WORKING MATERIAL

Assessment of Soil Erosion Through the Use of $^{137}$Cs and Related Techniques as a Basis for Soil Conservation, Sustainable Agricultural Production and Environmental Protection

(D1-50.05)

Final Report of the FAO/IAEA Co-ordinated Research Project

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Assessment of Soil Erosion Through the Use of $^{137}$Cs and Related Techniques as a Basis for Soil Conservation, Sustainable Agricultural Production and Environmental Protection

(D1-50.05)

Final Report of the FAO/IAEA Co-ordinated Research Project

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1. INTRODUCTION

Soil erosion and sediment deposition represent a serious threat worldwide, because of their impact on both sustainable agricultural production and environmental conservation.

Soil erosion causes not only on-site degradation of a non-renewable natural resource but also off-site problems such as downstream sediment deposition in residential areas and nearby road ditches, reservoir siltation, pollution of water courses with various agrochemicals adsorbed on the sediments and eutrophication of water bodies.

Despite the fact that erosion and deposition are well documented throughout the history of agriculture, and a half-century of research into the causes and effects of erosion has been performed, considerable uncertainty exists about the extent, magnitude and actual rates of erosion and deposition, as well as economic and environmental consequences.

The use of fallout radionuclides offers a potential tool to assess soil redistribution and soil erosion and sedimentation rates in the same watershed without the need for long-term financial commitments.

Based on the recommendations of an Advisory Group Meeting held in April 1993 at the Vienna International Centre, proposals for two Co-ordinated Research Projects (CRP) were developed: one CRP on Soil Erosion by the Soil and Water Management & Crop Nutrition Section of the Joint FAO/IAEA Division and another CRP on Sedimentation by the Isotope Hydrology Section of the Division of Physical and Chemical Sciences of the IAEA.

A Consultants Meeting on “The Use of Isotopes in Studies on Soil Erosion” was convened in November 1995 at the IAEA Headquarters in Vienna to further elaborate on the objectives and work plan of the CRP and refine the existing methodologies (refer to IAEA Report CT-2665). The Panel further recommended the co-ordinated implementation of the CRP on Soil Erosion (D1.50.05) with the CRP on Sedimentation (F3.10.01).

The First Research Co-ordination Meeting of both CRPs was held jointly in the IAEA Headquarters in Vienna, from 11 to 15 November 1996. F. Zapata and E. Garcia-Agudo were the Scientific Secretaries (Refer to IAEA Report D1-RC-629.1 and F3-RC-644.1).

The Second Research Co-ordination Meeting of both CRPs was held together from 25 to 29 May 1998 in Bucharest, Romania. Christian Hera and Ion Ionita were the local organizers (Refer to IAEA Report D1-RC-629.2 and F3-RC-644.2).

The Third Research Co-ordination Meeting of both CRPs, was held together in Barcelona, Spain from 4 to 8 October 1999. This meeting was the last for the Sedimentation CRP and the before last for the Erosion CRP. Ignasi Queralt was the
local organizer of the meeting (Refer to IAEA Report D1-RC-629.3 and F3-RC-644.3).

This final report describes the Fourth and Final Research Co-ordination Meeting of the Erosion CRP, which was held in Vienna, 21-25 May 2001 (Section 5). **F. Zapata was the Scientific Secretary** of the meeting. E. Garcia-Agudo, Technical Officer of the Sedimentation CRP, represented the participants of that CRP. In addition, this report also contains the description of the project (Section 2), overall implementation of the projects (Section 3), facts about the projects (Section 4) and the main conclusions and recommendations of both Soil Erosion and Sedimentation CRPs (Section 6).
The programme of the meeting, list of participants, summaries submitted by the participants and list of publications of the participants are included as annexes.

2. **THE CO-ORDINATED RESEARCH PROJECT**

2.1. Title

**Assessment of soil erosion through the use of $^{137}$Cs and related techniques as a basis for soil conservation, sustainable production and environmental protection (D1-50.05)**

2.2. **Project duration** 5 years (1996-2000)

2.3. **Overall Objective**

To develop guidelines for controlling accelerated soil erosion and associated soil degradation for sustainable development of agricultural production and environmental protection.

2.4. **Specific Research Objectives**

i) To refine (including validation and standardization) relevant methodologies for documenting soil erosion using the $^{137}$Cs technique across a range of environments which can then be used to test and calibrate existing models of soil erosion, and

ii) To evaluate the effect of specific land use management on soil erosion for providing data to underpin the selection of soil conservation strategies.

2.5. **Background**

Soil erosion and sediment deposition represent a serious threat worldwide, because of their impact on both sustainable agricultural production and environmental conservation. Soil erosion has an immediate deleterious effect on the long-term productivity of soil in several ways, i.e., through the loss of nutrient-rich arable layer, accumulation of toxic salts or acids, and the incorporation of potentially growth-limiting factors of the subsoil...
into the rooting zone. In many cases, soil erosion causes a progressive decline in soil productivity; this decline however is far more pronounced in agro-ecosystems, which rely on indigenous fertility than those with high input technology where this impact is masked by higher fertilizer inputs.

Soil erosion causes not only on-site degradation of a non-renewable natural resource but also off-site problems such as downstream sediment deposition in residential areas and nearby road ditches, pollution of water courses with various agrochemicals adsorbed on the sediments and eutrophication of the water bodies.

Despite the fact that erosion and deposition are well documented throughout the history of agriculture and a half-century of research into the causes and effects of erosion has been performed, considerable uncertainty exists about the extent, magnitude and actual rates of erosion and deposition, as well as on their economic and environmental consequences. Many methods, including models for predictions have been developed and used to obtain qualitative and quantitative data on patterns and rates of erosion/deposition. The existing classical techniques have significant limitations. The use of radionuclides in soil erosion/deposition research overcomes many of the problems associated with the traditional approaches and they have been used successfully in several developed countries. Among these, the $^{137}$Cs technique allows the assessment of both soil loss and deposition in the same watershed without the need for long-term financial commitments.

Based on the recommendations of an Advisory Group Meeting held in April 1993 at the Vienna International Centre, proposals for two Co-ordinated Research Projects were developed: a CRP on Soil Erosion by the Soil and Water Management & Crop Nutrition Section of the Joint FAO/IAEA Division and a CRP on Sedimentation by the Isotope Hydrology Section of the Division of Physical and Chemical Sciences of the IAEA.

A Consultants Meeting on “The Use of Isotopes in Studies on Soil Erosion” was held in November 1995 at the IAEA Headquarters in Vienna to further elaborate on the objectives and work plan of the CRP and refine the existing methodologies (refer to IAEA Report CT-2665).

2.6. Expected outputs

1. Standardized protocols of the $^{137}$Cs technique for documenting soil erosion.

2. Reliable data of soil erosion/sedimentation rates using the $^{137}$Cs technique across a range of environments. Testing and validation of soil erosion models.

3. Strengthening national institutes on soil erosion/sedimentation research through training, workshops and other activities.

5. Publication of protocols and research results. Provision of guidelines for soil erosion/sedimentation control.

2.7. Action Plan

Activity 1.
Establish a research network involving 8+3 national research institutes from developing countries engaged in soil erosion and soil conservation investigations, and 5 advanced research institutes. Selection was based on the recommendations of the Consultants Meeting held in November 1995. Other criteria were also expertise/qualifications of counterparts, availability of appropriate equipment for low-level gamma spectrometry and quality of proposals submitted.

Activity 2
Organize 1st RCM to evaluate both generalities and all aspects of the $^{137}$Cs technique (field reconnaissance study, detailed survey and soil sampling/samples processing/low-level counting of $^{137}$Cs and other radionuclides/calibration of equipment and reference materials/$^{137}$Cs inventories/potential use of other radionuclides in conjunction with the $^{137}$Cs technique).

Activity 3
Organize 2nd RCM to evaluate results obtained from the work plan elaborated at the first RCM.
- Training workshop on calibration models to convert $^{137}$Cs data in soil redistribution.
- Review on the use of the $^{137}$Cs technique in the research work of the various collaborators and made the necessary adjustments.
- Agreement on working protocols to apply the $^{137}$Cs technique. Start preparation of a training manual on the application of the $^{137}$Cs technique in soil erosion/sedimentation research.

Activity 4
Organize 3rd RCM to evaluate the data on soil erosion/sedimentation rates across a range of environments/land use management. Testing and validation of soil erosion models.
- Assessment of the impact of erosion on soil quality and productivity.
- Guidelines for preparation of final reports.

Activity 5
Organize 4th RCM to present final reports and review results of the CRP. Considering the objectives of the CRP, to critically examine the main achievements and to formulate recommendations for further research. Also, to
develop guidelines on the effect of specific land use management and soil conservation practices on soil erosion/sedimentation rates.

Activity 6
Produce final report of the project. Synthesize all reports on overall work and publish TECDOC. Terminate the project.

2.8 Participating Countries and Institutes
(See next page)
2.9. Inputs

Financial Resources Required

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<td>Co-ordination Meetings</td>
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<td>Barcelona, Spain</td>
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*Includes additional contractors from 1997 onwards.

2.10. Assumptions

Staffing and laboratory facilities to perform low-level gamma spectrometry determinations.
Suitable reference materials for calibration of equipment and establishment of Q.A. programme for \(^{137}\text{Cs}\) analysis.
Additional training of junior staff, as required
Research contract obligations are fulfilled.
Evaluations of soil erosion impact on soil quality parameters be made.
Appropriate geographical distribution of the participants.
Due consideration to Chernobyl fallout.

2.11. Logical Framework for Co-ordinated Research Project on assessment of soil erosion through the use of \(^{137}\text{Cs}\) and related techniques as a basis for soil conservation, sustainable production and environmental protection (D1-50.05)
(See next page)
## Narrative Summary

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<th>Objective Verifiable Indicators</th>
<th>Means of Verification</th>
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<td>N/A</td>
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### Specific Objectives

1. To refine (including validation and standardization) relevant methodologies for documenting soil erosion using the $^{137}$Cs technique across a range of environments which can then be used to test and calibrate existing models of soil erosion, and
2. To evaluate the effect of specific land use management on soil erosion for providing data to underpin the selection of soil conservation strategies

<table>
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<th>Outputs</th>
<th>1. Standardized protocols of the $^{137}$Cs technique</th>
<th>Harmonized $^{137}$Cs technique</th>
<th>Agreement holders' advice/approval</th>
<th>Continuity of research contract holders</th>
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<td>2. Field application of the $^{137}$Cs technique</td>
<td>Reliable data on soil erosion/sedimentation rates</td>
<td>Analysis of data. Testing and validation of erosion models</td>
<td>Meaningful and sufficient data collection. Operation of E.Q.A. for $^{137}$Cs analysis</td>
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<td>3. Increased skill levels.</td>
<td>Routine application of $^{137}$Cs technique</td>
<td>Preparation of a training manual</td>
<td>Additional training is provided to contractors</td>
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<td>4. Better understanding of soil erosion/sedimentation</td>
<td>Selection of effective soil conservation technologies</td>
<td>National reports on soil erosion control</td>
<td>Provision of recommendations to national soil conservation programmes</td>
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<td>5. Publication of research results and guidelines on soil erosion control</td>
<td>Reports by contract holders</td>
<td>Evaluation of reports</td>
<td>Timely submission of final reports by all participants</td>
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That 11 NAR'S are using the $^{137}$Cs technique to assess soil erosion

Reports of NAR'S

1. Continued national support be given
2. Establishment of Q.A. for $^{137}$Cs analysis
3. Constant co-ordination between 11 Contractors and 4 Agreement Holders through Project Officer
### Main activities

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<tr>
<td>2. Organize 1st RCM to develop standardized protocols of the $^{137}$Cs technique</td>
<td>Hold RCM Vienna November 1996</td>
<td>RCM/CRP Progress Report</td>
<td>Initial data. Site selection of $^{137}$Cs inventories standard protocols sampling/$^{137}$Cs analysis.</td>
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<td>3. Organize 2nd RCM to analyze soil erosion data obtained</td>
<td>Hold RCM Bucharest, Romania June 1998</td>
<td>RCM/CRP Progress Report</td>
<td>Testing calibration models for conversion of $^{137}$Cs data into erosion rates.</td>
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<td>4. Organize 3rd RCM to evaluate progress made in the CRP</td>
<td>Hold RCM Barcelona, Spain October 1999</td>
<td>RCM/CRP Progress Report</td>
<td>All participants have implemented research plans.</td>
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<td>5. Organize 4th RCM to synthesize final reports of participants for publication</td>
<td>Hold RCM Vienna, Austria May 2001</td>
<td>Compilation of final reports for TECDOC</td>
<td>Preparation and timely submission of final reports by all participants.</td>
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### 3. OVERALL IMPLEMENTATION OF THE PROJECTS

Following a recommendation of the Consultants Meeting, this CRP was implemented closely with the CRP on "Sedimentation Assessment Studies by Environmental Radionuclides and their Application to Soil Conservation Measures" (F3.10.01) because of similarities in documentation techniques. Erosion and sedimentation are particularly strongly inter-related when working at the watershed level.

The Consultants Meeting convened in November 1995 delineated the framework of the project to start implementation. The Soil and Water Management & Crop Nutrition Section of the Joint FAO/IAEA Division implemented the Soil Erosion CRP. Mr. F. Zapata was the Technical Officer.

The Soil Erosion CRP had 16 participants, of which eleven research contract holders from Argentina, Brazil, Chile, China (2), Greece, Morocco, Romania, Russian Federation, Slovakia, and Zimbabwe; one technical contractor from UK and four research agreement holders from Australia, Canada, Thailand (IBSRAM) and USA. Contractors of Argentina, Greece and Morocco were included after the initiation of the CRP.

The Isotope Hydrology Section of the Division of Physical and Chemical Sciences implemented the CRP on “Sedimentation Assessment Studies by Environmental
Radionuclides and their Application to Soil Conservation Measures" (F3.10.01). Mr. E. Garcia Agudo was the Technical Officer. The main characteristics of this project were:

a) The project was approved for implementation in five years, but funding was initially provided for the first three years (1996-1998). Additional funds were provided at a later stage to extend the duration of the CRP until the year 2000. The last RCM was the third one held in Barcelona, October 1999 and the project was terminated in 2000.

b) Initially this CRP had 10 participants, of which five were contract holders from China, Malaysia, Morocco, Poland and Romania, and five agreement holders from Australia, France, New Zealand, Spain and UK. After the second RCM, the contractor from Malaysia withdrew from the group due to problems in the availability of counting facilities. Canada was included as an additional agreement holder. A technical contract was also granted to UK, for developing a mathematical model for the estimation of $^{137}$Cs deposition budgets on a global scale.

During the first RCM it was found out that there was a lack of standardization in the application of the $^{137}$Cs technique among those groups with previous experience in this subject, and hence, a need for well-defined protocols to be utilized by those groups starting soil erosion and sedimentation studies at that time. In particular, key issues identified were: a) the need for an inter-comparison exercise among those laboratories for $^{137}$Cs analyses in soil and sediment samples, and b) further development of the available mathematical models to convert $^{137}$Cs residuals into soil erosion/sedimentation rates.

During the second RCM, most participants presented $^{137}$Cs data from their work. The results of the $^{137}$Cs inter-comparison exercise among the laboratories participating in the CRP were critically analysed and considered excellent, with a coefficient of variation of 9.3% for an average activity level of 3 Bq/Kg. Some participants presented also data on the use of $^{210}$Pb in association to $^{137}$Cs for the evaluation of soil erosion. The inter-comparison exercise for $^{210}$Pb was only partially met, as not all participant laboratories had the capacity to analyse this nuclide. Progress made in the development of the mathematical models for converting $^{137}$Cs data in soil erosion rates was also reported. A field trip was made to the Central Research Station for Soil Erosion Control in Perieni, Barlad to get acquainted with local soil erosion problems and soil conservation measures to control them.

In the third RCM that was the last for the Sedimentation CRP and the before last for the Erosion CRP, progress in the execution of the work plans of the CRPs was reviewed and recommendations were made to complete them, in particular the preparation of their final reports and publication of their research results. The field visit to the experimental catchments of the Vallcebre basin in the Llobregat Upper Valley, Pyrenees Range illustrated the erosion processes occurring in the area and the several methodologies used to measure sediment yields. From the results presented and discussions held it was found out that several expected outputs of the CRPs have been already achieved. As a result of the increased skill levels of the participants, they were able to formulate recommendations on the main aspects of the $^{137}$Cs technique and identify issues for further study. Overall, significant progress was made towards a
harmonized application of the $^{137}$Cs technique and the participants in a wide range of environments have produced a wealth of information on erosion and sedimentation.

During the final RCM of the Erosion CRP participants presented their research work conducted in the frame of the project, evaluated achievements/outputs and drew main conclusions of the project, and formulated recommendations for further research.

4. **FACTS ABOUT THE PROJECTS**

- Integrated approach at the landscape and catchment level
- Joint implementation of two CRPs
- Involvement of 16 (Soil Erosion) plus 10 (Sedimentation): a total of 26 institutions from developing and industrialized countries.
- Advisory and Consultants meetings for planning the projects
- Use of fallout radionuclides, with focus on $^{137}$Cs (bomb fallout and Chernobyl; fallout)
- Standardization of the protocols for field application of the $^{137}$Cs technique in an wide range of environments
- Preparation of the reference sample IAEA-0401 Loess soil sample
- External quality assurance/Laboratory Inter-comparison Exercise for $^{137}$Cs by high precision gamma spectrometry
- Model and database on $^{137}$Cs inputs.
- Development and refinements of calibration (conversion) models for $^{137}$Cs and $^{210}$Pb.
- Reliable soil erosion and sedimentation data
- Testing of soil erosion models using the $^{137}$Cs-based erosion estimates.
- Publications of the participants over the duration of the project.
- Collaborative projects and joint ventures.
- Presentation in international, regional and national meetings
- Production of the special issue in Acta Geologica Hispanica
- Production of a Handbook on the $^{137}$Cs technique (In preparation).
- Production of a special issue in Soil and Tillage Research (In preparation)
5. THE FINAL RESEARCH CO-ORDINATION MEETING

The Fourth and Final Research Co-ordination Meeting ((311-D1-RC-629.4) of the FAO/IAEA CRP on "The Assessment of Soil Erosion through the Use of $^{137}$Cs and related techniques as a basis for Soil Conservation, Sustainable Agricultural Production and Environmental Protection" was held in the IAEA Headquarters, Vienna, Austria, 21 to 25 May 2001. F. Zapata served as Scientific Secretary.

5.1 Objectives of the Third Research Co-ordination Meeting

The objectives of this RCM were:

a) To review and discuss the results obtained on the application of the $^{137}$Cs technique and other radionuclides in soil erosion/sedimentation studies during the implementation of the project, and

b) To evaluate the achievements/outputs in accordance with the objectives of the project, including the formulation of conclusions and recommendations.

5.2 Programme of the RCM

P.M. Chalk, Head of the Soil and Water Management and Crop Nutrition Section of the Joint FAO/IAEA Division opened officially the meeting. F. Zapata, Scientific Secretary of the meeting, made opening remarks on the objectives and programme of the final meeting and a short overview of the overall implementation of the project.

The programme of the meeting included seven technical sessions and a field excursion in Lower Austria (Annex A).

Some thirty scientists attended the meeting: twelve contractors, four Research Agreement holders, one consultant, three observers and the scientific secretary. In addition, staff members of the Soils Section and Unit, as well as, fellows presently on training at the Soil Science Unit, Seibersdorf Laboratory, participated. Refer to the list of participants (Annex B).

On Monday 21 and Tuesday 22 May, during the first five technical sessions, the presentations of the contractors focused on the application of the $^{137}$Cs technique and other radionuclides in soil erosion and sedimentation studies at several scales and in a wide range of environments. Summaries of the presentations are given in Annex C.

Prof. Dr. Andreas Klik, University of Agricultural Sciences, Vienna, delivered a lecture on soil erosion measurements and soil conservation studies in Austria to provide background to the field visit.
On Wednesday 23 May, a field trip was organized with the assistance of Prof. Dr. Andreas Klik and DI Dr. Josef Rosner, State Government of Lower Austria. The objectives were to visit field erosion plots and soil erosion protection measures utilized in the region of Lower Austria by the farmers in close collaboration with the specialists. Prof. Dr. Andreas Klik, excursion leader with his colleagues in Tulln and Krems explained their work to study soil erosion/sedimentation processes in field plots and to establish/monitor soil conservation measures in farmer’s fields. In Tulln we visited no-till experiments for erosion control and improvement of soil quality, and a lysimeter station to investigate nitrate leaching into groundwater under different management systems. Field erosion plots and related equipment to investigate the effect of different tillage practices on runoff, erosion, nutrient and pesticide loss were observed in Pixendorf. In the afternoon we visited the recently built bench terraces for vineyards in the Austrian Loess belt, around Krems. Participants got an insight of the agriculture and soil erosion problems/research approaches in Lower Austria. We are grateful to the organizers for the excellent arrangements and their kind hospitality.

On Thursday 24 May, the presentations of the agreement holders in a technical session illustrated further applications of the $^{137}$Cs technique in environmental studies. Thereafter participants divided in three working groups analysed the main outputs of the project and formulated conclusions and recommendations on the following: 1) Harmonized $^{137}$Cs technique; 2) Reliable soil erosion/sedimentation rates and 3) Increased skills levels of the participants, better understanding of the soil erosion and sedimentation processes and publications made in the frame of the project. A list of publications (work done under IAEA contract) is included in Annex D. Final reports and summaries of the participants were collected. Similarly, the manuscripts for the special issue in the journal Soil and Tillage Research were also compiled.

In the final plenary session the group leaders presented the conclusions and recommendations for consideration and approval of the participants. (Please refer to next section). The Scientific Secretary made an overview of the Log frame of the CRP to relate inputs, activities performed, outputs/achievements and the objectives of the project. The project was evaluated according to the criteria: efficiency, effectiveness, relevance and impact. P.M. Chalk officially closed the meeting. Individual discussions were held with some participants.

6. CONCLUSIONS AND RECOMMENDATIONS

During the final RCM of the CRP after the presentations of the individual participants, the overall implementation of the project was reviewed, and the outputs/achievements analysed in working groups. The participants made the following conclusions and recommendations:
6.1 Refined and Harmonized Application of the $^{137}$Cs technique

The $^{137}$Cesium technique was proven to work well in a range of environments and scales in the course of this CRP. The correct application of the technique provides reliable erosion and sedimentation data over a medium-term (40 year) period.

6.1.1 Conclusions

1. The adoption of the $^{137}$Cs technique requires a significant commitment by a team of researchers, trained technicians and the availability of the appropriate analytical facilities.

2. The technique was shown to work in many different environments in the course of this CRP, including regions (e.g. tropical environments) where it had not been expected to perform well.

3. Special attention should be paid when using the approach in areas influenced by Chernobyl fallout.

4. A suite of approaches (e.g. grid vs. transect approaches, composite vs. multiple samples) was developed for site selection and sampling by the various research groups. No single approach is universally applicable; instead the research team must make an informed selection from the available approaches. The sampling strategy adopted must reflect the processes believed to be operating at the site and the site conditions.

5. There are environments that the technique may not work in. Preliminary studies should be undertaken in regions where it has not been used previously.

6. Selection and adequate sampling of reference sites is critical for the successful application of the technique.

7. Standard volumetric soil sampling techniques are adequate for sampling soil for cesium content.

8. The research team must make detailed site and sampling point observations of those factors of relevance for the processes operating in the region.

9. Standard solid-state detectors proved to be appropriate for measurement of cesium concentrations. Low background shielding may be required in some environments.

10. The analytical equipment should be dedicated to the technique given the large number of samples required.

11. Analytical quality control must be included in laboratory routine.
12. Special care should be taken when analysing $^{210}$Pb due to its low gamma energy for instrumental measurement.

13. Gamma spectra should be analysed using appropriate software. The choice of software should be made by contacting the IAEA or a major analytical laboratory.

14. The measured $^{137}$Cs redistribution values should be calculated and analyzed prior to soil redistribution calibration. The cesium residual values (especially outlier values) should be checked against the field observations and against the processes likely to be operating in the area.

15. For calculating the soil redistribution values from the $^{137}$Cs observations, selection of a conversion (calibration) model is required. The model selected must be appropriate for the site (e.g. uncultivated vs. cultivated sites) and the required parameters must be available.

16. All parameters used in the model should be clearly reported.

17. The soil redistribution results should be compared to the field observations and the literature available for the region.

18. The results should be used to evaluate the effects of past land use practices and the possible future implications of the measured rates. The policy implications of these rates should be clearly stated.

6.1.2 Recommendations

1. $^{137}$Cs technique is now an established nuclear technology (over 2500 publications to date) that should be broadly disseminated. In this context, the IAEA should support requests from developing countries for training and the development of appropriate regional analytical facilities through Technical Cooperation Projects.

2. The IAEA should ensure that the results from both the Soil Erosion and Sedimentation CRPs are jointly disseminated.

3. The contents of the proposed Handbook should be evaluated to ensure adequate coverage based on the discussions at the final meeting. A glossary should be also included in each chapter.

4. The application of the $^{137}$Cs technique to evaluate soil conservation and environmental protection programs should be further explored.

5. The application of the $^{137}$Cs technique to medium and long-term engineering issues (e.g. reservoir sedimentation) should be encouraged.
6. Lead-210 and Beryllium-7 are important complimentary techniques to \(^{137}\text{Cs}\) for soil erosion and sedimentation. Both techniques should be further developed to bring them to the level of acceptance of \(^{137}\text{Cs}\).

7. The Agency should set up a Consultants Meeting to follow-up on these recommendations for future research in and development.

6.2 **Reliable data on soil erosion and sedimentation rates**

The reliability of the data on soil erosion/sedimentation rates obtained with the \(^{137}\text{Cs}\) technique was analysed. The data obtained were related to land use/management conditions and utilised for testing and validation of soil erosion models.

6.2.1 **Conclusions**

1. Standardised methods and protocols for application of the \(^{137}\text{Cs}\) technique have now been successfully developed. The reliability of the results obtained has been clearly demonstrated by several studies where it has proved possible to compare the \(^{137}\text{Cs}\)-based erosion results with independent evidence on soil erosion rates provided by erosion plots, instrumented catchments, and soil profile interpretation, as well as local experience (e.g. LI, ZHANG, WALLING, SCHULLER, IONITA, GOLOSOV, THEOCHAROPOULOS).

2. The data on soil redistribution rates assembled by the contributors to the CRP using \(^{137}\text{Cs}\) measurements and standardized protocols have provided directly comparable and representative information on soil erosion rates in a wide range of environments worldwide. Countries represented include Argentina, Australia, Brazil, Canada, Chile, China, Greece, Morocco, Romania, Russia, Slovakia, UK, USA and Zimbabwe. Values range from \(\approx 0 - >100\) t ha\(^{-1}\) year\(^{-1}\) and demonstrate that in general local land use exerts a more important influence on the range of values encountered than climate or lithology and soil type. However, the influence of the latter can be readily distinguished.

3. As indicated above, the data assembled by investigations undertaken within the framework of the CRP provide valuable evidence of the influence of land use and land management on rates of soil loss and sedimentation (cf. WALLBRINK, LI, ZHANG, SCHULLER, BACCHI, NEMASASI). For example, in southern Chile SCHULLER reports net soil losses from subsistence cultivation almost 6 fold greater than those from commercial cultivation in a similar environment. In the loess region of China LI reports rates of soil loss of 71, 37 and 17 t ha\(^{-1}\) year\(^{-1}\) from mid-slope areas under cultivation, cultivated terrace and grassland, respectively.

4. The potential use of \(^{137}\text{Cs}\) measurements for validating distributed soil erosion and sediment delivery models has been clearly demonstrated by several studies undertaken within the CRP. WALLING used \(^{137}\text{Cs}\) measurements to test the application of the AGNPS and ANSWERS models to
two small catchments in Devon, UK; GOLOSOV compared the soil redistribution rates within a small Russian catchment with the output from a soil loss model developed for Russian conditions and BACCHI compared the estimates provided by the WEPP and USLE models with the soil redistribution rates obtained using $^{137}$Cs measurements in a small catchment in Piracicaba, SP, Brazil.

5. The spatially distributed estimates of soil redistribution rates provided by $^{137}$Cs measurements represent an essentially unique source of information and several other potential applications have been explored by studies undertaken within the framework of the CRP. These include investigations on the following:

- the role of tillage in soil redistribution (Zhang, Li, Pennock)
- use of $^{137}$Cs–derived erosion rates as input to a regional soil organic carbon cycling model (Pennock)
- the relationship between soil erosion rates and soil organic carbon status (Ritchie)
- the relationship between on-site soil erosion and nutrient export and off-site impacts (Wallbrink)
- the relationship between soil quality parameters and rates of soil loss (Li).

6.2.2 Recommendations

1. Further tests of the reliability of the estimates of erosion rates provided by $^{137}$Cs measurements are required. These should involve carefully designed investigations aimed at making use of independent data provided by erosion plots, small monitored catchments, soil profile morphology and related sources.

2. The reliability of the data on soil erosion rates obtained using $^{137}$Cs measurements should be further tested using sediment budget studies based on closed catchments or catchments draining to small lakes or reservoirs.

3. Rates and patterns of soil redistribution estimated using $^{137}$Cs measurements should be cross-validated against estimates obtained using other environmental radionuclides (e.g. $^{7}$Be and $^{210}$Pb).

4. The potential for using $^{137}$Cs measurements for providing representative information on soil erosion rates should be exploited in large-scale reconnaissance studies aimed at establishing the influence of a range of environmental controls.

5. $^{137}$Cs measurements should be used in carefully designed programmes to assemble information on the influence of different land management and land use practices on soil loss rates, in order to inform the planning of effective soil conservation measures. Such studies should include the effects of
minimum tillage and could involve the conjunctive use of $^7$Be, $^{210}$Pb and $^{137}$Cs.

6. The potential for using $^{137}$Cs measurements to validate distributed erosion and sediment delivery models should be further exploited and such measurements should also be used as a basis for improving and developing such models.

7. The potential for using $^{137}$Cs measurements to gain an improved understanding of the relationship between rates of soil loss and soil quality, soil carbon and nutrient redistribution and the fate of agrochemicals and related contaminants should be further investigated.

6.3. Increased skill levels of the participants for the routine application of the $^{137}$Cs technique

6.3.1 Conclusions

There has been a marked increase in the skill levels of the participants and their laboratories, as well as their capacity to undertake routine application of the method. This is demonstrated by the following outcomes.

1. **Quality assurance:** All participating laboratories have successfully participated in quality assurance intercomparisons for $^{137}$Cs, and some laboratories also for $^{210}$Pb$_{ex}$ and $^{226}$Ra.

2. **Handbook:** Skill and knowledge levels have advanced to point that participants are able to produce an erosion assessment handbook, which includes guidelines for the implementation of the technique. This is a major outcome of the CRP.

3. **Skill Levels:** Presentations of experimental design, results, and interpretation of data at successive CRP meetings by members have demonstrated an increasingly sound application of methodology. Participants are able to objectively assess the strengths and weaknesses of each other’s projects and interpretation of the data.

4. **Participation in critical debate:** All members participated in discussions on the more critical aspects of the methodology, for example identifying reference sites as a major issue.

5. **Sample analysis -** Skill of participants have reached level where they can either generate their own data through gamma spectrometry, or critically assess the quality of radionuclide data provided by other laboratories.

6. **International Research network:** This is perhaps the most important outcome. We have established an international research network to foster sound implementation of the technique, including review of experimental
design, sample method collection, sample analysis and peer review of intellectual ideas (as evidenced through journal articles in Acta Geologica Hispanica and Soil and Tillage Research), as well as increased co-operation between laboratories in participating countries.

7. **Data processing:** Adoption of an accepted protocol for interpreting data, in terms of international activity units (Bq kg\(^{-1}\)), conversion to areal measurements (Bq m\(^{-2}\)), and then processing through a conversion (calibration) model.

### 6.3.2 Recommendations

1. The continuation of the functional research network should be encouraged. The expertise and new knowledge developed through the course of the CRP by the participating laboratories should be used by the IAEA to disseminate the technology among developing countries through its Technical Co-operation Programme.

2. The participating laboratories are encouraged to continue this work so that the relationship between sustainable systems and erosion rates can be better understood and defined.

### 6.4. Better understanding soil erosion processes

#### Provision of guidelines and selection of soil conservation technologies

### 6.4.1 Conclusions

Participants have gained a better understanding of soil erosion processes as well providing a set of guidelines for selecting soil conservation technologies. This is demonstrated by the following outcomes.

1. **Soil erosion assessment handbook:** This book is now being finalized with contributions from participants.

2. **Quantifiable data of erosion measurements:** \(^{137}\)Cs measurements have provided actual erosion data and remain the only method for quantifying soil loss rates, without long term monitoring.

3. **Cross fertilization of research and ideas:** The CRP has facilitated a cross fertilization of research and ideas, which has given greater understanding of erosion mechanisms such as:

   - detachment, storage and redistribution on slopes,
   - improved precision of role of tillage erosion in redistribution,
   - better calculations of surface delivery ratios,
   - role of erosion processes (i.e. subsurface vs. surface),
   - contribution of nutrients such as P, to off site sediments,
• determining the influence of different erosion processes on supply/delivery of sediment,
• providing data for validating and improving sediment delivery/erosion models (e.g. RUSLE, WEPP),
• understanding of the role of gullies in generation of sediment, also mechanisms for growth and development of discontinuous gullies,
• evaluation of long-term erosion rates.

4. Scaling: The method has the potential to provide a quantitative basis for scaling up from point measurements to catchments.

5. Individual processes: $^{137}$Cs technique allows the opportunity to investigate/discriminate the role of individual factors affecting soil erosion, (i.e. the role of landscape position in terms of sediment redistribution).

6.4.2 Recommendations

1. Explore opportunity for applying alternative tracers (such as $^7$Be) for measuring short-term erosion rates to compare with the long-term estimates from $^{137}$Cs. In this way we can quantify the impacts of changing land use on longer term monitored sites.

2. Investigate opportunities for improved transfer of the results of the CRP to end users, i.e. environmental groups, catchment managers, reservoir managers, policy makers, farmers.

3. Major impediments to reducing soil erosion may well be social, economic and/or political. Consider applying some expertise to investigate the influence of these factors in any new CRP.

4. Incorporate other disciplines into our understanding of influence of soil erosion, so as to gain a holistic understanding of erosion/sedimentation issues. (for example, hydrology, soil quality characterization, nutrients, trace elements, spatial analysis and GIS, remote sensing, geomorphology).

5. Undertake specific experiments to refine the comparison between $^{137}$Cs-based soil loss estimates and those from soil erosion models (for example, the relationship between slope length and Caesium content).

6. Clarify the conditions under which the various $^{137}$Cs conversion models operate and should be applied. This should be in the form of a handbook or rules of thumb, outlining assumptions and conditions and including case studies.
6.5 Publication of research results
Final reports, papers and manuscripts

6.5.1 Conclusions

There have been numerous publications arising from this CRP. A summary of these is given below:

2. IAEA TECDOC –1028 (1998) Use of $^{137}$Cs in the study of erosion and sedimentation
4. Progress report, First RCM, Vienna, 1996
5. Progress report, Second RCM, Bucharest, 1998
6. Progress report, Third RCM, Barcelona, 1999
7. Final report CRP, Vienna, 2001
9. Special issue of Soil and Tillage Research, In Preparation

6.5.2 Recommendations

1. Participants are encouraged to publish findings of their projects in peer-reviewed journals
2. Participants offer to review the manuscripts of other participants prior to submission to external journals.
3. Recommend to IAEA that all scientific reports from CRP meetings form part of ‘special issues’ in peer-reviewed journal. IAEA documents difficult to access.
4. Prepare a full list of publications, reports of individual contract and agreement holders over life of project.
ANNEX A

PROGRAMME OF THE MEETING
**P R O G R A M M E**

**Monday, 21 May**

08:30-09:00    Registration

09:00-09:15    Official Opening, P.M. Chalk

09:15-09:45    Remarks by Scientific Secretary, F.Zapata

**SESSION I**

Chairperson: Dr. P. Chalk (IAEA)

09:45-10:30    Alfonso Bujan (Argentina)
                “Studies on water erosion and sedimentation
                budgets as affected by topo-physiographic
                landscape units in the Tala river basin”

10:30-11:00    Coffee break

11:00-11:45    Osny Bacchi (Brazil)
                “$^{137}$Cs fallout redistribution analysis for soil erosion
                surveys in the Piracicaba river basin”

11:45-12:30    Paulina Schuller (Chile)
                “Estimating erosion rates in volcanic soils of
                Southern Chile under different land use/
                management using the $^{137}$Cs technique”

12:30-14:00    Lunch break

**SESSION II**

Chairperson: D. Pennock (Canada)

14:00-14:45    Yong Li (P.R. China)
                “Using $^{137}$Cs and $^{210}$Pb to assess the effectiveness of
                vegetation in reducing soil erosion and siltation in a
                dam reservoir catchment on the Loess Plateau”

14:45-15:30    Xinbao Zhang (P.R. China)
                “Soil loss assessment studies of cultivated land in the
                Upper Yangtze river basin”

15:30-16:00    Coffee break

16:00-16:45    Sideris P. Theocharopoulos (Greece)
                “Use of the $^{137}$Cs isotopic technique in soil water
                erosion studies on arable fields in Central Greece”

16:45-17:30    General discussion on papers presented in Sessions
                I and II (major achievements, limitations). Review of
                summaries, final reports, publications and MS.
Tuesday, 22 May

SESSION III  
Chairperson: P. Wallbrink (Australia)

08:30-09:15  
Brahim Damnati (Morocco)  
“Quantitative assessment of soil erosion and sedimentation in dam reservoirs of northern Morocco (Tanger-Tetouan region) using radionuclides”

09:15-10:00  
Ion Ionita (Romania)  
“Monitoring soil erosion losses on sloping cropland in Romania using environmental radionuclides”

10:00-10:30  
Coffee break

10:30-11:15  
Valentin Golosov (Russian Federation)  
“Investigation of sediment budgets in small river basins of the Chernobyl-contaminated zone by the $^{137}$Cs migration method”

11:15-12:00  
Emil Fulajtar (Slovak Republic)  
“Assessment of soil erosion through the use of the $^{137}$Cs as a basis for a Soil Conservation Program in Slovakia”

12:00-12:30  
General discussions on papers presented in Session III (major achievements, limitations). Review of summaries, final reports, publications and MS.

12:30-14:00  
Lunch break

SESSION IV  
Chairperson: J. Ritchie (USA)

14:00-14:45  
Happymore Nemasasi (Zimbabwe)  
“Use of $^{137}$Cs in soil erosion assessment in Zimbabwe”

14:45-15:30  
Des Walling (UK)  
“Using $^{137}$Cs measurements to validate the application of the AGNPS and ANSWERS erosion and sediment yield models in two small Devon catchments”

15:30-16:00  
Coffee break

16:00-17:00  
Andreas Klik (Austria)  
“Soil erosion measurements and soil conservation studies in Austria”

17:00-17:30  
General discussion on papers presented in Session IV (major achievements, limitations). Review of summaries, final reports, publications and
manuscripts.

**Wednesday, 23 May**

One-day field trip. Visit soil erosion measuring sites and soil conservation work in Austria (see separate programme).

Excursion leader: Prof. Dr. Andreas Klik,  
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Department of Hydraulics and Rural Water Management,  
Muthgasse 18, A-1190 Vienna. AUSTRIA.

**Thursday, 24 May**

**SESSION V**  
Chairperson: D.E. Walling (UK)

09:00-09:45  
Dan Pennock (Canada)  
“Landscape factors controlling soil erosion as assessed using 137Cs redistribution”

09:45-10:30  
Peter Wallbrink (Australia)  
“Use of fallout radionuclides in soil erosion and sedimentation studies”

10:30-11:00  
Coffee break

11:00-11:45  
Jerry C. Ritchie (USA)  
“Application of the 137Cs technique for measuring soil erosion in a sustainable agriculture test field”

11:45-12:15  
Edmundo Garcia-Agudo (Brazil)  
“Report on the CRP on “Sediment assessment studies by environmental radionuclides”

12:15-12:45  
General discussion on the papers presented in Session V. Review of summaries, final reports, publications and manuscripts.

12:45-14:00  
Lunch Break

**SESSION VI**  
Chairperson: E. Garcia-Agudo (Brazil)

14:00-15:00  
F. Zapata  
Introduction to the evaluation of the CRP (Log frame of the project)

15:00-18:00  
Working groups: Synthesis of data and formulation of conclusions and recommendations
Working group 1: Pennock (group leader), Garcia Agudo, Golosov, Xinbao Zhang,
Output 1 of project: Refined and harmonized $^{137}$Cs technique

Working group 2: Walling (group leader), Bacchi, Nemasasi, Schuller, Yong Li.
Output 2 of project: Reliable data on soil erosion/
sedimentation rates in relation to environments and
land use/management. Testing and validation of
erosion models

Working group 3: Ritchie (group leader), Wallbrink, Bujan, Damnati, Fulajtar, Ionita, Theocharopoulos.
Outputs 3, 4 and 5 of the project.

Friday, 25 May

**SESSION VII**

**Chairperson: P. Chalk (IAEA)**

08:30-10:30  Presentation and discussion of conclusions and recommendations

10:30-11:00  Coffee break

11:00-12:30  Presentation and discussion of conclusions and recommendations (Cont.)

12:30  Closing, P.M. Chalk

14:00  Individual discussions
ANNEX B

LIST OF PARTICIPANTS
FINAL RESEARCH CO-ORDINATION MEETING
of the FAO/IAEA Co-ordinated Research Project on
“The Assessment of Soil Erosion Through the Use of \textsuperscript{137}Cs and Related Techniques as a Basis for Soil
Conservation, Sustainable Agricultural Production and Environmental Protection”
(311-D1-RC-629.4)

21 – 25 May 2001
Vienna, Austria

Scientific Secretary: Felipe Zapata

List of Participants

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ANNEX C

SUMMARIES OF RESEARCH WORK
Soil erosion-sedimentation study in a small basin of the Tala River through the $^{137}$Cs technique

Alfonso Buján

Soil erosion significantly affects the most productive basin lands, in particular the region called “Pampa Ondulada” of Argentina. Quantification of the actual rates and patterns of soil loss is necessary for designing efficient strategies to control soil degradation. Also, there is a need to predict adequately the hydrological response of these basins under agricultural land use. The main objective of this investigation was to gather a reliable set of data of erosion and sedimentation rates using the $^{137}$Cs technique.

In this study to describe the long term erosive dynamics of the landscape in a 300 ha basin representative of the “Pampa Ondulada” region of Argentina. The selected small basin was located in the northern slope of medium basin of the Tala river (Arroyo del Tala) within the “Partido of San Pedro” (33° 50’ Latitude South, 59° 05’ Longitude West) in the province of Buenos Aires, Argentina, approximately 200 km NW of Buenos Aires City The general topography is undulated with slope gradients between 0 and 2.5 % and slope lengths up to 800 m long. The main land use is annual cereal cropping under conventional tillage. The soils are classified as Vertic Argiudolls.

Since 1994, rainfall, soil moisture and runoff studies were carried out simultaneously to support the erosion studies. Thus, an analysis of the incidence of the rainfall energy distribution on soil water dynamics and surface runoff was performed.

Soil water contents were measured almost monthly at 14 points representative for the landscape pattern of the studied basin by means of a neutron gauge. The main results showed that during dry winters the total soil water content and moisture distribution measured within the upper 100 cm of the soil profile showed homogeneity between landscape positions whereas during the summer or during humid periods there were outstanding differences between contrasting landscape positions. The analysis performed by applying the Chaos theory for the water content at two depths: 20 and 80 cm, the orthobiotic and the parabiotic zones respectively, proved that the system displayed a chaotic or a marginally chaotic behavior.

The runoff studies were performed by continuously measuring the water level stage at the main waterway of the basin. The resulting hydrographs were analyzed for total runoff and runoff dynamics regarding the rainfall events. The results obtained showed that there were periods with high-energy rainfalls, which promoted more than 30 runoff events, alternated with periods of low energy rainfalls with no runoff. The SCS method failed to accurately predict the total measured runoff volumes. Thus, an alternative method, which included a seasonal quantitative relationship between field-measured runoff, the rainfall energy level and the accumulated energy from previous rainfall events was developed. The analysis of the resulting hydrographs showed that the kinematic wave model (OCINE3) performance was better than that of the SCS Triangular hydrograph model associated with its ability to modify the Manning’s roughness parameter. Roughness was sensitive to climatic conditions and to the phenology and management of crops. Also, the time of concentration values for the studied basin proved to be in accordance to the models proposed by Sheridan for low gradient slope catchments.

In the present erosion study with the $^{137}$Cs technique, the Mass Balance Model 2 of Walling and He, 1997 was employed because the obtained estimates of soil erosion/deposition rates correlated well with field-measured soil loss. The estimated mean soil erosion rates ranged between -11.5 and -36 Mg ha$^{-1}$ y$^{-1}$ and fitted the low and moderate erosion classes according to FAO, 1980. Sedimentation rates ranged between + 7.7 and 49 Mg ha$^{-1}$ y$^{-1}$ and it was observed at the lower landscape positions, probably related to changes from convex to concave slopes. The application of the $^{137}$Cs technique proved to be a useful and sensitive tool for establishing erosion classes based on long-term...
erosion/deposition rates. In areas with low topographic gradients such as the Pampa Ondulada region, the slope length appears to be an important property for predicting spatial patterns of erosion rates. Although the slope gradients were relatively low, the soil erosion rate exceeded two or more times the recommended tolerance. This shows the need to enhance soil management towards a sustainable land use.

The hydrological measurements that were carried out during the studied period were in agreement with the 137Cs erosion results. They showed that the analysis of the water dynamics within this basin can be a valuable tool to understand the erosion processes that took place over the last 30 years.

137Cs fallout redistribution analysis for soil erosion surveys in the Piracicaba river basin, Brazil

O. Bacchi

This summary presents a short critical analysis of methodological aspects related to our experiences in the application of the 137Cs technique, the main results and conclusions of the study and an overall assessment of our participation in the CRP.

1 – Methodological aspects

1.1. Choice of detection system
The first aspect to be emphasized is related to the appropriate choice of the detection system. In this regard the very low 137Cs activity in the soils of the south hemisphere (less than 2Bq/kg), as it was found in our study site, is one of the main limiting factors for the success of the technique in our conditions. The use of detectors with less than 2% efficiency results in excessive and unfeasible counting time per sample. For more extensive studies it would be advisable to work with more efficient detectors and/or more detectors. One important aspect to be considered when working with such low activities is the use of available Compton suppression systems or more effective shielding to lower the detector’s MDA.

1.2. Software for spectrum analysis
Working with such very low 137Cs activities we faced some difficulties in using the available software developed for spectra analysis and peak integration. The main difficulty was to set the correct establishment of peak limits (ROI) for integration. For similar conditions, it is advisable to use some software that automatically sets the ROI adjustment based on statistical analysis and curve fitting of the background line and peak.

1.3. Facilities for field work
Depending on the soil type, the soil volume needed per sample and the number of sampling profiles, the sampling work becomes a very hard task, time consuming and expensive. There is a need for more appropriate devices for both depth incremental and bulk profile sampling. Based on the experience gained in this first application of the method, the sampling devices will be improved; in particular incorporating some motorized drilling equipment specially designed to our needs.

2. Main results and conclusions
The average activity for total 137Cs inventory was 419±30 Bq m⁻². The variation coefficient for the total inventory in the reference site would probably not exceed 10%. Although a sharp downward decline of the 137Cs activity was found at the eight analysed profiles, some 137Cs was detected up to
25cm depth. It is not yet clear if this $^{137}$Cs distribution in these profiles was naturally caused by $^{137}$Cs leaching or by some not recorded soil mechanical operations that occurred in the area. A comparative test between $^{137}$Cs, USLE and WEPP methods applied to the same area showed that the basic assumptions of the erosion prediction methods have a significant influence on both, mean erosion or deposition rates and geographic distribution patterns and consequently, in the final interpretation of erosion associated impacts.

Correlation tests between spatial patterns of sediment redistribution, as determined by the three models, and the distribution patterns of different soil chemical properties, showed that erosion rates evaluated by USLE are better correlated with most of the studied variables. This is likely explained because the empirical K factor of USLE (soil erodibility factor) is dependent on many soil attributes that will also well correlate with most of the tested variables.

**Erosion and deposition rates evaluated by $^{137}$Cs technique were well correlated with exchangeable potassium in the upper 20cm soil layer.**

The sediment distribution pattern estimated by $^{137}$Cs did not follow the classical and expected trend of water erosion shown by WEPP and USLE. Other sediment transport processes could explain better this distribution than water erosion.

Regarding the estimation of erosion and deposition rates, it was not possible to select the best method and the best absolute values for the study area. However, the high erosion rates estimated by the three methods confirm the very frequent field observations of severe erosion and siltation occurring all over the watershed studied.

Although not fully conclusive, the results obtained in the project, especially those regarding comparisons between methods, pointed towards the need of more detailed basic studies for validating methods. Future studies are being planned to compare the three methods under conditions of exclusive occurrence of water erosion, where data interpretation would be simpler and more reliable.

3. **Skills improvement on the use of the $^{137}$Cs technique**

Since this was our first opportunity of application of the technique, our participation in this CRP was very positive in terms of skills improvement. At the same time we are confident that the results obtained in our project somehow contributed to achieve the main objectives of the CRP. The main aspect to be remarked is the good results obtained with the technique in spite of the low $^{137}$Cs activity in the study site. The technique proved to be very useful in our specific conditions and it opens the possibility for important future applications.

**Use of $^{137}$Cs to estimate rates and patterns of soil redistribution on agricultural land under different use and management in Central-South Chile**

**P. Schuller**

In Chile there is an urgent need to obtain reliable information on erosion processes and rates affecting agricultural land. The potential for using $^{137}$Cs as a tracer in soil redistribution investigations has not been explored before in Chilean volcanic soils. The purpose of this research was to evaluate the applicability of the conventional $^{137}$Cs technique and to develop a simplified and faster method for
estimating spatial soil redistribution and medium-term soil erosion and sedimentation rates in agricultural land from Central-South Chile.

The study area was located in the Coastal Mountains of the 9th Region in Chile (38°40’S, 72°30’W) exhibiting a mean annual rainfall of 1160 mm y⁻¹. The soil was a Palehumult, of the Metrenco Series containing about 65% clay content and 7% organic matter. Four sites with contrasting land use and management were chosen: Cropland sites under subsistence management (A) and commercial management (B), and grassland sites under subsistence (C) and commercial management (D). First, in each study site conventional ¹³⁷Cs inventory evaluation was made on a grid pattern and a mass balance model incorporating soil movement by tillage was utilised to estimate tillage, water induced and total soil redistribution rates. Furthermore, the applicability of the same model was tested based on a faster simplified ¹³⁷Cs inventory evaluation in composite samples taken at contour lines along the slope transects.

The spatially integrated redistribution rates at the four sites are summarised in Table 1.

<table>
<thead>
<tr>
<th>Site code</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eroding zone:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean erosion rate (kg m⁻² y⁻¹)</td>
<td>1.27</td>
<td>0.93</td>
<td>0.27</td>
<td>0.29</td>
</tr>
<tr>
<td>Fraction of total area (%)</td>
<td>74.1</td>
<td>55.6</td>
<td>51.3</td>
<td>25.0</td>
</tr>
<tr>
<td>Aggrading zone:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean sedimentation rate (kg m⁻² y⁻¹)</td>
<td>0.73</td>
<td>0.87</td>
<td>0.98</td>
<td>0.68</td>
</tr>
<tr>
<td>Fraction of total area (%)</td>
<td>25.9</td>
<td>44.4</td>
<td>48.7</td>
<td>75.0</td>
</tr>
<tr>
<td>Total area:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gross erosion rate (kg m⁻² y⁻¹)</td>
<td>0.94</td>
<td>0.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net erosion rate (kg m⁻² y⁻¹)</td>
<td>0.75</td>
<td>0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment delivery ratio (%)</td>
<td>93.9</td>
<td>50.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net sedimentation rate (kg m⁻² y⁻¹)</td>
<td></td>
<td>0.34</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>Sediment accumulation ratio (%)</td>
<td></td>
<td>71.0</td>
<td>85.8</td>
<td></td>
</tr>
</tbody>
</table>

In all study sites, the tillage, water induced and total soil redistribution rates obtained based on simplified ¹³⁷Cs inventory evaluation correlated well with those obtained based on a conventional inventory evaluation.

In the cropland with subsistence management (site A) water-induced soil erosion predominates along the slope transects possibly due to the scarce vegetation cover during the months where about 72% of the yearly rainfall is concentrated. High erosion rates caused by tillage were observed at the upper border, where chisel ploughing operations have been yearly undertaken perpendicular to the downward slope direction.

In the cropland with commercial management (site B) water-induced erosion was the main process in the zone of steepest slope whereas tillage sedimentation was maximal in a slope concavity situated in the foothill.

The predominant soil redistribution process observed in grassland site under subsistence management (site C) was water-induced erosion and sedimentation. This site showed a reduced vegetation cover during the rainy period as a consequence of the intensive animal grazing. The highest erosion rates
were observed in the sector of the steepest slope and high sediment accumulation at the water run-on sector located in the foothill, at the border of an adjacent stream. The grassland with commercial management (site D) was affected by sediments coming from the upper adjacent area. The highest sedimentation sectors were located in water flow concentration sites: in the foot slope and the hollow midslope, possibly affected by sediments coming from lateral pronounced slopes. In the concavity situated in the midslope over imposed water and tillage-induced sedimentation take place.

Data on annual sediment loss measured in erosion plots located in site A and C were in good agreement with the erosion rates predicted by the $^{137}$Cs method. The spatial soil redistribution rates estimated on a relative scale by pedological observations was similar to that estimated by the $^{137}$Cs technique. Therefore, the rates obtained by the $^{137}$Cs method were considered a good estimate of the soil redistribution rates in the sites studied.

The $^{137}$Cs technique was found to be an efficient method to estimate medium-term soil redistribution rates under the climatic conditions and the soil types selected in this study in Chile. Further investigations are needed to study the applicability of the method in other Chilean climatic zones and soil types.

Tillage and water-induced erosion rates in the yearly ploughed cropland sites were higher than those observed on the semi-permanent grassland sites. Therefore, no-tillage or reduced tillage is suggested for testing in the region as a soil conservation measure to guarantee a sustainable agricultural production. A new research project dealing with this topic is being started now in the same region.

The simplified $^{137}$Cs evaluation method is suitable for giving an assessment on soil loss and sediment accumulation at the field scale, in areas exhibiting simple topography with similar slopes at contour lines, and where the low $^{137}$Cs inventories in soil does not allow in situ measurements. Under these conditions, the simplified method allows a fast estimation of soil redistribution rates, providing the possibility to obtain such estimates for large areas in short time. In order to optimise costs and benefits of the method, the sampling and $^{137}$Cs measurement strategies must be selected according to the resolution of the required information, availability of resources and extension and complexity of the landscape relief in the study area.

Use of $^{137}$Cs and $^{210}$Pb in assessing gully erosion and tillage erosion in the hilly area of the Chinese Loess Plateau

Yong Li

Water erosion in the hilly areas of Chinese Loess Plateau is the major contributor to the overall sediment load of the Yellow River. But the role of gully erosion in total sediment output has been mostly neglected. Soil redistribution from tillage and water erosion has the potential to modify the spatial patterns of soil quality on terraced and steep cultivated hill slopes. However, few studies have investigated this relationship. Against this background, the two studies reported below were done with support of the IAEA in the frame of the CRP.

**Summary Study 1:**
Evaluating gully erosion using $^{137}$Cs and $^{210}$Pb/$^{137}$Cs ratio in a reservoir catchment
The objective of this study was to assess the sediment production and sediment sources by gully erosion in Yangguangou reservoir catchments, characterizing the typical hills and gully topography, through sediment reservoir traps and fallout $^{137}$Cs technique and $^{210}$Pb/$^{137}$Cs ratio at both the hill slope
scale and catchments scale. Cultivated hills and gully slopes are the most eroded erosion areas and have sediment yields of more than 100-\(t\) ha\(^{-1}\) yr\(^{-1}\). Similar \(^{210}\)Pb\(^{137}\)Cs ratios in subsurface soils and the reservoir sediments suggest that gully erosion is the dominant erosion process operating on both cultivated hills and gully slopes. Major land use changes can greatly affect sediment production due to gully erosion. Planting grasses and forests with a cover of 70 per cent on steep slope locations can reduce soil export from the hill slopes areas by about 80 per cent and decrease soil export from the gully slopes by about 58 per cent. An increase in grassland and forestland by 42\% and a corresponding decrease in farmland by 46\% decreased sediment production by 30\% in the catchments. Comparisons of observed data from the catchments with published data for other areas on the Chinese Loess Plateau indicate that water erosion on gullied areas contributes more than 70\% of total sediment production for the entire Chinese Loess Plateau. Contribution of gully erosion to total sediment production on agricultural land is about 60\%. Thus, there is a particular need to monitor gully erosion for combating land degradation and improving the environment in China.

**Summary Study 2:**

Combining \(^{137}\)Cs and TEP for quantifying soil redistribution-soil quality relationship on steep hill slopes

The objectives of this study were to quantify soil quality parameters along terraced and steep hill slopes and determine the relationship between soil redistribution from tillage erosion and water erosion on soil quality parameters in the Chinese Loess Plateau. Soil quality indicators, i.e. soil organic matter (OM), available phosphorus (P), nitrogen (N), bulk density (BD), and clay and silt contents were measured at 5 m intervals on a terraced field and at 10 m intervals on a steep cultivated hill slope in a down slope transect. Soil redistribution rates from tillage and overland flow were obtained by \(^{137}\)Cs technique integrated with a tillage erosion prediction model (TEP). Water erosion was the primary cause for the overall decline in soil quality on the steep cultivated hill slope while tillage erosion had a comparable contribution to overall level in soil quality on the terraced hill slope. Soil movement by tillage controlled the spatial patterns in OM, N and P on both terraced and steep cultivated hill slopes. Selective removal of finer particles by water erosion caused a linear decrease in clay content of 0.02\% m\(^{-1}\) and corresponding increase in silt content of 0.04\% m\(^{-1}\) down slope on the steep cultivated hill slope. The impact of tillage erosion on OM, N and P on the steep cultivated hill slope can be assessed using the change in adjacent slope gradients (X) through a soil quality-topography regression model, Y=aX+b.

**Soil loss assessment studies in the Upper Yangtze River Basin of China**

**Xinbao Zhang**

The project on “Soil Loss Assessment Studies in the Upper Yangtze River Basin of China” was carried out jointly by research teams from the Chengdu Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, and the Physics Department, Sichuan University during the period of 1996-2000. Prof. Xinbao Zhang was the chief scientist of the project.

The Upper Yangtze River Basin, which is one of the regions in China severely affected by soil erosion, was determined to be a state key soil conservation region for in situ sustainable agriculture development and for reduction of sediment yields to the Three Gorge Reservoir. Thus, there is an urgent need for information on erosion rates erosion rates and sediment sources to predict future changes in sediment yield and to evaluate the effects of soil conservation measures on soil loss reduction.

The project employed the \(^{137}\)Cs technique to assess erosion rates and to investigate river sediment sources at study sites over the basin. A total of 809 samples were collected, of which 547 cores soil
samples 118 surface soil samples and 164 deposited sediment samples. To select reliable models for calculation of soil loss on cultivated land, the $^{137}$Cs measurement data of the Ansai site in the Loess Plateau and the Kaxian Site in the Upper Yangtze River Basin were utilised to test the Proportional Model, the Mass Balance Model 1 and the Mass Balance Model 2. The rates derived from the Mass Balance models 1 and 2 are very close. Both estimates agree with the realistic value for the Ansai site with low precipitation and they are 20% higher than that for the Kaxian site with high precipitation.

The most important achievements of the project are following:

1. To eliminate the effects of $^{137}$Cs surface enrichment, the “effective $^{137}$Cs reference inventory” was proposed and Mass Balance Model 1 was revised;
2. The erosion rates on cultivated slopes were estimated between 7558 t/km$^2$.a and 9854 t/km$^2$.a, while little erosion occurred on terraced fields. The severity of soil erosion on cultivated slope was strongly related to slope gradient and soil texture;
3. The erosion rates on forestland and grassland were estimated between 0 and 4435 t/km$^2$.a. It is clear that vegetation coverage has the most important influence on erosion rates.
4. Cultivated slopes are the major sediment source, if water shed is mostly under cultivation.
5. Under the present contract, 6 papers were published in international journal and 3 papers in domestic journals, and 3 papers are in press.

**Use of $^{137}$Cs technique in soil water erosion studies on arable fields in Central Greece.**

Sideris Theocharopoulos

Soil erosion is the most important soil and landscape degradation process in Greece, because of its geomorphological and Mediterranean climatic conditions as well as inadequate land use and management practices.

The scope of this project was to utilise, for the first time in Greece, the $^{137}$Cs technique to study soil erosion processes and in particular to produce medium-term erosion data. The contribution to the harmonisation of the technique on a global scale was a general goal of the CRP.

This project started from the survey reconnaissance phase where emphasis was given to study the $^{137}$Cs inventories and their spatial distribution along transects in five characteristic landscapes of central Greece. This as a first step to investigate the possibility for application of the technique in the study area.

Later the technique was applied on a small first order catchment (watershed) of about one ha in size, in the area of Mouriki village. A grid sampling scheme was followed and grid points were sampled and $^{137}$Cs residuals were determined in all grid sampling points. The $^{137}$Cs activities in the soil samples were measured in the less than 2mm soil fraction at the Environmental Radioactivity Lab., N.C.S.R “Demokritos”, using a Hp Ge detector of 25% relative efficiency and computerized multi-channel analyser in a total spectrum area 2000 KeV and a resolution of 0.5KeV/ch. The local reference inventory (11,822 Bq/m$^2$) was determined by a sampling scheme of ten bulk samples (points) and one depth incremental sampling. One of the complications in the study was to deal with Chernobyl fallout.

The latest version of models developed by Walling and He (2001) were utilised to estimate erosion and deposition rates. The models were validated using sensitivity analysis technique and comparison
with local short-term erosion data and data obtained using the Universal Soil Loss Equation, USLE-Wishmeier and Smith (1978). Soil erosion and deposition rates as well as the $^{137}$Cs residuals were correlated to soil properties.

The magnitude of the erosion resulting estimates of soil erosion rates were influenced by the model used. They depend on a number of factors, including the location of the sampling points, local slope, and the soil properties. The Mass Balance Model 2 and Mass Balance (MBM2) and the Mass Balance Model incorporating soil movement by tillage (MBM3) conversion models are able to take into account the Chernobyl fallout and they both predict soil redistribution rates of the same order of magnitude as the local experimental data. Estimated soil erosion rates for the catchment varied from 6.71 to 85.55 t ha$^{-1}$y$^{-1}$ using MBM2 and from 3.54 to 95.78 55 t ha$^{-1}$y$^{-1}$ using MBM3. Deposition rates varied from 1.23 to 168.19 55 t ha$^{-1}$y$^{-1}$ for MBM2 and from 3.24 to 189.18 t ha$^{-1}$y$^{-1}$ for MBM3.

High correlation was apparent between erosion/deposition rates (MBM2) and soil P (P<0.001), soil K (P<0.001), with soil organic matter % (P<0.05), point slope (P<0.05), clay % (P=0.053) and altitude (P=0.057).

The total soil losses from the catchment have been estimated at 18.34 t ha$^{-1}$y$^{-1}$ with the MBM2 and 22.12 t ha$^{-1}$y$^{-1}$ for the MBM3.

Main conclusions

$^{137}$Cs fallout inventories and their spatial distribution in central Greece are adequate for the application of the $^{137}$Cs as tracer to study soil redistribution and to estimate erosion and deposition rates in arable land in Greece.

The use of the $^{137}$Cs isotopic technique to quantify medium-term soil erosion and deposition rates was successfully applied in Greece.

The application of the $^{137}$Cs isotopic technique at the catchment scale presented many advantages and potentials for quantifying medium term soil erosion and deposition rates under Mediterranean conditions. Further studies are needed in other regions of the country.

Quantitative assessment of soil erosion in a drainage basin of El Hachef dam (North Morocco) using $^{137}$Cs

B. Damnati

In Morocco, soil erosion and sedimentation are a serious problem for the management and conservation of the soil and water resources. Every year dam siltation resulting from eroded lands causes losses equivalent to 70 million m$^3$ water. Also, it has been estimated that the NPK losses in agricultural land are of about US $ 100/ha/year. Measurements of soil erosion on the landscape using classical erosion methods have been the main objective of several research works. These classical methods however, are very laborious, time-consuming and very expensive. On another hand, the quantitative estimation of soil loss remains insufficient particularly in the North of Morocco.

In this study, the quantification of the soil erosion was made utilising the $^{137}$Cs technique. The study site is a small basin (catchment) of the Oued El Hachef dam located south-east of Tangiers in Northern
Morocco. The area has an average rainfall of 817 mm. The predominant soils are Vertisols. Land is mainly cultivated and there is some sparse residual natural vegetation (shrub and tree). The main catchment was subdivided into four sub-catchments based on the vegetation type. $^{137}$Cs inventories were established by depth incremental sampling was taken along transects. Complementary soil (pH, carbonates, organic matter, particle size distribution) and mineralogical analyses were made.

For the estimation of the erosion/sedimentation rates, the proportional and the simplified mass balance model were used. Mean $^{137}$Cs inventory in the reference soils profiles is 2313 ± 59 Bq m$^{-2}$. There is no apparent relation between the caesium inventories and the pH, granulometry or slope degree. The estimated erosion rates varied from 5 to 68 t/ha/yr and they are moderate to high losses. Important differences were obtained on the estimates of erosion/sedimentation rates, depending on the model used.

More information on the study area is required. The sampling strategy needs to be improved, in particular by increasing sampling density in uncultivated sites. Additional parameters are needed to utilise other conversion models. The estimated erosion rates should be validated by sampling sediments in the dam reservoir. It would be interesting to perform the $^{137}$Cs measurements in the fine fraction of the soil/sediment samples.

Use of $^{137}$Cs technique in soil erosion and sedimentation studies in Romania

Ion Ionita

In the frame of the FAO/IAEA CRP on soil erosion, a series of investigations were carried out in Eastern Romania utilizing the $^{137}$Cs technique to assess soil erosion and sedimentation.

Data collected from runoff plots located in the Tarina basin of the Moldavian Plateau have shown a strong correlation between individual soil and $^{137}$Cs losses.

Field measurements on the spatial distribution of $^{137}$Cs in a small area of Upper Gaiceana basin were conducted during the years 2000 and 2001 (seven transects, 57 pits and 253 samples). The catchment of the creek (named Poiana Neamtului for this study) is situated 490 m above sea level and has an extension of 7.1 ha. The area is covered by Brown Luvic soils. The relative relief of the basin is 35 m and its slopes are undulating (average 4 - 5 %). Despite its gentle topography, the following areas were identified based on $^{137}$Cs loss and gain:

- A reference range area (11 - 12 kBq m$^{-2}$ in the top 40 - 50 cm of soil profile) accounts for 6 % of the basin;
- A deposition area associated to 1.17 ha (16 % of the basin area);
- A soil eroded area, where rill and inter-rill erosion is the main feature of this small basin and covers 78 % of the total area.

The $^{137}$Cs technique was successfully used to assess the development of discontinuous gullies, near the Perieni Station and the following information was obtained from the studies:

- Dating of recent sediments in the gully head area;
- Documenting the mean aggradation rate, the age of the upstream gully, the gully head advance;
- Assessing the mean annual deposited mass along the gully floor and the average annual eroded material delivered by gully head, especially.

In the Upper Racatau basin (3912 ha), the gradual conversion of areas under conservation practices to an up-and-down hill farming system resulted in a doubling of the soil erosion and sedimentation rates, as suggested by the $^{137}$Cs depth distribution in the Bibiresti reservoir.
From the depth distribution and inventory of $^{137}$Cs across an agro-terrace from the Tarina it was found out that the height of the agro-terrace edge increased at mean annual rate of 5 cm/year.

On the other hand, the studies reported have also revealed a high variability in $^{137}$Cs inventories within the same catchment or between catchments of the Moldavian Plateau. This variation is likely associated to a non-uniform $^{137}$Cs deposition of the Chernobyl fallout.

**Investigation of sediment budgets in small river basins of Chernobyl pollution zone by method of $^{137}$Cs migration**

Valentin Golosov

Most studies utilising $^{137}$Cs to obtain information on soil redistribution rates have been undertaken in areas where bomb-derived $^{137}$Cs represents the sole, or at least the dominant, source of radiocaesium. Additional inputs of $^{137}$Cs associated with Chernobyl fallout are commonly seen as introducing complications, which may compromise the validity of the approach. In areas that received very high levels of Chernobyl-derived $^{137}$Cs fallout the Chernobyl-derived component of the total $^{137}$Cs inventory may be several orders of magnitude greater than the bomb-derived component and the latter can be effectively disregarded when interpreting measurements of $^{137}$Cs inventories.

Application of Chernobyl-derived $^{137}$Cs for the assessment of soil redistribution within cultivated fields and sediment redistribution along pathways from cultivated slopes to the river channel allows understanding the advantages and limitations of this tracer in areas with high level of Chernobyl contamination. Few small catchments with area ranging from 1 ha to 42 km² were chosen for detailed investigation in the Lokna river basin, located 250 km south Moscow in Tula region. A new approach was elaborated for study sediment redistribution in small basin using $^{137}$Cs-technique and other methods for quantitative assessment of erosion and deposition rates. This approach is based on large-scale geomorphologic mapping of catchment simultaneously with detailed topographic survey. A geodetic GPS system was used for fixation of each geomorphologic unit borders, as well as sampling points, pit locations and etc. Each depositional unit was characterized by several bulk samples and the curve of $^{137}$Cs depth vertical distribution. Before taking samples for laboratory analysis, $^{137}$Cs concentration was measured “in situ” in each sampling point by field-portable scintillation (NaI) detector “Corad”, which were produced in the Institute of Nuclear Energy (Kurchatov). The comparison of *in situ* and laboratory measurements of $^{137}$Cs inventories undertaken in this study has confirmed the potential for using *in situ* measurements as a rapid means of assembling information on the spatial distribution of $^{137}$Cs inventories in areas receiving high levels of Chernobyl fallout.

Few reference locations should be chosen within the study catchment for calculation of soil redistribution taking into account the initial systematic spatial variability of Chernobyl-derived $^{137}$Cs. On another hand considering the essentially instantaneous nature of Chernobyl fallout, compared with the extended period of bomb fallout, and improved knowledge of land use activities since the period of Chernobyl fallout, it should prove easier to develop reliable calibration relationships. Chernobyl-derived $^{137}$Cs is a good tracer for assessment of deposition rates. Detailed analysis of sediment redeposition in different geomorphologic units within study catchments allowed to calculate the total sediment storage along pathways from cultivated slopes to the river channel and to determine the sediment delivery coefficients. Evaluation of sediment budgets of small catchments for different time intervals was made using $^{137}$Cs technique and other methods of assessment of erosion and depositional rates. It was found that the role of dry creek (balka) bottoms as the main sink of sediments in the central part of the Russian Plain increased during the time. Further work is needed to trace the fate of the sediment and its associated $^{137}$Cs, once they enter the river system.
Assessment of soil erosion through the use of $^{137}$Cs in Slovakia

Emil Fulajtár

Soil erosion is the most important soil degradation process in Slovakia. Some 61.8% of agricultural soils (1'520,000 million ha) are affected by water erosion. The erosion data are needed for soil conservation programs. Some information has been obtained in recent years mainly from monitoring plots and few studies using radionuclides such as the $^{137}$Cs method.

The objective of this study was to provide a complete and well-representative set of data on the erosion intensity in topographical conditions typical for the loess areas of Slovakia. For this purpose, the Jaslovské Bohunice site situated in the north part of the Trnava Hilly Land and the Mochovce site in central part of Pohronská Hilly Land (both in Western Slovakia) were chosen. A multiple transect approach was used for sampling and determining the $^{137}$Cs inventories in both sites. The $^{137}$Cs analyses were performed at Nuclear Power Plant Research Institute, Trnava. The calibration models of Walling and He, 1997, in particular the Proportional Model and simplified Mass Balance Models 1 and Mass Balance Model 2 were utilised for estimating the erosion/deposition rates.

The results indicate that the study sites are affected by both water and tillage erosion. The examination and interpretation of the results on $^{37}$Cs spatial and depth distribution provided information on the role of slopes on the $^{137}$Cs inventories, the influence of Chernobyl fallout on the variability in the $^{137}$Cs distribution, in particular at Mochovce site, the relationship erosion and deposition to topography.

The calculated erosion/deposition rates differ according to the models used. The highest yearly erosion rates are provided by Simplified Mass Balance Model 1. Values calculated by Mass Balance Model 2 are considerably lower and the Proportional Model gives somewhat intermediate values. The results from last two models seem to be more realistic.

The erosion rates are similar at both sites. Jaslovské Bohunice have less steep and very short slopes, but they have very erodible soils. In contrary, at Mochovce site the soils are more resistant to erosion, but the slopes are considerably steeper and longer. Erosion rates from the Mass Balance 2 range from 10 to 60 t.ha$^{-1}$y$^{-1}$, with mean values of 10 - 20 t.ha$^{-1}$. The deposition rates varied from 15 to 37 t.ha$^{-1}$y$^{-1}$. The accumulations in the valley bottom are not homogeneous. The incremental sampling showed, that the depth of the accumulation ranges from 40 to 55 cm. The accumulation rate is usually close to 20 t.ha$^{-1}$, seldom over 40 t.ha$^{-1}$.

The erosion rates obtained through $^{137}$Cs method were compared to rates gained from field measurements in small experimental plots. They showed maximal rates from 80 - 160 t.ha$^{-1}$, but the rates are mostly negligible. The mean rate is around 13 t.ha$^{-1}$ that coincides quite well with the rates provided by Mass Balance Model 2. The higher values given by Mass Balance Model 2 can be explained because they express not only water erosion, which was measured at experimental plots, but also the tillage erosion.

The long-term analysis of the erosion may indicate that the strongly eroded areas in hilly lands of Slovakia are result of erosion processes occurring mainly in older periods but present erosion is not negligible.
Conjunctive use of unsupported $^{210}\text{Pb}$ and $^{137}\text{Cs}$ in soil erosion investigations in tropical Africa

D.E. Walling

The primary aim of this project was to support work on exploring and developing the potential for using $^{137}\text{Cs}$ and unsupported $^{210}\text{Pb}$ in soil erosion investigations in tropical Africa within the framework of the IAEA CRP ‘Soil erosion studies by environmental radionuclides and their application to soil conservation measures’. Most existing work in this field had been undertaken in temperate latitudes and there was therefore a need to confirm the validity and viability of the approach in tropical areas where soil erosion problems are frequently of greater significance. Zimbabwe was selected as a case study area and collaborative links were established with the Soil Productivity Research Laboratory at Marondera that was also a member of the CRP to which this project belongs and would also receive support from the CRP. Originally contact was established with Dr. Linus Mukurumbira, but, after his retirement, the main points of contact were Mr. Sithole and Mr. Nemasasi. Dr. Mukurumbira agreed to collect soil samples based on an agreed strategy and protocols and the set of samples was transported to Exeter for analysis of their $^{137}\text{Cs}$ and unsupported $^{210}\text{Pb}$ content in the laboratory within the Department of Geography. The $^{137}\text{Cs}$ analysis was completed during 1998 and the data were forwarded to Marondera. Some initial results from the study were presented at the CRP meetings held in Bucharest in May 1998 by Mr. Sithole and in Barcelona in 1999 by Mr. Nemasasi. In the past year emphasis has been placed on analysis of the excess $^{210}\text{Pb}$ content of the samples to assess their potential for using this radionuclide for obtaining estimates of soil erosion rates. Although it was understood that a further set of samples had been collected during 1999 the arrival of these samples in Exeter is still awaited. Problems of communicating with the Zimbabwe researchers, possibly reflecting the political unrest in that country, have hampered the final analysis and interpretation of the $^{137}\text{Cs}$ and excess $^{210}\text{Pb}$ data.

In support of this project and the CRP more generally, work has also been undertaken on the development and testing of numerical procedures for converting measurements of $^{137}\text{Cs}$ and unsupported $^{210}\text{Pb}$ inventories to estimates of rates of soil redistribution. Numerical algorithms have been produced to implement these procedures and user-friendly software has been produced to permit their easy application. In addition, the potential for using beryllium 7 ($\text{Be-7}$) as a complement to $^{137}\text{Cs}$ and excess $^{210}\text{Pb}$ and as a means of estimating the erosion rates associated with individual events has been investigated and more recently attention has been given to exploiting the potential for using $^{137}\text{Cs}$ measurements and associated estimates of soil redistribution rates to validate distributed soil erosion and sediment yield models. A major proportion of the funds made available by this contract were used to meet the costs of analysing the samples collected in Zimbabwe by Dr. Mukurumbira and his colleagues and forwarded to Exeter.

Use of $^{137}\text{Caesium}$ techniques in erosion assessment in Zimbabwe.

Happymore Nemasasi

Soil erosion is the most important land degradation process in the smallholder-farming sector of Zimbabwe. Agricultural productivity and sustainability is threatened by accelerated rates of soil erosion in the communal area farming systems. The capacity of most national dams and rivers has been reduced drastically by continuous siltation.
Conservation strategies are meaningful only if erosion rates are known in the different land use types. Past studies carried out in Zimbabwe concentrated on qualitative assessments but no quantification of erosion rates was made. Work undertaken at the Soil Productivity Research Laboratory was aimed at quantifying medium term erosion rates using the $^{137}$Cs method in Zimbabwe. In addition the studies contributed to test the applicability of the method in tropical areas of Africa.

The areas studied were Lake Manyame (also called Lake Chivero) and Mahusekwa Dam catchment areas. Manyame River passes through Seke communal lands and supplies water for Harare, the capital city of Zimbabwe. Mupfure River on which Mahusekwa dam was built, passes through Chiota communal lands. This river has the greatest number of water permits in Zimbabwe. The sampling strategy used in the study areas was the multiple transect approach. Three replicate cores were taken at each position and bulked to make composite samples of 0-10, 10-20 and 20-30 cm depths per sampling position. Samples were labelled according to land use type. The $^{137}$Cs measurements were made at the University of Exeter, UK and nutrient contents were analysed at the local laboratory in Zimbabwe.

The results indicate very high soil erosion rates of 54 - 65 t ha$^{-1}$y$^{-1}$ in cultivated fields, 37 t ha$^{-1}$y$^{-1}$ in cultivated vleis, 88-142 t ha$^{-1}$y$^{-1}$ in communal grazing lands and 35- 80 t ha$^{-1}$yr$^{-1}$ in disturbed woodland areas of the communal areas of Seke and Chiota respectively. In the small scale farming areas, erosion rates in the cultivated fields range from 39 -48t ha$^{-1}$y$^{-1}$ whilst in fallow and grazing areas the magnitude of soil loss is 16 t ha$^{-1}$y$^{-1}$. In the commercial farming areas studied, erosion rates are equally high. Cultivated fields were found to have rates of 36-40 t ha$^{-1}$y$^{-1}$ whilst pasture fields or natural grazing area had calculated soil losses of 25 t ha$^{-1}$y$^{-1}$. An analysis of edaphic, land use and topographic controls on these soil erosion rates was made. Also the relationship between the effect of erosion processes on soil nutrient status and distribution along slopes was studied in communal lands and commercial farming areas.

These results are a clear testimony of the threat to agricultural sustainability if soil erosion rates of this magnitude continue unchecked. National scientists and environmentalists, policymakers, farmers and various stakeholders are challenged to develop strategic and practical conservation measures to check erosion and environmental degradation in agricultural systems of Zimbabwe.

**Landscape factors controlling soil erosion as assessed using $^{137}$Cs redistribution**

D.J. Pennock

The $^{137}$Cs technique has greatly expanded our knowledge of the topography/soil redistribution relationship. The specific focus of this project was on the development of quantitative landform segmentation procedures to stratify landscapes into functionally distinct sampling units. These landform segments are the basis for a consistent, reproducible research framework for examining the redistribution-topography relationship.

The specific objective of this work was to: a) further develop the landform segmentation procedures and b) apply the procedures to develop a regional scale synthesis of $^{137}$Cs-derived redistribution rates for a major terrain type in the prairie region of Canada.

The landform segmentation procedures are based on a combination of slope morphological (gradient, plan and profile curvature) and positional attributes (specific dispersal area, specific catchment area). The morphological attributes were implemented using a Digital Elevation Model Network algorithm, and the inclusion of the positional attributes greatly improved the association between soil redistribution rates and the landform segments.
To assess the utility of the segmentation procedures, the association between $^{137}$Cs derived soil redistribution rates and quantitatively defined landform elements was examined at nine hummocky terrain sites in southern Saskatchewan, Canada. Shoulder elements with convex plan curvatures had the highest mean soil loss rates of 33 t ha$^{-1}$ yr$^{-1}$, followed closely by other shoulder and back slope elements. The erosional behaviour of level elements (i.e., those with gradients less than 3°) was highly dependent on the specific dispersal area of the element - elements with high dispersal areas were dominantly erosional (mean soil loss of 14 t ha$^{-1}$ yr$^{-1}$), whereas level elements with low dispersal areas were depositional (mean soil gain of 15 t ha$^{-1}$ yr$^{-1}$). Doubly concave foot slope elements had mean soil gain of 10 t ha$^{-1}$ yr$^{-1}$. The dispersion of values across the nine sites was much greater for the depositional units than the erosional units, indicating a complex relationship between deposition and terrain attributes in the depositional units. The results clearly indicate that regional-scale patterns of soil redistribution can be developed using the $^{137}$Cs technique.

**Application of $^{137}$Cs for measuring soil erosion in a sustainable agriculture test field**

Jerry C. Ritchie

Narrow, stiff grass hedges are biological barriers designed to slow runoff and capture soils carried in runoff water. This study was designed to measure quantitatively the deposition of soil upslope of a narrow, stiff grass hedge using topographic and Cesium-137 ($^{137}$Cs) surveys. Topographic surveys made in 1991, 1995, and 1998 measured 1 to 2 cm yr$^{-1}$ of recent sediment deposited upslope of the grass hedge. $^{137}$Cs analyses of soil samples were used to determine the medium-term (45 years) soil redistribution patterns. Erosion rates and patterns determined using $^{137}$Cs measured medium-term erosion near the hedge and do not reflect the recent deposition patterns near the grass hedge measured by topographic surveys. Using the combination of topographic and $^{137}$Cs surveys allows a better understanding of the role of grass hedges as barriers for capturing eroding soils and suggest that the recent deposition is associated with the grass hedge but that there is still a net loss of soil near the hedge position over the past 45 years. This study shows the importance of understanding the history and management of a study area as we interpret soil redistribution patterns using $^{137}$Cs. Topographic surveys show significant recent (since 1991) deposition rates near grass hedges while $^{137}$Cs data show a medium-term net erosion in the same area. This study reinforces the basic concepts that $^{137}$Cs provide estimates of medium-term (45 years) erosion rates not short-terms erosion rates. Using the combination of topographic and $^{137}$Cs surveys of an area provides better insights into the history and pattern of erosion of the area. The data also show that the hedges are acting to capture soil particles entrained in the concentrated flow. One interesting possibility from this study site is that with the current rapid rate of deposition near the grass hedges we may be able to return to this site in a couple years and with another set of $^{137}$Cs redistribution rates make an estimate of recent deposition rates.
Measuring the contributions of sediment and Phosphorus from different land uses at the local and catchment scale using fallout radionuclides and geochemistry

Peter Wallbrink

Eutrophication is a major issue in Australian waterways, and the persistent occurrence of algal blooms has been linked with excess available P. The total amount of P in these systems has been shown to be dominated by the sediment load derived from erosion of diffuse sources, although fertiliser P has also been implicated. In this paper we determine the relative contributions of both sediment and sediment-bound P from the major diffuse sources of sediment in the Bundella Creek catchment (8,700 ha) in the Liverpool Plains of NSW, Australia.

Erosion sources include surface erosion from cultivated, pasture and steep forested land as well as subsoil erosion from the significant number of channels and gullies present within these systems. Subsoil was found to dominate sediment (~68%) and P delivery (~58%) at the whole catchment scale. However, higher concentrations of P were found in surface soils, and these contributed significantly to the delivery of P at the individual land use scale. The greatest contribution of surface-eroded P was from the forested land use areas, mainly because of its large surface area and high concentrations of P in their surface soils. However, the relative yields per unit area of sediment and P from cultivated lands was many times higher than that from either forest or pastureland uses. There was little overall contribution of sediment or P from surface erosion of pastureland areas. The ratio of Nd/P was used to show that fertiliser P transported off land surfaces with sediments is highly variable but can impact on offsite P concentrations. For example fertiliser P contributed some 3% to total P in runoff from cultivated lands and about 18% from pastureland areas. The difference between the two was attributed to the method by which the fertiliser was applied and timing of catchment rainfall and sampling. The overall contribution of fertiliser P at the homestead and catchment outlet was found to be 13 and 9%, respectively.

Sediment assessment studies by environmental radionuclides

E. Garcia-Agudo

The CRPs on Soil Erosion (D1.50.05) and Sedimentation (F3.10.01) were initially conceived as a single approach to study these processes in an integrated manner utilising the same techniques. Both projects had the same background, justification and project proposal. Later however, they were split in two different projects due to some administrative constraints for implementation. Nevertheless, they were conducted simultaneously, allowing the creation of a network of institutions, to test the worldwide the applicability of the $^{137}$Cs technique and other fallout radionuclides in very different environments.

All the research proposals received for both CRPs covered erosion studies, and some included sedimentation as well. In addition to include some studies dealing with soil erosion, the main focus of the Sedimentation CRP was on methodological aspects of the $^{137}$Cs technique.

One of the main activities co-ordinated under the Sedimentation CRP was the laboratory intercomparison exercise on $^{137}$Cs- and $^{210}$Pb analysis. The need for this intercomparison exercise was identified from the initiation of the projects due to the great diversity of measuring techniques used in
the participating laboratories. These included detectors, geometries, standards and software for spectra analysis. Detector relative efficiencies ranged between 15 and 45%. Samples were mostly measured in Marinelli Beakers, of sizes ranging from 150 ml to 1500 ml. The 500 ml Marinelli Beaker were the most frequently used. Other laboratories measured the samples in cylindrical containers placed on top of the detector. Procedures for detector calibration were the most variable. The most popular calibration procedure was to prepare a standard with the same geometry as the sample, using an "inert" matrix spiked with some certified solution, of single or mixed radionuclides. The problems that may arise are related to the origin of the standard solution and to the matrix composition. The use of soil, silica, aqueous solution and epoxy resin as matrix materials has been reported in this study. Differences in density and atomic number may affect the final result if the appropriate corrections are not made. Forty independent analyses were carried out in this inter-comparison exercise for $^{137}$Cs. After discarding six outlier values, the average concentration reported was $3.00 \pm 0.28$ Bq/kg.

For comparison purposes, the average from 12 individual measurements made by the IAEA Chemistry Unit in Seibersdorf was $2.97 \pm 0.20$ Bq/kg.

In spite of the large diversity of detectors and analytical procedures used, almost identical values for the average concentration were obtained with very low standard deviation among the participating laboratories. This demonstrated that the accurate measurement of fallout $^{137}$Cs in soil is not a problem with the available standard techniques and equipment.

Under technical contract Q. He and D. Walling, University of Exeter, UK developed a mathematical model to estimate the $^{137}$Cs inventories in undisturbed sites, knowing the geographic coordinates (latitude and longitude) and the average rainfall in the site. This model has now been incorporated to the CSMODEL1.

The conclusions and recommendations provided by the participants at the fourth RCM of the Erosion CRP represent the combined results of the overall network consisting of the two CRPs (Erosion and Sedimentation), and need to be evaluated in this context.

The most important conclusions and recommendations elaborated by the participants at the third and last RCM of the Sedimentation CRP, held in Barcelona in 1999, can be summarized as follows:

- The participants of the CRP have made significant progress towards a harmonized application of $^{137}$Cs techniques. Specific recommendations concerning reference sites, sampling network, laboratory methods and calibration models were made by the participants.
- The work of the participants has greatly broadened the range of environments where the technique has successfully been applied and reliable data for erosion and sedimentation rates has been produced for these areas.
- The spatially distributed $^{137}$Cs data produced by the participants has been used to assess the relevance of other erosion models (e.g. tillage redistribution, water erosion models).
- The testing of the calibration models for calculating soil loss or gain has only been possible in few studies. Further work to test these models is required, although the participants recognized that the opportunities for this testing are limited.
ANNEX D

LIST OF PUBLICATIONS
PUBLICATIONS
(Papers submitted or published on work done under contract)

Note: Manuscripts submitted for final publication of the CRP are not included.

A. BUJAN


O. BACCHI


B. DAMNATI


E. FULAJTÁR


V. GOLOSOV


I. IONITA


YONG Li


D. PENNOCK


J.C. RITCHIE


**P. SCHULLER**


S. THEOCHAROPOULOS


P. WALLBRINK


**D.E. WALLING**


9. WALLING, D.E. and HE, Q. Using $^{137}$Cs measurements to validate the application of the AGNPS and ANSWERS erosion and sediment yield models in two small Devon catchments. Submitted to *Soil and Tillage Research*.

X. ZHANG


(12) ZHANG et al., Progress and final reports submitted to the IAEA.

(13) Other reports: