Secondary Resource: The Beneficial Applications of Phosphogypsum and the Need for Canadian Regulations

By

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A report submitted to the Department of Environment and Geography, University of Manitoba, in partial fulfillment of the requirements for the course ENVR 4500 (Honours Project)

And for the degree of

Bachelor of Environmental Studies (Honours)

April, 2012
Abstract

Phosphogypsum (PG) is a by-product of the fertilizer industry created from the reaction of sulfuric acid with phosphate rock which results in the creation of phosphoric acid. Millions of tonnes of this by-product are created annually around the world and stored on the land in large heaps known as ‘stacks’. Currently there is no acceptable application or secondary use established for phosphogypsum, despite its beneficial results when used to amend soils, when added to compost, when used as a landfill cover, and when used in as a road base. Concerns about the environmental and health implications of the naturally occurring radionuclides ($^{226}$Ra, $^{238}$U) found in PG have dampened research into the viable applications of PG. Phosphogypsum has been regulated by the U.S. Environmental Protection Agency (EPA) since 1989. Canada does not have any phosphogypsum specific regulations. Health Canada’s Guidelines for the Management of Naturally Occurring Radioactive Materials, published in the year 2000, regulates any substance that contains naturally occurring radionuclide concentrations over 300 bq/kg. Many of the stacks in Canada, and around the world, contain concentrations of radionuclides above Health Canada’s Guidelines. This study examines the beneficial uses of phosphogypsum, the regulations that dictate its use, and the necessary steps that must be taken in order to convert phosphogypsum from a waste to resource. The review of literature and interviews with experts has lead to the conclusion that PG has beneficial applications that will not be explored without additional regulatory guidance. Phosphogypsum specific regulations in Canada will encourage the treatment of PG as a resource, aid in the remeditation of land where stacks are located, and encourage the viable uses and applications of PG in a manner that is both environmentally beneficial and conscious of human health.
Acknowledgements

I would like to thank the experts I interviewed, not only for taking the time to converse with me, but also because they were kind enough to provide me with a wealth of insight, explanations, and literature references on the topics phosphogypsum, legislation, radiation, and soil science.

I would also like to thank my thesis Advisor Dr Rick Baydack for his guidance, direction, and support.

Finally, I would like to thank my family for their continued support and near superhuman ability to tolerate my many stacks of papers and complete take-over of the basement.
# Table of Contents

Abstract...........................................................................................................................................iii
Acknowledgments..............................................................................................................................iv

1.0 Introduction................................................................................................................................6
  1.1 Background.................................................................................................................................6
  1.2 Phosphogypsum Produced in Canada.........................................................................................6
  1.3 Phosphogypsum Produced in The United States.................................................................7
  1.4 Environmental and Health Issues............................................................................................7
  1.5 Environmental Concerns of Stacking PG..............................................................................8
  1.6 Beneficial uses..........................................................................................................................10
  1.7 Problem Statement.....................................................................................................................11
  1.8 Purpose and Objectives............................................................................................................12

2.0 Materials and Methods.............................................................................................................13
  2.1 Literature Review.......................................................................................................................14
  2.2 Panel Discussion.........................................................................................................................14
  2.3 Snowball Sampling....................................................................................................................14
  2.4 Development of Interview Guide.............................................................................................15
  2.5 Expert Input...............................................................................................................................16

3.0 Results.........................................................................................................................................16
  3.1 Agricultural Applications..........................................................................................................16
    3.1.1 PG applied to Soils with High Magnesium Concentrations................................................17
    3.1.2 PG applied to Acidic Soils....................................................................................................18
    3.1.3 PG as a Landfill Cover.........................................................................................................18
    3.1.4 PG as a Compost Additive..................................................................................................21
    3.1.5 PG as a Road Base................................................................................................................22
  3.2 United States of America Environmental Protection Agency Regulations on PG............23
    3.2.1 Risk Assessment..................................................................................................................26
    3.2.2 Downfalls of EPA’s Risk Assessment..................................................................................26
    3.2.3 Calcium Provision for Peanut Farms..................................................................................27
    3.2.4 Calcium Provision for Tomatoes and Peppers.................................................................28
    3.2.5 Sulphur Provision for Crops..............................................................................................29
    3.2.6 Applications for the Recovery of Acidic Soils..................................................................30
    3.2.7 Applications for the Recovery of Sodic Soils.....................................................................30
    3.2.8 Conclusions: EPA’s Regulations......................................................................................31
  3.3 Health Canada’s Guidelines....................................................................................................32
  3.4 Non-North American Regulations...........................................................................................33
  3.5 Barriers to the use of PG...........................................................................................................34
    3.5.1 Legislative Barriers...............................................................................................................34
    3.5.2 Public Perception and Education........................................................................................36
    3.5.3 Economics..........................................................................................................................37
      3.5.3.1 Low Cost of Stacking....................................................................................................37
      3.5.3.2 Lack of Funding.............................................................................................................38
      3.5.3.3 Cost of Transportation.................................................................................................38
  4.0 Discussion..................................................................................................................................39
    4.1 Necessary Actions to Establish Secondary Use of PG.........................................................39
List of Tables:

Table one: Recommended rates of gypsum applications for peanuts for one year..........................28
Table two: Recommended applications rates of gypsum to crops in order to supply optimal amounts of sulphur........................................................................................................30

List of Figures:

Figure one: PG Research Publications Per Year........................................................................34

Appendices:

Appendix A: Interview Questions..........................................................................................48
1.0 Introduction

1.1 Background

Phosphogypsum is a by-product formed during the production of phosphorus fertilizer when phosphate rock reacts with sulfuric acid. Approximately five tonnes of Phosphogypsum is created for every one tonne of fertilizer (Luther et al. 1993; Nifong et al. 1993; Rutherford et al. 1994; Alberta Environment 2006; Nichol et. al. 2011). The demand for fertilizer coupled with the above mentioned reaction has resulted in billions of tonnes of PG generated world-wide. Phosphogypsum is considered a waste product by nearly all of the eighty plus countries that generate it. The large quantities of the PG that can be found world-wide have spawned many organizations and regulatory bodies to research viable applications of this by-product. Phosphogypsum production can be represented by the following simplified formula:
\[ Ca_{10}(PO_4)_6F_2 + 10H_2SO_4 + 20H_2O \rightarrow 10 CaSO_4 \cdot 2H_2O + 6H_3PO_4 + 2HF \] (Luther et al. 1992; Rutherford et al. 1994)

1.2 Phosphogypsum Produced in Canada

In Alberta, PG is classified as a non-hazardous waste. (Alberta Environment 2006) As a result, Phosphogypsum is stored on the land in great mounds called ‘stacks’. 70 million tonnes of PG reside in stacks in Canada alone. Individual stacks take up a large amount of land, up to 740 acres with a height of 60 meters. Although the majority of the stacks are found in Alberta, PG stacks can also be found in British Columbia, Ontario, Quebec, and New Brunswick (Nichol et al. 2011).

Four locations across Alberta house PG stacks, Medicine Hat, Calgary, Redwater, and Fort Saskatchewan. Of the four, only the Agrium Corporation’s Redwater site is considered
active, as fertilizer production is still underway and PG continues to be generated. The other three locations have been inactive since 1980s and cover a combined area of 1,032 acres. The Fort Saskatchewan site, although not considered remediated by Alberta Environment’s standards, has been covered with soil and vegetation has been established (Luther et al. 1993; Nichol 2011).

All of the fertilizer produced in Alberta has sourced its phosphate rock from various places around the world including Idaho and Florida of the USA, Western Africa, and Kapuskasing Ontario. The array of source locations of the phosphate rock make for varying physical and chemical qualities of the rocks (Luther et al. 1993; Nichol 2011).

1.3 Phosphogypsum Produced in the United States of America

Like Canada, PG can be found in various locations across America, but it is the state of Florida that produces the largest amount of the Phosphogypsum, about 30 million tonnes annually. In the year 2000, Florida housed more than twenty PG stacks which can be equated to over 700 million tonnes of PG. Production of fertilizer and, subsequently phosphogypsum, has not slowed despite being classified as a toxic waste with “limited economic or environmental value” (Hilton 2007) . The enormous amount of space lost to Phosphogypsum stacks, as well as their proximity to many communities, have spawned research organizations to be formed in order to study the beneficial applications of the PG and its possible environmental and health impacts.

1.4 Environmental and Health Issues
There are some health and environmental implications surrounding the use of Phosphogypsum. The reaction that yields phosphogypsum causes it to be slightly acidic. Any of the impurities in the phosphate rocks may be transferred into the PG thus causing it to contain trace amounts of heavy metals, fluoride, and sulphates. The most concerning issue, both politically and environmentally, is the naturally occurring radionuclides (NORMS) ($^{226}$Ra, $^{238}$U) found in PG (Rutherford 1994). The presence of NORMs is encompassed in regulatory bodies and therefore PG’s ability to be used alternatively (not stacked) is dependent on the amount of radioactivity it contains and the risks associated with its use.

It has been suggested that stacking PG causes negative impacts on the environment due to the leaching of its trace elements and heavy metals into the ground water. Although much of the process water is reused in the fertilizer production process, this water is still inherent in the PG stacks and can further impact the groundwater below the stacks (Rutherford 1994; Eckenrod 2004).

1.5 Environmental Concerns of Stacking PG

Phosphogypsum is stored on the land in large formations known as “stacks” (Rutherford 1994; Alberta Environment 2006). These stacks are a form of long term storage and the acres of land on which they are stored are subsequently made unavailable. Stacking is the most cost effective way of dealing with Phosphogypsum, which is considered a waste product in many countries, which therefore limits its ability to be used as a secondary or processed resource. Alberta classifies phosphogypsum as a non-hazardous waste (Alberta Environment 2006). The reaction of phosphate rock with acid causes the by-product, phosphogypsum, to contain many of the impurities inherent in the rock and results in the generation of millions of litres of acidic
water. After the phosphogypsum is dry, it becomes a powdery, silty-sand like material with acidic properties. The types of impurities contained in the phosphogypsum depend on the level of contaminants contained in the sourced phosphate rock. The contaminants or impurities found in PG vary, but they can include: quartz, uranium, fluoride, phosphorous, metals, and uranium (Luther et al. 1992; Nifong et al. 1993; Rutherford et al. 1994; Alberta Environment 2006; Al Attar et al. 2011).

Environmental contamination could result due to the impurities contained in the stacks, especially in regards to the naturally occurring radionuclides, as they are concentrated in one place. This method of storage leaves the phosphogypsum exposed to the elements of nature and environmental contamination can occur in the form of: atmospheric contamination from toxic elements such as fluoride; groundwater pollution from trace elements, acids, or radionuclides; radon gas; inhalation of radioactive dust; surface runoff; erosion of the stability of the stacks; millions of litres of acidic process waters, and gamma ray radiation exposure (Luther et al. 1992; Rutherford et al 1994; Alberta Environment 2006; Al Attar et al. 2011).

Studies have examined the impact of PG stacks to the environment tend to have varying results. It has been indicated that the stacks do not radiologically affect surrounding aquatic ecosystems (Rutherford et al. 1994; Al Attar et al. 2011). This is partially due to the formation of a crust over the inactive sections of the PG stacks, which can help to decrease the amount of radiation being emitted by the stack (Button 2004). Although there is a risk from contaminant leachates, many of the newer stacks have mitigation measures such as plastic liners (Al Attar et al. 2011). In the case of Alberta stacks ground and surface water are intercepted before it can reach the surrounding bodies of water (Nichol 2011). The soil surrounding the stacks has been found to hold an increased concentration of radionuclides, although the concentrations are
slightly increased, they are still within the limits of normal soil concentrations. Scientists have suggested that mitigation measures are necessary in order to protect the environment surrounding the phosphogypsum stacks from the radiation, metals, and nutrients inherent in the stacks (Rutherford et al. 1994; Al Attar et. al 2011; Nichol 2011).

1.6 Beneficial Uses

While there are some environmental and health concerns surrounding phosphogypsum, many studies have proved that the by-product does have potentially beneficial secondary applications. There exist many application opportunities that have been studied, and even more application uses that need to be further examined, but theoretically should yield the same positive results as the other applications. These secondary uses include:

- Soil Amendment
- Landfill Cover
- Compost Additive

Theoretical applications that should be explored, as these applications are focused towards environmental remediation and will require large quantities of phosphogypsum, include its use in:

- Tailing Flocculant
- Cement Products
- Remediation of Brine Spills
- Oil well-site reclamation (Alberta Environment 2006)
Scientists have found that phosphogypsum positively improves the quality of soil when applied as an amendment. Its use may be related to the increase of calcium and manganese in the soils surrounding citrus trees, thus increasing their overall health and viability. PG contains some properties desirable in fertilizers and can provide soils with a slightly soluble source of sulfur (EPA 1992; Rutherford et al. 1993; Alberta Environment 2006; Abril et al. 2008). PG can also be shown to reduce methane emissions during beef cattle feedlot manure composting, as well as, reduce the loss of nitrogen (Hao et al. 2005; Zvomuya et al. 2005).

Phosphogypsum yields positive results when used as a landfill cover in lieu of soil. It increases the rate of waste degradation and can be considered more environmentally conscious, as the application would be using a ‘waste’ product to cover another waste product. PG can also be used as a source of gypsum for cement production and as a road base (Shieh 2004).

Theoretical applications are considered plausible due to indications made in literature reviews and through conversations with experts. More research, discovery, and monitoring is necessary in the above noted application processes before conclusions can be drawn regarding the benefits of adding PG to the remediation of sites. The Oil and Gas industry represents the potentially largest demand for the use of PG in the field of environmental remediation (Alberta Environment 2006).

1.7 Problem Statement

Millions of tonnes of PG are created annually. Without a viable use for this product it is wet stacked, laying waste to hectares of land around the world. There are environmental impacts associated with stacking PG; the most obvious implication is the loss of land as a direct result of its creation and storage. Although research has indicated that there are viable, and even,
beneficial uses of PG as a soil amendment, road base, landfill cover, and etc. most of the conclusions state that further research is necessary. Researchers have also indicated that the current USA EPA regulations in place for Phosphogypsum are overly conservative and impede new research projects and experiments. PG was used agriculturally for over thirty years prior to the legislation that was implemented in 1989 and severely limited its use. Studies have indicated that those fields have not suffered from any negative impacts from PGs use and that the amount of radiation found in the soil was comparable to background levels (Chambers 2004; Lloyd 2004; Sumner 2004). Necessary information must be provided to both the industries looking to use PG and the industries generating PG. A framework of use is necessary to encourage the employment of a resource management plan; encourage remediation of the land where PG is currently stacked, as well as, assesses and effectively manage environmental and health concerns associated with the naturally occurring radioactive material (Alberta Environment 2006).

1.8 Purpose and Objectives

This study concentrated on the current regulations in place that relate to Phosphogypsum management, its use in various countries around the world, and how existing regulations and frameworks for use can be applied to Canada. The main purpose of the study was to examine the viable applications of Phosphogypsum, assess the danger of the radionuclides present in PG, evaluate the environmental implications of its use and storage, and to determine the effectiveness of current world-wide regulations. Health Canada’s as well as the United States Environment Protection Agency regulations were examined closely. The EPA regulations were evaluated to determine if they could be considered realistic guidelines for any PG specific regulations that should be implemented in Canada. The purpose of this study and the subsequent research that
was carried out were essential in determining the challenges and barriers facing the use of PG in the industrial and agricultural sectors.

The objective of this study was to examine how PG specific regulations could influence the beneficial use of PG. In order to reach this objective, the research associated with the study included:

1. The collection of data relating to the beneficial uses of PG and the associated environmental and health impacts
2. The analysis and evaluation of current PG regulations
3. An assessment of the danger/risk of the radionuclides present in PG
4. The examination of the possible environmental and economic incentives toward PG use
5. The drawing of conclusions based on the above evaluation

The study’s objectives concentrated on evaluating the viable applications of phosphogypsum, the environmental/health impacts, and the effectiveness of various regulations. In order to ensure an economically valuable and beneficial use of phosphogypsum for the industrial and agricultural sectors, the environmental and health implications of the NORMs, trace elements, and other materials contained in the PG must be effectively characterized, regulated and managed. It is important to reduce the negative impacts that may accompany the mis-use of PG by educating the industries that would benefit from the use of PG, those industries generating PG, and public at large. Additional regulatory guidance is necessary in Canada in order to explore the beneficial uses of PG and mitigate any environmental and/or health impacts.

**2.0 Materials and Methods**
This study was conducted over a period of one year in a series of inquiries directly related to the above mentioned purpose and objectives. The information presented in this study was obtained by methods of non-experimental means, therefore through directed interviews with professionals and specialists, as well as, the compilation and analysis of existing data. The information contained in this study came from variety of sources: panel discussions, interviews, the internet, governmental bodies, peer reviewed literature, industry, and other organizations.

2.1 Literature Review

The study required the review of existing literature and data in order for the researcher to establish background knowledge of phosphogypsum, existing regulations, environmental and health implications, and its viable applications. The literature review included peer reviewed documents and scientific data, as well as, information generated by governmental bodies, universities, and organizations. The information gathered throughout the literature review process was analyzed and critically considered before being adapted into the study.

2.2 Panel Discussion

A panel discussion was held in Manitoba considering the use of phosphogypsum as a remediation product for existing mine tailings. The discussion included many experts from varying fields including Connie Nichol from the fertilizer industry (Agrium Corporation); Dr Douglas Chambers an expert on radiation (SENES Consultants Limited); and ATC Associates Inc. Experts representing the environmental management sectors were also present.
The conversations and questions generated during this panel discussion were transcribed and provided to participants. The panel discussion offered first-hand key insight into Canadian phosphogypsum and the ways in which its use are currently being examined, as well as, the key environmental issues surrounding its applications.

2.3 Snowball Sampling Technique

The Snowball Sampling technique was used to obtain primary data from key experts in the fields of phosphogypsum, radiation, and governmental regulations. This method identifies one expert who can be considered a primary contact. This expert is then interviewed and asked to provide additional experts or contact names that can be considered knowledgeable on the subject of the interview. This method continues until a sufficient sample size of interviewees is reached, or when no more new contacts can be identified. The initial stages of the study identified an environmental scientist working for the industrial sector as the primary contact. From this contact, others were identified, including academia, researchers, experts in radioactivity and risk studies, the federal government and organizations (Vasudevan 2004).

2.4 Development of Interview Guide

The contacts identified for this study had a wide range of expertise and backgrounds. It was difficult to find experts and/or professionals with consistent research and involvement with phosphogypsum. Therefore the questions posed to each contact tended to vary slightly based on their area of expertise and their type of involvement with PG.

The interviews were conducted in a manner of open-ended interviews, allowing room for discussion and expansion. The respondents were asked the same basic questions about
phosphogypsum but were able to expand their answers based on their areas of expertise and research. The interviews focused on the researcher’s/expert’s study of Phosphogypsum, but all experts were asked questions pertaining to their view on:

- The health and environmental risk of secondary phosphogypsum use;
- The regulations encompassing phosphogypsum and;
- The limitations and barriers to the use of phosphogypsum

2.5 Expert Input

Expert input varied according to the personal type of involvement examining the various aspects of phosphogypsum use. Experts who had worked with and applied phosphogypsum in experimental situations were able to give first-hand accounts as to the regulations and standards that had to be met in order to procure the phosphogypsum, as well as, their experience working with phosphogypsum and the beneficial results yielded during the conducted experiments. Experts in radiation were able to provide insight into the amount of risk posed by the use of phosphogypsum in various experimental scenarios, as well as, the nature of the regulations and standards that encompass phosphogypsum use.

3.0 Results

3.1 Agricultural Applications

PG is a byproduct of the fertilizer industry. The process that creates PG allows it to retain some important fertilizer-like qualities. Important nutrients, such as calcium, sulfur, and phosphorus, are made available to ranging soil types through the application of PG. Studies
investigating phosphogypsum as a source of plant nutrition have attributed its ability to supply soluble nutrients to growing crops as the reason behind its effectiveness as a soil additive. Not only does PG contain important nutrients easily available to crops, it can also increase the availability of other nutrients, such as iron and manganese around the roots, and nitrogen, phosphorus, potassium, and magnesium in soil with high calcium content (EPA 1992; Rutherford et al. 1993; Alberta Environment 2006; Abril et al. 2008).

Phosphogypsum has been used in agriculture in the United States and Spain for well over thirty years (Abril et al. 2007). Other parts of the world have also realized the benefits that accompany the use of PG as a soil conditioner. PG has been shown to improve sodic and clayey soils due to its ability to retain moisture and leach salt. Deficient soils may also obtain important nutrients, such as calcium and sulfur from the application of PG (EPA 1992; Lloyd 2004). Many of the southeastern states have benefited from the use of PG for crops such as peanuts, corn, almonds, tobacco, citrus fruits, tomatoes, sugar cane, and small grains (EPA 1992). The quality and yield of crops has been shown to increase when the soil is amended with PG for vegetables, grain, fruits, forage, and oilseeds. The use of PG in soil amendment has been researched greatly.

3.1.1 Soils with a High Magnesium Concentration

The amount of magnesium found in soils, due to its increase in irrigation waters, has been increasing in many parts of the world. This increase of magnesium in soils has shown to be detrimental to the physical properties of soil, such as hydraulic conductivity and the infiltration rate of water, and consequently crop growth (Vyshpolsky et al. 2010). This increase in soils causes the soil surface to attract the water and can increase erosion and crusting, due to the hydration energy and hydration radius of Mg\(^{2+}\) being greater than that of Ca\(^{2+}\). The resulting low
infiltration rates of water can be counter-acted with the application of calcium to areas where cation exchange occur, thus reducing the effects of “excessive exchangeable Mg\(^{2+}\)” (Vyshpolsky et al. 2010).

A study conducted by Vyshpolsky et al. found that the application of phosphogypsum in order to increase calcium levels in Mg\(^{2+}\) affected soils significantly improved soil quality, increasing the movement of water into and throughout the soil, especially in the root zone for use by the plant’s roots, and thereby enhancing the efficiency of irrigation. Crop yield increased with water productivity. The application of 3.3 t ha of PG in the fall, before snowfall, was shown to yield the most effective results, both economically and for crop and soil vitality (Vyshpolsky et al 2010).

3.1.2 Acidic Soils

Acidic subsoils have a tendency to decrease the ability of a plant’s root to penetrate this horizon due to high levels of Al and low levels of Ca. Soluble Al can be considered toxic at certain levels and disrupt cell division of a plant’s root during mitosis, therefore reducing root proliferation. Soils low in calcium tend to be clayey thus limiting the amount of water and nutrients available to plants, and ultimately, crop growth (Sumner et al 1988; Rutherford et al. 1994).

Although the application of lime has proven to be effective in the reclamation of acidic topsoil, it is slow moving and does not readily penetrate down the soil horizon. The application of the soluble PG to acidic soils has an ameliorative effect, providing for deeper root proliferation, as well as, increasing the density of the plant’s root which allows for water to be extracted from the soils. Lab and field studies have shown that the levels of exchangeable and
solution Al decrease and the levels of exchangeable and solution Ca increase with the application of PG. Acidic soils are reclaimed, resulting in the growth of the plant’s root being enhanced, thereby increasing crop growth (Pavan et al. 1988; Sumner et al 1988; Rutherford et al. 1994;).

3.1.3 Use as a Landfill Cover

A study conducted by Dr Chih-Shin Shieh has indicated that the application of phosphogypsum in landfills appears to have many beneficial outcomes, especially when compared to more traditional landfill covers. The three-phase study examined the feasibility of using phosphogypsum as a landfill cover in terms of both its environmental and technical implications. Two in lab studies simulated the application of PG to a regular municipal solid waste landfill at a ratio of 1:3 and is the basis for the outline of the third phase, which is to be a field study. The field study has been awaiting approval by EPA for over five years.

The first phase of the study proved the practicality of PG application to municipal solid waste landfills, upholding the hypothesis that the sulfates contained in PG can be used by the bacteria without the formation of environmentally harmful by-products. Phase one also established the optimal mixing ratio of 1 parts phosphogypsum to three parts waste (Shieh 2004).

The second phase of the study proved that phosphogypsum application to municipal solid waste landfills increases the rate of degradation by more than fifty percent in a period of three months (Shieh 2004).

The in-lab studies have proved that PG improves the rates of biodegradation due to its sulfate containing properties. The first stages of biodegradation are mainly aerobic, as oxygen is readily available to the bacteria that depend on it for survival; the process produces carbon dioxide and is modelled as follows: \( \text{Organics} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{SO}_4^{2-} \) (Shieh 2004).
As biodegradation continues, the oxygen is slowly depleted and the process becomes anaerobic and the primary gas generated is methane. This process change causes the bacteria to rely on bound oxygen in order to produce electron acceptors in a reaction that is now considered to be oxidation-reduction and is modelled as follows: Organics $\rightarrow$ CO$_2$ + CH$_4$ + H$_2$S + NH$^{4+}$. The sulfate found in phosphogypsum acts as another source of energy for bacteria colonies found in the landfill that depends on sulfate for survival. As a result, additional bacteria will be present in the decomposition process, thus increasing rate of degradation (Shieh 2004).

Phase two of the study indicated that the rates of degradation increased so much that in once the municipal solid waste underwent anaerobic degradation processes; the decomposition of the waste was increased by 50% in three months (compared to traditional landfill cover and degradation rates). Phosphogypsum also appears to prolong the emissions of carbon dioxide during the aerobic degradation process and delay the formation of methane, which in turn reduces the net greenhouse gas emissions of landfills and is also believed to further increase the rate of degradation during its anaerobic stages (Shieh 2004).

The study included the collection of leachates which were analyzed for various elements and trace metals, as well as, the concentration of sulfates. The analysis proved that the addition of phosphogypsum did not increase the levels of iron, zinc, or lead beyond the range typically found in landfill leachate. Dr Shieh noted that the lack of metals may be due the formation of metal sulfide precipitate by the dissolved sulphur component. This formation would also account for the lack of hydrogen sulfide. The only elements with concentrations increased beyond those typically found in a landfill waste matrix were calcium and sulfate (Shieh 2004).

It should be noted that in order to procure the phosphogypsum for this experiment that all of the phosphogypsum used had to follow the United States Environmental Protection Agency
Guideless. The third phase of the study would require 25 tonnes of PG for the infield test cells. The risk of radiation exposures was assessed for four possible receptor scenarios: PG researchers maintaining the test cell, on-site resident (if house is built on landfill after closure many years from now), resource recovery worker, and landfill workers. The life-time risk for all receptors, except the on-site resident, was many orders of magnitude below reasonable levels of concern ranging from $2.2 \times 10^{-7}$ to $2.5 \times 10^{-11}$. The life-time risk calculated for the on-site resident was considered acceptable by EPA’s standards and ranged from $2.8 \times 10^{-4}$ to $4.7 \times 10^{-8}$. The use of PG as a landfill cover generates low risk because of the mitigation measures already in place to keep the contents of landfills from negatively impacting the surrounding environment, as well as, the low accessibility and therefore the low exposure of the public to the landfills, their contents, and their products (Chambers 2004).

3.1.4 Compost Additive

Phosphogypsum was added to cattle feedlot manure in two separate studies in order to examine its co-composting capabilities and its effects on greenhouse gas emissions during composting.

The first study involved the addition of 40-140 kg of phosphogypsum Mg$^{-1}$ manure and PG dry weight over a ninety-nine day composting period in order to assess the chemical and physical changes in the compost. As a result of the addition of PG, the end compost product decreased its total nitrogen loss by 0.11% for every 1 kg Mg$^{-1}$ of PG and increased the total sulfur concentration by 0.19 g kg. Based on this information, it was suggested that the compost end product with PG should be examined as a soil amendment for soils deficient of sulfur. Composting with PG did not increase the phosphorous concentrations of the end products,
although there was a decrease in the overall loss of nitrogen during the composting period which results in less greenhouse gases being emitted into the atmosphere (Zvomuya et al. 2005).

The second study focused on the reduction of greenhouse gases as a result of the addition of phosphogypsum to cattle feedlot manure composting. PG was mixed with manure at a rate of 10%, 20% or 30% of the dry weight of the manure. The study lasted for one hundred and thirty-four days. PG was shown to decrease the amount of greenhouse gases, mostly methane, being emitted during the composting stages by upwards of 58% (Hao 2005).

Both of these studies were conducted in Canada and therefore had to meet with Health Canada’s guidelines on naturally occurring radionuclides. The amount of radioactivity contained in the end product of the compost was negligible, especially considering the effects of dilution. The first study determined that the concentration of Ra-226 in all of the treated final compost products was well below the limits set forth by Health Canada. Therefore the use of PG as a compost additive would not be limited and its co-composting abilities could be used in the agricultural sectors without posing environmental or health risks (Hao et al. 2005; Zvomuya et al. 2005).

3.1.5 PG as a Road Base

The Florida Institute of Phosphate Research has dedicated years of research and funding to studies involving the use of phosphogypsum in a practical and environmentally safe way. The institute focused on three uses of phosphogypsum: as a chemical raw material, a construction material, and in varying agricultural scenarios (Nifong et al. 1993; Lloyd 2004).

In the late 1980s two experimental roads were constructed using phosphogypsum as a road base located in Polk County and Columbia County. The roads were constructed under
the guidance of the University of Miami’s Civil Engineering Department. The research concluded that, from an engineering standpoint, phosphogypsum made for an appropriate and viable building material (Nifong et al. 1993). The Florida Department of Transportation has since conducted tests on the Polk Country road which has indicated that the road has gotten stronger, structurally, over time and has required fewer repairs over the years than other roads in the area (Lloyd 2004). Phosphogypsum as a road base proved to be a cost effective material, reducing the costs of road construction by 75% which was equal to savings of $100 000 per mile (the phosphogypsum was provided at for free) (Alberta Environment 2004; Lloyd 2004).

Concerns regarding the contaminants and radiation that could be inherent in the phosphogypsum used as the road base were not ignored. The Florida Institute of Phosphate Research continued the University’s environmental monitoring of the road every two to three month for a period of two and half years after the completion of the road. This monitoring was used to determine if there were any chemical or radiological environmental impacts resulting from the use of phosphogypsum. The monitoring included studies of the groundwater, soil, and air. The results of the samples were compared to the conditions of the sites before the roads were constructed. Water samples were collected monthly from monitoring wells drilled into the surficial aquifer located along both of the roads and included the analysis of radium as well as twenty four other parameters (Nifong et al. 1993).

The results of the monitoring established that the use of phosphogypsum as a road base does not pose environmental harm, as the local environments did not experience any significant effects. An increase in gamma radiation was detected directly around the pavement located above the phosphogypsum base, but the concentration of radiation did not surpass the Florida DHRS guidelines for indoor residential exposure. Any constituents of phosphogypsum detected
in the groundwater were well below the standards established for clean drinking water (Nifong et al. 1993). These positive results not only represent an environmentally sound reason for the use of phosphogypsum as a construction material and/or road base, but an economically sound reason as well (Nifong et al. 1993; Alberta Environmental 2004; Lloyd 2004).

3.2 United States of America Environmental Protection Agency Regulations on PG

Historically, due to its beneficial results, phosphogypsum was unregulated and was used in research and development projects, agriculture, and construction mainly in Florida (due to its large supply) as well as other locations around the US. The National Emissions Standards for Hazardous Air Pollutants (NESHAPS) introduced in December of 1989 changed this. The regulation specifically addressed the naturally occurring radioactive material contained in phosphogypsum and required that the by-product to be deposited in stacks. Further to this, the regulation also prohibited the use of PG. It was at this time that phosphogypsum became regarded as a waste product (Chambers 2004; Lloyd 2004; Sumner 2004) and all research into the alternative applications and viable uses of PG were terminated (Hilton 2007). A risk assessment on the health and environmental implications of PG use was not conducted at the time of the ban (Lloyd 2004).

Due to several petitions, in 1992 an amendment was made to the NESHAPS 1989 law. The revision of NESHAPS for 40 CFR Part 61 subpart R allowed the use of PG in the following circumstances:

- If the concentration of radium-226 contained in the phosphogypsum was less than 0.37 Bq/g, it could be used in outdoor agricultural settings.
• Upon approval from EPA, the use of up to 700lbs of PG for specific research and development activity; and
• Upon approval from EPA other applications could be permitted strictly on a case to case basis

The change in regulations permitted the use of phosphogypsum sourced from North Florida and North Carolina to be used in agricultural, research, and development purposes, as those stacks contained a Ra-226 concentration that fell below the 0.37 Bq/g regulations (EPA 1992; Chambers 2004; Lloyd 2004).

Questions began to arise from the Fertilizer Institute about the risk assessment conducted between in 1992 that established the revision and concurrently the 1992 regulations. In 1999 the regulation was amended further. EPA justified increasing the limit of PG that could be used in research due to revision in the original assumptions that were made when regulating PG in 1989 and revising the regulation in 1992. The 1999 revision increased the amount of PG that could be used in a laboratory from 700 pounds to 7000 pounds. This increase was due to the following changes in assumptions (EPA 1999; Lloyd 2004):

• Originally it was assumed that numerous (five) drums of PG could be opened at one time in a laboratory setting. The change made reflected the reality of a laboratory setting in which only one drum would be opened at one give time.
  o It is also important to note that 700 pounds of PG could only be contained in roughly one drum, therefore the original assumptions of five drums being opened at once where made impossible by the regulations in place at the time.
• It was also assumed that all of the radon-222 formed from the radium-226 found in PG would emanate into the air. After measuring the actual radon-222 emanation, it was found that the 1992 regulation did not accurately represent the true rate.
• Phosphogypsum in laboratory settings was regulated under the assumption that researchers would spend 4,000 hours in the laboratory exposed to PG. This was a very high assumption of the number of hours a researcher would work, and the number of hours was reduced to 1,000 to represent the time spent at work more realistically. (Lloyd 2004)

3.2.1 Risk Assessment

In order to support the revision of the NESHAPS regulations made in 1992, EPA conducted a risk assessment where the PATHRAE does assessment model was used to evaluate eight pathways of possible radiation exposure. The eight pathways included: erosion and transport to a river, groundwater migration to a river, groundwater migration to a well, atmospheric transport of contaminants, food grown on site, on-site dust inhalation, inhalation of radon in structures (built on fields where PG was applied historically), and direct gamma ray radiation. The model was for an individual’s lifetime maximum risk after one year of exposure and used EPA’s Environmental Impact Statement for radionuclide NESHAPS for the risk conversion factors (EPA 1992; Chambers 2004; Sumner 2004).

MicroShield was used to enhance the PATHRAE model to allow it to be applied to an exposure scenario that involved the gamma radiation researchers were exposed to when experimenting with PG (EPA 1992; Chambers 2004).
Seven agricultural scenarios, one research scenario, and four road construction scenarios were assessed by EPA. Through this assessment, EPA concluded that an annual dose and the extrapolated lifetime risk would be based on seventy years of exposure and equate to a lifetime risk of $3 \times 10^{-4}$ or 3 in 10,000 (EPA 1992; Chambers 2004).

3.2.2 Downfalls of EPA’S Risk Assessment

The application rate determined for the agricultural scenario did not represent the actual phosphogypsum application rates used by farmers. The risk assessment and subsequent ban of PG applications was based on an application rate derived by averaging the amount of PG applied to sodic soil treatments in California and the amount of fertilizer applied to peanut farms, based in Georgia (Lloyd 2004). Despite the fact that the application rates of a soil treatment and that of fertilizer should not be comparable nor are they overly related, EPA concluded that the risk assessment should be based on an annual PG application rate of 1,350 pounds per acre (EPA 1992; Chambers 2004; Lloyd 2004; Sumner 2004). Across America, the actual application rate of phosphogypsum was such that 95% of its uses would be below EPA’s calculated rate. This rate of application was unsuccessfully challenged by the Fertilizer Institute, who were adamant that this rate, used as a basis for the subsequent risk assessments, did not truly reflect the agricultural uses of phosphogypsum (Chambers 2004; Sumner 2004).

Agricultural applications rates based on those recommended by the Cooperative Extension Service, an imprimatur of the Federal and State Government, have been calculated to represent the maximum probable application rate of PG as being between 600 and 800 pounds per acre per year. The most likely rate of application falls between 100 and 400 pounds per acre per year. The Cooperative Extension Service’s rates are based on the applications of PG as a soil
conditioner to provide the nutrients calcium and sulfur, as well as, phosphogypsum’s ability to improve subsoil acidity. The different uses of PG call for different rates of applications. When combined and averaged, the maximum rates and likely rates of PG applications were calculated as stated above. The following tables represent the recommended rates of gypsum applications to varying crops depending on the nutrients or soil conditioning needed and justify the rates and numbers used in the Cooperative Extension Service’s calculations as well as the more realistic maximum application rates (Sumner 2004).

### 3.2.3 Calcium Provision for Peanut Farms

Many crops require calcium, especially peanut crops, as it is needed to build strong shells. If the soil contains a low level of calcium, gypsum is applied to improve what would be considered a deficiency. In order to protect the peanut crop from pests, these crops are rotated with other crops that are not susceptible to peanut pests on a two to three year rotation basis. It should therefore be noted that the rates of gypsum application listed in the table below should be divided by two or three, depending on the rotation schedule.

Table 1: Recommended rates of gypsum applications for peanuts for one year

<table>
<thead>
<tr>
<th>State</th>
<th>Peanut Type</th>
<th>Calcium in Soil</th>
<th>Gypsum recommendation: pounds/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plot application</td>
</tr>
<tr>
<td>Alabama</td>
<td>Runner</td>
<td>Low</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Med</td>
<td>250</td>
</tr>
<tr>
<td>Florida</td>
<td>Virginia Runner, Spanish-seed</td>
<td>All</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>Virginia Runner, Spanish</td>
<td>All</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Virginia Runner, Spanish</td>
<td>Low</td>
<td>400</td>
</tr>
<tr>
<td>Georgia</td>
<td>Virginia Runner, Spanish-seed</td>
<td>All</td>
<td>688-860</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All</td>
<td>344-430</td>
</tr>
<tr>
<td>North Carolina</td>
<td>Virginia</td>
<td>All</td>
<td>600-800</td>
</tr>
<tr>
<td>South Carolina</td>
<td>Virginia Runner, Spanish</td>
<td>All</td>
<td>600-800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All</td>
<td>400-500</td>
</tr>
</tbody>
</table>
Based on the table rates of application and on a two year rotation plot-crop basis, as is common in the cultivation of peanut crops, the maximum rate of application of PG per acre per year would be 600 pounds. It is more likely that farmers would use an application rate ranging between 125-430 pounds of PG per acre per year (Sumner 2004).

3.2.3 Calcium Provision for Tomatoes and Peppers

Calcium is also required by tomatoes and peppers in order to decrease the chance of blossom-end rot. Although gypsum applications are rare, as calcium has been made into an effective leaf spray, two states, Georgia and Tennessee, have outlined recommended gypsum application rates of these crops. The maximum recommended application rate is 430 pounds of phosphogypsum per acre per year, the most common application rate used by farmers is closer to 200-300 pounds of phosphogypsum per acre per year, and the minimum recommended application rate is anywhere from 0-143 pounds of phosphogypsum per acre per year. The recommended rate of application should be adjusted to account for two and three-year crop rotations; therefore it is likely that the annual application rates would be between 215 and 430 pounds for a two-year rotation and between 143 and 287 pounds per acre for a three-year rotation. The rate of application used as a basis in their risk assessment was 3.1-9.4 times higher than the actual rate of application used in this agricultural situation (Sumner 2004).

3.2.4 Sulphur Provision for Crops

Phosphogypsum is a great source of sulphur (due to its gypsum component). Sulphur is required for protein synthesis and is therefore essential to plant growth. Recommendations by the

<table>
<thead>
<tr>
<th>Virginia</th>
<th>Virginia, Seed</th>
<th>All</th>
<th>600</th>
<th>900-1500</th>
</tr>
</thead>
</table>

*Adapted from Gypsum as a Calcium and Sulfur Source for Crops and Soils in the SouthEastern United States-Malcolm E. Sumner
State and the Cooperative Extension Service for the rate of sulphur application that will optimize plant growth are based on extensive studies done to determine this optimal rate.

Table 2: Recommended applications rates of gypsum to crops in order to supply optimal amounts of sulphur.

<table>
<thead>
<tr>
<th>State</th>
<th>Crop type</th>
<th>Gypsum Rate pounds per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>All</td>
<td>54</td>
</tr>
<tr>
<td>Florida</td>
<td>Agronomic, grass</td>
<td>80-108</td>
</tr>
<tr>
<td>Georgia</td>
<td>All</td>
<td>54</td>
</tr>
<tr>
<td>North Carolina</td>
<td>Corn, small grains, tomato, bermudagrass, cotton</td>
<td>108-161</td>
</tr>
</tbody>
</table>

Adapted from Gypsum as a Calcium and Sulfur Source for Crops and Soils in the SouthEastern United States-Malcolm E. Sumner

Based on the information provided in Table 2, the maximum application rate of phosphogypsum would equal 161 pounds per acre per year, with a more probable application rate between 50 and 80 pounds per acre. Farmers wishing to increase the amount of sulphur available to crops would apply nearly eight times less phosphogypsum to their fields than the estimated application rate assumed in the risk assessment calculations made by EPA (Sumner 2004).

3.2.5 Applications for Recovery of Acidic Subsoil

Phosphogypsum has been applied to fields in the place of lime or limestone to improve the penetration of a crop’s roots in alkaline soils. Applications of PG have resulted in yield responses that manage to last over ten years, therefore reducing the application rate. The
maximum rate of application would be 800 pounds of phosphogypsum per acre per year, the most likely rate of application would be around 400 pounds of phosphogypsum per acre per year. The rate of application farmers use to improve acidic subsoil is therefore much less than EPA’s assumed rate of application (Sumner 2004).

3.2.6 Recovery of Sodic Soil

In sodic soils, phosphogypsum can be applied to improve the movement of water through the top twenty inches of the soil. Over one hundred years, a maximum application rate would be 700 pounds of phosphogypsum per acre per year, the most likely rate of application would be between 200-500 pounds of PG per acre per year. Actual application rates would be two to ten times less than EPA’s assumed rate of application used in their risk assessment (Sumner 2004).

3.2.7 Conclusions: EPA’s Regulation

As represented above, the assumed rate of phosphogypsum application by EPA does not truly reflect the rate of application used in real life scenarios. In order to better represent real life applications, the assumed rate of phosphogypsum application should be changed to a maximum rate range of 600-900 pounds of PG per acre per year so that true risk associated with the use of PG can be assessed and integrated into a more representative risk assessment. It can be extrapolated, based on the above information, that many of the conclusions drawn by EPA that lead to the banning of PG use in agricultural were flawed. A new risk assessment should be conducted using the maximum application rate of 900 pounds of PG per acre per year. This data would yield conservative results as experiments and the Cooperative Extension Service
recommended rates of PG application indicate that the more likely rate of application to be used by farmers would within the range of 100-400 pounds of PG per acre per year (Sumner 2004).

The original risk assessment did not limit the concentration of the radium-226 in the phosphogypsum found in the study. The assessment, not only over-estimated application rates, it also used phosphogypsum with a radium-226 concentration of 1,110 Bq/kg. Currently the regulations only allow the use of phosphogypsum in agriculture and experiments if the concentration of radium-226 has been certified as 370 Bq/kg, based on the assessment with an application rate of 2,700 pounds. The application rates estimated in the assessment combined with the radium-226 concentration inherent in the phosphogypsum used for the study lead to the overly conservative regulations that greatly limited the potential of phosphogypsum use. Science has suggested that, if the application rates of the EPA’s risk assessment were adjusted to reflect the maximum application rates of gypsum, 900 pounds per acre per year, then the maximum acceptable risk of 3 in 10,000 would not be breached. Therefore, phosphogypsum containing radium-226 concentrations of 1,480 Bq/kg could be used unrestricted provided that maximum application rates did not exceed 900 pounds per acre per year (Chambers 2004).

3.3 Health Canada’s Guidelines

Health Canada’s year 2000 guidelines for Naturally Occurring Radionuclides (NORM) is the only regulation that applies to phosphogypsum in Canada. This regulation limits the use of soil amendments to a radium-226 concentration of 300 Bq/kg, making it even more conservative than the regulations in the United States of America. Although the radium-226 concentration is more limited in Canada, phosphogypsum use is much less regulated. Phosphogypsum containing concentrations above 300 Bq/kg, as most stacks in Canada do (between 400-700 Bq/kg), cannot
be used as a soil amendment. Canadian PG can be used in oil well site reclamation, as additive to composting, as an additive to feedlot manure and as an additive to tailings generated by the oil sands, providing that it can be demonstrated that its use will not exceed personal exposures of 30% of the annual public dose limit (Alberta Environment 2006; Health Canada 2000, Zvomuya et. al 2005). Studies of PG use in agriculture and industry indicate that its use produces a personal exposure of less than 10% of the acceptable annual public dose limit, which is lower than the average exposure to natural background concentrations (Health Canada 2000, Zvomuya et. al 2005). Provided that the above regulations can be met, phosphogypsum will be released to the researcher without further consideration.

3.4 Non-North American Regulations

Many countries, including those in Europe and South America, are beginning to adhere to the International Atomic Energy Agency’s (IAEA) standards regarding radionuclides. The basic safety standard for Protection against Ionizing Radiation and for the Safety of Radiation Sources is an international initiative to establish international regulations/ guidelines on how to deal with and protect against exposure to naturally occurring radionuclides. As outlined by the IAEA, the standards limit the use of substances containing over 1 000 Bq/kg of radiation, including radium-226. Based on these standards, regulation is not necessary for any substance containing NORM concentrations less than 1,000 Bq/kg, as no significant health or environmental risk would arise as a consequence of those substances (Wymer 2007; Hilton 2007).

The established limits were based on modelled risk assessments of various scenarios and calculated exposure concentrations of both the workers in direct contact with the substances and the general public (Mrabet 2007). This limit applies to phosphogypsum and is based on the facts
that the naturally occurring radionuclides retained in phosphogypsum is generally of a lower concentration than that contained in many soils and radioactive material existing in the atmosphere. Therefore there is no scientific evidence that directly links the IAEA standards for use to any adverse long-term environmental impacts/consequences (Hilton 2007; Mradbet 2007).

The IAEA is currently developing a Safety Report that will address the radiological issues of the phosphate industry and how current practises can be made to comply with the IAEA Safety Standards. The report aims to provide safety regulations and information as well as protection management for NORM materials in the phosphate industry and will improve the public’s perception of phosphogypsum, its regulations, and its beneficial uses (Hilton 2007).

3.5 Barriers to the use of Phosphogypsum

3.5.1 Legislative Barriers

As it has been indicated in the above sections, the presence or absence of phosphogypsum related regulations can greatly affects initiatives exploring its alternative uses. The USA EPA phosphogypsum specific regulations caused a sharp decline in research into the beneficial and secondary uses of the by-product. This trend is illustrated in figure 1, in which Dr. Julian Hilton tracks the decline of phosphogypsum related research publications in the United States as compared to the rest of the World. Logically, there is a sharp decrease in the amount of research conducted following the 1989 ban of phosphogypsum. Despite the amendments of the regulation in 1992 and 1999, phosphogypsum research has yet to recover in the United States.
This lack of research publication recovery cannot be blamed solely on a lack of interest in this sector from scientists and industry. The process required to be granted permission to use certified phosphogypsum in research is lengthy and may take years to be approved as the petition process does not have a finite timeline (Cotsworth 2004; Shieh 2004).

The conservative regulations surrounding NORMs in both Canada and the United States negatively impacts the ease of access scientists experience in procuring phosphogypsum. Although Canada lacks phosphogypsum specific regulations, Health Canada guidelines for NORM limit their concentrations to 300 Bq/kg. All of Canada’s phosphogypsum exceeds Health Canada’s standards, NORM concentrations range from 400-600 Bq/kg, therefore eliminating the possibility of its use as a soil amendment (Health Canada 2000).

Despite many countries coming into alignment with IAEA standards for basic safety, the process of dilution whereby the addition to soil would reduce the concentration radiation in an application (Zvomuya et al. 2005), and the countless exposure scenarios that have indicated that

*Figure 1:*  PG research publications *per year.* (Hilton 2007)
levels of radiation below 1,000 Bg/kg do not pose significant risk to the public or workers, the current regulations in North America are not moving towards a change (Hilton 2007). The conservative regulations may result in a lack of interest in the beneficial uses of phosphogypsum by industries and scientists. The regulations will continue to cause bias towards the use of phosphogypsum by the public as the regulations propagate the perception of negative health and environmental impacts surrounding the use of phosphogypsum.

3.5.2 Public Perception and Education

The presence of NORM in phosphogypsum causes the public, stakeholders, and industries to have a negative perception toward the secondary uses of phosphogypsum. Industries are hesitant to invest in establishing secondary use due to this perception of environmental impacts and the subsequent liability.

The US EPA’s restrictive regulations helped to spawn much of the public’s and industries’ negative perception of Phosphogypsum. The US EPA’s influence was best noted in Andalucía Spain where, after thirty years of applying phosphogypsum in the local soils, environmental groups lobbied the government to ban its use following the decision of the United States. The government made an injunction to stop the use of phosphogypsum, which was only abolished after the lobbying of local farmers and the condition that its use must be monitored by the courts. The monitoring included residue uptake by crops, uptake through the food chain, and potential environmental impacts. A study conducted by Abril et al. examined the cumulative effect of three decades of phosphogypsum use in Andalucía Spain and determined that the use of phosphogypsum did not negatively impact the environment or affect the food chain. The study established the safe and beneficial uses of phosphogypsum and has resulted in its use as a
registered fertilizer in Spain providing applications follow the authorized rates as indicated on
the label (Hilton 2007; Abril et al. 2008).

Lack of positive public perception and education on the true risks posed by phosphogypsum use greatly impedes the exploration of its use in remediation and agricultural scenarios. Communities approached by the industries that produce phosphogypsum are wary and untrusting of the suggested beneficial applications. The idea of introducing a radioactive substance into their environment is illogical and lacks appeal, regardless of the beneficial outcomes or the lack of significant risk. This a common and obvious issue, not only because the corporations producing it appear to be the only ones interested in finding alternative uses, but because the government has classified phosphogypsum as a waste and has forgotten about it. The lack of government involvement in finding alternative uses to phosphogypsum raises the public’s bias towards searching out alternative uses because it is hard to comprehend how a potentially radioactive by-product could have beneficial uses.

3.5.3 Economics

There are several economic factors that discourage exploration into the alternative uses of phosphogypsum. They include: the low cost of stacking, the lack of money needed to research and market the product, and the cost of transportation. The fact that there is no established secondary use for phosphogypsum, despite its proven benefits, makes it difficult to establish a market value for the by-product.

3.5.3.1 Low Cost of Stacking
Stacking phosphogypsum represents a relatively cost-effective, low-risk, way to deal with the millions of tonnes of the by-product produced annually. Long term maintenance costs for the stacks are low and once inactive, they require very little work.

The acceptance and ease of stacking millions of tonnes of phosphogypsum leads to a lack of interest in the industrial sector, both from the producer and from the consumer, in finding alternative uses for the by-product. The affordability of stacks does not take into account the acres of land being laid to waste, nor the potential environmental affects as a result of the stack’s contaminants (Alberta Environment 2006).

3.5.3.2 Lack of Funding

The industrial sector is not forced to find alternative uses for the millions of tonnes of phosphogypsum it creates and the government is content to let the stacks pile up. In order to establish a secondary use for phosphogypsum the possibility of environmental or health risks much be eliminated. Funding is necessary in order to invest in studies and experiments that will support the applications of phosphogypsum described in the earlier sections of this study. The existing stacks of phosphogypsum must be tested and the contaminants inherent in the stacks must be characterized in order to further improve stakeholder and public perception. Infrastructure related to the transportation of phosphogypsum to the secondary use sites will be necessary. Finally marketing of the by-product must also be developed in order to improve communication, knowledge, and management between regulators, industry, and the public (Alberta Environment 2006).

3.5.3.3 Cost of Transportation
The cost to transport phosphogypsum may prove to be a large barrier to its use at secondary locations. Many of the possible and beneficial uses described in the earlier sections of this study may not incur a large enough demand for the by-product to justify the cost of shipping. It has been estimated that the cost of transportation (in Canada) would range between $13-$25 per tonne of phosphogypsum, depending on the distance to be hauled and the possible establishment of long-term contracts (Alberta Environment 2006).

4.0 Discussion

4.1 Necessary Actions to Establish Secondary Use of PG

The secondary uses of phosphogypsum will not further explored without dealing with the barriers established in the above section of this study. In order to promote and establish the secondary use of phosphogypsum in Canada, it will be necessary to implement phosphogypsum specific regulations and produce economic incentives to stimulate the involvement of the industry, potential consumers, and stakeholders (Alberta Environment 2006).

4.1.1 Phosphogypsum Specific Regulations

In order to mitigate the environmental and health risks posed by the contaminants inherent in phosphogypsum, Canada requires specific regulations that will direct industries and consumers on how to use phosphogypsum in a way that will eliminate risks to the environment and the public (Alberta Environment 2006; Hilton 2007).

The best way to understand and manage the potential risks surrounding the secondary uses of phosphogypsum would be to characterize and assess the contaminants inherent in the
stacks. A radiological survey of the stacks should be completed along with the analysis of nutrients, metals, and other impurities. Understanding the components of phosphogypsum will allow for the development of regulations that are based on the science of the stacks and will therefore represent the true risk posed by its secondary use. Once the components are understood, risk assessments can be done based on the analysis of the stacks and corresponding regulations and frameworks for use can be developed (Alberta Environment 2006).

The regulations and framework of use should follow the IAEA’s basic safety standard for Protection against Ionizing Radiation and for the Safety of Radiation Sources in order to allow for the stacks within Canada to be used. Health Canada’s guideline on NORMs would need to be amended in order to incorporate the phosphogypsum specific regulations and perhaps even incorporate the IAEA’s safety standards for the phosphate industry once they are completed. The overly conservative limitations of Health Canada’s regulations should no longer apply to the use of phosphogypsum as a soil amendment, considering the findings of the IAEA and the assessment SENES consulting conducted for the FIPR that established that the maximum acceptable risk resulting from exposure to NORMs would not be breached even with an application rate of 900 pounds per acre per year and a radium-226 concentration of 1,480 Bq/kg (Sumner 2004).

The characterization and analysis of the phosphogypsum stack, in order to better understand and manage the risks associated with its use, would increase the confidence of the stakeholders and the public in its ability to be a considered a secondary resource. Coupled with specific regulations, the communication between the industry, stakeholders, and the public would increase, thereby increasing and promoting secondary uses of phosphogypsum (Alberta Environment 2006).
The regulations would work to mitigate potential environmental and health risks, educate the public and potential users about the by-product, promote secondary uses of phosphogypsum, and improve the overall, public and industrial, perception of phosphogypsum (Alberta Environment 2006).

4.1.2 Further Research into Beneficial Applications

Further research into the beneficial and secondary uses of phosphogypsum is required in order to establish and raise demand for the by-product in large quantities. This research will also evaluate the applications for any risks and impacts that have not yet been established and therefore increase the confidence of stakeholders and the public in its use (Alberta Environment 2006).

The oil and gas industry in Alberta may represent a large market for secondary applications of phosphogypsum. Alberta also houses the largest amount of PG in all of Canada and finding applications for it in the same province would cut down on the costs of transportation. The theoretical applications mentioned in previous sections of this study should be explored in order to determine if all of the possible secondary applications for phosphogypsum have been established and the potential risks can be evaluated (Alberta Environment 2006).

4.1.3 Economic Incentives

In order to promote the use of phosphogypsum as a secondary resource, economic incentives must be established. A market must be created for phosphogypsum and an increase in
demand is necessary in order to engage the industries producing the by-products and the industries that could benefit from its use.

Studies have indicated that the use of phosphogypsum in building materials can be a cost effective application that would also reduce the amount of other aggregates needed in construction materials and projects. Increased research into the uses and benefits of phosphogypsum use would increase the demand for phosphogypsum and reduce the amount of land being laid to waste due to stacking (Alberta Environment 2006).

In order to encourage the producers of phosphogypsum to invest in research and secondary uses of phosphogypsum, the ease and cost-effectiveness of the current method of ‘disposal’, stacking, must become less available. The stacking of phosphogypsum should be discouraged by governments in order to force industries to invest in viable secondary applications and take responsibility for the vast amounts of land laid to waste by the current method of storage. Taxes could be allocated to the stacks and would be incremental and based on their age and size, the larger and/or older the stack, the more taxes that would be levied upon them. The taxes would create a situation that would favour investment into research, infrastructure, and promotion of the secondary uses of phosphogypsum and result in an increased demand for the by-product (Alberta Environment 2006).

5.0 Conclusions

In order to shift phosphogypsum out of the classification of waste and into the classification of secondary resource, governmental involvement is necessary. It is only through the implementation of new regulations that this shift can occur. The economic barriers that need to be overcome can only be met by a combination of government and industry; the latter will not
get involved unless there is incentive to do so. Current involvement to find secondary uses of phosphogypsum by the industries that generate it are not effective in building trust with the public and do not have enough funding invested in the exploration of its secondary use in environmental and economic markets.

Regulations can create programs or levy taxes to discourage the stacking of phosphogypsum by industrial producers. Any regulations specific to phosphogypsum introduced by the Government of Canada would give confidence to the public and stakeholders in the use of phosphogypsum as a secondary resource as its use would be accompanied by safety standards, approval requirements and frameworks of use. Phosphogypsum specific regulations would also require an analysis and characterization of the stacks in order to ensure the mitigation of potential environmental and health impacts. The involvement of the Government (Provincial or Federal) would raise awareness of phosphogypsum and the benefits of its use (Alberta Environment 2006).

The implementation of phosphogypsum specific regulations will educate the public and stakeholders, encourage secondary use, establish health and environmental standards, and discourage stacking. The beneficial applications of phosphogypsum will not be further explored without this additional regulatory guidance.
6.0 References


<http://www1.fipr.state.fl.us/fipr/fipr1.nsf/129fc2ae92d337ca85256c5b00481502/9f01ababbea7be2585256b2e0063b853/$FILE/01-037-055v1Final.pdf>.


Appendix A

Interview Questions:

1) When 'experimenting' with PG in Canada, where you limited by Health Canada’s Regulations?

2) It has been indicated to me that some Countries have been applying the IAEA standards of Radionuclides to PG management/use. Do you have an opinion on this? Should Canada do the same?

3) Do you think that regulating/ creating a framework of use for PG would increase research and the acceptance of its use in other fields? (ie Compost additive, landfill cap, road base)

4) My research has indicated that the NORM in PG is comparable to background radiation, why does radiation continue to be such a huge issue surrounding PG?