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REVIEW OF THE RADIOLOGICAL RISK ASSESSMENT IN SUPPORT OF PETITION FOR BENEFICIAL USE OF PHOSPHOGYPSUM PREPARED FOR THE FERTILIZER INSTITUTE

October 14, 2020

U. S. ENVIRONMENTAL PROTECTION AGENCY

Office of Radiation and Indoor Air

Radiation Protection Division

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Executive Summary:

This document details the review performed by the U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Radiation Protection Division, in response to the *Radiological Risk Assessment in Support of Petition for Beneficial Use of Phosphogypsum* prepared for The Fertilizer Institute (TFI) (Arcadis 2019). The purpose of the review was to evaluate first whether the risk assessment submitted by TFI was performed correctly and accurately in terms of scenario development, model selection, parameter selection, and results; and then whether those results fell below the risk thresholds previously defined by the EPA for approval of other uses of phosphogypsum. Because TFI submitted a generic risk assessment, intended to be used to support projects that could vary in location and design from the generic scenarios presented, it was also necessary to consider the sensitivity of the results to parameter values, and to assess the likelihood of whether changes in the scenario could cause the results to exceed the risk thresholds. These reviews were conducted by a technical team from the Radiation Protection Division, and supported through separate analysis provided by a contractor, SC&A, Inc.

The Agency's review found that TFI's risk assessment was executed correctly, and that the results of TFI's risk assessment agree closely with the generic risk assessments performed in 1992 by the EPA in support of amendments to the rule (40 CFR part 61, Subpart R). Comparing these two independently-developed risk assessments allowed the Agency to consider the possible range of results for four main scenarios: 1) construction workers who work with phosphogypsum to build the road, 2) road users, 3) residents near the completed road and 4) a future resident of the site of an abandoned road. Risks to road users and to nearby residents are low, that is, less than a 1×10^{-4} lifetime risk of fatal cancer. Risks to construction workers who build the road are higher than those for road users or residents, but still fall below a lifetime risk of 3×10^{-4}.

The future resident, or reclaimer, scenario represents a worst-case environmental exposure scenario in which, at some point in the future, the road is disused, partially dismantled, and a person resides full-time on the residual phosphogypsum in a structure without controls for indoor radon. TFI has stated in its request that this scenario is highly unlikely and does not fit within the Reasonably Maximally Exposed (RME) individual analysis. This scenario, however, was the technical basis for not including a blanket approval for road construction with phosphogypsum in the current rule. Initial research performed by the EPA as part of this technical review process indicates that road abandonment does take place, albeit infrequently. TFI presented a scenario in which construction techniques, favorable radon transport conditions, and a lower residence time on the site resulted in a lower lifetime cancer risk to the reclaimer. The TFI scenario is plausible; the possibility of managing exposure to indoor radon through construction techniques was expressly noted in the EPA's 1992 analyses. The Agency finds that more pessimistic scenarios are also possible. Because the future reclaimer scenario could potentially still present lifetime risks above the Agency's defined threshold of 3×10^{-4}, the EPA concludes that it cannot be dismissed out of hand.

The technical review concludes that for a road built using phosphogypsum in the manner described in the TFI risk assessment, the lifetime risks of fatal cancer to road users, nearby residents and workers constructing the road will not exceed 3×10^{-4}. Therefore, a road using phosphogypsum in the base and/or pavement may be constructed in accordance with the Agency's threshold value for evaluating

whether the risk of this use is no greater than the risk of maintaining the phosphogypsum in a stack. Generic risk assessments do not technically support unrestricted future use. It is recommended that any approval be restricted to use as a road, and that a legal or policy mechanism is used so that any other proposed future use is evaluated by a risk assessment before it is approved.

The following conditions are suggested to make sure that any proposed road project falls within the parameters of the generic risk assessment:

- Pavement contains phosphogypsum in proportion no greater than 2.25% by weight
- The road base immediately underlying the pavement contains phosphogypsum in proportion no greater than 50% by weight
- Average radium content in the phosphogypsum does not exceed 35 picocuries per gram (pCi/g)
- Road base containing phosphogypsum is limited in thickness and is completely covered by pavement as described in the TFI request
- The distance of any residence or full-time place of work to the completed road is at least 15.2 m (50 ft)

Table 1, below, summarizes the risk ranges for the scenarios discussed above as calculated by both EPA and TFI:

Table 1: Lifetime Risks Scaled to a Ra-226 Concentration of 35 picocuries per gram (pCi/g) in Phosphogypsum for the 1992 BID and the 2019 TFI Risk Assessment

	Scenarios (Exposure Duration)	**Lifetime Risk[1] (x 10^{-4})**	
		1992 EPA BID	**2019 TFI Risk Assessment**
1	Road Construction Worker (10 years)	2.0	1.3
	Truck Driver Transporting PG (10 years)	N/A	0.26
2	Road User (30 years)	0.39	0.15
3	Nearby Resident	0.0067	0.10
	Utility Worker (10 years)	N/A	0.26
4	Reclaimer (30 or 26 years)	35	0.4

[1]Number of estimated fatal cancers if 10,000 people were exposed to this scenario.

Purpose of the EPA's review:

40 CFR §61.206 sets the requirements for a request for other uses of phosphogypsum. This technical review focuses on the risk assessment required by §61.206(8): "An estimate of the maximum individual risk, risk distribution, and incidence associated with the proposed use, including the ultimate disposition of the phosphogypsum or any product in which the phosphogypsum is incorporated." In a Federal Register notice associated with amendments to this rule, the EPA referred an individual lifetime risk of fatal cancer risk of approximately 3×10^{-4} as a threshold for approving uses of phosphogypsum. (57 FR 23311-23312, June 3, 1992)

As stated in the executive summary, the goal of this review was to verify that TFI's submission was numerically correct, to draw conclusions about the likelihood of the various scenarios to remain within the stated risk range for road construction applications, and to identify the design parameters that are important, from a technical standpoint, for maintaining risks below the threshold.

Structure of the EPA's review:

EPA contracted with SC&A, Inc. to provide a detailed technical review of TFI's modeling methodologies, presented in "Technical Review of the Fertilizer Institute Risk Assessment for Additional Use of Phosphogypsum in Road Base" (SC&A Inc., June 2020). The report includes confirmatory calculations which show that TFI's computer modeling runs were performed correctly, and that its results are therefore numerically correct. See SC&A 2020, Section 2.

The contractor review raised some minor questions about how the various exposure scenarios were modeled. The principal scenarios modeled by TFI, however, were very close to those modeled in the EPA's 1992 Background Information Document (BID) for the final rule. This is not surprising, as TFI studied the 1992 BID prior to preparing the risk assessment and deliberately used the EPA's modeling approach to inform its efforts. Recognizing that this review is of a generic risk assessment, and that the intercomparison of independent modeling approaches to the same problem can provide more robust conclusions than refining a single modeling approach, the EPA used TFI's modeling results together with the results presented in the 1992 EPA risk assessment to draw conclusions about the radiological risks from the use of phosphogypsum in road construction. The results are presented below, followed by a more detailed discussion of the parameters for each exposure scenario, and other minor scenarios that were considered in each generic risk assessment.

Please note that this review addresses the "Radiological Risk Assessment in Support of Petition for Beneficial Use of Phosphogypsum," prepared by Arcadis, submitted as Appendix 2 to the TFI October 2019 request, and retained as Appendix 2 to TFI's April 2020 revised request (TFI, 2020). This technical review document also examines TFI's request to use phosphogypsum with an average Ra-226 concentration up to 35 pCi/g, whereas the Arcadis risk assessment uses a concentration of 27 pCi/g; the EPA scaled each risk calculation to the higher concentration (i.e. 35 pCi/g) as the basis for the detailed discussion of each scenario. To the greatest degree possible, the EPA technical team evaluated and interpreted the risk assessment performed for TFI by Arcadis in a manner that is consistent with risk assessments previously performed in support of 40 CFR part 61, and with the EPA's established practices for radiological risk assessment. There are a number of technical assertions within the body of the TFI request and the "Summary of the Risk Analysis of the Use of

Phosphogypsum for Road Construction" included as Appendix 1 which express TFI's views on how the risk assessment should be interpreted, and in some cases diverge from the EPA's conclusions and practices. The EPA notes that these materials were submitted by TFI in addition to the risk assessment that is required for any request. The analysis contained in this report addresses only the risk assessment itself and does not evaluate supplemental materials not directly related to the development of the risk assessment.

The review is likewise limited to a discussion of radiological risk, which is the basis for the regulation of phosphogypsum under the Clean Air Act. Further, while the title of the Appendix 2 "Radiological Risk Assessment in Support of Petition for Beneficial use of Phosphogypsum" prepared by Arcadis might imply that the EPA's decision rests, at least in part, on a determination that the proposed use of phosphogypsum constitutes a "beneficial use" or reuse of this material, the applicable sections of the rule make no provision for such an analysis as a basis for approval of other uses. The management and use of industrial waste are typically regulated by state environmental agencies, and these agencies are expected to play a role in the approval of any specific road project. A broader review of the beneficial use of phosphogypsum may be required in such cases. To that end, TFI provided a technical memorandum, "Human Health Risk Screening for Metals and Metalloids: Phosphogypsum in Road Construction" as Appendix 3 to its request (Exponent 2019). The TFI memorandum and EPA resources such as the "Methodology for Evaluating Beneficial Uses of Industrial Non-Hazardous Secondary Materials" (EPA 2016) may be of use to states during such a review.

Summary of Results:

Table 2 summarizes annual and lifetime risks calculated by TFI in its risk assessment, and by EPA in its 1992 BID, respectively, for various scenarios associated with use of phosphogypsum in road construction. The row numbers (1-4) denote exposure scenarios that are directly comparable. The lifetime risk of fatal cancer associated with the exposure is listed in the rightmost column. A value of 3×10^{-4} would be denoted as 3.0 in the "Lifetime Risk" column of these tables.

Table 2: Summary Table of Results for the 2019 TFI Risk Assessment

	2019 TFI Scenarios[1] for 27 pCi/g[2]	**Lifetime Risk per Year of Exposure[3]**	**Years of Exposure**	**Lifetime Risk[4] ($x 10^{-4}$)**
1	Road Construction Worker	1.0E-05	5 to 20	0.5 to 2.0
	Truck Driver	1.0E-05	5 to 20	0.5 to 2.0
2	Road User (Motorist/Bicyclist)	3.8E-07	26 to 70	0.1 to 0.3
3	Nearby Resident	3.1E-07	26 to 70	0.08 to 0.22
	Utility Worker	4.0E-07	1 to 5	0.0 to 0.02
4	Reclaimer	1.5E-06	26 to 70	0.4 to 1.1

[1] See "Radiological Risk Assessment in Support of Petition for Beneficial Use of Phosphogypsum, Prepared for The Fertilizer Institute," October 2019 (Arcadis, 2019).
[2] Average concentration of Ra-226 in the phosphogypsum prior to its use
[3] Estimated from the reported risk and exposure time in the risk assessment
[4] Number of estimated fatal cancers if 10,000 people were exposed to this scenario. The lifetime risk per year of exposure multiplied by the years of exposure produce the lifetime risk for each scenario.

Table 3: Summary Table of Results for the 1992 EPA BID

	1992 BID Scenarios[1] for 26 pCi/g[2]	Lifetime Risk per Year of Exposure	Years of Exposure	Lifetime Risk (x 10^{-4})
1	Construction Worker - No Shielding - Direct Gamma	1.5E-05	5 to 20	0.75 to 3.00
	Construction Worker - With Shielding - Direct Gamma	9.0E-06	5 to 20	0.45 to 1.80
	Construction Worker - Humid Site - Dust Inhalation	8.4E-08	5 to 20	0.00 to 0.02
	Construction Worker - Dry Site - Dust Inhalation	2.2E-07	5 to 20	0.01 to 0.04
2	Person Driving on Road - Direct Gamma	8.2E-08	26 to 70	0.02 to 0.06
3	Member of CPG[3] - Direct Gamma	1.6E-08	26 to 70	0.00 to 0.01
4	Reclaimer - Direct Gamma	2.6E-05	26 to 70	6.8 to 18.2
	Reclaimer - Humid Site[4] - Indoor Rn	5.9E-05	26 to 70	15.3 to 41.3
	Reclaimer - Dry Site[5] - Indoor Rn	6.2E-05	26 to 70	16.1 to 43.4

[1]See EPA 402-R-92-002, *Potential Uses of Phosphogypsum and Associated Risks, Background Information Document*, Tables 4-15 and 4-16
[2]Concentration of Ra-226 in the phosphogypsum prior to its use
[3]Critical Population Group (Nearby Resident)
[4]Typical of a site in the southeastern United States
[5]Typical of a site in the southwestern United States

Discussion of parameters:

Road dimensions:

The road modeled in the 1992 BID, as shown in Figure 1, included a road base that was 9.15 m wide and 25 cm thick and a road surface 7.32 m wide and 12 cm thick. The road surface was assumed to be either concrete with 15% phosphogypsum or asphalt. The road base was assumed to be composed of one part phosphogypsum and two parts of either sand or clay. The density of the road surface and road base were both assumed to be 2.25 g/cm^3. The road modeled in the 2019 TFI petition was a four-lane road with a road base and road surface both 15.24 m wide. The thickness of the road base and road surface were 25 and 12 cm thick, respectively. The road surface was assumed to be concrete with 2.25% phosphogypsum by weight, and the road base was assumed to be composed of one part phosphogypsum and one part soil by weight. The density of the road surface and road base were both assumed to be 2.25 g/cm^3. The thicknesses and densities were the same as those in the 1992 BID.

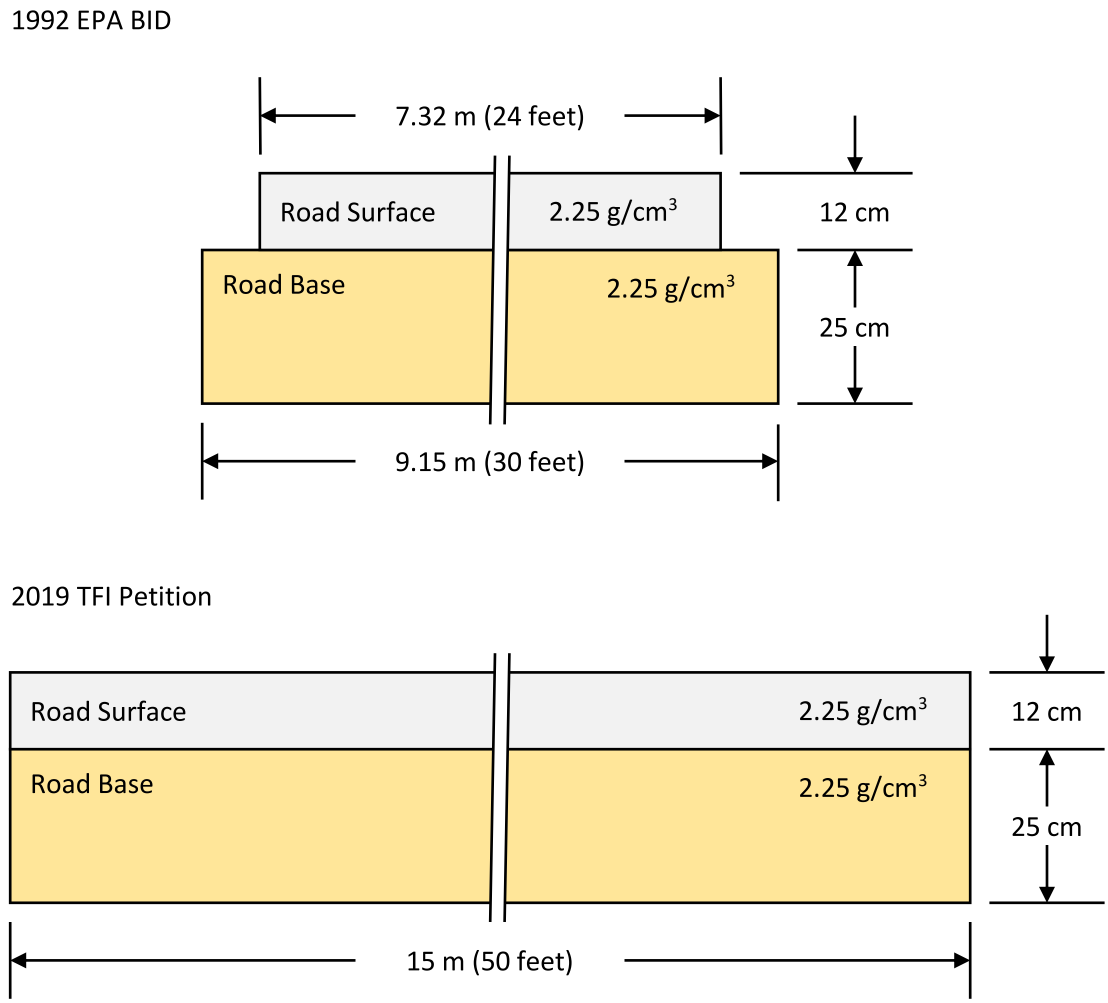

Figure 1: Road Construction Parameters

The 1992 BID modeled the dose and risk to the following five receptors:

- Construction Worker
- Person Driving on the Road
- Member of Critical Population Group (CPG)
- Reclaimer
- Offsite Individual

A summary of the scenarios included in the 1992 BID is provided in Table 4.

Table 4: Summary of Scenarios Included in the 1992 BID

	1992 BID Scenarios	
1	Construction Worker	The construction worker is assumed to be engaged eight hours per day for 250 days per year in constructing a 16-kilometer section of road. Gamma exposures are calculated for a worker who is employed directly on the road surface and a worker who uses equipment such as a bulldozer or road grader which provides some shielding from shielding from gamma radiation. The shielding coefficient is 0.6.
2	Person Driving on Road	The person driving on the road is assumed to use the road from home to work, and return. This person travels the road one hour per day for 250 trips per year. The automobile in which this person rides provides some shielding from direct gamma radiation. The shielding coefficient is 0.6.
3	Member of the CPG (aka Nearby Resident)	The member of the CPG is assumed to live in a house located 100 or 1,000 meters from the road. Potential doses to a member of the CPG could result from direct gamma exposure or from the use of contaminated well water.
4	Reclaimer	The reclaimer is assumed to build a house on the roadbed at some future time after the road is closed and the road surface has crumbled and been removed. In addition to living in a house at the site, the reclaimer drills a well for water and plants a vegetable garden in the contaminated soil. The vegetable garden provides 50 percent of the reclaimer's foodstuffs.

The 2019 TFI petition modeled the dose and risk to the following six receptors:

- Road Construction Worker
- Road User (Motorist/Bicyclist)
- Truck Driver
- Nearby Resident
- Utility Worker
- Reclaimer Resident

A summary of the scenarios included in the 2019 TFI risk assessment is provided in Table 5.

Table 5: Summary of Scenarios Included in the TFI Risk Assessment

	TFI Scenario	Description
1	Road Construction Worker	This scenario assumes a road construction worker works directly on the surface of the road as it is being constructed, 2,000 hours/year for 5 years. Although some road construction workers are on equipment during the workday which would provide shielding from external gamma exposure, shielding has not been included in the calculations. The doses are from direct exposure from gamma emission from PG, and inhalation and ingestion from potential dust emission during construction. In all three conceptual site models (CSMs) the active road area is 100 m long by 15 m wide, while thicknesses vary with the CSM. As the model used was RESRAD, the exposure point is at one meter above the surface, the RESRAD default. In addition, it was assumed the road construction worker moves around the surface of the road and the direct dose was calculated as the average of the dose at the road center and at the edge of the road.
2	Road User (Motorist/Bicyclist)	Two road users were considered for this scenario, a driver and a bicyclist. In both instances they were assumed to travel on a final constructed road with PG in the road base and the paving. No reduction was provided to the driver as the floor and auto body shielding are assumed negligible given the current materials used thin plastic/metal.
	Truck Driver	Another receptor is the truck driver who transports PG from the PG stack to the site of the road construction. The truck is assumed to be a standard dump truck. The dose to the truck driver was calculated using MicroShield®. The geometry selected was a rectangular volume, with the dimensions of the roll-off portion being 5.2 m long, 1.4 m high and 2.1 m wide which is the average for a 20-ton dump truck. The dose point was one meter from the center of the roll-off front face, where the driver would be sitting. The truck was assumed to be filled with phosphogypsum with a density of 1.12 grams per cubic centimeter (g/cm^3) which is somewhat lighter than soil. The isotopes in the PG were Ra-226 in secular equilibrium with the daughters. The activity was assumed 27 pCi/g as the PG was not yet mixed with road surface material. No credit or reduction was taken for the shielding effects of the truck cab.

	TFI Scenario	Description
3	Nearby Resident	This scenario assumes that a resident lives close to the site of the road as it is being constructed and after construction. In the first case, no shielding (road shoulders, etc.) was assumed during construction. After construction, a shoulder was established. During construction MicroShield® was used to determine the doses at various distances from the road. A rectangular volume was assumed, 15 m wide, 100 m long and 0.25 m thick. The contribution to the receptor is from the 25 cm thickness, 100 m long side face during construction and the 15m wide, 100m long surface of the road following construction. Doses were determined at 6.1 m and 15.2 m from the edge of the road at a receptor height of 1 meter above the road surface. The distance of 6.1 m is considered representative of urban settings with houses at a minimum separation from the road edge (urban setting may also have more shielding). The distance of 15.2 m is representative of more suburban setting where separation distances between roads and homes are expected to be greater.
	Utility Worker	It was assumed that a trench was cut across the road. The utility worker was assumed to work in the middle of the trench about one meter from the face of the road. The dose point was 7.5 m from the road edge, 51 m from the road end and 0.25 m high. The isotopes in the PG were Ra-226 in secular equilibrium with the daughters. The activity was taken as 13.5 pCi/g as the PG was mixed with road surface material at a 1:1 ratio. The direct exposure dose to the utility worker was calculated assuming the utility worker spends 160 hours per year in the PG road.
4	Reclaimer	The reclaimer scenario assumes that the home is a bungalow constructed slab on grade with a 16.2 cm underlying slab and a 16.2 cm gravel base underlying the slab. The basic scenario takes credit for a vapor barrier but takes no credit for any radon mitigation that might be required by local building codes. As with the case of the nearby resident, the house is presumed to be occupied for 26 years. In broad terms, the reclaimer scenario assumes the following: • Exposure to the reclaimer would be through gamma radiation and the inhalation of Radon (Rn-222) and progeny. • The reclaimer is assumed to be exposed for 26 years with approximately 75% of his/her time onsite and indoors.

TFI Scenario	Description
	The key assumptions are as follows: • The road surface has crumbled and has been removed as part of site preparation (50 years after closure also as assumed by the EPA in their 1992 BID). • Site grading for construction will almost certainly reduce the thickness of the layer containing PG; however, for present purposes, we have assumed that site preparation will reduce the PG layer to about 10 cm in thickness and the concentration of Ra-226 in the remaining layer to about 10 pCi/g. • Radon flux is reduced due to a 6-millimeter (mm) poly layer as a moisture barrier currently common in building codes. Such a layer would be expected to reduce the radon flux by at least a factor of 10.

In order to allow a more definitive comparison of the results, the total lifetime risk estimates for the scenarios in the 2019 TFI risk assessment and the annual risk estimates included in the1992 BID were scaled to reflect a concentration of 35 pCi/g of Ra-226 in phosphogypsum, consistent with TFI's request, and exposure times that were considered to be conservative but not unreasonably so. The discussion below documents these comparisons.

Scenario 1: Construction Worker

The 1992 BID evaluated the following exposure pathways or routes for the construction worker building the road:

- Direct gamma exposure
- Dust inhalation

The 1992 BID estimated the dose and risk to a road construction worker. The construction worker is assumed to work 8 hours per day and 250 days per year, or 2,000 hours per year. The 1992 BID estimated the external dose rate to be 41 and 16 mrem/yr, for Ra-226 concentration of 26 and 10 pCi/g in phosphogypsum, respectively. Scaling these results to 35 pCi/g, the external dose rate would be 56 mrem/yr, or 28 μrem/hr. The 1992 BID estimated the risk per year from 26 and 10 pCi/g in phosphogypsum, to be 1.5×10^{-5} and 5.9×10^{-6}, respectively. Scaling these results to 35 pCi/g, the risk per year is estimated to be 2.0×10^{-5}. The risk for 10 years of exposure would be 2.0×10^{-4} (2.0 in 10,000).

The 1992 BID estimated the dose and risk to a road construction worker from dust inhalation to the construction worker to be 1.0 and 2.5 mrem/yr for a radium concentration of 26 pCi/g in phosphogypsum for a humid and dry site, respectively. The corresponding risk per year of exposure for humid and dry sites, respectively, was 8.4×10^{-8} and 2.2×10^{-7}.

Scaling the risk to 35 pCi/g, the risk per year of exposure from dust inhalation for humid and dry sites, respectively, was 1.1×10^{-7} and 3.0×10^{-7}. The lifetime risk to the construction worker for an exposure duration of 10 years would be 1.1×10^{-6} and 3.0×10^{-6}, respectively, for humid and dry sites. The estimated dose and risk from dust inhalation are a small fraction of the dose and risk from direct external exposure.

The 2019 TFI risk assessment estimated the dose and risk to a road construction worker to be 22 mrem/yr, or 11 µrem/hr, assuming a radium concentration of 27 pCi/g. The estimated risk for 5 years of exposure was 0.5×10^{-4}. Scaling that risk to a radium concentration of 35 pCi/g and 10 years would result in lifetime risk of 1.3×10^{-4} (1.3 in 10,000).

The external dose rate was independently estimated using the external dose coefficients in Federal Guidance Report 15. The external dose calculation included the dose from Ra-226 and its decay products in secular equilibrium. The external dose rate was estimated to be 30.4 µrem/hr for a layer of infinite thickness with no cover layer. The estimated risk from working fulltime for 10 years assuming an infinite depth of phosphogypsum with no cover layer is 3.0×10^{-4}:

$$(304\ \text{nSv/hr})(2{,}000\ \text{hr/yr})(10\ \text{y})\left(\frac{\text{Sv}}{10^{9}\ \text{nSv}}\right)\left(0.05\ \text{Sv}^{-1}\right) = 3.0\times10^{-4}$$

For a 15-cm cover layer, the external dose rate was estimated to be 47 µrem/hr for a layer of infinite thickness. The estimated risk from working full-time for 10 years assuming an infinite depth of phosphogypsum with 15-cm cover layer is 0.5×10^{-4}:

$$(47\ \text{nSv/hr})(2{,}000\ \text{hr/yr})(10\ \text{y})\left(\frac{\text{Sv}}{10^{9}\ \text{nSv}}\right)\left(0.05\ \text{Sv}^{-1}\right) = 0.5\times10^{-4}$$

Provided that the average concentration of Ra-226 in the phosphogypsum is no more than 35 pCi/g and the phosphogypsum is no more than 2.25% of the road surface or 50% of the road base, the lifetime risk to a road construction worker for an exposure duration of 10 years is estimated to be below the acceptable risk of 3×10^{-4}.

Scenario 2: Person Driving on Road

The 1992 BID evaluated the following exposure pathways or routes for a person regularly driving on road:

- Direct gamma exposure

The 1992 BID estimated the dose and risk to a person driving on the road. The person driving on the road was assumed to use the road to travel to and from home to work. This person was assumed to travel one hour per day and makes 250 round trips per year. The automobile in which this person rides would provide some shielding from direct gamma radiation. A shielding coefficient of 0.6 was assumed.

The 1992 BID estimated the external dose rate to be 2.6 and 0.98 mrem/yr, for Ra-226 concentration of 26 and 10 pCi/g in phosphogypsum, respectively. Scaling these results to 35 pCi/g, the external dose rate inside the vehicle would be 3.5 mrem/yr, or 14 µrem/hr. The 1992 BID estimated the risk per year from 26 and 10 pCi/g in phosphogypsum, to be 9.6×10^{-7} and 3.7×10^{-7}, respectively. Scaling these results to 35 pCi/g, the risk per year is estimated to be 1.3×10^{-6}. The lifetime risk for 30 years of exposure would be 3.9×10^{-5} (0.39 in 10,000).

The 2019 TFI risk assessment estimated the dose and risk to a road user (motorist or bicyclist) to be 1.1 mrem/yr assuming a Ra-226 concentration of 27 pCi/g. The estimated risk for 26 years of exposure was 1.0×10^{-5}. Scaling that risk to a Ra-226 concentration of 35 pCi/g and 30 years would result in lifetime risk of 1.5×10^{-5} (0.15 in 10,000).

Provided that the concentration of Ra-226 in the phosphogypsum is no more than 35 pCi/g and the phosphogypsum is no more than 2.25% of the road surface or 50% of the road base, the lifetime risk to a person using road for an exposure duration of 30 years is estimated to be below the acceptable risk of 3×10^{-4}.

Scenario 3: Nearby Resident/Member of Critical Population Group (CPG)

The critical population group (CPG) member is a person living 100 m from the road. The 1992 BID evaluated the following exposure pathways or routes for member of the CPG:

- Direct gamma exposure
- Ingestion of drinking water from a contaminated well
- Ingestion of foodstuffs contaminated by well water

The member of the CPG is assumed to live in a house located 100 or 1,000 m from the road. Potential doses to a member of the CPG could result from direct gamma exposure or from the use of contaminated well water.

The 1992 BID estimated the external dose rate to be 0.50 and 0.19 mrem/yr, for Ra-226 concentration of 26 and 10 pCi/g in phosphogypsum, respectively. Scaling these results to 35 pCi/g, the external dose rate to the CPG member would be 0.67 mrem/yr. The 1992 BID estimated the risk per year from 26 and 10 pCi/g in phosphogypsum, to be 1.6×10^{-8} and 6.2×10^{-9}, respectively. Scaling these results to 35 pCi/g, the risk per year is estimated to be 2.2×10^{-8}. The lifetime risk for 30 years of exposure would be 6.6×10^{-7} (0.0067 in 10,000). According to the 1992 BID, no radionuclides were calculated to reach an on-site well via the groundwater pathway for almost 10,000 years, or an off-site river or well for more than 100,000 years.

The 2019 TFI risk assessment estimated the dose and risk to a nearby resident for a time duration of 26 years to be 72.8 and 20.0 mrem for residents living 20 ft and 50 ft (6.1 m and 15.2 m), respectively, from the road. Scaling to a Ra-226 concentration of 35 pCi/g, the total dose to a nearby resident for a time duration of 26 years to be 95 and 26 mrem for residents living 20 ft and 50 ft (6.1 m and 15.2 m), respectively, from the road. These doses correspond to total risks of approximately 5.0×10^{-5} (0.5 in 10,000) and 1.0×10^{-5} (0.1 in 10,000). Considering that the total estimated risk for 26 years of residence 20 feet (6.1 m) from the road is 0.5×10^{-4} for the direct gamma exposure pathway alone, and that lifetime risks are frequently calculated based on a longer time of residence (e.g., 70 years), it would be prudent to limit the proximity of nearby residences to 50 ft (15.2 m) to provide a margin of safety.

Provided that the Ra-226 concentration in the phosphogypsum is no more than 35 pCi/g and the phosphogypsum is no more than 2.25% of the road surface or 50% of the road base, the lifetime risk to a person living near the road is estimated to be below the acceptable risk of 3×10^{-4}.

Scenario 4: Reclaimer

As part of TFI's petition, the following statement is made about the Reclaimer Scenario:

"At EPA's request, the ultimate disposition of a PG roadway has also been evaluated. This evaluation was therefore, expanded to include a Reclaimer exposure scenario. It should be noted, however, this reclaimer scenario is not viewed as a reasonable maximum exposure (RME), given the nature and use of planned and constructed public roads." (Arcadis 2019, p. 1-3)

In 1992 EPA stated, "As shown in our risk estimates for road construction applications, even at radium-226 concentrations [of] 3 pCi/g, the risk to the maximum exposed individual is well above the acceptable level. However, the Agency's estimates for agricultural applications of phosphogypsum indicate that a threshold concentration of 10 pCi/g will protect public health with an ample margin of safety.

"The Agency agrees that there are several proven mechanisms which can be utilized to reduce the risk associated with radon exposure that do not affect the radium concentration of the material from which the radon emanates. The Agency also believes that these exposure control mechanisms should be instituted, as needed and where possible, to ensure that the risks presented by a particular application are acceptable. For these reasons the Agency has included a mechanism for applicants to obtain EPA approval for uses of phosphogypsum not explicitly addressed in the revised final rule." (57 FR 23315)

<u>Potential for Road Abandonment</u>

To explore whether future reuse of the road remains a credible scenario, the EPA investigated current practices for road abandonment and right-of-way easement vacation in the State of Florida. (Rustick, 2020) The process for road abandonment is broadly codified by state statute. For a road constructed with phosphogypsum within the county road system, road abandonment would be a public process conducted under the authority of county commissioners, who have the final say on any road abandonment petition. Each Florida county sets the requirements necessary for a successful petition to vacate the public's interest in a county road and transfer the property to a private entity. In general, most counties have similar procedures for road abandonment, with larger counties (or counties with greater population) tending to have more requirements for checking in with county departments (such as engineering and public works) for objections. The basic requirements include an application, posted notices of a public hearing to discuss the abandonment, and a vote by the commissioners at the hearing. Beyond these basics, there can also be significant differences between counties. Some relevant differences include requirements or lack thereof to obtain letters of "no objection" from specific public utilities and state level agencies (e.g. DOT), and the placement of permanent restrictions on utility easements under the abandoned road or right-of-way.

In addition to Florida state and county requirements, four case studies from the past 15 years were identified and researched to provide insight into the reclaimer scenario. In three of the four case studies, the petitioners were granted by the county or local government a stretch of government-owned road and associated right-of-way in order to remove the road and redevelop the land for a different use. The three uses were a parking lot, a golf clubhouse, and a commercial greenhouse. The fourth case study involved a private homeowners association taking over a stretch of road that no longer connected to the wider county road network. In two of the four case studies (the golf clubhouse and the homeowners' association), objections were raised during the petition review process by utilities that contained buried equipment within the identified right-of-way. As a condition for the approval for road abandonment, the county commissioners required modifications to the vacation permit for a perpetual public utility easement (stormwater/communications for one and drinking water for the other).

While the review of Florida statute and relevant case studies cannot speak to the specific scenario outlined in the 1992 BID and 2019 TFI petition, it does demonstrate the feasibility of a scenario in which a future private entity may have a desire to remove a section of public road for alternative purposes. This review was not exhaustive and therefore cannot discuss in technical terms a complete list of all scenarios that could occur. However, it does show that a reclaimer scenario in some form is a possibility for a future county road and should not be totally discounted. Depending on a technical evaluation for a given reuse scenario, conditions could be required to prevent the complete vacation of public right-of-way.

Parameterization of the Reclaimer Scenario

The reclaimer is assumed to build a house on the roadbed at some future time after the road is closed and the road surface has crumbled and been removed. The 1992 BID evaluated the following exposure pathways or routes for the reclaimer:

- Direct gamma exposure
- Indoor radon inhalation
- Use of contaminated well water
- Ingestion of foodstuffs grown onsite

In addition to living in a house at the site, the reclaimer drills a well for water and plants a vegetable garden in the contaminated soil. The vegetable garden provides 50 percent of the reclaimer's foodstuffs.

The 1992 BID estimated the external dose rate to be 71 and 27 mrem/year, for Ra-226 concentrations of 26 and 10 pCi/g in phosphogypsum, respectively. Scaling these results to 35 pCi/g, the external dose rate to the reclaimer would be 95 mrem/year. The 1992 BID estimated the risk per year from external radiation from 26 and 10 pCi/g in phosphogypsum, to be 2.6×10^{-8} and 1.0×10^{-5}, respectively. Scaling these radium concentrations to 35 pCi/g, the risk per year is estimated to be 3.5×10^{-5}. The lifetime risk from external radiation for 30 years of exposure would be 1.0×10^{-3} (10 in 10,000).

For a Ra-226 concentration of 26 pCi/g in phosphogypsum, the 1992 BID did not estimate the dose but did estimate the risk per year to the reclaimer from the inhalation of radon and its decay products to be 5.9×10^{-5} and 6.2×10^{-5}, respectively, for humid and dry sites. Scaling these results to 35 pCi/g, the risk per year is estimated to be 7.9×10^{-5} and 8.3×10^{-5}, respectively, for humid and dry sites. The lifetime risk from radon for 30 years of exposure would therefore be 2.4×10^{-3} (24 in 10,000) and 2.5×10^{-3} (25 in 10,000), respectively, for humid and dry sites.

The 1992 BID estimated the committed dose rate from ingestion of foodstuffs grown onsite to be 0.26 and 0.10 mrem/yr, for Ra-226 concentrations of 26 and 10 pCi/g in phosphogypsum, respectively. Scaling these results to 35 pCi/g, the committed dose rate from ingestion of foodstuffs grown onsite would be 0.35 mrem/yr. The 1992 BID estimated the risk per year from ingestion of foodstuffs grown onsite from 26 and 10 pCi/g in phosphogypsum, to be 1.5×10^{-8} and 5.9×10^{-9}, respectively. Scaling these results to 35 pCi/g, the risk per year is estimated to be 2.0×10^{-8}. The lifetime risk from external radiation for 30 years of exposure would be 6.0×10^{-7} (0.006 in 10,000). According to the 1992 BID, no radionuclides were calculated to reach an on-site well via the groundwater pathway for almost 10,000 years.

The lifetime risk from to the reclaimer from external radiation, inhalation of radon, and ingestion of foodstuffs for 30 years of exposure to the reclaimer was estimated to be 3.5×10^{-3} (35 in 10,000).

The 2019 TFI risk assessment estimated the dose and risk to a person living in a house built on the abandoned road. The TFI risk assessment assumed a 10 cm layer of granular fill and 6 mm poly barrier between the concrete slab of the house and the former road base. As described in detail below, the risk assessment also used a radon emanation factor more applicable to concrete, rather than soil, and a diffusion coefficient for intact concrete. The following is a summary of the review of the reclaimer scenario in the TFI risk assessment:

- The areal concentration of Ra-226 was reduced by 75-80% prior to construction of a new home, assuming the road base was 25 cm thick with a concentration of 27 pCi/g and the layer of phosphogypsum below the house is 10 cm thick with a concentration of 10 pCi/g.

- The calculation of the dose and risk from the external gamma radiation emitted by Ra-226 and its decay products was based on the assumption that there is a 10 cm cover layer between the layer of phosphogypsum and the 10 cm building foundation, with no mixing between the cover layer and the layer of phosphogypsum.

- The calculation of external dose using the RESRAD model assumed that the receptor spends all their time at home inside and used an increased cover layer thickness in lieu of default occupancy and shielding factors to account for the attenuation of gamma rays by the building foundation. While this may be appropriate if the phosphogypsum is limited to the area below the home, this approach likely underestimates the external dose when phosphogypsum is present throughout the site and/or receptors spend time outside their house.

- The calculation of the concentration of radon in the house is based, in part, on the following two input parameters: the radon emanation fraction in the ground and the diffusion coefficient through the building foundation.

    - The calculation used an emanation fraction that was measured for concrete, and not phosphogypsum. The value used by TFI is approximately 20% of the value used in EPA's earlier risk assessment, and half of the lowest expected value for phosphogypsum, soil, and similar materials.

  - The radon diffusion coefficient used for the building foundation is that for intact concrete. While likely appropriate in some instances, it is likely to result in an underestimation of dose and risk from radon where cracks or penetrations in the foundation provide additional pathways for radon to enter the house, including radon that flows from the road base through utility trenches into the building.

- The calculation of the concentration of radon in the house was assumed to be reduced by a factor 10 through the use of a vapor barrier.

The approach used in the TFI risk assessment results in significantly lower dose and risk estimates to a future resident than the more conservative approach used in the 1992 BID. The 2019 TFI risk assessment estimated the lifetime risk to a future reclaimer to be only 4.0×10^{-5} (0.4 in 10,000) for an exposure time of 26 years, compared to the 1992 BID estimate of 3.5×10^{-3} (35 in 10,000) for an exposure time of 30 years. Though likely an underestimation of the dose and risk to a future resident of a house built on the site of an abandoned road build with phosphogypsum, the TFI risk assessment does show that risk to a future resident of the site might be acceptable depending on the methods used to construct the house. Future uses of the site other than residential development might also result in acceptable risk but would need to be assessed separately.

Additional Scenarios: Offsite Individual and Water Pathways

The 1992 BID evaluated the following exposure pathways or routes for the reclaimer:

- Ingestion of river water contaminated via the groundwater pathway
- Ingestion of river water contaminated via surface water runoff

The 1992 BID estimated the committed dose rate from ingestion of river water contaminated by surface runoff to be 0.020 and 0.0076 mrem/yr for Ra-226 concentrations of 26 and 10 pCi/g in phosphogypsum, respectively. Scaling these results to 35 pCi/g, the committed dose rate from ingestion of foodstuffs grown onsite would be 0.027 mrem/yr. The 1992 BID estimated the risk per year from ingestion of foodstuffs grown onsite from 26 and 10 pCi/g in phosphogypsum, to be 1.5×10^{-9} and 5.9×10^{-10}, respectively. Scaling these results to 35 pCi/g, the risk per year is estimated to be 2.0×10^{-9}. The lifetime risk from external radiation for 30 years of exposure would be 6.0×10^{-8} (0.0006 in 10,000). According to the 1992 BID, no radionuclides were calculated to reach an on-site well via the groundwater pathway for almost 10,000 years.

TFI did not address these pathways in greater detail than the EPA BID, so some additional discussion is included here. EPA has both performed leaching experiments and examined studies and models quantifying radionuclide mobility from phosphogypsum (e.g., USEPA 1992, IAEA 2013, Mostary 2011). These studies and models indicate some radionuclide mobility, including U-238, U-234, Th-230, Ra-226, Pb-210, Bi-210, and Po-210, but the levels at which these radionuclides leached was well below concentrations for concern. An EPA study in 1992, for example, demonstrated that leachate from phosphogypsum experiments in soil columns resulted in Ra-226 concentrations that peaked between 0.8 to 6.5 pCi/L and quickly decreased thereafter, with concentrations depending on the type of soil being used and its adsorption capacity (EPA 1992). In its review of issues related to the groundwater pathway, SC&A noted some literature which indicates that experimental phosphogypsum road construction has not resulted in significant impacts to groundwater, and performed scoping analyses using the RESRAD-OFFSITE code (SC&A 2020, Section 5.3). In this analysis, SC&A assumed that the road base was not covered by pavement and therefore was open to infiltration for the duration of the modeling. The analysis varied the distance from the road to the well from 15.2 m to 100 m and used multiple sets of distribution coefficients for the radionuclides of concern – conservative defaults found in the code, average values, and values that reflect sandy soil. None of these cases resulted in a total risk in excess of 3×10^{-4} for a 26-year exposure.

SC&A performed additional scoping analyses to investigate the possibility of bioaccumulation of radionuclides (SC&A 2020, Section 5.4). The potential for bioaccumulation of radium progeny, particularly by crustaceans, is noteworthy. Although SC&A was able to calculate risks far in excess of the established limits for this approval, they were contingent on an extreme conceptual model in which surface water infiltrates phosphogypsum and dissolves radionuclides. Crayfish are assumed to live in this undiluted water and are harvested and ingested by humans, resulting in projected exposures above the risk threshold. Given that extensive contact between phosphogypsum and ground and surface water is not expected to occur given the generic road design proposed by TFI, further investigation is not necessary at this time. Should a different road design or use of a previous road site be proposed involving significant interaction between phosphogypsum and surface or ground water, further analysis should be conducted to fully rule out the possibility of the bioaccumulation of radionuclides.

In general, potential radiological risks due to leaching and water transport are low, compared to the risks posed by direct gamma exposure and the inhalation of radon gas, and particularly if there is little contact between phosphogypsum and sources of water. However, water transport is an area of considerable uncertainty. The mobility of metals and radionuclides will likely depend on many site-specific factors, such as the sorption properties of local soils, the amount of precipitation that occurs in an area, and the depth to groundwater. The presence of karst aquifers or the formation of colloids could lead to enhanced transport, and microbes and other biota have the potential to alter radionuclide mobility. TFI has proposed a generic road design in which phosphogypsum is fully covered by pavement and is therefore protected from infiltration. Additionally, the phosphogypsum is contained in a single, 25 cm layer, which presumably keeps phosphogypsum out of contact with groundwater under typical conditions. As long as these aspects of the generic design are maintained, it is reasonable to expect that the water pathway will not result in unacceptable radiological risks. Should the design change in a way that creates additional exposure of phosphogypsum to water, then this pathway warrants a more involved analysis.

Additional Scenarios: Truck Driver

The 2019 TFI risk assessment estimated the dose and risk to a truck driver transporting phosphogypsum to the road construction site to be 18.6 mrem/yr assuming a Ra-226 concentration of 27 pCi/g. The estimated risk for 5 years of exposure was 1.0×10^{-5}. Scaling that risk to a radium concentration of 35 pCi/g and 10 years of exposure would result in lifetime risk of 2.6×10^{-5} (0.26 in 10,000).

Provided that the average concentration of Ra-226 in the phosphogypsum is no more than 35 pCi/g and the phosphogypsum is no more than 2.25% of the road surface or 50% of the road base, the lifetime risk to a truck driver hauling phosphogypsum to road construction site for an exposure duration of 10 years is estimated to be below the acceptable risk of 3×10^{-4}.

Additional Scenarios: Utility Worker

The 2019 TFI risk assessment estimated the dose and risk to a utility worker in a trench to be 0.8 mrem/yr assuming a Ra-226 concentration of 27 pCi/g. The estimated risk for 1 year of exposure was 4.0×10^{-7}. Scaling that risk to a Ra-226 concentration of 35 pCi/g and 10 years of exposure would result in lifetime risk of 5.2×10^{-6} (0.052 in 10,000).

Provided that the average concentration of Ra-226 in the phosphogypsum is no more than 35 pCi/g and the phosphogypsum is no more than 2.25% of the road surface or 50% of the road base, the lifetime risk to a utility worker for an exposure duration of 10 years is estimated to be below the acceptable risk of 3×10^{-4}.

Summary and Conclusions

Estimated lifetime risks for members of the public from the use of phosphogypsum with an average concentration of Ra-226 up to 35 pCi/g in road construction are provided in Table 1. The results of both the 2019 TFI risk assessment and the 1992 BID demonstrate that risk to members of the public who construct the road, travel on the road, or live near the road will be below the acceptable risk of 3×10^{-4}, provided that the following conditions are maintained:

- The average concentration of Ra-226 in the phosphogypsum used for either the road surface or road base should not exceed 35 pCi/g.
- The road surface should contain no more than 2.25% phosphogypsum by weight.
- The road base should contain no more than 50% phosphogypsum by weight.
- The distance between the completed road and any nearby residence or full-time place of work should be at least 15.2 m (50 ft).
- The road base should be fully covered by pavement to prevent surface water infiltration and be limited to the single 25 cm layer proposed by TFI to prevent contact with groundwater.

The 1992 BID considered a future scenario if the road were abandoned and a house were built on the abandoned road base. The risk to a future resident was calculated to be significantly above the acceptable risk of 3×10^{-4}. The TFI risk assessment provided an estimate to a future resident of the site, with different assumptions than those in the 1992 BID. The results of the TFI risk assessment demonstrate that the risk to a future member of the public depends on the methods used to construct the house, and the risk to a future resident could be less than that estimated in the 1992 BID. To ensure that the risk to members of the public in the future is not above the acceptable risk, the redevelopment of any abandoned roads as anything other than a road constructed in accordance with this risk assessment should not be undertaken until an additional site-specific risk assessment demonstrates that risks to members of the public are acceptable.

References

40 CFR Part 61 Subpart R. *National Emission Standards for Hazardous Air Pollutants (NESHAP): National Emission Standards for Radon Emissions from Phosphogypsum Stacks*.

Arcadis 2019. Arcadis Canada Inc. *Radiological Risk Assessment in Support of Petition for Beneficial Use of Phosphogypsum*. Prepared for The Fertilizer Institute. October 2019.

EPA 2016. U.S. Environmental Protection Agency. *Methodology for Evaluating Beneficial Uses of Industrial Non-Hazardous Secondary Materials.* EPA 530-R-16-011, April 2016, 12 pp.

EPA 1992. U.S. Environmental Protection Agency. *Potential Uses of Phosphogypsum and Associated Risks: Background Information Document*, EPA 402-R92-002, May 1992, 124 pp.

Exponent 2019. Exponent *Human Health Risk Screening for Metals and Metalloids: Phosphogypsum in Road Construction*. Prepared for The Fertilizer Institute. October 2019.

FHWA 2017. U.S. Department of Transportation, Federal Highway Administration. *Tech Brief: Bases and Subbases for Concrete Pavements.* FHWA-HIF-16-005 (revised), Accessed 1/16/2020 at https://www.fhwa.dot.gov/pavement/concrete/pubs/hif16005.pdf, August 2017.

FIPR 2020. Florida Institute of Phosphate Research. *Phosphate Primer, Radiation and Phosphogypsum*. Accessed 1/23/2020 at: http://www.fipr.state.fl.us/about-us/phosphate-primer/radiation-and-phosphogypsum/.

Lutsey et al. 2004. Lutsey, N., C. Brodrick, D. Sperling, and C. Oglesby. "Heavy-Duty Truck Idling Characteristics, Results from a Nationwide Truck Survey," Transportation Research Record, *Journal of the Transportation Research Board*, No. 1880, pp. 29-38.

Mostary, S. 2011. Trace metals leachability characterization of phosphogypsum. Masters Thesis. Engineering, University of Florida, Gainesville, FL. 141 pp.

McHugh, Thomas, Lila Beckley, Terry Sullivan, Chris Lutes, Robert Truesdale, Rob Uppencamp, Brian Cosky, John Zimmerman, Brian Schumacher 2017. *Evidence of a Sewer Vapor Transport Pathway at the USEPA Vapor Intrusion Research Duplex*, Brookhaven National Laboratory, BNL-113837-2017-JA, April 2017.

Policy Navigation Group 2019. *Request for Approval of Additional Uses of Phosphogypsum Pursuant to 40 C.F.R. § 61.206 Appendix 6: Economic Analysis of Phosphogypsum Reuse*. Prepared for the Fertilizer Institute, 425 Third Street, S.W., Suite 950, Washington D.C. pp 12. December 2019.

Rustick 2020. *Public Road Abandonment Statutes, Implementation, and Case Studies for the State of Florida*. U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. August 2020.

SC&A, Inc. 2020. Technical Review of The Fertilizer Institute Risk Assessment for Additional Use of Phosphogypsum in Road Base. Prepared for U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Contract Number EP-D-10-042, Work Assignment No. 6-20.

TFI 2020. The Fertilizer Institute. *Revised Request for Approval of Additional Uses of Phosphogypsum Pursuant to 40 C.F.R. § 61.206.* Use in Road Construction projects authorized by federal, state and local Departments of Transportation or Public Works. April 7, 2020.

TFI 2019. The Fertilizer Institute. *Supplement to the October 11, 2019 TFI Phosphogypsum Reuse Petition: 2019 Radium-226 Results for U.S. Phosphogypsum Stacks*. December 5, 2019.