

SUGGESTED OUTLINE FOR THE PREPARATION OF WHITE PAPER

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Geoenvironmental Research Experience (list projects in progress or completed within the past 5 years): (selected projects)

1. Sorption-desorption cycling and potential contaminant spreading in the Artic Permafrost (National Oceanic and Atmospheric Administration (NOAA), 2000-2001; Inyang, H. I. and Ogunro, V. O.)
2. Scaling of barrier textural effects on source terms for contaminant transport modeling (US Army Cold Regions Research and Engineering Laboratory, 1997-2000; Inyang H. I.)
3. Modeling contaminant release and transport in the vadose zone (DuPont Engineering, 1998-1999; Inyang, H. I.)
4. Textural analysis for quantification of contaminant flow channels in high pressure jet-grouted sands (Sandia National Laboratories, 1997-1999, Inyang, H. I.)
5. Quantification of soil barrier composition effects on gamma radiation attenuation (Duke Energy Corporation, 2001-present; Inyang, H. I.)
6. Polymer solution-clay interaction effects on contaminant barrier integrity (Duke Energy Corporation, 2001-present; Inyang, H. I.)
7. Thermodynamics of temperature gradient effects on cation exchange in barrier materials (DuPont/Duke Energy Corporation; 1999-present, Inyang, H. I.)
8. Modeling and experimental investigation of heavy metal leachability from boiler aggregate (Federal Highway Administration, 1999-2001; Inyang, H. I. and Ogunro, V. O.)
9. Induced compaction effects on the long-term performance of capillary barriers (Bechtel BWXT/USDOE Idaho National Engineering and Environmental Lab, 2003; Inyang, H. I. and Ogunro, V. O.)
10. A Quantitative framework for long-term performance assessment of waste management infrastructure using Hazard Analysis Method (National Science Foundation, 2003-2006; Inyang, H. I. and Ogunro, V. O.)

Geoenvironmental Teaching Experience (list courses taught within the past 5 years):

1. Design and analysis of waste containment systems (graduate, 1995-2001)
2. Physico-chemical interactions in earthen barriers (graduate, 1996, 1998, 2001)
3. Disaster reduction engineering (graduate, 2002)
4. Fundamentals of contaminated site treatment techniques (graduate, 1997-2001)
5. Advanced and innovative concepts in waste containment (graduate, 1997-2002)

Geoenvironmental Consulting Experience (list major projects only):

1. Contaminated site assessment for facilities of the Lowell Regional Transit Authority (2000)
2. Comparative analysis of final cover system for the Willow Road Landfill, Lee, MA (for ERM, 1995)
3. Assessment of the potential effectiveness of selected remedial measures for contamination at Midvale Utah Mining Waste Site (for USEPA, 1993)
4. Evaluation of the performance of hazardous waste facilities during the 1993 Midwest Floods (for USEPA, 1993-1994)
5. Analysis of hazardous waste landfills in seismic areas (for NC Department of Environment, Health, and Natural Resources, 1992)
6. Determination of maximum safe values of chlorinated hydrocarbons in hazardous waste landfills (for CSD, Switzerland, 1992)
7. Several other projects in South America, North America, Africa and Europe under the auspices of corporations, continental banks, etc).

Views on Emerging Geoenvironmental Issues and Technologies

The development of civil and industrial infrastructure to support an increasing population and promote national competitiveness in trading of goods and services has provided the impetus for the amalgamation of a variety of traditional and emerging disciplines to form the new field: geoenvironmental engineering. As is the case with every emerging field, several researchers, practitioners and program managers have discussed the nomenclature and scope of geoenvironmental engineering during the past 12 years or so. However, advances in specific sub-disciplines which by necessity must be considered to be part of geoenvironmental engineering, preceded the evolution of the field.

The first organized attempt to define the field and its scope was the 1992 U.S.-Canada Workshop on Recent Accomplishments and Future Trends in Geomechanics, held in Norman, Oklahoma under the sponsorship of the U.S. National Science Foundation. At this event, a panel (1) was convened to identify and discuss key geoenvironmental issues. Right around this time, a number of researchers did individually espouse some concepts, catalog of issues and their justification as the scope of this field. As examples, Fang (2) suggested the framing of geoenvironmental problems within an "Energy Field Concept" in which macroscopic effects derive from balance among various forms of energy (mechanical, thermal, electrical, magnetic and radiation-induced); Daniel (3) discussed geoenvironmental principles in terms of staged processes of contaminated site remediation; and Inyang (4) as a contribution to the 1992 Norman Workshop, defined geoenvironmental engineering as "a field which encompasses the application of science and engineering principles to the analysis, design and implementation of schemes for treating, modifying, re-using and disposing of wastes and contaminated materials in or on the ground. As mentioned by Hamel (5), a number of conference sessions had been organized prior to the 1990's on issues that were collectively referred to as "environmental geotechnics". The most prominent of these conferences was the 1987 ASCE Specialty Conference on Geotechnical Practice for Waste Disposal.

Perhaps, because of the name: geoenvironmental engineering (which is frequently hyphenated), some stakeholders have defined the field erroneously as a binary combination of geotechnical engineering and environmental engineering, to the exclusion of other critical sub-fields. A review of the disciplinary coverage of many contemporary issues and field projects can easily reveal the invalidity of this approach. Bioremediation draws as much from soil science and biological sciences as it does from traditional environmental engineering; and radioactive waste containment requires strength in material science, earth science and aspects of nuclear engineering such as radioactive element decay and gamma ray attenuation in geotechnical systems. Essentially, geoenvironmental engineering represents an intersection of a variety of traditional and emerging fields.

Along these lines of thought and consistent with my suggestions in 1992 (4), geoenvironmental engineering and the two principally allied terms: environmental geomechanics and environmental geotechnology (or environmental geotechnics) can be defined as follows:

- **Geoenvironmental engineering:** a field which encompasses the application of science and engineering principles to the analysis, design and implementation of schemes for treating, modifying, reusing or disposing of wastes and contaminated geomaterials in or on the ground.
- **Environmental geomechanics:** a subfield of geoenvironmental engineering which covers geoenvironmental issues in rock mechanics, including fracture flow, coupled processes, chamber excavation, and underground storage of liquids and gases.
- **Environmental geotechnology:** any specific technology applied to the monitoring, characterization and treatment of contaminated geomaterials, and disposal of wastes and contaminated materials in the ground. Examples are bioremediation, pump-and-treat, compaction and solidification.

Being that geoenvironmental engineering is the focus of this year's Workshop on Emerging Geoenvironmental Technologies for Pollution Control and Remediation, it is necessary to identify the scope of

issues by categories, within which specific planning, analytical design and implementation elements of specific projects may fall. Accordingly, they are:

- a. Characterization of geomedia (soils, rocks, pore water, and pore gas) with respect to stability, contamination level, and fluid flow properties
- b. Assessment of the response of terrains that host waste containment systems to natural and/or man-made hazards such as earthquakes, global warming, subsidence, and floods
- c. Analysis of contaminant and radiation generation and migration through porous and fractured geomaterials, and fabricated materials
- d. Physicochemical, chemical, thermal, and biological treatment of wastes and contaminated geomaterials to reduce or eliminate pollutants
- e. Design and analysis of surficial waste containment systems such as landfills, monofills, slurry walls, grout curtains, and dewatering schemes; and deep disposal systems such as radioactive waste disposal chambers in rock

Basically every geoenvironmental issue can be shown to fit into one or more of the categories listed above. In the foregoing definitions and scope, treatment of wastes that are not geomaterials would not be within the scope of geoenvironmental engineering but engineering of a ground-embedded system to store it would fall within the scope of the field. The waste treatment aspect, along with other issues such as air quality control and surface drainage are generally considered to be part of environmental engineering. Another observation is that the purpose of deployment of a technique or use of an analytical technique is a determinant of its disciplinary classification. Furthermore, in practice, especially in public agencies, all elements of engineering that are targeted on environmental stewardship are generically classified under environmental engineering.

Several issues that require the application of geoenvironmental techniques have emerged. A few of these issues are Brownfields development, which requires the coupling of load and contaminant travel factors for analyses of health risks to residents; soil stabilization against erosion, where the presence of contaminants in urban soils affects the effectiveness of traditional materials and mix proportions; increasing proximity of waste sites to sensitive environments, which requires the development of durable barrier materials and more protective design configurations for waste containment systems; the need to manage large volumes of waste materials, which requires models of geomaterial/waste mix durability and leaching characteristics for risk assessments; and environmental security concerns, which require the development of a new family of sensors that can detect the distribution of sources and pathways of travel in the ground, for deadly substances to which the general population may be exposed.

References

1. Yong, R. N. and Inyang, H. I. (1992). (With contributions by Fang, H. Y., Rowe, R. K., Armaleh, S., Bhatia, S., Shackelford, C. D., Fleming, L. and Yeung, A. T.) Geo-environmental engineering. Proc. U.S.-Canada Workshop on Recent Accomplishments and Future Trends in Geomech. In the 21st century, Norman, OK, pp. 83-102
2. Fang, H. Y. (1992). Environmental Geotechnology: a perspective. Proc. Mediterranean Conf. on Enviro. Geotech., Cesme, Turkey, pp.11-19.
3. Daniel, D.E. (1992). Overview of Geoenvironmental principles applied to remediation of contaminated waste disposal sites. Proc. Mediterranean Conf. on Enviro. Geotech., Cesme, Turkey, pp. 311-317.
4. Inyang, H. I. (1992). Advances and trends in geoenvironmental engineering. An invited paper presented during the U.S.-Canada Workshop on Recent Accomplishments and Future Trends in Geomech. In the 21st Century, Norman, OK, 31 pages.
5. Hamel, J.V. (1993). Environmental Geotechnology in the United States: a consultants' perspective. Proc. Of Int. Conf. on Environ. Mgt., Geo-Water and Eng. Aspects, Wollongong, Australia, pp. 37-48.

Appraisal of Geoenvironmental Research, Education and Practice

The evolutionary path of geoenvironmental engineering has mostly involved the application of previously developed techniques and technologies from traditional science and engineering fields to new technical issues within the frameworks of waste management (including waste containment and recycling), site characterization and remediation, and site/facility monitoring for risk assessment. Within this context, grouting, which has for decades been used in tunneling and foundation improvement, is now used in waste containment; methods of soil stabilization against erosion in highway and agricultural engineering are now applied in contaminated dust control at Brownfield sites; heapleaching and other mineral processing techniques (1) drawn from mining engineering have been adapted for cleanup of contaminated geomedia in ways that the noted geochemist, Georgius Agricola, who detailed some of the mineral processing techniques as early as 1556 in his book, "De re Metallica," could not have imagined.

Considering that some environmental problems that never had to be addressed in the past have evolved, geoenvironmental research should keep pace with analytical, data and instrumentation needs. It is doubtful that the needed advances can be made within the bounds of any discipline. This leads to the issue of appropriate education of geoenvironmental engineers. My opinion is that the master's degree level is where the specialized courses should be taught to make room in curricula for introductory courses on such subjects as analytical/physical chemistry, thermodynamics, soil mechanics, engineering geology, biology, applied physics, hydraulics/hydrology and environmental engineering to be taught to interested students at the undergraduate level. Engineering students in the United States have very poor preparation in chemistry and related engineering sciences, yet knowledge in these subjects is essential for appreciation of concepts and formulation of physical and quantitative models to address the thermodynamics (will a process occur?) and kinetics (how fast will the process run?) of phenomena in geoenvironmental engineering. The exception is chemical engineering education, and this is why chemical engineers have comparative advantage in the job market for site remediation operations. It is also fair to state that the preparation of students trained in traditional physical sciences (except soil and earth sciences) and chemical engineering departments is deficient in knowledge on soil mineralogy. Interactions at the mineralogical level (not at the chemical level) define textural changes that control the durability and hence, long term performance of soil barriers of waste containment systems; affect sorption/desorption of contaminants on the surfaces of particles of contaminated geomaterials; and determine the solubility of substances that may leach out of matrices that contain recycled wastes. These issues are directly within the three major themes selected for this workshop.

Although most universities in the United States now admit non-civil engineering B.S. graduates into M.S. programs in civil engineering in which graduate study in geoenvironmental engineering is currently nested, a few schools do not do this. It seems that rather than specify graduation from a field or department, specification of preparation in prerequisite subject matter, i.e. the critical subjects aforementioned, is more appropriate. As a matter of fact, in some regions of the world, much of what is defined herein as geoenvironmental engineering is taught and practiced under different academic departments and professions, respectively. In China, it is commonly taught within earth science and mining science and technology; in Russia, it is usually in earth science although it can be given a unique name at any place; and in other regions, it can be variously tagged as reclamation engineering, environmental engineering, environmental geology (or geoscience) and geotechnical engineering. In some recent editorials and trip reports (2, 3, 4 and 5), we have attempted to appraise some of the issues.

The prominence and continuity of any field are usually enhanced not only by the criticality of policy support needs but by the development of textbooks that in some sense, establish the body of knowledge that define the field. Credit should be given to J. K. Mitchel for his book: fundamentals of soil behavior, which helped educate a generation of graduate-level geotechnical engineers on soil mineralogy and soil chemistry. Prior to the mid-1990's, documentation of new technologies and analytical methodologies on geoenvironmental

engineering issues were mainly in the form of technical guidance documents of agencies in Europe and North America. Other regions followed suit to provide technical guidance to support national policies that are generally referred to as National Environmental Action Plans (NEAPS) which almost every country agreed to develop at the 1992 Rio de Janeiro Conference (Agenda 21) on global sustainable development. Since the late 1990's, several textbooks have been authored to cover the entire field or segments of geoenvironmental engineering. Examples of these textbooks are those authored by Naftz et al. (6), Reddi and Inyang (7), Lagrega et al. (8), Daniel (9) and Gavaskar et al. (1998). Essentially, geoenvironmental engineering is a thriving field that will continue to grow as an intersection of a variety of disciplines. In developing countries, its growth will be driven by the intensification of industrial and civil infrastructure development activities. In the technologically advanced countries, energy infrastructure development, large-volume – low-toxicity waste management needs and the need to secure sensitive natural resources against intentional damage will drive developments in the field.

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2. Inyang, H. I. and Reddi, L. N. (2000). The scope and utility of geoenvironmental engineering. *ASCE J. Environmental Engineering*, 126 (2), 93.
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4. Inyang, H. I., de Brito Galvao, T.C. and Young, D. T. (2003). Integrating hazards control into sustainable development plans. *ASCE Natural Hazards Review*, 4 (2), 57-58.
5. Inyang, H. I. (1996). Geoenvironmental aspects of water pollution in Nizhnevartovsk, Siberia, Russia. A Trip Report under the auspices of the U.S. National Research Council/National Academy of Sciences, 17 pages.
6. Naftz, D., Morrison, S., Fuller, C. and Davis, J. (2002). *Handbook of Groundwater Remediation using permeable reactive barriers*. Academic Press, Amsterdam.
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8. LaGrega, M., Buckingham, P., and Evans, J. (2000). *Hazardous waste management*, 2nd edition, McGraw-Hill, New York.
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