RADIATION RISKS FROM SELECTED USES OF BY-PRODUCT PHOSPHOGYPSUM

Presented To:
THE NINTH INTERNATIONAL SYMPOSIUM ON NATURALLY OCCURRING RADIOACTIVE MATERIAL
DENVER, COLORADO
23-27 SEPTEMBER 2019

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Support and advice from the Florida Industrial and Phosphate Research Institute (FIPR) is gratefully acknowledged.
Topics for Discussion

✓ NORM
✓ Phosphogypsum in stacks
✓ International Uses of PG
✓ FIPR Study
  • Phosphate fertilizer production
  • PG as road base
  • PG as daily landfill cover
  • PG as agricultural soil amendment
✓ Main Observations
What is NORM?

“Naturally Occurring Radioactive Material

“not subjected to regulations under the Atomic Energy Act, disturbed or altered from natural settings, or present in a technologically enhanced state due to human activities, which may result in a relative increase in radiation exposure and risk to public above background radiation level.” [HPS]
Concentration Ranges of Uranium (and Thorium) Series Radionuclides

Activity concentration (Bq/g)

Data from UNSCEAR 2000

Non-optimum use of regulatory resources

Optimum use of regulatory resources

Uranium ores, U-238
Monazite, Th-232
Pyrochlore, Th-232
Zircon, U-238
Ilmenite, Th-232
Rutile, U-238
Phosphates, U-238
Bauxite
Other metal ores, U-238 or Th-232
Soil, U-238
Soil, Ra-226
Soil, Th-232

After Wymer, 2008
Background

Phosphate rock is naturally radioactive and contains uranium series radionuclides

Phosphogypsum (PG) is a by-product of the production of phosphoric acid for phosphate fertilizer industry

PG is also naturally radioactive and contains uranium and uranium decay products, notably radium (Ra-226)

Current PG management in US is land disposal in stacks
EPA defines Phosphogypsum
(40CFR61 Subpart R)

“...as a radioactive waste product that results from processing phosphate ore to make phosphoric acid that is later used in fertilizer. Because the phosphate ore contains uranium and radium, phosphogypsum also contains these radionuclides. The radium is of particular concern because it decays to form radon, a cancer-causing, radioactive gas. Phosphogypsum has few uses and is disposed of in large, aboveground stacks.”
EPA NESHAPs - 1

Prior to the NESHAPs 1989 ruling, PG was used as agricultural soil amendment

In 1989, EPA promulgated the National Emission standards for Radon Emissions from PG Stacks (Subpart R) which was revised in June 3, 1992 to allow for uses in the following areas:

1. Outdoor agricultural use: limited to PG containing Ra-226 at less than 10 pCi/g (0.37 Bq/g)

2. Up to 700 pounds of PG for use in research and development (later amended in 1999) to 7000 pounds of PG, and
3. Other alternate uses which would be approved by the EPA *on a case by case basis* provided

“…the proposed use of the phosphogypsum will be as least as protective of public health in the short-term and long-term, as disposal in a stack or mine”

The EPA concluded in 1992, “that certain uses of PG may be considered acceptable so long as those uses are restricted to limit the estimated lifetime risk to any individual to no more than 3 in thousand” (57 FR 23312, 3 June 1992).
Phosphogypsum: Sustainability and Utilization

Florida Industrial and Phosphate Research Institute
Founded in 1978 as the Florida Institute of Phosphate Research (FIPR)

Purpose

• Conduct research related to phosphate issues
• Educate stakeholders

Re-established in 2010

• Name changed to current version
• Mission expanded to include all industries
• FIPR was transferred to Florida Polytechnic in 2012
FIPR’s Role

Conduct Research
• Technology, Environment, Public Health

Provide Information
• All stakeholders, Education, Public Access
• Via public library and K-12 Education Program

Find solutions to practical problems
• Wherever the science leads
• Technologies must be economical and environmentally beneficial or at least neutral

Florida Industrial and Phosphate Research Institute
Where is phosphate found globally?
Phosphogypsum
A spectrum of Uses

Agriculture: Fertilizer/Soil Conditioner
Road building
Construction Materials
Landfill cover
Glass/ceramic
Marine projects
Sulfur recovery

Florida Industrial and Phosphate Research Institute
Stack Free Project

Engage International Community

International Atomic Energy Agency (IAEA) gets involved

Guidelines Issued

• Graded Approach to Use
A Spectrum of Use(s)

- Reclamation
- Restoration
- Crop production

- Roads (Finland)
- Roads (Florida)
- Waste Reduction
- Cement
- Housing?
Case Study: Huelva, Spain

Phosphate production next to coastal river

Local sodic soils were treated with PG by farmers turning unusable land to the most productive in Europe

Greenpeace successfully lobbied to end use of PG as “toxic waste”

Farmers fought back

Courts ordered the universities to conduct research on PG use and effects (this took years)

Florida Industrial and Phosphate Research Institute
Case Study: Huelva, Spain – Result

Numerous studies were conducted.

Cadmium uptake in crops was measured and many decades of PG applications to soils were simulated.

After judicial review, it was ruled that not only was use of PG in agriculture safe, but PG was specified in law as a fertilizer.
Huelva, Spain: Indicative Case

Former stack – now public park

PG reserve for farmers

200 metres – houses to stack
Parrish Road
View of portion of Parrish Rd. that was originally unpaved and covered with sand

This is how the entire road would look if phosphogypsum had not been used in the rest

Later paved at request of residents

Note end of test section 3 near telephone pole
Soil Repaired for Agriculture Using Phosphogypsum
FIPR Study* 2014

Describes an approach to evaluate potential radiological doses and risks arising from:

• The production of phosphate fertilizer
• Agricultural soil amendment
• Daily landfill cover, and
• Road base

The approach used in 2014 utilized the best data available at the time and can be applied to other scenarios

* SENES now part of Arcadis
Study Approach

Define the exposure scenarios to be assessed

For each exposure scenario, develop a Conceptual Site Model (CSM), including:

• Receptors; and
• Exposure pathways

Base case assessment

• Group identified to be the (reasonably) maximally exposed

Uncertainty analysis

• Investigate how confident we can be about estimated doses and risks (mean, expected value, 98\textsuperscript{th} percentile)
Exposure Scenarios Assessed

Evaluation of the radiation doses and consequent (lifetime) risks that are associated with the following exposure scenarios:

• Phosphate Fertilizer Production
  – which considered the atmospheric radiological releases associated with the operational phase of a phosphate fertilizer plant

• Potential alternative uses of PG:
  – In Agriculture (i.e., as a fertilizer conditioner for soils);
  – As Daily Landfill Cover; and
  – As Road-base (in the construction of a two-lane urban street).
Development of a CSM

• Receptors:
  – Workers; and
  – Members of the Public (Adult and 5-year old)

• Pathways considered*:
  – Gamma radiation
  – Inhalation of Radon/Progeny
  – Inhalation of Dust
  – Ingestion of Deposited Dust and Soil
  – Ingestion of Garden Produce

* Previous studies by EPA, FIPR and others have examined more than 20 exposure pathways and determined that the exposure pathways considered in the present study represent almost all of the dose (and risk)
CSM for Process Plant

EXPOSURE SCENARIO: PROCESS PLANT (Worker)
EMISSIONS SOURCE: PHOSPHATE ORE
ENVIRONMENTAL PATHWAY: DUST, GAMMA, RADON
EXPOSURE: INHALATION, INGESTION (Soil), EXTERNAL (Gamma), INHALATION

EXPOSURE SCENARIO: PROCESS PLANT [Member of the Public (OFF-Site Residents)]
EMISSIONS SOURCE: PHOSPHATE ORE
ENVIRONMENTAL PATHWAY: DUST, RADON
EXPOSURE: INHALATION, INGESTION (Soil and Produce), EXTERNAL (Gamma), INHALATION
Daily Landfill Cover

**Exposure Scenario**

- **PG in Landfill**
  - [Worker (Landfill Operator)]

**Emissions Source**

- DAILY COVER

**Environmental Pathway**

- DUST
- GAMMA
- RADON

**Exposure**

- INHALATION
- INGESTION
- EXTERNAL (Gamma)
- INHALATION

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**Exposure Scenario**

- **PG in Landfill**
  - [Member of the Public (OFF-Site Residents)]

**Emissions Source**

- DAILY COVER

**Environmental Pathway**

- DUST
- RADON

**Exposure**

- INHALATION
- INGESTION (Soil and Produce)
- EXTERNAL (Gamma)
- INHALATION
PG in Roads

EXPOSURE SCENARIO

PG IN ROADS (Construction Workers) → PG IN ROADBASE → DUST

EMISSIONS SOURCE

ENVIRONMENTAL PATHWAY

GAMMA → INHALATION
GAMMA → INGESTION (Soil)
GAMMA → EXTERNAL (Gamma)

EXPOSURE SCENARIO

PG IN ROADS (Member of the Public) → PG IN ROADBASE → GAMMA

EMISSIONS SOURCE

ENVIRONMENTAL PATHWAY

GAMMA

EXPOSURE

EXTERNAL (Gamma)
Agriculture
Base Case Assessment

To predict dose (and risk) for groups considered likely to be most exposed

Does not reflect exposures to the entire population

Generally conservative values more likely than not to overestimate exposures relative to the activity, model inputs, and parameter values
## Summary of Doses (mSv/y) and Lifetime Risks from Base Case

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Worker</th>
<th>Adult</th>
<th>Child</th>
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<tbody>
<tr>
<td><strong>Phosphate Fertilizer Production</strong></td>
<td></td>
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<tr>
<td>Annual Dose (mSv/y)</td>
<td>0.034</td>
<td>0.016</td>
<td>0.02</td>
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<tr>
<td>Lifetime Risk</td>
<td>7.0E-06 (5 y)</td>
<td>1.9E-05 (30 y)</td>
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<td><strong>Agriculture</strong></td>
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<td>Annual Dose (mSv/y)</td>
<td>0.0096</td>
<td>0.067</td>
<td>0.077</td>
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<tr>
<td>Lifetime Risk</td>
<td>3.2E-06 (8 y)</td>
<td>8.3E-05 (30 y)</td>
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<tr>
<td><strong>Landfill cover</strong></td>
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<tr>
<td>Annual Dose (mSv/y)</td>
<td>0.29</td>
<td>0.009</td>
<td>0.011</td>
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<tr>
<td>Lifetime Risk</td>
<td>6.0E-05 (5 y)</td>
<td>1.1E-05 (30 y)</td>
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<tr>
<td><strong>Road base</strong></td>
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</tr>
<tr>
<td>Annual Dose (mSv/y)</td>
<td>0.14</td>
<td>5.2E-05</td>
<td>5.9E-05</td>
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<tr>
<td>Lifetime Risk</td>
<td>2.9E-05 (5 y)</td>
<td>6.4E-08 (30 y)</td>
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</tbody>
</table>
FDOH data show that Median indoor radon in Marion and Polk counties is 81 Bq/m³ and 141 Bq/m³ respectively.
Natural Background Radiation

Ubiquitous Background (2006)

- Radon-222 (68 %)
- Space (11 %)
- Terrestrial (7 %)
- Thorium & uranium series (4 %)
- Potassium-40 (5 %)
- Radon-220 (5 %)
- Other (<0.01 %)

Total ~ 3 mSv (300 mrem)

Summary

Concentrations of radionuclides in PG have been measured in a number of studies (e.g., EPA 1988)

PG stacks can be managed as waste or as useful by-product

Numerous studies have been performed to support of applications for exemption from PG regulations for a variety of alternative uses

Current study estimates that:

- Doses from phosphate fertilizer production and alternative uses of PG are well within the natural variation in unavoidable background dose in the US [2.5 to 97.5 percentile range of about 0.94 mSv/y to 12 mSv/y (US NCRP 160, 2009)];
- Lifetime risks are below the suggested reference risk level of 3E-04; and
- PG is being used internationally for a variety of beneficial uses.