

Appendix 1

SUMMARY OF THE RISK ANALYSIS OF THE USE OF PG FOR ROAD CONSTRUCTION

Introduction

This Summary explains the elements of the risk analysis performed to support the use of phosphogypsum (PG) for road construction. The analysis comprises four risk evaluations provided in Appendices 2 and 3 to this Petition:

- *Radiological Risk Assessment (Appendix 2)*
 - *Assessment of the Ultimate Disposition for Roads Constructed with PG (Appendix 2)*
 - *The EPA Assessment of the Risk to An Individual Who Builds A House On An Abandoned Road (“Reclaimer Exposure Scenario”) (Appendix 2)*
- *Screening-level Risk Analysis of Metals in PG used for Road Construction (Appendix 3)*

Details and references are included in the Risk Assessment and supporting material.

Use of PG has many potential benefits as described in the Petition. The current practice of accumulating PG in stacks on the landscape is inconsistent with the increasingly accepted environmental philosophy of making use of manufacturing byproducts from a sustainability and lifecycle perspective. However, options for productive use of PG can only be implemented after they are demonstrated to be safe pursuant to the regulations at 40 CFR 61.206 and requirements in the U.S. Environmental Protection Agency (EPA) PG Workbook (2005¹). EPA’s health and environmental risk assessment approaches also set forth the factors and considerations involved (including risks, benefits, and costs). This risk assessment as outlined in Appendices 2 and 3 focuses only on the risks from the use of PG as construction material for roads.

The specific use of PG for road construction is as road base when mixed (e.g., at or less than 50%) with other materials such as soil, sand, or aggregate. As shown in Figure S-1, road base is a supporting layer of material ~0.25 m in thickness² beneath the pavement and above underlying soil and fill. It serves to provide resiliency to the road. PG may also be used in a smaller fraction (~2.25%) as part of the surface pavement. The design of new roads as depicted in Figure S-1 affects potential for exposures by creating a degree of isolation of the base layer from the environment. This limits direct contact by the community and also prevents water contact of PG

¹ ECRI. 2005. Applying to EPA for approval of other uses of phosphogypsum: preparing and submitting a complete petition under 40 CFR 61.206. EC/R Incorporated. U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Radiation Protection Division.

² This thickness was selected for the risk analysis.

isolated within the base layer. The constructed road surface also affords a degree of radiation shielding for people using the road for driving or for nearby residents.

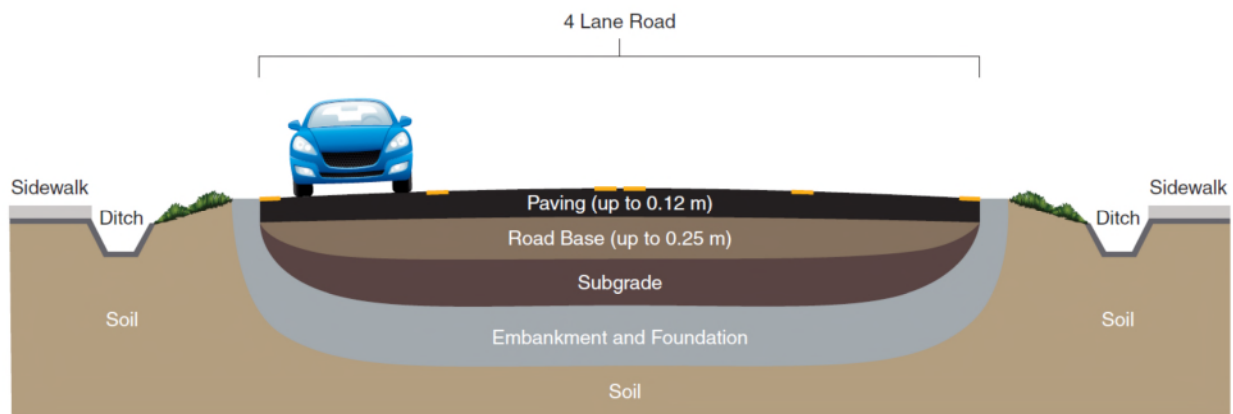


Figure S-1. Illustrated schematic cross-section of the road

Health and environmental risks of PG are considered for the low level of radiation naturally associated with this material as well as metals present in the material. The assessment of risks involves considering the exposures that may occur by using PG in road construction as well as the potential effects of radiation and metals at those exposure levels. Because radiation and metals occur naturally in the environment, the magnitude of risks from incremental exposures associated with using PG for road construction must be judged acceptable from a regulatory health and environmental standpoint. Such judgements rely on comparison to acceptability risk thresholds that EPA has established to define safe levels. The evaluation also considers background levels of naturally occurring radiation as this serves as a familiar gauge for assessing exposures.

The risk assessors, who conducted the analyses and prepared the four evaluations that compose Appendices 2 and 3, developed the approach in consultation with EPA. At various stages of the process, the methods, framework for judging risks, and results were reviewed with the agency. Input was taken, clarifications made, and additional information included and considered as requested by EPA. The petitioners chose to perform additional sampling to provide a fuller and current understanding of the nature of PG in existing stacks. A summary of this information will be submitted. The development of relevant and adequate exposure scenarios, the selection of methods for assessing exposure and effects, and the bases for judging risks are collectively referred to as technical and policy decisions. These underpin the risk assessment and the bases for judging risks.

Because the assessment is about proposed future use, there are aspects of the assessment that cannot be known completely or with absolute accuracy. Therefore, care has been taken in the process to manage such uncertainties. This is accomplished by choosing values and approaches

that are likely to overestimate rather than underestimate the risks. These result in exposures that are referred to as Reasonable Maximum Exposures (RMEs). The RME serves as a reasonable upper bound on the risk distribution and is a readily accepted approach for not only representing the maximum exposures but also providing insight into risks to people who might be exposed to PG. RMEs are constructed to likely overestimate risks for highest exposure situations; actual risks to these people and risks to the rest of the population would all be lower. Knowledge is relied upon for setting such bounds for the RME and when bounded values are used in calculation, the results are conservative (i.e., higher) estimates of the risks.

For example, if we consider three values used to calculate an exposure, each of which reflects the upper 10th percentile of the exposure factor, when these are combined in a risk calculation the mathematical result is a much smaller fraction of the population. For this example, $0.1 \times 0.1 \times 0.1 = 0.001$ (0.1% of population). As other upper bound values are incorporated such as the derivation of the cancer dose-response relationship for low-dose exposures, the percentiles decrease accordingly.

Technical/Policy Decisions and Approach

Technical and policy decisions for the risk assessment include 1) defining and characterizing relevant and appropriate exposure scenarios, 2) identifying the appropriate methods for estimating exposure for those scenarios, 3) defining the dose-response relationship for low levels of naturally occurring radiation in PG, 3) defining the risk threshold for judging whether risks from low-level radiation are acceptably small, 4) selecting a naturally occurring background radiation level for gaging incremental exposures associated with PG in road construction, 5) defining an approach for considering the ultimate disposition of a road constructed with PG, and 6) developing an approach for evaluating metals present in PG.

Five relevant and appropriate exposure scenarios were defined based on knowledge of how exposures might occur to workers and the public from using PG in road construction:

- 1) Road Construction Worker (builds roads exclusively with PG material for 5 years [based on actual road project experience])
- 2) Road User (motorist or bicyclist driving on PG-constructed roads for 26 years)
- 3) Nearby Resident (lives in a home located 20 ft [in paved, urban areas] or 50 ft from a road [for other areas]) over 26 years (26 years is EPA's recommended RME for living in a home³)
- 4) Truck Driver (delivers PG for road base material to construction site for 5 years)
- 5) Utility Worker (an individual who is involved in servicing pipes or electric lines alongside or crossing a PG-constructed road for 160 hours during a year).

The risk assessors chose exposure values such that each exposure scenario represented an RME for that group of people. These scenarios are presented in the following table:

³ 90th percentile recommended by USEPA (OSWER Directive 9200.1-120 (2014) and USEPA Exposure Factors Handbook (2011).

Table S-1. Exposure scenarios considered for radiological risk assessment

Exposure Scenario	Exposure	Exposure Pathway
Truck Driver (PG to construction site)	Gamma radiation	Direct external exposure
Road Construction Worker	Gamma radiation & PG dust	Direct external exposure Inhalation/Incidental ingestion of dust
Utility Worker	Gamma radiation & PG dust	Direct external exposure Inhalation/Incidental ingestion of dust
Road User (bicycle or auto)	Gamma radiation	Direct external exposure
Nearest Resident	Gamma radiation & PG dust	Direct external exposure Inhalation/Incidental ingestion of dust

Estimated exposures associated with the low level of radiation from PG are expressed in terms of millirems (mrem). Exposure estimates are developed for each scenario by considering activities of the types of individuals, distance from the potential source, duration of exposure, and physical barriers that serve to reduce exposure. This information is used as input in one of two accepted radiological exposure models, MicroShield and RESRAD. Exposure estimates are developed for the relevant period of exposure (in terms of mrem) and converted to a cancer risk by using an accepted dose-response relationship. The exposure estimates expressed as mrem can also be compared to exposure thresholds and background levels to provide perspective.

The exposure-risk (i.e., dose-response) relationship established by the International Commission on Radiological Protection (ICRP) (a widely respected group of experts) is consistent with the approach of the National Council on Radiation Protection and Measurements (NCRP), and is used to evaluate potential health effects from low-level radiological exposure associated with using PG in road construction. The relationship is derived by ICRP using a linear no-threshold (LNT) dose-response model. Because the effects of very low exposures are essentially undetectable, the LNT model assumes a straight line relationship to make it easier to extrapolate from data on observed effects at higher exposures to lower exposures for purposes of risk assessment and management where exposures are below those associated with readily observable effects. As a result of using this model, any exposure no matter how small has a corresponding risk estimate; this is why it is referred to as “no-threshold.” Utilizing an exposure-risk relationship derived with the LNT model helps ensure that risk estimates are more likely to be overestimated than underestimated; this provides managers with confidence in using the risk estimates to support health protective decisions.⁴

⁴ The linear no-threshold model is based on a science policy assumption, not direct evidence. A Nuclear Regulatory Committee (NRC) expert Advisory Committee noted that there is a “large and growing body of scientific literature as well as mechanistic considerations that suggest that the LNT model may overstate the

The linear slope cancer risk relationship from the ICRP modeling is 0.0000005 per mrem or 5×10^{-7} per mrem (5 in 10 million per mrem). The ICRP shows that it is a value that also approximates all cancers and effects.⁵ Thus, the ICRP concluded that this relationship continues to be appropriate for radiological protection. The value falls within the range of estimates and confidence intervals derived by EPA; the NCRP states that this relationship (i.e., 5×10^{-7} per mrem) represents a rounded value for radiation detriment used to inform all the NCRP recommendations regarding stochastic effects (that is, those occurring by chance).

Consistent with EPA policy related to PG reuse, the risk analysis framework incorporates a risk management level of a 3 in 10,000 (i.e., 3×10^{-4}) lifetime incremental cancer risk. This is the level utilized by the EPA Office of Air and Radiation for new PG uses. Cancer risks are estimated by multiplying the estimated doses for each exposure scenario by the linear exposure cancer risk relationship. This yields incremental risk estimates that can be compared to the accepted risk threshold for incremental risks over a lifetime. The estimated exposure doses as mrem can also be compared to the exposure level in mrem associated with the threshold, which is a value of 600 mrem. Either way, the comparison serves to indicate whether the estimate is above or below a threshold. Exposures below the threshold are deemed by EPA to be safe.

Annual incremental exposures for each scenario are compared to background radiation levels to provide insight into the relative magnitude of the exposure. The risk assessment uses the value of 310 mrem/year cited by EPA for average naturally occurring background radiation within the United States. Such radiation varies geographically (between states and even within states) and the assessment also points to a broad range of 100 to 1,000 mrem/year for the various states. While the assessment relies on the national average, inclusion of state ranges in background radiation permits comparisons at the state level. Average background radiation is also used to gauge exposures for exposure periods. For example, a 5-year exposure at average natural background would be 5 years \times 310 mrem/year or 1,550 mrem of cumulative background radiation. The cumulative natural background radiation for 26 years would be 8,060 mrem.

The last assessment in the risk analysis addresses possible exposure to metals present in PG (Appendix 3). These exposures were evaluated in two ways. First, a standard screening level risk assessment was used to evaluate whether metal concentrations within PG were above or below accepted benchmarks derived to be protective of direct contact⁶ for construction workers. Second, the potential for affecting surface and groundwater was evaluated, including a review of literature and road design features. Results of these two exposure evaluations determined that further numerical risk assessment is not warranted. PG can be used safely by workers in road

carcinogenic risk of radiation in...environmental doses.” The Advisory Committee did not recommend abandoning the science policy assumption of the LNT, but it did recommend not to use “excess conservatism.” See Official Transcript of Proceedings, Nuclear Regulatory Commission, “*Meeting of the Advisory Committee on the Medical Uses of Isotopes*,” teleconference, Wednesday, October 28, 2015, Work Order No.: NRC-1993, United States of America, at 16-17, available at <https://www.nrc.gov/docs/ML1532/ML15328A493.pdf>. For the purpose of this Petition, we use the LNT model.

⁵ “Short Note to Explain Risk Target Level and Dose-to-Risk Conversion Factor” submitted by TFI to EPA dated August 14, 2019).

⁶ Incidental ingestion, inhalation, and dermal contact.

construction. Paving limits direct contact by the community and also limits water contact of PG isolated within the base layer.

Findings

Radiological Risk Assessment

The use of PG for road construction does not result in exposures or incremental risks that exceed the thresholds (Table S-2). These are all based on RMEs and use of the LNT model. Thus, they reflect upper bounds and actual risks are expected to be considerably less.

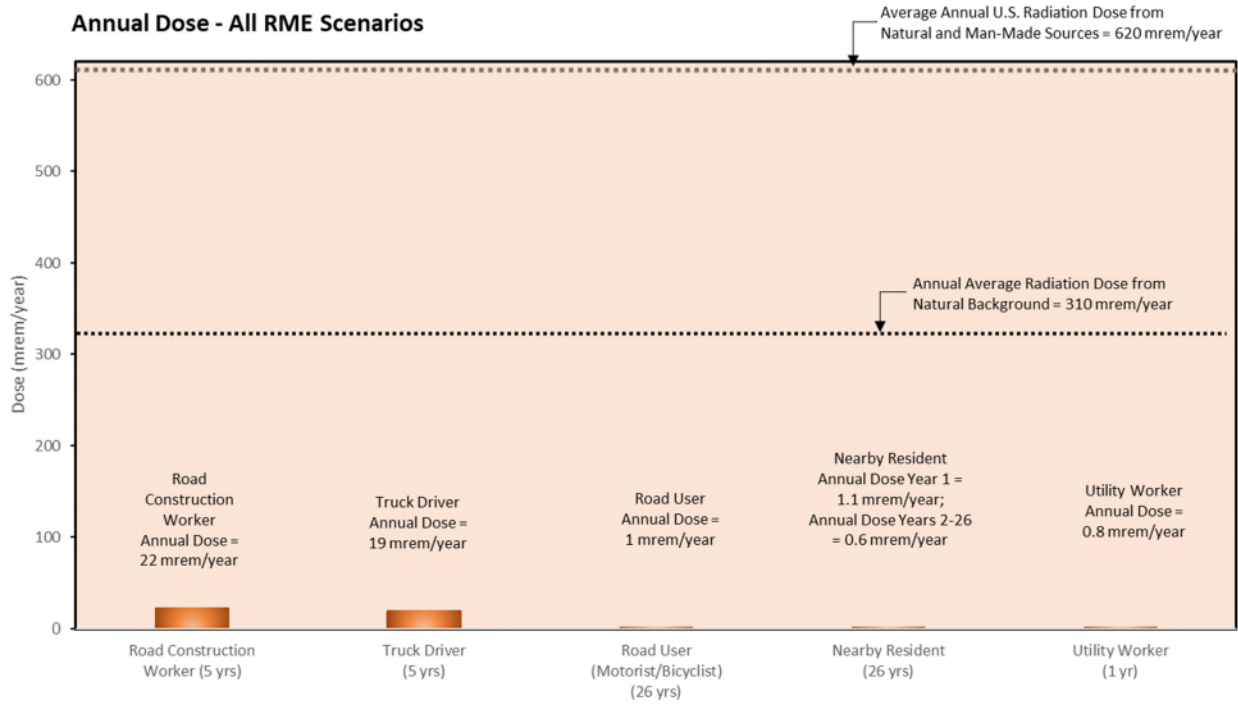
A summary of all RME scenarios, doses, and risks is provided below.

Table S-2. Dose and risk summary for all RME scenarios

Receptor	CSM	Exposure Duration (years)	Exposure Dose (mrem)	Estimated Cancer Risk	Background Dose from Exposure Duration (mrem)	Exposure Dose Percentage of Background Dose (%)
Reasonable Maximum Exposure Scenarios						
Road Construction Worker	PG in Road Base	5	110	0.5 in 10,000	1550	7%
Road User (Motorist/Bicyclist)	PG in Road Base & Surface	26	28	0.1 in 10,000	8060	0.3%
Truck Driver	PG-containing material for Road Base	5	93	0.5 in 10,000	1550	6%
Nearby Resident	PG in Road Base & Surface	26	16	0.08 in 10,000	8060	0.2%
Utility Worker	PG in Road Base	1	0.8	0.004 in 10,000	310	0.3%
EPA Cancer Risk Management Goal			600	3 in 10,000	600	

Estimated cancer risk below this goal.

Figure S-2. Estimated annual doses and annual background



Note: The mrem is a common unit of radiation dose. In this report, “dose” refers to effective dose, which simply means that when a person is exposed to a uniform radiation (i.e., external gamma radiation) all of the doses to the different organs are weighted by their radiosensitivity and added together.

Figure S-3. Comparisons of RME exposure doses and risks to thresholds

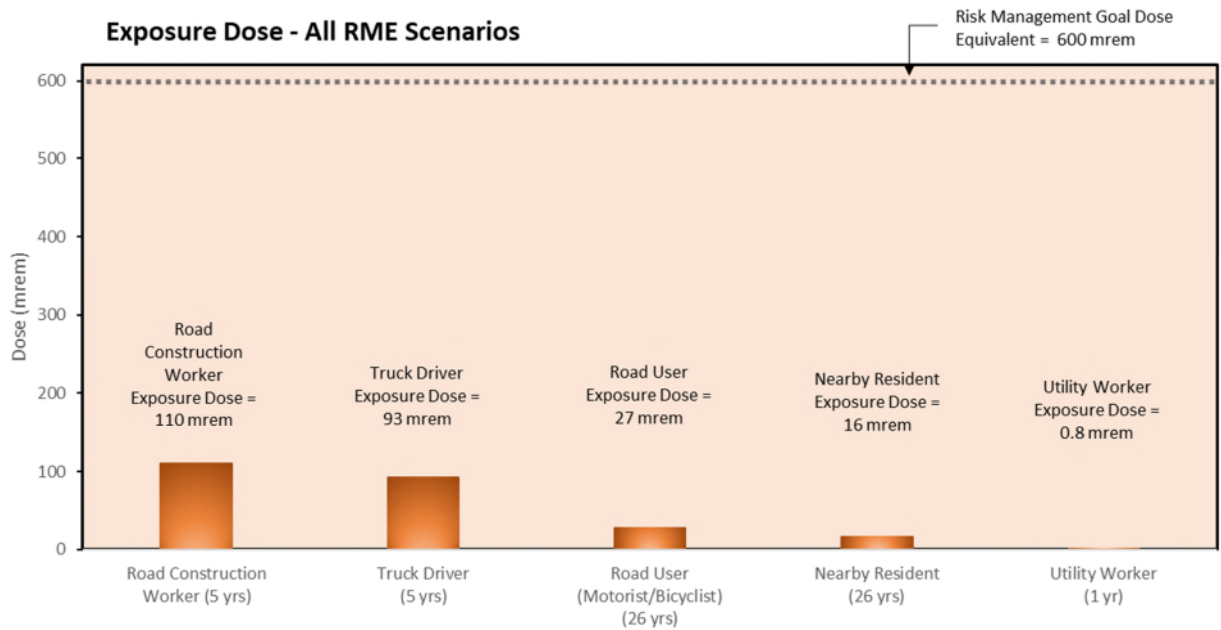
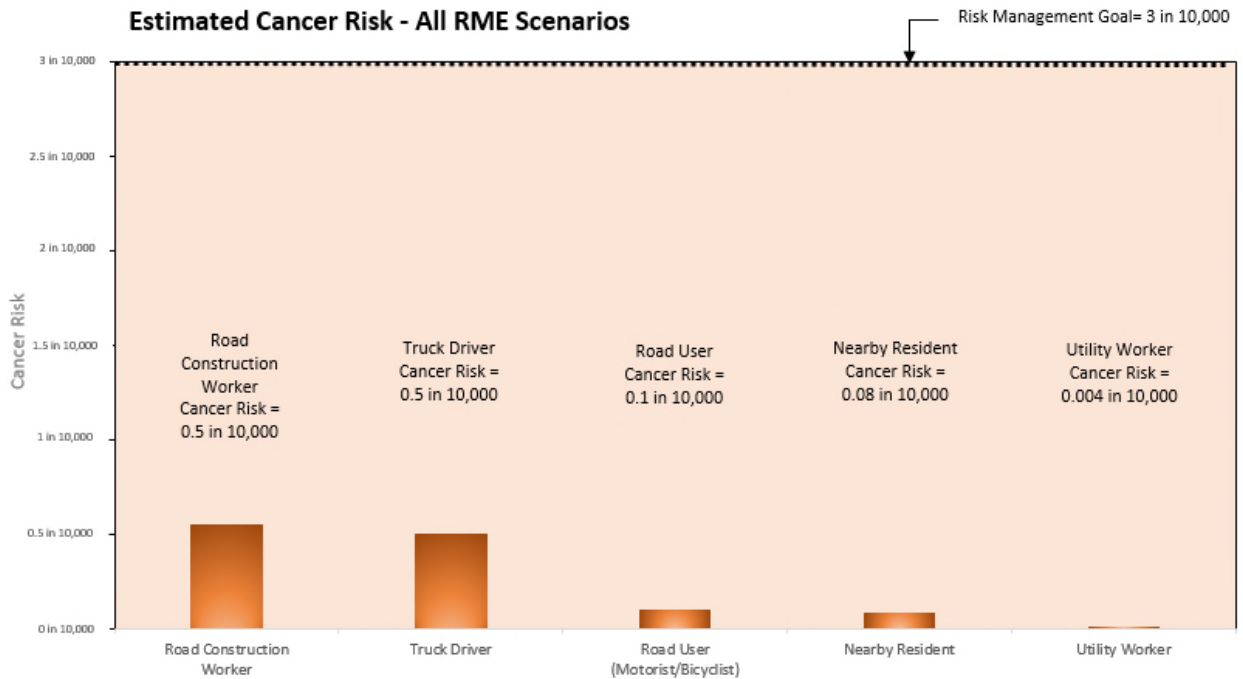


Figure S-4. Estimated cancer risks



Comparison to naturally occurring background radiation provides perspective on the relative magnitudes of RME exposures associated with using PG in road construction materials. As seen in Figure S-2, incremental exposure levels are significantly below the national average naturally occurring background radiation level of 310 mrem/year.

Among the five RME exposure scenarios, the highest incremental dose and risk is to the road construction worker. The dose was estimated to be 110 mrem for the 5-year period of time that a road construction worker is involved in placement of road base containing PG. The dose from this exposure is a fraction of the EPA's incremental threshold of 600 mrem; the incremental risk is 0.00005 (0.5 in 10,000), which is over 5 times less than the risk threshold of 3 in 10,000. This exposure level is also well below (i.e., within) the range of naturally occurring background radiation.

The risk assessment focused especially on residents who may live immediately adjacent to the road. Children were considered as part of this assessment as described in the report. Exposure depends strongly on distance with exposures dropping off quickly with increasing distance from the road. Nevertheless, for people living immediately adjacent to the road, the exposures and risks are well below EPA thresholds. The exposure doses and risks were estimated without considering shielding during the period of construction; shielding was included when estimating doses following construction of the road. Shielding of residents was afforded by the road surface as well as by embankments and other structures that cover the sides of the road base. The RME exposure dose and risk to nearby residents are well below the EPA thresholds.

Exposures of nearby urban, suburban, and rural residences to radiation associated with PG use in roads is reduced not only by the shielding afforded by the road itself but also as a result of distance from the source. At a distance of 20 feet from the completed road, the radiation is already a small fraction of background levels and, based on levels of naturally occurring radiation would be indistinguishable from natural variability. This already low level decreases by an additional 70% between 20 and 50 feet from the road and continues to rapidly decline with distance from the road. The risk analysis calculated the RME risk using a distance of 50 feet from the residence to the road. Residences located farther away from a road constructed using PG would be exposed to much lower levels of gamma radiation and, again, likely indistinguishable from the variability in naturally occurring background. Additionally, the risk analysis includes calculations of the dose and risk if the nearest residence was located 20 ft from the edge of the road, based on a sensitivity analysis concerning the degree to which the risk reduces due to distance and because some prior risk assessments have used 20 feet. The risk to such a receptor remained well below the EPA PG risk management level of 3 in 10,000.

Based on the above results, all exposures and risks are less than thresholds established by EPA to delineate safe levels for workers and the public. The exposures and risks are actually well below these levels. This together with the fact that these are constructed as RME exposures provides confidence for supporting decisions concerning the safe use of PG as a road construction material.

Ultimate Disposition of Roads Containing PG

The EPA PG use regulations require an assessment of the risk from the ultimate disposition of PG or any product in which the PG is incorporated (40 CFR § 61.206). The reasonably foreseeable ultimate disposition of a new road constructed with PG is that it serves as an established part of municipal (county, state, or federal) infrastructure and as such would require periodic repair and expansion as needed. These activities could include removing the surface,

grinding and reusing or disposing of the materials consistent with federal, state, and local regulations. Exposures and risks associated with maintenance of roads and reuse of construction materials are expected to be comparable or less than those detailed in the risk assessment for road construction.

Extreme Hypothetical “Reclaimer Exposure Scenario”

At EPA’s request, exposure for a hypothetical “Reclaimer Exposure Scenario” was calculated as an extreme bound on future hypothetical exposure. For this scenario, it was presumed that the pavement layer is removed and some leveling of the land occurs to allow for future construction. This leveling is expected to reduce the thickness of the remaining surface layer of PG-containing road base and cause some mixing that reduces the radium concentration in the remaining PG by a small amount. The house is then constructed directly on top of the residual road base. Radon exposure is the major exposure route and this occurs indoors. This scenario presumes customary construction methods for a house on grade. Indoor exposures are calculated using accepted models for gamma radiation and radon. The duration of exposure is 26 years (the same as the nearby resident exposure scenario). The risk from this extreme, hypothetical Reclaimer Exposure Scenario is 0.4 in 10,000, well below the EPA PG risk management limit of 3 in 10,000.

Receptor	CSM	Annual Dose (mrem/year)	Exposure Duration (years)	Exposure Dose (mrem)	Estimated Cancer Risk
Hypothetical Scenario Beyond RME for Screening Purposes					
Reclaimer Resident	PG in Road Base	3	26	78	0.4 in 10,000
EPA Cancer Risk Management Goal				600	3 in 10,000

Estimated cancer risk below this goal.

Table S-3. Evaluation of ultimate disposition of PG road

This analysis demonstrates that a numerical risk for the ultimate disposition scenarios need not be calculated because even this extreme (beyond RME) hypothetical exposure scenario risk does not exceed the EPA’s risk management level of 3 in 10,000.

The Radionuclide Groundwater Analysis in the 1992 BID Demonstrated No Impact

EPA performed extensive modeling of the likely migration of radionuclides from PG used in road construction in a 1992 assessment (i.e., the Background Information Document or BID).⁷ The BID concluded that the radionuclide “doses from the groundwater pathways are all zero.”⁸ The soil partition coefficient was arbitrarily decreased and still “no radionuclides are calculated to reach the onsite well via the groundwater pathway” nor are any “radionuclides calculated to

⁷ EPA, Potential Uses of Phosphogypsum and Associated Risks, Background Information Document at Chapter 4 (402-R92-002, May 1992), available at <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=0000055V.TXT> (BID 1992).

⁸ Id att 4-17.

reach the off-site river or well via groundwater.”⁹ EPA’s assessment demonstrates that the radionuclide risks were found to be zero.

Screening Level Risk Analysis of Metals

A screening level analysis is typically performed to determine whether it is appropriate to conduct a more detailed quantitative risk assessment. A screening level analysis was conducted for metals and demonstrates that a quantitative risk assessment is not necessary for metals.

Screening of metals considered two pathways: direct contact and potential for leaching.

Regarding worker exposure during construction, a screening-level analysis was performed wherein the concentrations of metals within PG were compared to EPA screening-level values. For the most part, all maximum metal concentrations in PG were less than EPA screening levels. Only two—lanthanum (La) and zirconium (Zr)—exceeded their respective screening levels. Upon mixing for use in either pavement or road base, the concentration of lanthanum in the pavement or road base is expected to be below its risk screening level. Zirconium was within U.S. background levels. Because the road materials are not accessible upon completion, there is no direct contact pathway from PG construction materials to residents and road users.

The second pathway considered was potential for leaching or influence on surface water bodies and groundwater. As noted earlier, the road base is constructed as a layer confined within the structure of the road. Given that it is located above the water table and that the PG material is isolated and not directly exposed to surface runoff, the potential for contact of the road base with water is extremely limited. This minimizes the potential for leaching to groundwater. Nevertheless, consideration was given to the nature of roads and available information on leaching of metals from the PG.

For comparison, we looked at metals content in PG roads and metals in biosolids continuously applied on agricultural fields regulated under the EPA Part 503 Rule. EPA evaluated the potential for leaching of metals and the associated potential for surface water and groundwater impacts from agricultural lands continuously receiving biosolids, and EPA concluded that these pathways are not a significant source of risk. Moreover, the footprint of a road on the landscape is very small compared to agricultural lands upon which biosolids and amendments with many higher allowable metal concentrations than those in PG are permitted for continuous use. The smaller footprint and lower likelihood of leaching from a constructed road compared to an agricultural field indicates that the influence on groundwater from PG in the road is likely to be comparatively very small. PG in road base is expected to be negligible in comparison and thus can be used safely in road construction given the lower metals content in PG and the smaller footprint and confinement of the base layer above the water table.

Finally, state and federal road construction requirements were evaluated. Agencies responsible for constructing municipal roads have the responsibility to ensure that roads

⁹ Id., at Scenario 8, Table 4-5, p. 4-31, footnote c and Scenario 11, Table 4-18, p. 4-34, footnote c, among other sources and . Id at 4-17.

are constructed and used in a manner that is judged adequately protective of the environment. Roadway design is comprehensive. Agencies governing road construction assess construction materials, potential impacts, and, if necessary, mitigating measures. Thus, all construction materials, including but not limited to PG, are addressed by the highway construction process. This decision-making is in the purview of the agencies that govern road construction.

Conclusion

The risk analysis considers RME exposures and screening levels analyses to evaluate radiological risks, potential considerations for the ultimate disposition of the roads constructed, in part, with PG, and the presence of radionuclides and metals in PG. The analyses indicate that use of PG in road construction is within EPA's acceptable risk thresholds and screening considerations. This means that PG can be used safely for this purpose.