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PROCEEDINGS OF THE PHOSPHOGYPSUM FACT-FINDING FORUM

December 7, 1995

Tallahassee, Florida

Co-Sponsored by
The Florida Center for Public Management
Florida State University
and

FIPR
Florida Institute of Phosphate Research

February 1996

PROCEEDINGS

OF THE

PHOSPHOGYPSUM FACT-FINDING FORUM

Co-sponsored by

FLORIDA INSTITUTE OF PHOSPHATE RESEARCH
1855 West Main Street
Bartow, FL

and

THE FLORIDA CENTER FOR PUBLIC MANAGEMENT
Florida State University
Tallahassee, FL

and held at

August B. Turnbull, III
Florida State Conference Center
Tallahassee, FL

December 7, 1995

February 1996

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PHOSPHOGYPSUM FACT-FINDING FORUM

EXECUTIVE SUMMARY

The Florida Institute of Phosphate Research and The Florida Center for Public Management at Florida State University co-sponsored this Fact-Finding Forum on December 7, 1995 in Tallahassee, Florida. The purpose of the Forum was to expose the audience and a select panel of Florida state and local government decision makers to a scientific discussion of the effects and uses of phosphogypsum.

In assembling the best national and international scientific talent for presentations, the Florida Institute of Phosphate Research staff made a determined effort to include scientists with opposing views on the effects of using phosphogypsum. However, it was very difficult to find scientifically-trained speakers, or groups who could recommend such experts, on the negative impacts of phosphogypsum usage. This factor understandably gave the panel and audience the perception that the presentations were unbalanced. We very much regret that, but it should not detract from the quality and value of the information presented at the Forum.

CONCLUSIONS FROM THE FORUM PAPERS AND Q & A SESSIONS

Environmental Effects of Phosphogypsum (PG)

1. There is no significant risk to human health for those individuals working with or around PG; for example, those building a road or spreading it agriculturally.

2. Whereas shielding materials placed over PG are able to protect people rather completely from the impacts of radon, they are less effective in attenuating gamma radiation, so that the gamma factor must always be considered.

3. There appears to be no significant risk to someone traveling over a phosphogypsum-based road, but only to someone who might build a house on it and occupy that house for 70 years (EPA scenario).

4. The marine studies at Louisiana State University employing PG/cement structures as oyster clutch substrates or artificial reefs have shown no bioaccumulation of toxic materials to date, but these studies need to be extended over longer periods to give confidence in the results.

5. The use of PG as a cover material in municipal waste landfills accelerates the decomposition of a “standard garbage” and has the promise of providing additional landfill space, but it also increases the evolution of hydrogen sulfide. There is technology available to recover economically the sulfur values of the hydrogen sulfide.

Uses of Phosphogypsum

1. Much structural and environmental data have been accumulated by various researchers in the use of PG in county and secondary roads, but its use in federal and state heavy-duty roads needs additional research.

2. Compelling economic benefits have been calculated for constructing county roads using PG mixtures.

3. Realistic agricultural PG application rates of from 250 to 500 lbs/acre/year constitutes an acceptable risk, even using the USEPA's conservative limits.

4. Preliminary economics show a distinct cost advantage to farmers or cattle ranchers in using PG to supply soil calcium or sulfur, and in improving the soil structure.

5. The economics of using PG in marine structures, as well as the environmental risks involved, need confirmation before this proposed use can be taken seriously.

Miscellaneous Interesting Points Made by the Speakers

1. The Canadian level of concern (action level) on radon is more liberal than USEPA's (roughly 5 times our 4 pCi limit).

2. The USEPA has set very low limits on acceptable radiation levels - of the order of 70 mrem/year - very close to the average USA background level.

3. Although the USEPA has stated that they are going to relax the present limit of 700 Ibs of PG they allow to be used for research purposes, it is probable that any demonstration-scale experiment will still require a variance.

The policy panel and the audience showed great interest in the uses and the effects of using PG. Discussion was often lively about what could be done to liberalize present USEPA rules so as to allow larger, demonstration-type projects using PG.

The panel proposed that FIPR and USEPA adopt a cooperative approach to resolving differences about the effects, uses and policies governing PG.

Dr. Larry K. Gross
Director, Florida Center for Public Management
Florida State University

HEARING PANEL POST-FORUM POSITION ON PHOSPHOGYPSUM

The Florida Institute of Phosphate Research has concluded from its experimental studies on phosphogypsum (PG) and those of other researchers that much of the official concern about the perceived environmental and public health risks of PG is reasonably debatable. Many of the proposed uses of PG appear to involve levels of risk which are below regulatory concern or which can be mitigated using currently available practices. Therefore, in light of the potential economic advantages of the proposed uses of PG, and the demonstrated environmental and economic penalties of stacking and monitoring PG, the Institute is seeking a partnership with the USEPA to set acceptable standards for current PG use and large scale research and demonstration projects.

Further, on completion of such large scale research and demonstration projects and substantial, appropriate peer review, USEPA policy should be reviewed to reflect the scientific consensus of the risk and of demonstrated mitigation measures governing the uses of PG.

1/29/96

PHOSPHOGYPSUM FACT-FINDING FORUM

DATE: Thursday, December 7, 1995

TIME: 8:30 a.m. - 5:00 p.m.

PLACE: August B. Turnbull, III
Florida State Conference Center
555 West Pensacola Street
(Four blocks west of the Capitol complex)
Tallahassee, Florida

RECEPTION: 5:30 p.m. - 7:00 p.m.
22nd Floor, the Capitol

The Florida Institute of Phosphate Research Board of Directors is sponsoring a fact-finding forum concerning phosphogypsum - its potential risks and its potential benefits.

Board members are conducting the forum as part, of the Institute's pro-active phosphogypsum program, which is striving to find the best way to deal with the controversial phosphate processing by-product that now sits in 27 stacks, 10 of which are active. Hundreds of millions of tons of phosphogypsum have been created in phosphate processing and approximately 30 million new tons are created each year.

The Environmental Protection Agency has passed regulations that prevent the gypsum from being used because of its trace amount of radium. Research the Institute has funded indicates that the EPA's risk analysis may be overly cautious and that the economic benefits of putting gypsum to use in agriculture, road building, construction and other proven areas could save money for taxpayers, farmers and the state.

The December forum is intended to air the facts before regulators, lawmakers, environmentalists and others in hopes of launching further discussion about putting this waste product to use and solidifying a FIPR position on the issue.

PHOSPHOGYPSUM FACT-FINDING FORUM
INTRODUCTORY REMARKS

BY

M. JACK OHANIAN
CHAIRMAN, FIPR BOARD OF DIRECTORS

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Author: M. Jack Ohanian - Associate Dean for Research & Administration, College of Engineering, University of Florida

Dr. Ohanian, immediate past chairman of the American Association of Engineering Societies (AAES) and past president of the American Nuclear Society, has recently been appointed by the Governor of Florida to his second term on the five-member Board of the Florida Institute of Phosphate Research. He serves as Chairman. Dr. Ohanian's research interests and his (over 60) technical publications have dealt with nuclear reactor dynamics and safety. More recently he has focused on nuclear energy systems, their safety and public energy policy. He serves on the Review Committee for the Reactor Engineering Division of Argonne National Laboratory and the Safety Oversight Committee of Florida Power Corporation's Crystal River Nuclear Plant.

Dr. Ohanian received his bachelor's degree in electrical engineering from Robert College (Istanbul, Turkey), and a master's degree in EE and a Ph.D. in Nuclear Science & Engineering from Rensselaer Polytechnic Institute.

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Good morning Ladies and Gentlemen! I welcome you on behalf of the Board of Directors of the Florida Institute of Phosphate Research. We appreciate the fact that you have taken the time and effort to attend a forum concerning an industrial by-product, phosphogypsum (PG), about which the average Florida citizen is not well-informed or may even be misinformed. Many of those who have heard about PG have heard statements about its impact on public health and the environment. Today, we will present to our "Policy Panel" a number of speakers, each one an expert in one or more aspects of PG: its possible uses, the economic attractiveness of using it, and the environmental/public health risks involved in its use.

Chemically, PG is calcium sulfate dihydrate or gypsum, produced by the reaction of phosphate rock with sulfuric acid during the process of producing phosphoric acid, the major ingredient of vital phosphate fertilizers. Gypsum is a very common inorganic compound with a myriad of industrial uses. The term "phosphogypsum" is used to specify the particular gypsum arising from the acidulation of phosphate rock, because it contains trace amounts of many of the mineral impurities that accompany phosphate rock. Of these impurities, perhaps the most notorious is radium, the parent of radon. Other trace impurities found in PG include fluoride, chromium, lead, zinc and uranium. But, it is primarily the radon concern that led the United States Environmental Protection Agency to restrict uses of PG and to stipulate that no PG with radium over 10 pci/gm can be removed from the PG stacks adjacent to the chemical plants.

This limit was intended to insure that the risks from indoor radon and direct gamma radiation exposure in residences constructed on land previously treated with PG do not exceed an acceptable level.

It is this EPA restriction, promulgated on December 15, 1989, and issued after several legal challenges on June 3, 1992 (Federal Register Vol. 57, No. 107 - 40CFR Part 61), that has frustrated the many proposed uses of the PG by-product in non-residential uses. Hundreds of millions of tons of PG have accumulated in Florida alone over the last 50 years. The industry has researched many proposed uses for PG in an effort to do what the EPA encourages with other industrial by-products. . . .recycle. Before the EPA restriction, a limited number of economic uses for PG had been developed for agriculture, industrial plant access roads and parking lot construction; now these uses are precluded.

At the outset, I would like to stress that when this forum was conceived, we intended to have several EPA speakers on the program. However, when we issued them an invitation and strongly encouraged their participation, we were informed by EPA Washington that their attorneys would not allow them to attend because of the legal challenges I mentioned. They did ask that we send them a copy of these proceedings and invited us to meet with them and “continue to work toward resolving some of the environmental issues associated with phosphogypsum”. We certainly intend to do that!

While there is controversy over the effects of low levels of radon on human health and the validity of the current EPA standard for indoor radon, this will not be the focus of this forum. Rather, we will present to the policy-makers testimony that there are economic advantages to using PG that benefit the public and the industry, and that such uses involve little risk to the public or to the environment.

As our program indicates, the first session will highlight agricultural uses, the second will feature miscellaneous uses of PG, and the afternoon speakers will discuss the potential for construction uses of PG. Following the third session, we will ask the various risk experts to comment on what they have heard and close with comments and observations from our panel members who have listened to and questioned the various speakers.

At the conclusion of the formal program, I invite all of you to a reception, starting at 5:30 on the 22nd Floor of the Capitol Building.

In summary, in keeping with the Institute’s legislative mandate to take a leadership role in assessing and resolving phosphate issues that affect the environment and the health and safety of Florida’s citizens, we present the following thesis to the assembled Policy Panel. We will ask them at the end of the day to agree with, modify, or disagree with the following FIPR position:

“FIPR has concluded from its experimental studies of phosphogypsum and its characteristics that much of the official concern about PG’s perceived environmental and public health risks is misplaced. Most of the proposed uses of PG involve minimal risk, and that minimal risk can be readily mitigated using common sense and well--established practices. Therefore, in light of the economic advantages of several of the proposed uses of phosphogypsum, the US EPA should be strongly urged to reevaluate its restrictions on the utilization of PG”.

Before we begin today’s presentations, I would like to introduce to you my fellow members of the FIPR Board and the other Policy Panelists who have generously given of their time to help us arrive at a conclusion at the end of the day.

THE REGULATION OF PHOSPHOGYPSUM
CHAPTER 62-673, F.A.C.

PHIL CORAM, P.E.
DEPARTMENT OF ENVIRONMENTAL PROTECTION

****

Author: Phillip Coram, Florida Department of Environmental Protection.

Mr. Coram has been the Administrator of the DEP's Industrial Wastewater Program for the last six years. He is responsible for rule and policy development and has served as a member of the technical Workgroup for the Phosphogypsum Management Rule. He was a member of the EPA's Dialogue Committee on phosphoric acid wastes, and is currently a member of the FIPR Policy Advisory Committee. During his 14 years with the DEP he has worked with a variety of programs including drinking water, air, solid waste, hazardous waste, stormwater and domestic wastewater.

Mr. Coram is a graduate of the University of Florida with a degree in environmental engineering, and is a Registered Professional Engineer.

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Background

Florida has over 20 phosphogypsum stack systems located at phosphoric acid fertilizer manufacturing facilities in Polk, Hillsborough, Manatee and Hamilton counties. Ground water monitoring at these stacks, begun in 1986, has shown that a majority of the stacks, at some time, have caused exceedances of drinking water standards (primarily sodium and sulfate) at the facilities' property boundaries in the surficial aquifer, or have caused increases above background concentration and/or exceedances of standards in the intermediate or Floridan Aquifers.

It was apparent from the ground water monitoring that phosphogypsum stack systems were facilities reasonably expected to be a source of pollution within the meaning of section 403.087, Florida Statutes, and that specific standards were needed for stack construction, operation and closure. Rulemaking on phosphogypsum stack systems was, therefore, initiated by a November 29, 1989 Policy Memorandum issued by former Department of Environmental Regulation Secretary Twachtmann. The policy memo established interim criteria for permitting and enforcement, and directed the Division of Waste Management, in coordination with the Southwest District and Division of Water Facilities to initiate rulemaking on phosphogypsum disposal.

Rulemaking

Rulemaking initiated shortly thereafter, with three workshops held in 1990-1991 in Jacksonville, Tampa and Tallahassee. The two major groups involved in the rulemaking were the Florida Phosphate Council, an industry trade association, and Manasota-88, an environmental interest group. There were two main issues debated during the workshops: 1) liner design reguirements for stacks systems, and 2) closure dates for existing unlined stack systems. Manasota-88 argued for stringent RCRA hazardous waste type liner requirements and for closure of existing unlined stack systems as soon as possible, while the Council argued for less stringent liner requirements and the ability to continue to operate the existing stack systems.

Much of 1992 was devoted to evaluating various liner design standards. Ardaman & Associates, consultants for the Council, prepared a series of technical reports on a proposed liner design which utilized compacted gypsum as the upper component of a gypsum/synthetic membrane composite liner. This design was peer reviewed by nationally recognized experts on liner systems, and was found to have a low leakage rate that modeling indicated would not cause violations of ground water quality standards.

In January 1993, Chapter 62-673, Florida Administrative Code, Phosphogypsum Management (the “Rule”), was adopted by the Environmental Regulation Commission (ERC). The major elements of the Rule include:

62-673.200, Definitions
Seventeen terms are defined, including: phosphogypsum, phosphogypsum stack, phosphogypsum stack system, process wastewater, closure, final cover, lateral expansion and liner.

62-673.220, Applicability
Provisions relating to liner and leachate collection are intended to apply to all new stack systems and lateral expansions of existing stack systems.

62-673.300, Prohibitions
Phosphogypsum is prohibited from being disposed outside a permitted phosphogypsum stack system. However, this prohibition does not preclude the use or reuse of phosphogypsum if otherwise allowed by law. Radioactive materials can only be disposed according to the requirements of the Department of Health and Rehabilitative Services.

62-673.310, Alternative Procedures and Requirements
The use of procedures other than those specified in the Rule are allowed if they provide a level of protection to human health and the environment equal to that required by the Rule.

62-673.320, Permitting of Phosphogypsum Stack Systems
Describes the process for permit application and processing. Prescribes application information requirements.

62-673.340, Phosphogypsum Stack System General Criteria
Specifies performance criteria and location requirements for stack systems.

62-673.400, Phosphogypsm Stack System Construction Requirements
Describes construction reguirements for liners, leachate control systems and other components of the stack system.

62-673.500, Operation Requirements
Describes operational requirements, including ground water monitoring, surface water management and leachate management.

62-673.600, Closure of Phosphogypsm Stack Systems
Describes the process by which stacks are to be closed, including provisions for temporary deactivation of a stack because of economic conditions, the development of a closure plan, and the requirements for final cover.

62673.610, Closure Plan Requirements
Describes the required components of a closure plan, including the final cover for the stack system.

62-673.620, Closure Procedures
Describes the procedure by which a stack system is finally closed.

62-673.630, Long term Care
Requires the monitoring and maintenance of a stack system for 50 years after closure, methods for maintaining leachate and stormwater control, and long-term ground water monitoring. Provisions are included for a reduced long-term care period under certain circumstances.

62-673.640, Financial Responsibility
Describes the process for estimating the costs of closure and long-term care, requires that a bond be posted equal to the costs of closure, and makes provisions for alternative financial instruments such as a letter of credit, trust fund agreement, closure insurance, financial test, and corporate guarantee.

62-673.900, Forms
Provides the forms to be used for permit application to construct, operate, and close a stack system, certification of construction completion, and for financial instruments.

The issue of closure of existing unlined stack systems was left open at the January ERC rule adoption hearing. The Department had proposed rule language requiring all existing systems which cause ground water contamination to stop accepting phosphogypsum within eight years and to complete closure in an additional four years (referred to as the "date certain for closure"). The industry argued that premature closure of these systems would be a tremendous economic burden. The Department's proposed language and a joint Department and Industry compromise amendment predicated on a legislative proposal were not adopted by the ERC. The Commission directed the Department to revisit the closure issue after the legislative session.

New Legislation

The Department and the industry in the 1993 legislative session successfully resolved the issue of existing stack systems by establishing the phosphogypsum management program, section 403.4154, Florida Statutes. The law authorizes the Department to assess registration fees on phosphogypsum stacks, and provides the Department with staff and resources (8 positions, $500,000/yr.) to:

1. Review and process requests from owners and operators of phosphogypsum stack systems for relief from the mandatory closure provisions.
2. Review and process applications for new or expanded phosphogypsum stack systems.
3. Review and process applications to close systems.

With additional resources, the Department would be able to conduct intensive, site-specific evaluations of existing stack systems to determine the adequacy of ground water assessment and corrective action plans to ensure compliance with ground water standards. However, the statutory provision for registration fees would only take effect if the ERC adopted rules that provide relief from mandatory closure requirements for existing unlined systems. At the June 1993 meeting of the ERC, the needed rule revisions were adopted.

Closure of Unlined Systems

Section 62-673.650 of the Rule prohibits the disposal of phosphogypsum and process wastewater in unlined stack systems after March 25, 2001. The systems may be used for water management purposes after this date, but final closure must be completed not later than five years after a system ceases to accept phosphogypsum. Relief from the mandatory closure provisions is provided if an owner of the phosphogypsum stack system can demonstrate:

a) Such system was not causing violations of water quality standards prior to March 25, 1993, and is not expected to cause violations after that date; or

b) The owner implements corrective measures to remediate any existing contamination, and such measures will result in compliance with all water quality standards by March 25, 2001.

Implementation of Rule and Legislation

Since adoption of the Rule and Legislation in 1993, the Department has worked aggressively in implementing the new rule requirements and legislation. The Phosphogypsum Management Section was created and is currently housed in the Southwest District. It is staffed with some of the Department's most experienced engineers and scientists. The section was recently presented an Outstanding Achievement Award for its actions related to the IMC-Agrico sinkhole incident.

Permitting of New Stack Systems

Since the Rule became effective in 1993, the Phosphogypsum Management Section has approved a new stack for the U.S. Agri-Chemicals facility in Ft. Meade, a new cooling pond for CF Industries Plant City Phosphate Complex, and a lateral expansion of a gypsum stack and cooling pond for the IMC-Agrico Nichols facility.

Closure Plans

In September 1993, general plans for closure were submitted for all stack systems regulated under the Rule. The total estimated cost for closure and long-term care of the these stack systems is about $200,000,000. Closure and long-term costs for an individual stack system averaged about $10,000,000.

Financial Assurance

Almost all the companies have sought to demonstrate financial responsibility for closure of the stack systems through use of a financial test or parent corporation guarantee. However, many companies have found the Rule's financial test requirement that working capital or tangible net worth be at least six times the estimated closure and long term care costs difficult to meet.

Because of these financial considerations, the Department contracted with a financial expert to review the existing financial test requirements as they applied the phosphate industry. Our contractor determined that the 6X requirement was inappropriate for the phosphate industry and recommended use of an alternative financial test to determine the ability of a company to fulfill its closure obligations. Based on this recommendation several companies have been authorized by the Department to use the alternative financial test to demonstrate financial responsibility.

Summary

The Phosphogypsum Management Rule reflects a practical balance between environmental protection and the continued economic viability of the phosphate industry. New phosphogypsum stack systems and existing system expansions are being constructed with liner systems that are protective of ground water quality.

Existing unlined stack systems, as highlighted by the IMC-Agrico sinkhole incident, represent a potential for ground water pollution. The Department will be closely reviewing the demonstrations required by rule 62-673.650 to allow continued use of unlined stack systems beyond March 25, 2001.

PHOSPHOGYPSUM HANDLING

BY

GERALD J. RUBIN
IMC-AGRICO COMPANY

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Author: G.J. (Jerry) Rubin, IMC-Agrico Company

Mr. Rubin has been with IMC since 1965 and currently holds the title of Director of Technical Services. He was project manager for the New Wales Chemical Plant, including the P_2O_5 section, the feed ingredients plant, the defluorinated phosphate plant, wet rock grinding and uranium recovery facilities. In 1991 he was given responsibility for the state-of-the-art phosphogypsum stack expansion, and also oversaw the remediation of the well-publicized sinkhole in the old stack.

Mr. Rubin is a graduate of Rensselaer Polytechnic Institute with bachelor's and master's degrees in chemical engineering; and is a Registered Professional Engineer in Florida and Louisiana.

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Basic Design and Operation of Phosphogypsum Stacks

For every 1 ton of phosphoric acid produced, expressed as P_2O_5, approximately 5 tons of by-product phosphogypsum are also generated. In conventional dihydrate plants, such as those predominating in the U.S., the gypsum is discharged from the phosphoric acid filters, slurried with recycle process water from the plant's cooling pond, and transported to the gypsum stack at 20-25 % solids by weight.

Once there, the slurry is diverted to generally two or more alternate settling areas via pipes or rim ditches around the perimeter of the stack. The rim ditches themselves are alternately excavated and used to construct perimeter or cross dams as the stack is raised. As the gypsum particles settle out, the excess transport water decants to collection ditches at the base of the stack and ultimately to the process cooling pond, where it co-mingles with recycle process water used in other areas of the plant.

The size of a gypsum stack is generally dictated by the minimum surface area required to settle gypsum and clarify the decant water, the time required for the rim ditch gypsum to consolidate sufficiently for excavation, and the personnel and equipment available for operation/maintenance of the stack. These are in turn generally dictated by the P_2O_5 production rate of the plant.

For a production rate of l,000,000 tpy of P_2O_5, and assuming a desired 10 year stack life, approximately 50,000,000 tons of gypsum must be stored. For a 200 foot high stack, common in Florida, and based on a final 4:1 horizontal:vertical slope, also typical, a land area of approximately 300 acres will be required. Under this scenario, the top surface area will end up at about 70 acres, which is still adequate for effective settling.

The IMC-Agrico Gypsum Stack Expansion Project

With the advent of the Phosphogypsum Management Rule in March, 1993, gypsum produced after 2001, which until now had been stored in unlined areas including mined out pits, would now have to be contained in lined systems. The New Wales Plant of IMC-Agrico Company became the first location in the phosphate industry to construct a new phosphogypsum stack on top of a high density polyethylene (HDPE) flexible synthetic membrane.

The permit application process for the Gypsum Stack Expansion began in 1988 and lasted approximately 2 years. Construction began in September of 1990. Because of the size of the expansion area, and to facilitate construction and minimize exposure time of the liner, construction was accomplished in two overlapping stages representing approximately equal areas. The West Area was completed in April, 1992, and the East Area in June of that same year. Following is a summary of the major segments of the expansion project and the capital cost associated with each.

Site Preparation **$15.8 MM**

The location chosen for the Gypsum Stack Expansion Project had been recently mined, and consisted of rows of spoil piles cast by draglines during mining. A total area of approximately 520 acres had to first be cleared and grubbed. This was especially important given the fact that a flexible HDPE liner was to ultimately cover the site. This was followed by excavation and removal of better than l,000,000 cubic yards of soft clays to prevent differential settlement beneath the liner. Much of the clay was present below standing water of variable depth in the mine cuts. Dredging and dragline excavation methods were both used.

Earthwork consisted of backfilling the mine cuts, levelling cast spoil piles to pre-set elevations, site grading and construction of compacted earthen dikes. Approximately 5,000,000 cubic yards of earth was moved in a balanced cut and fill operation to achieve a uniform liner subgrade.

As previously mentioned, the project was divided in two approximately equal areas separated by an earthen divider dike. A perimeter earthen dike surrounded the entire project site. In order to segregate and control surface water runoff, and facilitate and manage construction, each of the West and East Areas was subdivided into 5 cells separated by earthen divider berms and runoff ditches.

Being that the area was originally a mined out pit, dewatering was a major consideration during both site preparation and the following liner installation. Relief trench drains, drainage ditches and large capacity dewatering pumps were all used. All surface runoff, drainage and water from temporary dewatering operations was contained within the Company’s mined out pits and water circulation systems.

HDPE Liner Installation **$16.4 MM**

A 60 mil high density polyethylene (HDPE) liner was installed over the entire base of the expansion area including the upstream slope of the perimeter earthen dikes. In order to address the stability of the ultimate 200 foot high gypsum disposal area, textured liner was used around the perimeter of the facility, while smooth liner was installed within the central portion. The overall split was approximately 53/47, textured/smooth. With the exception of the West and East Area Flumes which connected the lined area with the existing cooling pond, there were no penetrations of the liner.

Panel layout and seam orientation was in accordance with the manufacturer’s design. Panel deployment generally proceeded from high to low ground. The center cell in each area was lined last. Wind ballast and anchor trenches were utilized to protect against uplift by wind.

Adjacent liner sheets were overlapped by at least 3 inches and welded together by one of two different methods. A total of approximately 925,000 lineal feet of field seams was required.

The liner itself was overlain by a system of three concentric drains, comprised of approximately 45,000 lineal feet of slotted HDPE pipe surrounded by silica gravel, and then completely wrapped with polypropylene filter fabric. The drains were constructed atop the liner in drain trenches resting on and covered by gypsum. Each slotted drain pipe was connected to at least one outlet pipe, which extended along the lined inboard slope of the perimeter earthen dike. The liner on the inboard slope was covered with a 2-foot thick layer of compacted gypsum hauled from the existing stack. An upper and lower discharge was provided to the lined seepage collection ditch from each outlet pipe. About 11,600 lineal feet of outlet pipes was grouped into approximately 18 outlet locations spaced around the periphery of the expansion area.

In addition to the gypsum used for drain trenches and the inboard slope of the perimeter dike, access roads and the internal gypsum dike were also constructed with gypsum hauled from the existing stack. Any runoff that came in contact with the gypsum placed in the lined expansion area during construction, had to be collected and diverted to the existing cooling pond.

Gypsum was excavated from a borrow area of the existing stack using draglines, backhoes and dozers. Continual dewatering of the borrow area in order to obtain the proper moisture gypsum was a major problem. Approximately 1,200,000 cubic yards of gypsum was "borrowed" from the existing stack, and hauled to the expansion area via lo-wheel dump trucks over newly constructed roads and bridges.

Concrete Flumes and Other Structures $1.1 MM

As previously mentioned, the only penetrations of the liner were the reinforced concrete flumes directing stack runoff and seepage to the existing cooling pond for re-use. Each of the two flumes was constructed of concrete and protected by a coal tar epoxy coating. The flumes were approximately 300 feet long, and passed through a perimeter dam, beneath two service roads, beneath two sets of railroad tracks and through a slurry wall separating the cooling pond from the expansion area.

Another structure that had to be constructed was a box culvert crossing of the existing pond water channel required for the trucks hauling gypsum from the existing stack. Other structures included those for gypsum pipelines crossing under railroad tracks and roads.

Gypsum Slurry Pipelines $5.0 MM

Two 30 inch diameter, 9,000 foot long, rubber lined steel pipelines were constructed to transport the gypsum from the production facilities to the new expansion area. Over five hundred (500) 40 foot long pipe spools and fittings were required. An elaborate relief system was installed to balance stresses and control pipe movement due to thermal expansion/contraction.

Engineering/Quality Control $6.1 MM

Ardaman & Associates, by virtue of its acknowledged expertise in the design and construction of phosphogypsum storage facilities, was chosen to provide all required engineering and consulting services. Its involvement was basically divided into the following four categories:

- Planning and Conceptual Design
- Development of Permit Applications

- Detailed Engineering
- Quality Assurance and Quality Control

Planning and conceptual design began as early as 1986. Submittal of Permit Applications was targeted for 1988. Due to environmental concerns, they were revised and resubmitted in 1989. A complicating factor was the development of the Phosphogypsum Management Rule during this same period. As it turned out, the New Wales Lined Gypsum Stack Expansion Project essentially became the basis for much of the Rule.

Engineering required not only the customary basic design, but also justification of numerous technical innovations to the Agencies because of the project being a "first". Key features included:

- Use of a 60 mil HDPE flexible liner, and development of acceptable QA/QC procedures.
- The combination of textured and smooth liner material.
- Development of the unique "composite liner" concept utilizing gypsum atop a synthetic membrane.
- Development of construction sequencing procedures to allow concurrent liner deployment, gypsum placement, dram construction and runoff management.

During the construction phase of the project, Ardaman's QA/QC procedures included:

- Determination of clay removal quantities and guidance to the dredge and dragline operators removing same.
- QC inspection and testing during construction of the Relief Drains.
- Monitoring of earthwork construction including backfilling of minecuts, rough site grading, perimeter earthen dike construction and fine grading operations.
- Density testing of compacted fill.
- Review and evaluation of factory testing of liner materials.
- Physical testing of delivered liner rolls and sheets.
- Non-destructive and destructive testing of field seams.
- Monitoring of stack drain materials and placement.
- Monitoring of gypsum placement and compaction atop liners.
- Monitoring of suitability of gypsum borrow.

During the course of construction, Ardaman provided a resident engineer and a staff of 5 to 20 full-time quality assurance inspectors, mobilized on an as needed basis.

Other Facilities **$1.5 MM**

In addition to the tasks and facilities associated with the expansion area itself, numerous additional projects were required because of the existing gypsum stack. Items such as slurry walls, capping of recharge wells and installation of an extensive series of monitoring wells, whose total cost was significant, are not included herein, as they would not be typical for most installations, other than a nominal number of monitoring wells.

Construction Staff/Facilities **$1.4 MM**

Work on the project began in 1986 with the formation of the Company's Project Group. Detailed design began in August, 1990, with field construction beginning in September of that same year. Utilizing "fast track" design and construction, the West Area started up on schedule in April, 1992. A computerized schedule was required to track the over 1000 activities associated with the project. Over 50 engineering and construction contracts were awarded, with most being "hard dollar." Clay removal and earthwork were "time and material."

The Project Group functioned both as owners representative and prime contractor. At peak construction, the Project Team consisted of a Project Manager, a Project Superintendent, two Project Engineers, a Cost/Scheduler and three Field Superintendents.

The bottom line capital cost for the Gypsum Stack Expansion Project totaled approximately $49.7MM, not including capitalized interest.

-From video, transcript of questions and answers of Present Practice Panel discussion:

POLICY PANEL QUESTIONS TO PRESENT PRACTICE SPEAKERS

OHANIAN: Now lets take no more than about 5 minutes and see if the panel has any questions of our two speakers before we go on to the next panel presentations.

YOUNG: Mr. Coram I think you mentioned that use and reuse under the rule is allowed if not otherwise prohibited. Could you tell me how that actually translates?

CORAM: Currently EPA prohibits reuse of PG under its NESHAPs regulations so if that regulation was changed or modified our rule would not prohibit the use or reuse of PG if shown you could do it in an environmentally sound manner.

YOUNG: Does that infer that FDEP, assuming that EPA rules were changed to allow it, would not undertake its own rulemaking or independent review but would defer to the EPA decision? Or would FDEP, at that point, proceed to make its own inquiry and develop its own rules?

CORAM: Well our rule currently classifies PG as a solid waste. However, there are provisions in (chapter) 403 Florida Statutes called “Industrial By-Products” where an industry can make a demonstration that the material can be beneficially used. As long as it does not represent a threat to human health or the environment it can be reclassified as an industrial by-product and no longer be considered a solid waste and therefore, we would simply relinquish reglatory control over that material.

SMITH: For Mr. Rubin, I think in your presentation you talked about putting 24 inches of compacted gypsum, which I am assuming is some of the by-product here. I heard the Chairman say, some of the concern in the regulation that EPA has is based on the radon gases. How are you able to handle those materials, if in fact, they were a threat to the workers? How are you able to move that gypsum, compact it, if there was a concern for radiation?

RUBIN: I am not sure I know how to answer that question. We do not believe that there is that risk to the workers.

SMITH: I don’t want to steal Dr. Ho’s thunder. But we have used those materials, and we have measured those properties, and we find some of those materials have less radioactivity than the native materials which we typically use everyday. I was just supporting the comments that Mr. Rubin made, because if you are going deal with materials that are radioactive, we are all concerned about the fellow worker and you have a lot of equipment out there and I don’t think you want to contaminate that; but our own use of early experiments with these materials in 1980, we found no real risk from radiation, our concern was with some acidity of some of the materials as you bring them in contact with pipes and so forth. This is a real mystery to me, the question on radiation at this point.

COLEMAN: A question that came to me from the audience really fits right in here, and that is how radioactive is the phosphate gyp. Maybe some one can place a relative risk on it.

B. SCHEINER: In the early 80's we probed every stack in Florida and did a composite study of radionuclides in all the stacks. The number we came up with was 22 pCi/gram across the state. You can get the individual stacks out of the data, this has all been published, but that's what we count for the whole state, all 13 stacks at the time, I believe.

COLEMAN: What does that mean, 22 pCi/gram? What are you saying is risk? How do you rate that next to a cigarette?

OHANIAN: Perhaps we should wait on that. We have the risk panel coming up. They will be able to address that.

COLEMAN: Fine, then let me go back to another question that was also put forward. Can an additional processing step, such as centrifugal separation, be used to reduce the radiation levels in PG as it is now? That may need to be asked of another group, too. Chemical processing, for example, may want to answer that.

GARRITY: Pursuing the radioactive issues here for a second. I would like to ask Phil (Coram), what do you think the role of any other state agency, such as HRS, might be in the future as far as regulating or not regulating any possible radiological issues with gypsum stacks.

CORAM: HRS is the state agency responsible for regulating the handling of radioactive materials. Our department simply gets involved when we are looking at groundwater and compliance with groundwater standards. But as far as human health impacts or occupational exposure, it's the the Department of Health and Rehabilitative Services that has the primary regulatory role.

GARRITY: As a follow-up, then, to Commissioner Young's question, if EPA were to change their regulations would the companines still need permission from HRS for these issues or do you think that they would be setting separate regulations or do you think they would just accept the change in EPA's regulations.

CORAM: It is my understanding that there are only a few of the materials that are disposed in gypstacks that are actually regulated by HRS. Scale from the filters, is one of those materials. I don't believe that PG in and of itself exhibits enough redioactivity to be reglated by HRS. A few of the materials that are disposed of in a PG stack mainly scale from the filters and I think that's about it.

WIEGEL: (To Rubin) I think in your presention, much of it concerns the engineering problems and the costs associated with expanding an existing gypsum stack. If, in fact, the regulations were changed so that PG could be used either in agriculture or construction or both, would this then necessitate additional tremendous capital investments on the part of the industry or is that something that could be relatively easily done without cost?

RUBIN: Ron are you talking about taking existing phosphogypsum from the stacks and utilizing it? I am not sure I understood the question.

WEIGEL: I guess I would first visualize new phosphogypsum being used, but perhaps eventually that which has already been deposited in the stacks as being consumed for some beneficial use.

RUBIN: Well, the cost of transporting the PG from the stacks is significant, but by the same token, if it has a useful purpose, I think the economics would have to stand on their own, as far as utilizing the material.

WEIGEL: So that you would, in essence, just add to what you have currently spent for your expanded gypsum stack.

RUBIN: As far as taking the gypsum and then utilizing it somewhere?

WEIGEL: Correct. You would have to provide some technique for reclaiming the gypsum, including whatever vehicle for transport and that sort of thing.

RUBIN: You would essentially be mining the gypsum stack as we did when we borrowed, so to speak, gypsum from our existing stack to place on top of the liner in the expansion area, and I would visualize that type of operation. I think you would probably be better off mining existing gypsum than trying to treat gypsum right out of the plant, but I think we would have to take a look at both sides of that.

OHANIAN: I know that some of you in the audience are eager to ask questions, but the way we are conducting this is that the main interaction is between the speakers and the policy panel. If you really have any hot questions you want to ask, perhaps you can write them down and bring them up here and we will see if we can work them in.

COLEMAN: Jack, I received one of those questions. We are going to have a problem in handling because many of the questions will come in for instance, asking about risks. If we as panelists bring those questions forward, perhaps those people assessing the risks, or the capability of, for instance, centrifugal separation, can answer, during their speeches, some of these questions. Otherwise, our panelists are going to have to determine, as experts, which questions go where.

OHANIAN: They should go to each specific panel as they come up. Otherwise, we will never get through.

APPLICATION RATES OF PHOSPHOGYPSUM IN AGRICULTURE

BY

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Preamble

In 1992, the Environmental Protection Agency (EPA) banned the use of phosphogypsum containing more than 10 pCi $^{226}Ra\ g^{-1}$ for application to soils (Environmental Protection Agency, 1992). This ban was based on calculations of risk assessment on the assumption that phosphogypsum would be applied to a given soil at a rate of 2700 lb ac^{-1} biennially for 100 years. As will be shown in this report, this assumption is incorrect. The Fertilizer Institute unsuccessfully challenged the Final Rule made by the EPA who contended that this application rate truly reflected the likely usage of phosphogypsum in agriculture.

Introduction

Gypsum is used in agriculture for the following purposes:

- as an ameliorant for sodium-affected (sodic) soils which occur mainly in arid areas and is therefore of minor interest in this report,
- as a source of the nutrients calcium (Ca) and sulfur (S) required by all crops,
- as an ameliorant for the subsoil acidity syndrome which commonly afflicts soils in the Southeast, and
- as an ameliorant for crust and seal formation at the soil surface, a condition commonly encountered in the sandy textured soils of the Southeast.

This report has been prepared for the Florida Institute of Phosphate Research (FIPR) with the following objectives:

- to independently assess the published experimental evidence on gypsum use in agriculture in the Southeastern United States and in Florida in particular, and
- to compare the gypsum application rate assumed by the EPA in their calculations to actual field practice by computing both on a lb $ac^{-1}\ yr^{-1}$ basis.

To achieve these objectives, a thorough literature review was undertaken in an attempt to survey all citations so that the final outcome cannot be contested on the basis of a limited data set.

Calcium (Ca) Requirements of Crops

The following are the essential roles Ca plays in the nutrition of all plants:

- serves vital functions in the development of cells,
- is essential for membrane integrity and functioning of hormones,
- aids in the signalling of environmental changes, and
- partially offsets the toxic effects of aluminum (Al).

The amounts of Ca required to be present in soil by various crops can differ widely and in circumstances where soil Ca levels are low, gypsum is often used to remedy this deficiency.

Peanuts. The major crop in the Southeast for which Ca is most critical, is the peanut (Arachis hypogea) which has received most attention in the literature. The responses obtained in the field have served as the basis for the development of State Recommendations by the Cooperative Extension Service for the application of gypsum to peanuts. Research has clearly demonstrated that substantial benefits are to be derived from rotating peanuts with other crops which are not susceptible to peanut pests. This is by far the cheapest and most effective way of controlling peanut pests in the field. Consequently, the Cooperative Extension Service in all southeastern states advises farmers to rotate peanuts with other crops on a routine basis. Rotation of peanuts in a 2- or 3-year rotation is practiced by over 75 % of the farmers in the Southeast. Therefore, the gypsum application rates recommended by the various states in Table 1 must be divided by 2 or 3 depending in whether peanuts appear every other year or every third year in the rotation. Rotational considerations do not appear to have been taken into consideration in the EPA's Ruling. Indeed, very few peanut farmers would ever be foolish enough to plant peanuts continuously on the same piece of land. As the literature review undertaken in this treatise indicates that these application rates are based on sound scientific data, they should be used as the basis for calculating an annual gypsum application rate. This aspect of peanut production was not apparently considered by the EPA in arriving at the Final Rule on Phosphogypsum.

On a whole field basis (broadcast application), the highest gypsum rate recommended for peanuts in the Southeast is 1720 lb gypsum ac^{-1}. Taking the most conservative approach assuming that peanuts are grown in a two-year rotation (practiced by only one-third of peanut farmers on average), the maximum recommended rate on an annual long-term basis would be 860 lb ac^{-1} yr^{-1}. Because there is substantial financial gain to be achieved by growing peanuts in a three- over a two-year rotation, many farmers follow a three-year rotation system which would reduce this figure to 573 lb gypsum ac^{-1} yr^{-1}. Thus by comparison with the maximum rate at which gypsum would ever be applied in practice on a long-term basis to a given field (860-573 lb gypsum ac^{-1} yr^{-1}), the figure of 1350 lb gypsum ac^{-1} yr^{-1} used by the EPA in their risk assessment calculations is too high by a factor of between 1.56 and 2.35.

However in many cases, farmers usually band place gypsum because this is much more economical as only between l/3 and l/2 of the amount is required. As a result the most likely rates at which gypsum would be applied to most production fields in any one year would be between 250 and 860 lb gypsum ac^{-1} yr^{-1} (Table 1). Consequently, the actual long-term rates would lie between 125 and 430 for a two- and 83 and 267 lb gypsum ac^{-1} yr^{-1} for a three-year rotation system. Thus in the most likely case, the EPA figure overestimates actual field practice by a factor between 3.1 and 16.3.

Table 1 **Recommended gypsum rates for peanuts in the Southeast (Hodges et al.,1994)**

State	Type	Soil Ca	Gypsum Recommendation			
			lb ac^{-1}		kg ha^{-1}	
			Band†	Broadcast	Band	Broadcast
Alabama	Runner	Low	250*		280	
		Low	500		560	
		Med	250		280	
Florida	Virginia	All	800	1600	898	1795
	Runner, Spanish-seed	All	400	800	449	896
	Runner, Spanish	Low	400	800	449	896
Georgia§	Virginia	All	688-860	1376-1720	772-956	1544-1913
	Runner, Spanish-seed	All	344-430	688-860	386-483	772-965
	Runner, Spanish	Low	344-430	688-860	386-483	772-965
North Carolina	Virginia	All	600-800	1200-1600	673-897	1346-1795
South Carolina	Virginia	All	600-800	1200-1600	673-897	1346-1795
	Runner, Spanish	All	400-500	800-1000	449-561	898-1122
Virginia	Virginia, seed	All	600	900-1500	673	1010-1683

† Band widths vary by State: Alabama = 30 cm (12 in); Florida, Georgia, North Carolina, South Carolina = 45 cm (18 in); Virginia = 50 cm (20 in)

§ Values for Georgia have been converted from Ca to equivalent pure $CaSO_4 \cdot 2H_2O$

* When lime is applied

Assuming that half the farmers would broadcast phosphogypsum in a 2-year rotation and half would band place phosphogypsum in a 3-year rotation, the maximum average rate over all situations would be (860+267)/2 = 563 lb gypsum ac^{-1} yr^{-1}. The maximum, most likely and minimum rates of gypsum application are presented below:

- Maximum Rate: 600 lb phosphogypsum ac^{-1} yr^{-1}
- Most Likely Rate: 125-430 lb phosphogypsum ac^{-1} yr^{-1}
- Minimum Rate: 0-83 lb phosphogypsum ac^{-1} yr^{-1}

Tomatoes and Other Vegetable Crops. Tomatoes and peppers also have a definite requirement for Ca to reduce the incidence of blossom-end rot that can take a heavy toll on the quality of the crop. However in most cases, leaf sprays of Ca salts in minute amounts are highly effective and seldom if ever would gypsum applications be made to the soil. Only two States (Georgia and Tennessee) have gypsum recommendations for soil application ranging from 430 to 860 lb ac^{-1}. Because vegetable crops are highly susceptible to a wide range of diseases, rotations with other more resistant crops would always be practised by farmers for phytopathological control. Consequently, the most likely long-term annual rates would range between 215 and 430 for a two- and 143 and 287 lb ac^{-1} yr^{-1} for a three-year rotation. These values are between 3.1 and 9.4 times lower than the assumed EPA figure of 1350 lb ac^{-1} yr^{-1}. The maximum, most likely and minimum rates of gypsum application are presented below :

- Maximum Rate: 430 lb phosphogypsum ac^{-1} yr^{-1}
- Most Likely Rate: 200-300 lb phosphogypsum ac^{-1} yr^{-1}
- Minimum Rate: 0-143 lb phosphogypsum ac^{-1} yr^{-1}

Sulfur Requirements of Crops

Sulfur (S) which is an essential element for plant growth, is a constituent of a number of amino acids and is therefore required for protein synthesis. Crops take up between 10 and 20 lb S ac^{-1} for normal growth. Extensive experimentation has been carried out in all States in the Southeast to determine the rate of soil-applied S for optimal crop production, and forms the basis of the State Recommendations complied by the Cooperative Extension Service. These recommendations which have been converted to an equivalent gypsum basis, are summarized in Table 2.

Table 2 **Recommended rates of gypsum application to crops in the Southeast to supply the essential element sulfur (S)**

State	Crop	Gypsum Rate ($lb\ ac^{-1}$)
Alabama	All	54
Florida	Agronomic, grass	80-108
Georgia	All	54
North Carolina	Corn, small grains, cotton, tomato, bermudagrass	108-161
South Carolina	All	54

Thus, the maximum recommended gypsum rate for any crop is 161 lb ac^{-1} yr^{-1} which is more than eightfold lower than the rate (1350 lb ac^{-1} yr^{-1}) assumed by the EPA in their risk assessment calculations. The maximum, most likely, and minimum rates of gypsum application as a source of S are presented below:

- Maximum Rate: 161 lb phosphogypsum ac^{-1} yr^{-1}
- Most Likely Rate: 50-80 lb phosphogypsum ac^{-1} yr^{-1}
- Minimum Rate: 0 lb phosphogypsum ac^{-1} yr^{-1}

Gypsum for Subsoil Acidity Amelioration

Only a limited amount of research has been conducted in the Southeast to study the beneficial effects of gypsum on soils with acid subsoils where root penetration is limited. Most of the research has been confined to Georgia where a single 2.2-4.4 t gypsum ac^{-1} application has resulted in substantial yield responses which have been sustained over a long period of time. Because the longevity of this effect is in excess of 10 years, the recommended rate on an annual basis would be 400-800 lb gypsum ac^{-1} yr^{-1} which is at least 1.7-fold less than the assumed EPA value. At present, very few farmers have attempted this amelioration strategy and because of the high initial cost in excess of $175 ac^{-1}, only very limited acreage devoted to highly remunerative crops is likely to be used in this cropping system in the future. The maximum, most likely, and minimum rates of gypsum application for the amelioration of subsoil acidity are presented below:

- Maximum Rate: 800 lb phosphogypsum ac^{-1} yr^{-1}
- Most Likely Rate: 400 lb phosphogypsum ac^{-1} yr^{-1}
- Minimum Rate: 0 lb phosphogypsum ac^{-1} yr^{-1}

Gypsum as an Ameliorant for Soil Physical Properties

Reclamation of Sodic Soils. Although sodic soils which are common in arid areas, do not occur to any appreciable extent in the Southeast, a brief overview of the gypsum requirements of these soils was undertaken because the EPA's Final Rule incorporated gypsum application rates for this purpose. The applications rates used in determining the Final Rule were based on commonly used rates and did not take the total amount required for reclamation into consideration. Based on a review of field reclamation studies, applications of between 7 and 35 t gypsum ac^{-1} would be required to reclaim the top 20 in (which is sufficient rooting depth for most crops under irrigation) of a highly sodic soil (exchangeable sodium percentage [ESP] =30) . On an annual basis, this would correspond to applications between 140 and 700 lb gypsum ac^{-1} yr^{-1} over a 100-year period which is between 2- and 10-fold less than the EPA assumed value. However in certain cases, applications in excess of these amounts have been made to certain soils, but these cases represent the exception rather than the rule.

If the biennial application rate (2700 lb phosphogypsum ac^{-1}) used by the EPA in arriving at the Final Rule was applied to a sodic soil over a 100-year period, this would amount to an application rate of 68 t ac^{-1} which is approximately twice the rates commonly used in practice. The maximum, most likely, and minimum rates of gypsum application for the reclamation of sodic soils are presented below:

- Maximum Rate: 700 lb phosphogypsum ac^{-1} yr^{-1}
- Most Likely Rate: 200-500 lb phosphogypsum ac^{-1} yr^{-1}
- Minimum Rate: 0-200 lb phosphogypsum ac^{-1} yr^{-1}

Crusting and Seedling Emergence. Most of the research in the Southeast on this aspect of gypsum use has been conducted in Georgia where, as a result of reduced crusting, substantial improvements in water entry into soils have been obtained, thereby reducing runoff and erosion. Typically, applications ranging between 0.5 and 2 t gypsum ac^{-1} have proven to be highly successful and currently the Cooperative Extension Service recommends 0.5-1 t gypsum ac^{-1} for this purpose. Such applications are only recommended as an interim measure in the establishment of a permanent vegetative cover on highly erodible soils. Thus, this should be considered as an application that would be made once only or, at the most, once in five years in a no-till system. Relatively few farmers have adopted this technology at present as many consider it to be too expensive. However, if applications are made only over the row, the application rates would be reduced by a factor of 2-3. Thus, the maximum amount of gypsum that would be applied over a 100-year period would not exceed 7-10 t ac^{-1}. The maximum, most likely, and minimum rates of gypsum application for the amelioration of crusting are presented below:

- Maximum Rate: 200-400 lb phosphogypsum ac^{-1} yr^{-1}
- Most Likely Rate: 100-200 lb phosphogypsum ac^{-1} yr^{-1}
- Minimum Rate: 10-50 lb phosphogypsum ac^{-1} yr^{-1}

Mechanical Impedence. Gypsum applications to the soil surface have been shown to reduce the mechanical impedence (resistance to root penetration) of subsoil horizons as a result of improved flocculation of the clay. A single 4.4 t ac^{-1} application of gypsum was sufficient for this purpose and the effect has lasted in excess of 10 years giving a long-term application rate of about 800 lb gypsum ac^{-1} yr^{-1}. Because of the high cost involved in the initial gypsum application, no farmers have yet attempted to use this strategy. The maximum, most likely, and minimum rates for this use are presented below:

- Maximum Rate: 800 lb phosphogypsum ac^{-1} yr^{-1}
- Most Likely Rate: 400 lb phosphogypsum ac^{-1} yr^{-1}
- Minimum Rate: ? lb phosphogypsum ac^{-1} yr^{-1}

Environmental Impacts Associated with the Agricultural Use of Phosphogypsum

Application of a phosphogypsum with a high ^{226}Ra content (35 pCi g^{-1}) at the maximum rates for the different uses described above for a 100-year period would result in a maximum cumulative ^{226}Ra concentration of 1.57 nCi ^{226}Ra kg^{-1} of soil (58.0 Bq kg^{-1}) which is much lower than the 5 nCi ^{226}Ra kg^{-1} (185 Bq kg^{-1}) considered to be the upper limit of a safe range. Where phosphogypsum has been used as a source of Ca or S for crops, radiation added to the soil has, in all cases, not significantly increased native background levels. Even where a single rate of 4.45 t phosphogypsum (17.6 pCi ^{226}Ra g^{-1}) ac^{-1} was applied, no significant increases in ^{214}Pb, ^{214}Bi, or ^{226}Ra could be detected anywhere in the profile of two different soils to a depth of 3 ft, 5 years after application. No significant differences in plant uptake of these radionuclides could be detected due to phosphogypsum treatment. However in a leaching experiment on a very sandy soil, elevated ^{226}Ra concentrations were found in the leachate but these concentrations were well below the maximum allowed in drinking water.

Based on the scientific data, the conclusion can be drawn that there should be little concern associated with the use of phosphogypsum containing more than 10 pCi ^{226}Ra g^{-1} provided that Cooperative Extension Service application rates are used.

Conclusions

All the soundly based experimental data strongly suggest that the phosphogypsum rate of 1350 lb ac^{-1} yr^{-1} for 100 years used by the EPA as the basis for formulating the Final Rule on phosphogypsum use, is too high. A more appropriate maximum figure would be in the range 600-800 lb gypsum ac^{-1} yr^{-1} with the most likely application rate lying in the range 100-400 lb gypsum ac^{-1} yr^{-1}.

GYPSUM AS A SOIL AMENDMENT IN CALIFORNIA

BY

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Dr. Meyer has been Extension Soils Specialist at University of California - Davis, LAWR Department since 1973. Prior to joining UC-Davis, he served as Area Agronomy Specialist with the University of Missouri Cooperative Extension and worked in fertilizer and agricultural chemical sales in North Central Nebraska with Farmland Industries, Inc. Since coming to UC-Davis, his research and extension activities have concerned the efficiency, economics and environmental impacts of fertilizer application to California crops. More recently he has been involved in evaluating the possible utitilztion of various waste products such as fly ash and bottom ash, animal manures, sewage sludge and composts of these and other materials as nutrient sources and soil amendments in agriculture, forestry and landscape settings.

Dr. Meyer has bachelor's and master's degrees from the University of Nebraska and earned the Ph.D. degree in Agronomy from Iowa State University.

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Gypsum is used for several purposes in California agriculture. The largest volumes are used in one or two manners, for the reclamation of salt affected soils and improving water infiltration in soils. The third largest use would be as a nutrient source for sulfur. Smaller volumes of gypsum are used in the amelioration of high magnesium soils and acidic soil conditions. The purpose of this presentation is to describe the use of gypsum in the reclamation of soils and improving water infiltration where the highest rates per unit of land area are normally found.

The gypsum used in agriculture originates from two primary sources, mined gypsum and the by-product from the manufacture of phosphate fertilizers called phosphogypsum. For the period from 1977 through 1990, phosphogypsum accounted for less than 2% of the total use in 1977, rising to nearly one third during the period 1983-1986 and down to less than 10% in 1990 (Figure 1). This use pattern was a reflection of the availability of phosphogypsum from the phosphate manufacturing industry. Recent implementation of gypsum injection equipment developed for drip and other low flow irrigation systems has necessitated the introduction of very fine gypsum, 99-100% smaller than 0.15 mm, 93-97% finer than 0.07 mm, and 3-78% finer than 0.04 mm.

In the reclamation of salt affected soils, particularly those having high sodium concentrations, gypsum is used as a source of calcium to replace the sodium. The process of reclamation usually begins by establishing adequate drainage which may involve the installation of underground tile drainage where natural soil drainage is insufficient. Additional steps involve testing the soil on some type of grid system to identify the degree of reclamation necessary followed by an initial rate of 3-5 tons gypsum application per acre before fall rainfall or irrigation begins. When sufficient leaching has occurred, a more salt tolerant crop such as barley is planted. Soils from the areas of poor barley growth are retested to develop additional gypsum recommendations which are usually in the 1-2 tons per acre range. Continued leaching with irrigation and winter rains along with additional applications of 1-2 tons gypsum per acre may be necessary before uniform crop growth is established throughout the field. Average application rates for the first ten to fifteen years are about one ton gypsum per acre with a range of 0.5 to 1.5 tons per acre. Rates of gypsum application will be considerably less after the reclamation is well underway with rates averaged over a 50 year time frame having a minimum and maximum of 0.2-0.7 tons per acre per year respectively.

The second major use of gypsum in California agriculture is the addition to very pure (EC < 0.2 dS/m) irrigation water to improve the infiltration in soils. This may in fact represent the highest use of gypsum on a unit soil area basis with broadcast rates on occasion exceeding one ton per acre per year. Water originating largely from snowmelt in the Sierra Mountains is of very pure quality and unless blended with higher concentration divalent calcium and magnesium salts from groundwater requires the addition of gypsum to prevent the soil surface from sealing. Various techniques have been used over the past 50 years to address this problem. Gypsum was applied to the soil surface at rates of 0.25 up to as much as 1 ton per acre every year or two. To increase the salt concentration of the water, large concrete chambers 6-8 feet wide and 10-20 feet long were used to contain the gypsum while the irrigation water was allowed to pass over the gypsum and dissolve appropriate amounts. Growers having flood or furrow irrigation systems currently use broadcast or banded gypsum on the soil surface at the rates mentioned previously. In crops where drip or other low volume irrigation systems are used, the injection of a quality finer grade gypsum is becoming more widely accepted. Rates applied typically range from 0.25-0.75 ton per acre with an average of 0.5 ton per acre each year.

Another common use of gypsum is in the case where soils and/or irrigation water have low to moderate levels of sodium. Rainfall amounts may be sufficient in some years to provide adequate leaching but significant improvement in water infiltration or the reduction of sodium levels is desired such that gypsum is applied at the rate of 1-2 tons per acre every four or five years. Long term average application rates would be of the order of 0.2-0.4 ton per acre per year.

Several areas of the state where alfalfa is the principle crop receive gypsum at the rate of 0.15 to 0.25 tons per acre every two years to provide adequate amounts of the plant nutrient sulfur. The rapid growth response from the readily available sulfate-sulfur allows it to compete economically with elemental sulfur which is less costly per pound of sulfur but has a much longer term release pattern.

The north coast of California and several other areas where serpentine parent materials give rise to soils having soluble calcium:magnesium ratios of less than 1:2 represent another use of gypsum in agriculture. Plant growth is dramatically increased when calcium from gypsum is increased in the soil and calcium:magnesium ratios are greater than 1:1. Rates on the order of 10 to 20 tons per acre as a one time application with a follow up treatment of 5 to 10 tons per acre after approximately 40 years could result in a 50 year average high use of 0.5 to 0.6 tons per acre per year.

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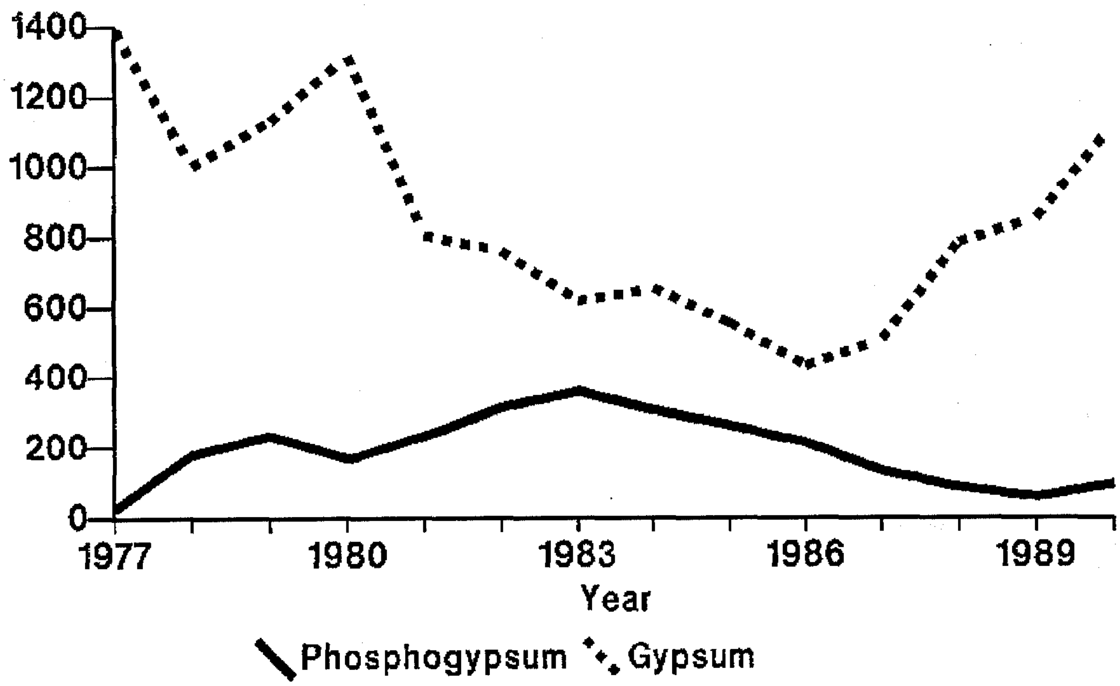
Figure 1. Gypsum use in California agriculture (in thousands of tons).



THE ECONOMIC BENEFIT OF PHOSPHOGYPSUM USE IN AGRICULTURE IN THE SOUTHEASTERN U.S.

BY

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Dr. Traxler has dealt with the economics and statistics of agricultural cropping since completing his Ph.D. in 1990, and he has published numerous articles in various agricultural economic journals on crop management practices.

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Introduction

Agriculture accounts for about 5 percent of the nearly 30 million tons of gypsum used in the United States each year. This report estimates the economic benefit of removing restrictions on phosphogypsum use in agriculture in the Southeast.

Size and Organization of the U.S. Phosphate Industry

A total of 14 companies produced phosphate in the United States in 1993. About 85 % of the U.S. production, or 35 million tons, is accounted for by the six companies located in central Florida and one in North Carolina. The U.S. also imported aproximately 850,000 tons annually during this period. The U.S. has no duties or tariffs on fertilizer imports.

Gypsum production

There are no operating gypsum mines in the Southeast. Gypsum used in the Southeast is either byproduct gypsum or is imported mined gypsum. Byproduct gypsum accounts for about three percent of the gypsum used in the U.S. Of the two major sources of byproduct gypsum, the desulfurization of stack gas in thermal powerplants provides the largest share of byproduct gypsum. Despite an overall rise in byproduct gypsum sales, phosphogypsum usage has fallen by 50% since me 1990 EPA ruling limiting its use. An average of 207,000 tons of phosphogypsum were used in 1988-90, while the 1990-92 average is just 102,000 tons in 1993 (Llewellyn). Over the same period, the share of phosphogypsum in total byproduct sales fell from approximately 30 percent to 10 percent.

Gypsum use in agriculture

A total of nearly 1.5 million tons of gypsum, including mined gypsum and byproduct gypsum, were used in agriculture in 1994 (TVA). Agricultural use accounts for about 5 percent of the total of nearly 30 million tons of gypsum used in the United States; construction uses account for 90 percent of total use. Agronomists have been unable to detect differences between the agronomic effects of phosphogypsum and mined gypsum (Mullins and Mitchell, Sumner).

The uses of gypsum in agriculture fall into three main categories (Sumner): 1) as a source of calcium for peanut production 2) as a source of sulfur for vegetable crops and forages 3) as an ameliorant for soil sodicity, crusting and subsoil acidity problems. Only 8,000 tons of sulfur from all sources were directly applied in the region in 1994 (TVA). The use of gypsum to reclaim sodic soils occurs primarily in irrigated agriculture, especially in California, but occurs very rarely in the Southeast. By far the most commercially important use of gypsum in the Southeast at present is as a source of calcium for peanut production.

An average of 1.29 million acres of peanuts are planted in the six southern states of Alabama, Florida, Georgia, North Carolina, South Carolina, and Virginia. The Southeast's "peanut belt" is centered about 150-200 miles from Florida's main phoshorus mining areas. About 80 percent of U.S. peanut production takes place within a 100 mile arc around the juncture of the Georgia, Florida and Alabama borders. Georgia accounts for more than half of the U.S. peanut area.

The value of gypsum as a source of Ca for peanut production has been recognized since the 1940's (Sumner). Among Southeastern states, recommended application rates range from 250 lb ac^{-1} to 860 lb ac^{-1} for banded application and from 688 lb ac^{-1} to 1720 lb ac^{-1} for broadcast application (Sumner).

An average of 198,626 short tons of gypsum are used in agriculture in Georgia, Florida, and Alabama each year (TVA). Virtually all of this gypsum use is for peanut production. Personnel at the USDA national peanut research laboratory collected information on input from a random sample of 84 peanut farmers in 1993 (Lamb). Forty-six percent of surveyed farmers applied gypsum. Of farmers using gypsum, the average application rate was 879 lb/ac. Ninety-five percent of surveyed farmers used an application rate of 1,000 lb/ac or less, 99% of application rates were 1,500 lb/ac or less, and the highest observed application rate was 3900 lb/ac. The average gypsum expenditure was $17.44 per season, and the average farm price was $40.00/ton..

The Potential Economic Benefit from Phosphogypsum Use in Agriculture

The net economic benefit from allowing unrestricted use of phosphogypsum in agriculture in Georgia, Florida and Alabama was calculated within the framework of economic welfare analysis. Welfare analysis, which is a form of benefit/cost analysis, is the most common method used by economists to quantify the costs and benefits of changes in government policies. Just, Hueth and Schmitz summarize the economic welfare literature which has been developed since welfare analysis was first used by Ricardo in the early nineteen century. Welfare analysis is a tool that is relatively easy to understand and apply as well as being theoretically justified.

Calculating the net benefit of unrestricted phosphogypsum use is quite straightforward. The most important parameters needed to calculate welfare changes are: a) the reduction in the gypsum price that will occur as new sources of phosphogypsum enter the market, b) the quantity of gypsum used in agiculture, and c) gypsum (phosphogypsum) supply and demand elasticities. Elasticities only have a minor effect on total estimated welfare but are important in determinig the distribution of welfare changes. In the case of phosphogypsum, because agriculture represents such a small proportion of total gypsum use, a change in the use of gypsum in agriculture will have a negligible effect on the price of gypsum. This implies that the supply of phosphogypsum can be assumed to be perfectly elastic and all benefits, or surplus increases, will accrue to farmers.

Because phosphogypsum is a byproduct of the competitive phosphorus industry, it is expected that phosphogypsum will be supplied at a zero price F.o.b. mines in central Florida. Each year the Florida phoshate industry adds some 30 million tons of phosphogypsum to the existing 600 million ton inventory (Llewellyn). The annual increment to stockpiles is 150 times the current total agricultural gypsum use in the Southeast. The huge phosphogypsum surplus and the significant storage costs imply that it is in the best interest of the industry to supply at any price below the marginal storage cost. In fact, it is not inconceivable that phosphorus producers would pay for phosphogypsum to be removed.

The formula for calculating the welfare change. or net benefit, is:

(1) Change in welfare = $Q_0\Delta P + 0.5\Delta P\Delta Q$

where Q_0 is current level of gypsum use, ΔP is the change in price of gypsum with phosphogypsum restrictions removed, and ΔQ is the change in gypsum consumption as the price falls. The ΔQ is based on an assumed elasticity of demand for gypsum of -0.2. The first term in (1) is simply the price change times the current quantity of gypsum used. The second term accounts for the small increase in gypsum use which will occur as the price falls. Equation (1) is the annual benefit of the fall in the price of gypsum. Since this is expected to be permanent price reduction, the total financial benefit is the net present value (NPV), which is the discounted sum of the annual benefit amounts for all future years.

The Tennessee Valley Authority (TVA) reports average annual gypsum use quantities for 1985-94 of 155,200 short tons in Georgia, 43,284 in Florida and 158 tons in Alabama. No published studies have estimated elasticity of demand for gypsum, but several reported elasticity estimates for phosphorus and nitrogen are reported (Larson and Vroomen, Roberts). A value of η=-0.2 was used in this study.

Some uncertainty exists about the equilibrium gypsum price when phosphogypsum restrictions are removed. Conservative estimates of the new gypsum price were used in the benefit calculations. Phosphogypsum can currently be purchased at White Springs, Florida from Occidental Chemical Agricultural Products for $l0.00/ton. It is assumed that with the entry of new phosphogypsum suppliers in central Florida, Occidental will be forced to reduce its price to meet this competition. It is assumed that central Florida suppliers will be willing to supply phosphogypsum at a zero price F.o.b. central Florida. The delivered farm price will then be determined by the transportation price of $7.00/ton/100 miles. Because Occidental is located approximately 100 miles nearer than other suppliers to the peanut growing areas, it will not be forced to supply phosphogypsum at a zero price, but rather will need to meet the effective North Florida price of other phosphogypsum suppliers of $7.00 (i.e. the cost of trasportation from central Florida to White Springs). The result is that the delivered gypsum price to Georgia, Alabama and north Florida peanut growing areas can be expected to fall by a minimum of $3.00/ton.

Because of the uncertainty involved with predicting this future gypsum price, benefit calculations were done using price assumptions ranging from the minimum expected price reduction of $3/ton up to $10/ton reduction. The annual net benefit is estimated to be $609,284 under the $3/ton price assumption. The net present value of this annual benefit flow is $11,942,236 using a 3% real discount rate. If prices fall by $5.00/ton the annual benefit will be $1,055,199 and the NPV will be $20,682,356. Finally if prices should fall by $10.00/ton the annual benefit will be $2,482,820 and the NPV will be $48,664,368.

Summary

Economic welfare analysis was used in this study to estimate the benefit of unrestricted use of phosphogypsum in agriculture in the states of Georgia, Florida and Alabama. An average of nearly 200,000 tons of gypsum are used in agriculture in these three states each year, primarily as a source of calcium for peanut production. Forty-six percent of peanut producers in Georgia apply gypsum. Of farmers using gypsum, the average application rate is 879 lb/ac. Ninety-nine percent of peanut producers in Georgia apply 1,500 lb/ac or less. Using conservative economic assumptions, the annual net benefit from removing the restrction on gypsum use in agriculture.is estimated to be between $609,284 and $1,055,199. The net present value of this annual benefit flow would be between $11,942,236 and $20,682,356.

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PHOSPHOGYPSUM AS A VALUABLE AND INEXPENSIVE SOURCE OF NUTRIENTS FOR CROPS

BY

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Dr. Rechcigl has been on the faculty of the University of Florida since 1986 and has published extensively in the fields of soil fertility, environmental quality, and (agricultural runoff) water pollution. A large part of his research program has included the environmental impacts of using industrial waste products (including phosphogypsum) in agriculture. He has published extensively and has edited several monographs on environmental quality, and is a well-traveled international speaker.

Dr. Rechcigl has a bachelor's degree from the University of Delaware and the master's and Ph.D. degrees from the Virginia Polytechnic Institute and State University,

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Introduction

Sulfur deficiencies in plants have been reported in more than 35 states, including Florida. Although sulfur is usually considered a secondary plant nutrient, it still needs to be viewed as one of the major nutrients essential for crop growth, along with nitrogen, phosphorus and potassium. Sulfur is required by plants for the synthesis of certain amino acids which are required for protein production. Thus, if sulfur is limiting, forage quality, as well as quantity, will be reduced. In fact, sulfur deficiencies are often confused with nitrogen deficiency. In less severe cases of sulfur deficiency, visual symptoms may not always show up, while crop yield and quality are affected.

Until recently, little attention has been given to the need for sulfur fertilization in Florida and other parts of the country. This is understandable since in the past low analysis fertilizers contained sulfur impurities sufticient to meet the nutrient requirements for forage production. However, today fertilizer manufacturing technology has become highly advanced and consequently high analysis fertilizers, such as triple super-phosphate and diammonium phosphate, are free of sulfur impurities. As a result, sulfur deficiencies are becoming more pronounced and widespread throughout the world. Coarse textured soils, such as those commonly found in Florida, may also exhibit sulfur deficiencies because of their very low nutrient holding capacity.

It is important to note that sulfur fertilization will increase yields and quality of crops only if the plants are deficient in sulfur. The sulfur status of a crop is best determined by having a plant tissue sample analyzed for sulfur which is more reliable than a soil test. For grasses, the level of sulfur in the plant tissue should range from 0.2-0.5 percent. If the level of sulfur falls below 0.2 percent, it is indicative of sulfur deficiency and the grass should thus respond to sulfur fertilization.

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Over the years, we have demonstrated that addition of sulfur can increase production of harvested forages, such as bahiagrass (*Paspalum notatum* L.), by as much as 25 percent and protein content by 1.2 percent. In these studies, the sources of sulfur were ammonium sulfate and potassium sulfate which are relatively expensive. Bahiagrass, which is an important forage crop in Florida, is grown on nearly 2.5 million acres annually, exceeding production of all other improved grasses combined. To provide sulfur for this size of land would be a considerable expense.

There is a need to find alternative economic sources of sulfur which would be more affordable to growers than traditional sulfur fertilizers. Phosphogypsum ($CaSO_4$), a by-product of the wet-acid production of phosphoric acid from rock phosphate, is a potential low cost source of sulfur and calcium for forages and other crops. Until now, phosphogypsum has had little commercial use because it contains low levels of radium (8-30 pCi Ra-226/g), raising concern over its potential harmful effects. In Florida alone, there are more than 700 million tons of phosphogypsum stored in waste stacks, with 30 million tons being added to the stacks annually. In the entire country the total amount of phosphogypsum in stacks is estimated at seven billion tons.

Experimental Design

Over the past six years, we have evaluated the agricultural and environmental impact of phosphogypsum use on forages grown in Florida. This paper discusses results of a part of that study from 1990 to 1992, dealing with the effects of phosphogypsum, applied at agronomic rates, on bahiagrass and the environment, at the University of Florida Range Cattle Research and Education Center at Ona. Results dealing with the environmental effects of phosphogypsum will be discussed in our subsequent paper.

Four phosphogypsum rates of 0, 0.2 (applied annually), 1.0, and 2.0 tons/acre (both applied once in 1990) were applied to established bahiagrass plots, located on a Myakka fine sand soil. Bahiagrass forage was harvested monthly from May until December in order to assess the influence of phosphogypsum on forage production and quality. Soil samples were collected annually to a depth of 3 feet. Water samples were collected after each heavy rain to a depth of 4 feet. Forage, soil, and groundwater samples were analyzed for various nutrients, including calcium, sulfur as well as fluoride.

Results and Discussion

Forage Yield. Regardless of the rate or time of application, phosphogypsum addition tended to increase regrowth and mature (hay) bahiagrass yields by approximately 20 percent (Figure 1) during 1991, 1992, and over the 3-year period. Significant increases in regrowth and hay yields were noted for the 0.2 ton/acre as well as at higher rates, for at least two years, and over the 3-year period for all rates. Other studies have also shown that addition of phosphogypsum, mined gypsum, or other sources of sulfur can increase forage production when sulfur is deficient (Alcordo and Rechcigl, 1993).

Forage Quality. Phosphogypsum tended to increase crude protein concentration of the mature bahiagrass forage, by as much as 1% in all years and over the 3-year period, and the digestibility, by as much as eight percentage units (Figures 2 and 3) in some individual harvests in 1990. This is in agreement with other studies, showing that addition of sulfur will increase the nutritive value of forages on sulfur deficient soils. Increases in both digestibility and protein content of forage are known to increase the weight gains in livestock. Phosphogypsum increased the sulfur and calcium content of the bahiagrass tissue (Figures 4 and 5). The calcium content ranged from 0.42-0.60 %, while the sulfur content ranged from 0.18 to 0.40 % for the 0 and 2.0 tons phosphogypsum/acre treatments, respectively.

Phosphogypsum addition also slightly increased the fluoride content of the bahiagrass tissue, however the content was well below the 30 ppm maximum acceptable level for livestock intake (Figure 6). The low levels of tissue fluoride found in this study are of some importance since high levels of fluoride may bring about the loss of teeth in cattle.

Conclusions

This study demonstrates that phosphogypsum can increase both the yield and quality of forage grasses, such as bahiagrass. This can, in turn, lead to greater livestock weight gains and increased stocking rates, resulting in increased profits of ranchers. This could potentially increase cattle production by 10% which could result in an increase of 36 million dollars a year to the Florida Beef Industry. As the accompanying paper will show, the addition of phosphogypsum (up to 2 tons per acre) to agricultural land does not appear to present any serious environmental problems. Thus, phosphogypsum may be a viable and an economical source of sulfur and calcium for forage production.

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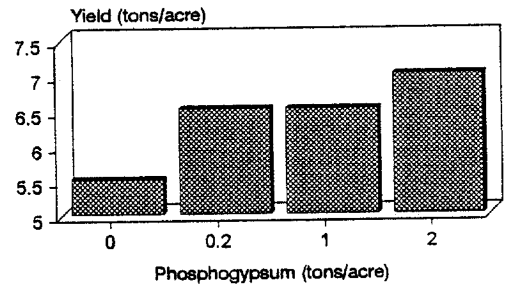

Figure 1.
Influence of phosphogypsum on bahiagrass yields.

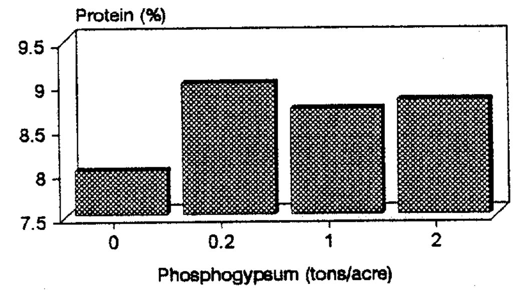

Figure 2.
Influence of phosphogypsum on bahiagrass protein content.

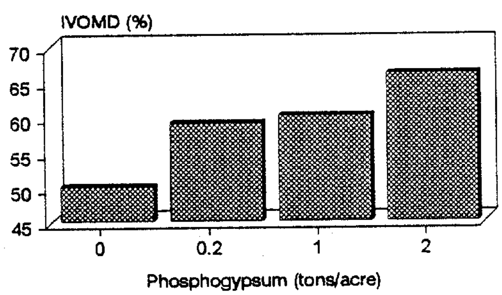

Figure 3.
Influence of phosphogypsum on bahiagrass digestibility.

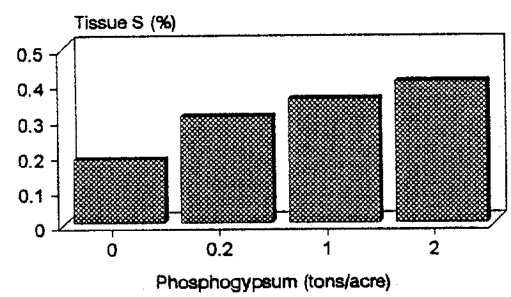

Figure 4.
Influence of phosphogypsum on bahiagrass tissue sulfur content.

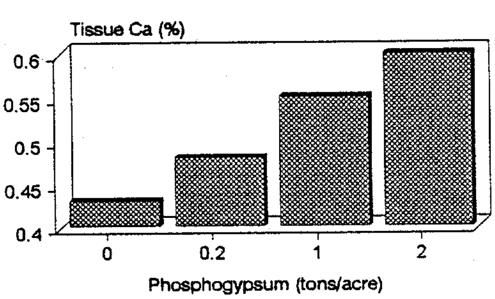

Figure 5.
Influence of phosphogypsum on bahiagrass tissue calcium content.

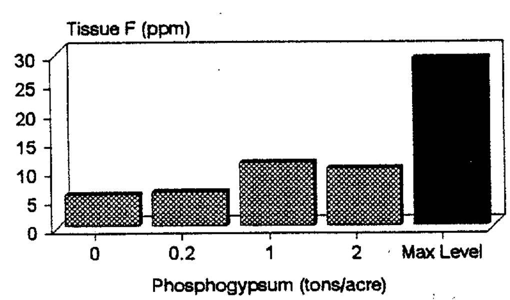

Figure 6.
Influence of phosphogypsum on bahiagrass tissue fluoride content.

RADIOLOGICAL ASSESSMENT OF THE APPLICATION OF PHOSPHOGYPSUM TO FLORIDA FORAGE LANDS

BY

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Dr. Roessler an extensive background in radiation chemistry and biology (health physics). He has taught radiation protection, dosimetry, measurements and techniques and has conducted research on radiation dose assessment from medical, occupational and environmental sources. His investigations have included naturally-occurring radioactive materials (NORM), indoor radon, radioactivity of mining-related lands and materials, and phosphogypsum. Dr. Roessler has authored over 50 publications and over 40 technical reports, including "Control of Radium in Phosphate Mining, Beneficiation and Chemical Processing".

Dr. Roessler has a bachelor's degree from Mankato State College, a Master of Science in radiation biology from the University of Rochester, a Master of Public Health in occupational health from University of Pittsburgh and received his Ph.D in environmental engineering sciences from University of Florida.

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Introduction

Naturally-occurring uranium and its radioactive decay series are associated with phosphate mineral deposits. Consequently, the uranium-series member, radium-226, and its radioactive decay products appear in the phosphogypsum (PG) by product of wet-process manufacture of phosphoric acid from phosphate rock. Because of this radionuclide content and the concern for human radiation exposure, particularly if PG-treated lands, roads, etc. are converted to other uses in the future, the U.S. Enviromnental Protection Agency has placed stringent restrictions on the use of PG as a resource material (Federal Register 1992).

This paper presents an assessment of the radiological impact of the use of PG to fertilize forage lands. Data were collected as part of agronomic and environmental studies of PG at the Range Cattle Research and Education Center of the University of Florida Institute of Food and Agricultural Sciences, Ona, Florida (Rechcigl, et al., 1995a).

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Methodology

In the initial phase of this work, PG was applied to forage lands at agronomic rates -- up to 4 Mg/ ha (1.8 tons/ acre). When it became evident that radiological effects could not be measured with a consistent degree of confidence, a second phase was initiated with additional replication and higher PG rates -- up to 20 Mg/ha (8.9 tons/ acre). The purpose of Phase II was to improve the probability of determining quantitative relationships between PG application rates and radiological parameters and thus provide the necessary factors for projecting the effect of repeated PC use scenarios.

Table 1 summarizes the experimental conditions for the two study phases. Details of the experimental design, the sampling, analytical, and statistical methods, and the measurement results are presented elsewhere (see Table 1 for references). The bases for data reduction, projections, and comparisons are presented in Table 2. Results of the measurements were converted to initial effect per unit single application of PG. These factors were adjusted to the radionuclide concentrations of a reference Central Florida PG. Phase II data were used to estimate future radiological values expected from extended PG use. The projections were made for the case of PG application to established bahiagrass in Central Florida at the recommended annual rate of 0.4 Mg/ha (0.18 tons/acre) with the practice continued for 100 years. For this stage of assessment, it was assumed that the radionuclides accumulated linearly in the soil with successive treatments -- no corrections were made for any environmental loss of radionuclides because data have not been collected over a long enough time to estimate the loss rate.

Table 1. Field Studies of PG on Florida Forage Lands -- Experimental Conditions

	Phase I	Phase II
Purpose	Scoping; study effects of PG application at agronomic rates	Develop quantitative relationships by elevated PG application rates
Dates	Summer-1990 - Spring 1993	Spring 1993 - Spring 1995
Crops, Application Method	Two crops: - Established bahiagrass, surface application; - Ryegrass, Tilled into soil & cropped each yr for 3 yrs.	One crop: - Established bahiagrass, surface application.
Soil Type(s)	One soil type for both crops: - Spodosol (Pomona & Myakka sands)	Two soil types: - Spodosol (Myakka) - Alfisol (Malabar)
Treatments, Mg/ha (tons/acre)	- 0.0 -- Control - 0.4 (0.18) annually fro 3 yrs. - 2 (0.8), single application - 4 (1.8), single application	- 0.0 -- Control - 10 (4.5), single application - 20 (8.9), single application
References	Rechcigl, et al. 1994a, 1994b; Roessler, et al. 1994.	Rechcigl, et al. 1995b.
Radiological Measurements	**Radon flux** -- Radon collection by charcoal canister; submission to commercial laboratory for analysis by gamma counting. **External gamma radiation exposure and ambient aitborne radon** -- Field measurement using electret ion chambers. **Radionuclides (^{226}Ra, ^{210}Pb, ^{210}Po)** -- Field sampling; submission to commercial laboratory for analysis: · PG · Soil profile · Water (runoff and surficial groundwater) · Forage	

Table 2. Bases for Data Reduction, Projections and Comparisons in Tables 3,4, and 5.

Data Source: From field study using PG with ^{226}Ra, 20.6 pCi/g; ^{210}Pb, 30.8 pCi/g; and ^{210}Po, 24.3 pCi/g.
Radiation/radioactivity factors and projections to the future: Scaled to reference PG with ^{226}Ra, 30 pCi/g; ^{210}Pb, 36pCi/g; and ^{210}Po, 27 pCi/g (from Table 2-3 of US EPA 1992).
Projections for 100th year: Projected cumulative effect and/or concentration in 100th year of annual applications of reference PG at recommended rate of 0.4 Mg/ha (0.18 tons/acre); cumulative addition of 40 Mg/ha (17.8 tons/acre). Without corrections for radioactive decay or any loss of PG or Pg-attributable radionuclides from upper soil layer.
Background: Mean represents overall average for untreated land at Range Cattle Research and Eduction Center. Standard deviation represents the variation among averages for different sites (different sets of plots) at the Center.

Results and Discussion

Radionuclides in Soil. Calculated additions to the concentrations of PG and radionuclides in the upper 15-cm (6-in) soil layer per unit single application of the reference PG and projections to the 100th year are presented in Table 3. A single treatment at agronomic rates cannot be detected with current analytical methods; after 100 years of annual treatment, the projected added radionuclide concentrations are roughly equal to the existing background at the test sites and within the range of variations seen in Florida lands without enhanced or elevated radioactivity.

Table 3. Soil Radioactivity, Radon Flux, and Gamma Radiation Attributable to PG Treatment of Soil

Parameter, Units	Addition per Mg/ha	Projected for year 100	Background, Mean (Std Dev)
Soil, 15-cm (6-in) Layer[a]:			
PG Add'n, g PG/g Soil:	0.00044	0.018	--
226Ra, pCi/g:	0.013	0.5	0.5 (0.08)
210Pb, pCi/g:	0.016	0.6	0.7 (0.12)
210Po, pCi/g:	0.012	0.5	0.8 (0.40)
Radon Flux, $pCi/m^2 \cdot s$	0.0026	0.11	0.026 (0.0109) [0.2 (<0.1 -1.7)][b]
Gamma Radiation, $\mu R/hr$	0.015	0.6	5.5 (0.42)

a) PG addition averaged over tilling depth of 15 cm (6 in); soil density 1.5 g/cm^3.
b) Geometric mean and range observed for other Florida undisturbed, non-mineralized lands.

Radon Production. A major concern centers around radon-222 (radon), the product of the radioactive transformation of radium-226. The concern is whether the application of radium-containing PC to land would increase radon production in the soil sufficiently to result in harmful levels of indoor radon in future structures built on previously-treated land. Surface soil radon flux measurements were performed as an indicator of radon originating in the soil.

In Phase I, no statistically-significant radon flux increases were observed for PG applications to bahiagrass up to 4 Mg/ha (1.8 tons/acre). Phase II data were used to calculate radon flux contribution per unit of the reference PG and to project to the 100th year (Table 3). The 100th year value of 0.1 $pCi/m^2 \cdot s$ is about 4 times the low-background radon flux at the research site but less than 25 % of the U.S. average of 0.43 $pCi/m^2 \cdot s$ (NCRP 1989) and about 50% of the 0.2 $pCi/m^2 \cdot$ s mean value reported by earlier studies for undisturbed, non-mineralized lands in Florida.

The indoor radon contribution due to this added radon flux was estimated using several empirically-derived indoor radon/radon flux relationships and a baseline case of 0.2 $pCi/m^2 \cdot s$. The PG-attributable contribution to indoor radon after 100 years of land treatment was estimated to be on the order of **0.02 to 0.19 pCi/L.** This contribution is small relative to the variation due to different types of land in Florida and within the uncertainty in indoor radon measurements. When added to the 1 pCi/L or less that might be expected without PG treatment for undisturbed, non-mineralized land, the resulting concentration is well within the action level of 4 pCi/L.

No increases in ambient outdoor airborne radon could be detected over any of the test plots in Phase I or the first year of Phase II; subsequent data are still being analyzed.

Gamma Radiation. A second concern might be human exposure to external gamma radiation over PG-treated land. Table 3 also presents the PG-attributable radiation level and the 100th-yr projection for gamma radiation. The PG-attributable gamma radiation contribution projected for the 100th year is on the order of 11% of the background gamma radiation levels at the experimental site. For the 100-yr land treatment scenario, the maximum external gamma radiation dose would occur to an individual who spent 24 hrs every day over the treated land. Using the conversion of 0.001 mrem whole-body dose equivalent per µR exposure, the annual radiation dose contribution resulting from the projected PG-attributable 0.58 µR/hr exposure rate is 5.1 mrem/yr. This is an upper bound -- most Florida houses are of slab-on-grade construction and, for the time spent indoors (8 or more hours per day), the indoor radiation level would be reduced because of the attenuation effect of the concrete slab.

The projected 5.1 mrem/yr dose contribution is about 5 % of the 100 mrem/yr (above background) that is recommended as a limit for continuous exposure by members of the general public (NCRP 1993). This is also consistent with proposed Federal Radiation Protection Guidance for Exposure of the General Public that recommends that doses from individual sources be limited to a fraction of the limit for all sources combined (Federal Register 1994).

Radionuclides in Water. In the Phase I study (PG application at agronomic rates), PG attributable radium-226 was observed in initial collections of runoff; and its presence was suggested, but not statistically significant, in groundwater samples collected at 0.6-m (2-ft) and 1.2-m (4-ft) depths. No statistically-significant effects were observed among 3-yr averages. The maximum individual sample result of 1.8 pCi/L was well below the current and proposed Maximum Contaminant Levels (MCL's) for drinking water (Federal Register 1976, 1991).

In Phase II, statistically-significant treatment effects were observed for some, but not all, of the radionuclide-depth-collection date combinations. There was general, but not unanimous, evidence for linearity of radionuclide concentration with treatment for the various samplings. Best estimates of PG-attributable radioactivity factors and corresponding 100th-yr projections in runoff and shallow groundwater are presented in Table 4 along with the background values observed at the experimental sites.

Radium-226. The l00th-yr additions to concentrations of radium-226 are about four times the background values at the experimental site for runoff and about 120% of the background for shallow groundwater; but the projected total values (background plus additions) are below the current, and well below the proposed, MCL's for radium-226 in drinking water (Table 4).

Lead-210. The projected 100th-yr additions to concentrations of lead-210 are on the order of 130 to 240% of the site background values. Currently there is no drinking water standard for lead-210 (a naturally-occurring beta emitter). Since it appears that even background lead-210 concentrations in ground water approach or exceed the 1 pCi/L concentration that corresponds to the proposed 4 mrem/yr dose limit for all beta emitters in drinking water, the entire question of lead-210 in water deserves further evaluation.

Polonium-210. The projected 100th-yr additions to concentrations of polonium-210 are comparable to (in the range of 50% of to 150% of) the site background values. The projected total concentrations resulting from the 100-yr practice are 10% or less of the standard for gross alpha activity in drinking water.

Table 4. Radionuclides in Surface and Shallow Groundwater from PG-Treated Land

Radionuclide	PG-Attributable Radioactivity, pCi/L		Background, pCi/L	Drinking Water Std, pCi/L	
	Addition per Mg/ha	Projected for year 100	Mean (Std Dev)	Current[a]	Proposed[b]
Radium-226:				5	20
- Runoff	0.04	1.7	0.5 (0.2-0.7)[c]		
- Shallow Groundwater	0.02	0.9	0.7 (0.16)		
Lead-210:				No Std	1[d]
- Runoff	0.02	0.8	0.6 (0.4-0.7)[c]		
- Shallow Groundwater	0.05	1.9	0.8 (0.51)		
Polonium-210:				GA:15[e]	GA:15[e]
- Runoff	0.01	0.3	0.5 (0.4-0.5)[c]		
- Shallow Groundwater	0.02	1.0	0.6 (0.30)		

a) Federal Register, 1976.
b) Federal Register, 1991.
c) Background runoff data available from only two sites; range is given in lieu of standard deviation.
d) Derived from 4 mem/yr dose limit for beta emitters.
e) Limit for gros alpha emitters (excluding uranium, radium-226, radon-222); no explicit limit for polonium-210.

Radionuclides in Forages. Concentrations of PG-attributable radionuclides in forage from treated bahiagrass pastures appear to potentially have two components -- 1) a long-term, low concentration component persisting beyond the year of PG treatment and 2) a potential, short term, higher-concentration component that may occur in the first post-application year.[4] A second observation was that whereas the other radiological parameters responded proportionally to the PG treatment level, the radionuclide concentration in forage was "sub-linear" in response to PG treatment level ("saturation" effect). Hence a simple "slope" factor (pCi/g per Mg/ha) does not appear appropriate for describing radionuclide concentrations. The behavior of PG attributable radionuclides in forages is still being evaluated.

Preliminary estimates of PG-attributable radioactivity is presented in Table 5 along with the background values observed at the experimental sites. Projections for the 100th yr consist of 1) the Lower Bound -- a long-term component developed by sub-linear scaling from the 100-yr cumulative 40 Mg/ha PG addition to the soil, 2) the potential short-term component due to the 0.4 MG/ha addition in the 100th year, and 3) the Upper Bound (long-term plus short-term components). Whereas the short-term component, when present, represents the major contributor to the forage radioactivity in the first year following a single treatment, it has a much lower impact on the projected activity following long-term, continuous treatment practice.

The projected PG-attributable radium-226 in the 100th year is comparable to the background at the test plots. The projected contributions to lead-210 and polonium-210 are less than the variations in the background values. These small contributions to forage radioactivity will result in only small contributions to radionuclide intake by animals feeding on this forage, only small contributions to radionuclide content in food products of animal origin and very small contributions to human radiation dose from ingestion of such food.

[4]The long-term component is presumably due to uptake from the soil and related to the radionuclide concentration in the root zone of the soil. In the Phase II field study, a transient, elevated (five-fold) concentration was observed in the first harvest after PG treatment in one of the two sets of test plots. This short-term component is presumed to be the effect of direct foliar deposition resulting in foliar uptake of radionuclides or surface retention of PG. The reasons and mechanisms for this short-term component are still under investigation.

Table 5. Radionuclides in Bahiagrass Forage from PG-Treated Land

Radionuclide	PG-Attributable Radioactivity, pCi/g		Background, Mean (Std Dev) pCi/g
	First yr following 1 Mg/ha application	Projected for year 100	
Radium-226:			0.10 (0.044)
Lower bound (LT)[a]	0.01	0.08	
Potential ST[b]	0.09	0.06	
Upper bound (LT+ST)	0.10	0.14	
Lead-210:			0.63 (0.395)
Lower bound (LT)	Non-detectible	<0.09	
Potential ST	0.11	0.07	
Upper bound (LT+ST)	0.11	<0.16	
Polonium-210:			0.25 (0.046)
Lower bound (LT)	0.01	0.05	
Potential ST	0.08	0.05	
Upper bound (LT+ST)	0.09	0.10	

a) LT="long-term" or persistent component; projected from cumulative treatment practice.
b) ST="short-term" component; may or may not be present; expected only in the first yr after PG treatment.

Summary and Conclusions

Factors for PG-attributable radon flux, gamma radiation, radionuclides in water, and radionuclides in forage were developed from field experiments involving application of PG to established bahiagrass pastures at high rates (up to 20 Mg/ha or 8.9 tons/acre). Radiological values were then projected for the 100th year of a continuous practice of annual treatment at the recommended rate of 0.4 Mg/ha (0.18 tons/acre). The 100-yr projections presented here are believed to be overestimates since corrections were not made for any environmental loss.

Summary of results:

1. Radionuclides in soil - A single treatment at agronomic rates cannot be detected with current analytical methods. The projected radionuclide concentrations added to the top 15 cm (6 in) by 100 years of annual treatment are roughly equal to the existing background at the test sites and within the range of variations seen in Florida lands without enhanced or elevated radioactivity.
2. Radon production - The PG-attributable contribution to radon flux (indicative of radon originating in the soil) was projected to be about 0.1 $pCi/m^2 \cdot s$ in the 100th year -- about 50% of the mean for undisturbed, non-mineralized Florida lands (0.2 $pCi/m^2 \cdot s$). The corresponding contribution to indoor radon was estimated to be on the order of 0.02 to 0.19 pCi/L -- these values are small relative to the variation due to land type differences in Florida, are within the uncertainty in indoor radon measurements, and would result in concentrations well below the 4 pCi/L action level if added to the 1 to 2 pCi/L concentrations otherwise expected for undisturbed, non-mineralized land.

3. Gamma radiation - The PG-attributable gamma radiation contribution projected for the 100th year is less than 1 µR/hr and on the order of 11% of the background gamma radiation levels at the experimental site. This would contribute an annual whole-body dose equivalent of about 5 mrem/yr to an individual spending full time outdoors over PG-treated land. The actual annual dose contribution would be lower for a person living in a slab-on-grade house because the radiation intensity during the time spent indoors would be lower due to the attenuation (shielding) effect of the slab. The projected 5 mrem/yr dose contribution is about 5% of the recommended limit for continuous exposure by members of the general public (100 mrem/yr above background) and conforms with proposed federal guidance stating that doses from individual sources be limited to a fraction of the limit for all sources combined.
4. Radium-226 in surface and around water - The projected additions after 100 years for runoff and shallow ground water are several times the background values at the experimental site. However, the projected total values (background plus additions) are below the current, and well below the proposed, MCL's for radium-226 in drinking water.
5. Lead-210 in surface and ground water - The projected additions after 100 years are comparable to the site background values. Interpretation is clouded by the fact that the background lead-210 concentrations in ground water approach or exceed the 1 pCi/L concentration value that corresponds to the proposed dose limit for all beta emitters in drinking water. The entire question of lead-210 in water deserves further evaluation.
6. Polonium-210 in surface and ground water - For the 100-yr practice, the projected additions are comparable to the site background values and the projected total concentrations are 10% or less of the standard for gross alpha activity in drinking water.
7. Radionuclides in forages - The projected PG-attributable radium-226 in the 100th year is comparable to the background at the test plots. The projected contributions to lead-210 and polonium-210 are comparable to the variations in the background values. Any human radiation dose contribution through ingestion of foods originating from animals feeding on these forages would be very small.

Conclusions. For application of Central Florida PG at agronomic rates to bahiagrass pastures:

1. Additions to environmental radioactivity and radiation from limited application will be essentially non-detectible.
2. For long-term, continued (up to 100-yr) annual application of this PG at recommended agronomic rates (0.4 Mg/ha):
   a) additions to the background environmental radiation and radioactivity levels would generally be within the range of background variation,
   b) contributions to indoor radon in future structures built over treated land would not be significant in light of uncertainties in indoor radon measurement and variations expected from other causes,
   c) gamma radiation doses would be well within current limits,
   d) PG-attributable contributions to radium-226 and polonium-210 in surface and ground water would be expected to be a fraction of the applicable drinking water standards and thus should not be of concern, and
   e) PG-attributable doses to humans through ingestion of animal products traceable to the treated forage should be within the range of variation in the normal diet and, thus, negligible.
3. One issue requiring further evaluation is that of lead-210 in water where existing background levels may already correspond to a significant fraction of the dose limit in proposed drinking water standards.

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CRITICAL DOSE AND RISK ASSESSMENT FOR USE OF WASTE PRODUCT PG IN AGRICULTURE

BY

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Presenter: Anthony C. James, ACJ & Associates.

Dr. James has recently become an independent consultant after holding the position of Associate Professor in the College of Pharmacy at Washington State University. Prior to this Dr. James was the Chief Scientist in the Occupational and Environmental Health Protection Section of the Health Physics Department at Battelle, Pacific Northwest Laboratories. At Battelle, his primary research interest was in the development and application of dosimetry of body tissues in humans and experimental animals, in order to address issues involved in setting practical standards for radiological protection, and in relating cancer risks to environmental conditions of exposure. Before joining Battelle in 1988, Dr. James had 17 years of research experience, much of it relating to radon, at the National Radiological Protection Board, Chilton, United Kingdom.

Dr. James has a B.Sc. in physics from University College in London and received the Ph.D. degree from the Royal Free Hospital School of Medicine in London in 1969.

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Paper not available. The following is a transcription from video of Dr. James' presentation at the Forum.

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This project was started when I was at Washington State University, with the prime contractor being Battelle Pacific Northwest Labs. The objective of the study was essentially to focus on the EPA's final ruling and to look at the science behind the dose assessments that went into the judgements that EPA made about the risks of using PG in different scenarios. The document that we are concerned with is the NESHAP, the National Emission Standards for Radon Emissions from Phosphogypsum Stacks, which as we've heard already, was published in June of 1992. There has been some response from EPA following a petition from The Fertilizer Institute which has led to relaxation in the limitation of the use of phosphogypsum in research and development. These are the people who were involved (in this study) at Battelle: John Johnson, Chief Scientist, Health Protection Department; Richard Traub, Certified Physicist, he's a Staff Scientist, Health Protection Dept. and up until recently, I was Associate Professor at the College of Pharmacy at Washington State University.

The scope of our study is quite narrow and focused on the critical issues that limit the potential application of PG to agriculture and to construction. I will be talking briefly about construction after lunch. What we have done, we are not trying to critique EPA's exposure scenarios, although we have heard from the agronomists that maybe the application rates are higher than would be reasonable, certainly over long periods of time. But our assessment actually takes, as the boundary conditions, the application rates that EPA has used in formulating the background information document. What we are setting out to do is to try to evaluate the maximum individual risk to an individual. For example, a house that is built on a plot of land that has had an application for a hundred years, it is assumed that the individual lives for 70 years in that house in order to come up with the risk, which is an unlikely assumption, it is very much a maximum. But, we are following the methodology that EPA uses in proximity of the occupants of the house and the inhalation of radon that seeps into the indoor air. We are not questioning or commenting on EPA's risk factors. In fact, EPA is following the ICRP risk estimates fairly closely, in terms of, if you get a given dose per year, how much additional risk of lung cancer or other cancers does that correspond to. So, we are taking the EPA's adopted and recommended risk factors.

I would like to illustrate the approach we are taking to try and put some quantitative numbers on what Chuck Roessler was trying to extrapolate from his field observations. We are looking at a realistic, as realistic as possible, model of the way that radon gets into a house built on a typical Florida construction, slab-on-grade. We are essentially checking out calculations that were published in 1993 by Revzan, et al. of Lawrence-Berkeley Laboratory using a different code which was developed in-house at PNL, and we are applying these calculation techniques to the full range of exposure scenarios that EPA has examined. What we are modeling .is not diffusion across the concrete slab, which is the process that EPA chose to model, but rather the bulk entry of air into the building which takes into account things such things as pressure gradients. Quite often the inside of a home is a negative pressure compared to the soil gas. And that is, in fact, the mechanism that dominates suction of soil gas into the house. The model treats various pathways by which gas can seep through cracks and find its way past gaps between the concrete floor and the wall into the indoor air. We look at various source terms, for example, when you build a slab foundation, you normally introduce a backfill layer, so normally you would excavate the native soil, which is something very relevant in the case of PG use in agriculture because the excavation depth is around about the tillage depth. You could reasonably claim that the surface layer from underneath the house itself would have been removed in the construction process. But you don't remove the surface layer that is contaminated with radium and additional radon from the surrounding soil around the house. So there still is a source there that leads to ingress of radon into the house. Now, that is for the radon calculation. For the direct gamma radiation, we paid close attention to the degree of shielding that the concrete layer introduces; the degree of protection that the concrete slab introduces in reducing the dose to the occupants of the house. EPA did not do that.

Let's take gamma dose rates. This is an example of the rates, the calculations we come up with, compared with the numbers that appear in the background information document from EPA. This is one scenario with a, biennial application of 1,500 lbs. of PG/acre over 100 years. The tillage mixing to a depth of 22 cm. The calculated increase in the radium concentration in that layer of soil is 0.6 pCi/g which is about 60% of the typical soil concentration. So you go up from 1 pCi/g up to about 1.6 pCi/g with the addition of PG. EPA came up with a calculation using a fairly primitive generic model, which didn't include such things as concrete slabs, of 7.6 mrem/y. If we do the same calculation we come up with 6.0 mrem/y which is which is very close to EPA's model. That is assuming no floor shielding. The person is just walking around on the soil surface essentially. The reason for the difference is, if you look at the composition assumed by the EPA for the PG they include too much of the thorium nuclides in relation to the radium concentration. So we're pretty close to the baseline calculation of the external gamma dose rate for unshielded soil. However if you add in the 10 cm thick slab you see that the dose rate you come up with is reduced by rather more than a factor of 2 from our baseline or about a factor of 3 from the value calculated by the EPA's analysis. If you then assume that the 30 cm of the native soil has been removed and backfilled with uncontaminated material, then you come down to a much lower dose rate, significantly lower. Its about a factor of 60 lower than the unshielded soil.

Now let's use the risk factors that EPA has adopted and translate those numbers into lifetime risks. EPA didn't worry about the doses themselves, they considered the projected lifetime risks in terms of so many deaths/10,000. And they considered that in absolute terms. They had in mind a number that was acceptable and this is an incremental number. It has nothing to do with the actual level of the background. It's by how much the risks would be increased if you adopt the practice of using PG. What I have looked at here is a high application rate, initial application this is the scenario 5 and 6, 18,000 lbs/acre, biennial application of 9,000 lbs/acre. Tillage depth of 30 cm. That leads to an incremental radium concentration in the soil of 2.7 pCi/g. In other words, it multiplies the radium concentration by a factor of about 4 over a typical Florida background soil. Now to calculate incremental risks from the gamma exposure; it is 10 in 10,000. And that compares with EPA's acceptable number in mind of 3 in 10,000 total risk. So you see this one scenario exceeded just from the gamma radiation component alone by about a factor of 3, EPA's acceptable risk. Now when we repeated those calculations, we came up with a similar number, as I showed on the previous slide, we got about the same dose; 8 in 10,000, if you ignore the shielding provided by the floor. If you take into account the 10 cm thick concrete shielding, then that risk drops to 3 in 10,000, which is EPA's reference value. But you'll notice it applies to an extremely high application rate. If you remove the contaminated soil and replace it with imported backfill, then the dose rate is rather more than a factor of 10 below the implied lifetime risk.

Now let's look at the indoor radon exposure situation with the same maximum application rate. The incremental radium concentration in the soil, as I showed you in the last slide, is 2.7 pCi/g. EPA used a very simple diffusion model through concrete. They did the calculations for two air changes/hour (ach) which is really too high of a ventilation rate. If they'd done the calculation for something more realistic, such as one air change/hour (ach) they would have come up with twice the risk. The concentration of radon is roughly inversely proportional to the ventilation rate. So the reference risk number that they came up with for this application scenario, very high usage rate of biennial application 9,000 lbs/acre, is 8 in 10,000 which exceeds the number they had in mind for acceptable risks by about a factor of 3. We've looked at that Revzan model and we've applied it for a more realistic ventilation rate of 0.5 air changes/hour. When we did that we were gratified to find that we had pretty well predicted the average indoor air concentration of 1 pCi/L in Florida homes taking the typical Florida soil radium content. So the model works very well and it matches typical Florida conditions for a ventilation rate of about 0.5 air changes/hour (ach). Now with no imported fill, in other words, if the house is built on the native soil which contains the contamination in the top surface layer, we come up with, even though we used a different ventilation rate and a different model, we come up with a very similar risk estimate to EPA's, numerically; it's about 9 in 10,000. However, if you remove that surface layer at the time of building the house or possibly as a result of a regulation for building houses on that type of land, then the calculated lifetime risk drops below the level that EPA would consider unacceptable. In other words, the risk is acceptable in EPA's terms.

To summarize, these calculations are by no means complete, but I think we can come to some preliminary findings that we expect to be evaluated at the end of the study. For the agricultural uses of the waste product PG, if you assume no side excavation and no backfill with uncontaminated material, then the EPA numbers, both the dose rates and therefore the projected lifetime risk, are too high by about a factor of 3. As for the gamma component, the radon component, EPA's numbers are about right but they apply to a much lower ventilation rate rather than the 2 air changes/hour that they assume. If however you take what I consider a more realistic scenario with a backfill of uncontaminated material, then the maximum individual risk from PG application for agricultural purposes is lower than the acceptable 3 in 10,000 taking into account both components, radon and external gamma.

Scope of Dose and Risk Assessment for Agricultural Uses of Waste Product PG

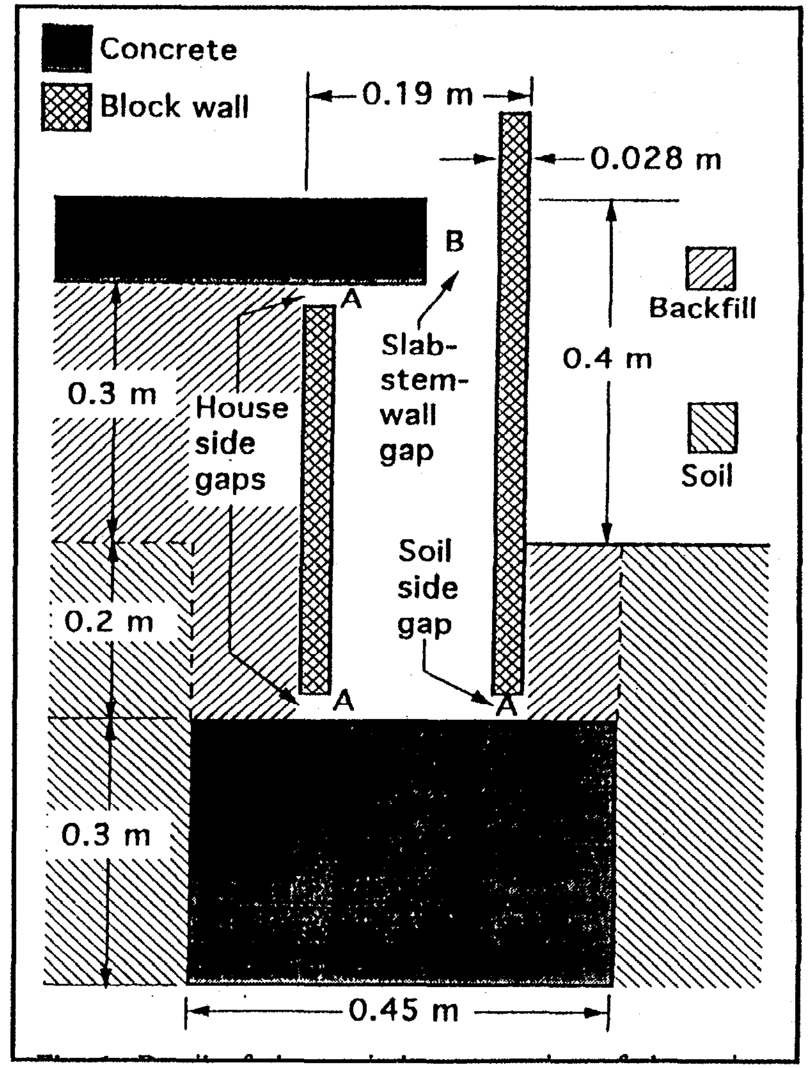
- ✔ Assume EPA's exposure scenarios for evaluating the Maximum Individual Risk (MIR) from lifetime exposure in a home built on reclaimed agricultural land, *i.e.*, after 100-y application of PG containing 26 pCi/g of ^{226}Ra and its radioactive progeny.

- ✔ Model the two critical exposure pathways
  - direct gamma irradiation
  - inhalation of radon progeny that seep into indoor air.

- ✔ Assume EPA's adopted risk factors.

Detail of Floor and Wall for Florida Slab-on-Grade House Showing Backfill and Native Soil

(Revzan et al., 1993)



MIR from Direct Gamma Exposure

- ✔ **Exposure scenario ## 5 & 6**
  - **- Initial application of 18,000 lbs/acre**
  - **- Biennial application of 9,000 lbs/acre**
  - **- Tillage depth of 30 cm**
  - **- Incremental ^{226}Ra concentration in soil is 2.7 pCi/g.**

- ✔ **EPA's calculated incremental lifetime risk is 10 in 10,000.**

- ✔ **Battelle's calculates the following values:**
  8 in 10,000 - ignoring shielding provided by floor
  3 in 10,000 - with 10-cm thick concrete slab
  <3 in 100,000 - with 30-cm thick imported backfill.

MIR from Indoor Radon Exposure

✔ Exposure scenarios ## 5 & 6
- Initial application of 18,000 lbs/acre
- Biennial application of 9,000 lbs/acre
- Tillage depth of 30 cm
- Incremental ^{226}Ra concentration in soil is 2.7 pCi/g.

✔ EPA's calculated incremental lifetime risk is 8 in 10,000 for 2 air changes per hour(ach).

✔ Battelle calculates the following values for 0.5 ach:
9 in 10,000 - with no imported fill
<3 in 10,000 - with 30-cm thick imported backfill.

Preliminary Findings of Battelle's Study for Agricultural Uses of Waste Product PG

- ✔ **Assuming no site excavation and no backfill with "uncontaminated" material, then EPA has overestimated lifetime risk from direct gamma irradiation by about a factor of three.**

- ✔ **With these same assumptions, EPA's calculated incremental lifetime risk from indoor radon is about right, but for a much lower ventilation rate of 0.5 ach.**

- ✔ **A 30-cm thick backfill with "uncontaminated" material would give an incremental lifetime MIR from PG application lower than the "acceptable" value of 3 in 10,000.**

-From video, transcript of questions and answers of Agriculture Panel discussion:

POLICY PANEL QUESTIONS TO AGRICULTURE SPEAKERS

ZAMANI: (to Rechcigl) I was just wondering if, during application of the PG, while looking at the cation exchange capacity and transfer of calcium, did you look at the fate of the sodium either in California or Florida, to see if there was any ground water impact of sodium or sulphate during (PG) application?

RECHCIGL: No, we really didn't look at sodium levels in the groundwater, though that is something we could still look at.

BANDY: Yes, a comment for Dr. Traxler on the economic impact, and also a question related to the use of PG. First I work at PCS phosphate in White Springs. You said that about 200,000 tons of PG was used in peanut farming.

TRAXLER: That is total gypsum, not phosphogypsum.

BANDY: Was your assumption that all that gypsum was switched from White Springs to central Florida? Is that your assumption?

TRAXLER: The assumption is not that. It's that the threat of competition from central FL sourcing would force the White Springs price to fall, to meet the competition.

BANDY: OK. White Springs supplies about 60,000 tons of that total of 200,000 tons you are talking about. We thought we used perhaps 400,000 to 500,000 tons total in Alabama, Georgia and Florida. Perhaps Dr. Sumner could comment on that.

TRAXLER: My source of data was an IFDC publication. I can't speak to the reliability of that number very well. Just doing some rough calculations using our survey application rates and just assuming that gypsum is applied only on peanuts in Georgia, it gives a reasonably close congruence with that estimate.

SUMNER: No. I don't have any data on that at all.

YOUNG: Dr. Traxler, with regard to the economic analysis, do I understand that the rate differential was determined according to the cost of transport; that you assume that the industry wouldn't place a charge (on the PG) other that what the cost of transport was, and is that how you accounted for your differential?

TRAXLER: Yes, that would be the assumption. It's hard to predict these future events, but one assumption that seemed reasonable to me was that as long as the cost of offering it for use in agriculture is less than the cost of adding it to the stacks, that is what would happen. It seems a rather conservative estimate; that they would just offer it for free. It also seems reasonable to me, purely as an economist, that they would offer it at anything less than the marginal cost of dumping it on the stack and increasing the stack (volume).

YOUNG: That is really what I was trying to get. Does the economical analysis attempt to calculate the benefits achieved through the avoided costs of having to provide that stack capacity, or not having to provide that future stack capacity?

TRAXLER: Yes. That is a very appropriate economic cost to include. I just have not included that yet in my own estimates.

YOUNG: So presumably it would be greater than what it is. Yet, the economic analysis reflected is really that to the agricultural industry, but there is an additional component.

TRAXLER: Yes, precisely. That would just be the benefits of the accruing to agricultural producers and I have not assumed the real economic costs of maintaining and adding the stacks that are accruing to other parts of the economy. Those are things that need to be addressed in the final study.

YOUNG: (To Dr. James) In talking about the shielding factor that apparently was ignored by EPA, does that shielding factor affect both the direct gamma as well as the indoor radiation or only one of these?

JAMES: It affects the direct gamma only.

YOUNG: What is the logic or rationale for ignoring that shielding factor, assuming that minimum housing standards universally require flooring, probably slab flooring, but certainly some kind of flooring that would provide a shielding factor.

JAMES: I don't know, but its an obvious deficiency in the study. There is a factor of three, just there. I think that the calculations were done by different people and they did not talk to each other.

GLASSMAN: (To Dr. Rechcigl) Are you aware of any cases where PG is being used currently for non-agricultural uses or non-residential uses such as highway landscaping or industrial activities?

RECHCIGL: No, that's not my area of expertise.

OHANIAN: (To Glassman) We'll come to that this afternoon. That is a good question.

WENZEL: (To Rechcigl and Roessler) For the two gentlemen involved with the IFAS study, from a socioeconomic standpoint, it appears to me that if we approach the Florida cattlemen and Florida Cattlemen's Association with such cost savings, which are millions of dollars certainly that is an attraction for use. Have any surveys or any anecdotal research been done in which farmers and cattlemen have been approached about the cost savings for the use of PG but at the same time balancing that compared to an analysis with the potential loss of resale if their farmland is converted on the urban edge. Especially where resale of farmland potentially goes to residential subdivisions.

RECHCIGL: There really have not been any surveys like that. We are just in the early stages of showing them the benefits of using sulfur and doing some simple calculations on that. On the economic end of it, I'm certainly not an economist but I have done some simple calculations. If it were grown for hay, and hay sells for \$60/ton gross, the net would be \$30/ton and I calculate a cost of shipping the material and actually spreading the material, I came up with a cost of \$12/ton. This would be if we were applying two tenths of a ton. There would actually be a profit of about \$18/acre. That would be in a haying situation, for example.

WENZEL: Has there been any concern from the farming industry about affecting potential resale because of previous controversial use?

RECHCIGL: There have not been any formal surveys. During my presentation when we show the pros and cons and we show the whole picture and the results we are getting they are still very interested assuming that this material would be available and that EPA would condone this.

WENZEL: (To Roessler) When will we be seeing some results from the food chain studies?

ROESSLER: Within the next project year. It was not an issue in the EPA model and so it has not been a high priority item, I am focusing on high priority items. We will focus on that as soon as we get some annual reports out of the way.

BANDY: (To James) In your assessment you use 18,000 lbs/acre initial application and 9,000 biennial. I am a little confused with that versus the EPA's use of 1,300 lbs/acre in their assessment. Could you comment on that?

JAMES: Yes. I think I got the comma in the wrong place. It's a numerical slip. The highest application rate was 2,700 biennial.

ZAMANI: (To Roessler) You are in the process of doing some work on the fate of the lead-210 and the immobilization of that within groundwater. Could you please explain this.

ROESSLER: Yes. We are collecting runoff by means of the perimeter ditches. The first year we had a dry year and the ground absorbed all the water. The second year we were able to collect some runoff, so we have a limited amount of runoff. We collect runoff data when there is runoff. We make collections from the shallow wells. They are two and four feet deep. We analyze those samples for Lead and Lead-210, both from control plots that have not been treated and the treated plots. We will be doing some more samples in the coming year. The field work involves that kind of sampling and the analytical work. The assessment involves trying to compute a long term average and scaling it to unit application to get the factor and then propagating it to one hundred years. That is the extent of what we are doing. We are not doing any bench-top or any special studies of the fate and transport of lead-210. That is another issue in the state of Florida but that is not a part of our project.

GARRITY: I have tried to list the points on which both the speakers and the EPA have agreed and disagreed. There is more disagreement than agreement. The agreement appears to be just on the measurements of radium in the PG from this area and the PG from Occidental, north Florida area. Disagreement seems to be on everything else, including the total that would be used per year in applications. I am not sure anybody said where the 2,700 lbs/ acre/year came from that EPA's using. I don't understand that. I'm not sure why, as opposed to a total prohibition, how you couldn't come up with a series of best management practices that you could follow, including application rates, house construction, etc. I would like some comments addressing those issues.

ROESSLER: My comment to the last statement is bingo.

SUMNER: The 2,700 lbs was a figure that the EPA latched onto based on a survey that was done in the fertilizer industry of use rates of gypsum throughout the country. They came up with the 2,700. You can use all sorts of caveats to limit the use of the stuff, certainly. One of the things that's important is that north Florida is exempt at 10 pCi/g. So you can spread 2,000 tons/acre with impunity. Yet, it's a violation to put on 1 ton of the stuff from south Florida. That's bureaucratic bungling.

JAMES: I just want to make a correction for Dr. Bandy. Actually those numbers were correct. The highest application rate in the EPA document was 8,000 kg/acre. So the numbers I gave you were really the extreme that they considered. I'm sorry.

MEYER: Regarding your suggestion of looking at best management practices, California uses higher rates than are indicated. But most of our sources are non-PG (mine sources).

PARKER-GARVIN: (To Sumner) I think my question has already been answered but I am going to ask it anyway. To what extent was regional geology taken into account in making your application rates. In the numbers that you gave were they more uniform or average?

SUMNER: The numbers were based on all the experimental evidence that has been conducted mainly in the southeast on the use of any kind of gypsum, whether it be phosphogypsum, mined gypsum or other sources of calcium and/or sulfur which are then all converted to a scenario of, had it been phosphogypsum. That's what the rates were based on. So it's the maximum, minimum, and most likely rates that would be applied for each of those particular uses if the only source of material was phosphogypsum.

OHANIAN: Again I want to thank the agricultural panel for their contributions.

UTILIZATION OF PHOSPHOGYPSUM TO ENHANCE BIOLOGICAL DECOMPOSITION AND INCREASE CAPACITY RECOVERY AT MUNICIPAL SOLID WASTES LANDFILLS

BY

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Dr. Shieh received his Ph.D. degree from the Florida Institute of Technology and his Master's degree from the State University of New York at Stony Brook.

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Introduction

A two-year study is currently being carried out to develop a methodology to use phosphogypsum as cover material in landfills to enhance biological decomposition of municipal solid waste (MSW) and at the same time reduce the accumulation of phosphogypsum and the volume of cover material remaining in a MSW landfill. The study is being undertaken by the Research Center for Waste Utilization at Florida Institute of Technology in Melbourne, Florida, under the sponsorship of the Florida Institute of Phosphate Research (FIPR). The study meets the guidelines for approaches (2) and (3) in the FIPR's 1993 Research Priority Report to achieve Objective #1 of Priority #1 "Phosphogypsum and Phosphogypsum Pond Water".

Biodegradation of MSW is a microbiological process. Wastes containing substantial amounts of fermentable organic components can be treated biologically under anaerobic conditions. Under anaerobic conditions, sulfate can be used by bacteria to replace oxygen as energy source that is needed during biodegradation process. Phosphogypsum, which contains more than 70% of sulfate, could be used as an alternative oxygen source for microorganisms to conduct anaerobic biodegradation of MSW in landfills.

Project Objectives

The overall goal of the study is to demonstrate that phosphogypsum can be used as an oxygen source for sulfate-reducing bacteria, and hence, enhance the decomposition of MSW in landfills. Studies in year 1 were conducted to determine the extent that phosphogypsum can be used to enhance biodegradation processes for MSW in landfills and to investigate the methodology for the application of phosphogypsum in landfills. Studies in year 2 are to develop optimum conditions and a standard procedure that can be practically used for a landfill operation. The successful completion of this study will help Florida minimize the problems of managing both phosphogypsum and municipal solid waste.

Research Approach

To obtain meaningful results on biodegradation of the waste within a short period of time, grass clippings and wood mulch were used as the waste matrix in the study. A series of studies were carried out to define reaction conditions for biodegradation using phosphogypsum. The approach to the study initially was to develop an anaerobic biodegradation system (ABS) that allows a study to simulate landfill conditions. The waste matrix was then prepared for exposure to designated conditions. By-products of biodegradation were continuously monitored throughout the period of the study. At the end of each exposure the residual waste matrix was recovered and then was determined for the reduction in total biodegradable solid (TBS), which was then used to assess the degree of biodegradation.

The following tasks are being conducted to achieve the goal of the study.

Task I: Development of An Anaerobic Biodegradation System

Task II: Determination of Applicability of Using Phosphogypsum for Anaerobic Biodegradation

Task III: Development of Optimum Conditions

- determination of phosphogypsum/MSW ratio
- application as final cover or operational cover (layers)
- determination of thickness and number of layers

Task IV: Evaluation of Feasibility

Task V: Development of a Practical Procedure and Formation of Recommendations

Primary Findings

As a result of a series of operational testing, an effective equipment configuration for the biodegradation of stimulated landfill materials involving application of phosphogypsum was developed. The anaerobic biodegradation system, in general, consists of the lysimeter, gas monitoring system, temperature control system, and leachate collection system.

The experimental results showed that the use of freshly clipped grass and mulch as the waste matrix provided needed information on anaerobic biodegradation within a certain period of time. The results also showed that lysimeters actively produced gases, indicating that the digestion system developed in the study was suitable for conducting anaerobic digestion of waste material.

For the purpose of the study a hypothesis was developed suggesting that, by introducing phosphogypsum to a anaerobic digestor, the production of CO_2 would be prolonged and the formation of CH_4 would be delayed. The net outcome would be an additional degradation of organic matter during the stage of sulfate reduction. Data on gas composition collected from the study support the hypothesis.

Results on the reduction in total biodegradable solid (TBS) of the waste matrix showed that, when less than 40% of phosphogypsum was mixed thoroughly with the waste at different phosphogypsum/waste ratio, higher percent reduction in TBS was found for the lysimeter containing higher contents of gypsum indicating that use of phosphogypsum provided a favorable condition for anaerobic biodegradation, and hence, enhanced the biodegradation under anoxic conditions.

Assessment of Feasibility

Based on the laboratory results, an effort is being made to assess the engineering, environmental, and economic feasibility of using phosphogypsum to enhance biodegradation of MSW in landfills. Technically, application of phosphogypsum in landfills is an engineering and environmentally sound approach since no special equipment would be needed and no release of leachate from the lined site would occur. Economically, use of phosphogypsum in landfills would save cost on daily cover material, space and cost for piling up phosphogypsum on the existing sites. The transportation cost, however, would reduce the economic value of using phosphogypsum in landfill application. Detailed analyses of the feasibility assessment will be orally presented and discussed at the forum.

Recommendations

Though the ongoing laboratory study has revealed that, using phosphogypsum in landfill application is an engineering, environmentally, and economically sound approach in managing phosphogypsum, further information is needed to determine the function of phosphogypsum on enhancing microbiological activities in landfills under natural environment. Therefore, a field study is needed to demonstrate laboratory findings. The field study shall further determine the method of application, e.g., mixing phosphogypsum with the waste or using phosphogypsum as daily or final cover.

SULFUR RECOVERY FROM PHOSPHOGYPSUM

BY

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Mr. Kendron has been KEMWorks vice president since 1995 and has more than 25 years of technical and management experience involving various aspects of engineering. He has specialized in the thermal processing of solid materials and various wastes such as phosphogypsum, municipal waste, coal and biomass. He has co-authored several papers with FIPR Research Director G.M. Lloyd describing the recovery of sulfur from phosphogypsum and given presentations at conferences around the world on processing solid wastes.

Mr. Kendron is a graduate of the Illinois Institute of Technology with a Bachelor's degree in Mechanical Engineering and a graduate of the Management Development Program at Georgia State University.

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Introduction

Sulfur value recovery from phosphogypsum (typically as sulfuric acid) has always been of interest to the wet process phosphoric acid industry. Its implementation would close the sulfur loop and help isolate phosphoric acid economics from periodic sulfur price increases. Sulfuric acid was produced from natural calcium sulfate in Germany prior to World War II. In South Africa, a similar process has operated since 1972 using phosphogypsum as the sole raw material to produce 300 tons per day of sulfuric acid. Newer plants have been built and operated in China. The typical drawbacks of the conventional, installed technologies are: high investment and production costs, high energy consumption, environmental problems and by-product marketability problems. Advanced technologies targeting these problems have been explored. The Florida Institute of Phosphate Research (FIPR) has been instrumental in the development of an innovative technology incorporating sintering on a circular grate as the main processing step. The process produces sulfuric acid and a solid by-product suitable for road construction primarily from phosphogypsum. This process was developed in conjunction with the Davy McKee Corporation with major support from Freeport McMoRan. In this presentation, this technology is referred to as the FIPR Process.

FIPR Process Background

The FIPR Process incorporates processing equipment widely used in the iron and steel industry for sintering of large quantities of solids. This equipment is designed to thermally react phosphogypsum, waste pyrites, waste clays and a low cost carbon source for the production sulfuric acid and aggregate for road construction. Patent protection for this process has been assigned to FIPR The process development began in 1985 and has progressed through the construction and operation of a process test plant in Louisiana. The test plant demonstrated that the main technical goals of the process were achievable on a relatively large-scale. The plant consumed 35 tons per day of phosphogypsum to produce about 25 tons of aggregate and 30 tons of sulfuric acid per day. Other work following completion of the demo plant test program has been completed to further analyze, improve and refine this process.

As with any process technology, it is necessary to consider optimization steps to keep the process up-to-date and in-line with new enhancement possibilities. One example of such improvements with advanced process testing and development can be seen with work completed at FIPR a few years ago. A brief series of phosphogypsum sintering tests incorporating a new enhancement technique were completed with FIPR's assistance. The primary goal of the tests was to evaluate thermal processing improvements that could be achieved by introduction of low frequency sound (infrasound) into reaction systems such as the FIPR Process. The infrasound technique had been successfully demonstrated in other process and combustion applications.

The tests confirmed that reaction rates could be significantly increased with the introduction of the low frequency sound into the reaction zones. The Figure 1 indicates the reductions in equipment sizes which could be expected. The section on economics evaluates the impact of this aspect of process improvements.

This type of evaluation for process optimization is important and would be impractical today due to the limited amounts of phosphogypsum available for use.

Leaching and Radioactivity Concerns

The positive impacts of the FIPR Process on certain characteristics of concern associated with phosphogypsum is very significant. The typical definitions used in most published descriptions and almost all media sources is that "phosphogypsum is a solid waste generated by the phosphate industry that contains **traces of heavy metals** and is **slightly radioactive."**

The heavy metals contained in a typical aggregate sample from the FIPR Process are shown in Figure 2. The metals leaching (metals removal from the solid by acidic liquid) characteristics for two common testing procedures is given. As you can see the metals are "locked" in the material resulting in leachates well below EPA leaching standards.

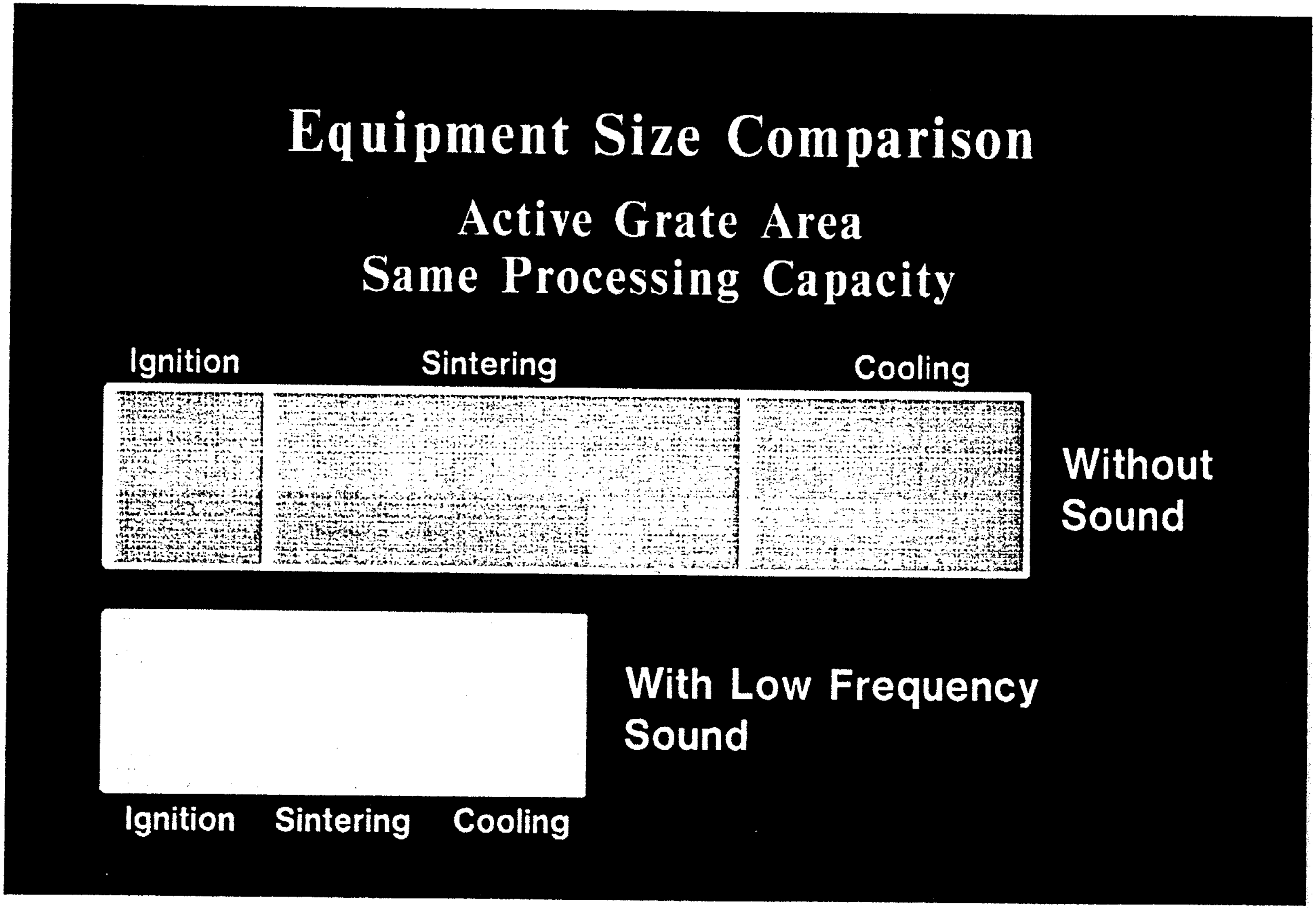
Equipment Size Comparison
Active Grate Area
Same Processing Capacity
Ignition
Sintering
Cooling
Without Sound
With Low Frequency Sound
Ignition
Sintering
Cooling

Figure 1

Figure 2

FIPR Process
Aggregate Leachate Analysis

Element	EP Toxicity (Mg/l)	TCLP (Mg/l)	EPA Leachate Standards (Mg/l)
As	1.6	0.882	5.0
Ba	0.52	0.17	100.0
Cd	0.01	0.01	1.0
Cr	0.01	0.05	5.0
Pb	0.05	0.1	5.0
Ag	0.01	0.05	5.0
Hg	0.001	0.005	0.2
Se	0.01	0.1	1.0

The radiation assay measurements in raw phosphogypsum and the FIPR Process aggregate are presented in Figure 3. After the material is processed to remove sulfur in this process, the remaining solid residue (proposed aggregate) is significantly lower in available radon and gamma radiation. The increased concentration of radium is expected as the process acts to reduce total amount of solid materials but encapsulates any radium present. The important fact is that the emissions produced by the remaining radium are lower and in the key area of concern; radon emanation. The processed solid is nearly 27 times lower in radon gas release than that emitted by stacked phosphogypsum.

Figure 3

Radiation Assay Measurements
Phosphogypsum and Aggregate

Material	**Radium 226 (pCi/gm)**	**Available Radon (pCi/gm)**	**Gamma (μRem/h)**
Phosphogypsum	**29**	**3.50**	**30**
Aggregate	**51**	**0.13**	**20**

Process Economics

The technical viability of removal of sulfur from gypsum is well demonstrated. The significant improvements and production of a salable by-product as offered by the FIPR Process have been confirmed at a large-scale demonstration facility. The process economics when evaluated by "standard" methods have continued to discourage the commercialization of the recovery of sulfur from phosphogypsum.

When evaluated in the late 1980s, the FIPR Process was economically breakeven with a price of sulfur at about $135/ton, assuming an aggregate value of $5/ton. This was based on a detailed analysis prepared by SRI International of Menlo Park, CA. This assumed a cost penalty for supplying phosphogypsum to the plant; $1/ton of phosphogypsum, a carbon source price of $55/ton and a power cost of $50/MW and $2.50/MMBtu natural gas.

Recent Economic Factors

There have been some recent developments that have an impact on these economics. Some of these developments and their cost implications are particularly important for the FIPR Process when evaluated for central Florida locations. The following highlights some of these developments:

- Aggregate value

Aggregate for road construction is actually being imported from foreign countries into the Gulf Coast area. The demand for high quality aggregate for road construction in the Gulf Coast region and particularly Florida presents a strong potential market. Current value of these aggregates in central Florida is $4.50 to $7/ton. Vulcan Materials with central offices in Birmingham, AL has opened a large quarry in Mexico producing road construction materials. Large quantities of aggregates from this operation are being barged to the Port of Tampa and delivered to Florida markets. There have been rejections of at least a portion of these materials for use in friction courses (highest value material $6 - $10/ ton) in Florida. Phosphogypsum aggregate as produced in the FIPR Process was evaluated as acceptable for friction courses. If the Florida Department of Transportation projections are realized over the next 10 to 15 years, demand for high quality aggregates in Florida will be very high.

The Strategic Highway Research Program sponsored by the U.S. Department of Transportation recently released findings indicating that the real area of concern for improved asphaltic concrete highways is the quality and specifications of the so-called filler materials; aggregates, sand etc. not the liquid asphalts. The implementation of specifications for more suitable aggregates needed for the proposed "Super Pave" highway system for North America could open even more valuable markets for the FIPR aggregate.

- Real costs of phosphogypsum storage in new, lined stacks

Some companies which stack phosgyp have implemented lined storage systems. This results in a cost of about $1.50 - $2 /ton of stored waste. This does not include containment and treatment of runoff from rainfall or control of seepage from the stack. Also, stack closure costs are not included in this number but must be considered when stacking continues. Independent surveys and evaluations have indicated that an "all-in-cost" for proper phosphogypsum storage approaches $5/ton.

Rather than penalize the process economics, I suggest that a credit be given for the consumption of phosphogypsum by avoiding higher stacking costs.

- Relatively low energy and carbon source prices

The costs for natural gas and avoided costs for electric power production have remained fairly stable. The carbon source required for the FIPR process could be obtained from a new process recently put into commercial operation by SGI of La Jolla, CA. The process produces a low cost, low-volatile solid fuel and various liquid fuels from high sulfur, inexpensive coal. A circular grate system is the coal processing reactor. This solid fuel could be used to reduce raw material costs for the FIPR Process.

The availability of this material and continued low cost for natural gas would reduce the capital cost and operating expenses particularly when considering replacement of electricity generated by existing sulfuric acid plant power generation installations.

- Improved FIPR reactor design

The sintering, circular grate reactor is the single most expensive equipment item in the capital requirement for a commercial-scale plant using the FIPR Process. Taking advantage of the reduction of reactor size predicted by the infrasound tests previously discussed, the estimated cost for the entire battery limits plant would be reduced by about 4 % .

Updated FIPR Process Economics

By applying these factors to the previously presented base economics, the FIPR Process could be considered breakeven with $105/ton sulfur for a plant producing 920,000 tons/year of sulfuric acid from about 1.2 million tons of phosphogypsum. This represents a reduction in product cost of about 21% when compared to the earlier economics. A
summary of these factors and impacts on the process economics are included in Figures 4 and 5.

Even with the relatively low price of sulfur currently in place in Florida, the alternative of recycling sulfur values from phosphogypsum may be closing the economic gap.

Figure 4
ECONOMIC COMPARISONS
Cost Impact Comparisons

Parameter	1988 SRI Economic Bases	1996 Impacts on Parameter	Net Impact on FIPR Process Economics
Aggregate Value	$5.00/ton	$8.00/ton	-$2.70/ton of H_2SO_4
Phosphogypsum Storage	$1.00/ton cost	$2.00/ton credit	-$2.45/ton of H_2SO_4
Raw Materials and Utilities	$18.00/ton H_2SO_4 $5.56/ton H_2SO_4	$16.29/ton H_2SO_4 $4.70/ton H_2SO_4	Total Reduction: -$2.57/ton H_2SO_4
Reactor Grate Factor	4 lbs/ft^2/min	10 lbs/ft^2/min	4% capital cost reduction

Figure 5

Sulfuric Acid Production Cost Comparison - FIPR Process

SRI International PEP Review 86-2-2 1988
920,000 tons/year of Sulfuric Acid

Cost Category	Sulfuric Acid Production Cost -1988	Modified Sulfuric Acid Cost - 1996	Source of Impact
Investment - BL $MM U.S.	70	67	Increased Grate Factor
All Raw Materials and Utilities	\$24.56/ton H_2SO_4	\$18.59/ton H_2SO_4	Lower Carbon Source/Utilities Cost Gypsum Costs
By-Product Value (Credit)	\$5.00/ton	\$8.00/ton	Increase in value of high quality aggregate
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Total Direct	\$26.84/ton H_2SO_4	\$18.02/ton H_2SO_4	Includes All Variable and Fixed Costs
Other Costs	\$17.71/ton H_2SO_4	\$17.29/ton H_2SO_4	Plant Overhead, Taxes and Insurance, Depreciation
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Net Production Costs for H_2SO_4	\$44.55/ton	\$35.31/ton	21% reduction in net cost

Need for Access to Phosphogypsum

The restriction for removal of phosphogypsum from stacks for the various proposed uses has severely limited the development of advanced utilization techniques. This prohibition also essentially guarantees future additions to the already extensive inventory of this waste. The knowledge that the raw material would essentially be unavailable even if a “breakthrough technology” were developed is extremely restrictive to any interest in effective, alternative utilization of stacked phosphogypsum.

Summary

Phosphogypsum is a technically and environmentally suitable source for sulfur to an industry currently consuming large quantities of this raw material. The FIPR Process has demonstrated some attractive advantages over older technologies particularly in markets needing large quantities of high grade road construction materials. The environmental advantages of reducing rates of phosphogypsum stacking from the long term perspective are extremely important.

The economics have historically placed sulfur recovery from phosphogypsum at a disadvantage when compared to simply purchasing sulfur. The new developments discussed here may be closing the “sulfur value” gap.

In order to take advantage of these developments and any other promising technologies, **phosphogypsum should be available as a raw material** for the production of both sulfuric acid and other valuable by-products. The environmental concerns associated with stacking phosphogypsum can be significantly lessened only by implementation of environmentally responsible methods of utilization.

PHOSPHOGYPSUM AND ARTIFICIAL REEFS: AN ARTIFICIAL REEF MANAGEMENT PERSPECTIVE

BY

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Mr. Lukens has been the Assistant Director of the Marine Fisheries Commission since 1987, developing interjurisdictional policies and programs and coordinating an interstate technical subcommittee on artificial reef development and management. He has been involved with assessing and monitoring artificial reefs since 1975 and has published seven papers on the topic.

Mr. Lukens has a Master's degree in Marine Biology.

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Background

It has been said that one man's trash is another man's treasure. It is simply good business to convert what would ordinarily be considered a waste material into a useful and valuable commodity. This, however, must be done under careful scrutiny that assures the public that the proposed use of a waste material is beneficial, non-hazardous, and is not being proposed merely as a way to get rid of waste burden, particularly as it relates to impacts on the environment. Is phosphogypsum a treasure? Is it an opportunity? While the answer to these questions will depend upon the application and gathering a great deal of technical data, I would like to frame the questions in the context of artificial reef applications and the kinds of issues that concern artificial reef program managers.

Artificial reef development in the United States began in earnest in the late 1960s and 1970s. Early efforts were accomplished by volunteer groups who were primarily interested in improving recreational fishing opportunities, a situation which continues. Throughout this history of development, "materials of opportunity" have been used to build reefs. What are materials of opportunity? Loosely defined, they are largely man-made materials which have outlived the useful life for the purpose for which they were originally intended. Examples include oil and gas structures, ships and other vessels, automobile bodies, tires, concrete rubble, among a long list of others. This reliance on materials of opportunity has been at once both beneficial and burdensome to artificial reef managers; beneficial in that they are usually readily available and cheap to obtain, and burdensome because waste managers view artificial reefs as a good way to dispose of their "product" while benefiting the environment. I classify the last as burdensome, because not all waste materials can be considered compatible for use as artificial reef material, and because political pressures from local governments, industries, and others can be brought to bear to force the use of materials that may otherwise not be desirable by an artificial reef program.

Standards and Criteria

The following are categories for criteria and standards for artificial reef materials as established in the National Artificial Reef Plan (Stone 1985):

a. function in providing habitat for marine organisms,
b. compatibility with the marine environment,
c. durability and stability in the marine environment, and
d. availability

These are the areas which are considered by an artificial reef manager when determining whether or not a material will be used.

There are a number of examples of materials of opportunity that have been used that can help illustrate these concerns. Many years ago, automobile tires, a significant waste disposal problem, were used experimentally as artificial reef material. From a practical standpoint there are a number of benefits and drawbacks to using automobile tires; however, once it was widely known that tires could be used in this context, pressure was brought to bear on artificial reef programs to use tires as a means of reducing the waste burden on local governments. As a result, a number of problems have arisen, not the least of which is tires being deposited on beaches after storms and ending up in shrimp fishermen's nets. Today we know that there are some very basic engineering principles that can be applied to using tires in this context to make them more suitable. Related to the standards and criteria, the function of tires as beneficial marine habitat is still being debated, and can best be characterized as applicable on a case-by-case basis. Tires are basically compatible with 'the marine environment, because they do not break down very easily. Tires are unstable in water unless significantly ballasted. Finally, tires are readily available but labor intensive to use. Currently, use of tires as artificial reef material has nearly ceased.

Another good example is the need to find a suitable use or disposal mechanism for the ash residue from combustion of coal for energy production. This ash material can be combined with portland cement and create designed structures for use as artificial reef material. There has been pressure on artificial reef programs for several years to use this material; however, until relatively recently there were no general guidelines for analyzing the ash for marine applications, nor for mixing the material to produce a chemically stable structure with adequate compressive strength to withstand the rigors of the marine environment. Recently, a set of general guidelines were adopted for the Gulf of Mexico region for use of coal fly ash, which is only one of the waste streams resulting from coal combustion. Related to the standards and guidelines, structures can be built from aggregate mixtures using coal fly ash that will provide habitat for marine organisms. The compatibility question related to the potentially toxic components in coal fly ash required much research and testing before guidelines for its use could be developed. Structures constructed from coal fly ash and cement mixtures are durable and stable, and the material is readily available.

Research

Research must be conducted that clearly determines whether or not phosphogypsum is a biological or environmental threat when used in artificial reef or other marine applications. In the case of coal fly ash, the ash resulting from the combustion of coal from different geographic sources resulted in ash that has different chemical compositions. Testing must be done on ash proposed for use in the marine environment to determine is composition. If this is the case with phosphogypsum, the range of chemical composition of the material from different sources must be determined and related back to that source. If materials in phosphogypsum are known to be toxic to living organisms, then it must be determined if such substances are chemically bound in the mixing process, or if they are physically bound. In the case of coal fly ash, it was determined that toxic components were chemically bound, such that if a block of ash and concrete were pulverized, no trace of the toxic chemicals could be detected. If the toxic components are physically bound, there is a concern related to releasing the material if the phosphogypsum/concrete structure deteriorates over time. There is also concern about potential bioaccumulation in marine organisms if such toxics are made available.

Protocols must be developed for testing the chemical composition of phosphogypsum, and for determining if differences exist in the chemical composition of the material from different sources. Protocols must also be developed for mixing the material to provide the compressive strength necessary to assure durability over time. These protocols must be published and made available to the public.

State Artificial Reef Programs

A recent survey of marine fishery management agencies revealed that artificial reef programs within those agencies have a relatively low priority. This, of course, varies from agency to agency; however, the obvious result of this conclusion is that funding available to conduct artificial reef activities is always limited and seldom flexible. There are personnel, equipment, and funding constraints on almost all coastal artificial reef programs in existence. This situation, as you might guess, affects much of what the programs can accomplish in any given year. The various sources of funding needs include staffing and overhead, cost of materials, cost of preparation of materials for deployment, at sea deployment operations, biological and physical monitoring of artificial reefs, among others. Materials that are inexpensive to obtain, readily compatible with the marine environment, and relatively easy to deploy are very attractive to artificial reef managers. Materials that must be purchased, are labor intensive to prepare for deployment, must undergo processing to assure environmental compatibility, and are difficult and expensive to deploy are typically avoided.

Assuming that research and testing determine that phosphogypsum can be used safely in the marine environment, it is my belief that the following things must be in place if the material is to be successfully used in the context of artificial reefs or other marine applications.

- the material cannot be considered a commodity, but must be made available at no cost.
- fabrication of artificial reef structures or units can be costly and labor intensive. This cost should be borne by the industry, unless arranged otherwise with individual programs.
- delivery of phosphogypsum or structures to construction and staging sites can be difficult for artificial reef programs with limited resources. The industry should work out arrangements for delivery with individual programs.
- deployment and other at-sea activities related to using phosphogypsum can be expensive and labor and equipment intensive. Arrangements must be made to provide the artificial reef programs with the equipment and expertise needed to conduct such at-sea activities.
- The demand, on an annual basis, for artificial reef materials that must be purchased by artificial reef programs is very low in comparison to the amount of phosphogypsum that is available, especially in light of the availability of coal fly ash for this use.
- The availability of a quantity of waste material cannot be the driving force behind the type of materials used by an artificial reef program. Artificial reef managers must have the freedom to select those materials that satisfy the standards and guidelines established, while at the same time can be used within the programmatic limitations of funding, manpower, time, and equipment availability.

While it is true that in general artificial reef programs do not enjoy a high priority within the state marine resource agency's fisheries programs, they all enjoy a great deal of public support and encouragement. The primary reason for this is that the creation of a new artificial reef automatically creates new opportunities for anglers to catch fish and divers to enjoy diving activities. Artificial reef program managers are sensitive to this public support and are concerned with anything that may erode that support. One of the concerns is the public perception of using “questionable” materials as artificial reef material. This concern was of major importance during the development of the guidelines for using coal fly ash. This concern must be addressed if phosphogypsum is to be used by state artificial reef programs.

Finally, one promising marine application of phosphogypsum/cement aggregate is the enhancement of oyster beds through the development of a cultch material on which oysters can settle. Historically, clam and oyster shell have been used as oyster cultch; however, clam shells are no longer available due to political and environmental issues associated with dredging of the shell, and oyster shells are economically difficult to reclaim from oyster processing plants for cultch. Typically, oyster fishery programs must replenish cultch for settlement of oysters on a regular basis to replace the material taken during the harvesting process. This could prove to be a steady market for application of phosphogypsum; however, there are a number of related concerns, including

- competition with coal fly ash, which is being proposed for this use,
- potential to pulverize the cultch material by using tongs and dredges to harvest oysters
- sedentary nature of oysters related to potential for bioaccumulation of the chemical components of phosphogypsum
- related public health implications
- public perception related to the use of a byproduct as cultch and its impact on the already burdened oyster industry

Conclusions

I believe that the phosphate industry has a great deal of work to do if natural resource managers are to be convinced that phosphogypsum can be used safely and effectively as artificial reef material and oyster cultch in the Gulf of Mexico. Assuming that the industry is interested in pursuing marine applications of the material, a close working relationship with the marine resource management agencies, and in particular the artificial reef program managers, must be established. We should all proceed with a positive attitude toward finding value in byproducts that result from the various industries that serve the American public and contribute to our quality of life. But, we must proceed cautiously with a sincere concern for the long-term protection of this space ship we call Earth.

PRELIMINARY EVALUATION OF THE USE OF PHOSPHOGYPSUM FOR REEF SUBSTRATE IN THE GULF OF MEXICO REGION

BY

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Dr. Wilson received his Bachelor's degree from Hampton Sydney College and the Master's and Doctoral degrees in Marine Fisheries from the University of South Carolina.

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Phosphogypsum (PG), a solid by-product of phosphoric acid production, has been classified as a "Technologically Enhanced Natural Radioactive Material" because it contains radionuclides and some trace metals in concentrations which may pose a potential hazard to human health and the environment. The main disposal method, onsite stockpiling, has resulted in at least 33 PG stacks (average area of 224 acres per stack) located in all Gulf States except Alabama and has created a tremendous management problem. Environmental concerns associated with PG disposal, coupled with increasing land costs for stockpiles, has promoted research on alternative beneficial uses of this solid waste that will result in applications considered protective of public health.

A sound alternative to present disposal practices must address the issue of airborne radioactive contact with the public, while providing evidence that PG reuse or recycling is more economical than the long term cost of disposal. This issue has prompted states including Louisiana, Florida and Texas to investigate alternatives for the utilization of this material. Commercial utilization is the best long term, economical solution to reducing current and future PG inventories. Four broad categories for alternative uses of phosphogypsum have been identified: 1) agriculture, 2) building construction, 3) road construction, and 4) other applications including artificial reefs, riprap, retaining wall back-fill, coastal erosion barriers, and jetty stone. In addition to the above mentioned coastal applications, the use of PG as an artificial substrate for oyster settlement has been suggested to complement the declining supply of natural oyster shell substrate in the Gulf region.

The utilization of phosphogypsum for underwater applications provides the best means for minimizing public exposure because the airborne vector of transmission is eliminated or, at least, significantly diminished. Most other alternatives, while proposing economic solutions to the growing phosphogypsum inventories (agriculture, roadbed aggregate, building material, etc.) do not address the fundamental issue. That is, the high potential for human exposure to radium and its decay products (principally radon). An initial uncontrolled pilot demonstration study and a follow up two year study conducted at Louisiana State University showed that PG/cement test blocks placed in the Gulf of Mexico supported a diverse population of surface attached and burrowing organisms, indicating the potential of using PG for offshore artificial reefs.

In addition to radionuclides, PG contains some trace elements in concentrations which EPA believes may pose a potential hazard to human health and the environment. The EPA has identified a number of potential constituents in PG from some facilities that could, under the appropriate conditions, cause adverse health effects or the restriction of potential uses of nearby surface or groundwater resources. Elements identified include arsenic, lead, cadmium, chromium, fluoride, zinc, antimony, and copper. Among these elements, only chromium and arsenic were identified in PG from some facilities at concentrations that may pose significant health risks.

There has been some research related to the leachability of toxic substances from PG stacks. To date no significant leaching of trace elements (copper, nickel) from nine phosphogypsum stacks located in Florida. More importantly, all core samples contained toxic element concentrations lower than the EPA definition of toxicity, with the exception of arsenic. In the case of arsenic, analyses indicated the metal could not be leached thus, would not be available to impact the environment. In our studies leaching tests performed on compressed PG/sand-cement blocks (70%/30%) we found that all elements measured (Cd Pb Cr and As) were below EPA drinking water quality standards. In fact, Pb and Cr leachate was higher from sand-cement controls than the PG composites.

In a similar study on artificial reefs of coal ash, it was found that toxic elements might diffuse at an extremely slow rate. Various short-term assays and longer exposure experiments made in the laboratory and open sea in the same study showed no evidence of uptake or concentration to toxic levels. However, a few of their tests indicated an inhibition of biological functions at very high concentrations of leachates, or of suspended coal ash particulates. Therefore, it was recommended that more investigations should be conducted to better determine and clarify potential infiuences of reef building materials in marine environment. Research on cement stabilized coal ash has now progressed to large scale demonstration projects with positive results.

Both Florida and Louisiana have a need for low-profile material for use in their inshore reef programs. Louisiana also needs suitable substrate material for maintaining suitable oyster habitat. The economic value of the fisheries associated with these needs is significant. In 1986 it was estimated that the recreational fishery of Louisiana spent over 200 million dollars (not including multipliers). The Louisiana oyster industry is valued at over $40,000,000 per year. Most of this fishing activity occurs in the shallow, inshore and near shore coastal waters.

In a preliminary offshore trial that involved the investigators, PG-cement and sand-cement control blocks were attached to oil rigs and the blocks were inspected for fouling organisms after 60 days. For blocks that remained intact, no differences in the densities of amphipods, barnacles and total organisms were found. Most impressive were the number of attached animals present on the control and test blocks. Amphipods are important food sources for many fish, and were found in abundances of 4000 - 6000 per 4" diameter x 4" height cylindrical blocks. The artificial reef phenomenon partly results from increases in diversity and quantity of food, and phosphogypsum blocks appear to develop fouling communities that are similar in diversity and abundance to the sand-cement control blocks.

Phosphogypsum stabilized with cement should provide suitable substrate for oyster sediment based on its chemical constituents. In the process of settling, oyster larvae key in on hard substrate as a settling substrate. This life history strategy assures that oyster larvae will settle in areas where other oysters are present. Although it has been shown that oyster larvae will settle on other materials, oyster larvae will preferentially select out areas where calcium is present. Phosphogypsum (calcium sulphate) provides a chemically suitable substrate for the settlement of oyster larvae. However, it is necessary to thoroughly investigate the effect of associated contaminates that are mixed in with calcium sulphate on oysters as they grow.

To investigate the possibility of accumulation of radium[226] and selected heavy metals over time when organisms are cultured in the presence of PG, we designed an aquarium experiment consisting of four components representing different levels of an aquatic food chain: algae (Chaetoceros muelleri), copepods (Harpacticus obscurus), grass shrimp (Palaemonetes sp.), and gulf killifish (Fundlus grandis). Cultured algae were provided to copepod mass culture systems to which unconsolidated PG was added on a regular basis. The PG cultured copepods were subsequently fed to grass shrimp which were held in a three aquarium array. Three 70% :30% (PG:cement) blocks were placed in each of these aquaria to provide an environmental exposure to PG. After two weeks of feeding on the PG cultured copepods, the grass shrimp were fed to aquarium-held gulf killifish at an average rate of one shrimp per fish per day. Each of the three killifish aquaria were also provided with six 70% :30% (PG:cement) blocks to maximize contact opportunity. The killifish were maintained in this manner for three time periods (45, 90, and 135 days) before being removed for analysis. Controls were provided by gulf killifish which were fed grass shrimp cultured with commercial shrimp pellets as their food source. Both the control grass shrimp and the control killifish aquaria were also furnished with 70%:30% (sand:cement) blocks. Control killifish were also harvested at 45, 90, and 135 day intervals for analysis.

Whole body nitric acid digests of the experimental (N = 14), control (N = 13), and wild caught (N= 10) killifish were analyzed to determine the constituent concentrations of seven elements: radium[226], copper, zinc, cadmium, lead, chromium, and arsenic. In comparisons of their concentrations with the concentrations found in the wild-caught specimens, only copper (1.5 times higher in experimental fish) and cadmium (8 times higher in experimental fish) showed any statistically significant differences in mean concentrations between the experimental and control groups. The tissue level of cadmium in killifish was 0.058 ppm. Mean concentrations for equivalent exposure times between the experimental and control groups showed statistically significant differences for cadmium, lead, chromium, and arsenic. However, these results are difficult to interpret as both groups evidenced maximum mean concentrations at 90 days exposure which were subsequently reduced at 135 days exposure.

The next step in our investigation employed four one-quarter acre ponds located at the Louisiana Department of Wildlife and Fisheries Marine Laboratory located on Grand Terre Island, Louisiana. Two of the ponds were seeded with 600 four inch by two inch cement consolidated PG cylinders (70% :30%, PG:cement) arranged in six equidistantly spaced “reefs” of 100 cylinders each. The two remaining ponds were similarly seeded with cylinders of cement consolidated sand of like proportions. A ten horsepower submersible pump was used to deliver ambient seawater to the ponds in a flow through manner. All four ponds were allowed to become naturally stocked with eggs and larvae of a variety of marine organisms. At the end of one year, the ponds were drained and seined to harvest the macrofauna of each and the blocks were removed for assessment of oyster growth.

A total of three species of macroinvertebrates (oyster, white shrimp, and blue crab) and 15 species of fishes were collected from the four ponds. Representative individuals from each species found in each pond were frozen for future elemental analyses. Mean numbers of species (and biomass) for the two experimental ponds and the two control ponds were 10.5 (32.35 kg) and 14 (32.41 kg), respectively. The mean number of species in the control ponds, however, was inflated by five species which were represented by single individuals. Blue crab were abundant (and quite large) in all four ponds; the fish species silver perch, spotted seatrout, and spot were also particularly abundant in all. Statistical comparisons of the distributions of proportional species abundances and proportional species biomasses among ponds revealed all four ponds to be quite dissimilar. Only Pond 1 (control) and Pond 4 (experimental) showed similar distributions of species abundances and all ponds showed unique distributions of biomasses among species. The two ponds seeded with PG blocks were subjectively judged by the authors to be suffered no ill affects from their presence.

Oyster growth was evident and abundant on both the PG:cement and the sand:cement blocks; all exposed block surfaces were blanketed with a dense growth of these organisms. In many cases the oysters had formed a crown on the top of the blocks which measured 6-8 inches in diameter. Again, no evident differences in oyster growth were noted between the experimental and control ponds.

The ultimate decision for using PG as colonizing substrate for oysters, reef material, or other aquatic application will depend upon completing this line of research and active dialogue with regulatory agencies. Results to date warrant continued pursuit of lab trials and field testing of the ecological safety of PG towards this goal.

THE MERSEBERG PROCESS--A PARTIAL SOLUTION TO THE PHOSPHOGYPSUM PROBLEM? A POSITION PAPER

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Dr. Burnett earned a Ph.D. from the University of Hawaii in 1974.

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The Problem

Florida has 600-700 million metric tons of phosphogypsum in storage on 27 stacks with another 30 million tons being added each year. The U.S. Environmental Protection Agency (EPA) has ruled that phosphogypsum must be placed on stacks or mine cuts and that only gypsum containing less than 370 $Bq \cdot kg^{-1}$ (10 $pCi \cdot g^{-1}$) ^{226}Ra can be removed for agricultural purposes. The EPA regulates the distribution and fate of this by-product principally because of its radium content and its potential for generating the gaseous radioactive daughter, ^{222}Rn. This is an important consideration as the main use of gypsum in the United States is for construction of wall board or "sheetrock" used in houses. The stacks themselves, however, are a serious problem. Besides the obvious waste of a potentially valuable by-product and the unsightly physical appearance of the stockpiles, the main problem associated with phosphogypsum storage is the potential effect on the surrounding environment, especially the water resources in the vicinity of gypsum stacks. Can anything be done about this wasteful and potentially enviromnentally-damaging situation?

Some Ideas

Many previous suggestions have been made for phosphogypsum use including: (1) use for construction of road beds; (2) recovery of elemental sulfur either chemically or microbially; (3) direct agricultural application as a fertilizer; and (4) use of phosphogypsum blocks for construction of artificial reefs. At present, there does not appear to be a high degree of confidence that any of these approaches will be successful in terms of large-scale volume reduction. Can large-scale radiochemical purification be done economically? Perhaps, especially if combined with a process that will also result in an economically-attractive product.

The Merseberg Process

One possibility for such a process is the conversion of phosphogypsum to the two end products (calcium carbonate and ammonium sulfate) of the so-called "Merseberg" ammonocarbonation reaction. One of these products, ammonium sulfate, is an excellent fertilizer that adds both sulfur and nitrogen to the soil. The other reaction product, calcium carbonate, could be used for neutralizing acidic process waters associated with the phosphate industry, used as an additive for cement, or calcined to drive off the CO, which could be recycled for the production of the ammonium carbonate needed in the Merseberg process. Chemically, this procedure may be represented by the following reaction:

$$CaSO_4 \cdot 2H_2O + (NH_4)_2CO_3 \dashrightarrow (NH_4)_2SO_4 + CaCO_3 + 2H_2O$$

dihydrate gypsum	ammonium carbonate	ammonium sulfate	calcium carbonate

This method is now used on a commercial scale with waste phosphogypsum in India, China, and Indonesia. Furthermore, a FIPR-sponsored study conducted recently in my laboratory at Florida State University investigated the flow of radionuclides through the entire process. The results showed that while concentrations of uranium and radioactive daughter products varied in the phosphate rock samples (and thus in the resulting phosphogypsum) from these overseas plants, the radionuclides which originally concentrated in the phosphogypsum all reported to the by-product calcium carbonate. The resulting ammonium sulfate is thus very low in radium and other radionuclides, lower than found in most natural materials.

Need For Ammonium Sulfate

The expanding role of sulfur in accelerating crop production, especially in tropical countries, has become more widely recognized in the last few years. Sulfur is an essential nutrient for plants and it contributes to increased crop yields both by providing a direct nutritive value and by improving the efficiency with which plants use other essential nutrients, especially nitrogen and phosphorus.

During the last two decades, changes in agricultural practices and fertilizer manufacture have had a major impact on sulfur availability. "Green Revolution" technology, with corresponding increases in crop yields and multiple cropping, will continue to increase demands for sulfur. The aggregate sulfur availability to agricultural soils, on the other hand, has been declining over the last several years for 3 reasons: (1) many countries never had any policy of supplying sulfur to soil (although it was applied inadvertently *via* the use of fertilizer that also contained sulfur); (2) the fertilizer industries have been replacing sulfur-containing fertilizers (such as ammonium sulfate) with sulfur-free fertilizers (as urea) because of high distribution costs and the perception that sulfur itself was of little importance; and (3) the environmental concern for cleaner air has reduced the supply of sulfur *via* "acid rain" from the atmosphere.

Thus, we are now facing a serious "sulfur gap" in many areas. Although sulfur deficiencies in soil are not always easy to recognize, there is a growing body of evidence that the lack of sulfur is often responsible for lower productivity. In general, the situation is that while higher crop yields require more sulfur, the actual trend is of a decreasing sulfur supply as a result of lower levels of inadvertent addition and atmospheric pollution. Consequently, sulfur deficiency problems in soils are now becoming widespread.

Economic Considerations

We thus have an interesting situation where, it appears, that two problems could be resolved by the same solution. We need more ammonium sulfate to fill the "sulfur gap" and we have a lot of waste gypsum in Florida. Furthermore, it has been demonstrated that one can produce good quality, radionuclide-free ammonium sulfate from phosphogypsum by the Merseberg reaction. So, what's the big deal? -- Let's get started! Unfortunately, it isn't that simple.

One of the principal reasons that the Merseberg process can be economically realized in India and some other Asian countries is because sulfur is in short supply there and has to be imported. The availability of by-product gypsum, therefore, provides an inexpensive raw material for producing a sulfur-containing fertilizer. In countries with plentiful supplies of sulfur resources, the principal economic problems lie with the relatively low nitrogen content of ammonium sulfate and the availability of ammonium sulfate from other sources. Since $(NH_4)_2SO_4$ contains only 21% N while urea contains 46% N, the production and subsequent transport costs per unit nitrogen is obviously higher for ammonium sulfate. Fertilizer manufacturers have thus tended to favor the so-called "high analysis" fertilizers (note that "high analysis" here refers to content of nitrogen or phosphorus, not sulfur). In spite of this apparent cost disadvantage, the prospect of being able to provide sulfur as well as nitrogen to soil to overcome the sulfur deficiency problems referred to earlier <u>and</u> to address the problem of phosphogypsum disposal in the phosphate industry has great practical appeal.

Commercial-scale production of ammonium sulfate has not been considered economically feasible in Florida because the price has been kept low due to the by-product production of ammonium sulfate from other industries. Most ammonium sulfate today is a co-product from the manufacture of the nylon intermediate, caprolactum. The U.S., now the leading ammonium sulfate producer, accounts for 75 % of its product *via* caprolactum. However, new technologies have developed recently which have lowered the amount of ammonium sulfate to product ratio from 5:1 to about 1.3:1. In addition, BASF is said to be developing a method for recycling carpets for nylon that wouldn't produce any ammonium sulfate at all. Thus, the demand for ammonium sulfate has been improving over the last few years as the sulfur requirements are recognized and the main supply *via* caprolactum production may diminish substantially. These trends have produced a relatively steady increase in the world ammonium sulfate prices over the last three to four years. The situation is improving.

Synopsis

The current phosphogypsum situation in Florida is unfortunate, as the practice of stockpiling is unattractive from many points of view. Not only are the gypsum stacks unsightly and present a possible environmental problem, but they will require long-term expenditures for maintenance and monitoring. A "pass-through" technology, which would convert the waste product to a useful commodity is clearly a more efficient use of our resources.

Although the economics of large-scale ammonocarbonation of phosphogypsum remain uncertain, I suggest that the following points make the Merseberg process potentially attractive: (1) fully-developed fertilizer infrastructures are already in place in Florida; (2) the gypsum is readily available; (3) the need for sulfur will drive the demand for ammonium sulfate while supplies from other industries are diminishing; (4) the stoichiometry of the ammonocarbonation process is such that about 30% more gypsum is consumed than ammonium sulfate produced -- waste minimization is thus achieved; (5) significant amounts of the by-product $CaCO_3$ could also be used by the phosphate industry; and (6) the significant construction and maintenance costs associated with gypsum stacks, estimated to be in excess of several million dollars per year, could be reduced and eventually eliminated. Furthermore, now that the State of Florida has decided to "close" inactive and unlined gypsum stacks within the next several years, there are new costs to consider. Although the cost estimates vary widely depending upon the size of the stack and other variables, an average closure cost of ~ $20 million per stack is realistic. It is also important to note that these cost estimates do not include the on-going costs of environmental monitoring. Is this really how we want to solve our problems?

A Suggestion

I suggest that it seems appropriate at this stage to review our strategies in terms of dealing with this waste. Additional research should be encouraged to find a cost-effective means to reprocess phosphogypsum. Conversion to a useful product, even without a significant profit margin, should be preferable to the huge expense and endless monitoring required for environmental isolation.

Closing stacks is not only an expensive proposition, it is following a very pessimistic route. After spending a few tens of millions of dollars on the closure process and performing the required decades of environmental monitoring, “new” uses for phosphogypsum would be of little interest. Why not give Florida’s environmental scientists, chemists, engineers, and radiochemists an opportunity to develop a viable scheme to purify or convert phosphogypsum into environmental safe and commercially useful products. Lets take the optimistic course and encourage research to find answers. If only l0-20% of the cost of closing a single stack were devoted to research on this specific problem, there is an excellent chance that better solutions could be found. Creative ideas are needed to solve thorny problems.

PHOSPHOGYPSUM UTILIZATION AS A CHEMICAL RAW MATERIAL

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Mr. O'Hanrahan is President and Chief Chemist of Galloway Chemical Division, a 35-year-old company that O'Hanrahan Consultants, Inc. acquired in 1980. Mr. O'Hanrahan has been instrumental in developing the first low pressure drop catalyst composite unit used in an automotive emission control device and has many other joint patents involving heat transfer machinery for the chemical and food industries. His current interest in putting phosphogypsum to use as a chemical raw material source.

Mr. O'Hanrahan has a Bachelor's degree in Chemistry from Dublin University in Dublin, Ireland.

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Phosphogypsum is a man-made source of several valuable raw materials. It is the purpose of this paper to outline the recovery of a few of these elements, and to show the potential value of three of them.

SULPHUR: From sulphuric acid (H_2SO_4) to Calcium Sulphate ($CaSO_4$) - phosphogypsum - to Hydrogen Sulphide (H_2S) through a Claus Unit to Sulphuric Acid.. . seems like a perpetual motion machine. It is in the chemical world, Sulphur is a cost item, a raw material.

CALCIUM SULPHIDE: Resulting from the reduction of calcium sulphate with carbon (C) in the temperature range, 850 to 1,000 degrees centigrade.

$$CaSO_4 + 2C = CaS + 2CO_2$$

easy to write, but difficult to do

My corporation has funded research on this process at a dollar expenditure of six figures. We have learned that our investment was not enough to start the commercial production of CaS.

CaS has to be manufactured under strictly controlled conditions to produce a product of 90% purity or better.

Moisture will cause CaS to release H_2S prematurely; oxygen will lower the, percentage of CaS recovered.

Technical research has shown that with ideal temperature control, an inert nitrogen blanket, accurate feed control and a constant RPM of the kiln.. .gram quantities of calcium sulphide (of 90 % or better purity) can be prepared from phosphogypsum. Our objective is to make CaS, not in gram, but in tonnage quantities on a continuous basis.

We believe that using the controlled conditions above and a controlled cooling regimen, we can manufacture CaS in large quantities. Further work will require commercial scale equipment at an estimated investment cost of three million dollars.

Calcium sulphide (55%) has an f.o.b. market value of $500/ton in moisture-tight packages. Current tonnage available worldwide is less than 500 tons. However, an estimated 100,000 tons of CaS will be required within five years to treat and remediate heavy metal contaminated soils.

Pro-Forma

Assumptions:

Volume: 12,000 tons the first year, with growth to 50,000 tons by year five.

Revenue: $500/ton

Sales	$6,000,000
Less: coal cost	600,000 (15,000 tons @ $40)
phosphogypsum	250,000 (25,000 tons @ $10)
labor costs	150,000
fixed capital cost	300,000 ($3 million amortized over 10 years)
Gross margin	$4,700,000
Payout:	Less than one year

CaS has a special usage in the hazardous waste management of sites contaminated with heavy metals (copper, chromium, lead, arsenic, et al.) After reacting these soils with calcium sulphide, they meet or exceed the TCLP Standards of the EPA, and in particular, the California standards.

At this cost per ton, the remediation industry would use more. The U.S. EPA favors the use of the dry powder over the related compound, a liquid 29% active calcium polysulphide. Calcium polysulphide readily releases H_2S into the environment during its reaction with metals in the contaminated soils. CaS powder treatment releases much less H_2S and charcoal filters are able to control those H_2S emissions.

RADIUM: Treatment of the CaS in a wet cycle generates the hydrosulphides of calcium and the small quantity of radium present in the phosphogypsum. The silica contamination in the gypsum can be filtered off and discarded. The solution containing the soluble radium can be treated in an enclosed ion exchange system to recover the radium for use by the nuclear medicine industry.

AN EXTENDED MORTALITY FOLLOW-UP STUDY OF FLORIDA PHOSPHATE INDUSTRY WORKERS

FINAL REPORT

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Note: Dr. Heyer was unable to attend the Forum due to other commitments.

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Executive Summary

This report presents findings from an updated cohort study of workers in the Flonda phosphate industry. The original study was performed in the early 1980s by a research team from the Occupational Health Studies Group at the University of North Carolina (UNC). This updated study was conducted by researchers at the University of Washington, Department of Environmental Health. Both the original and updated studies were sponsored by the Florida Phosphate Council, and Dr. Harvey Checkoway was Principal Investigator in each instance.

The original study was prompted by reports in the late 1970s of lung cancer clusters among industry employees. Ionizing radiation from phosphate ore sources was of particular interest in this regard. A further motivating factor for the UNC study ‘were reports by the Environmental Protection Agency of elevated indoor radon levels in homes built on land that had been reclaimed subsequent to phosphate mining.

The UNC study traced the mortality experience, during 1949-78, of approximately 23,000 male workers employed for a minimum of 12 months cumulative service in the Florida operations of the 15 then member companies of the Florida Phosphate Council. Cohort membership further required that workers had been employed for at least 3 months continuous service in the industry between 1949 and 1978. The original analysis was restricted to male workers. The most noteworthy results form the UNC study were small excesses of lung cancer mortality in both white and non-white male workers compared to U.S. white males. However, there were no lung cancer excesses when the workers’ death rates were compared to Florida state mortality rates. Analyses were next performed to identify work areas and specific agents that may have been associated with

disease excesses within the industry. The study revealed no evidence of causal associations with specific agents, including ionizing radiation, dust, and acid mists.

Two other mortality studies among Florida phosphate industry workers were conducted, respectively, by researchers from the National Institute for Occupational Safety and Health and Johns Hopkins University. Neither study revealed any clear exposure/disease associations for lung cancer, although the Johns Hopkins study findings were suggestive of an elevated lung cancer risk in workers employed in shipping and drying jobs where radiation and dust exposures were assumed to be highest. The present study was an update of the original UNC study. The same cohort of male workers from the UNC study was included in our update. In the update, we examined the cohort's mortality patterns during the years 1949-92, thus adding 14 years of follow-up to the UNC study. In addition, separate analyses were performed and are presented for female workers. The principal focus of our update was lung cancer. The goals of the study were: 1) to determine whether phosphate industry workers have experienced increased risks from lung cancer and other diseases compared to national, state, and local county rates; 2) to determine whether there have been lung cancer hazards concentrated in various work areas or jobs; and 3) to examine associations between lung cancer and exposures to specific chemical and physical agents. The agents considered were: total dust, silica, sulfuric and phosphoric acid mists, fluorides, ammonia, alpha radiation, gamma radiation, and elemental phosphorus.

The cohort included 18,446 white male, 4,546 non-white male, 1,523 white female, and 306 non-white female workers. The median duration of follow-up for the race/gender groups ranged from 17 to 23 years. Vital status as of the end date of the study, December 31, 1992, was ascertained for 98 percent of male workers, and 96 percent of female workers. Death certificates indicating cause of death were obtained for 95 percent of identified decedents.

The first set of analyses compared mortality rates, by cause of death, between the cohort and the national, state, and local county rates. Standardized mortality ratios (SMR) were computed to estimate relative excesses and deficits of mortality in the cohort. An SMR of 1.0 indicates that mortality in the cohort was identical to that in the comparison population (e.g., national population), whereas an SMR greater than 1 .0 indicates a relative excess in the cohort, and an SMR less than 1.0 reveals a relative deficit in the cohort. Among white males, total mortality was nearly identical (SMR=0.99) to that of the U.S. white male population during the same time period, 1949-92. A small excess of lung cancer was observed for white male workers compared to U.S. (SMR=1.19) and Florida state (SMR= 1.12) rates; however, compared to local county rates there was no overall lung cancer excess (SMR=0.98). Non-white males experienced a deficit of all causes mortality combined compared to U.S. rates (SMR =0.80). There was a small excess of lung cancer in non-white males relative to U.S. rates (SMR=1.13), but no elevations compared to either state (SMR=0.95) or county rates (SMR=0.94). White females had lower than expected mortality for all causes (SMR =0.80), and lung cancer (SMR=0.80) when national rate comparisons were made. Similar lung cancer deficits were found for white female workers relative to state and county rates. The small numbers of total deaths (22) and from lung cancer (1) in non-white females precluded a meaningful interpretation of their mortality data. Mortality from diseases other than lung cancer was largely unremarkable in all race/gender worker groups.

On the whole, the mortality patterns of the workforce did not demonstrate excessive risks. The findings for non-white males were typical of the healthy worker effect, which is characterized by a lower all causes mortality rate in workers compared to national and regional populations. Selection for adequate health to gain and maintain employment is the principal reason for the healthy worker effect. White males did not experience a healthy worker effect, in regard to all causes and cardiovascular disease mortality, as would be anticipated. We have no explanation for the apparent differential healthy worker effect by race among males.

The detailed analyses that followed focused on lung cancer among male workers because lung cancer was of greatest prior interest. These analyses were limited to males because there were very small numbers of female workers in production jobs. We conducted a series of mortality rate comparisons among subgroups of the wolkers in which lung cancer risk was related first to employment duration in any of 23 job groupings defined according to process type, and second with respect to cumulative exposure to chemical and physical agents (total dust, silica, sulfuric and phosphoric acid mists, fluorides, ammonia, alpha radiation, and gamma radiation). The classification of exposures was not based on actual worker exposure levels because such data were sparse or in many instances missing. Instead, a qualitative exposure rating scale was devised in consultation with knowledgeable industry personnel. The cumulative index for each of the chemical and physical agents took into account exposure level differences between jobs and over time. Process changes and improvements in industrial engineering were reflected in the exposure rankings. A worker's cumulative exposure value for a particular agent (e.g., silica) thus represents the product of the duration of his exposure to the agent and the relative exposure intensity for that agent for each job held. Exposures occurring within the preceding 15 years were not included in these analyses under the assumption that 15 years is the average latency period for lung cancer.

There were no consistent associations observed between lung cancer mortality and employment duration in any of the 23 process groupings of jobs. The results for cumulative exposure to specific agents revealed only modest or irregular risk gradients. The most noteworthy findings were slightly increasing lung cancer risk trends with cumulative exposure to both alpha and gamma radiation among white males, but no associations with radiation in non-white male workers. Two other agents, silica and acid mists, had been linked etiologically with lung cancer in some previous studies of other industries, but we did not detect consistent or strong associations in this study.

The findings from this study are in general agreement with those of the original UNC study. There continue to be only small overall lung cancer excesses in males compared to national rates. Mortality rates from other diseases were usually less than national averages, which is consistent with a healthy worker effect selection phenomenon. Exploration of potentially causative relations with work in particular job types, or in relation to exposures to various chemical and physical agents, did not suggest evidence of a clear work-related hazard for lung cancer.

A possible association of lung cancer and ionizing radiation has heen of concern to the industry since the late 1970s. The observed trends of lung cancer risk with alpha and gamma radiation were not prominent and were seen only among whites. The absence of consistent relations between radiation and lung cancer in non-white workers weakens arguments of cause-and-effect. We did not find any strong associations with exposures to other agents, especially silica and acid mists which were of a priori interest. Our conclusions concerning lung cancer are that this disease has not occurred excessively throughout the industry, and that there are no identifiable occupational exposures that have created consistently elevated risks among segments of the workforce.

One important limitation of this study is that there was insufficient workplace exposure data spanning past time periods to enable a true quantitative assessment of exposure/disease associations. The net effect of this deficiency, which occurs quite commonly in occupational epidemiology studies, is that some true associations may be missed or, more likely, understated because of exposure classification errors. It is doubtful that we have failed to identify or have seriously underestimated important associations of phosphate industry exposures with lung cancer.

-From video, transcript of questions and answers of Other Uses Panel discussion:

POLICY PANEL QUESTIONS TO OTHER USES SPEAKERS

OHANIAN: The papers for this morning's presentation are on the table. There should be enough copies for everyone but if there is not, leave your name and we'll get it to you by mail. I also have to apologize and make a correction. We do have an EPA representative here from the Atlanta office, Paul Wagner. He is from the EPA radiation Atlanta office. The next panel is on several other uses of PG. The two people who couldn't be with us today, one of whom is Dr. Zeller, it turns out that he went to Bosnia. He is working on constructing housing using PG as a base. Also Nicholas Heyer from the University of Washington was unable to be with us this morning. We have his paper and if time allows our Executive Director, Dr. McFarlin, will give a brief summary of the paper.

COLEMAN: (To Kendron) You commented on the aggregates as having anti-skid qualities. Would you tell me who did that testing?

KENDRON: I received most of the figures from a company called Macasphalt which is located in Winter Haven.

GLASSMAN: (To Wilson) Was any follow-up research done on Cadmium levels that were found as far as health risks in the toadfish?

WILSON: No those were very recent results and we have not followed them up at all. We still have another six or seven months left on the project so we will address that.

GARRITY: (To Shieh) In your process did you notice any production of odors from using Calcium Sulfate because I know that when we have disposals of sheetrock in construction demolition debris landfills and other types of landfills, that kind of problem does arise. I was wondering if you noticed anything like that.

SHIEH: Yes. The process generates hydrogen sulfide. I think that is where the odor comes from. We expect that this is also an indication of the coolness??? of the process. Hydrogen sulfide production has been a concern. However, right now we have an approach to solve that problem. In landfill operation they use a flaming or flaring system to bum off hydrogen sulfide. Also, new technology is coming up that will convert hydrogen sulfide using a solar system. The Solar Energy Center has come up with a device which will do that. So with future technology, I think that the production of hydrogen sulfide could be beneficial to the sulfur production. Also an area of research, the hydrogen sulfide could react with the metal components in the municipal solid waste to form the metal sulfide precipitation. Without precipitation some trace metals that are an environmetal concern could be also precipitated out from the leachate. So that area requires some further investigation. We are not able to do it now.

GARRITY: This is a question submitted from the audience. It is addressed to Dr. Burnett. You mentioned trying to get some additional funds for research. The question is posed that if we were able to arrive at some agreeable way to permit more extensive use of phosphogypsum, would there be ways for the money saved by the industry to be used to fund research such as you're talking about. So I guess that the question goes beyond just yourself.

BURNETT: I think that question raises an interesting point. I think it is better answered by someone from the phosphate industry because I don't really know. My understanding is that with the current rule from DEP that the closure is going to be paid for by the industry. Those costs are obviously passed on to the consumer. It's an interesting point and I would definitely support it. The main point I was trying to make was that I think that research is an optimistic way of looking at a problem because you don't get involved with research unless you think your going to find a solution. My feeling is that there are solutions. You've heard some very creative ideas today. With a concerted effort, even short term 3 to 5 years, with that kind of funding basis, I think you could come up with some things that have not even been thought of.

YOUNG: (To Shieh) You suggest that your work is now ready for field investigation. Do you in fact intend to proceed with field investigation ? Do the current rules even allow a field investigation? Are you going to be using a municipal land fill and do you need a test site?

SHIEH: From the research viewpoint, I hope that I can carry on a field study but right now the EPA has a limitation in terms of the quantity of PG that can be used so that issue needs to be addressed. If the EPA cannot lift that limitation, even though we have very positive levels that the results show that this would be a good approach, then further studies may not even be a question. If this is a research project, the EPA may allow us to use more PG for the purpose of the study.

COLEMAN: Dr. Wilson, I had several questions from the audience. I think one will basically sum it up. What were the results of comparing the meiofauna and shrimp treated and control populations with respect to cadmium and other substances?

WILSON: That analysis is being done right now. We just harvested the pond two months ago and we don't have any heavy metal data from the organisms that were reared in the two ponds yet, or the tanks, that's being done right now. Except for the fish.

COLEMAN: There was a follow-up question and that is, are we to understand that only a two week period was chosen for shrimp feeding?

WILSON: Yes.

COLEMAN: Are you sure that's long enough?

WILSON: No. By no means. This was our first shot at doing it and in a bioaccumulation study that is a very good question, 'how long do you run an experiment like that?' We certainly like to raise the shrimp from hatch all the way up to harvest size, or a size at which they would be consumed, and that would be a follow-up study. But this was our first pass at doing it with very limited funds.

OHANIAN: We would like to thank the other uses panel. Thank you very much.

DESIGN, CONSTRUCTION AND EVALUATION OF EXPERIMENTAL STABILIZED GYPSUM ROADBASES

BY

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Dr. Saylak joined the Materials Science Division of the Civil Engineering Department at Texas A&M University in 1972. He holds a joint appointment with the Texas Transportation Institute and is the Director of the By-Products Utilization and Recycling Research Center. Prior to this, he was Head of the Engininneering Mechanics Laboratory at Thiokol Chemical Corporation and Chief of the Mechanical Behavior Section at the Air Force Rocker Propulsion Laboratory. His research activities have included pavement materials development and testing, recycling, experimental mechanics, fracture and age-life prediction of polymeric materials. He has numerous publications in each of these areas. He served as Chairman of the Joint Army-Navy-NASA-Air Force Working Group on Mechanical Behavior of Solid Propellant, was named AIAA Outstanding Contributor of the Year (1969) and received the Air Force Systems Command Award for Distinguished Research and Development (1970).

Dr Saylak holds a bachelor's degree from the University of Pittsburgh, a master's degree from the University of Delaware and the Ph.D. from Texas A&M University.

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Introduction

Rising costs associated with assuring high quality construction and maintenance of highway systems is spurring the continued development of more cost effective construction methods and materials. Waste and "pollution" by-product gypsums from coal-burning power plants, hydrofluoric acid, and phosphoric acid production industries are currently being given considerable attention in Texas, Louisiana, Florida and other states.

A number of researchers (1, 2, 3, 4, 5) have provided evidence that by-product gypsum can be used as a roadbase or subbase material through stabilization with either portland cement, fly ash or combinations of both. When properly mixed, compacted and cured, these materials will develop sufficient strength for field applications. Both laboratory and field results show that gypsum, when sufficiently stabilized and compacted should qualify for most roadbase and subbase applications.

Roadbases for city streets, shopping centers, truck terminals, parking lots and loading platforms have been successfully constructed in the Houston area of Texas using cement and fly ash-stabilized Phosphogypsum and Fluorogypsum. Personal contacts with two suppliers; Gulf States Materials (Fluorogypsum) (6) and Mobil Chemical Compay near Pasadena, Texas (Phosphogypsum) have revealed a better-than 95 percent success rate on over 700 projects (7). TTI was involved in the mix design development of the base courses utilizing both of these by-product gypsums (8, 9, 10). The use of Phosphogypsum has been discontinued due to concerns resulting from excessive radon and heavy metal concentrations in this by-product.

Problem Areas with By-Product Gypsum Roadbase Construction

It is when attempts were made to extend the stabilized-gypsum roadbase concept to state and federal roads that construction difficulties have been encountered. One project using a ten percent cement-stabilized phosphogypsum base on Texas SH 146 proved unsuccessful (11). Two other projects in Texas (5) using varying amounts of fly ash and cement as stabilizers also had to be replaced after less than a year in service. In virtually every case, when construction difficulties were encountered, the problems could be related to one or more of the following sources:

a. Excessive moisture added during construction.
b. Over stabilization.
c. Incomplete mixing.
d. Incompatible stabilizers, prime coats, etc.
e. Insufficient compaction and weather scaling.
f. Road opened to traffic too soon.

a. **Moisture:** Overwatering in the field, either while trying to achieve a specified moisture content or to maintain dust control, will weaken the base during its most critical period of strength development. One of the prime locations for this type of damage is at transitions from one day's work to the next. An improperly prepared transition at the end of a roadway or when changing from one mix design to another are also potentially vulnerable to swelling due to the accumulation of excessive moisture or improper compaction.

b. **Stabilization:** Different states qualify their allowable strengths for stabilized bases based on different numbers of days permitted for curing. For example, Texas requires 650 psi strength after seven days, whereas Illinois specifies 650 psi after fourteen days. Strengths above 350 psi are considered sufficient for light to medium traffic loads. Strengths from 550 to 650 psi are required for medium to heavy traffic loading. The chemical interaction between gypsum and cement is one which proceeds at a slow rate of hydration. The rate is further affected by the need to use slower curing sulfate resistant cements. As a consequence, the inability to reach a required seven-day strength is usually compensated by adding excessive stabilizer.

c. **Mixing:** Blending of mix ingredients can be accomplished successfully either in-place (2) or in a pug mill (5). The latter has advantages of allowing for field calibration checks to ensure compliance with job mix specifications, and achieving good mix homogeneity. Smaller projects, or projects which cannot be conveniently located near a pug mill, may favor mixing in-place. In any case, the ability to deliver good mix homogeneity is imperative. Experience with one project in Texas indicated that the lower two inches of an 8-inch base constructed by mixing in-place was not successfully blended by the pulverizer (5). This problem could have been alleviated by constructing the section in multiple lifts or using a pulverizer with longer tines. Unfortunately, these deficiencies are not normally encountered until core samples are taken usually long after the road has been opened to traffic.

d. **Incompatible Stabilizers and Prime Coats:** Cement type and content have a great influence on strength development in stabilized byproduct gypsum mixtures. Tricalcium aluminate (C_3A) is one of the principal aluminate compounds in portland cement. To achieve sulfate resistance in portland cement concretes ASTM C150 recommends that the C_3A content in Type II cements should be kept below seven percent. Studies involving cement-stabilization of gypsum-based mixtures have shown that C_3A contents no greater than 4 percent should be used to prevent sulfate attack and swelling (1, 5). The hydration of C_3A in portland cement involves a reaction with sulfate ions which are supplied by the dissolution of gypsum. The primary initial reaction is:

$$C_3A + 3CSH_2 + 26H \longrightarrow C_6AS_3H_{32} \text{ (Ettringite)}$$

Ettringite is a stable hydration product only while there is an ample supply of sulfate available. If all the sulfate is consumed before the C_3A has completely hydrated, the Ettringite transforms to a monosulfoaluminate (MSA) which contains less sulfate.

$$2C_3A + C_6AS_3H_{32} + 4H \longrightarrow 3C_4ASH_{12}\text{(MSA)}$$

When monosulfoaluminate is brought into contact with a new source of sulfate ions, Ettringite is reformed.

$$C_4ASH_{12} + 2CSH_2 + 16H \longrightarrow C_6AS_3H_{32}$$

This potential for reforming Ettringite is the basis for sulfate attack of portland cements when exposed to an external supply of sulfate ions. Once Ettringite has formed, it continues to grow expansively. If the temperature of the system drops below approximately 15°C (59°F), Ettringite, through a series of intermediate compositions is transformed to Thaumsite, (12), a complex calcium- silicate- hydroxide- sulfate- carbonate- hydrate mineral. Both Ettringite and Thaumsite are hydrous minerals. Without an abundance of water or excessive C_3A they cannot form.

Typical mixtures of cement stabilized by-product gypsum contain between 3 and 8 percent cement. The remainder of the mix ingredients is gypsum and water. Therefore, it is correct to assume that there is a large supply of sulfate ions available to hydrate all the aluminate ions in the cement. Monosulfoaluminate, C_4ASH_{12} will never form since there is no sulfate ion deficiency and consequently the phenomenon of reforming Ettringite in poland cement does not apply to by-product gypsum systems. However, Thaumsite may form at temperatures below 15°C. Since both Ettringite and Thaumsite are expansive products, extreme caution should be taken in the indiscriminate specification of sulfate-resistant cements and mortars to be used for the stabilization of by-product gypsum.

For many years, fly ash (primarily Class C) has been widely utilized in concrete as a partial replacement of cement. Presently, research is underway in Canada (CANMET) and at Texas A&M to increase the weight percentage of fly ash used as a cement substitute from the typical 25 percent levels to 50-60 percent for many structural and mass concrete applications (2). At these levels the mixtures are referred to as high-volume fly ash (HVFA) concretes. Aside from the work in Canada, Great Britain and Australia, very little work on HVFA concretes especially those using Class F ash has been done in the United States.

Up to the late 1970's concretes containing fly ash also referred to as "pozzolanic cements" were generally proportioned by modifying traditional concretes containing portland cement, by replacing part of the cement content with fly ash. Since portland cement is produced at the expense of substantial amounts of energy, a partial substitution of portland cement by fly ash, which is generally available at comparatively lower prices, would clearly represent a cost-effective use of both materials. Furthermore, there is evidence that fly ash is able to improve workability, durability and ultimate strength and to reduce the heat of hydration creep and drying shrinkage (3). The incorporation of Class F fly ash has also shown to significantly enhance sulfate resistance. This could permit the use of HVFA concretes using cheaper Type I cements instead of the higher-cost, less available low C_3A (i.e. high sulfate resistant) cements to stabilize by-product gypsums. Test results show that the HVFA laboratory concretes can meet or exceed the demands of most normal structural applications (4). It is well known that during 1994 many concrete construction jobs had to be put on hold for lack of cement. It could be assumed that HVFA concrete could represent an attractive low cost alternatively reducing or extending the demand for concrete.

Two prime coats which have shown to work well as a seal over compacted stabilized gypsum bases have been MC30 and RC250 cutback asphalts. Attempts to use emulsions on cement-treated bases have proven unsuccessful since they tend to add additional water to the surface while it is in its initial curing phase and most vulnerable. The presence of this excess water increases the water to cement ratio and tends to create a weak shear plane about 0.5 inches below the surface during compaction subsequently compromising the integrity of the entire base when traffic is introduced or when deep freeze climates are encountered.

e. **Compaction and Sealing:** Degree and type of compaction are critical factors affecting the ultimate strength achieved in stabilized gypsum bases. The effect of compaction on both optimum moisture content and dry density and consequently on tensile and unconfined compressive strength has been well established. The specification of a field density testing method should be coordinated with the local state highway department. Similar to state standards for 7-day strengths, some deviation from standard practice should be permitted in the determination of laboratory density values given the slow hydration rates encountered when mixing gypsum with cement.

A set of recommended testing procedures and material selection for phosphogypsum mixtures criteria were and have been shown to be applicable for other types of gypsums developed by Saylak et. al., (9). The laboratory compaction recommended for stabilized gypsum is Modified Proctor as prescribed by ASTM D1557 which delivers 32.6 ft-lb/in^3 of energy to the specimen (12). The Texas Department of Transportation uses its own Modified Proctor test and specimen configuration under Texas Method 113-E which only delivers 13.3 ft-lb/in^3 of energy and would predict a higher optimum moisture content and consequently achieve a lower strength than would be obtained using ASTM D1557. Using Texas Method 113-E on stabilized-gypsum base mixtures tends to produce non-conservative decision criteria for the design of roadbases by usually indicating an unnecessary need for more water and stabilizer.

Insufficient sealing of the base can make it susceptible to premature damage. Two treatments of a standard chip seal surface treatment or a one and a half to two inch thick highway department approved hot mix asphalt concrete wearing coarse has been found to be effective.

Experimental Field Tests

Since 1988, TTI has constructed several experimental test sections directed towards establishing a materials selection criteria, suitable mix design rationale and construction procedures to permit stabilized Phosphogypsum roadbases to perform on Texas State roadways. More recently the concepts generated out of these projects were successfully demonstrated during the Summer of 1991 when a 2-lane, 300-foot long test section was placed at Texas A&M's Riverside Campus, The roadbase consisted of 7-percent cement stabilized by-product gypsums mixture with a 7-day unconfined compression strength of 450 psi. Post construction field tests are indication that the integrity of this road is sound, with no signs of incipient distress. Falling Weight Deflectometer data indicate the roadbase, after 36-months of service, is still maintaining its strength.

A second experimental test section was built during the Summer of 1992 whose roadbase was comprised of a 50/50 blend of gypsum and bottom ash; the latter at a ratio of 3 parts boiler slag to 1 part cinder ash. The mixture was stabilized with 7 percent of a high early strength sulfate resistant (C_3A = 2.3) Portland cement and achieved a 7-day compression strength of 850 psi. A 22-month post-construction evaluation of the roadway was carried out involving visual and state-of-the-art pavement performance monitoring technology. The results were compared with those of the test section built in 1991 that did not contain bottom ash indicates the latter section to be stiffer with enhanced resistance to permanent deformation compared to the 1991 section. Except for some "block-type" surface cracking which appeared only in the 1992 section and was attributed to an unstabilized expansive subgrade, both sections are in excellent condition and performing well. It is suggested that care should be taken with future roadbase mix designs not to overstabilize and that 7-day compressive strengths be in the range of 450 to 550 psi.

Two additional road sections were built in 1993 using a Class C fly ash and a cement fly ash blend respectively as stabilizers. After two years these sections are performing well and show little sign of incipient failure.

The environmental impact of the 1991, 1992 and 1993 roadbases was evaluated through TCLP analysis of mixture components along with ground water, surface water and leachates. The concentrations of chemical components tested were found to be either negligible or well below their respective EPA allowables.

Conclusion

Research on other types of by-product gypsums has continued following the EPA restriction in use of Phosphogypsum. The results of laboratory and field test indicate that mix design rationale and construction procedures successfully demonstrated on these gypsums can applied to Phosphogypsum as well.

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POLK COUNTY EXPERIMENTAL ROAD

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Mr. Kenley has been County Engineer of Polk County since 1984. Before becoming County engineer, he spent seven years as Assistant County Engineer in charge of road and bridge maintenance and construction. Mr. Kenley also spent 22 years in private practice with consulting engineers doing a wide variety of civil engineering work, including supervising design and construction of subdivisions, industrial sites, and public works projects. He is currently the southeast Regional Vice President of the National Association of County Engineers and past president of the Ridge Branch Florida section of the American Society of Civil Engineers and the Florida Association of County Engineers and Road Superintendents. He has served terms as Chairman of the Florida Advisory Committee to Polk County MPO and has served on the Florida Technology Transfer Center Advisory Committee.

Mr. Kenley has a Bachelor's degree in Civil Engineering from the University of Illinois and is registered as a Professional Engineer and a Professional Land Surveyor in Florida and Illinois.

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In October 1986, the Polk County Division of Public Works built an experimental road utilizing phosphogypsum mixtures. This one and one-half miles of secondary road is located south of US 98 and east of Fort Meade (1).

The experimental project was to provide alternate methods of rebuilding county and other secondary roads in Florida. It was intended to provide comparable or better material to repair or replace existing roads with the best possible utilization of locally available aggregates.

Construction practice in building these secondary roads consists of mixing generally granular soil subgrade with fine grained soils transported to the site. Granular soil such as sand is abundant throughout Florida. However, lack of adequate source of fine-grained soils such as clay, has been a major concern of builders of such roads. Furthermore, it has been found that roads built with clay-sand mixtures tend to be greatly affected by changes in moisture regime, tending to become soft and muddy during the long and rainy summer. This prompted the Polk County Division of Public Works to take the initiative in finding alternative methods of rebuilding their roads.

The design and testing of the road was a collective effort of the University of Miami, the Florida Department of Transportation and Polk County. The road was built by the Polk County Division of Public Works, and phosphogypsum used for the project was supplied by the US Agri-Chemicals. The experimental project called for a thorough environmental impact investigation which include pre and post construction sampling of air, soil and groundwater. Environmental monitoring, conducted by the University of Miami and the Florida Institute of Phosphate Research in cooperation with the Florida Department of Environmental Regulation and the Florida Department of Health and Rehabilitative Services, detected no significant environmental impacts (2)(3). Construction was as follows: The existing road surface layer was levelled with a motor grader and compacted.

Phosphogypsum at its natural moisture content was delivered by means of dump trucks and evenly spread to meet the appropriate lift thickness. A pulvimixer was used to thoroughly mix the phosphogypsum with the subgrade material. Following the mixing phase, the road cross-section profile was shaped according to the design drawings. The road was then compacted and the asphalt laid down atop the phosphogypsum base.

The road has been open to traffic since October 1986. The experimental project has successfully demonstrated the use of phosphogypsum in road construction. Evaluation of the construction crew was as follows:

1. Phosphogypsum can be used as a binder for base course mixture.

2. Phosphogypsum mixtures are easier to work with than clay mixtures.

3. Operation at cost including equipment time for constructing phosphogypsum roads are lower than that of clay roads.

4. Rain storms during construction did not cause excessive delays because the compacted mixture did not absorb water to any great extent.

5. Shrinkage cracks, frequently occurring in clay roads, did not appear in this construction.

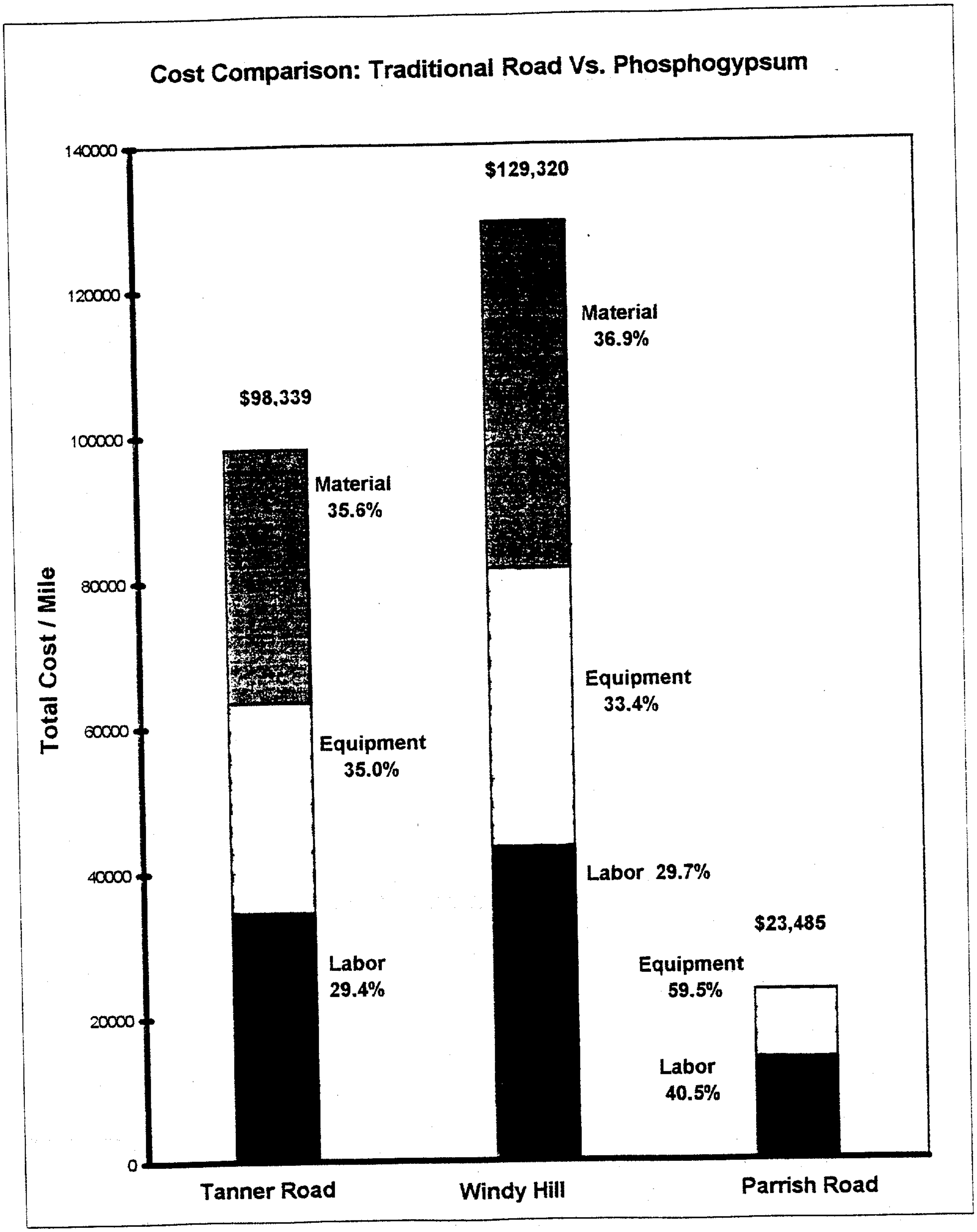
6. The stability of compacted phosphogypsum mixtures is superior to that of clay mixtures.

To date, Parrish Road has performed as well as any traditionally constructed road.

In order to accurately determine the cost of building a secondary road utilizing phosphogypsum, the University of Miami Department of Industrial Engineering prepared a detailed analysis and comparison of the construction cost for Parrish Road and two similar roads built with traditional materials (4).

The cost analysis (Figure 1) makes it obvious why Polk County would use phosphogypsum for secondary roads if not prohibited by EPA regulations. Polk County faces the same problems faced by the other counties and even the state, never having enough money to build and adequately maintain their road systems. While we would not want to claim that every road project would have the same cost advantage as Parrish Road shown in this graphic comparison, we are convinced that our road building and maintenance monies would go much farther using phosphogypsum.

Earlier this year I read a newspaper article (5) that estimated that state transportation funding had a projected long-term short fall of up to $30 billion and I cannot help but wonder if the planned research on phosphogypsum primary road construction that was curtailed after the EPA prohibition on phosphogypsum use, would have provided the answers that would enable our state not only to maintain but to actually upgrade our existing highway system, without the need for additional tax dollars.


Cost Comparison: Traditional Road Vs. Phosphogypsum
Total Cost / Mile
140000
120000
100000
80000
60000
40000
20000
0
$98,339
Material
35.6%
Equipment
35.0%
Labor
29.4%
$129,320
Material
36.9%
Equipment
33.4%
Labor 29.7%
$23,485
Equipment
59.5%
Labor
40.5%
Tanner Road
Windy Hill
Parrish Road

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PRELIMINARY INVESTIGATION OF PHOSPHOGYPSUM FOR EMBANKMENT CONSTRUCTION

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Author: Robert Ho, Florida Department of Transportation.

Dr. Ho is head of the Materials and Research Section of the state DOT where he has spent more than 24 years working with soils, materials, aggregates and road construction problems statewide as well as testing and variability studies for specification preparation. Dr. Ho also spent six years with geotechnical consulting engineers in Hong Kong and Canada. He has published reports on using phosphogypsum to construct experimental roads and embankments.

Dr. Ho earned a Bachelor's of Science degree in Hong Kong, a Master's degree in English at McGill University in Canada and a Ph.D. at the University of Florida.

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Over the years phosphogypsum, a waste by-product of phosphoric acid production, has been accumulating at phosphate mining sites in Florida. This waste material has been used as base and fill material for local haul roads in the phosphate mines. It is believed that this abundant waste material can provide an economical source of fill for some suitable local projects.

As part of a research program on the investigation of waste materials for use in highway construction, the State Materials Office in 1982 conducted a preliminary study on phosphogypsum as a potential fill material in embankment construction.

Laboratory Tests

Seven sources of phosphogypsum from various mining sites around the state were selected for the study. A comprehensive laboratory testing program was performed on samples from all the sources. These tests include:

1. Grain size distribution
2. Plasticity tests
3. Specific gravity
4. Moisture - density relationship (how well they compact)
5. Limerock bearing ratio (LBR) and triaxial compression tests (for strength)
6. Permeability
7. Gypsum content and pH (acidity)

All tests were conducted in replicates of three to determine the inherent variability between samples.

Test Pit Study

The phosphogypsum was placed in the test pit and compacted to a specified density. A cyclic load of 50 psi (one cycle for every 2.5 seconds) was applied through a 12-inch diameter circular plate. This is to simulate moving traffic wheel load. Ten thousand cycles were applied in an 8-hour day. The settlement of the plate together with the number of applied load cycles were recorded to determine the performance of the material under traffic load. Results were plotted on a semi-log plot.

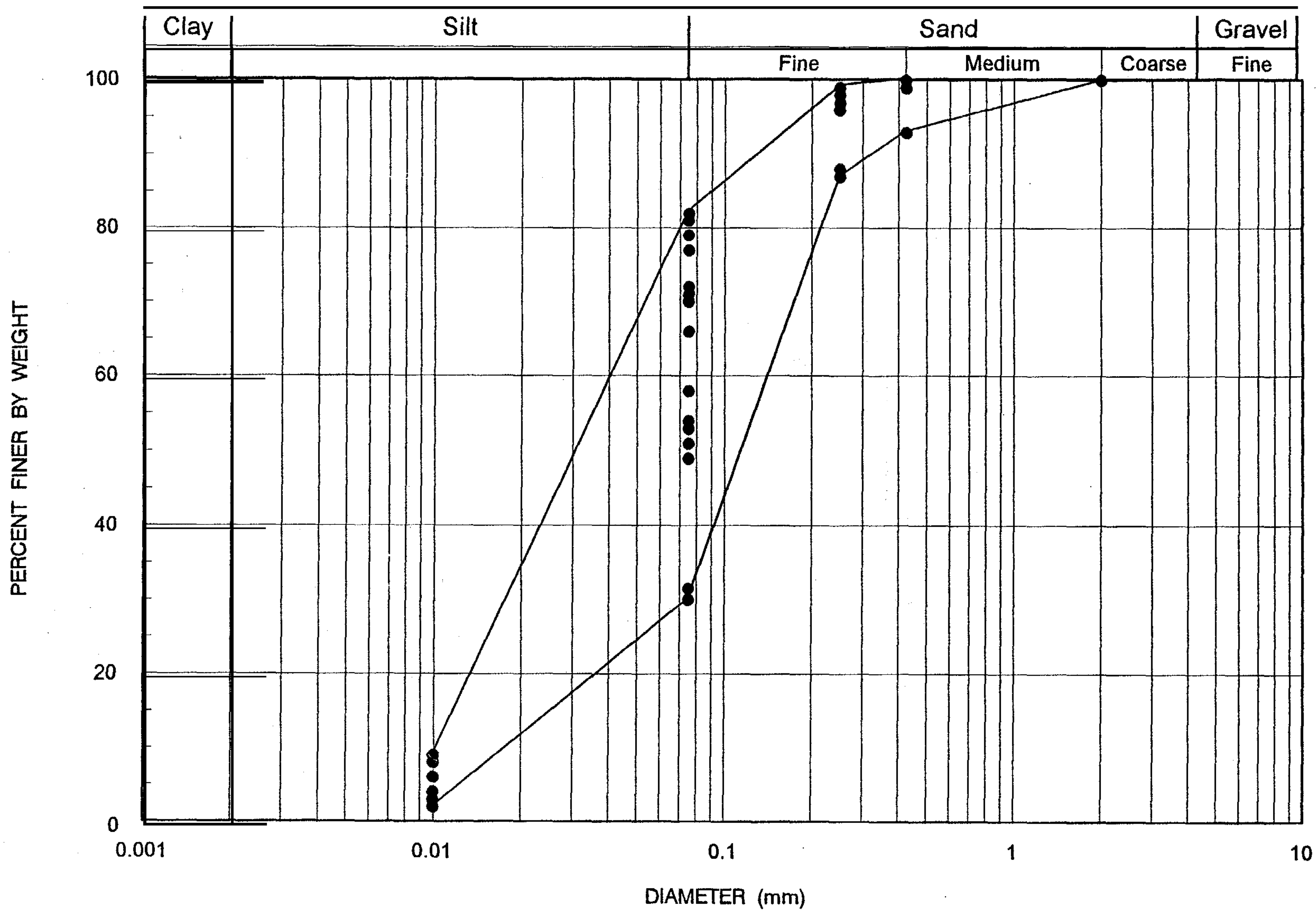
Test Results and Discussion

Test results indicated engineering properties of phosphogypsum vary from source to source. These differences are manifested in their grain size distribution, percentage of fines, bearing strength and deformation under cyclic loading.

According to the soil classification procedure used by all State DOT's, phosphogypsum is classified as a A-4 silty soil with a rating of fair to poor as a subgrade material. Florida DOT design standard only permits A-4 silty soil be used at least 5 feet below grade elevation and above the water table. That means that only embankments greater than 5 feet above the water table can phosphogypsum be used provided that leachate through the embankment will not affect water quality or other environmental constraints.

One field problem that has not been investigated is the moving and handling of large quantities of phosphogypsum. Because of the silty nature of the material, it is very sensitive to moisture during compaction especially on the wet side of optimum moisture content. Handling and placing of this material should be avoided during the rainy season.

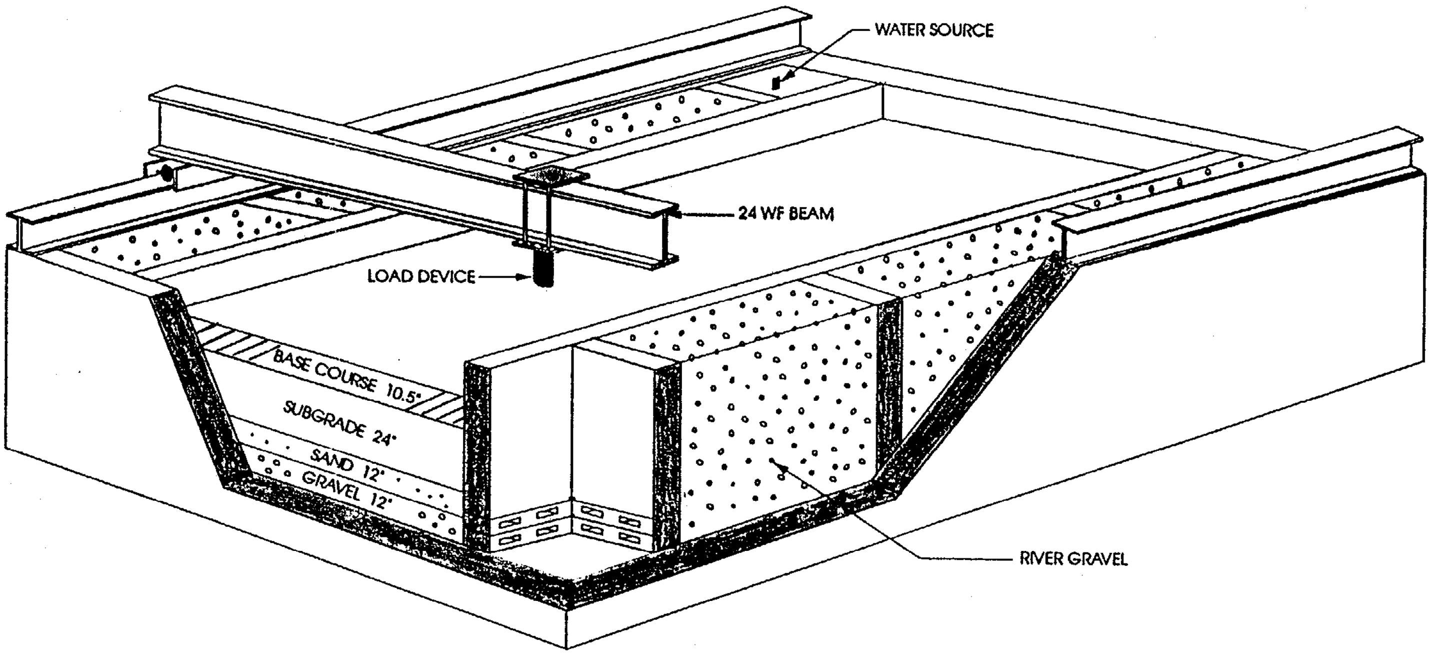
This preliminary study on unstabilized phosphogypsum indicated that the material may be used in embankment projects provided environmental constraints can be met and also be competitive with local fill material. Research done by others have indicated that phosphogypsum stabilized with cement may be used as a roadway base.



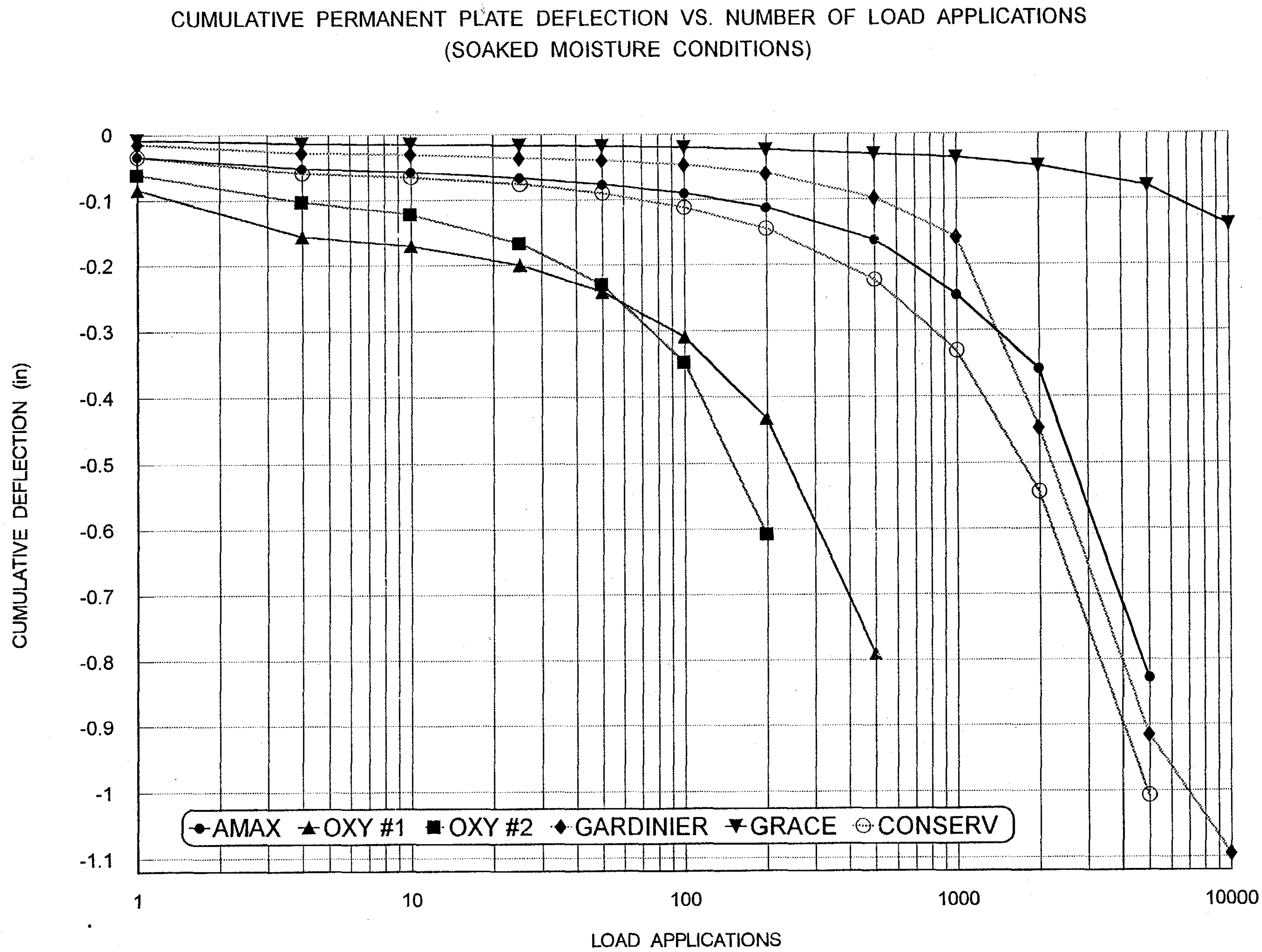
GRAIN SIZE DISTRIBUTION OF SEVEN GYPSUM SOURCES

Classification of Soils

General Classification	Granular Materials	Silt - Clay Materials	
Group Classification	A-1, A-3, A-2-4	A-4, A-5	A-6, A-7
Material Type	Gravel, Fine Sand, Silty Sand	Silty Soils	Clayey Soils
Rating	Excellent to Good	Fair to Poor	



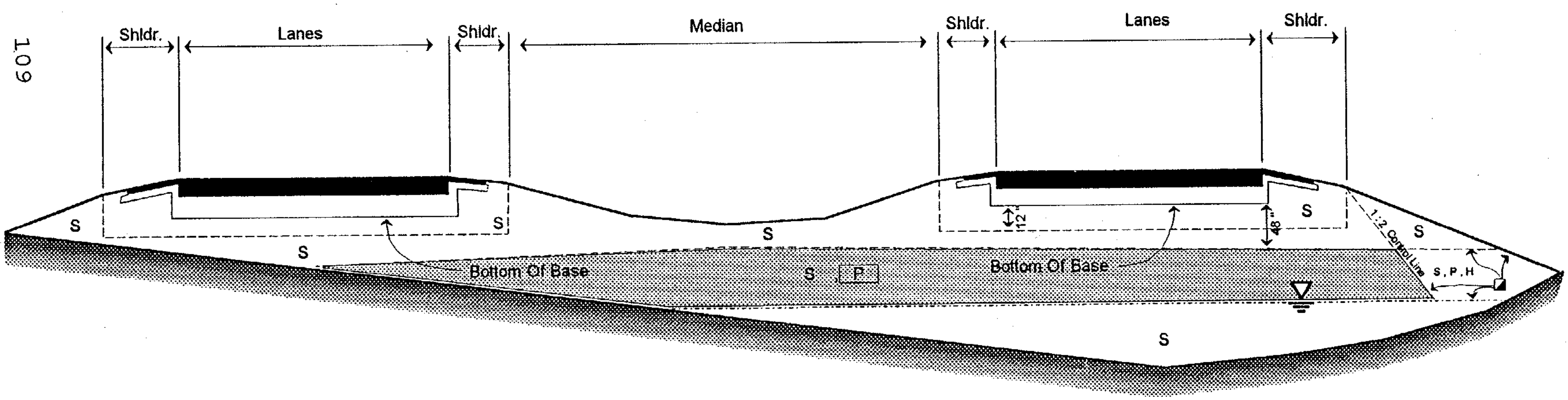
A SECTIONAL VIEW OF THE TEST-PIT



CUMULATIVE PERMANENT PLATE DEFLECTION VS. NUMBER OF LOAD APPLICATIONS
(SOAKED MOISTURE CONDITIONS)
CUMULATIVE DEFLECTION (in)
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
1
10
100
1000
10000
LOAD APPLICATIONS
AMAX
OXY #1
OXY #2
GARDINIER
GRACE
CONSERV

SYMBOL	SOIL	CLASSIFICATION (AASHTO M - 145)
S	Select	A-1, A-3, A-2-4
P	Plastic	A-2-5, A-2-6, A-2-7, A-4, A-5, A-6, A-7 (ALL With LL < 50)
H	High Plastic	A-2-5, A-2-7, A-5, Or A-7 (ALL WITH LL > 50)

1.09



EMBANKMENT - DIVIDED ROADWAYS

THE USE OF PHOSPHOGYPSUM IN ROAD CONSTRUCTION

BY

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INSTITUTE FOR RECYCLABLE MATERIALS
LOUISIANA STATE UNIVERSITY

****

Author: J.B. Metcalf, Louisiana State University.

Dr. Metcalf was appointed Freeport-McMoRan Chaired Professor of Engineering at Louisiana State in 1992 and joined the Institute for Recyclable Materials, which is conducting a research program to investigate the utilization of phosphogypsum. Dr. Metcalf has experience in engineering and road construction worldwide. His interest is in low cost roads, non-standard pavement materials, pavement design, construction quality control and technology transfer. He has worked in the United Kingdom, Canada, and Australia where he was materials engineer with the Queensland Main Road Department from 1964-1969 and was appointed Deputy Director of the Australian Road Research Board in 1975. He is the author of some 80 technical papers and has been the keynote speaker at national and international conferences. He has acted as a consultant/advisor to the United Nations, the World Bank, the Australian International Development Assistance Bureau, the Kingdom of Saudi Arabia, Australian Federal and State Road Authorities, and various branches of industry. Dr. Metcalf is currently an advisor to the Federal Highway Administration.

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The material

Phosphogypsum is a tine grained material composed of crystals of gypsum (Calcium Sulphate Di-hydrate) with small quantities of impurities, usually less than 20 per cent, of which about half is silica. The pH ranges from 3-5. Phosphogypsum has a specific gravity of 2.35, close to that of soils. On average about 75 per cent of the material will pass the No 200 sieve.

Phosphogypsum can also be processed for recovery of sulphuric acid to yield a slag by-product. This material consists mainly of iron oxides, calcium silicate compounds and an amorphous glass and is formed as irregular rough and honeycombed aggregate of about 30 mm maximum particle size. It is non plastic.

The Institute for Recyclable Materials has identified applications of Phosphogypsum (1).

The road engineering properties

Phosphogypsum can be classified as a silty soil(2), an A-4 or ML soil, with little or no plasticity. It is available in bulk from stockpiles at several locations in the USA, and overseas. In the stockpiles it contains some water, often in the range from 8-18 percent and varying with depth, but can usually be taken from mature stockpiles in a form very similar to a damp soil. The fact that it can be stockpiled to substantial heights indicates that it is not entirely unsuitable for fill and embankment construction but any silt-like material is inherently unstable, particularly when water is present. It is easily eroded, relatively impervious and very susceptible to frost heave.

It can be compacted to a dry unit weight of between 80 and 100 pcf at optimum moisture content of 12-20 per cent, when a CBR (California Bearing Ratio) of about 30 can be measured (3). However, because the material is soluble it is not suitable for road pavement construction in the untreated state.

A number of laboratory studies of methods to improve me material for use in roads have been conducted using cement stabilization. In this process, a small (4-15 per cent) amount of cement is mixed with soil, usually in place, and the mixture is compacted and cured. Full scale experimental road sections also have been placed, in Florida and Texas (3,4).

The critical properties required of cement stabilized road base are compressive strength and durability; which are very closely related. A typical specification for cement stabilized road base requires that the compressive strength of the mix, after compaction and curing, reach a minimum figure. The Louisiana Department of Transportation and Development, for example, until 1992, specified a minimum of 250 psi after 7 days. The Department now requires a minimum cement content for soils which is prescribed by soil type and Parish, usually between 8 and 12 percent, but up to 15 per cent is necessary for some soils. At these cement contents there is little doubt that cement stabilized phosphogypsum will meet the previous strength criteria (4).

Thus most studies have sought to determine the appropriate mix to achieve the required compressive strength and to evaluate the treated phosphogypsum against other specification criteria. The results achieved with phosphogypsum and cement alone may be marginally low when the early (7 day) strength is considered, and ways to improve early strengths have included the addition of fine grained soils or sand to the mix, or more recently, the use of a cement set accelerator. Both methods proved effective and it has been demonstrated in the laboratory that cement stabilized phosphogypsum can meet the usual specification requirements for road base (6).

The slag will meet LADOTD specifications for aggregate and EPA toxicity and TCLP leachate standards. A feature of the aggregate process that it reduces the radon emanation (7). The material has been shown to meet LADOTD hot mix asphalt requirements with 6.5 % binder (8). More work is necessary to quantify stripping and frictional parameters.

The use of many natural, by-product or recycled materials for road construction is constrained by conservative specifications and, whilst the first evaluation of any material must be against the existing standards, there is also potential for the examination of the standards and modification of the requirements to reflect our increasing knowledge of the response of pavements to traffic loads (9). A major change in pavement design is being implemented in which the structural properties of the materials are evaluated, in the laboratory, under repeated loads to better simulate the real world. The measurement of the ‘resilient modulus’ of materials is becoming the accepted way of determining the structural capacity of road base materials and recent studies have followed this new approach, to establish appropriate testing protocols and design acceptance (10).

The research conducted at IRM showed the resilient moduli measured for cement stabilized phosphogypsum are usually lower than for most soil cement mixes but still adequate for road base construction. Studies of the aggregate resilient modulus are about to commence.

The problems

There are two concerns; the potential for dissolution and/or leaching of the mix, and the potential for volume change due to changes in water content and/or chemical reaction.

Laboratory tests show that leaching from cement stabilized phosphogypsum is well within EPA standards even under the extreme physical degradation applied in the TCLP test (11), in fact, the cement contributes more heavy metals than the phosphogypsum. Compaction and cementation effectively reduce the leachability of salts thus it appears unlikely that leaching of any potentially harmful component of the cement stabilized materials will occur, even where the road base is exposed to free water (3). The water environment under a road does not change very quickly because most construction materials have low permeability, and road surfaces are designed to be impermeable. The radon emissions are also reduced by compaction, which reduces the air and water permeability of the mass.

The potential for volume change is also constrained by the usually stable environment but there is a reaction between cement and phosphogypsum which forms the mineral ettringite, and in so doing can increase the volume of the mix. The potential for disruptive expansion is now being investigated but it may well be that this effect could offset an existing problem with cement stabilized soils, which is the formation of cracks due the tendency for cement treated materials to shrink.

Both leaching and volume change can be significant factors affecting the durability of cement stabilized phosphogypsum as road base and require further study.

The potential

One mile of secondary road will use about 5000 tons of phosphogypsum.

Laboratory tests show that cement stabilized phosphogypsum can meet typical specification requirements for cement stabilized soil for road bases at cement contents similar to those for Louisiana river silts. However, it is likely that most potential users will require some evidence of a successful application in practice before adopting stabilized phosphogypsum for bases. The trials in Florida and Texas were useful in this regard but the lack of follow up, caused in part by EPA regulations, has decreased the impact of these demonstrations.

It will require new full scale experiments to convince users that cement stabilized phosphogypsum road pavement bases can be effectively and economically constructed and that they will have adequate performance. Estimates of the design lives of stabilized phosphogypsum pavements were therefore made for a possible full scale experiment to be built within the Louisiana State University agricultural area (12). These estimates were based on a 12 per cent cement content for the phosphogypsum, selected to exceed the strength attained with a ten per cent river silt soil typical of the Baton Rouge area. A subgrade of clayey sand, with a CBR of 2-5 was determined, and a crushed limestone base was selected for comparison. The test results for the cement stabilized phosphogypsum showed a compressive strength of c. 450 psi at 28 days, which allowed for the interval between construction and trafficking of the road.

Assuming typical structural coefficient values for the limestone and asphalt surface courses and interpreting the strength and resilient modulus data for the phosphogypsum in terms of structural coefficients allowed comparable designs to be developed. Adopting the LADOTD standard base course thickness of 8.5 in, designs were compared using the AASHTO procedure to estimate pavement life. The results showed that for a road carrying 900 vehicles per day (a typical secondary road) for 20 years, cement stabilized phosphogypsum would be a viable competitor to the crushed limestone bases currently in common use.

The next steps

There remain three areas of study before cement stabilized phosphogypsum can confidently be marketed as road base. First, a more comprehensive study of the variability of phosphogypsum is needed, to ensure that a consistent product can be offered. This will require a laboratory program to measure strength and moduli for a substantial number of samples. Second, a better understanding of durability, particularly in relation to possible leaching and volume change effects will require further laboratory study. Third, one or more field demonstration projects will be necessary. Such demonstrations could take the form of test roads, subject to normal or some form of accelerated traffic, the former is slow the latter expensive, or an accelerated full scale test using the LTRC Pavement research facility.

The slag aggregate should now be assessed in the laboratory for suitability as unbound base aggregate and for cement and bitumen stabilized applications. The possibility of full scale trials of slag aggregate should be considered when a supply of the material is available.

Finally, the results of the studies will need to be assembled into an implementation package, including design guidelines, construction specifications, QA/QC procedures and a training manual.

The bottom line, as always will be the comparative economics of stockpiling versus utilization, or other disposal practice.

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CRITICAL, DOSE AND RISK ASSESSMENT FOR USE OF WASTE PRODUCT PG IN ROAD CONSTRUCTION

BY

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ACJ & ASSOCIATES
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Presenter: Anthony C. James, ACJ & Associates.

Dr. James has recently become an independent consultant after holding the position of Associate Professor in the College of Pharmacy at Washington State University. Prior to this Dr. James was the Chief Scientist in the Occupational and Environmental Health Protection Section of the Health Physics Department at Battelle, Pacific Northwest Laboratories. At Battelle, his primary research interest was in the development and application of dosimetry of body tissues in humans and experimental animals, in order to address issues involved in setting practical standards for radiological protection, and in relating cancer risks to environmental conditions of exposure. Before joining Battelle in 1988, Dr. James had 17 years of research experience, much of it relating to radon, at the National Radiological Protection Board, Chilton, United Kingdom.

Dr. James has a B.Sc. in physics from University College in London and received the Ph.D. degree from the Royal Free Hospital School of Medicine in London in 1969.

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Paper not available. The following is a transcription from video of Dr. James' presentation at the Forum.

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EPA, in their assessment, assumed that the concrete surface of the road had crumbled and had been removed. You just mentioned that it may not be a very sensible thing to assume. What we've got is the roadbed, either with the contaminated concrete as the slab or with the contaminated concrete, being removed and replaced with fresh concrete. The dimensions of the road base are about the same as the typical fill in the slab-on-grade house. We have not gotten very far with the specific calculations for this case, but it looks from our experience with the agricultural scenario that the numbers that EPA came up with, in terms of doses compared with concentrations, or the proportion of PG that is used in the roadbed agglomerate, relating those to indoor exposures are going to be in the right ballpark.

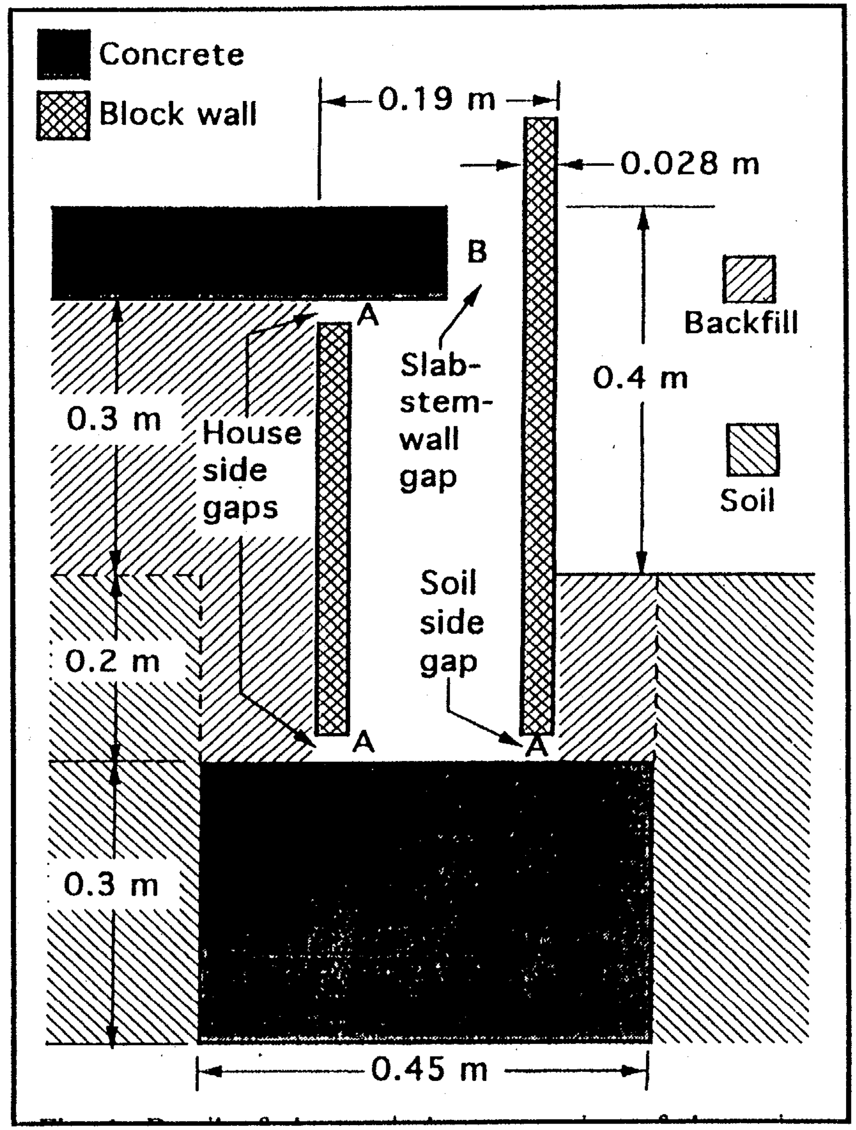
There are a couple of factors that do have an impact on this. EPA tries to assess the effect of moisture content on the emanation efficiency and the amount of radon that comes into the structure. A paper (Rutherford et al., 1995) was published in Canada in Health Physics just a couple of months ago which is very useful in this analysis. What was looked at was the effect of water saturation on the emanation coefficient of three different types of PG. One of the types studied was Florida PG, another type was from Idaho, and the third was from Togo, which is in Africa. Several samples were studied from each source and the results were really amazingly internally consistent. There does not seem to be too much dispute about the emanation coefficient that would be most appropriate to apply in these assessments. There also is a consistent picture of what happens with water saturation. Dry PG has a de-emanation coefficient that is relatively high but you notice that it is about a factor of 2 lower than the EPA standard assumption of 30 % . At moderate saturations the de-emanation coefficient drops further, but as the saturation goes up to 100% emanation becomes more efficient. It's unlikely that the 30% value assumed by the EPA would be realistic. That lower emanation coefficient was folded into the calculations that I showed you the results of earlier on. It's one of the factors that caused the assessment that was done in a very different way, including other determining physical factors, is one of the things that led to the same relationship between subsurface radium content and radon exposure indoors. So its fortuitous, but it happens to yield very similar numbers to EPA's.

We heard about size fractionation. These values apply to Florida PG. The bulk PG is the average for the whole sample. Several samples were size classified by settling in the coarse fraction with particles larger than 50 micron, medium fraction between 20 and 50 micron. You see that the size fractionation does not have much impact on the de-emanation efficiency. However, for the very fine particles less than 20 microns the emanation efficiency is quite substantially larger. This is not an important observation, however, because there is only a couple percent of the actual radioactive content present in the fine aggregate. So the emanation coefficient is pretty well determined and I think it agrees with what Chuck Roessler found quite some time ago.

In terms of the gamma dose calculation, it really depends on whether or not an additional level of shielding is put on; whether you come down below EPA's estimates or whether you come up with about the same conclusion. If we can sum up the position for the assessment of risk of building a home on a roadbed, in terms of EPA's criterion for acceptability, which is a lifetime risk coefficient of 3 in 10,000, it does not look like a very good prospect. So it's a different situation for the road building case and for the agricultural use. If you take reasonable application rates for agricultural use, then the calculated doses come down within EPA's acceptability criteria. But if you build a house on a roadbed, whether or not you leave the concrete in place; it's worse if you leave contaminated concrete in place rather than putting uncontaminated concrete on top, but with the astringent criteria of 3 in 10,000 as an acceptable lifetime risk, it will be hard to overcome that test of acceptability.

Detail of Floor and Wall for Florida Slab-on-Grade House Showing Backfill and Native Soil

(Revzan et al., 1993)



Preliminary Findings of Battelle's Study for Use of Waste Product PG in Road Construction

- ✔ Assuming no site excavation and no backfill with "uncontaminated" material, then EPA has overestimated lifetime risk from direct gamma irradiation by about a factor of three.

- ✔ With these same assumptions, EPA's calculated incremental lifetime risk from indoor radon is about right, but for a much lower ventilation rate of 0.5 ach.

- ✔ A 30-cm thick backfill with "uncontaminated" material would give an incremental lifetime MIR from PG in an old roadbase would not be significantly lower than the "acceptable" value of 3 in 10,000.

-From video, transcript of questions and answers of Construction Panel discussion:

POLICY PANEL QUESTIONS TO CONSTRUCTION SPEAKERS

OHANIAN: And now we have some time for the panel to ask some questions of the panel who just presented their papers so please have a go at it. Who wants to go first?

SMITH: I'm not sure this is a question but I would make an observation, having some knowledge of road construction for 35 years. I think it's interesting to note, and I think its a point that this group needs to consider, there's quite a bit of variation in the way all these gentlemen looked at things. And I really doubt that Texas ***** break in tape ******* but I think it suggests that if you are going to get into road construction there's a lot of barriers between the various states, because we do things differently, and those would trace back to native materials, and here we're dealing with a different animal. So I don't really have a question but I wanted to make that comment.

*******BREAK IN TAPE***************

SAYLAK: .... Texas acceptance criteria for stabilized bases has been this magic number 650 psi in 7 days. Illinois requires 650 psi in 14 days. When you look at where this magic number came from, you find out that it was based on a 2 sigma survivability for freeze thaw testing. You need to look at your various locale to find out if you need to be held to a 7 day 650 psi. That's why when we really looked into this, we found out that all we needed was 400.

SMITH: I wasn't referring to the psi, I was referring to the so called coefficient which is used in design.

SAYLAK: Oh, the structural coefficient?

SMITH: Yes.

SAYLAK: Okay.

BANDY: Earlier this morning there was a question that came up from the panel. I think Mr. Coleman asked the question regarding centrifuging of the gypsum to remove radioactivity. From the data that Dr. James presented a few minutes ago where he showed the fines had more radon emanation, although that is the case, but that is a very small contribution to the total picture. If I conclude that removing those fines would change the radon emanation very much from the PG, would I be correct?

YOUNG: Though I am no engineer, it seems reasonably demonstrated to me that there can be standards in design criteria developed to make this material very suitable, even given the distinctions regionally and with the different soils. The concern for EPA would have to be in terms of the risk assessment and the health risk. But I'm not clear even what EPA's real concern is, with regard to using the material in a road base. I hear you suggesting that we need to somehow meet a standard assuming someone would build a house. Yet I can't imagine any local or state government allowing someone to build a house on a public road, and I can't really envision it on a private road. What are the issues that we really need to be concerned about? Is it the leaching of the materials, or is it the radiation? I thought that ventilation and just the exposure to the air would take care of the risk to individuals. If that does not take care of it, what mitigation can be used to address this particular concern?

JAMES: Well unfortunately in this case you've got two sources of radiation. You've got external gamma radiation so if you mitigate to prevent radon from coming in you still don't reduce the direct gamma exposure. It would be very difficult to do that unless you remove the road. If you actually dug up the road under the house then that would be acceptable but that would be a pretty costly thing to do, wouldn't it?

YOUNG: Well I guess I'm assuming that we're not going to build a house. So lets address it from a different perspective and say okay, the rules say you just can't build houses on these roads. Then what is the risk to the traveling public or the public that just might be in the area of the road.

JAMES: The EPA themselves determined that the only significant risk is to someone who builds a house. And that they used as a justification in their own thinking to banish use in road construction. So they've already looked at the other potential sources of exposure and they are negligible compared with the exposure to someone living in a house built on a road bed. So it is really a political issue. You just have to find some way of convincing them that it's an artificial limitation on the use of PG. But if they insist on applying the 3 in 10,000 risk criterion, I think their sums are good enough that use of 2 to 1 dilution PG in roadbed would prevent application of PG for road building.

OHANIAN: (To James) Isn't the issue that they are concerned that 100 years, 500 years, 1000 years from now somebody will go back and do something like that? Build a house. It's the same kind of argument as the nuclear waste issue. That 10,000 years from now someone will go and dig up the nuclear waste unknowingly or knowingly. Isn't that the same situation with the house building on the roadway?

JAMES: Yes, I think its exactly the same.

SMITH: (To James) Isn't the EPA risk assessment based on some level of radiation in the material to begin with? Someone else may have to answer the second part of my question, but from what little I know there is a large sum of PG out there that will not have that level of radiation.

JAMES: Yes. The level of radiation we looked at is about 30 pCi/g so its at the top end of the range. So it wouldn't prevent use of northern Florida gypsum I presume.

SMITH: Many of these materials have been stacked for numerous years. When we looked at these materials it seemed to me that those were little or no threat, from a radiation point of view. So there has to be some dissipation within the stacks themselves and yet what I'm hearing is that the EPA regulation tends to overlook that. Is that correct?

JAMES: Yes. The ruling is based on a hypothetical concentration.

GLASSMAN: A general question. In Florida most of the highway construction is co-mingled funding with the state government and the Federal Highway Administration, which brings Federal Highway into the issue. I'm just curious if anyone knows the status right now of the Federal Highway's position on this or what work has been done through the state associations, AASHTO (the American Association of State Highway and Transportation Officials) Or if AASHTO and the Federal Highway might be working together with the EPA on this issue at this time? Is there any discussion going on? Is this being an AASHTO policy position, or is there any discussion at the national level about this?

SAYLAK: It's not so much a policy issue. I think that what has happened is that the search for a way of using alternate aggregate materials has caused a lot of the construction industry to go to something other than phosphogypsum. It's not that they are not using a by-product gypsum. They are. Its just the fact that there is this one particular entity (PG) that has all the technology to perform just like all the other stuff and at least for the moment, it is not available for use. Once that burden was taken off, I don't see where either state or federal would have any problems incorporating that into their programs.

SMITH: I'll comment on that last question. You kind of put in perspective the Federal Highway Administration in its relationship to us. Generally each state will decide for itself what it wants to do, so the only knowledge that I have of any major activities of the Federal Highway Administration is currently **** break in tape ****** which is looking into all the waste, as I recall, PG is on that list. And I think their goal is to summarize things and to offer opportunities to other states. They tend to encourage us rather than obstruct us, so I don't think they have a general policy on it. But if we want to use something as a state then it would be up to us to take it to the Federal Highway Administration. And generally we've been very successful. So if we wanted to use these materials and felt like we could use them I don't think that's an obstacle. I think they would encourage it. Again though you have to consider economics in all this.

THE INTEGRATED APPLICATION OF ENVIRONMENTAL EPIDEMIOLOGY AND HEALTH RISK ASSESSMENT TO PHOSPHOGYPSUM EXPOSURE

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Dr. Varney is Vice President, Environmental Risk Management with Chastain- Skillman. His work focuses on comprehensive contamination assessment, environmental epidemiology and health risk assessment related to the general environment and man-made structures. Dr. Varney has worked extensively the past 24 years throughout Florida and the eastern United States on issues related to environmental contamination, health risk assessment, environmental and occupational exposure assessment, risk management and regulatory compliance in the public and private sectors. He has also appeared as an expert witness in courts of law and public hearings in matters involving environmental contamination and occupational exposure. He is also an adjunct faculty member at the University of South Florida College of Public Health where he lectures in environmental chemical fate, exposure measurement and hazardous waste management.

Dr. Varney received a Bachelor's degree in Geology with an emphasis in Geochemistry from the University of South Florida and a Master's degree in Public Health from the university's College of Public Health. He has recently completed the requirements for a Ph.D. in Public Health from USF as well.

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During the past decade the general public has become increasingly sensitive to all forms of toxicant exposure in the general environment irrespective of the true health risk associated therewith. The true risk associated with such exposures has now been replaced by the perceived risk and this problem has been accentuated by scientists, managers and regulators who have oftentimes sent mixed signals about a subject that everyone agrees is highly complex. Most members of the public are so overly concerned by even the most trivial exposures to chemicals and radiological agents in the environment that it has even become difficult to design and implement remedial measures when they are truly needed. The net result is a confused, scared and sometimes hostile public that sees industry and big business as the source of the problem. While this may have been the historical case in some instances, business practices have changed greatly but public perception has not. Clearly, a fresh perspective is needed, one that places environmental exposures in an objective context with health-related risks and a changing regulatory agenda--a perspective the public can understand and trust.

Historically, from a regulatory context, the approach to protecting the public has relied on setting maximum contaminant levels (MCLs), action levels and remediation levels for toxicants in the environment based predominantly on animal models and occupational cohort exposure measurements. In general, as a starting point, there is nothing terribly wrong with this approach. However, approximations of health-related risks have traditionally relied on very conservative upper bound (95 % confidence interval) deterministic methods aimed at protecting the most highly exposed and most sensitive individuals in the population. From a purely humanistic viewpoint it is hard to find fault with such an approach. However, many individuals in the scientific community and the business sector have argued that such an approach is not objective with respect to the true underlying distribution of risk and, most importantly, the distribution of uncertainty related to the component factors of risk. Moreover, it is also felt that this approach has often led to the misguided expenditure of resources for the remediation of low risk sites or the over regulation of industrial wastes that could be safely handled by other methods. However, the conventional manner by which these problems have historically been addressed cannot simply be abandoned. Rather, the old approach must be replaced by a new paradigm that also embraces methods in environmental epidemiology and probabilistic risk analysis so that we may move towards a more logical handling of the problem.

Environmental epidemiology can be generally defined as the study of those environmental factors having an influence on the origin and distribution of disease in the general population. Such studies may take the form of disease or injury recognition in conjunction with an evaluation of the subject population and potential causal factors relative to time and space. Conversely, the study may also proceed from the opposite direction beginning with the exposure factor and working forward to a potential health endpoint. Obviously there are strengths and weaknesses inherent in both approaches. One of the most pressing aspects of such studies, however, is the challenge of obtaining adequate exposure data. This challenge becomes even greater when one considers that exposures to environmental toxicants are often specified in the parts per million or parts per billion range. However, several investigative methods are available and applicable to environmental epidemiologic studies in association with exposures to phosphogypsum in nearby communities and the general population.

The first step in this research process would typically involve identifying those constituents of phosphogypsum that exhibit toxicant behavior of specific environmental concern. These might involve both chemical and radiologic agents that have been previously determined to be mobile in the surrounding environment, such as heavy metals and radon daughters. The next step would involve defining the preference for environmental partitioning, particularly as it relates to air, soil and water. Most importantly, is there a preferential exposure vehicle such as groundwater or ambient air, and is there a definable population at risk along this pathway? Of paramount importance, is there biologic plausibility for a specific disease endpoint? For instance, if one is concerned with radiologic agents, then the disease endpoint of interest might well be the most radiogenic forms of cancer. For study purposes these could include the leukemias and cancer of the thyroid gland, or the list could be expanded to include cancers of the bone and lung. These cancers are offered as examples of one group of disease endpoints that could be considered. Obviously, other chronic and/or acute diseases and adverse health occurrences can also be included in the research design.

Several excellent study designs exist for this purpose and these consist of differing levels of complexity. The overall approach could begin with an ecologic or correlational level study, in which case the geographic area of interest would be defined first. As an example, this might include the entire geographic area previously delineated as the Central Florida Phosphate Mining District, or be more focused, including only those areas of active and historical phosphogypsum disposal. Having outlined the area of study, the population within this geographic area can now be defined with respect to total count, characteristics and proximity to phosphogypsum disposal. This portion of the research may also identify the need to adjust the geographic limits of the study area to, let's say, census or zip code delineations to accommodate the availability of population and chronic disease data. Chronic disease data in the form of the radiogenic cancers previously noted could be obtained from the DHRS, Florida Cancer Data Systems office in Miami for any pre-defined time period beginning about 1982 forward. Likewise, health data referencing other disease endpoints could be obtained from the DHRS office of Vital Statistics in Jacksonville. These data could then be evaluated to determine the geographic distribution of incident cases, case rates and standardized incident ratios when compared to some pre-defined reference population. Of particular interest would be the proximity of cases to phosphogypsum disposal areas and if statistically significant space/time clustering is found.

A variation on this design was recently employed by the writer to study the occurrence of acute leukemias in adults and children in Florida on a county-by-county basis for the period of 1982-92. In addition to determining the occurrence of statistically significant ALL and AML incidence rates, a portion of this work also evaluated the potential for space/time clustering of leukemia cases and associations with selected environmental variables. One facet of this research included a regression and correlation analysis of leukemia incidence rates with radiologic data from the DHRS mandatory radon measurement program in conjunction with the FIPR Land Based Radon Study conducted in 1987. While aimed primarily at the occurrence of acute leukemias, the results of this work also identified a strong statistically significant correlation ($r=0.78$, $p = < 0.001$) for the FIPR and the DHRS indoor radon data sets. These findings suggest that the 1987 FIPR study provided a very representative picture of radon occurrences throughout the state. This is rather remarkable given the difference in the size of both data sets (FlPR-n=3500, DHRS-n= 18000). A statistically significant correlation was also found for indoor radon and radon in soil ($r=0.70$, $p= <0.001$), radon in soil and uranium in soil ($r=0.54$, $p=0.00l$), indoor radon and uranium in soil ($r=0.41$, $p= <0.001$), radon in soil and indoor gamma levels ($r=0.29$, $p= <0.05$), and uranium in soil with gross alpha activity in groundwater ($r=-.32$, $p= <0.01$). A weak to moderate statistically significant correlation for the acute leukemias was also found but this was limited to gross alpha activity in groundwater only. More definitive follow up studies are planned. The point here is that large existing data sets can be creatively applied to a variety of research objectives.

Depending on the results of work at this level a decision can be made to end the research effort at this point or go on to more definitive studies. More definitive studies would typically include a determination of toxicant exposure levels in air, soil or water in the hope that some dose response effect could be identified in association with cancer rate excesses. These studies might also focus on specific population subgroups based on the geographic occurrence of cases and case rate excesses. Such studies could employ rigorous case-control and cohort epidemiologic designs aimed at a clearer definition of environmental exposures and disease endpoints. Factors related to exposure confounding and effect modification can also be included in these study designs. A key element in the design and execution of these studies is the need to include sound data collection and statistical analysis methods. While the aim is to identify statistically significant exposure relationships and disease rate excesses, it is also important to elucidate the range of uncertainty and to establish the statistical power of these findings. This kind of approach provides a strong foundation for intervention (if required) and future research efforts.

In addition to employing research methods in environmental epidemiology, a parallel effort should be advanced in the area of health risk analysis. In doing so it is possible to partition the identified health risk into its component parts employing both deterministic and probabilistic risk analysis methods. Such an approach provides an opportunity to test both analytical methods against the results of the epidemiologic study. Moreover, applying the probabilistic risk analysis methodology provides an opportunity to “see” the distribution of risk and uncertainty for each of the component factors. This is an extremely powerful quantitative approach and it can be readily facilitated with Monte Carlo Simulation and other probabilistic methods. Computer models designed for this purpose are now in general use at the state and national level. It must also be emphasized that the overall design of the research approach discussed herein should proceed from a multi-discipline base bringing together expertise in public health, medicine and the environmental sciences. This kind of approach will foster a more thorough and applicable end product that the public will find easier to embrace and that industry and the regulatory community will find more inherently sound for decision-making purposes.

NORM RISK ASSESSMENT
THE WESTERN CANADIAN NORM GUIDELlNES

BY

DENNIS NOVITSKY
WESTERN CANADIAN COMMITTEE ON NATURALLY OCCURRING RADIOACTIVE MATERIALS

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Author: Dennis Novitsky, Western Canadian Committee on Naturally Occurring Radioactive Materials (NORM).

Mr. Novitsky was the chairman of the Western Canadian NORM Committee that developed environmental radioactivity guidelines for industry and government. He is currently a private consultant, but has spent about a decade with the Alberta government working with radiation issues. Among Mr. Novitsky's career highlights is consulting work with the Japanese government on environmental radiation contamination concerns and administering a province-wide radiation protection program for workers, the public and the environment in Canada.

Mr. Novitsky earned a Bachelor's degree in Physics from the University of Winnipeg, and an MBA from the University of Calgary. He also received a Diploma of Technology in Nuclear Medicine from the British Columbia Institute of Technology.

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Introduction

The issue of Naturally Occurring Radioactive Material, or NORM, has been of increasing concern to government and industry in western Canada for well over 10 years. A Committee, the "Western Canadian Committee on Naturally Occumng Radioactive Matenal (NORM)", has developed a guideline that is unique in its philosophical approach to NORM.

In Canada, NORM falls under the jurisdiction of the Provinces and the Territories. This has led to both gaps and overlaps within each province and to inconsistency between all provinces and territories in the administration of NORM Canada-wide.

In 1990, as head of the the Province of Alberta's radiation protection program, I approached the Alberta based fertilizer and petroleum industries, to propose the formation of a bi-partite government/industry NORM Committee.

Industry representatives recommended that the Committee mandate be expanded to other provinces. As well, having recognized that each province had its own unique set of NORM concerns, I approached the other western Canadian provinces to participate in the Committee's work.

Due to the state of flux present in the development of NORM regulations, Western Canadian government regulators supported the option of NORM guidelines development rather than pursue the traditional regulation development approach. Our industry colleagues on the Committee also supported this approach.

On October 8, 1991 representatives from the fertilizer manufacturing and petroleum industries, met with several Alberta government agencies and representatives from the provinces of British Columbia and Saskatchewan to discuss the establishment of a western Canadian NORM committee. A complement of 15 met and established the Terms of Reference for this committee. From this first meeting the "Western Canadian Committee on Naturally Occurring Radioactive Materials (NORM)", was officially formed and development of NORM Guidelines commenced.

The Norm Problem in Canada

As the acronym NORM implies, Naturally Occurring Radioactive Material contributes to the terrestial background radiation environment. It only creates a radiation protection problem whenever the radioactive component of a material, is concentrated through some human activity.

NORM accumulates and concentrates in a variety of industry processes creating possible radiation exposure risks to workers and the public. Industries in Canada with the <u>potential</u> for NORM problems include;

- <u>Fertilizer Manufacturing and other Mineral Extraction Industries</u>
  In the Province of Alberta's fertilizer manufacturing industry, over 40 million tonnes of NORM contaminated phosphogypsum have been stockpiled in four large stacks throughout the province.
- <u>Petroleum Industries (oil and gas)</u>
  Accumulation of NORM contaminated scale occurs in pipes, filters and other associated equipment both up and downstream.
- <u>Coal Fired Power Generation</u>
  Combustion of NORM contaminated coal in power generating stations, creates NORM contaminated fly ash emissions.
- <u>Pulp and Paper Mills</u>
  Large volumes of airborne low level NORM contaminated fly ash could deposit and contaminate the surrounding countryside.
- <u>Underground Mining Operations</u>
  Operations involved with the mining of non-radioactive materials where low levels of NORM are found in the mined ore material.
- <u>Other Underground Commercial/Industrial Activities</u>
  Any industrial activity involving the use of underground caverns, tunnels, vaults and large underground conduits.
- <u>Water Treatment Facilities</u>
  The possible extraction of mineral impurities from water containing low levels of NORM.

The Western Canadian NORM Committee

An Alberta intiative, the ***"Western Canadian Committee on Naturally Occurring Radioactive Material (NORM)"*** was formed in October 1991. The Committee's Mission Statement best describes the philosophical approach taken its adoption of NORM guideline standards.

MISSION STATEMENT OF THE WESTERN CANADIAN NORM COMMITTEE

> **"Develop guidelines for the control of N.O.R.M. designed to ensure the same degree of protection for all workers and members of the general public, as those standards which have been internationally accepted"**

The Committee's Main Objective best describes both the methods and the holistic philosophy taken to overall development of the NORM guidelines.

MAIN OBJECTIVE OF THE WESTERN CANADIAN NORM COMMITTEE

"Development of a set of guidelines around; Classification of N.O.R.M., Worker Protection, Transportation, Waste Management and an Overview (What is N.O.R.M./Where is it found)."

The primary goal of industry representatives on the Committee has been to develop a consensus NORM guideline to serve as a reference for the development of Industry Codes of Practice while government representatives had a goal of developing a concensus set of NORM standards to expedite the development of consistent interpretation criteria for the numerous provincial government agencies with some form of NORM jurisdiction.

As a whole, the Committee would like to see the Western Canadian Guideline, evolve into a National one. A national Guideline can greatly enhance the development of consistency in the handling of NORM-related activities, throughout Canada.

The Western Canadian NORM Guidelines

Overview;
This guideline is by intent, a reference for two specific industries affected by NORM; petroleum producers and fertilizer manufacturers. We divided the guideline into three parts to provide appropriate information, tailored to three distinct groups of readers:

Part I, For The General Reader, provides information to senior managers and administrators who may need to know what NORM is, what responsibilities their company has in managing possible NORM problems, and what their budgetary implications for managing NORM may be. Part I provides general background information.

Part II, Technical Reference Manual, provides more detailed technical information to persons who have responsibility for preparing detailed plans for handling NORM. These persons are technical specialists such as Engineers, Occupational Hygienists and other Safety Professional who may have no direct experience in dealing with radioactive material. Part II provides specific information on;

The NORM Standards-Basis and Criteria,
Detection, Assessment and Monitoring of NORM
Protection of Workers Exposed to NORM
Transportation Guide
Environmental Protection and Waste Management

Part III, Operational Guidelines, provides more specific information to worksite foremen and line supervisors who, upon encountering NORM problems, must then make decisions on what precautions to take. Industry specific information has been prepared for this group of readers. Part III has sections on;

NORM Operational Guidelines: Introduction
NORM and the Upstream Oil And Gas Industry
NORM Management in the Phosphate Fertilizer Industry

The Appendix includes a glossary of radiation terminology, a listing of radiation monitoring instrument manufacturers, radiation unit conversion factors, examples of NORM field survey and assessment forms and a listing of Radiological Laboratories and NORM Consultants.

The guidelines have been designed to allow for separation of parts I, II and III into stand-alone references. This format allows subsequent expansion of Part III of the document, to include other industries as NORM becomes an identified concern to that industry sector.

NORM Standards and Criteria;
The Committee chose to establish NORM guideline standards by adopting the latest internationally recognized standards whenever feasible. A corollary consideration was to ensure that any adopted standard was identical to existing federal regulation or planned amendments, or by reciprocity with other government agencies, deemed equivalent to those same regulations as administered by the Atomic Energy Control Board in their administration of nuclear fuel cycle radioactive materials.

Above all else, the standards had to be recognized as scientifically sound and universally acceptable by nature of the involved international standard setting organizations and world renowned scientific experts involved with their development. The Committee wanted the guidelines to be as universally acceptable as possible given the increasingly global nature of business today. As a result, the standards adopted by the Western Canada NORM Committee were those developed by the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA) and when compatible, Canadian national standards promulgated by the Atomic Energy Control Board (AECB) and Health Canada.

Several issues were encountered and resolved by the Committee's Standards Review Working Group including;

De minimus or Below Regulatory Concern (BRC) Quantities
Confusion exists in the radiation protection community as to the criteria to establish De Minimus quantities for radioactive material versus those for Below Regulatory Concern. From a scientific perspective, a De Minimus quantity is derived by calculation based on an acceptable level of risk assumed by individuals (personal risk) or by society (collective risk) using risk based models. On the other hand, a BRC quantity, in addition to the scientific criteria, also incorporates other non-scientific societal concerns (eg. political) to establish an exempt quantity therefore, BRC quantities are almost always greater than the equivalent De Minimus ones. Since the Committee's overall objective was to adopt only scientifically based standards, the two quantities were viewed as essentially equivalent.

The Committee chose to use the IAEA set of Exempt Quantities and Concentrations since these are more likely to reflect only the scientific criteria for their development

Exempt Concentrations and Exempt Quantities Limits
NORM can be either a diffuse source extending over a large volume or area or a discrete one. The Exempt Quantity standard is meaningless when assessing the risk associated with a diffuse source such as a phosphogysum stack. The Committee recognized that two sets of limits had to be incorporated into its De Minimus standards in order to address this difficulty.

Radon
Radon has generated considerable controversy due to the lack of international consensus on its radiological risk factors. Conflicting studies have resulted in conflicting interpretations of the inhalation risk from radon gas and its radioactive progeny. As a result, Canada has a different interpretation of radon risk than does the United States. Canada's current recommended standard for residential radon exposure is based on a risk vs. benefit analysis conducted by a federal/provincial working group in the late 1970s using radon house measurements obtained from a cross-Canada radon survey as source data. In this analysis, the relative costs per cancer averted was factored into the calculations. In the early 199Os, a Health Canada funded epidemiological study in the city of Winnipeg, failed to show an association between radon exposure and an increased risk of cancer. Winnipeg has the highest average residential radon gas concentration measurements of all major Canadian cities.

This led our Committee to select the Canadian standard of 800 Bq/m^3 over the recent 1994 ICRP 68 recommended values of 200 to 600 Bq/m^3. The Committee simply did not see research results that were sufficiently compelling to warrant a change. The Canadian standard has remained unchanged for similar reasons.

The U.S. EPA standard was not considered.

Occupational Exposure Levels
To support the implementation of the ALARA Principle, the Committee developed two exposure categories within the Occupational Exposure Level; NORM-CONTAMINATED and RADIOACTIVE. (see attached figure)

As with many other aspects of NORM, the NORM-contaminated category was defined by default to be the region of exposure which exceeded public exposure levels but failed to reach exposure levels sufficient to classify a worker to "Radiation Worker".

In the "grey area" of NORM-contaminated, there is sufficient NORM material or radiation exposure present in the workplace such that ALARA is the dominant objective;

- Area monitoring should be performed on a regular basis (at least annually) and,
- Workers with the potential to exceed the public dose limit of 1 mSv/y are required to participate in a personal radiation dosimetry program.

NORM Classification
The NORM Classification scheme then falls within the Occupational Exposure Level categories. Public Exposure Levels can have only De minimus NORM quantities. The NORM-contaminated category of Occupational Exposure Levels can only have NORM-contaminated quantities of NORM (exceeding De minimus but less than Radioactive). Finally, the Radioactive Exposure category of Occupational Exposure Levels have NORM quantities in excess of the traditional Radioactive Possession limits regulated by federal government agencies.

Issues Summary

- De minimus risk values were adopted which provided the primary criterion for specifying exposure levels.
- Two Occupational Exposure Level categories were defined to account for the gap between a Radiation Worker exposures and Public exposures.
- Exposure Levels in turn provide the primary criterion to further develop NORM Material Classifications within the Exposure Levels. This provides for a consistent and comprehensive framework for the development of the balance of the guidelines. It is toward the NORM-contaminated Exposure Category for Occupational Exposure (the grey area) where the NORM Guidelines are directed.

Summary

This guideline development process represents a new way for government and industry to solve problems. By involving all affected stakeholders in this consensus building process, an effective and practical NORM Guideline has been produced. As a guideline, rapid updates and revisions can be made which affords affected industry groups the opportunity to obtain current information.

DE MINIMUS NORM LIMITS

OVERVIEW

Discrete NORM Sources

(Core sample/filter sample/contaminated pump/)

External (Direct Exposure)

Rad^{n} Intensity	(μSv/hr)
Surface Contam^{n}	(Bq/cm^2)
Total Source Activity	(Bq)

Internal (ALI)

Radon	(Bq/m^3)
Radon Progeny	(WL)
Material Conc	(Bq/g)
Total Source Activity	(Bq)

Diffuse NORM Sources

(P-Gyp Stacks/Ground Contam^{n}/Air Contam^{n}/)

External (Direct Expsoure)

Rad^{n} Intensity	(μSv/hr)
Surface Contam^{n}	(Bq/cm^2)

Internal (ALI)

Inhale or Ingest

Radon Conc.	(Bq/m^3)
Radon Progeny	(WL)
Material Conc	(Bq/g)
- Env'l Pathways	(ALI)
- Biochemical Pathways	

DE MINIMUS NORM LIMITS

LIMITS

Discrete NORM Sources

External Exposure

Rad^{n} Intensity	0.5 μSv/hr
Surface Contam^{n}	1.0 Bq/cm^2

Internal Exposure (ALI)External (Direct)

Radon	150 Bq/m^3
Radon Progeny	0.02 WL

Diffuse NORM Sources

External Exposure

Rad^{n} Intensity	0.5 μSv/hr
Surf. Contam^{n}	1.0 Bq/cm^2

Internal Exposure (ALI)

Radon	150 Bq/m^3
Radon Progeny	0.10 WL

Discrete Source Exempt Quantities (IAEA)

Radioisotope	**Exempt Quantity (Bq)**
U(natural)	1,000
Ra-226	10,000
Th(natural)	1,000
Pb-210	10,000

Extended Source Exempt Concentrations (IAEA)

Radioisotope	**Exempt Conc. (Bq/g)**
U(natural)	1
Ra-226	10
Th(natural)	1
Pb-210	10

NORM OCCUPATIONAL EXPOSURE LEVELS

OCCUPATIONAL EXPOSURE LEVELS	**RADIOACTIVE**
	NORM-CONTAMINATED
PUBLIC EXPOSURE LEVELS	**DE MINIMUS**

ANALYSIS OF RISK ASSESSMENT FOR USE OF WASTE PRODUCT PG IN BOTH AGRICULTURE AND ROAD CONSTRUCTION

BY

TONY JAMES, Ph.D
ACJ & ASSOCIATES
RICHLAND, WA

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Presenter: Anthony C. James, ACJ & Associates.

Dr. James has recently become an independent consultant after holding the position of Associate Professor in the College of Pharmacy at Washington State University. Prior to this Dr. James was the Chief Scientist in the Occupational and Environmental Health Protection Section of the Health Physics Department at Battelle, Pacific Northwest Laboratories. At Battelle, his primary research interest was in the development and application of dosimetry of body tissues in humans and experimental animals, in order to address issues involved in setting practical standards for radiological protection, and in relating cancer risks to environmental conditions of exposure. Before joining Battelle in 1988, Dr. James had 17 years of research experience, much of it relating to radon, at the National Radiological Protection Board, Chilton, United Kingdom.

Dr. James has a B.Sc. in physics from University College in London and received the Ph.D. degree from the Royal Free Hospital School of Medicine in London in 1969.

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Paper not available. The following is a transcription from video of Dr. James' presentation at the Forum.

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I would just like to make one or two observations. The main one is that I am now in the interesting position of working for EPA as one of my consulting jobs, as one of a very large team which is putting together a criteria document, very much like the background information document. The criteria would be criteria to decide whether or not the standard for exposure to particulate materials in the environment should be revised, the so-called PM-10 standard. So I'm working for the National Center for Environmental Assessments in Research Triangle Park. Next week I'm going to the second public review process which is a very stringent two day event. So I have got a lot of respect for the effort that goes into putting together these EPA documents. Essentially you can't please both sides at the same time, but what they are trying to do with the PM-10 document is get the science right. I think they have largely done that with the background information document, but you do have some philosophical points that you can take exception to, such as using the scenario of building a house on a disused roadbed is a realistic way of deciding if that is an unacceptable hazard. These are philosophical points. I don't think you can criticize the science too much. It's just whether or not that standard should be applied in the first place. The other point that you can debate is the level of risk that EPA has set as the pivotal index of whether a practice is acceptable or not. Three times ten to the minus four is a very low risk. Now I have not actually produced my paper and I apologize for that, but what I will promise to do is put things into perspective. I have been working with lawyers too on several cases and lawyers are very good at putting things into perspective which I think you want me to do. I do have a presentation, for example, comparing the risk of so many hours at age 70 is equivalent to in rems/year. So I will take on a duty to try and tailor that specifically to the dose rates that EPA is setting as the limiting factors in deciding on the acceptability of PG.

The average background for someone in the United States is somewhere between 1 mSv/year and 2 mSv/year. Now there are 100 mrem in 1 mSv so the general population is exposed to 100 to 200 mrem/year of background radiation. Now if you are living somewhere like Colorado, which is a fairly healthy place to live, the background could be 3 times higher than that. Now EPA is setting unacceptable doses in the order of 70 mrem/year. In other words, it is roughly doubling, or of the same order of magnitude as, background. That is the criterion that they are applying to ban the use of PG in road making in relation to potential doses and risks from a reclaimer living on a road. We're talking very much down at the background level. I would be very surprised if any epidemiological study would have the power to even hint at finding any effect at that sort of dose rate. You only stand a chance when you go to well identified populations that are exposed to pretty high levels. 3×10^{-4} is a vanishingly small risk for any standard. If you can actually see it then someone is out by several orders of magnitude in their risk estimate.

As far as agriculture, one of the two limiting scenarios that concern, the critical issue I think is establishing what usage rates, what application rates on agricultural land are realistic. I think that if that can be established then it should be possible to convince the EPA that use of PG in agriculture poses negligible risk. As far as road construction, I think they should change their philosophy in terms of what criterion they set to judge acceptability.

-From video, transcript of questions and answers of Risk Panel discussion and conclusions:

POLICY PANEL QUESTIONS TO RISK SPEAKERS
AND
POLICY PANEL DISCUSSION AND CONCLUSIONS ABOUT THE PROPOSED FIPR POLICY BASED ON WHAT'S BEEN HEARD

OHANIAN: Now before I turn to our policy panel with some questions I want to pose to them, are there any additional points that any of the speakers, either from this morning or afternoon, want to make, amplify on anything they have said before? I know Chuck Roessler wants to make a point.

ROESSLER: A question came up regarding whether the EPA had issued a permit for special uses with regard to road construction. The answer is no, but if we expand that to include agricultural uses, yes our Phase II study is being carried out under a permit through EPA to use PG. In the middle of our work we got caught by the rule and we did successfully get a permit to continue.

KENDRON: How much did you use?

ROESSLER: Jack?

JACK RECHCIGL: We got by with under 700 lbs.

OHANIAN: We have about 45 minutes to talk about a number of things and get the panel's reaction on both what was presented today, as well as the proposed FIPR Statement which you have in front of you, I believe. But let me first pose four questions that came to my mind. The first one is, are there clear-cut conclusions regarding phosphogypsum utilization based on what you heard today? If yes, which ones? If no, what else needs to be done now? Based on what you have heard today, is the proposed FIPR Position Statement realistic and what additional information would be necessary if it is not? And fourth, where should we go from here with all the information that we now have at hand? So now I'll let anybody who wants to take a crack at one or more of those questions.

ZAMANI: . .question of Dr. James or Dr. Roessler, on the level of radiation associated with the material used in today's road construction and how does it compare with the use of phosphogypsum, and what the EPA's position is on it?

ROESSLER: If we are talking about phosphogypsum from Central Florida, around 20-30, 25 pCi/g, and we are comparing that to sand and clay and other gravels and aggregate, usually these other materials are going to be down around 1 or 2 pCi/g. On the other hand, if you are using various slags as a course aggregate, you could have concentrations comparable to the phosphogypsum but with lower emanation coefficients. Certain types of granite rock and certain gravels, on the other hand, could be starting at 1 pCi/g and going up to, I suppose, 5 or 10, but I don't have anything more specific than that, other than, generally the materials are lower, and the ones I have encountered are lower in activity, but there are exceptions.

GARRITY: This is not a question or answer to your questions, but I did have a question of Dr. Novitsky about some of his work, I was wondering if you could go back over the comparison of 150 vs. 800 standard and try to put that in terms of how that would correlate to U.S. standards.

NOVITSKY: O.K., the 150 Bq/cubic meter is the S.I. equivalent to your 4 pCi/liter; is the same thing. The 800 Bq/cubic meter, Canadian standard was developed as a result of a cross Canada-Radon Survey done in the late 1970's plus a working group which was formed between the Provinces and the Federal government to address, not only the health risk associated with radon, but the economic factors in terms of how many dollars per cancer averted is feasible. So the 800 Bq/cubic meter was basically a distilled quantity that came out of the analysis. Does that help?

COLEMAN: Could you give an equivalency for me?

NOVITSKY: The 800 Bq/cubic meter is equivalent to 22 pCi/liter, so 5 times.

YOUNG: Further following up on that, is one a mitigation level and one an action level?

NOVITSKY: That's right.

YOUNG: Maybe you could explain the distinction there.

NOVITISKY: Yes, the action level would be for a home owner, if they measure a quantity above 800, they would need to mitigate to below 800, and the question is how far below 800 should you go. It is recommended, that is why it is not quoted in the guidelines, that you should mitigate, if it is economically feasible, to 150.

GARRITY: Maybe I should try to rephrase this in another way. Given the data that we have from Central Florida on levels of radium in phosphogypsum, if you had those levels in Canada, how would they be regulated?

NOVITSKY: Well, I should make a comment first of all, we do not have a federal equivalent set of regulations that you have here with EPA, so each province is on its own. That's another reason why we came up with guidelines, because it was a way to sort of harmonize a disjointed regulatory framework. Basically, all I can say in terms of regulations, is we go by what's in the guideline because there is no formal regulation. As far as I am concerned, it is the table I presented in terms of the de minimus limits, because those de minimus limits were derived in the I.A.E.A. Standard and called exempt quantities. Those quantities were generated through scenario exposure analysis as to what kind of resulting dose would result, and 10 μSv dose to the individual over a year was the criteria to establish the exempt quantity. This could be considered a de minimus.

GARRITY: So do you think the levels in Central Florida would fall in the de minimus region?

NOVITSKY: Pretty well, 10 Bq/gram or 270 pCi/gram, according to the standard.

GARRITY: 10 Times higher?

NOVITSKY: 10 times.

YOUNG: I hate to dominate the discussion here, but as a policy maker who doesn't have the technical background and understanding that most of this group does, I am most intrigued by the assumptions that EPA has made in developing its rules that have resulted in this prohibition, even for significant research projects. I hear that there certainly is reason to question some of those assumptions. The assumption about the application rates, which in some instances might be that high, but, as was suggested best management practices or just limits could easily address that concern. The assumption about the lack of shielding, because we're assuming there won't be floors in those houses, which will have a mitigating affect; assumptions about dose levels, what's really an acceptable dose level. And then the biggest one, the assumption that I have the hardest time dealing with is this assumption that we're going to allow houses to be built on roads. Which, again, seems to me easy to remedy, through a public policy which simply prohibits the building of houses on roads, even old road beds. And there are ways to deal with that. I guess my question to this group is how can we effectively challenge those assumptions? Because I don't think there is a lot of dispute about the science. But its the assumptions that are going to get us into trouble when we go to the public and try to deal with these issues in terms of public policies that make sense to lay people like myself. It seems to me that is where we need to begin. I'm not convinced there needs to be a lot more technical research, although, certainly we need to continue to refine research. But with all the research we will never get to agreement unless we have some understanding at the outset as to what those assumptions are, what the acceptable dose levels are, and from there we can reach the standards.

WENZEL: I certainly agree with those remarks. I think the journalist comes out in me to a degree though in that, if these are the assumptions, why is EPA to a degree being what could be called just out-and-out unrealistic about this? If these are the assumptions, I would think that we are living in a policy making time in the United States where if the economic benefit is high and the health risk assessment is low, then there certainly should be, within the policy realm, a good chance to get the EPA to take another look and to take another look at the research which exists. What I'm not hearing is the EPA's side of things. I think that would have been very valuable to this conference. If EPA couldn't have represented their side, at least someone who could have interpreted the EPA side. So, with that, I am wondering why EPA is basically being stoneheaded as they apparently are, because I certainly agree with these assumptions to where, when there is a huge economic benefit, and especially where we can reduce transportation costs in a state like Florida that will have huge transportation shortfalls for funding. We certainly need an alternative.

OHANIAN: Very good point, Rod. As I explained our frustration at the beginning, EPA for legal reasons, wasn't willing to do that. I don't know, Tony, but since you've been working with EPA, maybe you could shed some light on that point.

JAMES: No.

OHANIAN: Does anyone else want to comment on this, any of the speakers or the panelists here, on what Rod brought up.

GLASSMAN: I'd like to pick up where Rod left off talking about transportation shortfalls. The groups I represent are the Florida Metropolitan Planning Organizations. They represent the expenditures on federal and state funding within the urbanized areas in Florida. By no means is that the only organization interested in reducing the cost of transportation. Other groups, particularly the Florida Association of County Engineers and Roadway Superintendents, which is a national organization, not only co-founded in Florida, its also located nationwide. In your policy statement I think what's interesting is you note that the PG perceived environmental and public health risk is misplaced. I think you would probably also want to say the risk and the issue itself is not really known by that many folks as well. Although I'm involved in the transportation community, this is one option that should probably be surfaced with other organizations and they too should become a party to this discussion and participate in a dialog on it as far as a remedy. And I'd hope you'd advance it with those types of organizations so that they can participate.

OHANIAN: What particular organizations?

GLASSMAN: I'd look at the Florida Association of County Engineers and Roadway Superintendents for starters. They're a subset of the Florida Association of Counties. If there's an issue there on a statewide basis, I think they could advance that issue. The MPO's of to the state, which deal more with the urbanized areas of the state are another organization to look at. But the discussion I heard today, particularly from Polk County, is that this might be a very good option for the county road system. The county road system in this state is under-funded. And typically the application of state and federal funds to the state highway system. Consistent with that, I think DOT's presentation has been that possibly this effort may not be as successful on high volume interstate and high volume arterial facilities, but the county road system might be an appropriate area to focus.

GARRITY: I had a comment on the position paper and I would like to say that I agree with everything that Commissioner Young said. But in observing EPA these days, I see a different organization than might have existed 3, 4; or 5 years ago. I see an organization that is expressing interest in facilitated discussions and partnerships in working with different groups. I think the mood of the position paper should be not so much hitting them over the head and saying they are awfully stoneheaded and they had better do something or else. It should be more, "hey, we have all this evidence here indicating that we don't see where the risk is, and what we want to have is a facilitated neutral type workshop maybe chaired by a good facilitator." It's going to involve EPA, It's going to involve industry, it's going to involve state and local governments and is going to involve citizens groups sitting around the table coming up with some answers here. I just don't see how they can say no to that.

OHANIAN: Thank you. That is an excellent suggestion. We do actually have a facilitator. His name is Larry Gross and we can probably call on him.

O'HANRAHAN: I have this paper here. It's about the benefits and costs that came out of Scientific American, Science and Medicine. It was published in Jan./Feb. 1995. And I'll quote here, "U.S. Environmental Protection Agency estimates that residential radon exposure causes approximately 14,000 lung cancer deaths annually, with an uncertainty rating of 7,000 to 30,000," again uncertainty. "These deaths are presumed to be preventable if indoor radon could be reduced to the concentration of outdoor air. Additionally, because the majority of," this is very interesting, "because the majority of the 14,000 deaths are to smokers, smoking prevention and cessation would decrease these numbers." By the way, in my company smokers have a nicotine fit from the time they come in until they go out at the mandatory lunch period. And then they come back in to work and have a nicotine fit until they go home. No smoking allowed. "EPA has advocated the measurement of radon concentrations in residences,' and by the way, the key word is that they are in residences, not out of doors, "and mitigation at the annual average is above 4 pCi/L, the action level."

WIEGEL: I want to attempt to respond to Mr. Garrity. The reason we are here today is because six months ago we tried to establish that dialogue with EPA and you see where we are now. We're talking to ourselves. I also would like to ask the rhetorical question, how long before EPA gets its legal morass cleaned up? I mean, are we going to wait for 2 years, 5 years, 10 years and then go back to them again and ask for a conversation and be told "our lawyers say we cannot talk". So I think your suggestion sounds great, but it is not going to work based on our experience.

COLEMAN: (To Garrity) Rick, I don't want to seem like someone who is piling on, but as I mentioned you in the hall, it was well over 6 months ago, it was more like 2 years ago, that we started to go through the head of your agency to have a direct dialogue. In fact to determine what the best expenditure of our funds for the public good on this issue might be, the best research that they would agree to at the same time, so that when we spent money it would be of value both to the EPA and to FIPR. We could not break through. We could not arrange a sit down to discuss that. Now you know that I believe in exactly the process that you proposed. Then we sat down 7 or 8 months ago and began this forum that you are now sitting in attempting to have both the pros and the cons one after another speak, have all the experts in the room at the same time, give equal weight. But what we found is that they refuse to come or refuse to talk. And as a conservationist I'm really irate and upset that we cannot break through this barrier regardless of the good intent that may have initiated it.

OHANIAN: Are you going to talk on the same topic Larry?

SMITH: No, I'll tell you why.

OHANIAN: Can you hold on for just a minute?

SMITH: Sure.

OHANIAN: I'd like Rick to respond.

GARRITY: I hope I'm not being Pollyannish, but I have great empathy with the frustration that you are showing from having tried to make this effort with EPA and them not responding. But still I would say that it would be better worth our time and effort to try maybe once more to make some incisive strikes into the heart of the agency. As opposed to duking it out legally which can go on and on and on. Our agency is involved right now with discussions directly between our secretary, secretary Weatherall, and Administrator Browner. And Ginger did get in there directly to see Carol. It was not easy, but she got in there. To have Florida designated a state to essentially take over EPA regulatory activity, but do it in a way that makes the best sense for Florida to do things. To try to make common sense decisions based on different geographical areas of the state. Ginger got a very positive response from Carol on that. Maybe its hard to get that philosophy to filter down within the federal agency. But its there, and if we can grasp hold of it somehow, I think we can make it work.

OHANIAN: Well perhaps you can help us with that issue.

YOUNG: Just adding to that. I think that Howard's suggestion that we've really got to get a coalition of interests that goes beyond the industry or at least what is perceived to be basically an industry interest. And although, at FIPR, we know the quality of the research and the objectivity of the research I think that there is still a perception or there could be a perception that it is still industry supported and that its there to serve the industry primarily. What we have got to do is get the public interest groups who understand the necessity and benefits of either proceeding with research projects or going forward and actually utilizing this material in roadbeds. Its a huge economic issue, not just for the phosphate industry, but particularly for the tax payers of this state as it relates at least to road building. In my county alone, to give you an idea of the magnitude, we are dealing with a $300,000,000 transportation deficit at the county level. That is just the county road system. Now if road materials represented just 10% of that cost we're talking about $30,000,000 to my county tax payers. And of course overlay in all of that, the city cost, the state cost. We have got to partner here and we've got to get our city government, our county government, our state government, and moreover our state agencies. We need FDEP here with us on this issue. I have to believe that EPA is going to be a lot more receptive to a sit down if FDEP is there as our partner at that table. So I think that we've really got to branch out now. And I think that the research is there to support that position and to make a very powerful and persuasive argument to the public and to all those affected groups.

OHANIAN: Anything else on this same topic? Larry.

LARRY: You may interpret this to have some affect on what we've been talking about. In dealing with contractors there is an old saying that they want a level playing field. And I think that is what we are talking about here. Translated that means that I'm going to be honest and you are going to be honest about the subject at hand. To give you an example, in 1988 the state of Florida passed a rather aggressive bill requiring many state agencies to involve themselves in recycling. There was a scenario that came forward then that has proven to be very successful. It enticed the political, regulatory groups and such agencies as the Department of Transportation. It's by no accident that we were the first state to utilize ground tire rubber consistently in our production programs. From what I'm seeing here and what I'm hearing, I'll say it in a negative fashion and I'll try to say it in a positive fashion. We have a disjointed effort. In a more positive since we are not coordinated. When we were finishing the ground tire rubber research the question of worker risk came forward. Now as an agency, the Florida DOT cannot, and neither can the counties or other agencies assume large liabilities that they don't have to. We spent a quarter of a million dollars to do an air quality study with the ground tire rubber. In order to get the contractor to do that we had to indemnify him. So the stakes are big. And phosphogypsum is just one of them. Take construction debris, take all the ashes that are on the ground in this country and you have the same scenario. But I think one of the concerns that I see and it has been stated here, and I'm not going to be as negative. But from an engineering point of view we can do a lot. It's no mystery to go out and assess the strength of a road and make some general predictions. But what I'm hearing is that there are no ground rules on assessing risk. And that's the bottom line. And only now in this state, and we have to give DEP credit here, to move into that assessment arena. Now I want to make several suggestions. This state has large sums of money which we used to spend in over coming corrosion activities. Today we have gone beyond that and when we do research in corrosion now we require the researcher through some very extensive modeling to make some long term predictions. That is what is needed here. I don't have the answer. Dr. James skirted that issue. But you need to be able, with some assurance, pinpoint down the road. And I think initially your going to have to assume some risks. And Dr. Ohanian, I think the conclusions can be stated yes, from a technical point of view we probably know what we are doing. But we are stymied by the fact that we will not, or I will not recommend for my agency to assume the risk. It is impossible for us to do that. As far as the position statement, it is kind of innocuous. All you are saying is take a second look. So I would have no problems with that. Where we go from here, I think, and it was mentioned earlier, and what we are trying to force in this state alone is when DEP starts some of their regulatory issues, we sit down as a technical group and show them the engineering side. With the stroke of a pen EPA yielded the ashes coming out of the coal plants in this state to eventually be of no value to us. In our program alone we use 500,000,000 tons of concrete. We approach every utilization of waste as a positive direction. That enhanced our concrete. That's the program today by which we can put concrete in bridges, and with a great deal of assurance say that that's going to last 75 years without corrosion problems. Twenty years ago that time frame was 15 years. So we can use waste, and I think that needs to be a core of any action you take forward. You want to do it in a positive way and you want to do it with economics. The economics have not been discussed in great detail. But in 1975, when we started recycling asphalt, we did it because of the oil embargo. And if you ever get another oil embargo or any type of energy crisis you will find out what transportation is again. You know we've forgotten those days. But you need a level playing field. I encourage you to try to work at the national level. We are trying to work at the state level. I agree with the comment DEP is your transition to EPA. They will listen. They've got some good people. I admire those people. But we have to have a real target on liability or this whole thing comes to a halt. Thank you.

WENZEL: I'd like to follow up on the economics. I think that in trying to sell this to the mass media, and that is where you will end up getting your largest audience, we can sit here in a room of 200 but as soon as you put a message out to the media 200,000; 2,000,000 start to quickly understand it. I think as best you can start to sell your story to the general public, the better chance you will have of catching the type of political and national attention you will need to then, for a second look potentially, to be taken. Within the policy arena in D.C. and around the country today, I think what we've just heard at the county level is an important point. Three hundred million dollar shortfall for transportation? If ten percent of that could be saved, that's $30,000,000 for a county to use, on what? On children. In handling the child crisis in our state instead of spending the money on concrete and cement. And to me that's a good sell. I think when you start to be able to properly interpret what can be the real public benefit, and public benefit really isn't cheaper roads. The public benefit is, we then take the money that we would have spent on roads and spend it on something like healthcare or something like children that is a human cause. I think when we start to capture mass media attention with that type of analysis and interpretation you will go a long ways toward getting this on the public agenda. One thing I've heard today, I really hope the group can better articulate what is the risk assessment here. I don't know that I properly understand EPA's 3 in 10,000. I know I would not go to the airport tomorrow and get on a jet plane if my chances of a crash were as high as 3 in 10,000. Airways are safer than that, etc. And I think that what the risk assessment is needs to be properly interpreted and articulated and hopefully accurately articulated. In dealing with mass media and trying to get your message across, there is a real error rate that occurs if you're trying to build a campaign and yet any part of that campaign has error in it. That is where your environmental groups, your health groups, and your political groups will really take fast and quick exception. I think my best suggestion I can give you from my background would be to try to articulate what the issue is in terms of the human benefit and the human benefit as a side effect of what really would become the economic benefit which is certainly of an interest, too.

SAYLAK: I want to follow up on what Rod was saying, and possibly make a suggestion. I really and truly agree with you that the media, the mass media would be a tremendous force in helping us start to move forward, but some of us in this room remember reading papers frivolously written with cartoons asking for directions to the road which lights up in the dark. In other words, it made fun of a situation and scared people for the sake of, whatever. If we can get objectivity in the media, to counteract what they brought to this situation, I think we would be further along. Now, my suggestion is, and with all of this risk aspect, there is one thing that I, and I guess it is because I come from a research community, that maybe selling hundreds and thousands and millions of tons of this stuff might have to move along, but for the life of me, why I can't get a 55 gallon drum off of Mobil Chemical Co. 's stockpiles so I can do research. My people do research on far more radioactive material than this, to try to encapsulate it. Why I say this is if we can get off the dime and at least get a concession to allow us to do research, then when comes time to make these convincing arguments we are not going to be doing it with data that dates back to 1983 like I have been showing. So I think we can go a long way by being able to get back into the research arena again and at least present our results in terms of current results rather than something that's over 12 years old.

JAMES: The EPA has conceded the point about being unrealistic to eliminate research, hasn't it?

OHANIAN: No, not as far as we know. Mike?

LLOYD: EPA, in march of 1994, said that the research ruling was erroneous, it had to be changed, and that they would promptly issue a change. This is December of 1995. Now your promptly may be a little bit different from theirs. They have told me in the last several months that this ruling would be issued momentarily. Well, I'm waiting.

OHANIAN: Richard, you have something?

COLEMAN: Yes, there are a couple of things, and I think I'll take them in a reverse order, no, no I won't. This really came from the audience, and let me go over this rather cautiously. Florida has, I used to think 600 million tons of phosphogyp. We're hearing 700 and everybody seems to be accepting 700 now, almost all of which are in unlined stacks awaiting for proper closure. The major gut environmental issue concerning these stacks is ground water contamination from process water and leachate from the existing unlined stacks. Opportunities for cost savings relating to maximizing efficient use of new expensive lined stacks or the opportunities for cost savings really come in the use of the new expensive lined stacks. If gyp could be used for other purposes, it appears likely it would come from current production at 30 million a year. It would be a wonderful achievement to productively use 30 million tons a year, the amount of gyp that is currently produced, that's a lot of product. If we achieve that goal, Florida will still have 700 million tons of phosphogypsum in unlined stacks awaiting for, or undergoing closure. Diversion of closure funds, which has been suggested for research, does not seem, in light of statements, to be an appropriate or reasonable source of funds. Other sources need to be identified. If someone wants to comment on that any where in here, I'll be glad for them to do it. It is something that came from the audience.

ZAMANI: I think Phil (Coram), this morning, mentioned the financial responsibility in the requirement that is associated with the closure of the gypstacks. This money is just a demonstration of their financial strength. This is not the amount of money that is put aside, that somebody could tap that money and use it towards alternative use for gypsum. It is just a financial test that each company goes through, I just want to clarify that point.

COLEMAN: Something that I see coming out of the discussions here might be a revised version of the Florida Institute of Phosphate Research proposed position. And the more I hear coming from the speakers and the experts and the audience, the more I think of a proposal that came to me here might be appropriate. And let me read it, Jack. “FIPR has concluded from its experimental studies of phosphogypsum and that of other researchers, that much of the official concern about phosphogypsum’s perceived environmental and public health risk is reasonably debatable.” I believe that actually, Mr. James used the term, ‘Reasonably debatable’. “Many of the proposed uses of phosphogypsum appear to involve levels of risks which may have potential for mitigation using currently available practices.” We have all been saying that. “Therefore, in light of the potential economic advantages of proposed uses for phosphogypsum and the demonstrated environmental and economic costs in stacking and monitoring phosphogypsum, the U.S. EPA should be strongly urged to re-evaluate its restrictions on phosphogypsum research.” What we have just been hearing. “Further upon completion of large scale research and substantial appropriate peer review, EPA policy should be amended to appropriately reflect the scientific consensus of the risk and mitigation of the storage and use of phosphogypsum.”

OHANIAN: Any comments on that.

YOUNG: In light of all of the comments that have been made, but particularly the one about the need to involve the public and get the public to support these efforts, I think that is a much preferred substitute policy. I was concerned in looking at this after several times, that the way that it was phrased might suggest that we were dismissing the concerns, and we certainly don’t want to give that message to the public. But I think that is very well thought out. I would support that.

OHANIAN: Thank you. Any other comments on this? Does anyone have anything else?

LLOYD: As an action point. Ms. E. Ramona Trovato, head of the NESHAPs branch of EPA in Washington has indicated a willingness to sit down and talk about this. It might be worthwhile to the panel to suggest that the board meet with her within some reasonable time or be able to say that she just won’t talk to you.

OHANIAN: Well Mike, as you recall, we did discuss that at the last board meeting and we agreed that we would do something like that. So that is not an issue. Let me make a couple of comments and then I think we should end. It is almost 5:00 and it’s been a long day. I hope you all come to the reception on the 22nd floor of the Capitol so that we can continue our discussions. It seems to me that we need to make a commitment to continue the discussion/dialogue. In fact I’ve asked the board members to stay over night so that we can meet at 7:00 tomorrow morning with the staff and see where we will go from here. But also by the same token I hope that, especially, not the board because they are already committed, but the others that we have invited will commit themselves to working with us for the next couple of months to get to a specific point. We will create a summary of these deliberations; obviously there are eight or nine hours on the tv tape. We’ll do that with the help of Larry Gross. We’ll get that to everyone who was here probably within the next month. Certainly by the middle of January and no later than that. I think that’s very important. With that I want to thank all of you for being here. I especially want to thank all the speakers this morning and this afternoon who came. They made excellent presentations. And I want to thank all the panelists at the table here for your time. I think it is very important that we help both the state and the federal government, and especially all of the citizens in this state to resolve this health issue, and more importantly as some people have pointed out, a very important economical issue as well. Again thank you and we’ll see you in about half an hour.

Assessment of Doses and Risks from Uses of Waste Product Phosphogypsum in Agriculture and Road Construction

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BIOGRAPHIC SKETCH

Dr. James holds a B.Sc. in Physics and a Ph.D. in Radiation Biology, both from the University of London, England. His principal research and professional interest is in the development and application of radiation dosimetry of the respiratory tract and other body tissues in the human and in experimental animals, in order to address the issues involved in setting practical standards for radiological protection, and in relating human cancer risks to environmental conditions of exposure. In September, 1995, Dr. James completed a one-year appointment as an Associate Professor in the College of Pharmacy, Washington State University Tri-Cities Campus, Richland, WA, together with part-time private consulting work. He is now the Proprietor and Chief Consultant of ACJ & Associates, a company specializing in consultancy in the areas of internal radiation dosimetry, inhalation hazard assessment, and related scientific disciplines. Until December, 1994, Dr. James was a Chief Scientist in the Health Protection Department of the Life Sciences Center, Battelle Northwest Laboratories, Richland. Before joining BattelIe in 1988, Dr. James had 17 years of research experience at the National Radiological Protection Board, United Kingdom, relating to radioactive aerosols (especially plutonium and radon progeny) and their dosimetry in humans and experimental animals. In the United States, he was a member of the National Research Council's Scientific Panel which reported on "Comparative Dosimetry of Radon in Mines and Homes." His international work has included membership of two Task Groups of the International Commission on Radiological Protection (ICRP), reporting on: "Protection Against Radon-222 at Home and at Work" (ICRP Publication 65, 1993); and a "Human Respiratory Tract Model for Radiological Protection" (ICRP Publication 66, 1994). He is currently a corresponding member of the ICRP Dose Calculations Task Group, and also a member of the U.S. Interagency Nuclear Safety Review Panel/Biomedical and Environmental Effects Subpanel (INSRP/BEES), which advises the Department of Energy, National Aeronautics and Space Administration, and Department of Defense on the adequacy of safety assessments for spaceflight missions involving reactors or radionuclide heat sources. He was recently appointed as a U.S. Delegated Expert on Internal Dosimetry for the joint USNRC/Commission of the European Communities (CEC) study of "Uncertainties in Radiological Consequences." Dr. James has been published over 100 articles in the scientific literature.

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INTRODUCTION

In 1992, the United States Environmental Protection Agency (EPA) issued the National Emission Standards for Air Pollutants (NESHAP); National Emission Standards for Radon Emissions from Phosphogypsum Stacks, 40 CFR Part 61, *Federal Register*, Vol. 57, No. 107, June 3, 1992. The EPA's NESHAP ruling was based on the Background Information Document (BID) on "Potential Uses of Phosphogypsum and Associated Risks," published by the EPA two months earlier, in April, 1992 (Conklin *et al.*, 1992).

In the anticipation of small but finite risks to human health that might arise from the radionuclide content of phosphogypsum (PG), the 1992 NESHAP ruling (I) required the disposal of PG in monitored stacks or mines; (ii) prohibited the use of PG for the purpose of road construction; (iii) prohibited the agricultural use of PG containing more than 10 pCi g^{-1} of ^{226}Ra, and; (iv) limited the quantity of PG that could be used in any particular research and development project to 700 lb. In response to a "Petition for Reconsideration," submitted by The Fertilizer Institute (TFI) to the Administrator on August 3, 1992, the EPA acknowledged in March, 1994, that the latter limitation should be relaxed to allow the use of 3,500 lb of PG in research and development work. This decision was occasioned by the discovery of an error in the BID, whereby EPA's calculations had in fact been performed for five drums of PG in a laboratory setting, rather than the "single drum" stated inadvertently in the BID. However, the EPA denied TFI's petition for reconsideration of the ruling that PG must be disposed of in monitored stacks or mines, and that it must not be used for agricultural or construction purposes without an appropriate reduction of the ^{226}Ra concentration.

In deciding whether or not PG (with an assumed "typical" ^{226}Ra concentration of 26 pCi g^{-1}) could be used for agricultural or construction purposes without regulation , the EPA applied the criterion that the estimated maximum additional lifetime risk to any individual who might be exposed to radiation by such practices should not exceed 3 x 10^{-4}. The EPA considered several hypothetical scenarios to define the maximum reasonable exposure (MRE) from agricultural and construction uses of PG. For very heavy, loo-year-long agricultural application of PG as a source of nutrients or as a soil conditioner, the resulting maximum individual risk (MIR) was calculated to be 1.8 x 10^{-3}. This estimated risk applied for a so-called "reclaimer," who was assumed to have lived for 70 years in a house built on redeveloped agricultural land. The corresponding MIR for use of PG in construction was calculated to be 9.3 x 10^{-3}, for a reclaimer who had lived for 70 years in a house built on a disused road (with both a PG-concrete surface and road bed left intact).

TFI's petition to the EPA's Administrator was based on the findings of a preliminary review of EPA's final ruling and BID, which was carried out in July 1992 by SENES Consultants Ltd. (Richmond Hill, Ontario). SENES's review indicated several factors in EPA's exposure assumptions which may have led the Agency to overestimate the MRE of potentially exposed individuals by an overall factor of approximately six for the application of PG to soil and the use of PG on roadbeds, and by a factor of forty for work with PG in a research and development laboratory. If substantiated, such degrees of overestimation would seem to be sufficient justification for the EPA to reconsider its ruling.

Accordingly, in September, 1993, the FIPR Board of Directors commissioned the Battelle Northwest Laboratories (BNWL) of Richland, WA to perform an in-depth analysis of the accuracy of EPA's exposure assumptions, calculational models, and resulting risk determinations. This study was conducted by Dr. John R. Johnson, Chief Scientist of BNWL's Health Protection Department, with assistance for computations and modeling by Dr. Richard J. Traub, Staff Scientist. The author (ACJ), in his capacity as an Associate Professor at Washington State University's Tri-Cities, WA branch campus served as a consultant to BNWL for this project.

At the time of this Forum, BNWL's study and final report is not yet complete. However, based on the available results of calculations, I will provide for discussion my personal view of the outcome of the study. I will focus on the assessments of individual risks for the exposure scenarios that the EPA deemed to be critical in preventing the widespread use of PG in agriculture and construction. In these scenarios, two components of exposure were considered to be significant in terms of risk to health; (I) the additional gamma radiation to the occupants of a house built on PG-treated land, or that from a contaminated road bed under the house, and (ii) the additional exposure to radon progeny that would occur inside such houses. Finally, I will attempt to put the calculated lifetime risk of 3×10^{-4} (ie., EPA's criterion for an "acceptable" risk), into some perspective in comparison with risks of premature death that are present in general, "everyday" living.

DOSES AND RISKS FROM AGRICULTURAL USES OF PG

The EPA evaluated seven scenarios in which PG might be used in agriculture. The exposure pathways estimated to produce the highest risk (i.e., increased external gamma radiation plus increased inhalation of radon progeny) were for an individual living and working in a house constructed on land previously treated with PG. The range of application rates of PG, and the soil conditions considered, are shown in Table 1.

Scenarios 1 through 4, were assumed to represent the application of PG to add calcium and sulfur to soils deficient in these elements; 1 and 3 representing "average" and "maximum" biennial application rates, respectively, for a clay soil, and 2 and 4 the same application rates for sandy soil. The PG is mixed and diluted in the tilled layer of soil, but over time the initial ^{226}Ra-in-soil concentration increases with continued application, until equilibrium is reached with loss of PG and its constituent radionuclides (i.e., by plant uptake, leaching by infiltration of surface water, wind and water erosion). The steady-state concentrations of ^{226}Ra that are calculated to be present in the tilled layer of soil, after 100 years of biennial application of PG at these rates, are also shown in Table 1. It is notable that the assumed "maximum" increment in the ^{226}Ra soil concentration from use of PG to add soil nutrients (scenarios 1 through 4) is less than the value of about 1 pCi g^{-1} that is present naturally in Florida soils. The corresponding "maximum" calculated increment in lifetime risk is the sum of 3.2×10^{-4} from increased direct gamma irradiation, and 4.8×10^{-4} from increased indoor exposure to radon progeny, i.e., -8×10^{-4}. This is about a three times *higher* risk than the value that EPA considered "acceptable."

Table 1. EPA's assumed rates at which PG might be applied to agricultural land, with the resulting incremental ^{226}Ra concentration in soil after 100-year application of PG containing 26 pCi ^{226}Ra per g, together with the estimated annual dose rates and/or incremental lifetime risks.

Parameter	Exposure Scenario						
	1	2	3	4	5	6	7
Soil base	Clay	Sand	Clay	Sand	Clay	Sand	
Initial application (kg/acre)	N/A	N/A	N/A	N/A	17,600	17,600	N/A
Biennial application (kg/acre)	1,461	1,461	4,470	4,470	8,800	8,800	500 - 10,000 (2,622)
Tillage Depth (cm)	22	22	46	46	30	30	23
Increase in ^{226}Ra concentration in soil (pCi/g)	0.60	0.60	0.88	0.88	2.70	2.70	0.45 - 9.0 (2.36)
BID - Direct gamma							
Annual dose rate (mrem/y)	7.6	7.6	12.0	12.0	35.0	35.0	(27.5)
Lifetime risk	2.1×10^{-4}	2.1×10^{-4}	3.2×10^{-4}	3.2×10^{-4}	1.0×10^{-3}	1.0×10^{-3}	(7.7×10^{-4})
BID - Indoor radon							
Lifetime risk	1.8×10^{-4}	1.8×10^{-4}	4.8×10^{-4}	4.8×10^{-4}	8.4×10^{-4}	8.4×10^{-4}	(7.0×10^{-4})

The EPA assumes that scenarios 5 and 6 apply to the use of PG as sediment control, for soils that have been eroded and leached. Based on an example from California, it was assumed that the amount of PG initially applied is 8,000 kg/acre (17,600 lb/acre), followed by biennial application of 4,000 kg/acre (8,800 lb/acre) for 100 years. The resulting increase in the concentration of ^{226}Ra (through the tillage depth) was calculated to be 2.7 pCi g^{-1}, *i.e.*, almost three times the natural ^{226}Ra level in the soil. The corresponding calculated increment in lifetime risk was then the sum of 1.0×10^{-3} from increased direct gamma irradiation, and 8.4×10^{-4} from increased indoor exposure to radon progeny, *i.e.*, $\sim 1.8 \times 10^{-3}$, which is about a six times *higher* risk than the value that EPA considered "acceptable."

The seventh scenario considered by the EPA was included to illustrate that the incremental dose rates and/or lifetime risks are proportional to the product of the PG application rate and the ^{226}Ra concentration. On this basis, the EPA ruled that it would be acceptable to use PG for agricultural purposes, provided that the ^{226}Ra concentration did not exceed 10 pCi g^{-1}. The values shown in parentheses in the right-hand column of Table 1 give the gamma dose rate and components of lifetime risk calculated for a median application rate (2,622 lb/acre, biennially) of PG containing a ^{226}Ra concentration of 26 pCi g^{-1}, which is typical of the PG produced in central Florida. The resulting estimate of the increased lifetime risk was about 1.5×10^{-3}, or slightly less than that for application scenarios 5 and 6.

Reassessment of Risks for a Land "Reclaimer" from Agricultural Use of PG

The scope of BNWL's reassessment of doses and the associated risks from agricultural uses of waste product PG is as follows.

- Assume EPA's exposure scenarios for evaluating the maximum individual risk (MIR) to a so-called "reclaimer" from lifetime exposure in a home built on reclaimed agricultural land, *i.e.*, after 100-y application of PG containing 26 pCi g^{-1} of ^{226}Ra and its radioactive progeny.

- Model the two critical exposure pathways;
  - direct gamma irradiation, and;
  - inhalation of radon progeny formed from radon that seeps into the indoor air.

- Assume EPA's adopted risk factors (EPA, 1994), which are similar to those currently recommended by International Commission on Radiological Protection (ICRP, 1993).

Direct gamma exposure

In calculating the direct gamma dose to the occupants of a home from a historical accumulation of ^{226}Ra-bearing PG in the soil under the home, the EPA assumed that the floor of the home provided no shielding, and that no imported backfill material had been used in the foundation structure. However, the most common type of home construction in central Florida is the so-called "slab-on-grade" construction, whereby a thickness of about 0.3 m (1 ft) of imported backfill material is laid inside the foundation walls. The house floor is then formed by a 0.1 m (4 inch) thickness of concrete laid on top of the backfill. Taking as an example EPA's exposure scenarios 1 or 2 (from Table l), the effect of introducing these layers of shielding material in reducing the direct gamma dose rate to the occupants of a home built on reclaimed agricultural land is as follows. For 100-y biennial application of 1,500 lb/acre of PG, and a tillage depth of 22 cm:

- the incremental ^{226}Ra concentration in the surface soil is 0.6 pCi g^{-1}; and,
- EPA's calculated incremental dose rate is 7.6 mrem y^{-1}.

The corresponding dose rates calculated by BNWL are:

- 6.0 mrem y^{-1} - ignoring the shielding provided by the floor and backfill;
- 2.4 mrem y^{-1} - allowing for the shielding provided by the 0.1-m thick concrete slab; and,
- 0.1 mrem y^{-1} - allowing for the additional shielding provided by a 0.3-m thick layer of imported backfill.

It is seen that BNWL's calculated value of the gamma dose rate in the absence of the shielding layers is somewhat lower than EPA's (6.0 mrem y^{-1} *cf.* 7.6 mrem y^{-1}). This difference is due to EPA's assumption that PG contains a higher proportion of the ^{232}Th isotopic series of radionuclides in relation to the ^{226}Ra series than is actually the case. However, neglect of the shielding provided by the concrete slab and backfill material led to a much greater overestimate of the direct gamma dose rate in EPA's analysis; by a factor of almost eighty.

EPA based their ruling to prohibit the use of "undiluted" PG in agriculture on the assumption of the maximum individual risk (MIR) defined by exposure scenarios 5 or 6 (see Table 1). Using the EPA's risk factor (3.83 x 10^{-7} per mrem) that is attributable for a lifetime (70 y) of whole body gamma irradiation at the calculated dose rates, the resulting estimated increases in lifetime risk from direct gamma exposure in a home built on land that had received biennial PG applications of about 9,000 lb/acre for 100 y (giving an incremental ^{226}Ra concentration in soil of 2.7 pCi g^{-1}), are as follows:

- 10 in 10,000 (1 x 10") estimated by EPA;
- 8 in 10,000 (8 x 10^{-4}) estimated by BNWL for "no shielding" provided by the floor;
- 3 in 10,000 (3 x 10^{-4}) estimated by BNWL for the shielding provided by a 0.l-cm thick concrete slab; and,
- <3 in 100,000 (<3 x 10^{-5}) estimated by BNWL for shielding by both the concrete slab and backfill material.

It is seen that, having taken account of the shielding provided by the "slab-on-grade" construction of a typical central Florida home, the additional lifetime risk for a lifelong occupant contributed by direct gamma irradiation is less than one-tenth of the 3 x 10^{-4} value deemed by the EPA to be "acceptable."

Indoor radon exposure

Realistic assessment of the build up of radon in a central Florida home built on soil contaminated with an elevated concentration of ^{226}Ra requires the application of a quantitative model of the ingress of radon through the floor-wall junctions of a slab-on-grade foundation. Such a model was described by Revzan et *al.* (1993). These authors used their model to calculate the variation in the radon entry rate caused by wide variations in each of the many physical parameters (e.g., soil, fill, and stem-wall permeabilities, and the widths of various gaps in the foundation through which soil gas flows under the positive pressure gradient that exists between soil gas and indoor air), and available pathways that affect radon entry. The details of the foundation structure that are included in the Revzan *et al.* model are shown in Figure 1.

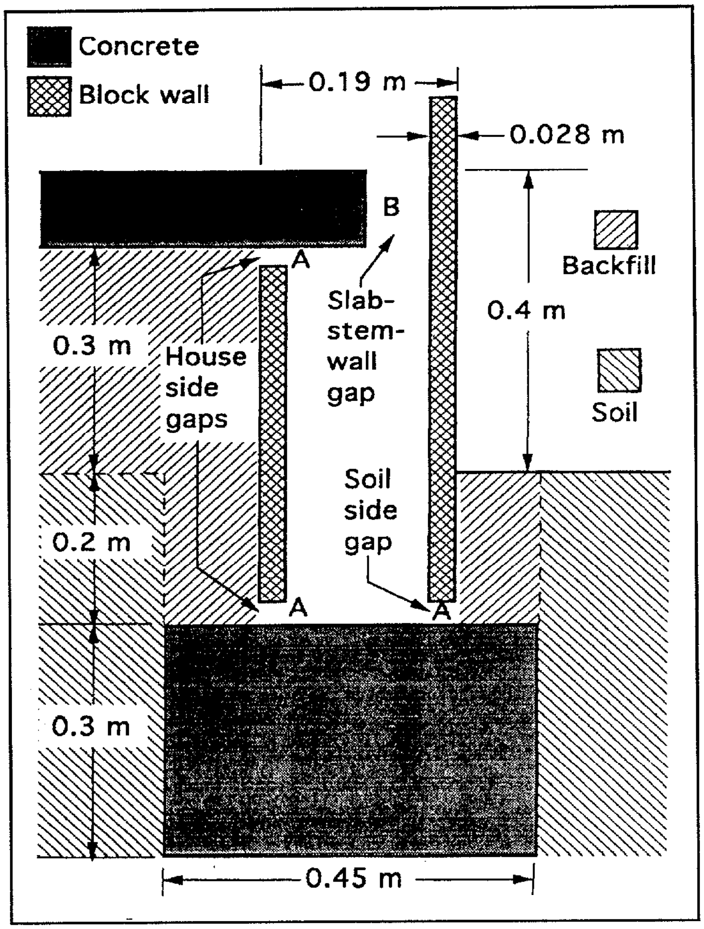


Figure 1. Detail of floor and wall for Florida slab-on-grade house showing air gaps, backfill and native soil.

Source: Revzan et al. (1993).

Revzan *et al.'s* model calculates a "best estimate" of 2.3 Bq s^{-1} (62 pCi s^{-1}) for the total rate of entry of radon into the indoor air of a slab-on-grade constructed home, assuming that the concentration of "free" radon in soil gas is 1 pCi g^{-1}. However, on comparing their calculated values with experimental results in real homes, these authors concluded that the model tends to underestimate the actually observed entry rate of radon by a factor of two. Thus, to assess the effect on radon entry into indoor air of increasing the concentration of radon in soil gas, it is prudent to multiply by a factor of two the values given by the Revzan *et al.* model. I have done this to derive the radon exposure estimates given below.

The concentration of radon in soil gas is determined by the product of the ^{226}Ra concentration and the so-called "emanation fraction" for radon gas, *i.e.,* the fraction of the total number of radon atoms produced inside the particles of soil (or PG) that are released into the soil gas spaces. The emanation fraction is significantly less than unity. Rutherford *et al.* (1995) found that the value for Floridian PG is approximately 0.12. Assuming a "rounded" value of 0.15 for the emanation fraction (which is half the value of 0.3 assumed by the EPA in their calculations), together with twice the radon entry rate calculated by Revzan *et al.,* it is estimated that an incremental ^{226}Ra concentration of 1 pCi g^{-1} in soil (from added PG) would result in an increased radon entry rate into a home built on that soil of about 0.7 Bq s^{-1} (19 pCi s^{-1}). For a typical indoor ventilation rate of 1 air change per hour (ach), this would produce an increase in the indoor radon concentration of about 0.3 pCi L^{-1}.

According to the EPA's exposure scenarios 5 or 6 (Table l), *i.e.,* previous 100-y biennial PG applications of about 9,000 lb/acre, the ^{226}Ra concentration in the soil under and around a land reclaimer's home would be increased by 2.7 pCi g^{-1}, with a consequent increase in the indoor radon concentration of about 0.9 pCi L^{-1}. This would approximately double the "background" indoor radon concentration, which is typically about 1 pCi L^{-1} in Florida. However, the resulting total radon concentration would still be less than half of EPA's currently recommended "Action Level" of 4 pCi/L the value at which homeowners are advised to take remedial action to reduce their risk from indoor radon exposure (EPA, 1992b).

The EPA chose a much simpler (and less realistic) model to calculate the increment in indoor air concentration caused by a PG-enhanced ^{226}Ra concentration in the soil beneath a home built on reclaimed agricultural land. Their model considered only the diffusion of radon through assumed cracks in the concrete floor slab, *i.e.,* an assumed "radon diffusion coefficient" for the floor slab. For an unusually high assumed ventilation rate (2 ach), and exposure scenarios 5 or 6, the EPA calculated an incremental radon concentration in indoor air of 0.3 pCi L^{-1}. For a more realistic ventilation rate (1 ach), this value should be increased to 0.6 pCi L^{-1}, which is then comparable to (but slightly lower than) the value derived from Revzan *et al.*'s study.

The EPA's recommended estimates of lifetime risk (of lung cancer) from exposure to radon progeny in a home are 29 in 1,000 (2.9×10^{-2}) for cigarette smokers, and 2 in 1,000 (2×10^{-3}) for non-smokers, for an average radon gas concentration of 4 pCi L^{-1} (at the Action Level). For the U.S. population as a whole, of which 34% are smokers, the estimate of lifetime lung cancer risk attributable to indoor radon is therefore about 2.8 in 1,000 (2.8×10^{-3}) per pCi L^{-1} concentration of radon indoors. Thus, the estimated additional lifetime risks from indoor radon according to EPA's exposure scenarios 5 and 6 are:

- 8 in 10,000 according to EPA's calculation, with 2 ach;
- 16 in 10,000 according to EPA's calculation, with 1 ach; and,
- 24 in 10,000 according to the Revzan *et al.* study, with 1 ach.

Overall lifetime risk

Adding together the estimates of additional lifetime risk resulting from increased direct gamma irradiation and indoor radon exposure, the EPA's and my own estimates of the overall risk (based on exposure scenarios 5 or 6) are:

- 26 in 10,000 according to EPA's calculations (with 1 ach); and,
- 24 in 10,000 according to my analysis.

Therefore, this reassessment supports the EPA's evaluation of the total additional risk to an individual who lives for 70 years in a home built on reclaimed agricultural land after 100 years of heavy application of PG. However, the estimated risk depends critically on the assumed application rate; if the assumed PG application rate is too high, then the estimated risk is too high *pro rata.*

Realistic application rate for PG use in agriculture

As Dr. Sumner has reported at this Forum, the maximum rate at which PG is applied to agricultural land in practice is about 800 lb/acre (for the treatment of subsoil acidity). This would correspond to about 1,600 lb/acre of biennial application, *i.e.*, about one-fifth of the maximum rate assumed by the EPA in carrying out their assessment of the MIR. Therefore, according to Dr. Sumner's research and my analysis of the dose from indoor exposure, the MIR should be reduced to approximately 5 in 10,000 (5×10^{-4}). However, even that value depends on the assumption that the 800 lb/acre/y application rate is maintained for 100 years, which appears to be a grossly conservative assumption. In reality, the MIR is likely to be substantially less than 5×10^{-4}, and in all likelihood less than 3×10^{-4}, the value deemed by the EPA to be "acceptable" in relation to unrestricted use of PG.

Conclusions from reassessing the MIR for PG use in agriculture

In summary, my conclusions concerning the MIR for use of PG in agriculture are as follows.

- For a given assumed increment of ^{226}Ra concentration in soil, the EPA's calculations substantially *overestimate* the direct gamma dose received by the occupant of a home built on that soil, but *underestimate* by about a factor of two the indoor exposure to radon and its progeny.

- The sum of these two components of risk that is obtained from EPA's calculations is confirmed by the BNWL reassessment, given that EPA's assumptions about the maximum rate of application of PG to agricultural land are correct.

- The more reasonable assumption of realistic values for the maximum application rate of PG, and for the likely duration of soil treatment, would reduce the estimated MIR below EPA's criterion for "acceptability," *i.e.*, below 3×10^{-4}.

DOSES AND RISKS FROM CONSTRUCTION USES OF PG

To assess the MIR for use of PG in construction, the EPA considered four “maximum reasonable exposure” (MRE) scenarios. The most critical exposures were found to be those received by a reclaimer; an individual who builds a house on an old roadbed that incorporated PG in its construction. All four scenarios (numbered 8 through 11) assumed that the road surface had been laid on a 0.25-m thick base composed of a 1:2 ratio mixture by mass of PG:soil. Scenarios 8 and 9 assumed that the road surface was of asphalt, with the “soil” composed of “clay” or “sand,” respectively. Scenarios 10 and 11 assumed that the road surface was of concrete, which incorporated PG (15% by mass), again with clay or sand as the soil type.

In the Background Information Document (BID), Section 4.4.2 on page 4-35, the EPA stated that “Reclaimer doses were evaluated for a time (presumed to be 50 years after road construction) when the road is closed and the road surface has crumbled *and been removed* [my italics].” If the PG-containing surface of the concrete road had indeed been removed before building the reclaimer’s house, then one would expect the exposure conditions to be similar for all four scenarios, *i.e.,* for scenarios 8 and 9 where the road surface was of asphalt, and for scenarios 10 and 11 where the road surface was of concrete; only the PG-containing road bed would be left in both cases. However, the doses and risks calculated by the EPA, as presented in the BID and Final Ruling, were substantially higher in the case of the old concrete road surface than for the old asphalt surface, as follows.

For the home built on a road bed with a net ^{226}Ra concentration of 8.7 pCi g^{-1} *(i.e.,* one-third the 26-pCi g^{-1} ^{226}Ra concentration in undiluted PG), which had previously been surfaced with asphalt, the Final Ruling stated that:

- direct gamma dose rate is 71 mrem y^{-1}, with corresponding lifetime risk of 1.8 x 10^{-3};
- lifetime risk from indoor radon of 4.3 x 10^{-3}, and;
- summed lifetime risk is 6.1 x 10^{-3}.

For the home built on the same road bed which had previously been surfaced with concrete, the Final Ruling stated that:

- direct gamma dose rate is 140 mrem y^{-1}, with corresponding lifetime risk of 36 in 10,000 (3.6 × 10”);
- lifetime risk from indoor radon of 57 in 10,000 (5.7 x 10^{-3}), and;
- summed lifetime risk is 93 in 10,000 (9.3 x 10^{-3}).

Clearly, the results presented for the case of the “old concrete” road surface were not calculated as stated in the BID, *i.e.*, on the assumption that the concrete surface had crumbled and been removed. However, according to the EPA’s calculations, even the lower dose and risk cases represented by scenarios 8 and 9 (the old asphalt road surface) yielded an unacceptable estimate of additional lifetime risk. The estimated value of 61 in 10,000 (6.1 x 10^{-3}) exceeds the “acceptability” criterion by a factor of twenty.

Reassessment of Risks to a "Reclaimer" from Use of PG in Road Construction

It would seem reasonable to assume, as was suggested in the BID, that the old road surface, whether of asphalt or concrete, had been removed before building the reclaimer's home. It would also seem reasonable to assume that a new concrete floor (of standard 0. l-m thickness) had been laid over the old road bed.

Direct gamma exposure

In this case, the old road bed would contribute a direct gamma exposure (above the "normal" background) amounting to that received from a 0.25-m thick layer of PG-containing soil material with a net ^{226}Ra concentration of 8.7 pCi g^{-1}. Taking account of the shielding provided by the new concrete floor, the net additional dose rate from the roadbed would then be approximately fifteen times the value shown earlier for the example of sub-floor soil with a ^{226}Ra concentration of 0.6 pCi g^{-1}. This additional dose rate from direct gamma exposure is therefore estimated to be ~15 x 2.4 mrem y^{-1}, *i.e.*, ~ 36 mrem y^{-1}. Thus:

- the corresponding value of additional lifetime risk from direct gamma exposure is approximately 9 in 10,000 (9×10^{-4}).

Indoor radon exposure

Application of the Revzan *et al.* model to the case of a home with a 0.1-m thick concrete floor built on soil containing ^{226}Ra at a concentration of 8.7 pCi g^{-1}, the additional concentration of indoor radon is estimated to be approximately 3 pCi L^{-1}. Thus:

- the corresponding value of additional lifetime risk from indoor radon exposure is approximately 80 in 10,000 (8×10^{-3}).

Overall lifetime risk

The estimated overall lifetime risk to a reclaimer is about 90 in 10,000; a value close to the EPA's estimate. This is about thirty times *higher* than 3 in 10,000 criterion used by the EPA to gauge "acceptability." Clearly, in this exposure scenario, the additional lifetime risk would be dominated by the contribution from indoor radon exposure. Even so, it is of interest to note that the estimated 3 pCi L^{-1} increase in the indoor radon concentration is still less than the EPA's currently recommended Action Level (of 4 pCi L^{-1}).

Conclusions from reassessing the MIR for PG use in road construction

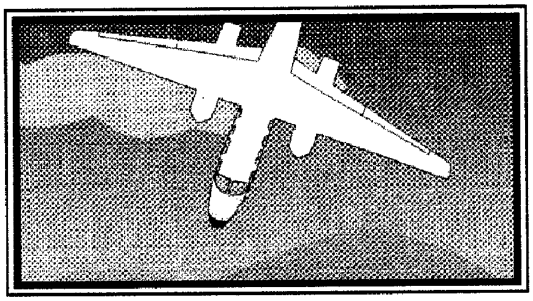
Given that the criterion for an acceptable additional lifetime risk is 3 in 10,000, it is clear that a reclaimer would be subjected to an unacceptable risk if he or she built a home on a disused road bed that had been constructed using PG, and lived in the home for 70 years. In order to reduce the exposure and resultant risk of premature death to an acceptable level, the ground would first have to be prepared by excavating the road bed material from under and around the building site. This would add to the cost of the home, but possibly not an unreasonable amount in relation to the total building cost.

RISKS IN EVERYDAY LIVING

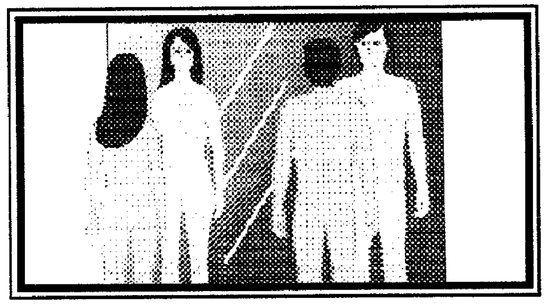
In closing, we can examine the EPA's criterion for an "acceptable" additional risk to individuals who would choose to live their whole life in a home built on reclaimed agricultural land or an old road bed that had been treated with PG in relation to the scale of risks that are part and parcel of everyday living. Figure 2. illustrates six examples of such risks. Taking the risk criterion of 3 in 10,000 as the reference:

- the risk of dying in an airplane crash is *about the same;*
- the risk of dying prematurely from cancer caused by the natural radionuclide potassium-40 (^{40}K) that is present in your own body is *two times greater;*
- the risk of being killed in a fire in your home is *three times greater;*
- the risk of being killed by drowning is *seven times greater;*
- the risk of being killed in a car crash is *twenty five times greater,* and;
- the risk of being killed in a violent crime is *twenty seven times greater.*

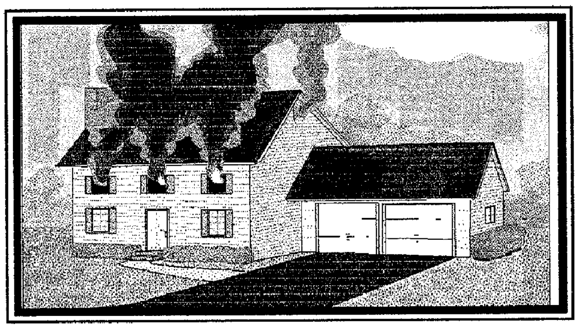
It should also be borne in mind that these examples of the risks of violent death are each likely to result in a substantially reduced life-span for the individual concerned. In contrast, any additional cancer caused by long term exposure to radiation will necessarily occur in old age, and thus have a relatively small effect on the "normal" life-span.



Risk of dying in an airplane crash - same lifetime risk.

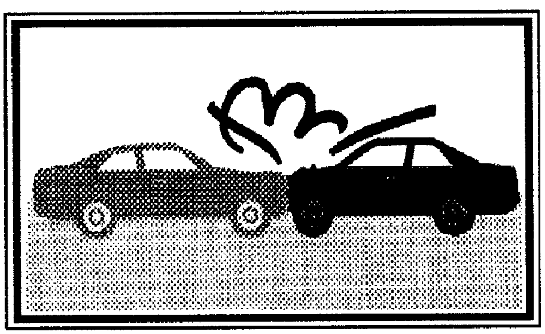


Premature death from cancer caused by natural ^{40}K in own body - twice as likely.

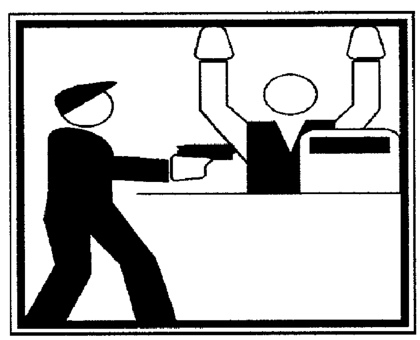


Likelihood of being killed by a home fire - three times as likely.

Likelihood of being killed by drowning - seven times as likely.



Likelihood of being killed in a car crash - twenty five times as likely.



Likelihood of being killed in a violent crime - twenty seven times as likely.

Figure 2. Comparison of Life's Everyday Risks with EPA's Criterion for "Acceptable" Individual Lifetime Risk of 3 in 10,000 from Uses of Phosphogypsum.

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