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Advanced science and technology for biological decontamination

of sites affected by chemical and radiological nuclear agents

ABSTRACT

The main objectives of the NATO ASI "Advanced Science and Technology for Biological Decontamination of Sites Affected by Chemical and Radiological Nuclear Agents", Zhytomyr (Ukraine), August 2005 were training of participants in the science and technology of biological decontamination related to radionuclides and chemical substances, explosives, ammunitions and fuels; and describing and discussing the present state-of-the-art, and the further developments required for commercial applications. These topics are up-to-date in a global context because of increased sensitivity towards environmental problems in many countries. The main output of the school is to set off collaborations of scientists and technicians with state and governmental agencies, with regulators, economists, and evaluators. Viable and successful communication is a priority for factual implementation of decontamination practices.

The NATO ASI "Advanced science and technology for biological decontamination of sites affected by chemical and radiological nuclear agents" held in Zhytomyr (Ukraine) on 17-28 August 2005 addressed the topics of biological decontamination of pollution related to chemical, radiological and nuclear agents. The main objectives of the initiative were: (i) to train participants for principles of scientific and technology of biological decontamination, bioremediation and phytoremediation, with particular emphasis on sites contaminated by radionuclides and chemical substances connected with explosives, ammunitions and fuels; (ii) to describe and discuss the present state-of-the-art, the latest developments, and the further advances required for commercial applications; (iii) to stimulate future interactions and collaborations in this technologically important field of study.

Contamination of soils and waters by human activities is an important and widespread problem. Among the sources of contamination, organic and inorganic substances can affect in different ways individual organisms, human populations, and ecosystems (1). In particular, sites which have been in the past utilised for military instalments, weapon production and nuclear power plants represent a considerable threat to environment and human health because of the specific pollutants that can be dispersed, for example: solvents, explosives, fuels, radionuclides, heavy metals, and metalloids (2). Remediation technologies for these contaminated sites have been developed based on conventional systems utilising physical and chemical treatments, such as excavation and incineration, pump-and-treat methods, ultraviolet oxidation (3, 4).

However, these approaches are usually very expensive, and can involve the removal of large amounts of soil or water, which often leads to resources depletion and limitation in the future utilisations of the site. Recently, new decontamination approaches, based on living organisms, in particular micro-organisms and plants, have been prospected as a more sustainable alternative characterised by low costs, reduced environmental impact, and increased public acceptance. Development of biological decontamination techniques has been carried out in several laboratories and research institutions worldwide, and practical applications in the field on contaminated sites have been recorded in several countries. In particular, it's worth being underlined that in the USA and Canada several commercial companies have been utilising these approaches for years, alongside conventional techniques, with great success; a bright example is in the context of U.S. EPA "Superfund innovative technology evaluation program". (http://www.cluin.org/download/remed/phytoresgude.pdf http://www.epa.gov/ORD/NRMRL/lrpcd/rr/phytores.htm).

In the European Union commercialisation of phytotechnologies and bioremediation technologies is still scant, even though groups of high-level scientists are actively involved in research on this very topic.

Constraints to the application of biological decontamination technologies can be attributed to the legislation and to the endpoints requirements for cleanup, to economic considerations about costs and benefits, and to the limited knowledge about long-term effects on the environment.

There is a strong need for training of new professionals to be employed in commercial or governmental initiatives, who should master both the scientific background of biological decontamination and specific features of "in-field" applications. As the most relevant pollution

problems are localised in the less favoured countries, training per se may not suffice. A complete capacity building policy is needed, that encompasses training, infrastructures, as well as human and financial resources necessary to implement these new technologies. Capacity building can be obtained by bringing together both scientists and experts in the field, finalized to the application of biological decontamination, in order to favour the merging of specific expertise. The function of these specialists is instrumental to governmental institutions with a mission in environmental protection, but could be important for postgraduates and post-docs who are willing to improve their professional chances with a factual point of view. Also commercial companies and enterprises already acting or willing to move into this sector can benefit from the initiative. The environmental sector is gaining pace in many countries, and in particular in those originated after the collapse of the former USSR area of influence, which have been left with a plethora of environmental problems. There are no exact data available on the extent of environmental contamination in Eastern Europe, whereas Western Europe, North America and other continents are just more knowledgeable about their own situation. A gross estimation of about 200'000 contaminated sites in former USSR countries has been made by David Glass (5).

The purpose of the ASI was to bring together lecturers of worldwide renown in this subject and let them meet with interested stakeholders and end-users, coming from academy, research, public administration, military institutions, and private companies. The participants were 51 in total, in the age range 23-65 (Figure 1A), from newly appointed PhD students to University Professors and executives of private enterprises (Figure 1B). Female-scientist were 23, slightly less than 50 percent (Figure 1C); in view of the specific field of the ASI, decontamination of radiological and chemical pollution, this result is of great value for the gender equal opportunity. Participants came from 18 countries, representing Asia, Africa, most of Europe and North America (Figure 1D).

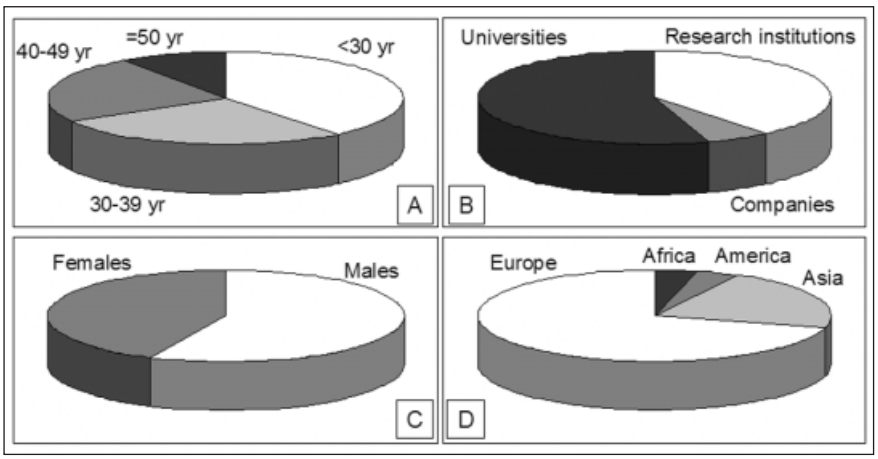

Figure 1. Distribution of the 51 participants to the NATO ASI according to (A) age; (B) affiliation type; (C) gender; (D) continent of origin

The ASI was organised to provide detailed, advanced, and provocative information about possible decontamination approaches, alternative technologies, cost effectiveness, feasibility, with the support of literature data, personal experience of lecturers, and case studies. Daily activities of the school were: main lectures, posters presentation and discussion, panel discussions and general discussions. Special events were the poster-contest and the best posters awards, as well as specialised workshops and press conferences. Twenty-four main lectures and three workshops addressed all aspects of phytoremediation and bioremediation.

The main achievements of the lectures were:

- The increased understanding by the participants of the global subject of phytoremediation-bioremediation
- The improved understanding between the board of lecturers and participants
- The continuous discussion within the board of lecturers and an exchange between lecturers and participants
- The possibility of deepening inside very specialised subjects like decontamination of radionuclides and ammunitions or propellants
- The discussion about the need of a holistic approach with integration of different expertises: scientific, technological, legal and juridical, economical
- The understanding of the role played by all actors: scientists, economists, managers, regulators, public
- The discussion about the use of conventional vs. non conventional technologies
- The identification of faults and drawbacks in the process, as well as of strengths and advantages
- The need for a policy of communication of the results achieved to stakeholders and to national and supranational regulators
- The relevance of capacity building and training,

Site characterisation procedures and related measures were addressed by Tomas Vanek (Academy of Sciences of Czech Republic), Michael Pupeza (Golder Associates Srl, Italy), Oleksandr Orlov (Ukrainian Scientific-Research Institute of Forestry and Agro-Forest Amelioration, Ukraine) and Anja Hebner (BioPlanta GmbH, Germany), addressing in particular the problems connected with sampling and assessment of sites contaminated by radionuclides and explosives. Pollution problems generated after the Chernobyl accident were addressed considering the contamination incurred to the forest ecosystems and the hazards to human health.

The main processes of bioremediation have been addressed starting from the site conditions, analysing the microbial features, both genetic and physiological-biochemical, in lectures provided by Zeev Ronen (Ben-Gurion University of the Negev, Israel) and Ludo Diels (Flemish Institute for Technological Research, Belgium). These basic biological considerations led further on to analyse and elucidate case studies that compared together bioremediation with conventional remediation techniques. Speakers brought also their experience in technologies based on chemical reactions and construction of physical barriers, discussed alongside with examples of bioremediation. Specific cases of explosives and radionuclides decontamination were

also addressed, citing European and non-European experience. New contaminants of interest were also addressed, such as the MTBE (methyl-tert-butyl-ether). The basic biochemical mechanisms of phytoremediation were explained by lecturers Steven McCutcheon (University of Georgia, USA) and Stanislaw Gawronski (Warsaw Agricultural University, Poland), considering also the differences between plant and microbial metabolism of contaminants, together with a record of the natural and cultivated plants more frequently used for decontamination. The role of genetics and genetic engineering in increasing the knowledge on detoxification processes and to produce and obtain more specific types of decontaminating plants was explained during the lecture of Nelson Marmiroli. Practical implementation of remediation technologies was addressed starting from feasibility studies at the laboratory level, to pilot scale experiments and large scale tests. Several examples of applications were provided by researchers and private companies' representatives, both for decontamination of explosives and of radionuclides, in particular with a significant contribution by Dave Russell (Global Environmental Operations, Inc., USA), Petr Soudek (Academy of Sciences of Czech Republic) and Christian Kunze (WISUTEC WISMUT Umwelttechnik GmbH, Germany). Constructed wetlands were prominent among successful applications and the lecturers brought several examples. A straightforward analysis of case studies led to identification of advantages and limitations of constructed wetlands technology.
The program was implemented by two thematic workshops in which lecturers and participants brought their own experiences. The Workshop on Risk Management and Communication, coordinated by Borys Samotokin, evidenced the problems connected with risk assessment in contaminated sites and hindrances in communication to stakeholders and public opinion about measures and solutions. The Workshop on Regulatory Issues, coordinated by Wolf-Uwe Marr (Bundesministerium der Verteidigung, Germany) addressed the relationships between legislators and regulators on one side, and on the other side scientists and private companies acting in remediation.
The Workshops gave to participants the opportunity to:

- Discuss very specialised items like relationships between risk assessment, risk management and risk communication
- Discuss about the role of the different entities involved in remediation
- Identify possible common rules applicable to risk assessment, risk management of bioremediation-phytoremediation technologies
- Discuss the relevance, spatial and temporal, of the residual management policy need at the moment of site closure (i.e. the fate of the "contaminated" decontamination material).

Panel discussions were also particularly intense and they provided:

- Possibilities of linking up different subjects
- Opportunities to the participants to verify their level of understanding by addressing to lecturers in straightforward terms

- Extension of lecture discussion on specific topics
- Holistic interpretation of problems and solutions

Posters presentation and discussion obtained a general consensus: participants and lecturers seemed to appreciate this daily appointment because:

- It provided a complete integration of the participants within the school
- It favoured active vs. passive teaching
- It gave a great opportunity to participants for peer reviewing their own work with fair suggestions
- It provided an opportunity of challenge between participants emphasised also by the Poster Award contest
- It increased greatly the socialisation between participants
- It increased the participants' confidence in their work and skills

The state-of-the-art as it emerged from lectures, workshops, poster presentations and panel discussions was that bioremediation and phytoremediation are both applied, in most cases, without a precise and detailed knowledge of all molecular mechanisms occurring within cells. This can have consequences on several aspects, and especially concerning decisions to be taken case-by-case according to site characteristics, type of pollutant(s) and endpoints to be reached.
Some main considerations emerged during the panel discussions and the final closure of the meeting.

1) There is a great necessity of understanding the basic aspects of microorganism and plant physiology, biochemistry and genetics, because only from sound scientific knowledge may in future derive the possibility to drive these technologies on more applied aspects.
2) Interactions between plants and microorganisms in remediation must be studied further with greater attention, because in many contaminated sites they can be beneficial at the same times, and synergy may enhance the individual capacities. This holistic approach would consider interactions in the environment, not only between organisms, but also between contaminants, and between biotic and abiotic factors.
3) Interaction of scientists and technicians with state and governmental agencies, regulators, economists, and evaluators is of paramount importance. The need to communicate and of making each other understandable is therefore a priority for successful implementation of biological decontamination practices.
4) Eastern European participants and scientists are convinced that phytoremediation and bioremediation can be a more sustainable solution to their environmental problems and are willing to learn more and to apply them extensively in the field.
5) It was recognised the need for more cooperation between public and private sectors by integrating basic academic and private technological research into a common social goal.
6) To promote a better understanding among countries, in particular Western and Eastern countries, favours and opens a free access to guidance materials and basic information on contaminated sites and previous decontamination attempts, in order also to increase security through science and cooperation.
7) To support the increase in capacity building of personnel, resources and infrastructures, with a particular attention to young scientists and female-scientists.

A result of the ASI will be the publication of a book by Kluwer Academic Publisher (the Netherlands), edited by Nelson Marmiroli, Borys Samotokin, Steven McCutcheon, Stanislaw Gawronski, Dave Russell, and Marta Marmiroli, to be published in 2006.
Other results worth mentioning have been (i) the training of new professionals who will hopefully be involved in private or public initiatives, aware of the scientific background of biological decontamination and of their specific application; (ii) a fruitful exchange of information among lecturers and participants, with benefits from both the scientific and applicative sides; (iii) the presentation to attendees coming from countries with specific environmental problems of waste disposal in the field of nuclear and military industry (e.g. former Eastern Europe) of non-conventional and innovative approaches to decontamination; (iv) the creation of a network of contacts and collaborations.

ACKNOWLEDGEMENTS
The authors acknowledge the financial support of NATO (EST.981075) and the cooperation of staff members of their respective Institutions: Zhytomyr State Technological University and University of Parma, Department of Environmental Sciences.

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