*Case44*	400	⇨	0.8	0.2	$1x10^4$	$3x10^5$	$5x10^2$	$5x10^2$	$1x10^{-1}$	$1x10^{-4}$
Case13	10	*Case29*	80	*Case45*	400	⇨	0.2	0.8	$1x10^3$	$1x10^4$	$1x10^1$	$1x10^1$	$1x10^{-4}$	0
Case14	10	*Case30*	80	*Case46*	400	⇨	0.2	0.8	$1x10^4$	$3x10^5$	$5x10^2$	$5x10^2$	$1x10^{-4}$	0
Case15	10	*Case31*	80	*Case47*	400	⇨	0.2	0.8	$1x10^3$	$1x10^4$	$1x10^1$	$1x10^1$	$1x10^{-1}$	$1x10^{-4}$
Case16	10	*Case32*	80	*Case48*	400	⇨	0.2	0.8	$1x10^4$	$3x10^5$	$5x10^2$	$5x10^2$	$1x10^{-1}$	$1x10^{-4}$

Soil erosion rate [$kg\ km^{-2}\ d^{-1}$]

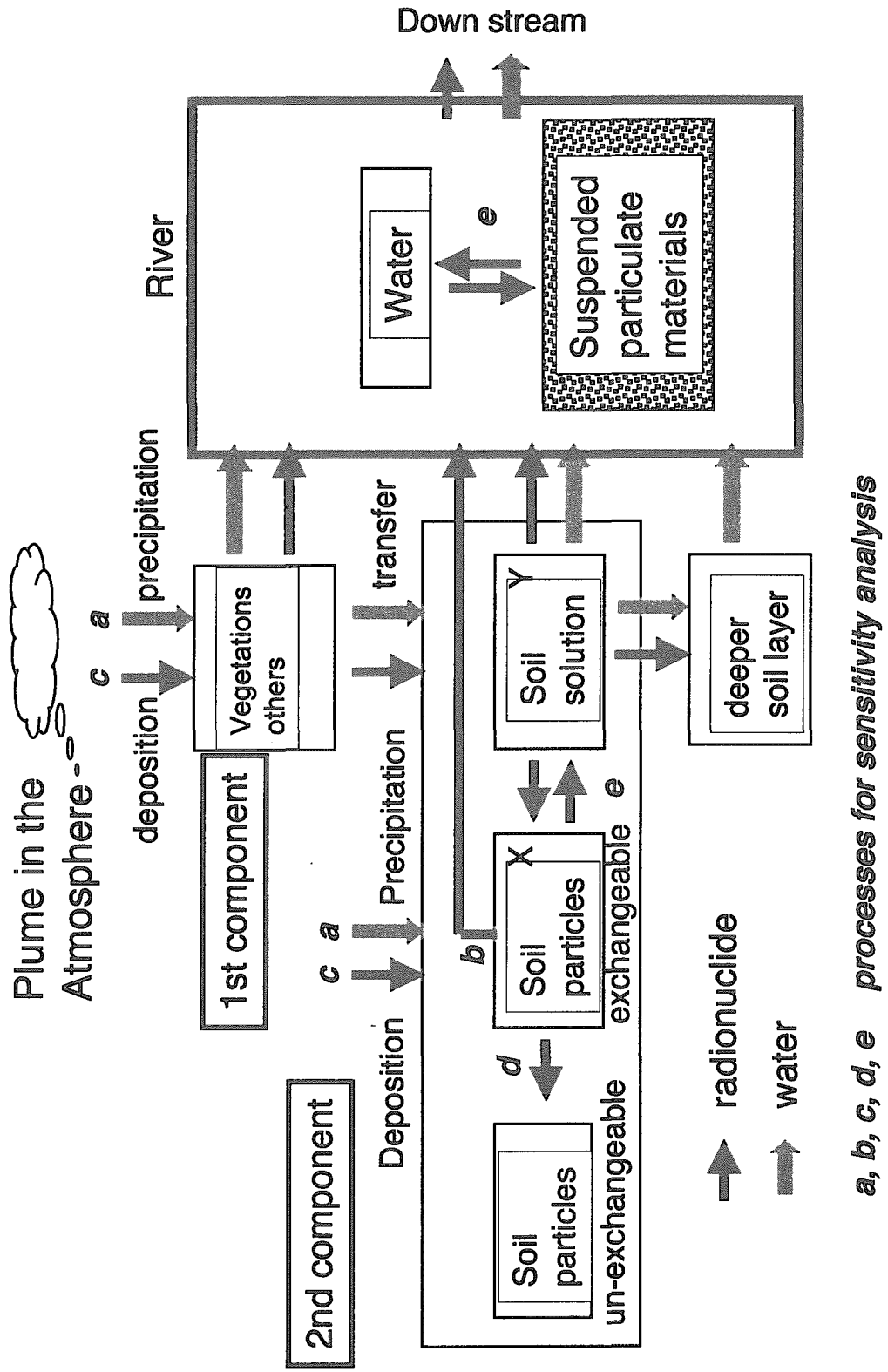
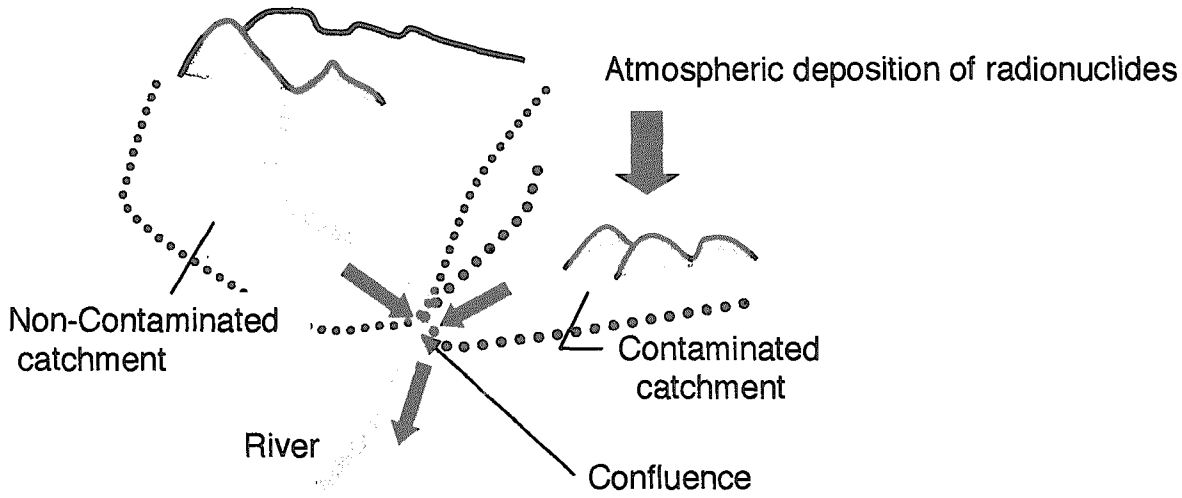


Fig. 4.2-1 Model MARTE used in the sensitivity analysis for migration of atmospherically-derived radionuclides to river system. See text for X and Y.



■ Assumptions

Area of non-contaminated catchment : 400 km^2

Area of contaminated catchment : 100 km^2

Discharge rate of effective precipitation:

0.2 (surface run-off, 2nd layer in Fig.1) ;

0.3 (infiltration from the 2nd layer to 3rd layer)

Atmospheric deposition:

Duration : 5 days

Deposition rate : 600 MBq d^{-1}

Total deposition 3000 MBq km^{-2}

Fig. 4.2-2 Model catchments in the sensitivity analysis.

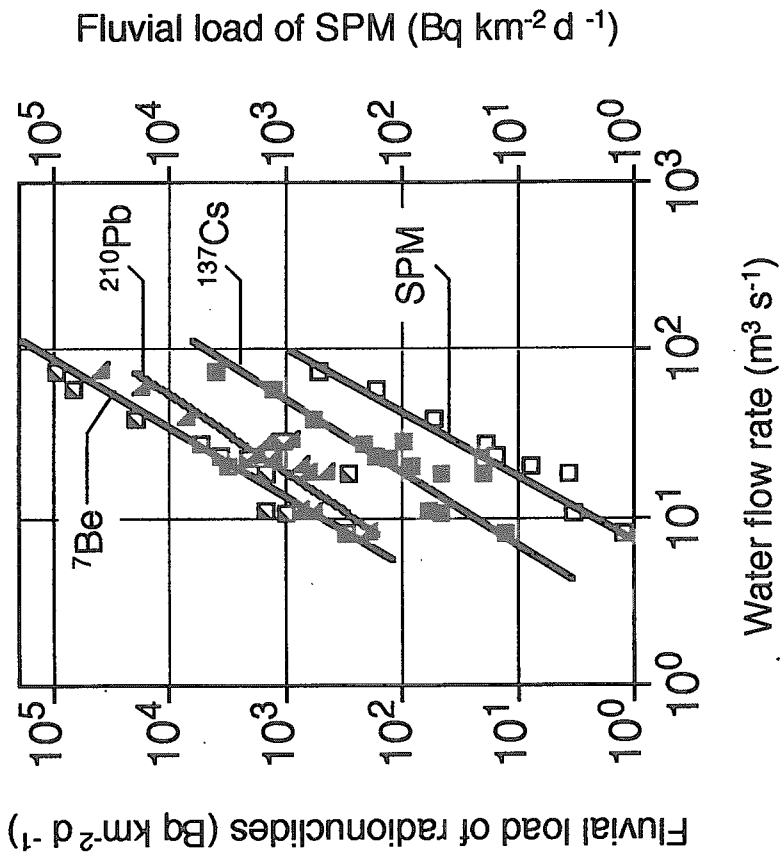


Fig. 4.2-3 Rating curves of suspended particulate materials (SPM) and associated radionuclides, observed in the Kuji River (1987-1990). ^{210}Pb: unsupported fraction.

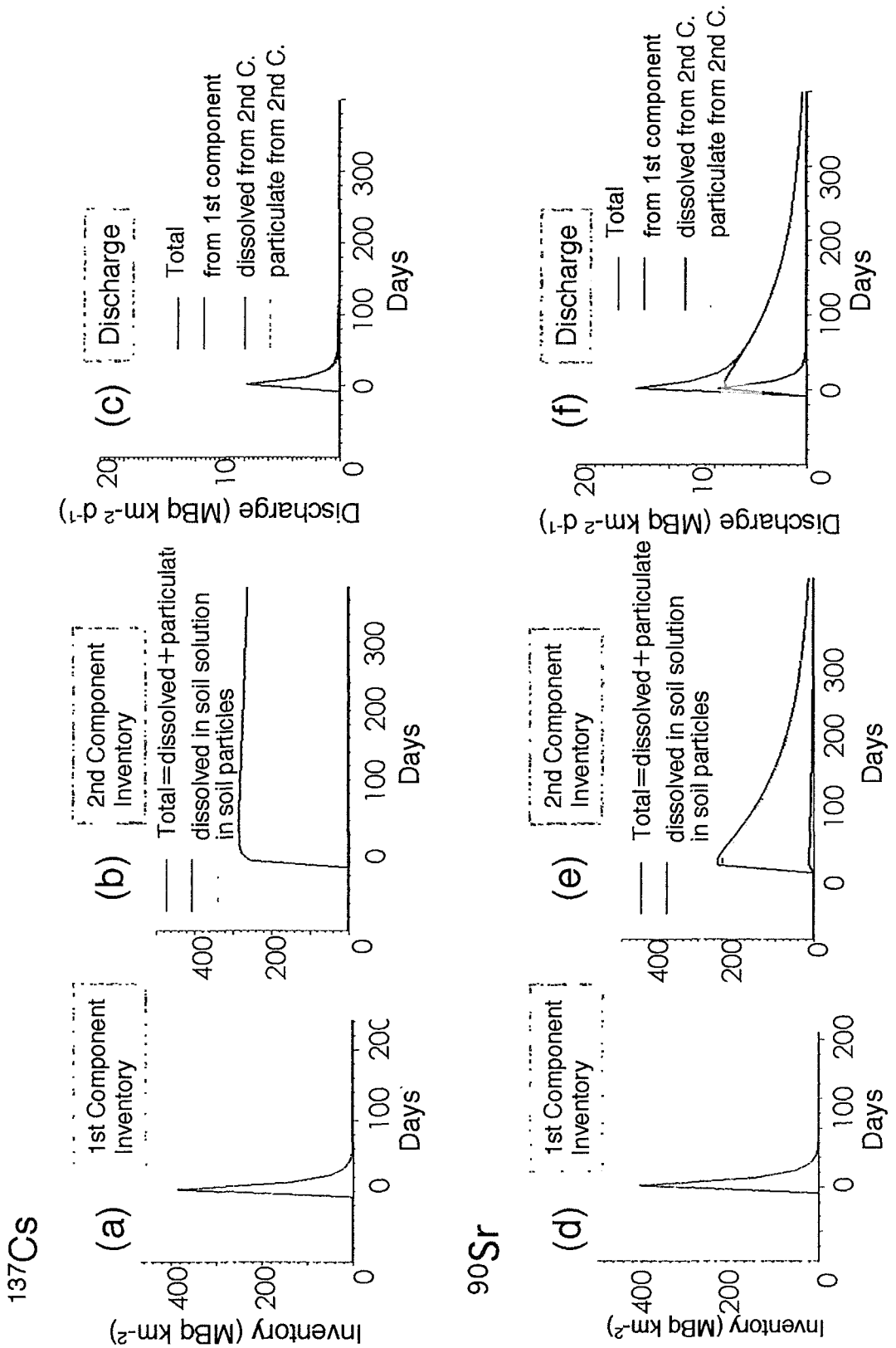


Fig. 4.2-4 Typical temporal variation of radioactive inventories of the components and the related discharge to river water. (Case 25).

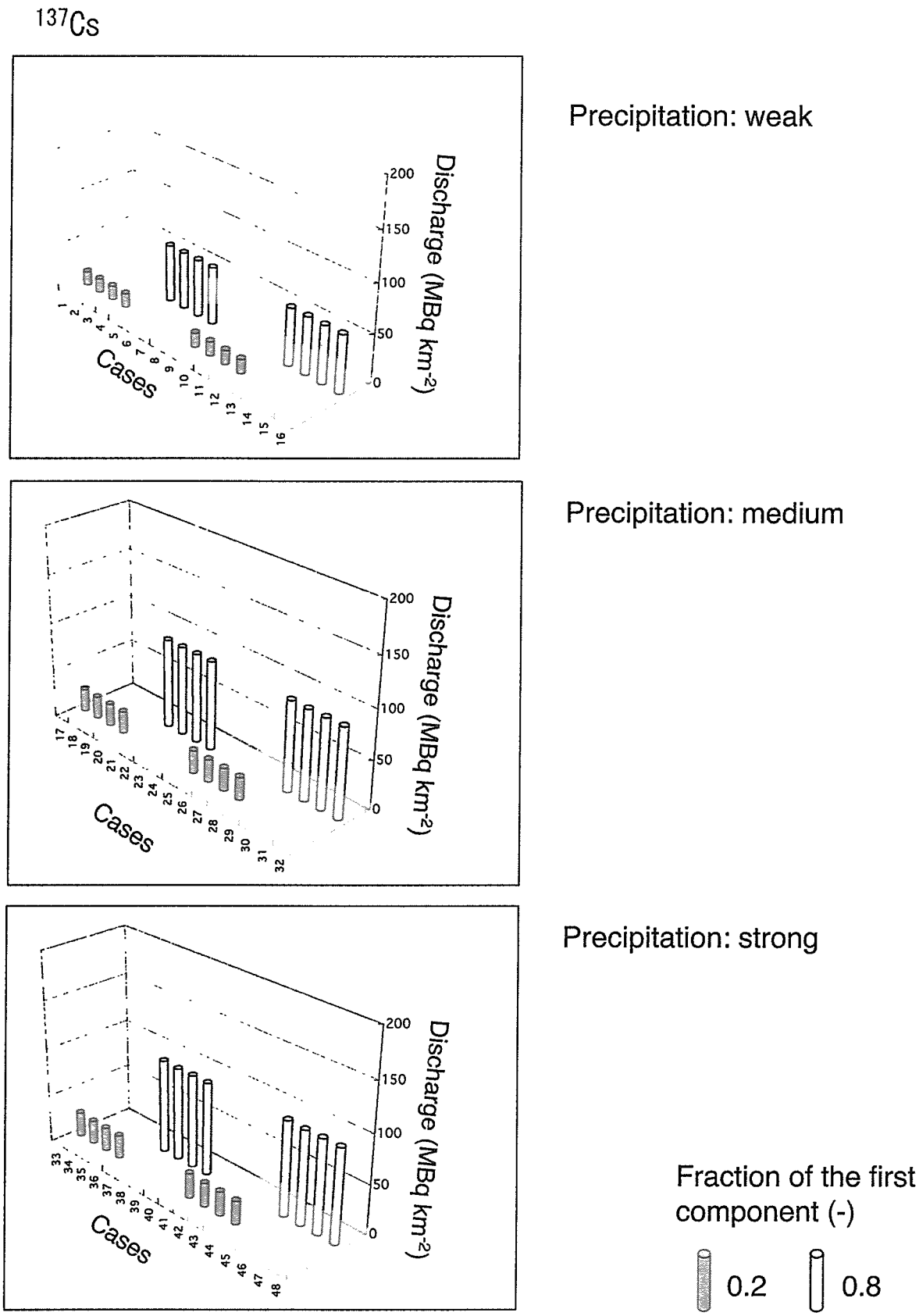


Fig.4.2-5 Total discharge of ^{137}Cs during first 30 days after deposition.

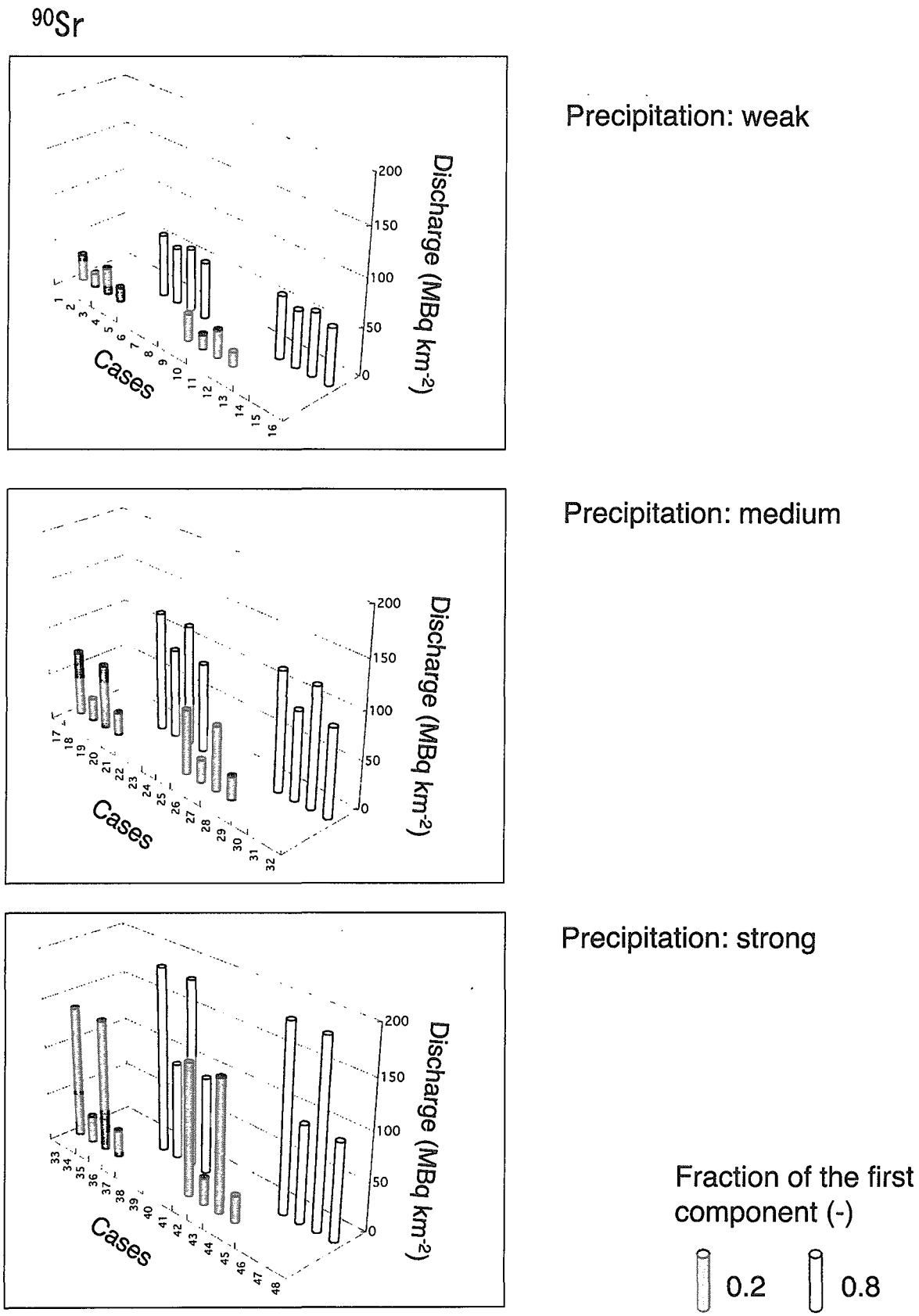


Fig.4.2-6 Total discharge of ^{90}Sr during first 30 days after deposition.

5. Presentations by the guest scientist at JAERI

5.1 Modelling the migration of radionuclides and toxic substances through complex fresh water systems and catchment areas. Principles and applications: the model MARTE

Luigi MONTE

(Presented at JAERI, Tokai-mura, 10 June 2003)

Abstract

Rivers and catchments are very complex environmental systems. Such a complexity is reflected in the complicated web of interacting processes that control the migration of radionuclide and, more generally, of toxic substances through these systems. Consequently, the development of models for predicting the behaviour of pollutants in complex catchments is a real challenge for modellers.

Model MARTE (Model for Assessing Radionuclide Transport and countermeasure Effects in complex catchments) was developed to predict the migration of ^{137}Cs and ^{90}Sr in rivers and complex systems and the effects of selected countermeasures on the contamination levels. The model, that was implemented in the MOIRA (A Model-based computerised system for management support to identify optimal remedial strategies for Restoring radionuclide contaminated Aquatic ecosystems and drainage areas), provides assessments of radionuclide behaviour in water systems comprised of rivers, lakes and reservoirs. It accounts for the radionuclide fluxes from the catchment, from the water column to the sediment and vice-versa and for the transport of contaminant through the water body.

The main principles used to develop the model will be presented. Examples of validation will be described. In demonstration of MOIRA system, a complete exercise of application of the Decision Support System MOIRA to a water body in Europe will be carried out. The demonstration will show:

a) the procedures for the selection of the water body;

b) the model applications and the relevant results;

c) the assessment of the output;

d) the results following the application of some countermeasure strategies and,

e) the application of the Multi-Attribute Analysis module for the ranking of the countermeasures in order to select the most appropriate intervention strategy.

The demonstration will also include some quick description of the features of the codes of MOIRA and of the software tool used for their development aiming at modelling radionuclide migration through complex catchments

5.1.1 Importance of the pollutant contribution from a catchment

The importance of the pollutant contribution from a catchment is strictly related to the mean water retention time of the considered water body. We can see this by using a simple model.

Let be

Fiw = the water flux from the catchment to the water body ($m^3\ s^{-1}$);

Fow = the water flux from the water body ($m^3\ s^{-1}$);

Crw = the pollutant concentration in the runoff water from a catchment ($Bq\ m^{-3}$);

Cw = the pollutant concentration in the water body ($Bq\ m^{-3}$);

V = the volume of the water body (m^3);

Frws = the pollutant flux from the water column to the bottom sediment (Bq s^{-1});

Frsw = the pollutant flux from the bottom sediment to the water column (Bq s^{-1}).

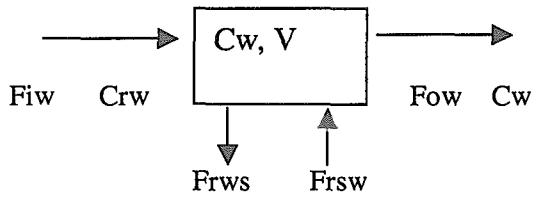


Fig. 5.1-1 Main fluxes of a pollutant in a water body.

The balance of the substance in the water body is controlled by the following equation

$$\frac{dVCw}{dt} = CrwFiw - CwFow + Frws - Frsw - Dp \qquad (5.1.1)$$

where Dp represent the effect of any degradation processes. VCw is the total amount of radionuclide in water. In case of radionuclide Dp=-λCwV where λ is the radioactive decay constant.

Equation (5.1.1) may be written as follows when V is constant on time::

$$\frac{dCw}{dt} = Crw\frac{Fiw}{V} - Cw\frac{Fow}{V} + \frac{Frws - Frsw - Dp}{V} \qquad (5.1.2)$$

The ratio Fow/V is the inverse of the so called mean water retention time of the water body. If the mean water retention time is very small, Fow/V is very high. In such a case if, moreover, the pollutant has a small degradation rate or a small radioactive decay constant (this is for instance the case of long-lived radionuclide, such as ^{90}Sr and ^{137}Cs, in a reach of a river) the terms Frws/V, Frsw/V and Dp/V are negligible compared with the other terms in the right side of equation (5.1.2). It is possible to suppose that $Fiw \approx Fow$ (indeed, the effect of evaporation can be considered negligible when the mean water retention time is sufficiently small), therefore we get:

$$\frac{dCw}{dt} = Crw\frac{Fow}{V} - Cw\frac{Fow}{V} \qquad (5.1.3)$$

The solution of equation (3) is:

$$Cw = \int_0^t Crw\frac{Fow}{V}e^{-\frac{Fow}{V}(t-\tau)}d\tau + Cw(0)e^{-\frac{Fow}{V}t} \qquad (5.1.4)$$

where Cw(0) is the initial contamination of the water body (concentration in water at time 0.

Following simple calculations, equation (5.1.4) becomes:

$$Cw = Crw - Crw\,e^{-\frac{Fow}{V}t} + Cw(0)e^{-\frac{Fow}{V}t} \qquad (5.1.5)$$

It is quite obvious that, if the mean water retention time is very short, the ratio Fow/V is very

high and therefore the last two terms in the right side of the previous equation approach quickly to 0, then

$$Cw=Crw \qquad (5.1.6)$$

We can conclude that the concentration in the water body, on the above hypotheses, approaches the values of the concentration of water flowing from "its" catchment (notice that, for a river reach, the catchment must include the entire upstream part of the river).

The above simple example clearly shows the importance of pollutant migration from catchment of rivers and water bodies showing a very short mean water retention time. The example was aimed at illustrating, in a simple way and without claming to give a general demonstration, the complex relation existing between the time behaviour of radionuclide concentrations in the water body and in its catchment.

5.1.2. Modelling the migration of radionuclides from catchment.

It was widely recognised that the migration of radionuclides from catchments is related to the interaction of radionuclide itself with the catchment components. In particular, many studies related the migration of dissolved radionuclides to the partition coefficient (k_d). An interesting example of such an approach was described by Joshi & Shukla [1].

We will carry out our calculations in a very general way. Let us consider a soil layer contaminated by a radionuclide

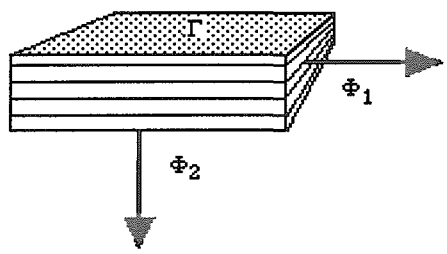


Figure 5.1-2 The total water flux (Φ) from a soil layer: surface runoff (Φ_1) and infiltration (Φ_2).

The amount F_{sc} (Bq s^{-1}) of substance removed, per unit time, by the water from a soil layer is:

$$F_{sc} = \Gamma \Phi C_w \qquad (5.1.7)$$

where Γ is the surface of the layer (m^2), Φ is the yearly average flux of water per square metre (m^3 s^{-1} m^{-2}) and C_w is the average contaminant concentration in interstitial water (Bq m^{-3}). The flux Φ of water is the sum of two components: the infiltrating water (Φ_2) and the surface run-off (Φ_1)

(Fig. 5.2). Due to the relatively high values of k_d, it is assumed that Φ_2 does not contribute significantly to the migration of radionuclide through the catchment.

The inventory I (Bq m^{-2}) of radionuclide in the layer is controlled by the following first order differential equation:

$$\Gamma \frac{dI}{dt} = -F_{sc} \tag{5.1.8}$$

Let be K (m^{-1}) the ratio of the radionuclide concentration in water divided by the radionuclide inventory:

$$K = \frac{C_w}{I} \tag{5.1.9}$$

We get

$$C_w = KI \tag{5.1.10}$$

Therefore, from equation (5.1.8) it follows

$$\frac{dI}{dt} = -\Phi KI \tag{5.1.11}$$

Thus

$$I = I_0 \exp(-\Phi Kt) \tag{5.1.12}$$

where I_0 is the deposit at time 0 and

$$F_{sc} = -\Gamma \frac{dI}{dt} = \Gamma \Phi KI = I_0 \Gamma \Phi K \exp(-\Phi Kt) \tag{5.1.13}$$

The yearly average radionuclide flux, F_ρ, due to the surface run-off is obviously:

$$F_\rho = I_0 \rho \Gamma \Phi K \exp(-\Phi Kt) \tag{5.1.14}$$

where ρ is Φ_1/Φ.

Function (5.1.13) show a very peculiar characteristic. The term ΦK is present both at exponent and as a multiplicative factor. Consequently, if ΦK, function (5.1.13) declines very slowly but show a small initial value. On the contrary, if the value of ΦK is high, the above function shows a fast decline and a very high initial value.

By the way, when it is possible to apply the concept of partition coefficient, the inventory I may be calculated as follows:

$$I = C_w \zeta (\theta + \delta k_d) \tag{5.1.15}$$

where ζ (m) is the thickness of the soil contaminated layer, θ (m^3 m^{-3}) is the water content in soil and δ (kg m^{-3}) is the soil density. For radionuclides such as ^{137}Cs and ^{90}Sr

$$\delta k_d >> \theta \tag{5.1.16}$$

therefore, it follows, from formulae (5.1.15) and (5.1.10) that

$$K = \frac{1}{\zeta \delta k_d} \tag{5.1.17}$$

It is quite clear that equation (5.1.17) represents a particular case of a more general situation. All the calculations done up to now (and that will be done in next pages) remain valid for any kind of environmental component, no matter what is its nature, provided that the ratio between the concentration in the transporting medium and the inventory in the considered component is (at least approximately) constant (equation 5.1.9).

In principles, a complex catchment is composed of a large number of such components (for instance, small sub-catchment element showing homogeneous characteristics) each characterised by specific values of the parameter K in equation (5.1.9) (Fig.5.1-3).

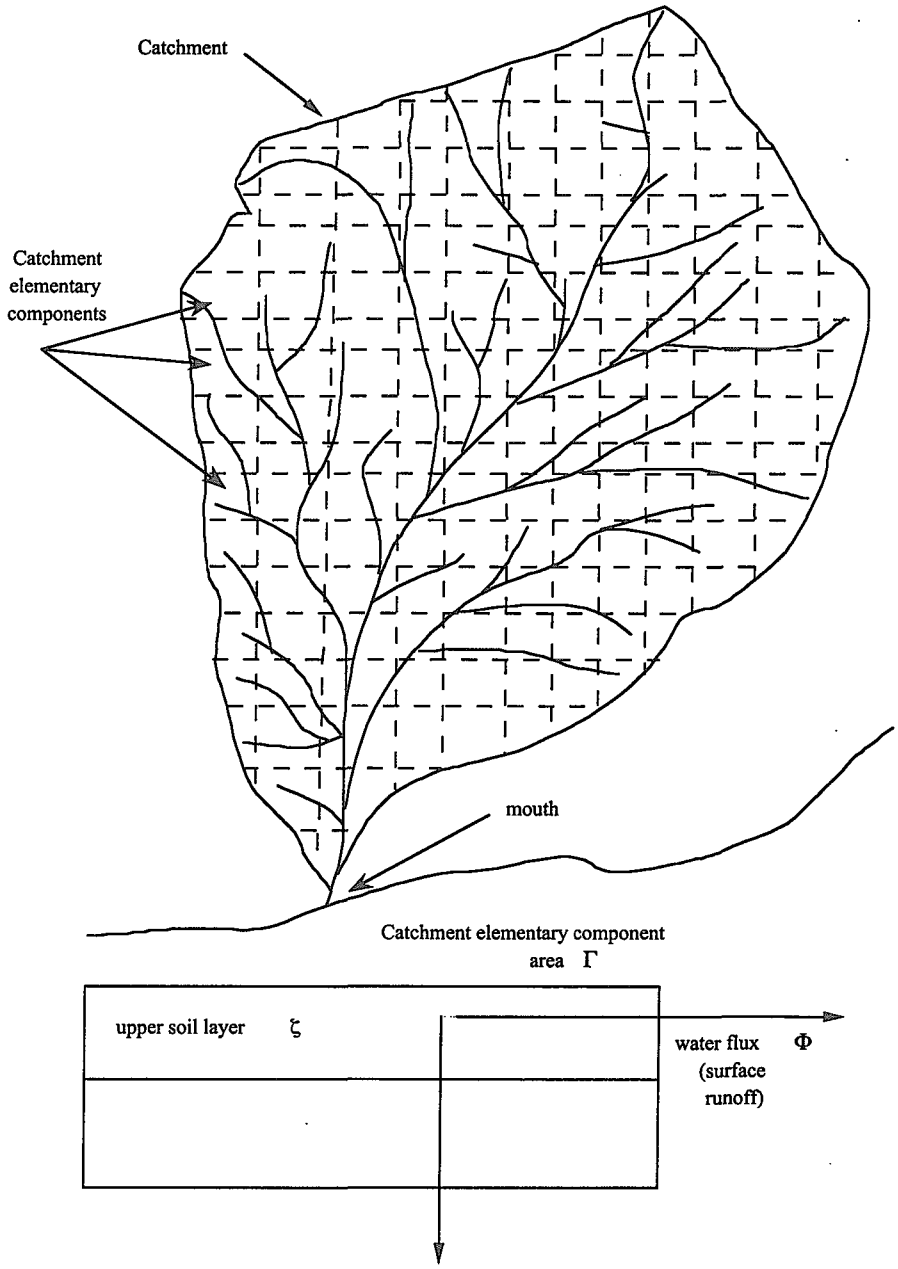


Figure 5.1-3. A complex heterogeneous catchment can be supposed as an ensemble of small approximately homogeneous sub-catchmets.

Putting ΦK=ω and A= area of the catchment, we get, by integrating the radionuclide transport contribution over the entire catchment:

$$GF(t) = A\rho D\int_0^\infty \omega f(\omega)\exp(-t\omega)d\omega \qquad (5.1.18)$$

f(ω) is the distribution function of ω. GF is the radionuclide flux from the catchment as a function of time for a single pulse D (Bq m^{-2}) of radioactive substance deposited on the catchment.

GF(t) can be considered as the sum of an infinite series of exponential terms ωexp(-tω). We

study now the behaviour of GF(t) in the interval of time (t_1,t_2) and let us suppose that t_1 and t_2 are of the same order of magnitude.

During this time interval, the most important exponential component of the series are the ones for which $1/\omega$ is of the order of t_1 and t_2. Indeed, if $1/\omega >> t_2$ (and t_1) the relevant components are negligible due to the low values of the coefficient ω; on the other hand, if $1/\omega << t_1$ (and t_2), the components are negligible due to the low values of $\exp(-\omega t)$.

Therefore, during the period of observation, the prevailing exponential component of the pollutant flux depends, solely, on the order of magnitude of t. Although the model is a rough approximation of a complex real situation, the above discussion suggests a good reason for a "regular" time dependent behaviour of radionuclide removal from catchment.

As previously noticed, the above model can be applied in very general circumstances. It is not necessary that the box in Fig. 5.2 is a soil layer. It can be any component of the environment from which radionuclide is washed off. Particulate radionuclide can be also considered as subject, at least at a conceptual level, to similar processes. The model does not make any particular hypothesis about the nature of the box. The only essential hypothesis is that the removal rate (ΦK) varies significantly within the catchment.

Experimental evaluations of the effective decay constants of radionuclide from catchments were obtained for many European rivers following the Chernobyl accident by fitting the radionuclide fluxes to a two components (short and medium term) exponential function. Table 5.1-1, 5.1-2 and 5.1-3 report some of such evaluations.

Table 5.1-1. Experimental evaluations of short term component for ^{137}Cs migrating from catchments

River	$\lambda_1+\lambda$ (s^{-1})	standard error	r^2	Period of collection of fitted data
Po (*)	$2.3\ 10^{-7}$	$5.5\ 10^{-8}$	0.619	20 May - July 1986
Rhine	$6.5\ 10^{-7}$	$1.3\ 10^{-7}$	0.903	May-July 1986
Prypiat	$5.2\ 10^{-7}$	$6.5\ 10^{-8}$	0.969	May-August 1986
Dnieper	$8.8\ 10^{-7}$	$1.1\ 10^{-7}$	0.973	May-August 1986

(*) Values obtained without subtracting the long term component

Table 5.1-2. Evaluation of effective decay constant of short term component of transfer function for dissolved radionuclides other than ^{137}Cs (r = correlation coefficient).

River	Radionuclide (s^{-1})	$\lambda_1+\lambda$ error	Standard	r^2	Period of collection of fitted data
Po	^{131}I	$1.1x10^{-6}$	$6.5x10^{-8}$	0.962	16 May - July 1986
Po	^{103}Ru	$4.7x10^{-7}$	$4.0x10^{-8}$	0.902	16 May - July 1986
Prypiat	^{90}Sr	$9.0 x10^{-7}$	$1.1x10^{-7}$	0.973	May - August 1986
Dnieper	^{90}Sr	$5.2x10^{-7}$	$1.5 x10^{-7}$	0.857	May - August 1986

Table 5.1-3. Evaluation of parameters of long term component of transfer function for dissolved ^{137}Cs and ^{90}Sr (r = correlation coefficient).

River	Radionuclide	α_2	Standard error of α_2	$\lambda_2+\lambda$ (s^{-1})	Standard error of $\lambda_2+\lambda_r$ (s^{-1})	r^2	Period of collection of fitted data (days after May 1st, 1986)
Dnieper	^{137}Cs	0.86	0.06	$1.1x10^{-8}$	$0.7x10^{-9}$	0.712	240 - 2000
Prypiat	^{137}Cs	1.08	0.06	$1.8x10^{-8}$	$0.7x10^{-9}$	0.819	240 - 2000
Rhine	^{137}Cs	0.53	0.3	$2.7x10^{-8}$	$0.6x10^{-8}$	0.861	240 - 600
Teterev	^{137}Cs	0.96	0.15	$8.2x10^{-9}$	$2.0x10^{-9}$	0.592	240 - 1700
Uzh	^{137}Cs	1.02	0.1	$1.5x10^{-8}$	$1.8x10^{-9}$	0.762	240 - 1700
Geometric mean		0.86		$1.5x10^{-8}$			
Dnieper	^{90}Sr	1.4	0.08	$5.5x10^{-9}$	$0.9x10^{-9}$	0.656	240 - 2000
Prypiat	^{90}Sr	1.41	0.08	$4.9x10^{-9}$	$0.9x10^{-9}$	0.679	240 - 2000
Teterev	^{90}Sr	1.12	0.14	$3.6x10^{-9}$	$2.1x10^{-9}$	0.586	240 - 1700
Uzh	^{90}Sr	1.31	0.09	$5.9x10^{-9}$	$1.8x10^{-9}$	0.827	240 - 1700
Geometric mean		1.30		$4.9x10^{-9}$			

Let us verify that some of the previous conclusions are coherent with the experimental assessments.

(a) The values of the effective decay constants are almost similar for the different radionuclides.

The order of magnitude of the decay constant of short term component is 10^{-7} s^{-1} for ^{137}Cs, ^{90}Sr and ^{103}Ru. The value for ^{131}I seems somewhat different. Nevertheless we must account for the radioactive decay rate of such a radionuclide that is not negligible. ^{131}I has a half-life of, approximately, 8.02 days corresponding to a radioactive decay rate $\lambda_r = 0.693/(8.02*24*3600)$ s^{-1} = $1.x10^{-6}$ s^{-1}. Subtracting such a value from $1.1x10^{-6}$ s^{-1} in Table 5.1-2 we get again the predicted order of magnitude 10^{-7} s^{-1}. The order of magnitude of the long term effective decay constants for ^{137}Cs and ^{90}Sr are almost similar (the ratio between the geometric means of these values is approximately a factor 3). We must account for the occurrence that the environmental parameters of importance for determining the mobility of radionuclides in a catchment, such as the partition coefficient k_d, range over orders of magnitude for any given radionuclide and show similar huge differences among different radionuclides as it is well known for Sr and Cs. Obviously, this is not the case for the above estimated effective decay rates.

(b) The order of magnitude of the effective decay components is equal to 1/t where t is the order of magnitude of the observation period.

Data relevant to the short term component were prevailingly obtained for a period of few months following the Chernobyl accident. Using t=2 months we get $1/t=1.9x10^{-7}$ s^{-1}. Data relevant to the long term component were obtained from 240 to 2000 days following the accident corresponding to a centroid of 1000 days. Therefore we get $1/t=1.2x10^{-8}$ s^{-1}. The above values show the same order of magnitude of the experimental assessments of the effective decay rates.

We have now to answer to the following question: how is it possible to use the above results for developing a model predicting the migration of radionuclides from catchments?

It is quite obvious that the use of integral (18) for practical applications is absolutely ineffective. Luckily, there are other simpler approaches for developing a model accounting for the above results. From a mere pragmatic point of view we have noticed that the function describing the migration of a radionuclide from a catchment contaminated by a pulse deposition event (D=deposition in Bq m^{-2}), is a function of time and of water flow, that can be approximated by the sum of some time-dependent exponential components :

$$\Phi_r(t) = \varepsilon D \sum_i \Phi\ (t) A_i e^{-(\lambda + \lambda_i)t} \qquad (5.1.19)$$

$$\sum_i A_i = 1 \qquad (5.1.20)$$

the symbols are described in Table 5.1-4.

Table 5.1-4. List of symbols.

A_i	=	relative weight of the ith component of the Transfer Function (TF) from the catchment (dimensionless)
D	=	radionuclide pulse deposition per square meter (Bq m^{-2}),
D(t)	=	radionuclide deposition rate (Bq m^{-2} s^{-1})
S_i	=	radionuclide, per square meter, in i^{th} catchment storage compartment (Bq m^{-2})
t	=	time (s)
ε	=	transfer coefficient from catchment (m^{-1})
λ	=	radioactive decay constant (s^{-1})
$\lambda+\lambda_i$	=	effective decay constants of the ith component in the Transfer Function from catchment (s^{-1})
Φ(t)	=	water flow from catchment (m^3 s^{-1})
$\Phi_r(t)$	=	radionuclide flux from catchment (Bq s^{-1})

The above formulae were used to fit radionuclide concentration data collected, in contaminated rivers, by European Laboratories following the Chernobyl accident. The parameters in the formula have the following meaning: ε is the ratio between the initial concentration of radionuclide in flowing water divided by the deposition (that is the concentration per 1 Bq m^{-2} of radionuclede deposition), A_i are weights that account for the shape of the fitting function. Condition (5.1.20) can be derived by equation (5.1.19) as, at time 0, $\exp(-(\lambda^1+\lambda_r)t)=1$ and, for any value of t, $\Phi_r(t)/\Phi(t)=C_w$.

If the deposition is a function of time (D(t)= deposition rate [Bq m^{-2} s^{-1}] at instant t) the radionuclide flux may be evaluated by the convolution integral:

$$\Phi_r(t) = \varepsilon \sum_i \Phi\ (t) \int_0^t D(\tau) A_i e^{-(\lambda+\lambda_i)(t-\tau)} d\tau \qquad (5.121)$$

Equation (5.1.21) is based on the obvious hypothesis that the response $\Phi_r(t)$ is linear in D.

Of course

$$\Phi_r(t) = \varepsilon \sum_i \Phi(t) S_i \qquad (5.1.22)$$

where S_i are solutions of the following system of differential equations:

$$\frac{dS_i}{dt} = -(\lambda + \lambda_i) S_i + A_i D(t) \qquad (5.1.23)$$

This can be verified by solving equation (5.1.23) and by putting the obtained expression of S_i in formula (5.1.22).The definition of compartments S_i is merely heuristic. To say, for instance, that the first component is mainly due to the vegetation wash out is a simplification aimed at giving only a possible example of the mechanisms controlling such a component. It is worthwhile to notice that the Chernobyl accident took place in a period of snow and ice melting in Europe. Consequently it is realistic that the short term component was also significantly influenced by the migration processes related to this seasonal effect.

Obviously

$$C_w = \varepsilon \sum_i S_i \tag{5.1.24}$$

where C_W is the concentration of the dissolved radionuclide in water as

$$C_w = \frac{\Phi_r(t)}{\Phi(t)}. \tag{5.1.25}$$

It is possible to account for any non-linearity effect related to the water flux $\Phi(t)$ through the catchment by including parameters α_i as exponent of $\Phi(t)$ in equation (5.1.19). Evaluation of such a parameters for the second component are reported in Table 5.1-3.

The above model was used for predicting the contribution of radionuclides to river systems as implemented in the Decision Support System MOIRA.

The model is basically composed of "elementary boxes" (EB). An EB is any part of a water body and of its catchment. A lake (or a part of it), a part of a river are examples of elementary boxes. A complex catchment is assumed to be composed of a chain of interconnected EBs.

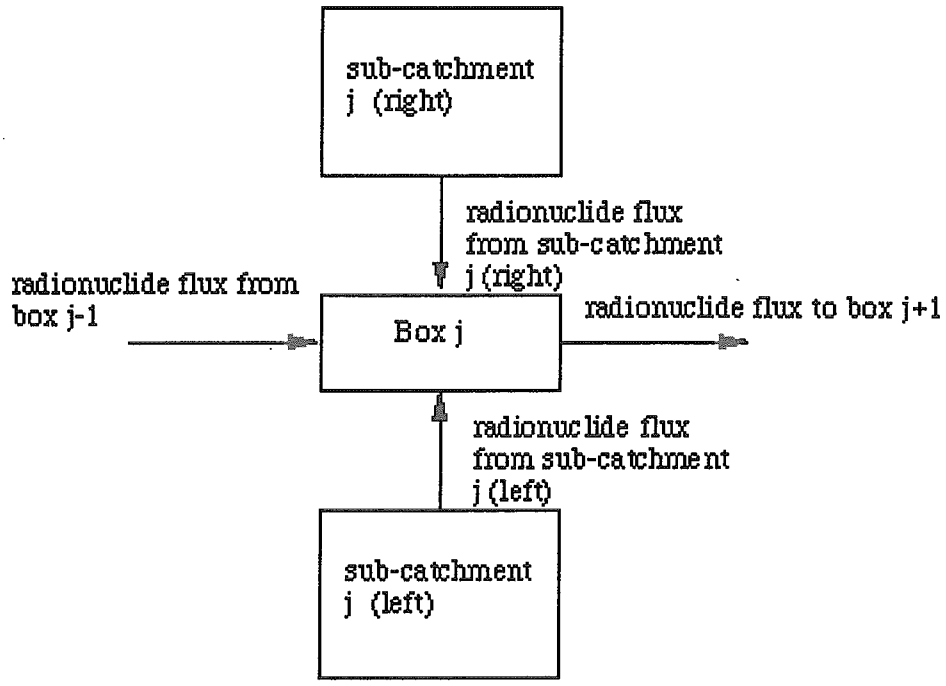


Fig. 5.1-4 Radionuclide fluxes to and from an elementary box.

Each EB is comprised of

- The water column;
- An upper sediment layer strongly interacting with water ("interface layer);
- An intermediate sediment layer below the "interface layer" ("bottom sediment");
- A sink sediment layer below the "bottom sediment";
- The right and left sub-catchments of the EB.

The models for predicting the radionuclide behaviour in each EB and the radionuclide migration from the catchment have been extensively described in previous papers and reports.

Each box is identified by an index j ranging from 1 to N, where N is the total number of the elementary boxes. Fig. 5.1-4 shows the radionuclide fluxes to each elementary box. Figure 5.1-5 shows the EB components and the fluxes of radionuclide, within an EB. The radionuclide fluxes are due to the following processes:

- Sedimentation;
- Radionuclide removal due to water withdrawal;
- Radionuclide migration from water to sediment (diffusion component);
- Radionuclide migration from sediment to water (resuspension);
- Radionuclide migration from catchment;
- Radionuclide transport through the EB chain;

The process of interaction of radionuclide dissolved in water with suspended solids was investigated by many researchers. In the present paper, the radionuclide absorption by suspended matter and by the sediment interface layer was modelled according to the well-know "k_d concept" (k_d = partition coefficient "particulate form/dissolved form") based on the hypothesis of a reversible quick equilibrium between the dissolved (C) and the adsorbed phases (C_s) of radionuclide

$$\frac{C_s}{C} = k_d \qquad (5.1.25)$$

More details about the model can be found in the scientific literature[2].

References (5.1)

(1) Joshi, S. R., Shukla, B. S., The role of water/soil distribution coefficient in the watershed transport of environmental radionuclides. *Earth Planetary Sci. Lett.*,105, 314-318 (1991).

(2) Monte, L. A generic model for assessing the effects of countermeasures to reduce the radionuclide contamination levels in abiotic components of fresh water systems and complex catchments. *Environmental Modelling and Software,* 16, 669-690 (2001).

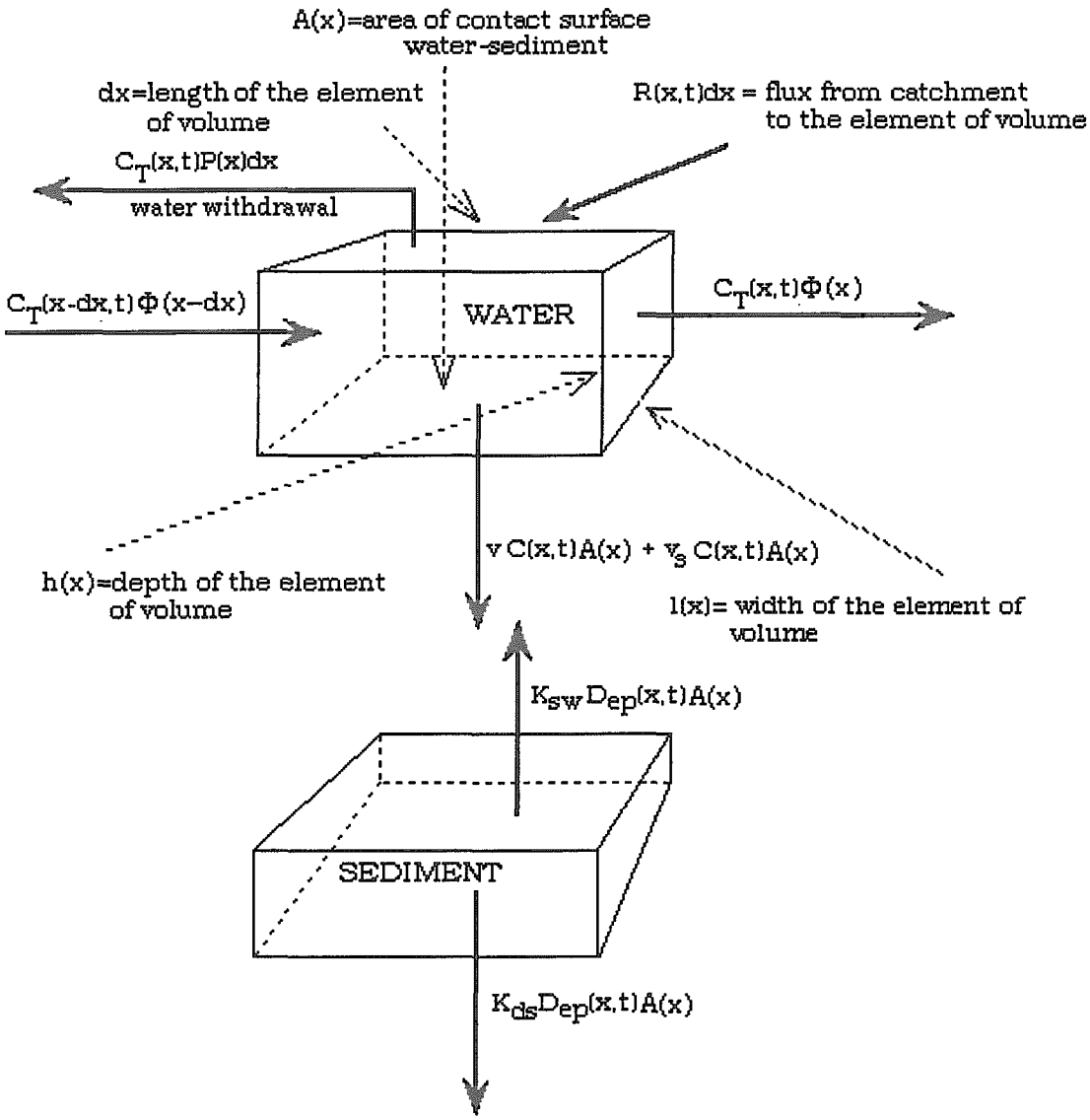


Fig. 5.1-5 Radionuclide migration fluxes within an elementary box.

5.2 Computerised Decision Support Systems for the management of fresh water environment contaminated by radionuclides: experiences in Europe following the Chernobyl accident

Luigi MONTE

(Presented at JAERI, Tokai-mura, 18 June 2003)

Abstract

The introduction into the environment of radioactive substances following nuclear accidents can cause high and persistent levels of contamination of the aquatic ecosystems. The necessity of reducing the consequent doses to man and of rehabilitating the contaminated areas implies the implementation of suitable countermeasures and restoration strategies.

Unfortunately, despite their obvious benefits represented by the reduction of doses, countermeasures may have non-desirable effects on the ecosystem, on the economy and on the society (cost of application, cost of food and resource bans, disturbance of the environment and of the ecosystems, living restrictions, etc.). A reliable and credible evaluation of the balance between those detrimental effects and the benefits following the application of a feasible countermeasure or restoration strategy is essential for the development of appropriate plans for the management of contaminated aquatic ecosystems.

Such an evaluation requires the assessment of radionuclide behaviour in the contaminated water system, of the effects of planned strategies of management on the environmental contamination levels and of the social, economic and ecological detriments. Therefore, suitable models and Decision Analysis tools are necessary for helping Decision-Makers to select the most appropriate intervention strategies. Computerised Decision Support Systems (CDSS) are the response to these necessities.

Following the Chernobyl accident, research and technological implementations were carried out in Europe to developed CDSSs for the management of the consequences of a nuclear accident. Among these CDSSs, MOIRA (A model-based computerised system for management support to identify optimal remedial strategies for restoring radionuclide contaminated aquatic ecosystems and drainage areas) has emerged as a friendly tool based on validated environmental models and on a Multi-Attribute Analysis module for the selection of intervention strategies that achieve the optimal balance between the benefits and the detrimental effects of countermeasures. In the presentation, the main characteristics of MOIRA models and methodologies was described and discussed. An exercise of MOIRA application was also supplied.

6. Presentations by the guest scientist and discussion during visits to Japanese Institutions

6.1 Outline of the visit

The subject of the invitation, "Modeling study on migration of accidentally released radionuclides in a river watershed", is really an interdisciplinary matter. Various study fields are closely related to the subject. Therefore, it was considered that it would be very necessary to have discussion with scientists who have special knowledge and experience in relevant study fields. As a result, visits to Japanese institutions were carried out from May 28 to June 3 of 2003. Visited institutions were : Hokkaido University, Institute for Environmental Sciences, Japan Nuclear Fuel Limited, Kyoto University, University of Shiga Prefecture, and Lake Biwa Research Institute. This visit was attended by Luigi Monte (the guest scientist, ENEA), Takeshi Matsunaga (JAERI) and Katsunori Tsuduki (JAERI) from the JAERI side. Experienced scientists of each institution participated in intensive discussion. Those participants are listed in Appendix C. In these visits, the following issues were the main ones discussed. Summaries of the discussions are provided in each section.

Issues to be discussed in the visit at the Japanese institutions:
1) The adequateness of the structure of the model under development for the domestic environmental conditions;
2) The data used for validation of the model;
3) Countermeasures for river-borne contaminants;
4) Application of the model to toxic trace elements;
5) Characteristic features of Japanese catchment from natural, social and economical points of view.

6.2 Presentations and demonstration by guest scientist

In this section, presentations and demonstration by guest scientist Dr. Luigi Monte during the research trip in Japan (28 May - 3 June 2003) are recorded. Main subjects among these presentations and demonstration dealt at each institution are denoted in Section 6.3 followed by corresponding discussions.

6.2.1 Lecture N.1 - The EVANET-HYDRA Network: Aims and achievements

Luigi MONTE

EVANET-HYDRA (Evaluation and Network of EC-Decision Support Systems in the field of Hydrological Dispersion Models and of Aquatic radioecological Research) is a thematic network financed by the European Commission in the framework of the research and training programme "Key action Nuclear Fission" (Contract n° FIGE-CT-2001-20125

Duration: November 2001 - October 2004) for

- users
- experts from environmental protection agencies and scientific community
- model and software developers

The network is aimed at reviewing and assessing Decision Support Systems (DSS) for the management of contaminated fresh water ecosystems.

During the IV research framework programme of the European Commission, several projects focused on developing computerised Decision Support Systems for the management of contaminated fresh water environments. Environmental models and techniques for the assessment of countermeasure effectiveness and DSSs were developed.

Therefore, it was recognised of paramount importance a detailed assessment of the results of such projects, the developed models, the used methodologies and the computerised DSSs, also by inter-comparison and testing, in view of the needs of the user and of the scientific communities.

Many European organisation are members of the network:

ENEA (coordinator, Italy), NRG (principal contractor, The Netherlands), Universidad Politécnica de Madrid (Spain), University of Oslo (Norway), Uppsala University (Sweden), Utrecht University (The Netherlands), CEH (UK), Studsvik Eco&Safety AB (Sweden), IRSN (France), IMMSP (Ukraine), OINPE (Russia), VUJE (Slovak Republic), IITA (Czech Republic), NCPH (Hungary), IAE (Poland), IFIN-HH (Romania), CEPN (France).

CDSSs (Computerised Decision Support Systems)are software codes showing a high degree of complexity and which address problems of great relevance for the practical management of the aquatic environment. These software products reach certain defined goals running quantitative evaluations, simulating the consequences of selected interventions, calculating costs and analysing benefits. They organise and structure the knowledge of experts and allow decision makers to use many different types of models appropriate for different environmental, social and economic situations and for each specific contamination scenario.

- The development of the CDSSs is necessary as any environmental intervention (countermeasures, restoration) may cause non-desirable effects of ecological, economic and

social nature. Critical evaluations of alternative management strategies are necessary to determine which of these reach the optimal balance between the related benefits and costs.

Such an evaluation requires two sets of tools:

- Models for predicting the behaviour of radionuclides in the fresh water environment, the effects of the countermeasure interventions (restoration actions) on the levels of pollution and the ecological, the social and the economic impacts of such interventions;
- Methodologies for ranking the different countermeasures according to their global effectiveness

The overall objective of the network is to assess the state of the art of existing DSSs and to plan their necessary improvements on the basis of critical evaluations by experts and experiences gained during the processes of application and customisation by potential end users.

This overall objective has being achieved, in detail, by:

- providing a wide dissemination and exchange of experts' knowledge and users' experience;
- reviewing and assessing the DSSs to ensure that they comply with expectations and needs of potential users;
- identifying and classifying the approaches of the different DSSs;
- defining the application domains of the DSSs;
- supporting and harmonising the customisation and application activities of the user community;
- synthesising the gained experience for the rational utilisation of DSSs;
- developing recommendations for the improvement and the rational use of the DSSs and of their components (models, methodologies, software products);
- supplying suggestions for further studies.

A first step of the assessment is to determine the horizon of the aims of the products (what is the level of the DSS; is it simply a model for predicting the concentration of radionuclides in the environmental components and the doses to man, or is also aimed at assessing the effects of countermeasures on these concentrations and dose or better is it aimed at evaluating the countermeasures impact on a global perspective on the economy, the society and the ecosystem supplying a ranking of effectiveness of different strategies?)

Moreover DSSs must e assessed in relation to their three fundamental components:

- Environmental models
- Methodologies for the assessment of interventions
- Software

In relation to the horizon of the DSS aims there are two CDSSs for the fresh water environment that cover, at least partially, a complete sequence of analysis from the evaluation of the contamination levels to the ranking of different countermeasures strategies :

RODOS-HDM
MOIRA

At present the following assessment have been accomplished:

- Assessment of the state-of-the-art of models for predicting the behaviour of radionuclides in lakes (Critical analysis of the models, Exercise of model intercomparison and model application);
- Assessment of the state-of-the-art of models for predicting the migration of radionuclides from catchments (Critical analysis of the models).

The identification of appropriate intervention strategies is done by applying the most up-to-date techniques of DECISION ANALYSIS that is a systematic and logical procedure for rationally analysing complex decision problems

In particular Multi-Attribute Analysis, used by the CDSS MOIRA, is a DA technique based on the assessment of "attributes" that measure the degree of achievement of certain objectives.

The preliminary needs envisaged in view of future developments and improvements of DSSs for the management of fresh water systems contaminated by radioactive substances can be summarised as follows:

- integration and harmonisation of existing CDSSs (models, application domains)
- exploitation of the entire potential of the CDSSs.

One of the possible and ambitious objective is the development of an integrated system of CDSSs for the management, in an ecological, economic and social perspective, of radionuclide contaminated fresh water and coastal ecosystems in view of a wide application to the different European environments and conditions and to the various types of contamination scenarios.

Moreover the preliminary results of the assessment suggest some conclusions:

A significant effort for harmonising environmental models and for the rational exploitations of the results of the assessed projects has been done in the frame of the network;

Models are characterised by uncertainty levels that, for a variety of reasons, cannot be lowered below certain limits;

Decision are influenced by many contingent factors that can change according to the economical and cultural conditions of society;

DSSs based on models are essential for selecting appropriate intervention if they are used as tools for critical assessments to guide decision making.

Therefore to develop scientifically guaranteed Decision Making based on models is of paramount importance for a scientific guaranteed support to the Decision Making process.

More information on EVANET-HYDRA and the relevant documents can be obtained at the following :

www address: www.casaccia.enea.it/evanet-hydra (E-mail: evanet-hydra@casaccia.enea.it).

6.2.2 Lecture N. 2 - Presentation on MOIRA CDSS

Luigi MONTE

The accidental introduction of radioactive substances into the environment has caused high and persistent levels of environmental contamination such as experienced following the Chernobyl accident.

The necessity of reducing doses to man has lead to restrictions in the economic exploitation of the contaminated areas. Moreover, a variety of strategies for restoring polluted fresh water ecosystems have been proposed to reduce these restrictions and thus the economic costs.

Countermeasures and restoration interventions may have significant impacts on the society and the economy and may imply non-desirable effects on the ecosystem.

Consequently, critical evaluations of alternative rehabilitation actions are necessary to determine which of these meet the optimal trade-off between the related benefits and costs.

The identification of the optimal remedial actions for restoring radionuclide contaminated aquatic systems requires two essential tools:

- A complete set of models for predicting the time behaviour of radionuclides in the fresh water environment, the effects of the countermeasure interventions (restoration actions) on the levels of pollution and the ecological, the social and the economical impacts of such interventions;
- Methodologies for ranking the different applicable countermeasures according to their effectiveness when the benefits due to the dose reductions and the ecological, the social and the economic detriments are accounted for.

It is of paramount importance to assess the effectiveness of countermeasures or restoration strategies in terms of feasibility, impacts and environmental improvements. Such a kind of evaluation requires the management of a great deal of data and information as well as the use of techniques and methodologies for quantifying and predicting the evolution of the environmental contamination levels and of the countermeasure (restoration) effects and impacts.

Computerised Decision Support Systems (CDSS) are the response to these needs

CDSSs for the management of contaminated environmental systems are computer programmes that organise and structure the knowledge of experts and allow non-experts to use many different types of models, within the framework of the "traffic rules" appropriate for different environmental, social and economic situations and for each specific contamination scenario.

The project MOIRA (A MODEL-BASED COMPUTERISED SYSTEM FOR MANAGEMENT SUPPORT TO IDENTIFY OPTIMAL REMEDIAL STRATEGIES FOR RESTORING RADIONUCLIDE CONTAMINATED AQUATIC ECOSYSTEMS AND DRAINAGE AREAS) was financed in the frame of the 4th research framework programme of the European Commission

The objective of MOIRA was to develop a user-friendly computerised tool to choose optimal intervention strategies for different kinds of aquatic ecosystems and contamination scenarios.

MOIRA makes use of:

- validated models to assess the behaviour of ^{137}Cs and ^{90}Sr in the contaminated water bodies, the effect of countermeasures and the radiation dose caused;
- a module based on Multi-Attribute Analysis technique (MAA) for testing the effectiveness of different countermeasure strategies.

Social, ecological and economic detriment costs and environmental and health improvements are

taken into account.

The MOIRA software is constructed to organise and structure the knowledge of experts to allow the use of many different types of models, within the framework of the "traffic rules" appropriate for each model, by decision makers not necessarily expert in environmental modelling.

Elements of MOIRA software system are:

- Software realisation of mathematical models
- Geographical information system (GIS)
- The MOIRA user interface
- The Multi-Attribute value Analysis module
- The MOIRA HTML result report.

MOIRA includes:

- Models for assessing the migration of 137Cs and 90Sr in fresh water systems and the effects of a variety of countermeasures on the contamination levels;
- Dynamic dose assessment model;
- Individual and collective dose from contaminated water;
- Economic cost model;
- Environmental models for assessing the most important environmental characteristics affected by the countermeasures.

The models in MOIRA are structured to be simple and reliable tools for environmental management. They include the key processes regulating the transport of a given pollutant (e.g. 137Cs) in a given ecosystem (e.g. a lake) and have a relevant and simple structure, i.e., involve the smallest possible number of driving variables. The values of these necessary driving parameters are easy to access or to measure.The models have a high predictive power and are validated for a wide range of environmental characteristics of ecosystems for which the model should be applicable.

The following countermeasures are considered by MOIRA:

- Chemical and Physical (active) Countermeasures:
- Reduction of radionuclide remobilisation from sediments (e.g. lake liming).
- Reduction of uptake by aquatic organisms (e.g. potash treatment of water).
- Reduction of radionuclide transfer from contaminated drainage areas to water bodies (e.g. dam building in floodplains, soil decontamination, wetland liming).
- Removal of radionuclides from aquatic systems (e.g. dredging).

- Social (restrictive) Countermeasures: Restrictions on people's normal living habits:
- Uses of Water:
- Drinking
- Irrigation of crops and pasture (food ingestion)
- Recreation (e.g. swimming, diving, sunbathing, boating)

We can conclude by summarising the most important features and advantages of MOIRA:

- MOIRA is a friendly software system, based on scientific and theoretical foundations, for the management of intervention strategies to reduce the dose via aquatic pathways.
- MOIRA evaluates several types of countermeasures, and advises the user on the most effective method, taking into account ecological, social and economic consequences.
- The use of the decision system MOIRA offers a quick insight in the effectiveness of countermeasures.
- Implementation of wrong and expensive countermeasures can be avoided by using the MOIRA system.

MOIRA can be a helpful tool for different users such as:

- Organisations responsible for maintaining the state-of-the-art knowledge in radioecology and in environmental protection.
- Environmental protection agencies and administrators.
- education and training organisms in environmental management.

More information on the different modules of MOIRA can be obtained by the MOIRA developers that are listed below:

MOIRA: A MODEL-BASED COMPUTERISED SYSTEM FOR MANAGEMENT SUPPORT TO IDENTIFY OPTIMAL REMEDIAL STRATEGIES FOR RESTORING RADIONUCLIDE CONTAMINATED AQUATIC ECOSYSTEMS AND DRAINAGE AREAS
Web site: http://moiradss.topcities.com/

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6.2.3 Lecture N.3 - Demonstration OF MOIRA computerised decision support system

Luigi MONTE

The Decision Support System MOIRA starts with the definition of the water body for which assessment of management strategies is requested (Fig. 6.2.3-1).

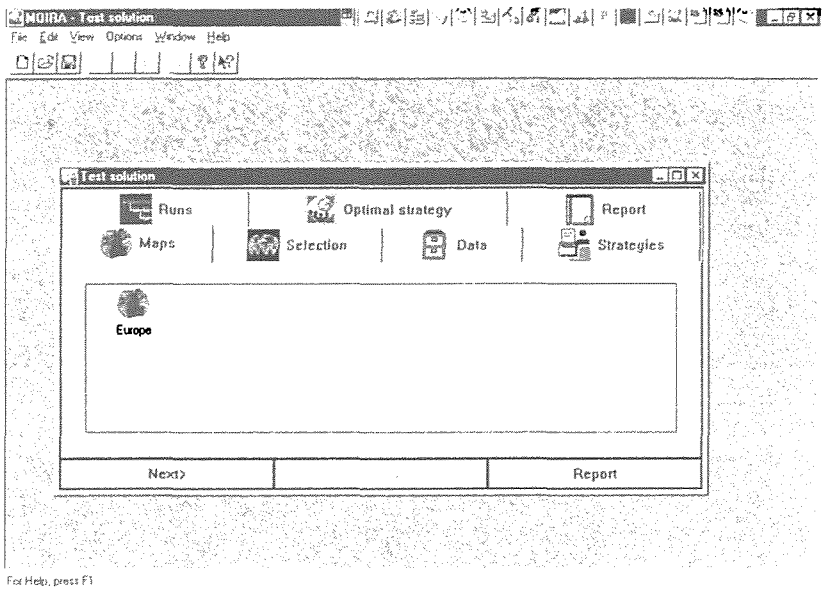

Fig. 6.2.3-1 Starting view of MOIRA system

When the user click on the icon "Europe", MOIRA calls a subroutine for the management of the GIS showing a map of Europe. Now it is possible to select the water body to which MOIRA will be applied, in the present example the water body is located in central Italy. MOIRA will automatically obtain from the GIS the data necessary for running the radionuclide migration models. If, for any reason, these data are not available, they can be supplied by the user or, if user have no site specific information, can be evaluated by some environmental sub-models implemented in MOIRA that account for the environmental and geographic characteristics of the area of interest (Fig. 6.2.3-2).

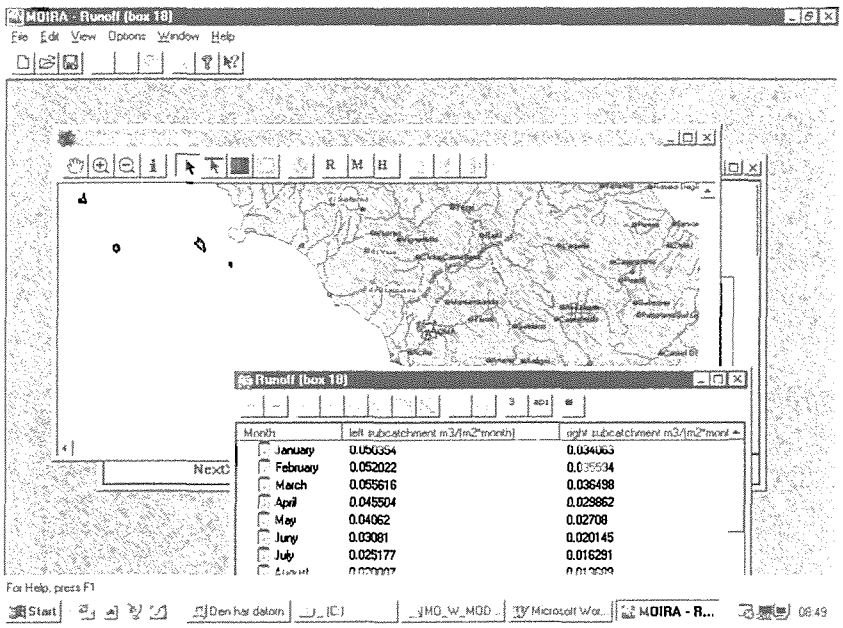

Fig. 6.2.3-2 Selection of the area for evaluation

Once the water body has been selected, it is possible to supply data of radionuclide fallout. Clicking on the icon "run", MOIRA models start to assess the radionuclide contamination in water and in biota and the doses to man.

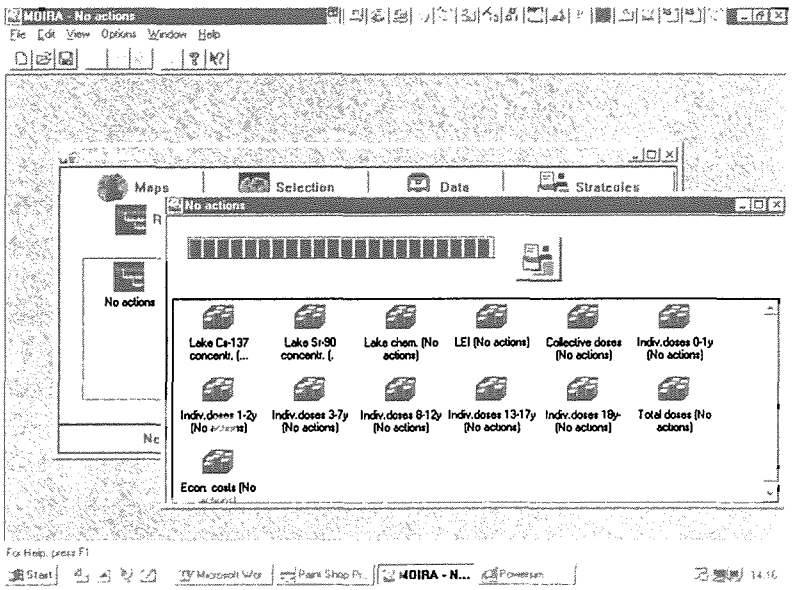

Fig. 6.2.3-3 Selection of the area for evaluation

Following this first run, the user can select one or more countermeasures and carry out new evaluations for the hypothesised countermeasure applications (Fig.6.2.3-3). Finally, MOIRA evaluate the economic cost of countermeasures that have been eventually applied.
MOIRA is ready now for a global evaluation and ranking of the different countermeasure strategy by accounting for the economic, ecological and social impacts (Fig.6.2.3-4).

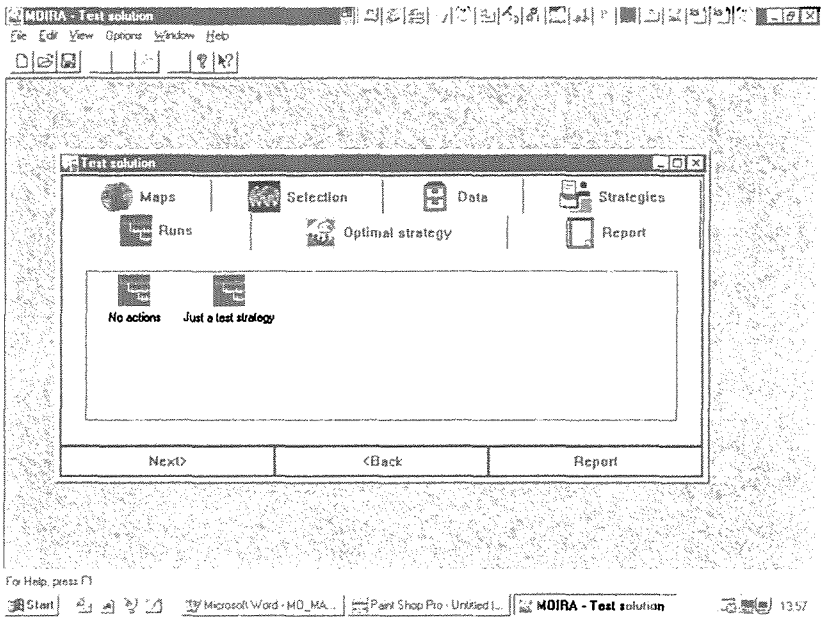

Fig. 6.2.3-4 Selection of countermeasures.

Clicking on the icon strategy the Multi Attribute Analysis module is activated and ranking of countermeasure strategy is carried out (Fig.6.2.3-5). The results are shown by graphs and tables (Fig.6.2.3-6).

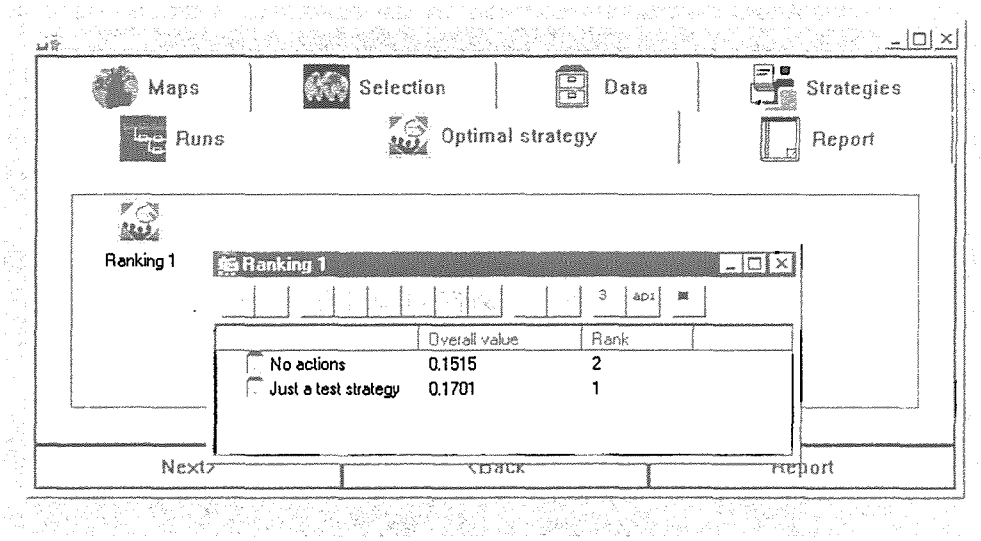

Fig. 6.2.3-5 Result of quantitated effectiveness of countermeasures.

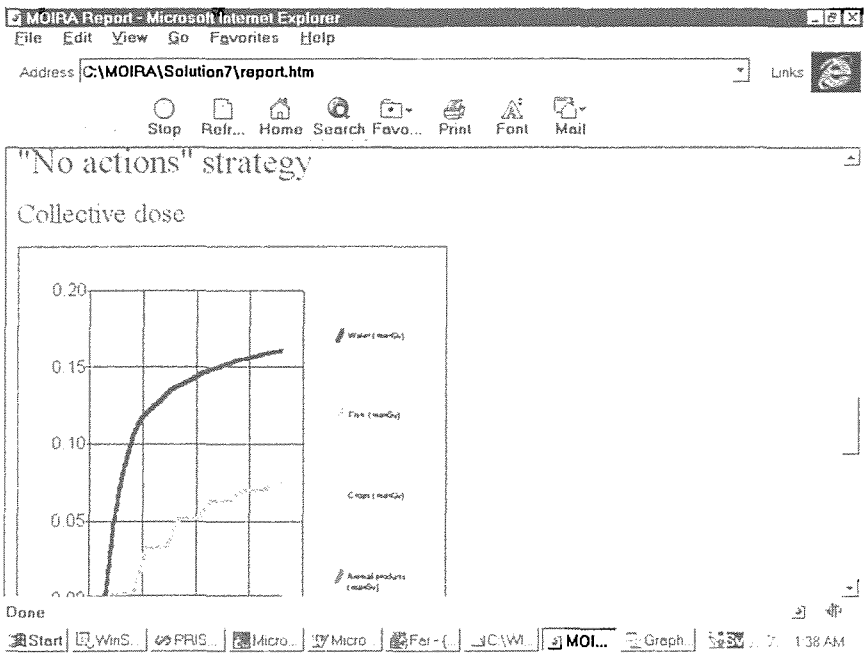

Fig. 6.2.3-6 Graphical representation of results

6.2.4 Lecture N. 4 - Methodology of collective models -Model uncertainty and environmental complexity-

Luigi MONTE

The results of the models for predicting the migration of toxic substances through the environment are, generally, affected with large uncertainties that are due to the complexity of the modelled environmental systems and to the difficulty of obtaining reliable values of the model parameters It is therefore necessary to search for appropriate strategies that can allow the proper management of such a difficulty.

Example of traditional strategy for the development of environmental model: conceptual approach of an "omniscient model", the wet deposition rate, Dw (g m^{-2} s^{-1}), on the ground surface of a contaminant introduced into the atmosphere can be hypothetically calculated as follows:

$$D_w = \int_0^H \Lambda \chi(z) dz \tag{6.2.4.1}$$

$$\Lambda = \int^{\infty} \pi R^2 E(a,R) N(R) u(R) dR \tag{6.2.4.2}$$

where Λ is the washout rate (s^{-1}), $\chi(z)$ is the pollutant concentration (g m^{-3}) in the atmosphere at height z from the ground, R is the radius of raindrops, E(a,R) is the collection efficiency of particle of size "a" by raindrops of radius "R", N(R) is the drop-size distribution function (the number of raindrops of radii between R and R+dR per unit volume), u(R) is the velocity of raindrop of radius R and H is the thickness of the contaminated atmospheric layer.

The above model includes "all" the occurring processes. The model is, in principle, omniscient; indeed, at least conceptually, it exhaustively comprises the whole set of the processes involved in the rain scavenging. Unfortunately, it is inconceivable that reliable values of the model parameters and of the distribution functions in formulae (6.2.4.1) may be available for the predictions relevant to the specific environmental and meteorological conditions. Despite the completeness of the model, in practical applications, an accurate evaluation of the wet deposition of a pollutant is almost impossible.

Therefore, a fundamental question is:

- Is it possible to take advantage from the complexity of environmental systems to develop simple and reliable models that can be useful for practical applications?

Examples :

- Radionuclide diffusion to and through sediment

Solution approach: definition of migration velocity to sediment of contaminant substance that are, prevailingly, in dissolved form. The migration velocity (m s^{-1}) of a pollutant from the water column to the sediment is the ratio between the contaminant flux and the contaminant concentration in water. Migration velocity, as function of the kd and of the depth of the water column, of a pollutant from water to sediment can be obtained as

$$\frac{\partial}{\partial t} C_W(x,t) = D \frac{\partial^2}{\partial x^2} C_W(x,t) \tag{6.2.4.3}$$

where D is the effective diffusion coefficient and Cw(x,t) is the concentration of the contaminant in interstitial water at time t and at depth x from the sediment surface. It is assumed that the pollutant is homogeneously distributed in the surrounding water column. As consequence, the concentration of the pollutant in the water above the sediment is Cw(0,t). D is related to D* by the well known formula

$$D = \frac{D^*}{R} \tag{6.2.4.4}$$

where R (dimensionless) is the so called retardation factor:
The flux of the contaminant from the water to the sediment is:

$$R = 1 + \frac{K_d \rho}{\theta} \tag{6.2.4.5}$$

The velocity of migration of radionuclide to sediment is the ratio J/Cw.

$$J = -\theta D^* \frac{\partial}{\partial x} C_W(x,t)\Big|_0 \tag{6.2.4.6}$$

$$v = -\theta D^* \Omega + \frac{\theta D^* e^{-\Omega^2 Dt}}{\mathrm{erfc}(\Omega\sqrt{Dt})\sqrt{\pi Dt}} \tag{6.2.4.7}$$

In general, large variations of environmental characteristics (kd values, sediment density, sediment water content, etc.) do not involve similar large variation of the migration velocity of the pollutant to the sediments as it is possible to see from the following figure (Fig. 6.2.4-1).

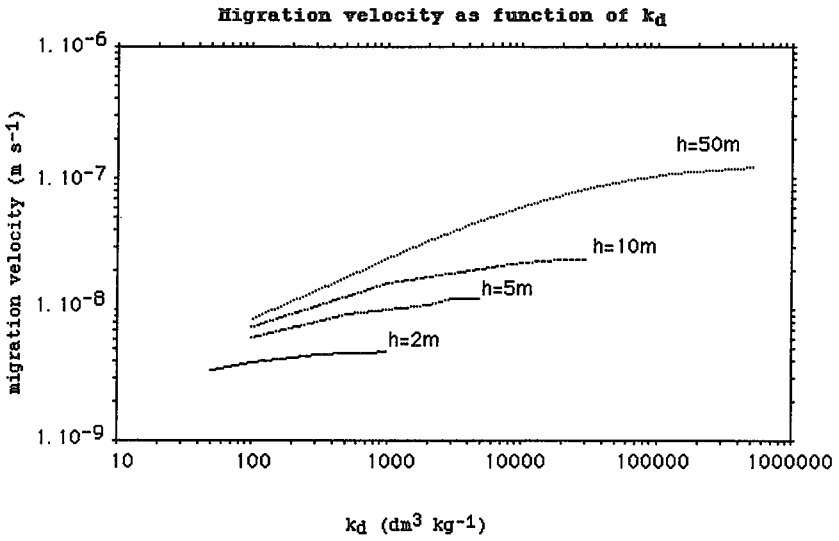

Fig. 6.2.4-1 Migration velocity, as function of the kd and of the depth of the water column, of a pollutant from water to sediment (the present example refers to a period of 6 years after a single pulse contamination event).

The following table (Table 6.2.4-1) shows a comparison of the model prediction with some experimental assessments of the migration velocity to sediment of ^{137}Cs in some deep Italian volcanic lake characterised by a negligible sedimentation of suspended matter and, therefore, of particulate radionuclide. The values refer to the period 1987-1992.

Table 6.2.4-1 Observed and simulated migration velocity of radionucl.ides to lake sediments

Lake velocity	Transport transport velocity (m s^{-1})	Predicted (m s^{-1})	95% confidence limit (up) of the transport velocity (m s^{-1})	95% confidence limit(down)ofthe transport velocity (m s^{-1})
Albano	$1.0x10^{-7}$	$1.4x10^{-7}$	$4.4x10^{-8}$	$8.3x10^{-8}$
Bolsena	$1.1x10^{-7}$	$2.1x10^{-7}$	-	$8.1x10^{-8}$
Bracciano	$3.0x10^{-8}$	9.9x10-8	-	$8.3x10^{-8}$
Nemi	$8.4x10^{-8}$	$1.4x10^{-7}$	$4.0x10^{-8}$	$4.1x10^{-8}$
Vico	$2.4x10^{-8}$	$4.6x10^{-8}$	$0.2x10^{-8}$	$4.3x10^{-8}$
Geometric Mean	$5.9x10^{-8}$			$6.3x10^{-8}$

The migration of a radionuclide from a catchment offers a further example of a collective model. The sub-catchment can be indeed considered as composed of a large number of similar sub-systems. Therefore some parameters controlling the process of radionuclide migration, may be obtained as "ensemble average" over the class of the sub-systems. Consequently, they show somewhat regular behaviours due to statistical aggregation.

Examples of experimental assessment of these parameters have been decribed (see Table 5.1-1, 5.1-2, 5.1-3 of the present JAERI-Reiview report). These parameters are the effective decay constants of radionuclide in water flowing from the catchment at different time scale (short term = few months following the Chernobyl accident; medium term = some years following the accident).

A model structure can be written, in general, as follows

$$L(m1,m2...mn;\ s1,s2...sk)\ X = Y \qquad (6.2.4.8)$$

where
L= operator (it identifies the model structure)
Y = input
X = output
m = generic parameters (site specific values are not available)
s = site specific parameters

The suggestions from this study are:
- Find a the most suitable structure but do not add details that increase the model uncertainty (optimal structure)
- Try to take advantage from those parameters that do not vary too dramatically with the environmental conditions (collective parameters)
- If the model is very sensitive to some generic parameters try to get experimental values of them; if this is not possible try to use sub-models for their assessment but be aware that they can add significant uncertainty to the model output (uncertainty analysis).

6.2.5 Lecture N. 5 - Water stratification and influence on the distribution of dissolved substances in deep lakes

Luigi MONTE

The mechanisms controlling the heating of the lake water by the solar and the atmospheric infrared radiation imply a seasonal process of thermal stratification of water. Figure 6.2.5-1 shows the flux of solar radiation penetrating the water of Lake Bracciano. Thermal stratification is clearly shown in Fig. 6.2.5-2.

The thermal stratification is reflected into the non-homogeneous profiles of dissolved substances in the lake (Fig. 6.2.5-3).

The distribution of toxic substances introduced in the lake during the thermal stratification period is influenced by the depth dependent values of the effective diffusion coefficient in lacustrine water. Indeed, the diffusion coefficient shows very low values in correspondence with the so-called thermocline corresponding to a marked decline of water temperature with depth. Figure 6.2.5-4 shows the time behaviour of the concentration of ^{134}Cs of Chernobyl origin in Lake Bracciano. As radionuclide introduction into the lake started during the stratification period (summer 1986), high values of concentration in water were measured. The measured values significantly decreased when, during winter 1986-1987, the de-stratification of water involved the dilution of the radionuclide from the upper water layer to the entire water column.

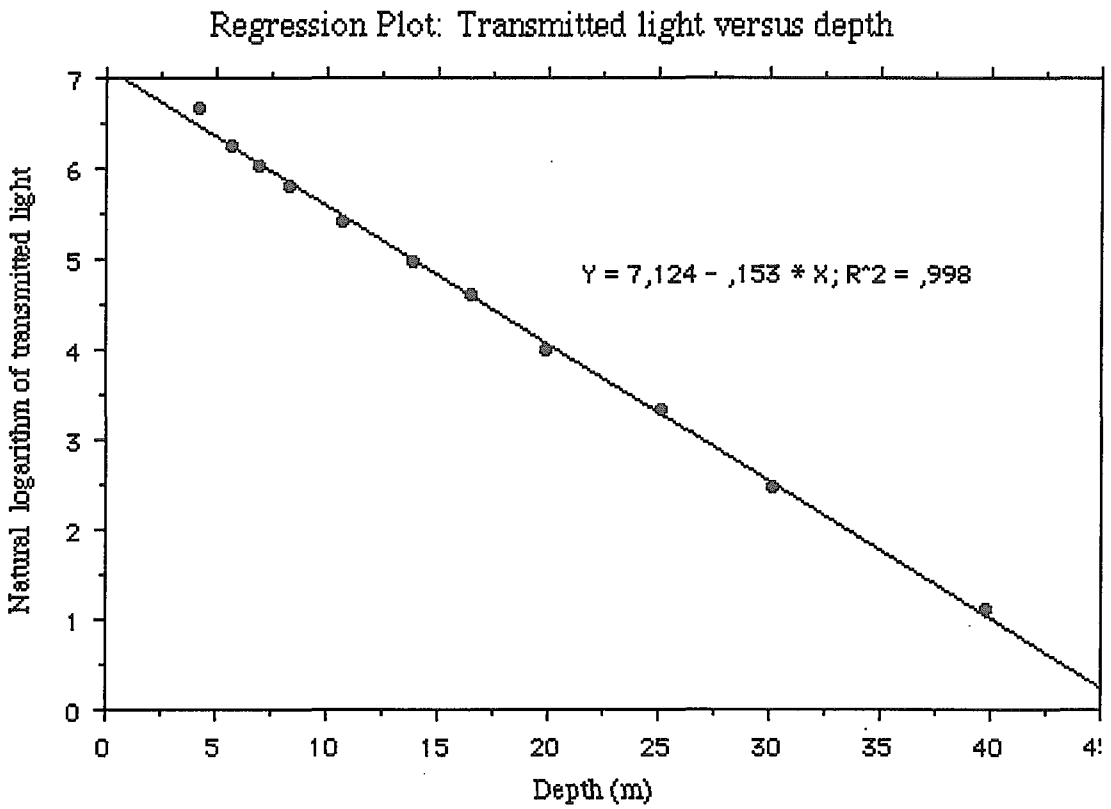

Fig. 6.2.5-1 Transmitted light in water of lake Bracciano as function of the depth.

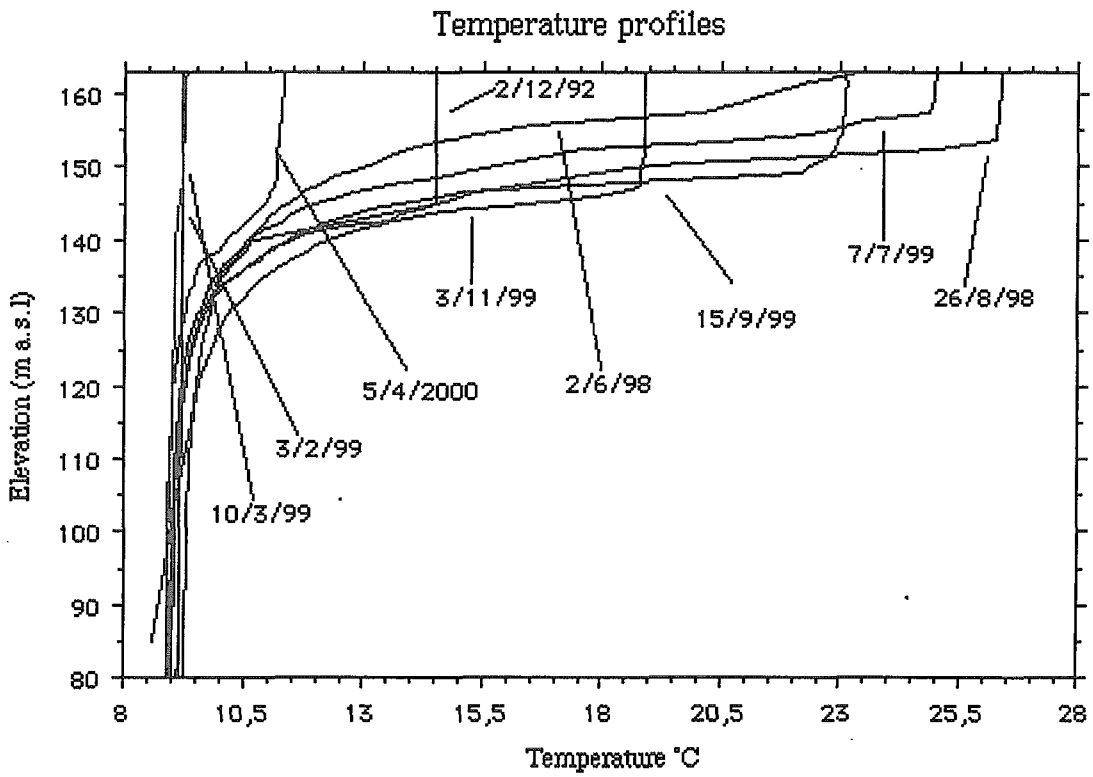

Fig. 6.2.5-2 Temperature profiles of water of Lake Bracciano.

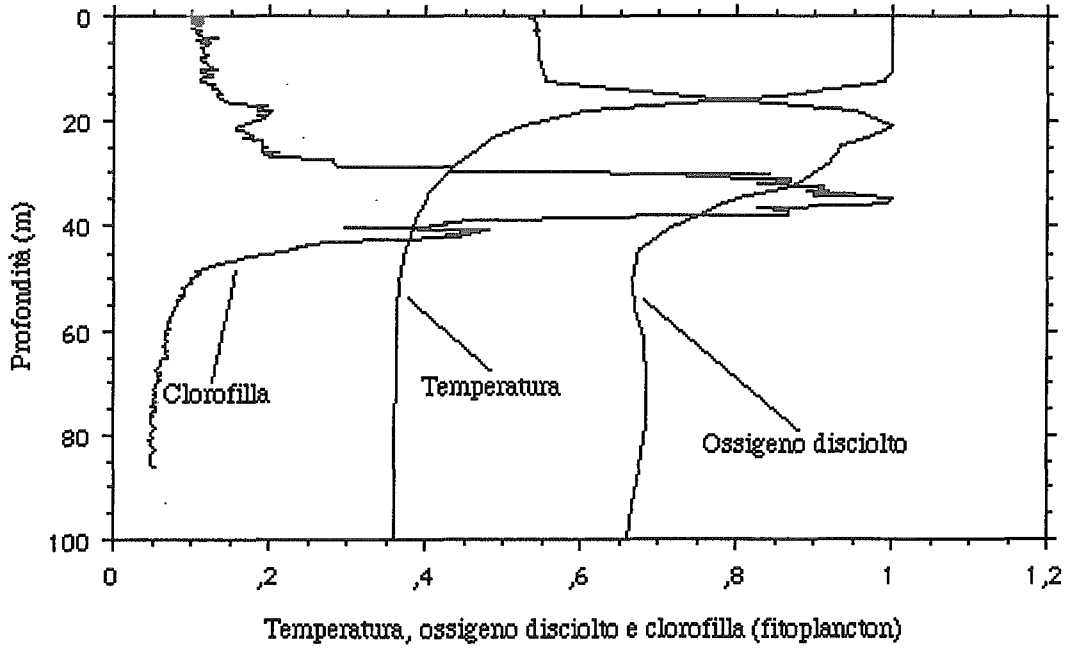

Fig. 6.2.5-3 Comparison of profiles of Chlorophyll, Dissolved Oxygen and temperature in lake Bracciano.

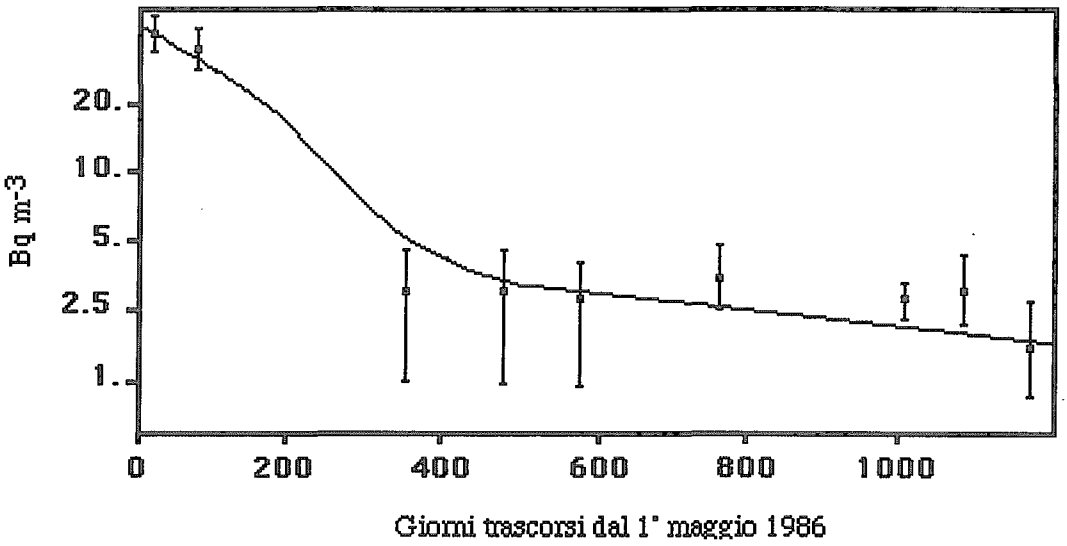

Figure 6.2.5-4 Time behaviour of ^{134}Cs concentration in Lake Bracciano. The x-axis reports the day from the Chernobyl accident.

6.3 Summary record of the visit

6.3.1. Laboratory of Geosphere Science, Hokkaido University

(1) Record of visit

Visited scientist: Dr. Seiya Nagao, Associate Professor, Laboratory of Geosphere Science, Graduate School of Environmental Earth Science, Hokkaido University, Sapporo.

Visitors : Luigi Monte, Takeshi Matsunaga

Date of visit: 28 May 2003

(2)Summary

Dr. Nagao gave a presentation on characteristics of ^{137}Cs and ^{40}K content in suspended solid collected from the Kuji River and the possibility of identifying the origin of the solid. The aims and the results of the Network EVANET-HYDRA and a presentation and a demonstration of MOIRA CDSS were provided by Monte. The presentations and the demonstration are reported in Section 6.2 (6.2.1 Lecture N.1 - The EVANET-HYDRA Network: Aims and achievements; 6.2.2 Lecture N. 2 - Presentation on MOIRA CDSS: 6.2.3 Lecture N.3 - Demonstration OF MOIRA computerised decision support system).

(3) Discussion

The followings is a summary of the discussion associated with the above presentations. Some of them are comments, and the others are questions followed by corresponding answers.

1) The concentration of ^{137}Cs in suspended solids is virtually unchanged with changes in water flow rate. When looking at the observed data more closely, a slow decrease in the concentration with increase in the flow rate is found. This seems to be reasonable. When water flow increases, particulate materials of larger size will increase. Those larger size particles must carry smaller amount of ^{137}Cs than fine particles. (comment)

2) By combining these radioactivity data with the mass concentration of suspended solids per unit volume of water, one will obtain data that give the opportunity of assessing the ratio of concentrations of dissolved and particulate radionuclides per unit volume of river water. (comment)

3) What is the lake ecosystem index? Is it related to levels of variation in radioactive contamination of a lake water body?

It is an ecological factor, not related to the contamination levels. It is used to assess the balance between costs and benefit of a countermeasure from a comprehensive point of view. The application of some countermeasures to lower the radiation dose to the population such as these based on chemical approaches may cause significant perturbations to the lake ecosystems. The question is whether this reduction of dose is a significant benefit compared with the damage to the lacustrine ecosystem. All these information (benefits and ecological damage, social impacts) are used by the Multi-Attribute Analysis module of MOIRA. The Multi Attribute Analysis module carries out comprehensive assessment of all those non-homogeneous values

(doses, economic costs, ecological detriment). (answer)

4) Is this the first model that evaluates economic, social and ecological impact simultaneously?

MOIRA is just one of such systems. At least concerning aquatic ecosystems, it is surely one of the most complete in this respect. The radionuclide migration model is only a part of the system. This is why the system is called a decision support system. The system consists of environmental models plus all the components that give a decision maker the possibility of assessing the result of an action or of an intervention in a comprehensive economic, ecological and social perspective. (answer)

6.3.2 Division of Quantum Energy Engineering, Hokkaido University

(1) Record of visit

Visited scientist : Professor Sadashi Sawamura,Division of Quantum Energy , Engineering, Graduate School of Engineering, Hokkaido University, Sapporo

Visitors : Luigi Monte, Takeshi Matsunaga

Date of visit : 28 May 2003

(2)Summary

Monte made a lecture entitled "Methodologies to predict the migration of radionuclides in fresh water systems and to assess the effectiveness of countermeasures to reduce the radiological consequences of nuclear accidents -The MOIRA Project". This lecture was co-sponsored by the Graduate School of Engineering and the Hokkaido Division of the Atomic Society of Japan, under the auspices of Prof. Dr. Sawamura - the Division President. The presentations and the demonstration are reported in Section 6.2 (6.2.1 Lecture N.1 - The EVANET-HYDRA Network: Aims and achievements; 6.2.2 Lecture N. 2 - Presentation on MOIRA CDSS: 6.2.3 Lecture N.3 - Demonstration OF MOIRA computerised decision support system).

(3) Discussion

The following is a summary of the discussion associated with the above presentations. Some of them are comments, and the others are questions followed by corresponding answers.

1) The system seems to be quite large. Accordingly, there must be many parameters to be evaluated. How much time did the development of the system take?

The MOIRA system development lasted for three years during the first stage financially supported by the European Commission (EU). In the second stage of another three years, the validation and the verification of the 1st version of the system was completed. At present, MOIRA is an object of assessment in the frame of the network EVANET-HYDRA, financed by the European Commission, that aims at the evaluation of computerized decision support systems (CDSS) like MOIRA. In the frame of this network, not only the MOIRA but also other similar systems are also examined. We have carried out further validation of MOIRA and further improvement of the system. I want to draw to your attention that MOIRA makes use of a small amount of parameters, whose values can be easily achieved by the user. (answer)

2) What about the applicability of the system MOIRA to the Japanese environment? It seems that we will have to assess the appropriateness of the (many) parameters.

This is the essential point of MOIRA. The idea of MOIRA was to develop environmental models that have simple structures so that the parameter values are easily obtained and, at the same time, so that the model can be applied to different kinds of environments and geographical conditions. MOIRA has been applied to lakes in Sweden and in Nordic countries and also to lakes in Mediterranean countries like Italy. In this way, we have already experienced applications of MOIRA to very different conditions not only with regard to the climate, but also to the kind of soil, the kind of vegetation, etc. (all these factors are important when assessing the behaviour of radionuclides in lake and through complex catchments). (Answer)

3) This system includes a cost-benefit analysis. The result of the analysis surely depends on what kind of parameters are used and on their values. The system will be helpful provided that one has a deep recognition on this point. (comment)

This is a very important point. I agree with you. The MOIRA has a multi-attribute analysis module that aims at an assessment of the most appropriate countermeasures. In the process of analysis, we are concerned with factors that show very different levels of importance depending on different economic, social and environmental conditions. The result will be influenced by the subjective importance attributed to these factors in relation to the above conditions. The weight of the attributes in the analysis are functions of social, economical and cultural conditions of the specific society. However, if one considers the situation of the society, it is possible to define, beyond the application of a CDSS, appropriate weights to the parameter values involved in this analysis. For instance, the manpower cost can be very different in different countries, but can be defined in some way. Obviously, this difference can affect the assessment of the most appropriate countermeasures. (answer)

4) Even in one country, there can be many bureaus responsible. Then, who will make the final decision (about the countermeasures)?

This is no more a question for MOIRA. As a personnel opinion, a decision support system will play the role of a support in decision making process. It does not aim at making the decision, but at giving help. Giving help in the decision means to supply a decision maker with all the scientific and technological knowledge in a coherent, simple way, so that he can easily manage such a complicated matter. (answer)

5) Concerning the emergency reactions, we should have had learned much from past accidents. (answer)

6.3.3 Japan Nuclear Fuel Limited

(1) Record of visit

Visited facilities : The Rokkasho Nuclear fuel cycle facilities, Environmental and Radioactivity Monitoring Centre. Safety Technology Office, Japan Nuclear Fuel Limited, Rokkasho-mura.

Aomori.
Organizer :Dr. Akihisa Takita, Japan Nuclear Fuel Limited, Rokkasho-mura. Aomori.
Visitors : Luigi Monte, Takeshi Matsunaga
Date of visit :29 May 2003

(2) Summary

The Japan Nuclear Fuel Limited operates three facilities at Rokkasho: a uranium enrichment plant, a low-level radioactive waste disposal plant and a vitrified high-level waste storage centre. Moreover, a nuclear spent-fuel reprocessing plant is under construction to complete the nuclear fuel cycle. Sufficient documentation was supplied to understand, at a deep level, the main principles for the operation of such complex nuclear facilities. Care was particularly devoted to clarify how the entire management of the nuclear cycle takes care for the environment and for human health safety.

Nuclear energy accounts for almost one-third of the Japan electricity consumption with, approximately, fifty reactors located in various sites of the country. This large use of nuclear energy is motivated by the finite availability of fossil fuel and of the huge attention recently given to the global environmental problems (for instance, global warming and acid rain) caused by tCO_2 emission.

6.3.4 Department of Environmental Behavior Research, Institute for Environmental Sciences

(1) Record of visit

Visited scientist : Dr. Jiro Inaba, Department Director; Dr. Kunio Kondoh, Deputy Director; Dr. Shun-ichi Hisamatsu; Dr. Shin-ji Ueda; Dr. Hirofumi Tsukada; Dr. Hideki Kakiuchi; and Dr. Yoshihito Ohtsuka of Department of Radioecology, The Institute for Environmental Sciences, Rokkasho-mura, Aomori.
Visitors : Luigi Monte, Takeshi Matsunaga
Date of visit :29-20 May 2003

(2) Summary

Dr. S. Ueda described a hydro-dynamical model of brackish lake Obuchi. Lake Obuchi is located in the Aomori prefecture. It has an area of 3.7 km^2 and a mean depth of 2 m. (maximum depth 4.5 m). The lake is connected to the Pacific Ocean through the Obuchi river. River Futamata is the main inlet of the lake. It is surrounded by the nuclear facilities in Rokkasho: a uranium enrichment plant, a low-level radioactive waste disposal plant and a vitrified high-level waste storage centre.

The distribution of dissolved substances in the lake water are strongly affected by stratification phenomena of the water column. These are particularly significant for the formation of halocline in the lake.

The lake has been object of many research projects in order to assess the behaviour of those processes that can influence the migration of radionuclides. The hydro-dynamical model presented by Dr. Ueda is based on the most relevant processes that determine the behaviour of the water current in the lake. These are important for assessing the water fluxes from and to the ocean. A practical demonstration of how the model works was supplied.

Dr. L. Monte (guest scientist from ENEA) presented the results of some researches carried

out for modelling the behaviour of radionuclides in lakes. The performance of this model in predicting ^{90}Sr and ^{137}Cs in many Italian lakes contaminated both from the fallout due to the Chernobyl accident and to the nuclear weapon tests in atmosphere of past decades was presented. In particular, data of transfer parameters determined for the volcanic lakes in central Italy was presented and discussed.

The presentation demonstrated also the important influence that the thermal stratification of lake water has on the distribution of dissolved substances and on phytoplankton . Such an influence has been clearly demonstrated by measurements of the profile of dissolved oxygen, of chlorophyll and ^{137}Cs and ^{134}Cs introduced in the lake following the Chernobyl accident that happened during the formation) of the water thermocline (months of April and May. A demonstration of MOIRA CDSS was also supplied. The presentations and the demonstration are reported in Section 6.2 (6.2.2 Lecture N.2 - Presentation on MOIRA CDSS: 6.2.3 Lecture N.3 - Demonstration OF MOIRA computerised decision support system).

(3) Discussion

The following summarizes the discussion associated with the above presentations. Some of the items are comments, and the others are questions followed by corresponding answers.

1) It is known that ^{90}Sr shows very sensitive behavior for introducing of organic materials to water body. Has this point been considered in your study ?

Strontium-90 is prevailingly in dissolved form in water. Probably, to model ^{137}Cs will be more complicated because of the effect of sediment deposition. This is the most unpredictable process in the environment, for which it is necessary to have much site-specific information. The site-specific information needed differs for different kinds of environmental conditions. Moreover, different kinds of lakes showing different ecosystem properties can exist in the same environment. For ^{90}Sr, the situation is more simple, because it is essentially in dissolved form in water. This means that the sedimentation is absolutely negligible, whereas the migration of ^{90}Sr to the sediment generally being due to a direct interaction process. The other second important point is migration to the biota, namely from the viewpoint of dose evaluation. ^{90}Sr prevailingly accumulates in bones. Therefore, generally speaking, ^{90}Sr will not contribute much to human exposure dose except cases when freshwater fish is consumed including fish bone. The transfer of radionuclides to biota for human consumption and also the relevant countermeasures are considered in the MOIRA system. (answer)

2) Suspended solids are considered in the model. Is this also the case for the ^{90}Sr?

Consideration of suspended solids are in order to give generality to the model. For ^{90}Sr, the suspended solid is less important. Taking into account the uncertainty in parameter values, suspended solids can be neglected in the case of ^{90}Sr. Particulate form of ^{90}Sr has a very minor contribution. (answer)

3) Have you ever tried to analyze the radioactivity in the bottom sediment of a lake ?

We have done a campaign of such kind of measurement in the Lake Monterosi in Italy. We

have measured the vertical profile of ^{137}Cs and ^{90}Sr. As a result, it was found that ^{137}Cs concentrated in the upper sediment layer, then showed a fast decrease with depth. In case of ^{90}Sr, the situation was different. Strontium-90 showed lower concentration in the first layer with prolonged distribution for deeper layers. It tends to migrate faster. This is the reason why the transport velocity from the water column to the sediment is not so strongly dependent on the value of the distribution coefficient (k_d). The kd of ^{90}Sr is very small compared to that of ^{137}Cs. There are two competitive mechanisms involved in the transport from the water column to the sediment. Cesium-137 strongly interacts with the sediment, but it has less ability to migrate within the sediment. So the flux is limited by a slow migration into the sediment matrix.. The case of ^{90}Sr is exactly the opposite. It has slow interaction with the sediment and fast migration in the sediment. These two processes operate inversely. As a result, the whole process of the migration from the water column to sediment yields results which are somewhat similar for these two radionuclides. Of course I am speaking of the migration of the dissolved fraction of radionuclides. Migration processes due to sedimentation of particulate forms are very different for the two radionuclides.(answer)

4) Is resuspension of the bottom sediment considered in the model?

A flux of a radionuclide from the bottom sediment to the water column is considered. Further, one should note that the flux is based on the diffusion process in the case of ^{90}Sr. Resuspension process for a radionuclide of high kd value like ^{137}Cs is significant, so the flux is based on the resuspension of particulate matter. Also, the non-reversible adsorption to the sediment is considered for ^{137}Cs. It is well known that ^{137}Cs exhibits non-reversible adsorption in various circumstances. Due to this non-reversible process, a part of ^{137}Cs can never migrate back to the water column. The first interaction with the surface of the bottom sediment, the following migration within the sediment, and the non-reversible adsorption processes are concurrently accounted for modelling the behavior of the radionuclide in the water-sediment system in relation to the specific characteristics of the radionuclide. (answer)

5) It seems that the diffusion process is more important in deep lakes than in shallow lakes. (comment)

All the problems relevant to mechanisms of diffusion have been studied for volcanic, deep lakes. Deep volcanic lakes have clear water and have a small amount of suspended solids, so that sedimentation processes are negligible. Those lakes are very useful to evaluate the diffusion process. However, the model included in the MOIRA is not necessarily only for such deep lakes. In fact, MOIRA has been successfully applied to many other kind of lakes such as shallow lakes with large surface area in which the radionuclides are subject to sedimentation and resuspension.

By the way, some conclusions from the assessment carried out in the frame of EVANET-HYDRA suggest that most of the models developed by different researchers in Europe have similar features and structure and that they can be applied to many different circumstances.

In the paper distributed, there are applications of the models to many different lakes in terms of the water depth, are of lake surface and chemical and environmental characteristics as well (for instance, the Lake Kyshtym in Russia that has only about two meters depth, a Swedish lake of 1-2 m, and another lake having a mean depth of 150 m and about 300 m at the deepest point).

(answer)

6) Comparison of the behavior of a radioactive element with that of a corresponding stable element is an important subject. (comment)

7) Some results from the International Project of BIOMOVS deals with the assessment of models for predicting the behaviour of substances and radionuclides other than ^{137}Cs and ^{90}Sr. The problem is that comparison of model results with experimental data sets is not always possible. For ^{137}Cs and ^{90}Sr, we have a very large amount of data-sets following the Chernobyl accident, the Kyshtym accident and others. On the other hand, for other radionuclides the dataset is not so extensive. I want to focus your attention on the fact that, according to real experience such as the Chernobyl accident, the most important radionuclides in the fresh water environment on the medium and long term are the isotopes of ^{90}Sr and ^{137}Cs. Surely, the prediction uncertainty will be higher for other radionuclides (due to shortage of experimental datasets). But they will be less important compared to those two radionuclides (^{90}Sr and ^{137}Cs). (comment)

8) Anyhow, I want to draw your attention on the fact that a model is not a tool for making a magic prediction. In my opinion, a model is a tool to be used to manage knowledge. A model gives the opportunity to use acquired knowledge in a mathematical and logical way to consider interrelations among the different components of the afforded problem. It allows understanding of what is happening in the environment and what will happen, in a critical way. One can summarize all the knowledge on the environment in a model. Then, the model will become a pathway to use the knowledge in a rational and an effective way. Accordingly, if one has acquired more knowledge, the model that includes these becomes more reliable. (comment)

9) In one of the BIOMOVS reports, the problem of the behavior of mercury in river water has been discussed. (comment)

I do not know the detail of the discussion because I did not participate in the mercury subject. Besides mercury, they discussed the question of radium in water. In general, to my opinion, the model results will be uncertain for those kinds of elements or radionuclides. This is because there are less experimental data for those elements, whereas much data exist for ^{137}Cs and ^{90}Sr. Moreover, the Chernobyl accident was a so-called pulse accident. According to the theory of a system, you can get the maximum information about the behaviour of the system if you set an input to the system as a pulse function. This could be done following the Chernobyl accident. (answer)

10) This is a question about the movement of radionuclides from the catchment to river water. This process seems to be very important in this geographical area. This because there is a reprocessing plant here, a shallow lake, and a river system in connection with the lake. Do you have any plan to investigate the movement of the fallout from a catchment to a river water body ?

That is a good point. Following the Chernobyl analysis, it was possible to carry out such kind of work. Actually it has been done by many researchers. The behavior of migration of

radionuclides from catchments to rivers in Ukraine such as the Pripyat River, the Dnieper River in Ukraine, the Techa River in Russia and so on, that was strongly contaminated by the Chernobyl deposition, has been assessed. Similar work has been done in the United Kingdom, Dr. Smith , a member of the EVANET-HYDRA project. And we have prepared a report to make an assessment of all the models used in Europe. Most of the analyzed models are lake models that have been developed in Europe for accounting for the experimental evidence following the Chernobyl accident. Common structures in different models have been recognized. It has been also recognized that it is possible to have a good dataset of transfer parameters from a catchment to a river water body for realistic applications. Results of this assessment will be opened on the website of EVANET-HYDRA in soon. (answer)

11) It is really important to have a look at the ecological consequences that result from the migration of radionuclides in the water body. (comment)

12) How the people use this lake for hobby-fishing or fishery ?

Fishing is prohibited in the lake. Still, there are several fishing boats on the lake. The result of fishing is not very good. (answer)

13)From the dosimetric point of view, the influence will be negligible. Research on the radiological safety in the lake has environmental significance. The lake is a symbol of the nature of this area. Therefore, preserving the lake from any radiological contamination will surely be very much appreciated. (comment)

6.3.5 Kyoto University Research Reactor Institute, Kyoto University

(1) Record of visit

Visited scientist : Dr. Masami Fukui, Associate Professor; Dr. Tomoyuki Takahashi,; Dr. Fukutani of Division of Nuclear Safety Research, Kyoto University Research Reactor Institute, Kumatori.

Visitors : Luigi Monte, Takeshi Matsunaga and Katsunori Tsuduki

Date of visit : 2 June 2003

(2)Resume

An interesting visit to the 2 MW research reactor of the University of Kyoto was organised. L. Monte gave a demonstration of MOIRA and a presentation on the principles for structuring migration models based on collective processes. Presentation of the concepts behind the hydrology model of JAERI under development was made by K. Tsuduki. Following the presentations, issues for i) adoption of a model for Japanese environment and ii) validation of a model were discussed. The presentations and the demonstration are reported in Section 6.2 (6.2.3 Lecture N.3 - Demonstration OF MOIRA computerised decision support system; 6.2.4 Lecture N. 4 - Methodology of collective models -Model uncertainty and environmental complexity-).

(3) Discussion

The following is a summary of the discussion associated with the above presentations. Some of them are comments, and the others are questions followed by corresponding answers.

1) Do we need a contaminated area for which experimental observations are possible to determine the values ? Or can we determine them by theoretical evaluation ?

Let us talk about the distribution coefficient (k_d value), for instance. Suppose one uses the concept of the distribution coefficient, there can be two ways further. They are i) to consider the kd as a basic parameter, and ii) to consider it as a secondary parameter that can be derived by other parameters. In other words, there are two ways to consider the k_d; as a generic parameter or as a site-specific parameter. Then, a question how to classify parameters into generic and site-specific ones comes out.

Strictly speaking, in case of radionuclides, only the physical decay constant of a radionuclide is a genetic parameter. All the others are site-specific ones. Therefore, an answer to the above question can not be a single, rigorous one. A wide variety of answers can exist. (answer)

2) Clarification of the terms of "generic" and " general":

The term "generic" is used to indicate a parameter for which one has no site-specific data, and for which one has to use an estimated value. Those generic values are sometime provided in literature. For instance, IAEA has published several reports of the set of generic values used in models concerning environmental radionuclides. (comment)

3) Values of kd and even transfer coefficients are compiled in IAEA Technical Report Series No.364 (Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments, 1994). Are those listed values considered as generic values ?

That publication is a supplementary report of another publication. The latter is IAEA Safety Series Report No.57. This report is on generic models and generic parameters. The Report No.364 chiefly consists of a list of parameter values determined in a wide range of different conditions. For instance, it compiles kd values for lake sediments and so on. These are the results of measurement in specific, complicated conditions. Of course, those specific values are never generic, because the systems in which those measurement were made are different from the system of him (the system of concern at present). One has to do some evaluation to obtain a generic value. The resultant generic value will be much different from values of actual measurements. In short, the values in the Report 364 should be considered as "example" values.(answer)

4) Still, in some cases it will be possible to use values listed in the IAEA Safety Series Report No.57 as generic values. Appropriateness of such depends on the purpose of the syudy. For example, the values in the report can be used for a safety assessment, whereas they can not be used as generic parameters for a realistic case study. In the latter case, site specific values shall be used, rather than those in the report.(comment)

5) That statement is correct. But, that does not mean it is possible to use values from other

publications in a specific application. This is because these values are specific for some environment. When one has a specific environment to be assessed, he will have a similar problem. Suppose one wants to estimate a value of k_d for the Lake Biwa without field measurement. None of the values one finds in the literature will be satisfactory. There is no possibility that this is the right value. One can find a list of parameters are relevant to different systems and different materials, but he(she) can never find his(her) system in the list. (comment)

6) Indeed, the Report 364 provides a list of parameter values. But they do not include an answer to the question what are the parameters in your system. This is the point. (comment)

7) But they are still important., because they offer a possibility of understanding how much that parameter varies. This is significant information for many studies. (comment)

8) In those IAEA publications, k_d values for Japanese environments are fewer than those for other countries. How can the Japanese modeller, they obtain k_d values for Japanese environments? Possible answers may be, i) he(she) must carry out experiments in Japanese environments, ii) still he(she) can use the listed values from those publications nevertheless.

IAEA has published a new version of the publication. There some surprising differences between the new Tables of kd and the old ones. This is a demonstration of how difficult it is to obtain reliable values of k_d. They are very variable for different environments. For instance in Italy, kd of ^{137}Cs ranges from 10^6 l kg^{-1} for the Po River in north Italy to 10^3 l kg^{-1} for a certain lake in central Italy. (answer)

9) There is another point of view. Let me take an example of ^{137}Cs. Cesium-137 interacts with sediments in a number of ways. It seems, following a number of experiments on adsorption of that radionuclide, that its interaction with sediments and/or particulate materials can not be simply modelled by the k_d concept. This is because that there are many non-reversible interactions. Therefore, the adsorption process becomes much complicated. There is high variability in its k_d values. Also, the adsorption behaviour of radionuclides is complicated. (comment)

10) As for the second point, when one tries to make a laboratory experimental measurement of k_d, one can be never sure that he(she) is determining a value that can be used for a real application. Firstly, he(she) has completely changed the environmental conditions. On the one hand is the laboratory conditions. On the other hand is what happens really in natural systems. Secondly, one doesn't know the manner of contamination; it can be very complicated. When one carries out experiments in laboratory, pH value, chemical composition of a solution, and other conditions can be controlled. (comment)

11) Fundamentally, a modelling is a way of critical assessing, not of prediction. (comment)

12) What must be appreciated is the effort made for a bridge between the laboratory experiment and the field observation. An analysis of the k_d database of the National Institute of Radiological Sciences showed how significant to control experimental conditions in the laboratory and to

report them in detail.(comment)

13) The problem is, in general, that k_d is not so effective as a model parameter. This is especially true in case of ^{137}Cs. Cesium-137 has a very peculiar behaviour. For instance, just after an accident such as the Chernobyl accident, you will find its kd value is lower than that observed after some years. This is because of irreversibility of its adsorption. This implies that a modelling of the behaviour of ^{137}Cs requires more parameters. The idea of the collective modelling is practically related to this point. By using the field observation data on concentrations of both dissolved and particulate forms of a radionuclide in river water, it is possible to construct a model on both forms directly, skipping over the k_d concept. (comment)

14) On the other hand, it is really a matter of question what method can be used in Japan? In Japan, it is not practical to use the described method because no significant radioactive contamination in the environment has occurred. (comment)

15) What natural factors should be taken into account in a model for Japanese environment ?

One of such factor is the presence of rice paddy fields. The rice paddy fields play different roles in dictating the migration of toxic substances in a watershed. The roles are: i) the paddy fields provide anoxic conditions that may make toxic metal and some radionuclides more mobile or less mobile; ii) the water mass balance may be affected by the intake flow to the fields and the return flow from the fields. (comment)

16) Concerning the first point, the presence of cyclic change among periods of wet and dry conditions may act as a factor to accelerate the mobility of toxic substances. And, as for the second point, inter-exchange of irrigation water between different watershed sometimes makes the water mass balance complex. (comment)

17) The presence of paddy fields is obviously important. Similarly, an influence of snow melting on water quality is also important. It has been found that some toxic substances show high mobility in the period of snow melting. A part of the fallout of those substances stays on the snow. When the snow melts, that part starts to move. The paddy field can have a similar effect. When the water in the fields is drained through a dyke, some deposited fallout on the fields will be drawn to a stream. (comment)

18) The different tools we have spoken of should be used in an integrated manner. This is because no tool alone is enough to describe a particular situation.(comment)

19) We had better abandon the "either-or" approach in model development and choice of parameter values. A kind of integration of different ideas must be prerequisite. One good example is an effort to seek for a bridge between the datasets of laboratory k_d values and those of field observations. (comment)

6.3.6 University of Shiga Prefecture

(1) Record of visit

Visited scientist : Prof. Dr. Takao Kunimatsu, Department of Ecosystem Studies, School of Environmental Sciences, Hikone.
Visitors : Luigi Monte, Takeshi Matsunaga and Katsunori Tsuduki
Date of visit : 3 June 2003

(2)Summary

A presentation of the concepts behind the hydrology model of JAERI under development was provided by K. Tsuduki. After the presentation and demonstration of MOIRA by Monte, some general discussion on modelling methodologies, modelling aims and modelling applications was carried out. Models are tools for managing problems. They are essentially aimed at framing in a rational scheme the acquired knowledge concerning a system. Therefore the real, definitive usefulness of models lies in their true nature as "tools for thinking". The presentations and the demonstration are reported in Section 6.2 (6.2.2 Lecture N. 2 - Presentation on MOIRA CDSS: 6.2.3 Lecture N.3 - Demonstration OF MOIRA computerised decision support system).

(3) Discussion

The followings is a summary of the discussion associated with the above presentations. Some of the items are comments, and the others are questions followed by corresponding answers.

1) Concerning the problem of contaminant transport in a watershed, a modeling approach has not been widely used in Japan so far. It seems that, in Europe, the Chernobyl accident stimulated that modeling approach for the problem of atmospheric deposition of radionuclides.(comment)

2) Japan has no such serious contamination of a land due to atmospheric deposition. A method using a production ratio of contaminants per unit area or per unit population has been applied long for most cases in this country. Still, such a new necessity related to environmental radionuclides and other toxic substances can lead to a new approach. (comment)

3) From the experiences of Prof. Dr. Kunimatsu in the study of a compartment model in urban areas, possible reasons for changing the methodology would be as follows: i) changeable weather of Japan, located in a region affected by the Asian monsoon climate; ii) complexity of Japanese geology coming from the pre-Cambrian strata. These natural conditions require so many parameters that it is hard to construct a model adequate for a practical use. (comment)

4) In a case when a large area has a uniform nature with respect to its climate, geology and other environmental conditions, it will be possible to make a practical model.(comment)

5) What has been missing in the modeling study in Japan that how integrate different types of sub-models into a single system. Those sub-models are of i) hydrology, ii) contaminant transport, and iii) economy. They have their own, specific time-scales e.g. in hours, days or even years. Therefore, the problem of time-scales adjustment remains, for instance. These difficulties have not been solved yet in academic communities of Japan. (comment)

6) When we look at an environmental problem at some specific locality, the most experienced and informed specialist is a local authority. He(she) may have a good way to solve problems. Under this circumstance, a model will be able i) to confirm the reasonability of the solution, ii) to present general solutions , and then iii) to provide an occasion to find the most reasonable solution. However, it will be difficult to deduce the best solution only from results of a model.(comment)

7) Regretfully, there has been a lack of practical use of a model in the catchment management in Japan. There is a possibility that a model will gain reliability, when the model is applied to actual situations and improved repeatedly after each application. (comment)

8) Japanese modelers have developed their models just to show their individual creativity. The models have been developed like works of arts, not to be valuable in real situations. Even if a model is very sophisticated and "brilliant", it is of no use if it can not solve a practical problem. (comment)

9) In response to the matter of time scale, the MOIRA has a well-defined time scale. It is used for medium-term and long-term assessment. The MOIRA is not aimed at management of emergency situations.

10) MOIRA is chiefly designed to support decision making on action to be taken in the future. The prediction by MOIRA for events in a short period of time after the incident may include relatively larger uncertainty. Therefore, if it is to be applied to short-term assessment for the management of actual contamination, it must be used accounting more carefully for experimental results, or results of monitoring. (comment)

11) One needs a model to be able to assess the medium- and long-term behavior of the radionuclide concentration. It has been demonstrated that many processes which are included in the medium and long-term assessment can be assessed by the MOIRA statistical approach. Let's take a simple example, raining. One can not predict definitely rain tomorrow. But, there certainly is reliable statistical data on the average precipitation for next month. This is one of the essential points of the MOIRA system. (comment)

12) Concerning how the expert can use MOIRA, one should note that MOIRA is a so-called decision support system. It is not a decision making system. (comment)

13) The MOIRA has two functions. Firstly, it can provide a critical assessment. The output of the MOIRA will be more reliable if it is modified according to observations of transport modes for a specific area and judgments of the expert. comment)

14) Europe has, fortunately or unfortunately, a very unique radiological situation. The land of Europe has been contaminated to an easily measurable level of radionuclides due to the Chernobyl accident. The MOIRA system has been applied to many aquatic systems in Europe such as lakes in Sweden, UK, Italy, Ukraine and also in Russia. Therefore, it can be said that this model has been well validated through those applications. We have also tried an application of

the entire system to a real case. The result of this exercise was somewhat surprising itself. Still, it demonstrated the importance of such MOIRA tools for critical assessment in a case of a nuclear accident. This is because this is very useful for deciding what kind of interventions are absolutely inappropriate for management of aquatic systems.(comment)

15) Concerning the unique Japanese characteristics with regard to natural conditions or land use, what should or should be given weight in a modeling work for catchment management ?

Relatively low weight should be given to phenomena that occur between a precipitation event and the water inflow to a large water body such as a lake. This is because the traveling time of the water is so short only a few hours in most of streams in the Biwa Lake catchment. It is efficient to concentrate our attention on macroscopic aspects when we adopt a modeling approach. Otherwise, a model becomes too complicated for practical use. Exceptionally, a detailed model may needed to follow quick response of water flow in time and space. (answer)

16) Essentially, the simpler model is the better one. However, a sophisticated model is often admired by researchers. One should remind oneself that a model is a tool. Modeling is far from real science, but it is still important. Recognition of these points is strongly required for modelers. (comment)

17) A model is not a means for exploring new principles. The role of a mode is to predict what will occur with greater confidence by re-arrangement of existing knowledge.(comment)

18) The critical difficulty for a model is that it is not possible to accommodate unexpected phenomena. This is because a model is combination of existing knowledge, as has been pointed out already. For instance, let's consider a countermeasure for lake contamination by a certain substance. One may introduce a special species of fish that concentrates the toxic substance, with an aim of clean-up of the water body. It may be possible to predict the uptake of the substance by the fish based on an ecological model including the habitat of the fish, the favorite locations in the lake and so on, provide that the fish are always alive. However, one can never be certain when the fish will die and then what will follow regarding the management of the toxic substance in the fish body. (The death of the fish is supposed an unexpected event for a convenience of this explanation.) What is most important must be to respond to an unexpected event. As long as a model is based on the observations up to the present, this mandate -to respond to an unexpected event- will be an ever-lasting difficulty for a model.(comment)

19) It is often disliked to use a model developed by others. One tends to use his own model. At the same time, there is a limited effort to open a model in an available manner for others, in case of Japan. (comment)

20) Of course, what is the real advantage of the model is to put together a great deal of experimental evidences, natural phenomena, and practical experience into a logical, rational frame. This is the ultimate feature of a model. A model uses this knowledge and organizes it in a rational structure that is reflected in a mathematical structure. This means that the goal of modeling work is management of our knowledge in most effective way. It is not for acquiring

new knowledge.(comment)

21) A model requires a various kinds of data sets of specific knowledge, and experimental evidence. In those data sets there may be erroneous registration of the parameter values or experimental evidences with disregarding the limits of use, and so on. In such cases, who will be responsible for correctness of the data and for updating of them? In past, there was an such argument in Japan related to the so-called expert-system for a medical diagnosis.

In European society, there is a different way of approaching this kind of problem for practical application. Different bureaus with different responsibilities are involved in the accident management. In general, there is a group of experts that is involved in such assessment on countermeasures for environmental contamination. This group has responsibility to supply consultancy to these organizations which are making decisions. The responsibility of the experts is limited to the group. They are not responsible for the result of the decision support system.

The group mentioned above is capable of using different kinds of tools and information to predict and assess consequences of countermeasures for an accident. Results of the monitoring, software of decision support systems, and the experiences of the members of the group are include in those tolls and information. They have no direct responsibility for each single tool. The responsibility of the entire group of the advisers is to decide if the result of a decision system and other tools is reliable or not. (answer)

23) Consider a case when a wrong scientific result has been registered in a data base of a decision support system. who should be blamed for this? The original scientist ? The manager of the data base ? The advisory group or the decision maker who relied on the result ?

In the case of the MOIRA system, it has been constructed for different kind of users, namely i) for expert users and ii) for non-expert users. An expert user can go inside the system and modify the data base or even the model itself. He(she) can do this when it is necessary to fix the erroneous registration. Anyway, the question is not a real problem. This is because there is no problem related to responsibility of an individual. Of course, in case of an accident, there will be a group that will be surely responsible to authorities for the quality of the results. This group that must decide if a specific result of MOIRA is appropriate or not. The same applies for the result of any other tools, any other assessment.

The decision support system itself is not responsible. The group does its best to get the most accurate advice by using various kinds of tools and information. For instance, IAEA (the International Atomic Energy Agency) has published much guidance related to models and model parameters for management of environmental problems. These surely are tools or supports for decision makers. However, when they make a wrong decision using those published documents, the responsibility lies with the people who used those documents.(answer)

24) Listening to that statement, it sounds like the final user must have all the responsibility. This means that the advisory group must have complete knowledge, and it also requires great investment to have a staff that carries out updating the knowledge data base of a decision support system. Even if the software of a decision support system can be obtained cost-free, its maintenance will require a large cost. The maintenance of a decision support system will be a

serious question when it has been adopted by the authorities for practical use after its development. (comment)

25) All the models included in the MOIRA system have been developed following the experiences in the aftermath of the Chernobyl accident. State-of the art models are available for the behavior of radionuclides in lakes. The models can be driven with the limited data which is absolutely necessary. Therefore, a large amount of site specific data is not necessary at all. (comment)

26) A problem of acquiring a site specific data does not occur with the models in MOIRA. The system MOIRA is not costly. The system MOIRA has been validated under many circumstances. This is a good guarantee for the advisory group. (comment)

27) Indeed, there exists the problem of improvement of parameters. The improvement of the parameters shall be carried out together with an improvement of a model structure itself based on new experimental evidence. (comment)

6.3.7 Lake Biwa Research Institute, Shiga Prefecture

(1) Record of visit

Visited scientist : Dr. Takuya Okubo; Dr. Yoshiro Azuma, Lake Biwa Research Institute, Shiga.

Visitors : Luigi Monte, Takeshi Matsunaga and Katsunori Tsuduki

Date of visit : 3 June 2003

(2)Summary

Firstly, a presentation of Lake Biwa Research Institute (LBRI) activities was done by Dr. T. Okubo. LBRI is aimed at carrying out interdisciplinary studies and research for the definition of sound policy of management of Lake Biwa and its watershed environment. Impact of human activities on Lake Biwa are indeed significant. Dr. Azuma presented the project, Examination of Alternative Policy Measures by GIS for Restoration and Enhancement of the Watershed Environments. This project has been led by Dr. Azuma. Interestingly, in this project, participation of the local citizens was realized for examination of the water quality restoration. It turned out that this participation worked very successfully. The importance of considering the environmental problem altogether with local citizens was stressed.

Dr. Ohkubo further explained a recent study carrying out a numerical simulation of the water quality includingas turbidity, chlorophyll-a concentration. The first validation of the model has been carried out based on daily monitoring of the water quality during two months. The present model is for a shallow lake. A model for a deep lake having a stratification will be developed hereafter.

The performed research are both of basic and specific character in view of the awareness that the proper and effective management of lakes requires the understanding of natural and social sciences. Dr. Tsuduki gave a presentation on the concept of the hydrology model of JAERI under development. Dr. L. Monte supplied a description and a demonstration of MOIRAand a

brief discussion about the main processes affecting the distribution of dissolved substances and phytoplankton in stratified lakes. The presentations and the demonstration are reported in Section 6.2 (6.2.2 Lecture N. 2 - Presentation on MOIRA CDSS: 6.2.3 Lecture N.3 - Demonstration OF MOIRA computerised decision support system; 6.2.5 Lecture N. 5 - Water stratification and influence on the distribution of dissolved substances in deep lakes).

(3) Discussion

The following is a summary of the discussion associated with the above presentations. Some of the issues are comments, and the others are questions followed by corresponding answers.

1) What factors do you consider in the final evaluation of the effectiveness of the countermeasures that you have applied or planned? For instance, you have shown countermeasures to reduce the load of suspended solid. Have you ever carried out an assessment in terms of balance between the total environment improvement and the economical cost ?

In spite of various countermeasures tried in this area, an effective one has not been found yet. This is one the reasons why a different kind of countermeasures has been tested. Observed decrease of the load of suspended solid is mainly due to the decrease of area of arable fields. It is not necessarily attributable to the countermeasures.(answer)

2) Concerning the cost assessment, several presented methods are costly so that these have not yet developed for the area. It seems that a proper lecture on the meaning of the countermeasures to the public is required at first. (comment)

3) To save the water amount for irrigation use is an important issue. Many facilities have been constructed for this objectives However, they have not been as fully utilized as expected. (comment)

4) One of the problems of a lake certainly is the overuse of fertilizers in agriculture. A load of fertilizers from arable fields to a lake gives excess nutrients to the water body. Have the people involved in the agriculture accepted the suggestion of reducing the amount of fertilizers ? Is it possible to lead them to manage use of fertilizers more effectively ?

A suggestion that the discharge of fertilizers to water bodies will not be beneficial for crops seems to have been effectively accepted.(answer)

5) One the aims of the lecture seems to be development of an appropriate use of fertilizers. Isn't it ?

The lecture mentioned is about the environmental impact of the overuse of fertilizers. (answer)

6) Concerning the solute transport from the catchment of the lake Biwa, the inflow of nitrogen and phosphorus to the lake has been studied. This is in order to clarify the contribution of those two nutrient elements to the growth of phytoplankton in lake water. The contributions depend on

their form of inflow. The particulate form is considered to have less contribution because the particulate materials will deposit on the bottom of the lake. Desorption of those elements from the sediment seem to hardly occur except a release of some phosphorus in anoxic circumstances. It has been well known that the load of the particulate form increases drastically in a precipitation event. In order to discriminate the load of two forms, field observations including precipitation events have been continuing. (comment)

7) As found in the observed data, the load of suspended form of the nutrient elements depends not simply on a precipitation event. The load is related to the length of the period of certain agricultural practices. In a period of irrigation, the load increases much more than that in a non-irrigation period.(comment)

8) Agro-chemicals are also in the scope of the study at the Lake Biwa catchment. In case of agro-chemicals, their load in a precipitation event is not that much larger than that in fine days. This is a feature contrasting to the load of nitrogen and phosphorus. It was found that desorption of agro-chemical bound to suspended solid is not significant. For these reasons, for agro-chemicals, their dissolved form has been give much more study. (comment)

9) In the Lake Biwa, it is difficult to detect the dissolved form of agro-chemicals because they are already diluted greatly. A method of a bio-assay is of no use for those low concentrations. Therefore, a development of a mathematical model to simulate the fate of discharged agro-chemicals in the lake, rather that carrying out field observations is needed. (comment)

7. Concluding remarks

7.1 Summary of discussion

(1) Key problems

After the discussion and the presentations at JAERI (Chapters 3, 4 and 5) at the selected Japanese institutions (Chapter 6), it was clarified that the key problems in the modeling study on migration of harmful substances and accidentally released radionuclides in a river watershed are as follows.

1) Need for the study relevant to fluvial transport of radioactive/non-radioactive contaminants
2) The significance and the cautions in use of mathematical modeling for the fate tracking of contaminants and the decision support system
3) Past and present status of development of mathematical modeling in Japan
4) Adaptation of the model to the natural and social conditions of Japan.
5) Model validation

These problems were analyzed and possible solutions were elucidated through the discussion and the comments from the scientists of the institutions, the staff of the river sub-group of JAERI, and the guest scientist Luigi Monte. The resultant idea are described in following sections.

(2) Consideration on the key problems

Need for the study relevant to fluvial transport of radioactive/non-radioactive contaminants

This study is firstly needed to preserve the quality of freshwater resources. Today, maintaining good quality of freshwater is really important in the face of increasing water demand, a keen concern about health risk, and already contaminated water bodies due to past human activities. For instance, in agriculture, authorities have attempted to decrease the amount of fertilizers, and increase re-use of irrigation water. As another instance, dioxin compounds are deposited on rice fields whose soil particles can be eroded and transported to a river (Dr. Ohkubo, the Biwa Lake Institute). This observation has made necessary the investigation of migration of solid-bound contaminants that have been released into the environment in past decades. Research on the fate of those harmful substances in water bodies are the basis for planning measures to preserve the quality of freshwater resources.

Study relevant to fluvial transport of harmful substances is also needed in order to respond to the public concern regarding the daily use of water. This is i) to demonstrate that the authorities have good management strategies, and that the situation is under control and ii) to assure that the contamination is not serious even though it may appear serious. In this context, especially, a modeling study will play a role as possible tool to demonstrate the reasonability of strategies of environmental protection to the public and decision makers.

The significance and the cautions in use of mathematical modeling for the fate tracking of contaminants and the decision support system

The mathematical modeling has significance in that it can provide a set of general solutions to a problem of contamination at a specific site. One can take the advantage of these general suggestions into consideration to solve the problem. The model enables one to make a judgment based on a more complete grasp of situation than what could be obtained without a mathematical model.

On the other hand, a mathematical model does not necessarily give the most appropriate solution to a specific site of concern. The most appropriate solution can be attained only when based on a good amount of knowledge on the local conditions accumulated over a long time.

The use of mathematical modeling has distinct advantages. It is an intelligent way to use the knowledge from experimental theoretical and bibliographical sources. Monte stated that "One can summarize all the knowledge he/she has on the environment in a model. Then the model will become a pathway to use the knowledge in an effective way". Re-arrangement of the existing knowledge on the environment, often experimental data, in some ordered way according to a theory will lead to a new angle to consider a problem in that environment, despite several partial gaps in the data array. This is what a model can do.

Past and present status of development of mathematical modeling in Japan

In past, in Japan, there were several modeling efforts to simulate the migration of contaminants in a watershed. The largest deficiency in those models is a lack of an opportunity for practical application. Measures to make the computer code usable for others has been also limited. As a result, an approach using a mathematical model has not been popular in Japan. The Institute for Environmental Sciences is developing a mathematical model to describe hydrodynamics in the lacustrine system. They have realized a calculation of water mass movement in a visual way by movement of a hypothetical particle representing a mathematical unit of water mass.

Adaptation the model to the natural and social conditions of Japan.

Special consideration of the paddy fields for rice will be necessary with regard to several aspects such as the water balance and the influence on the population of the contamination via crops (rice). The paddy fields can modify the migration of contaminants by promoting erosion of soil, or by receiving atmospheric deposits of them. On the other hand, there is an opinion that one should avoid detailed adaptation to local conditions. This is because that the detailed adaptation will make the model so complex that it will lose suitability for general use. Obviously, two requirements i) taking account of local conditions and ii) simplification of the model are contradicting. As has been pointed out by Dr. Takahashi of the Kyoto University, a wise attitude will be a kind of harmonization without neglecting or emphasizing either.

Model validation

Model validation is essential for assuring the reliability of a model. Unfortunately it is not always possible to find experimental data that can be used for validating a model designed for specific geographical and environmental conditions. In such circumstances, comparison of model results with experimental data available for other geographical areas can be considered of importance for the analysis of the model performances. It is quite obvious that, in such situations, we must be aware that the model outcome can hardly achieve the degree of accuracy that it could have at those sites for which the model itself was developed. The results of such a "off-site" validation must be carefully assessed, accounting for the differences existing between the environmental properties of the respective geographical areas of the experimental data and models. Once we have cautiously accounted for the above issues, such application exercises can supply significant information on the model fitness

It will be difficult to carry out a direct model validation in Japan, where no area highly

contaminated by artificial radionuclides exists. Possible ways are : i) use of data obtained in contaminated areas of foreign countries, ii) use of weapon fallout. In the former, one should limit its importance, taking the cautions mentioned above. Indeed, it is not possible to have sets of observation data at any location even when they are situated in the same nation. Therefore, it is important to make great effort to consider the ability and the limits of the model in view of the difficulties in obtaining experimental, complete data suitable for numerical validation.

Concerning the use of the weapon fallout data, there is difficulty in using the weapon radionuclides present today to represent an atmospheric deposition. And, unfortunately further, there is no good continuous record of their concentration in fresh water since 1950's in Japan. (There is a good data set concerning the monthly atmospheric deposition in determined several locations in Japan.) Still, a possibility exists to use weapon fallout-derived radionuclides present today under certain circumstances. The coastal seawater contains higher concentration of ^{239,240}Pu than in freshwater. According to Dr. Hisamatsu of the Institute of Environmental Sciences, therefore, this isotope can be used to investigate the intrusion of seawater to a brackish lake. One should note that the facilities for the nuclear fuel cycle in Japan are located by a brackish lake. Accordingly, study of the surface water dynamics is important for safety assessment of the facilities. Using such weapon fallout ^{239,240}Pu in this specific circumstance can serve for this study.

In a fluvial transport model that depends on the concept of a constant partitioning coefficient (or a distribution coefficient, k_d), a critical evaluation of model parameters such as k_d values is very necessary. There has been long argument on the difference between the laboratory k_d values and their field values. What is important may be to utilize both values by taking into account the advantage of each.

7.2 Future work

As a remark for future work, what may be stressed at first is to increase opportunities of practical use of a mathematical model with a linkage to experimental studies. This has been stressed by Prof. Dr. Kunimatsu of the University of Shiga Prefecture. For a long time in Japan, a mathematical model has not been fully developed because of its limited use of in a practical, environmental problem of contaminants in terrestrial and in-land water environments. Difficulties associated with using a mathematical model such as validation and others will be overcome eventually through a use of a model.

Secondly, to assess and identify the performance of a developed model must be an important future work. This can be realized through a review of different models by common scenarios for simulation. Concerning mathematical models for predicting the behavior of radionuclides in the fresh water environment, this kind of work has been continued since 1980's. Nowadays, a community has been launched to evaluate a decision support system related to radioactive and non-radioactive aquatic contamination. That is EVANET-HYDRA (Evaluation and Network of EC-Decision Support Systems in the field of Hydrological Dispersion Models and of Aquatic radiolecological Research) organized by the European Commission. It is necessary to promote such kind of activities further hereafter.

Acknowledgements

Kind arrangement and collaboration for discussion are acknowledged for management staffs and scientists of the institutions of the Hokkaido University, the Japan Nuclear Fuel Limited, the Institute for Environmental Sciences, the Kyoto University, the University of Shiga Prefecture, and the Lake Biwa Institute. The guest scientist wants to thank the management staff of the Department of Environmental Sciences of JAERI, especially, Dr. Takeo Adachi and Dr. Toshi Nagaoka, who hosted the fellowship. It is dutiful to notice that many of the ideas supporting the work done during this fellowship and the development of MOIRA Computerised Decision Support System are due to the collaboration, in the frame of European Commission projects, of the following scientists: Lars Hakanson of University of Uppsala (Sweden), John Brittain of University od Oslo (Norwey), Eduardo Gallego Diaz of Universidad Politecnica de Madrid (Spain), Dmitry Hoffman of Studsvik Eco&Safety AB (Sweden) and Rudie Heling of NRG (The Netherlands). The invitation of the guest scientist was supported by the Japan Society for the Promotion of Science as a research fellow (No. S03095, 2003).

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Appendix A

Subsidiary explanations to Chapter 2

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Expected issues for discussions (1)

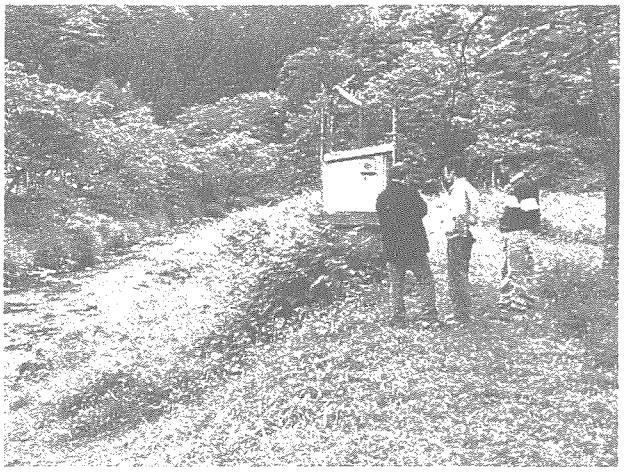
- Appropriateness of the model structure under development.
  - With regard to its applicability to the environment in Japan.
- Experimental data needed for the validation of the model.
  - What kind of local data should be obtained in a watershed for validation...
  - What general data is needed in the same context...
  - Classification of the local data and the general data.

Expected issues for discussions (2)

- capability of the model to utilize the experimental dataset obtained in the Chernobyl or other contaminated watershed in foreign countries.
  - For validation of a model that will be applied to Japanese environment.

Characteristics of Japanese watersheds (1)

Hilly, Steep, Well-vegetated



Characteristics of Japanese watersheds (2)

A large, sudden increase in water flux
in a precipitation event.

Less silty bed materials

Characteristics of Japanese watersheds (3)

Importance for agriculture, industry, potable waters

Further, as a source of any materials to coastal regions...

Expected issues for discussions (4)

■ Approaches for further applications of the experimental findings and the results from a mathematical model.

- Application to predict the fate of toxic elements, chemicals
- Application as a tool to evaluate effectiveness of countermeasures for
  - an event of radioactive contamination
  - a non-point source pollution in a watershed from agricultural, industrial, populated areas

OUR PAST AND PRESENT STEPS IN THE STUDY OF RADIONUCLIDES AND TRACE ELEMENTS IN RIVER WATERSHED

At the beginning (1987)

Studies on the behavior of artificial radionuclides in river water were sparse.

It was be necessary to investigate that behavior in order to

i) increase the understanding of behavior of the radionuclides in various circumstances in the environment, and
ii) consider the migration of the radionuclides over different environmental media.

(Consideration of the link between different media (the atmosphere, the terrain, the waters) in a study of environmental radionuclides was sparse, at least domestically.)

Research Group of Terrestrial Environment
Department of Environmental Sciences
Japan Atomic Energy Research Institute

Three periods

1 Field study on several apparent rules regulating discharge of radionuclides ➡ Kuji river study 1987-1993

2 Deeper investigations on the form of radionuclides in river ➡ Chernobyl study 1995-1999

3 Expansion of investigations to relevant reaction processes and to mathematical modeling

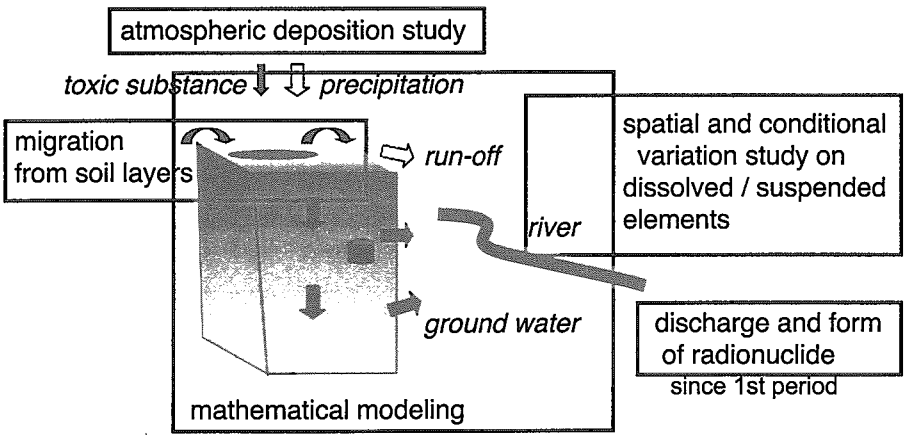
Expanded investigations
to relevant reaction processes
and to mathematical modeling

Present steps
2000-

- Long-term investigation on atmospheric deposition of radionuclides and stable elements. (1993 -
- Study on migration behavior of trace elements from soil layers of forested and arable plots. (2002-
- Study on spatial and conditional variations of behavior of trace elements in dissolved and particulate forms. (including uranium chemistry) (2000-
- Development of a mathematical model to describe the transport of artificial radionuclides and trace elements in a river watershed. (2001-

aiming at .....

- Generalization: e.g. inclusion of toxic elements, various pathways other than atmospheric deposition.
- Practical use: e.g. prediction of the fate of accidentally released radionuclides.



Appendix B

Official report to the Japan Science Promotion Society from the guest scientist

Research report

The activities here summarised were carried out in the frame of the "FY2003 JSPS Invitation Fellowship Program for Research in Japan (short-term)" (fellowship ID No. S-03095, fellow Luigi Monte) from May 22nd to June 19th 2003. The period from May 28th to June 3rd 2003 was devoted to a domestic trip in Japan. The remaining periods (from May 22nd to May 27th and from June 4th to June 20th) were spent at JAERI, the host Institute, in Tokai-mura, Ibaraki-ken.

Table 1 shows the list of the visits and of the activities object of the domestic trip during which I presented lectures and environmental model demonstrations.

Table 1. Summary of the activities carried out during the visit to Japan Universities and Research Institutes (domestic trip)

Institutes and scientists	Objectives	Date
Laboratory of Geosphere Science, Graduate School of Environmental Earth Science, Hokkaido University, Sapporo. Dr. S. Nagao.	The aims and the results of the Network EVANET-HYDRA and a presentation and a demonstration of MOIRA CDSS were provided.	28 May 2003
Division of Quantum Energy Engineering, Graduate School of Engineering, Hokkaido University, Sapporo. Dr S. Sawamura.	The aims and the results of the Network EVANET-HYDRA and a presentation and a demonstration of MOIRA CDSS were provided.	28 May 2003
Environmental Radioactivity Monitoring Centre. Safety Technology Office. Japan Nuclear Fuel Limited. Rokkasho-mura, Aomori-ken. Dr. H. Kumakura.	Visit to the Rokkasho-mura facilities.	29 May 2003
Department of Environmental Behavior Research, The institute for Environmental Sciences, Rokkasho-mura, Aomori-ken. Dr. J. Inaba.	Presentation of MOIRA. Discussion on hydro-dynamical models.	30 May 2003
Division of Nuclear Safety Research, Kyoto University Research Reactor Institute, Kumatori, Sen-nan-gun, Osaka Prefecture.	Visit to the 2 MW research reactor of the University of Kyoto. Presentation and demonstration of MOIRA. Presentation of the principles for structuring migration models based on collective processes and	2 June 2003

Dr. T. Takahashi.	relevant discussion.	
Department of Ecosystem Studies, School of Environmental Sciences, Hassaka-cho, Hikone City, Shiga. Dr. T. Kunimatsu.	Presentation and demonstration of MOIRA. General discussion on modelling methodologies, modelling aims and modelling applications.	3 June 2003
Lake Biwa Research Institute, Shiga. Dr. T. Okubo, Dr. Y. Azuma	Presentation and discussion of the research relevant to the main processes affecting the distribution of dissolved substances and phyto-plankton in stratified lakes	3 June 2003

Lectures and demonstrations were also presented at JAERI as shown in Table 2. These were aimed at describing and discussing the objectives and the results of the research activities I have carried out in the frame of some European international co-operation projects financed by the European Commission following the Chernobyl accident.

The introduction into the environment of radioactive substances following nuclear accidents can cause high and persistent levels of contamination of the aquatic ecosystems. The necessity of reducing the consequent doses to man and of rehabilitating the contaminated areas implies the implementation of suitable countermeasures and restoration strategies. Unfortunately, despite their obvious benefits represented by the reduction of doses, countermeasures may have non-desirable effects on the ecosystem, on the economy and on the society (costs of application, costs of food and resource bans, disturbance of the environment and of the ecosystems, living restrictions, etc.). A reliable and credible evaluation of the balance between those detrimental effects and the benefits following the application of a feasible countermeasure or restoration strategy is essential for the development of appropriate plans for the management of contaminated aquatic ecosystems. Such an evaluation requires the assessment of radionuclide behaviour in the contaminated water system, of the effects of planned strategies of management on the environmental contamination levels and of the social, economic and ecological detriments. Therefore, suitable models and Decision Analysis tools are necessary for helping Decision-Makers to select the most appropriate intervention strategies. Computerised Decision Support Systems (CDSS) are the response to these necessities.

Table 2. List of meetings, presentation and lectures at JAERI

Object	Date
Presentation of the research activities carried out at JAERI by river sub-group (group for terrestrial environment)	23 May 2003
Field survey of Kuji river watershed	26 May 2003
Presentation of the activities carried out by ENEA for the development of models predicting radionuclide migration through fresh water ecosystems in the frame of EC projects. Expectation of JAERI from the fellowship activities.	27 May 2003
Presentation of the activities carried out at JAERI for the development of models predicting the bahaviour of radionuclides and toxic substances through fresh water systems. Presentation of JAERI	6 June 2003

activities relevant to the study of C-14 and tritium behaviour in the environment.	
Summary report on the visit to Japan Universities and Research Institute: salient issues emerged from the visit 28 May - 3 June 2003	9 June 2003
Lecture "Modelling the migration of radionuclides and toxic substances through complex fresh water systems and cat chment areas. Principles and applications: the model MARTE" by L. Monte	10 June 2003
Discussion on the issues of the visit 28 May - 3 June 2003	11 June 2003
Discussion on the activities of the river sub- group of JAERI	12 June 2003
Discussion on model MARTE applications	13 June 2003
Discussion on model MARTE applications (continued)	17 June 2003
Lecture "Computerised Decision Support Systems for the management of fresh water environment contaminated by radionuclides: experiences in Europe following the Chernobyl accident." By L. Monte	18 June 2003

Following the Chernobyl accident, research and technological implementations were carried out in Europe to developed CDSSs for the management of the consequences of a nuclear accident. Among these CDSSs, MOIRA (A model-based computerised system for management support to identify optimal remedial strategies for restoring radionuclide contaminated aquatic ecosystems and drainage areas) has emerged as a friendly tool based on validated environmental models and on a Multi-Attribute Analysis module for the selection of intervention strategies that achieve the optimal balance between the benefits and the detrimental effects of countermeasures. The main characteristics of MOIRA models and methodologies were described and discussed during the lectures and the demonstrations. As many other CDSSs and models have been developed in Europe following the Chernobyl accident, it was recognised of importance to carry out an assessment of all these products for the rationale of the whole sector. This was the main aim of the European Commission network EVANET-HYDRA "Evaluation and Network of EC-Decision Support Systems in the field of Hydrological Dispersion Models and of Aquatic radioecological Research" that also was object of presentations and discussions. I have presented the activities, the objectives and the results of MOIRA and of EVANET-HYDRA as co-ordinator of both projects.

The fellowship was also aimed at investigating the possible application of sub-model MARTE (Model for Assessing Radionuclide Transport and countermeasure Effects in complex catchments) to the specific environmental conditions of Japan and, in particular, to river Kuji. Model MARTE is implemented in the MOIRA CDSS.

Rivers and catchments are very complex environmental systems. Such a complexity is reflected in the complicated web of interacting processes that control the migration of radionuclide and, more generally, of toxic substances through these systems. Consequently, the development of models for predicting the behaviour of pollutants in complex catchments is a real challenge for modellers.

Model MARTE was developed to predict the migration of ^{137}Cs and ^{90}Sr in rivers and complex systems and the effects of selected countermeasures on the contamination levels. The model accounts for the radionuclide fluxes from the catchment, from the water column to the sediment and vice-versa and for the transport of contaminant through the water body. The main

principles used to develop the model were discussed and examples of validation were described. The structure of the model is relatively simple and accounts for these environmental processes that are of importance for controlling the migration of radionuclides and toxic substances through fresh water systems. The model makes use of "collective parameters" that summarise the effects of the aggregation of competitive processes occurring in the environment.

During my stay, I had the opportunity of contacting many Japanese scientists of international level and of having a deep insight in the excellent research carried out in Japan in the field of environmental studies, in general, and of the behaviour of radioactive substances in the environment, in particular. The high advanced level of these specific sectors and the remarkable management efficiency of the work and of the infrastructures is impressive. Moreover, during my stay iat JAERI, I was associated to a very efficient and qualified group of researchers with which I had the opportunity of sharing scientific experience and of carrying out profitable technical discussions.

My belief is that the "JSPS invitation fellowship in Japan" is a profitable tool for encouraging scientific collaboration between Japanese and foreign research Institutes in consideration of the excellent management by JSPS.

The management of the scientific aspects of the fellowship and of the organisation of all practical aspects (logistic, support to research activities of the guest, availability of research facilities, etc.) by JAERI through Dr. Takeshi Matsunaga, the host Scientist, was also particularly effective. The organisation of the domestic travel was highly efficient, cautiously planned to optimise time and efforts and clearly focused on the scientific objectives of the fellowship. Indeed, visited Institutes and researchers were proper targets for the dissemination of my work and, on the other hand, they were significant sources of scientific information for me within the frame of my expertise.

In conclusion, the period I have spent at JAERI was extremely profitable from the scientific point of view and has offered the valuable opportunity of enlarging the horizon of my professional experience and of making, possibly and hopefully, the foundation for further co-operation.

In particular, Dr. Takeshi Matsunaga should be congratulated for his valuable work, for the excellence of his fellowship management, for the great capacity of affording and solving any practical problem related to the fellowship, for the high level of the scientific and technical work carried out by him and by his group and, last but not least, for the friendly and warm atmosphere he could confer to this fellowship period.

Luigi Monte
ENEA CR Casaccia
Via P. Anguillarese, 301
00100 Roma
Italy

Appendix C

Visiting schedule of Japanese institutions

The Hokkaido Univ.

Persons involved	
Dr. Seiya NAGAO, Associate Professor Laboratory of Geosphere Science, Graduate School of Environmental Earth Science Sapporo 060-0810, Japan Phone +81-11-706-2349 Fax +81-11-706-4867 Dr. Sadashi SAWAMURA, Professor Dr. Ryouko FUJIYOSHI Division of Quantum Energy Engineering, Graduate School of Engineering Sapporo 060-0810, Japan Phone +81-11-706-6672 Fax +81-11-736-1149	
Date May 28	
13:00 - 14:40	At the Graduate School of Environmental Earth Science Presentation by Dr. NAGAO - Characteristics of Cs-137 and K-40 content in suspended solid collected from the Kuji River, and the possibility to identify the origin of the solid Presentation by Dr. MONTE - the EVANET-HYDRA research project - the MOIRA decision support system Discussion
15:00 - 17:00	At the Graduate School of Engineering, co-sponsored by the Graduate School of Engineering and the Hokkaido Division of the Atomic Society of Japan. Lecture by Dr. Monte Methodologies to predict the migration of radionuclides in fresh water systems and to assess the effectiveness of countermeasures to reduce the radiological consequences of nuclear accidents -The MOIRA Project - Discussion

The Japan Nuclear Fuel Limited (JNFL)

Persons involved	
Presentator: Mr. Hiroaki KUMAKURA Director & General Manager Rokkasho Visitor Center Japan Nuclear Fuel Limited (JNFL) Rokkasho-mura, Aomori-ken, 039-3212 Phone +81-175-71-3101 Fax +81-175-71-3107 Organizer (absent at the visit): Dr. Akihisa TAKITA, Director Environmental Radioactivity Monitoring Center Safety Technology Office Japan Nuclear Fuel Limited (JNFL) Rokkasho-mura, Aomori-ken, 039-3212 Phone +81-175-71-2027 Fax +81-175-71-2030	
Date May 29	
13:30 - 14:00	Field survey at the Rokkasho village, guided by Dr. UEDA of IES
14:00 -14:20	General Presentation of the Rokkasho site of JNFL by Mr. KUMAKURA
14:20 - 16:00	Visiting at the facilities of the JNFL (associated with Dr. UEDA of IES) - Visitor Center - Uranium enrichment facility - Repository of low-level radioactive waste - Reprocessing plant (under construction)

The Institute for Environmental Sciences (IES)

Persons involved	
Organizers (absent at the discussion) : Dr. Jiro INABA, Department Director Dr. Kunio KONDOH, Deputy Director Department of Environmental Behavior Research The Institute for Environmental Sciences Rokkasho-mura, Aomori-ken, 039-3212 Phone +81-175-71-1200 Fax +81-175-72-3690 Participants: Dr. Shun-ichi HISAMATSU Dr. Shin-ji UEDA Dr. Hirofumi TSUKADA Dr. Hideki KAKIUCHI Mr. Yoshihito OHTSUKA	
Date May 29	
9:00 - 12:00	At the Department of Environmental Behavior Research. Background information on the modeling efforts in JAERI, by Matsunaga. Presentation on the successful modeling of the behavior of radionuclides in Italian lakes affected by the Chernobyl accident, by Dr. MONTE Presentation of the hydrodynamic modeling of water mass transport in the lacustrine system, by Dr. UEDA Demonstration of the MOIRA system, by Dr. MONTE Discussion

Kyoto University Research Reactor Institute

Persons involved	
Organizer (absent at the discussion) : Dr. Masami FUKUI, Associate Professor Scientists: Dr. Tomoyuki TAKAHASHI, Researcher Dr. FUKUTANI, Researcher Division of Nuclear Safety Research Kyoto University Research Reactor Institute Kumatori, Sen-nan-gun, Osaka Prefecture, 590-0494 Pnone +81-724-51-2477 Fax +81-724-51-2620	
Date June 2	
13:00 - 14:00	Visit at the research reactor, guided by Dr. FUKUTANI and Dr. TAKAHSHI
14:00 - 16:10	Presentation on the concept of the hydrology model of JAERI under development, by Dr. TSUDUKI Presentation of the methodology of the MOIRA, by Dr. MONTE Discussion

The University of Shiga Prefecture

Persons involved	
Dr. Takao KUNIMATSU, Professor Department of Ecosystem Studies School of Environmental Sciences 2500 Hassaka-cho, Hikone City, Shiga 522-8533 JAPAN Tel: +81-749-28-8301 Fax: +81-749-28-8477	
Date June 3	
10:00 - 11:40	Background information by T. M. Presentation on the concept of the hydrology model of JAERI under development, by Dr. TSUDUKI Presentation of the MOIRA system, by Dr. MONTE Discussion:

The Lake Biwa Research Institute

Contact Persons	
Dr. Takuya OKUBO, researcher Dr. Yoshihiro AZUMA, researcher Lake Biwa Research Institute 1-10, Uchidehama,Otsu, Shiga 520-0806,JAPAN Phone: +81-77-526-4800 Fax: +81-77-526-4803	
Date June 3	
14:00 - 16:30	General feature of the Lake Biwa, by Dr. Okubo Problems in the water quality in the Lake Biwa and the countermeasures, by Dr. OHKUBO. Presentation on the concept of the hydrology model of JAERI under development, by Dr. TSUDUKI On the use of geographical information (GIS) for describing the Lake Biwa environments, a new approach including a participation by citizens for environmental protection, by Dr. Azuma Presentation of the MOIRA system, by Dr. MONTE Discussion:

国際単位系（SI）と換算表

表1　SI基本単位および補助単位

量	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表2　SIと併用される単位

名称	記号
分，時，日	min，h，d
度，分，秒	°，′，″
リットル	l，L
トン	t
電子ボルト	eV
原子質量単位	u

1 eV=1.60218×10^{-19}J

1 u=1.66054×10^{-27}kg

表5　SI接頭語

倍数	接頭語	記号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表3　固有の名称をもつSI組立単位

量	名称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	m·kg/s^2
圧力，応力	パスカル	Pa	N/m^2
エネルギー,仕事,熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量等量	シーベルト	Sv	J/kg

表4　SIと共に暫定的に維持される単位

名称	記号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

1 Å=0.1nm=10^{-10}m

1 b=100fm^2=$10^{-28}$$m^2$

1 bar=0.1MPa=10^5Pa

1 Gal=1cm/s^2=10^{-2}m/s^2

1 Ci=3.7×10^{10}Bq

1 R=2.58×10^{-4}C/kg

1 rad=1cGy=10^{-2}Gy

1 rem=1cSv=10^{-2}Sv

（注）

1．表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし,1 eVおよび1 uの値はCODATAの1986年推奨値によった。

2．表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。

3．barは，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。

4．EC閣僚理事会指令ではbar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換　算　表

力	N(=10^5dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　1 Pa·s(N·s/m^2)=10 P(ポアズ)(g/(cm·s))

動粘度　1m^2/s=10^4St(ストークス)(cm^2/s)

圧力	MPa(=10bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7 erg)	kgf·m	kW·h	cal(計量法)	Btu	ft·lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal= 4.18605J（計量法）

= 4.184J（熱化学）

= 4.1855J（15℃）

= 4.1868J（国際蒸気表）

仕事率　1 PS(仏馬力)

= 75 kgf·m/s

= 735.499W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

（86年12月26日現在）

Consideration for Modeling Studies of Migration of Accidentally Released Radionuclides in a River Watershed